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Los Alamos, New Mexico 87544
(505) 667-7203/FAX (505) 665-4504

Date: July 7, 2005
Refer to: ER2005-0461

Mr. James Bearzi
NMED – Hazardous Waste Bureau
2905 Rodeo Park Drive East
Building 1
Santa Fe, NM 87505-6303

RECEIVED
JUL 2005
NMED Hazardous
Waste Bureau

SUBJECT: **RESPONSE TO THE NOTICE OF DISAPPROVAL FOR THE VOLUNTARY CORRECTIVE MEASURE COMPLETION REPORT FOR SOLID WASTE MANAGEMENT UNIT 21-011(K) AT TECHNICAL AREA 21, LOS ALAMOS NATIONAL LABORATORY EPA ID#NM0890010515 HWB-LANL-03-025**

Dear Mr. Bearzi:

Attached are two hard copies with electronic files of the "Response to the Notice of Disapproval for the Voluntary Corrective Measure Completion Report for Solid Waste Management Unit 21-011(k) at Technical Area 21." The enclosures include the responses to the notice of disapproval comments, a crosswalk table of New Mexico Environment Department's comments and revisions to the report, and the revised pages of the report. The revised pages include an updated reference section for the main text and the responses clarify whether the references were cited in the report. Relevant references are also provided as electronic files.

If you have questions, please contact Mark Thacker at (505) 665-5342 (mthacker@lanl.gov) or Woody Woodworth at (505) 665-5820 (lwoodworth@doeal.gov).

Sincerely,

David McInroy, Deputy Program Director
Environmental Remediation & Surveillance
Los Alamos National Laboratory

Sincerely,

David Gregory, Federal Project Director
Department of Energy
Los Alamos Site Office

MT/jk

Enclosures: 1) Response to Notice of Disapproval for the Voluntary Corrective Measure Completion Report for Solid Waste Management Unit 21-011(k) at Technical Area 21 (ER2005-0455) (two copies with electronic files on CD)
2) Certification by the ENV-ERS Program Technical Representatives

Cy: (w/enclosure)
P. Reneau, ENV-ECR, MS M992
M. Thacker, ENV-ECR, MS M992
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RPF, MS M707
S-7, MS F674
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A. Dorries, ENV-ECR, MS M992
D. McInroy, ENV-ERS, MS M992
B. Rich, ADO, MS A104
L. Woodworth, DOE LASO, MS A316
D. Pepe, NMED-OB

CERTIFICATION

CERTIFICATION BY THE ENVIRONMENTAL STEWARDSHIP– ENVIRONMENTAL REMEDIATION & SURVEILLANCE PROGRAM TECHNICAL REPRESENTATIVES

Document Title: **RESPONSE TO THE NOTICE OF DISAPPROVAL FOR THE VOLUNTARY CORRECTIVE MEASURE COMPLETION REPORT FOR SOLID WASTE MANAGEMENT UNIT 21-011(K) AT TECHNICAL AREA 21, LOS ALAMOS NATIONAL LABORATORY EPA ID#NM0890010515 HWB-LANL-03-025**

I certify under penalty of law that these documents and all attachments were prepared under my direction or supervision in accordance with a system designed to ensure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violation.

Name: _____ Date: 7/7/05

David McInroy, Deputy Program Director
Environmental Remediation & Surveillance Program
Los Alamos National Laboratory

or

_____ Date: _____

Ken Hargis, Division Leader
Environmental Stewardship Division
Los Alamos National Laboratory

_____ Date: 7/7/05

David Gregory, Federal Project Director
Environmental Restoration Program
Department of Energy/Los Alamos Site Office

or

_____ Date: _____

John Ordaz,
Assistant Area Manager of Environmental Projects
Department of Energy/Los Alamos Site Office

Response to Notice of Disapproval
for the Voluntary Corrective Measure Completion Report
for Solid Waste Management Unit 21-011(k) at Technical Area 21
Los Alamos National Laboratory (LANL),
EPA ID #NM0890010515 HWB-LANL-03-025
Dated June 2, 2005

INTRODUCTION

This submittal is the response by Los Alamos National Laboratory (LANL) to the "Notice of Disapproval (NOD) for the Voluntary Corrective Measure Completion Report for Solid Waste Management Unit 21-011(k) at Technical Area 21," issued by the New Mexico Environment Department (NMED) Hazardous Waste Bureau on June 2, 2005, and received by LANL on June 8, 2005.

To facilitate review of these responses, NMED's comments are included verbatim in italics. The comments are divided into general and specific categories as presented by NMED. LANL's responses follow each NMED comment. In addition, LANL has provided a table in this response (Table 1, p. 5) that crosswalks NMED comments with revisions to the voluntary corrective measure (VCM) completion report for Solid Waste Management Unit (SWMU) 21-011(k).

This response contains data on radioactive materials, including source, special nuclear, and by-product material. The management of these materials is regulated under the Atomic Energy Act and is specifically excluded from regulation under the Resource Conservation and Recovery Act and the New Mexico Hazardous Waste Act. Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to NMED in accordance with U.S. Department of Energy policy.

GENERAL COMMENTS

NMED Comment

1. *Based on analytical results from previous RFI sampling completed in 1993, three radionuclides (tritium, uranium-234, and uranium-235) had values above background/fallout values. However, the 1996 IA confirmatory samples were only analyzed for isotopic plutonium, strontium-90, cesium-137, and americium-241. The Permittees must explain why they did not analyze for tritium, uranium-234, and uranium-235 in their 1996 IA confirmatory soil samples. (Must be included as a response)*

LANL Response

1. The interim action (IA) conducted in 1996 focused only on the chemicals of potential concern that substantially contributed to the dose to an on-site worker (i.e., exceeded screening action levels), isotopic plutonium, strontium-90, cesium-137, and americium-241. The ten surface soil samples from six locations were collected to confirm that the most pervasive radionuclides, those that were the primary contributors to the dose, had been removed by the IA. In removing the primary radionuclides as part of the IA, the other radionuclides such as tritium, uranium-234, and uranium-245 were also removed.

NMED Comment

2. *The Permittees must provide a brief description of investigation, sampling or analytical methods and procedures in documents submitted to NMED that includes sufficient detail to evaluate the quality of the acquired data in accordance with Section IX.A, Standard Operating Procedures of the Order. (Must be included as a revision to the Report)*

LANL Response

2. Brief descriptions of field investigation methods used during the VCM are included as a new Appendix N. Appendix N is included as Attachment 1 to this response.

SPECIFIC COMMENTS

NMED Comment

1. ***Section 2.3 Preliminary Conceptual Model, page 7, paragraph 1:***

   The reference to Langmuir (1997, 56037) is not included in Section 4.0, References. The Permittees must provide this reference as well as all other references missing from the TA-21 Reference Set. NMED cannot adequately evaluate the VCM without reviewing the references provided throughout the report. The Permittees must supply these references to the NMED for review. For your convenience, a list of these references is attached. (Must be included as a revision to the Report)

LANL Response

1. The missing reference to Langmuir (1997, 56037) has been added to the list of references in Section 4.0. In addition, references erroneously included in the list but not cited in the report have been removed. The revised Section 4.0 is included as Attachment 2 to this response. Attachment 3 is a CD of electronic versions of the documents (as pdf) that were cited but missing from the reference set, per the list NMED sent with its transmittal letter. That list of main text and Appendix B references has been annotated below to show the documents LANL is providing with this response.

   Main Text:

   - CRC Press 1984, 40244: Not cited in main text
   - EPA 1993, 59384: Not cited in main text
   - EPA 1997, 58968: Not cited in main text
   - EPA 1999, 64695: Not cited in main text
   - EPA 2000, 73306: Not cited in main text
   - LANL 2002, 73115: Included on CD
   - LANL 2002, 73116: Included on CD
   - LANL 2002, 73702: The ECORISK database; an updated version of this general reference is provided electronically to NMED annually and is not resubmitted herein.

- LANL 2002, 73725: Included on CD
- WGII 2002, 76842: Included on CD

Appendix B:

- Cavazza 1998, 21501: Included on CD
- Environmental Protection Group 1993, 23249: Included on CD
- LANL 1998, 59599: LANL's "Hydrogeologic Workplan"; this general reference was previously submitted to NMED and is not resubmitted herein.
- MacFadden 1977, 21569: Included on CD
- Purtymun et al. 1997, 11846: Included on CD
- Self et al. 1986, 21579: Included on CD
- Smith 1960, 48819: Included on CD
- Smith 1960, 48820: Included on CD
- Spell et al. 1990, 21586: Included on CD
- Stix et al. 1988, 49680: Included on CD

NMED Comment

2. *Table 2.4-2, Summary of VCM Plan Specifications, Fieldwork, and Rationale for Deviations, page 25:*

   NMED specified that 10 confirmation samples from two depth intervals (0-12 and 24-36 inches beneath an elevation equal to the bottom of the drainline) must be obtained from 5 locations along the outfall drainline. The Permittees collected 27 confirmation samples from 15 locations, which is well over the number specified by NMED. The Permittees provided a rationale for this deviation; however, the Permittees must explain why they did not collect samples from 2 depths at each drainline trench location, as required by NMED (for example, sample location 21-03-21396). (Must be included as a response)

LANL Response

2. Samples were collected at 2 depth intervals at 11 of the 15 confirmation sample locations, which is more than what was proposed in the approved VCM plan. The additional samples were collected based on real-time gross gamma screening. At the locations where only one depth interval was sampled, low contaminant concentrations were detected by real-time screening.

NMED Comment

3. ***Section 2.4.3 Site Restoration Activities, page 26, paragraph 6:***

   Permittees' Statement: *"In June 2003, the final walk-over gross gamma survey was performed to document the post-VCM count rates across the site (Figure 2.4-7). This survey indicated that all areas of elevated contaminant concentrations had been remediated, and that no additional "hot spots" had been exposed during restoration activities. Nearly 15,000 gross gamma counts were recorded during this survey with an average of 23,285 cpm. This count rate roughly corresponds to a contaminant concentration of 40 pCi/g for cesium-137 based on known correlations between real-time*

gross gamma screening and fixed laboratory analysis reported in Appendix F of the SWMU 21-011(k) VCM Plan."

NMED Comment: *Figure 2.4-7 shows areas of elevated contaminant concentrations near the southern end of the SWMU, approximately 120 feet north of DP Road. There is a significant improvement over the values seen in April 2003 (Figure 2.4-3) and December 2002 (Figure 2.4-2) gross gamma surveys; however, Figure 2.4-7 still exhibits concentrations in the 60001-80000 cpm range in discrete areas. The Permittees must revise this statement to clarify that there is still contamination present, but it is below the cleanup levels specified in the VCM Plan. (Must be included as a revision to the Report)*

LANL Response

3. LANL revised Section 2.4.3, page 26, paragraph 6, sentence 2, to state the following: "This survey indicated contaminant concentrations are below cleanup criteria specified in the VCM plan and no additional areas of elevated concentrations above cleanup criteria had been found during restoration activities." The revised page 26 is included as Attachment 4 to this response.

NMED Comment

4. *Appendix D Analytical Suite and Results, Table D-2.0-1, Analytical Results for SWMU 21-011(k), page D-5:*

   NMED Comment: *The Permittees state that this table presents the analytical results from samples collected in 1993, 1996, 2001, and 2003; however, there is no way to distinguish one sample date from another. The Permittees must revise Table D-2.0-1 to reflect the dates on which samples were obtained. (Must be included as a revision to the Report)*

   Section 2.1, Site Description and Operational History (SWMU 21-011(k)), states, "effluent contained a variety of radionuclides and chemicals." The Permittees must explain why a full analytical suite was not performed on all samples, especially samples obtained in 1993, as these were used to characterize contaminants present at SWMU 21-011(k). (Must be included as a response)

LANL Response

4. The sample identification (ID) includes the year the sample was collected, e.g., the "01" in MD21-01-0030 indicates that the sample was collected in 2001, with the exception of the 1993 samples, which are designated with "AAA." Table D-2.0-1 has been revised to include a note with this information. The text in Section D-2.0 was also revised to include the following correction regarding the 1996 samples: "The confirmation results from the 1996 interim action are not included in Table D-2.0-1 because these sample locations were removed as part of the VCM and are no longer present." The revised Appendix D is included as Attachment 5 to this response.

   Previous sampling and analyses were based on the history of site operations. Because this SWMU was a plutonium-processing facility, radionuclides were the focus of the investigations, especially early on. As a result, only a limited number of samples were collected and analyzed for organic and inorganic chemicals.

Table 1
Crosswalk of NMED NOD Comments (June 2, 2005) with
Revisions to the VCM Completion Report for SWMU 21-011(k) (LA-UR-03-7293)

NMED NOD Comment No.	Section Revised[a]	Page(s) Revised[b]	Nature of Report Revision
General Comments			
1	No revision required	n/a[c]	n/a
2	Addition of Appendix N	n/a	Table of descriptions of field investigation methods
Specific Comments			
1	Section 4	59 through 61	Missing reference added References not cited in main text removed
2	No revision required	n/a	n/a
3	Section 2.4.3	26	Text revised
4	Section D-2.0 Table D-2.0-1	D-4, D-46	Text revised Table note added

[a] This crosswalk reflects changes made to the VCM completion report in response to NMED comments.

[b] The page numbers listed here refer to the original document.

[c] n/a = Not applicable.

Attachment 1

Response to General Comment #2

Appendix N

Descriptions of Field Investigation Methods

APPENDIX N DESCRIPTIONS OF FIELD INVESTIGATION METHODS

Method	Summary
Spade-and-Scoop Collection of Soil Samples	This method is typically used for collecting shallow (i.e., approximately 0–12 in.) soil or sediment samples. The "spade-and-scoop" method involves digging a hole to the desired depth, as prescribed in the sampling and analysis plan, and collecting a discrete grab sample. The sample is typically placed in a clean stainless-steel bowl for transfer into various sample containers.
Hand-Auger Sampling	This method is typically used for sampling soil or sediment at depths of less than 10–15 ft but, in some cases, may be used to collect samples of weathered or nonwelded tuff. The method involves hand-turning a stainless steel bucket auger (typically 3–4 in. inner diameter), creating a vertical hole that can be advanced to the desired sample depth. When the desired depth is reached, the auger is decontaminated before advancing the hole through the sample depth. The sample material is transferred from the auger bucket to a stainless steel sampling bowl before filling the various required sample containers.
Headspace Vapor Screening	Individual soil, rock, or sediment samples may be field-screened for volatile organic compounds (VOCs) by placing a portion of the sample in a plastic sample bag or in a glass container with a foil-sealed cover. The container is sealed, and shaken gently, and allowed to equilibrate for 5 min. The sample is then screened by inserting a photoionization detector probe into the container to measure and record any detected vapors.
Handling, Packaging, and Shipping of Samples	Field team members seal and label samples before packing and ensure that the sample and transport containers are free of external contamination. Field team members package all samples to minimize the possibility of breakage during transportation. After all environmental samples are collected, packaged, and preserved, a field team member transports them either to the Sample Management Office (SMO) or to an SMO-approved radiation screening laboratory under chain of custody. The SMO arranges to ship the samples to analytical laboratories. The field team member must inform the SMO and/or the radiation screening laboratory coordinator when levels of radioactivity are in the action-level or limited-quantity ranges.
Sample Control and Field Documentation	The collection, screening, and transport of samples are documented on standard forms generated by the SMO. These include sample-collection logs, chain-of-custody forms, and sample-container labels. Collection logs are completed at the time of sample collection and are signed by the sampler and a reviewer who verifies the logs for completeness and accuracy. The corresponding labels are initialed and applied to each sample container, and custody seals are placed around container lids or openings. Chain-of-custody forms are completed and assigned to verify that the samples are not left unattended.
Field Quality Control Samples	Field quality-control samples are collected as follows as directed in the March 1, 2005, Compliance Order on Consent: Field Duplicate: At a frequency of 10%, collected at the same time as a regular sample and submitted for the same analyses. Equipment Rinsate Blank: At a frequency of 10%, collected by rinsing decontaminated sampling equipment with deionized water that is collected in a sample container and submitted for laboratory analysis. Trip Blanks: Required for all field events that include the collection of samples for VOC analysis. Trip blank containers of certified clean sand are opened and kept with the other sample containers during the sampling process.

Method	Summary
Field Decontamination of Drilling and Sampling Equipment	Dry decontamination is the preferred method to minimize the generation of liquid waste. Dry decontamination may include using a wire brush or other tool to remove soil or other material adhering to the sampling equipment, followed by using a commercial cleaning agent (nonacid, waxless cleaners) and paper wipes. Dry decontamination may be followed by wet decontamination, if necessary. Wet decontamination may include washing with a nonphosphate detergent and water, followed by a water rinse and a second rinse with deionized water. Alternatively, steam cleaning may be used.
Containers and preservation of samples	Specific requirements/processes for sample containers, preservation techniques, and holding times are based on Environmental Protection Agency guidance for environmental sampling, preservation, and quality assurance. Specific requirements for each sample are printed on the sample collection logs provided by the SMO (size and type of container, i.e., glass, amber glass, polyethylene, preservative, etc.). All samples are preserved by placing them in insulated containers with ice to maintain a temperature of 4˚C. Other requirements, such as the use of nitric acid or other preservatives, may apply to different media or analytical requests.

Attachment 2

Response to Specific Comment #1

Contaminated soil, tuff, and sediment: This waste stream was generated from the excavation of soil, tuff, and sediment throughout the site with concentrations of cesium and americium above the cleanup levels. The waste stream is treated as low-level waste (LLW) due to the presence of radionuclides (principally cesium-137, strontium-90, americium-241 and plutonium-239) in the waste stream.

Metal outfall drainline: This waste stream was generated from the removal of the outfall drainline north of the MDA T fence line to the slope where it historically discharged. The waste stream is treated as LLW due to the potential presence of radionuclides (principally cesium-137, strontium-90, americium-241 and plutonium-239) in the waste stream.

Lead drainline collars: This waste steam was generated from removing the lead collars from the excavated drainline. The lead drainline collars were decontaminated by removing the soil component; screened by the HSR-1 radiation control technician and free-released with no detectable activity. The lead collars were the managed as hazardous waste EPA hazardous waste number D008 was applied to the lead collars.

Vegetation: This waste stream was generated during pre-mobilization activities that required the clearing and grubbing of the site for road construction. The vegetation originated on-site and is treated as LLW due to the potential presence of radionuclides (principally cesium-137, strontium-90, americium-241 and plutonium-239) in the waste stream.

Plastics, PPE, and other IDW: This waste stream consisted of a variety of IDW, including various types of plastic sheeting, polyvinyl chloride (PVC), PPE, and disposable sampling supplies such as plastic scoops, plastic bags, and dry decontamination wipes. IDW was generated during all phases of the fieldwork including excavation, sampling, and site restoration activities. These materials were managed as LLW due to direct contact with contaminated environmental media and debris. IDW was packaged into 55-gal. drums for transport and disposal.

PCS, and absorbent material: A spill of hydraulic fluid on clean base coarse was cleaned up, sampled for total petroleum hydrocarbons and found to be below New Mexico special waste (NMSW) regulatory levels. A spill of diesel fuel into the plastic-lined secondary containment berm around the generator was cleaned up with absorbent materials and disposed as NMSW.

As discussed in section 2.4.2, contaminated soil and tuff that had been excavated was placed in individual stockpiles at the site. In accordance with no longer contain-in determination received from NMED on November 25, 2002, a sample was collected from each 100 yd^3 of excavated material and submitted for offsite contract laboratory analysis of Appendix VIII VOCs (NMED 2002, 73720). A total of 19 samples were collected from the excavated material and submitted for VOCs analysis. The results were provided to NMED for review and approval prior to disposal of the material at Area G at TA-54.

All of the waste sample results indicated that VOC concentrations in the excavated material were consistent with those presented in the no-longer-contained-in determination request. After VOC sample results were reviewed and approved by NMED, the associated stockpiles of excavated material were loaded into lined rolloff bins and disposed of at Area G at TA-54. Additional waste samples were collected independently by TA-54 to confirm that the excavated soil generated as part of the VCM was profiled appropriately. The results of the samples collected by TA-54 indicated that the profiling of the excavated soil was appropriate. Hard copies of the VOC analytical results and the Area G waste profile results for the excavated soil are presented in Appendix L.

4.0 REFERENCES

The following list includes all references cited in this document. Parenthetical information following each reference provides the author, the publication date, and the ER ID number. This information is also included in the citations in the text. The Records Processing Facility (RPF) assigns ER ID numbers to track records associated with the project. These numbers can be used to locate copies of the actual documents at the RPF and in the project reference library titled “Reference Set for Material Disposal Areas, Technical Area 21.”

Copies of the reference library are maintained at NMED-HWB, the DOE Los Alamos Area Office, EPA Region VI, and RRES-RS. This library is a living collection of documents that was developed to ensure that the administrative authority has all the necessary material to review the decisions and actions proposed in this document. However, documents previously submitted to the administrative authority are not included in the reference library.

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NMED (New Mexico Environment Department), December 18, 2000. "Technical Background Document for Development of Soil Screening Levels," Volume I, Tier 1: Soil Screening Guidance Technical Background Document, Santa Fe, New Mexico. (NMED 2000, 68554)

NMED (New Mexico Environment Department), November 25, 2002. "Contained in determination for Solid Waste Management Unit (SWMU) 21-011(k), Technical Area 21, Letter from Vickie Maranville (NMED) to John Browne (LANL), Santa Fe, New Mexico. (NMED 2002, 73720)

Nyhan, J., Hackler, L., Calhoun, T. and E. Young. June 1978. "Soil Survey of Los Alamos County, New Mexico," Los Alamos National Laboratory document LA-6779-MS informal report, Los Alamos, New Mexico. (Nyhan et al. 1978, 05702)

WGII (Washington Group International Inc.). “Spade-and-Scoop Method for the collection of Soil Samples”, Washington Group International Inc., procedure WGII-SOP-6.09, Rev. 1, Los Alamos New Mexico. (WGII 2001, 76841)

WGII (Washington Group International Inc.). “Use of Gamma Scintillation Detectors for Soil Screening”, Washington Group International Inc., procedure WGII-SOP-10.15, Rev 1, Los Alamos, New Mexico. (WGII 2002, 76842)

Attachment 3

Response to Specific Comment #1

(on CD only)

73725

ENVIRONMENTAL RESTORATION PROJECT

Los Alamos National Laboratory (LANL)
Environment Restoration Project (ER)
Records Processing Facility (RPF)
ER Record ID Number Barcode Label

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION
Records Processing Facility
ER Records Index Form

ER ID NO. 73725 ***Date Received:*** 1/29/2003 ***Processor:*** YCA ***Page Count:*** 17

Privileged: (Y/N) N ***Record Category:*** P

FileFolder: N/A

Correction: (Y/N) N ***Corrected No.*** 0 ***Corrected By Number:*** 0

Administrative Record: (Y/N) Y

Refilmed: (Y/N) N ***Old ER ID Number:*** 0 ***New ER ID Number:*** 0

Miscellaneous Comments:

REFERENCE CITED

(17) #73725

ENVIRONMENTAL RESTORATION PROJECT COMMUNICATION RECORD		
Date: 11/18/02	**Time:** 9:00 a.m.	**Recorded By:** P. Bertino
To: Vickie Maranville VM · 11·18·02	**From:** P. Bertino, LANL RRES-R	**Telephone No.:** 665-2198
Affiliation: NMED-HWB		
Other Parties: Mark Thacker (LANL RRES-R), Woody Woodworth (OLASO), and John Crocker (WGII)		

Discussion: This communication record was prepared at the request of Vickie Maranville, of the New Mexico Environment Department Hazardous Waste Bureau (NMED-HWB) to document the submittal of offsite analytical laboratory data to validate the proposed screening method to be used during the implementation of the voluntary corrective measures (VCM) at Solid Waste Management Unit (SWMU) 21-011(k) at TA-21. The provision of this data to NMED-HWB is called for in Sections 4.2.2 and 4.2.3 of the VCM Plan for SWMU 21-011(k), Revision 2, (LA-UR-02-6797).

Action Items: LANL will discuss the radiological screening methodology and provide all screening and offsite analytical results from the VCM at SWMU 21-011(k) in the VCM completion report.

Distribution:
V. Maranville/J. Young, NMED-HWB
M. Thacker, RRES-R
L. Woodworth, OLASO
P. Bertino, RRES-R
J. Crocker, WGII
RPF

DI-4.3, R0	**LOS ALAMOS Environmental Restoration Project**

V Maranville 11·18·02
Reviewed/approved.

RECEIVED
JAN 29 2003
By RPF/

Pre-Excavation Offsite Contract Laboratory Analytical Results for Verification of Field Screening Approach to be used During the VCM of SWMU 21-011(k)

In accordance with Section 4.2 of the VCM Plan for SWMU 21-011(k), Revision 2, 14 soil, tuff and/or sediment samples were collected at SWMU 21-011(k) between August 16 and 21, 2002 and screened in the field in accordance with the Washington Group International's (WGII) SOP 10.15, Rev. 0 *(Use of Gamma Scintillation Detectors for Soil Screening)*. Following this procedure, count rates from each sample were used to calculate estimated cesium-137 (Cs-137) and americium-241 (Am-241) concentrations (pCi/g). For comparison, aliquots of each of the 14 samples were analyzed at the ARS screening laboratory by gamma spectroscopy. The approximate sample locations are shown in the attached map.

Cs-137 and Am-241 results from the two data sets were compared by linear regression. A correlation coefficient of greater than 99.5% was obtained for the Cs-137 data sets. However, the screening method was found to underestimate Cs-137 activity reported from the ARS screening lab by a factor of 2.4593, (i.e., fixed lab results = 2.4593 x screening results). This empirical correction will be incorporated into the calculation used to estimate Cs-137 concentrations in accordance with WGII SOP 10.15, Rev 0.

A correlation coefficient of 94% was obtained for the Am-241 data sets. The screening method was found to underestimate Am-241 activity from the ARS screening lab results by a factor of 1.5039. This empirical correction will be incorporated into the calculation used to estimate Am-241 concentrations in accordance with WGII SOP 10.15, Rev 0. With the correction factors applied to the screening results, the accuracy and precision of the screening procedure are deemed sufficient to guide excavation of contaminated material in the field during implementation of the VCM at SWMU 21-011(k).

For final confirmation of the SOP 10.15, Rev. 0 procedure, a subset of the 14 soil samples discussed above was submitted to Severn-Trent Laboratories for offsite contract laboratory analysis. Linear regression was performed using the field screening data ***after applying the correction factors, as stated above***. The Severn-Trent gamma spectroscopy results for Cs-137 and Am-241 are presented below in Table 1. Linear regression of the Cs-137 and Am-241 data sets yielded the following results: 1) use of the screening data overestimates Cs-137 activity by approximately 31%, and 2) use of the screening data overestimates Am-241 activity by approximately 34%.

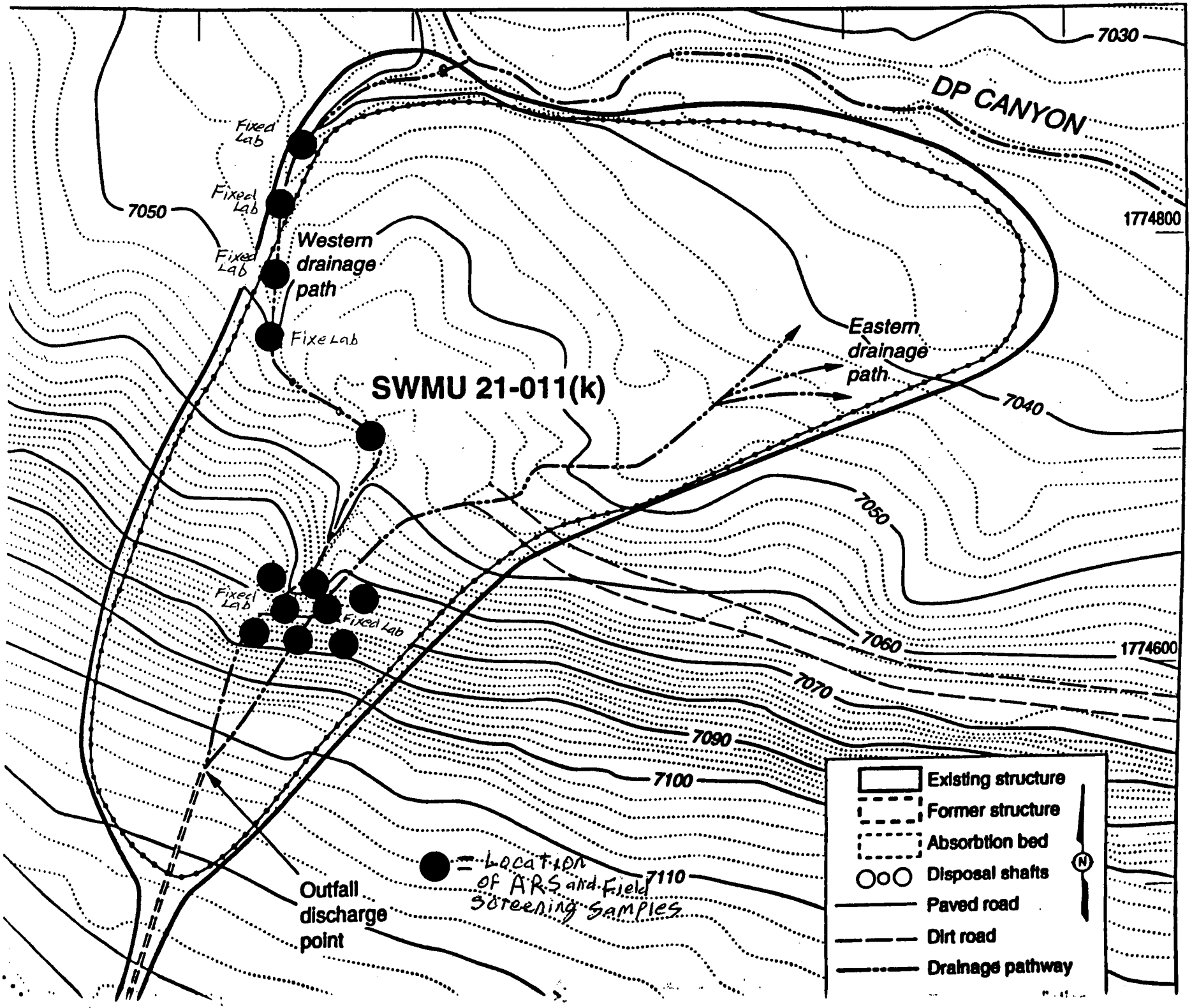
The second comparison indicates that correction factors derived in the first analysis were larger than necessary. However, use of these factors with screening results will result in overestimation of Cs-137 and Am-241 activity in the field and ensure that the cleanup goals (150 pCi/g for Cs-137 and 170 pCi/g for Am-241) will be met. Specifically, when the screening results indicate that a cleanup goal has been achieved, offsite contract laboratory results for post-excavation confirmation samples should indicate that the residual activity level is actually lower than the cleanup goal.

Table 1: Offsite Contract Laboratory Pre-Excavation Gamma Spectroscopy Results for Americium-241 and Cesium-137

		Severn-Trent Results for Cs-137 pCi/g	Severn-Trent Results for Am-241 pCi/g
Location ID	**Sample ID**		
21-02-19961	21-02-49373	10	12
21-02-19962	21-02-49374	2	3
21-02-19963	21-02-49375	24	73
21-02-19964	21-02-49376	13	23
21-02-19967	21-02-49377	72	184
21-02-19967	21-02-49378	82	281
21-02-19969	21-02-49380	384	211
21-02-19970	21-02-49381	166	32

Pre-Excavation Offsite Contract Laboratory Analytical Results for Verification of Field Screening Approach to be used During the VCM of SWMU 21-011(k)

Copies of the Severn-Trent gamma spectroscopy analytical data for Cs-137 and Am-241 are attached. The screening and offsite contract laboratory analytical results discussed herein will be included in the VCM completion report for SWMU 21-011(k) in addition to correlation coefficients from the post excavation screening and confirmation sample analytical results.



VCM Plan for SWI

Data Validation Cover Sheet

Section I. Data Record Package Identification

Request Number: 1186S Validation Date: 04-Nov-02 Lab Code: _____

Contract Laboratory Name: Severn- Trent- St. Louis

Validator: Keith Greene Organization: RRES

Analytical Suite(s): (check all that apply)

- ☐ Volatile Organics
- ☐ Semivolatile Organics
- ☐ Organochlorine Pesticides/Polychlorinated Biphenyls
- ☐ Other: _____ (describe)
- ☐ High Explosives
- ☐ Inorganics
- ☒ Radiochemistry

Section II. Completeness Check

Yes	No	n/a	(check one)	Yes	No	n/a	(check one)
☒	☐	☐	1. Chain-of-custody form(s)	☒	☐	☐	6. Raw/BSS data
☒	☐	☐	2. Case narrative	☒	☐	☐	7. Quality control forms
☒	☐	☐	3. Sample result forms	☒	☐	☐	8. Quantitation reports
☐	☐	☒	4. Sample chromatograms	☐	☐	☒	9. TICs forms
☐	☐	☒	5. Standard chromatograms	☐	☐	☒	10. TICs mass spectra

Identify any samples in the assigned Request Number that are missing:

_____ _____ _____ _____ _____ _____ _____ _____

_____ _____ _____ _____ _____ _____ _____ _____

Comments/problems noted (include information about requests for further information submitted to the contract laboratory and agreed upon date of resolution and contract laboratory point of contact): ISOPU - All Qc within limits.

Sr-90 - All QC within limits.

Gamma spec - results qualified not detected (U, R5) because results were less than the MDC. Several analytes qaulifed as not detected (U, R11) because the results were less than 3 times the total propagated uncertainty.

All other QC within limits.

(Attach additional comment sheets as necessary)

Validator's signature: _____ Date: 11/4/02

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49380

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110280-001
Work Order: E73P4
Matrix: SOLID

Date Collected: 09/06/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	211		13	1	0.0	09/13/02	09/17/02	2256499	
Antimony 125	0.70 U, R5	U	0.68	2.3	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	2.5	U	1.3	4.3	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	1.11 U, R11		0.40	0.96	0.0	09/13/02	09/17/02	2256499	
Cadmium 109	0.3 U, R5	U	2.1	6.8	0.0	09/13/02	09/17/02	2256499	
Cerium 139	0.11	U	0.11	0.37	0.0	09/13/02	09/17/02	2256499	
Cesium 134	0.13	U	0.14	0.43	0.0	09/13/02	09/17/02	2256499	
Cesium 137	384		21	0.4	0.0	09/13/02	09/17/02	2256499	
Cobalt 60	0.054 U, R5	U	0.044	0.18	0.0	09/13/02	09/17/02	2256499	
Europium 152	0.30	U	0.15	0.72	0.0	09/13/02	09/17/02	2256499	
Europium 154	0.10	U	0.39	1.4	0.0	09/13/02	09/17/02	2256499	
Europium 155	-0.08	U	0.35	1.2	0.0	09/13/02	09/17/02	2256499	
Lead 212	1.33		0.37	0.87	0.0	09/13/02	09/17/02	2256499	
Lead 214	0.82 U, R5	U	0.44	1.4	0.0	09/13/02	09/17/02	2256499	
Mercury 203	0.03	U	0.18	0.62	0.0	09/13/02	09/17/02	2256499	
Potassium 40	31.8		2.4	0.8	0.0	09/13/02	09/17/02	2256499	
Protactinium 233	0.49 U, R5	U	0.34	1.2	0.0	09/13/02	09/17/02	2256499	
Radium (226)	1.11 U, R11		0.39	0.96	0.0	09/13/02	09/17/02	2256499	
Radium 228	1.57 U, R5	U	0.30	1.6	0.0	09/13/02	09/17/02	2256499	
Radium 223	-1.5	U	1.5	4.9	0.0	09/13/02	09/17/02	2256499	
Radium 224	6.0	U	3.9	10	0.0	09/13/02	09/17/02	2256499	
Ruthenium 106	-0.02	U	1.3	4.2	0.0	09/13/02	09/17/02	2256499	
Sodium 22	-0.035	U	0.048	0.17	0.0	09/13/02	09/17/02	2256499	
Strontium 85	-0.30	U	0.19	0.63	0.0	09/13/02	09/17/02	2256499	
Thallium 208	0.41	U	0.17	0.53	0.0	09/13/02	09/17/02	2256499	
Thorium 227	0.8	U	1.2	3.3	0.0	09/13/02	09/17/02	2256499	
Thorium 231	1.1	U	1.1	3.8	0.0	09/13/02	09/17/02	2256499	
Thorium 234	-0.3	U	1.4	4.5	0.0	09/13/02	09/17/02	2256499	
Tin 113	-0.10	U	0.29	0.95	0.0	09/13/02	09/17/02	2256499	
Uranium 235	-0.25	U	0.73	2.5	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	0.012	U	0.021	0.11	0.0	09/13/02	09/17/02	2256499	
--- Other Detected Radionuclides ---									
Thorium 232	1.62		0.40	1.4	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	141		13	0.8	3	09/16/02	09/27/02	2259564	87
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	12.3		1.2	0.02	0.006	10/09/02	10/17/02	2280439	97
Plutonium 239/40	52.3		5.0	0.006	0.0	10/09/02	10/17/02	2280439	97

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49381

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110280-002
Work Order: E73QQ
Matrix: SOLID

Date Collected: 09/06/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	**32.4**		**2.1**	**0.7**	**0.0**	**09/13/02**	**09/17/02**	**2256499**	
Antimony 125	-0.34	U	0.47	1.5	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	2.26	U	0.85	2.9	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	**1.01**		**0.26**	**0.71**	**0.0**	**09/13/02**	**09/17/02**	**2256499**	
Cadmium 109	1.6	U	1.5	5.0	0.0	09/13/02	09/17/02	2256499	
Cerium 139	0.047	U	0.076	0.26	0.0	09/13/02	09/17/02	2256499	
Cesium 134	-0.289	U	0.0997	0.25	0.0	09/13/02	09/17/02	2256499	
Cesium 137	**166**		**11**	**0.3**	**0.0**	**09/13/02**	**09/17/02**	**2256499**	
Cobalt 60	-0.014	U	0.040	0.16	0.0	09/13/02	09/17/02	2256499	
Europium 152	-0.12	U	0.18	0.64	0.0	09/13/02	09/17/02	2256499	
Europium 154	0.12	U	0.31	1.2	0.0	09/13/02	09/17/02	2256499	
Europium 155	0.06	U	0.24	0.82	0.0	09/13/02	09/17/02	2256499	
Lead 212	**1.06**		**0.21**	**0.60**	**0.0**	**09/13/02**	**09/17/02**	**2256499**	
Lead 214	0.48	U	0.28	0.94	0.0	09/13/02	09/17/02	2256499	
Mercury 203	0.11	U	0.13	0.43	0.0	09/13/02	09/17/02	2256499	
Potassium 40	**28.4**		**2.2**	**0.9**	**0.0**	**09/13/02**	**09/17/02**	**2256499**	
Protactinium 233	-0.20	U	0.23	0.77	0.0	09/13/02	09/17/02	2256499	
Radium (226)	**1.00**		**0.26**	**0.71**	**0.0**	**09/13/02**	**09/17/02**	**2256499**	
Radium 228	1.02	U	0.35	1.2	0.0	09/13/02	09/17/02	2256499	
Radium 223	-0.8	U	1.0	3.3	0.0	09/13/02	09/17/02	2256499	
Radium 224	**14.5**		**4.8**	**7.4**	**0.0**	**09/13/02**	**09/17/02**	**2256499**	
Ruthenium 106	-0.68	U	0.79	2.7	0.0	09/13/02	09/17/02	2256499	
Sodium 22	0.028	U	0.036	0.14	0.0	09/13/02	09/17/02	2256499	
Strontium 85	0.17	U	0.13	0.44	0.0	09/13/02	09/17/02	2256499	
Thallium 208	**0.69**		**0.16**	**0.33**	**0.0**	**09/13/02**	**09/17/02**	**2256499**	
Thorium 227	-0.91	U	0.82	2.3	0.0	09/13/02	09/17/02	2256499	
Thorium 231	-1.14	U	0.81	2.7	0.0	09/13/02	09/17/02	2256499	
Thorium 234	2.17	U	0.996	3.4	0.0	09/13/02	09/17/02	2256499	
Tin 113	0.12	U	0.19	0.64	0.0	09/13/02	09/17/02	2256499	
Uranium 235	-0.52	U	0.54	1.7	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	0.019	U	0.028	0.13	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	3.43		0.37	0.63	0.43	09/16/02	09/26/02	2259564	79
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	3.39		0.33	0.02	0.009	10/09/02	10/17/02	2280439	95
Plutonium 239/40	16.2	•	1.5	0.03	0.01	10/09/02	10/17/02	2280439	95

NOTE(S)

Data are incomplete without the case narrative.

MDC is determined by instrument performance only.
Bold results are greater than the MDC
U Result is less than the sample detection limit.

CHAIN OF CUSTODY DOCUMENT NUMBER: 1186SC

Los Alamos
NATIONAL LABORATORY

REQUEST NUMBER: 1186S

ANALYSIS TYPE: RAD

ATTN: Mark Loeb
Severn Trent Laboraties, Inc., St. Louis
13715 Rider Trail N.
Earth City, MO 63045

SAMPLE ID	CONT ID	CONTAINER DESCRIPTION	ORDER TEMPLATE CODE	PRESERVATIVE	MATRIX
MD21-02-49380	2	1 L POLY	GS+ISOPU+SR90	NONE	S
MD21-02-49381	2	1 L POLY	GS+ISOPU+SR90	NONE	S

Final Page of CHAIN OF CUSTODY DOCUMENT FOR REQUEST NUMBER 1186S

linquished By:		Date	Time	Received By:		Date	Time
Padilla	[illegible]	9/10/02	1400	CHAS CLIFFORD	[illegible]	9/11/02	0900
NTED NAME	SIGNATURE			PRINTED NAME	SIGNATURE		
NTED NAME	SIGNATURE			PRINTED NAME	SIGNATURE		
ITED NAME	SIGNATURE			PRINTED NAME	SIGNATURE		

eived for DISPOSAL By:		Date	Time	Remarks:
TED NAME	SIGNATURE			

T# F2T110280

Data Validation Cover Sheet

Section I. Data Record Package Identification

Request Number: 1182S Validation Date: 04-Nov-02 Lab Code: _____

Contract Laboratory Name: Severn- Trent- St. Louis

Validator: Keith Greene Organization: RRES

Analytical Suite(s): (check all that apply)

- ☐ Volatile Organics
- ☐ Semivolatile Organics
- ☐ Organochlorine Pesticides/Polychlorinated Biphenyls
- ☐ Other: _____ (describe)
- ☐ High Explosives
- ☐ Inorganics
- ☒ Radiochemistry

Section II. Completeness Check

Yes	No	n/a	(check one)	Yes	No	n/a	(check one)
☒	☐	☐	1. Chain-of-custody form(s)	☒	☐	☐	6. Raw/BSS data
☒	☐	☐	2. Case narrative	☒	☐	☐	7. Quality control forms
☒	☐	☐	3. Sample result forms	☒	☐	☐	8. Quantitation reports
☐	☐	☒	4. Sample chromatograms	☐	☐	☒	9. TICs forms
☐	☐	☒	5. Standard chromatograms	☐	☐	☒	10. TICs mass spectra

Identify any samples in the assigned Request Number that are missing:

_____ _____ _____ _____ _____ _____ _____ _____

_____ _____ _____ _____ _____ _____ _____ _____

Comments/problems noted (include information about requests for further information submitted to the contract laboratory and agreed upon date of resolution and contract laboratory point of contact): ISOPU - Results qualified as not detected (U, R5) because result was less than the MDC.

Sr-90 - Results qualified as not detected (U, R5) because result was less than the MDC.

Gamma spec - results qualified not detected (U, R5) because results were less than the MDC. Several analytes qaulifed as not detected (U, R11) because the results were less than 3 times the total propagated uncertainty.

All other QC within limits.

(Attach additional comment sheets as necessary)

Validator's signature: _____ Date: 11/4/02

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49373

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110288-001
Work Order: E73RW
Matrix: SOLID

Date Collected: 08/15/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	11.9		0.73	0.36	0.0	09/13/02	09/17/02	2256499	
Antimony 125	0.06	U, R5 U	0.22	0.79	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	4.33		0.55	1.9	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	1.16		0.16	0.59	0.0	09/13/02	09/17/02	2256499	
Cadmium 109	10.2		2.8	7.7	0.0	09/13/02	09/17/02	2256499	
Cerium 139	1.3	U, R5 U	1.2	4.3	0.0	09/13/02	09/17/02	2256499	
Cesium 134	0.025	U	0.075	0.26	0.0	09/13/02	09/17/02	2256499	
Cesium 137	9.90		0.61	0.14	0.0	09/13/02	09/17/02	2256499	
Cobalt 60	0.036	U, R5 U	0.044	0.19	0.0	09/13/02	09/17/02	2256499	
Europium 152	0.12	U	0.11	0.58	0.0	09/13/02	09/17/02	2256499	
Europium 154	-0.16	U	0.35	1.3	0.0	09/13/02	09/17/02	2256499	
Europium 155	0.006	U	0.13	0.47	0.0	09/13/02	09/17/02	2256499	
Lead 212	3.22		0.28	0.44	0.0	09/13/02	09/17/02	2256499	
Lead 214	1.34		0.17	0.59	0.0	09/13/02	09/17/02	2256499	
Mercury 203	3100	U, R11	3200	0.0	0.0	09/13/02	09/17/02	2256499	
Potassium 40	26.2		2.2	1.3	0.0	09/13/02	09/17/02	2256499	
Protactinium 233	-0.155	U, R5 U	0.081	0.26	0.0	09/13/02	09/17/02	2256499	
Radium (226)	1.25		0.10	0.27	0.0	09/13/02	09/17/02	2256499	
Radium 228	1.35	U, R5 U	0.40	1.7	0.0	09/13/02	09/17/02	2256499	
Radium 223	-0.04	U	0.40	1.4	0.0	09/13/02	09/17/02	2256499	
Radium 224	3.7	U	1.4	4.9	0.0	09/13/02	09/17/02	2256499	
Ruthenium 106	-1	U	1.4	4.9	0.0	09/13/02	09/17/02	2256499	
Sodium 22	-0.008	U	0.079	0.30	0.0	09/13/02	09/17/02	2256499	
Strontium 85	-470	U	170	0.0	0.0	09/13/02	09/17/02	2256499	
Thallium 208	1.04		0.16	0.60	0.0	09/13/02	09/17/02	2256499	
Thorium 227	-0.11	U, R5 U	0.31	0.92	0.0	09/13/02	09/17/02	2256499	
Thorium 231	0.36	U	0.38	1.3	0.0	09/13/02	09/17/02	2256499	
Thorium 234	0.56	U	0.45	1.7	0.0	09/13/02	09/17/02	2256499	
Tin 113	-1	U	5.1	18	0.0	09/13/02	09/17/02	2256499	
Uranium 235	0.09	U	0.21	0.72	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	1.6	U	4.0	19	0.0	09/13/02	09/17/02	2256499	
--- Other Detected Radionuclides ---									
Actinium 228	1.76		0.32	0.64	0.0	09/13/02	09/17/02	2256499	
Thorium 232	1.39		0.21	0.38	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	4.04		0.58	0.94	0.37	09/16/02	09/26/02	2259564	51
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	0.483		0.055	0.020	0.007	10/09/02	10/17/02	2280439	85
Plutonium 239/40	1.59		0.16	0.02	0.006	10/09/02	10/17/02	2280439	85

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49374

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110288-002
Work Order: E73TG
Matrix: SOLID

Date Collected: 08/15/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	3.27		0.26	0.29	0.0	09/13/02	09/17/02	2256499	
Antimony 125	-0.34 U, RS	U	0.15	0.48	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	4.50		0.49	1.6	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	1.20		0.14	0.29	0.0	09/13/02	09/17/02	2256499	
Cadmium 109	9.9		1.6	5.8	0.0	09/13/02	09/17/02	2256499	
Cerium 139	-1.1 U, RS	U	1.1	3.8	0.0	09/13/02	09/17/02	2256499	
Cesium 134	-0.051	U	0.087	0.25	0.0	09/13/02	09/17/02	2256499	
Cesium 137	1.70		0.17	0.16	0.0	09/13/02	09/17/02	2256499	
Cobalt 60	-0.035 U, RS	U	0.058	0.21	0.0	09/13/02	09/17/02	2256499	
Europium 152	0.12	U	0.19	0.78	0.0	09/13/02	09/17/02	2256499	
Europium 154	-0.49	U	0.31	1.0	0.0	09/13/02	09/17/02	2256499	
Europium 155	0.19	U	0.12	0.42	0.0	09/13/02	09/17/02	2256499	
Lead 212	3.34		0.26	0.35	0.0	09/13/02	09/17/02	2256499	
Lead 214	1.35		0.099	0.21	0.0	09/13/02	09/17/02	2256499	
Mercury 203	1300 U, R11		2500	0.0	0.0	09/13/02	09/17/02	2256499	
Potassium 40	35.7		2.8	1.4	0.0	09/13/02	09/17/02	2256499	
Protactinium 233	-0.011 U, RS	U	0.057	0.20	0.0	09/13/02	09/17/02	2256499	
Radium (226)	1.04		0.15	0.52	0.0	09/13/02	09/17/02	2256499	
Radium 228	1.53 U, RS	U	0.55	1.8	0.0	09/13/02	09/17/02	2256499	
Radium 223	0.23	U	0.35	1.2	0.0	09/13/02	09/17/02	2256499	
Radium 224	6.4	U	2.1	7.9	0.0	09/13/02	09/17/02	2256499	
Ruthenium 106	0.2	U	1.4	5.1	0.0	09/13/02	09/17/02	2256499	
Sodium 22	-0.059	U	0.087	0.30	0.0	09/13/02	09/17/02	2256499	
Strontium 85	-230	U	130	0.0	0.0	09/13/02	09/17/02	2256499	
Thallium 208	1.16		0.18	0.54	0.0	09/13/02	09/17/02	2256499	
Thorium 227	0.38 U, RS	U	0.27	0.83	0.0	09/13/02	09/17/02	2256499	
Thorium 231	0.23	U	0.33	1.2	0.0	09/13/02	09/17/02	2256499	
Thorium 234	2.19		0.36	1.6	0.0	09/13/02	09/17/02	2256499	
Tin 113	7.9 U, RS	U	4.0	15	0.0	09/13/02	09/17/02	2256499	
Uranium 235	0.153	U	0.077	0.56	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	-1.3	U	4.7	19	0.0	09/13/02	09/17/02	2256499	
--- Other Detected Radionuclides ---									
Actinium 228	1.56		0.24	0.55	0.0	09/13/02	09/17/02	2256499	
Thorium 232	1.56		0.23	0.34	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	11.1		1.1	0.5	0.7	09/16/02	09/26/02	2259564	88
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	0.187		0.025	0.011	0.003	10/09/02	10/17/02	2280439	91
Plutonium 239/40	0.934		0.097	0.011	0.003	10/09/02	10/17/02	2280439	91

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49375

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110288-003
Work Order: E73TN
Matrix: SOLID

Date Collected: 08/14/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	72.7		4.5	0.7	0.0	09/13/02	09/17/02	2256499	
Antimony 125	0.63 U, RS	U	0.35	1.2	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	3.31		0.61	1.9	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	0.60 U, R11		0.21	0.56	0.0	09/13/02	09/17/02	2256499	
Cadmium 109	6.9 U, RS	U	3.3	8.0	0.0	09/13/02	09/17/02	2256499	
Cerium 139	-0.8	U	1.6	5.4	0.0	09/13/02	09/17/02	2256499	
Cesium 134	-0.04	U	0.11	0.32	0.0	09/13/02	09/17/02	2256499	
Cesium 137	24.2		1.7	0.2	0.0	09/13/02	09/17/02	2256499	
Cobalt 60	0.015 U, RS	U	0.060	0.25	0.0	09/13/02	09/17/02	2256499	
Europium 152	0.24	U	0.19	0.85	0.0	09/13/02	09/17/02	2256499	
Europium 154	-0.51	U	0.36	1.2	0.0	09/13/02	09/17/02	2256499	
Europium 155	0.08	U	0.16	0.56	0.0	09/13/02	09/17/02	2256499	
Lead 212	2.35		0.34	0.71	0.0	09/13/02	09/17/02	2256499	
Lead 214	1.02		0.19	0.58	0.0	09/13/02	09/17/02	2256499	
Mercury 203	3000 U, R11		4300	0.0	0.0	09/13/02	09/17/02	2256499	
Potassium 40	26.5		2.1	0.9	0.0	09/13/02	09/17/02	2256499	
Protactinium 233	-0.1 U, RS	U	0.11	0.36	0.0	09/13/02	09/17/02	2256499	
Radium (226)	0.90		0.12	0.36	0.0	09/13/02	09/17/02	2256499	
Radium 228	0.78 U, RS	U	0.34	1.1	0.0	09/13/02	09/17/02	2256499	
Radium 223	0.59	U	0.53	1.8	0.0	09/13/02	09/17/02	2256499	
Radium 224	29.7		9.0	11	0.0	09/13/02	09/17/02	2256499	
Ruthenium 106	-2.7 U, RS	U	1.8	5.8	0.0	09/13/02	09/17/02	2256499	
Sodium 22	0.150	U	0.082	0.34	0.0	09/13/02	09/17/02	2256499	
Strontium 85	-610	U	210	0.0	0.0	09/13/02	09/17/02	2256499	
Thallium 208	1.34		0.21	0.64	0.0	09/13/02	09/17/02	2256499	
Thorium 227	0.52 U, RS	U	0.42	1.2	0.0	09/13/02	09/17/02	2256499	
Thorium 231	-0.58	U	0.52	1.5	0.0	09/13/02	09/17/02	2256499	
Thorium 234	1.18	U	0.56	2.0	0.0	09/13/02	09/17/02	2256499	
Tin 113	-3.1	U	7.9	27	0.0	09/13/02	09/17/02	2256499	
Uranium 235	-0.17	U	0.26	0.85	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	4.6	U	4.0	20	0.0	09/13/02	09/17/02	2256499	
--- Other Detected Radionuclides ---									
Actinium 228	1.39		0.30	0.57	0.0	09/13/02	09/17/02	2256499	
Thorium 232	1.79		0.28	0.55	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	4.21		0.77	0.59	0.41	09/16/02	09/26/02	2259564	76
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	3.79		0.36	0.01	0.004	10/09/02	10/17/02	2280439	110
Plutonium 239/40	11.8		1.1	0.004	0.0	10/09/02	10/17/02	2280439	110

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49376

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110288-004
Work Order: E73TQ
Matrix: SOLID

Date Collected: 08/14/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	23.3		1.5	0.5	0.0	09/13/02	09/17/02	2256499	
Antimony 125	-0.35 U, RS	U	0.25	0.85	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	4.20		0.59	1.8	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	1.15		0.18	0.61	0.0	09/13/02	09/17/02	2256499	
Cadmium 109	5.5 U, RS	U	4.8	7.9	0.0	09/13/02	09/17/02	2256499	
Cerium 139	-1	U	1.3	4.4	0.0	09/13/02	09/17/02	2256499	
Cesium 134	-0.036	U	0.087	0.26	0.0	09/13/02	09/17/02	2256499	
Cesium 137	12.5		0.75	0.17	0.0	09/13/02	09/17/02	2256499	
Cobalt 60	-0.048 U, RS	U	0.053	0.19	0.0	09/13/02	09/17/02	2256499	
Europium 152	-0.004	U	0.19	0.76	0.0	09/13/02	09/17/02	2256499	
Europium 154	-0.09	U	0.35	1.3	0.0	09/13/02	09/17/02	2256499	
Europium 155	0.13	U	0.14	0.48	0.0	09/13/02	09/17/02	2256499	
Lead 212	3.56		0.31	0.53	0.0	09/13/02	09/17/02	2256499	
Lead 214	1.30		0.18	0.57	0.0	09/13/02	09/17/02	2256499	
Mercury 203	3700 U, R11		3300	0.0	0.0	09/13/02	09/17/02	2256499	
Potassium 40	28.8		2.3	0.9	0.0	09/13/02	09/17/02	2256499	
Protactinium 233	0.106 U, RS	U	0.085	0.31	0.0	09/13/02	09/17/02	2256499	
Radium (226)	1.31		0.11	0.26	0.0	09/13/02	09/17/02	2256499	
Radium 228	0.63 U, RS	U	0.38	1.0	0.0	09/13/02	09/17/02	2256499	
Radium 223	0.33	U	0.43	1.5	0.0	09/13/02	09/17/02	2256499	
Radium 224	3.1	U	1.4	5.3	0.0	09/13/02	09/17/02	2256499	
Ruthenium 106	1.4	U	1.4	5.5	0.0	09/13/02	09/17/02	2256499	
Sodium 22	0.015	U	0.069	0.28	0.0	09/13/02	09/17/02	2256499	
Strontium 85	-410	U	170	0.0	0.0	09/13/02	09/17/02	2256499	
Thallium 208	1.11		0.18	0.65	0.0	09/13/02	09/17/02	2256499	
Thorium 227	-0.03 U, RS	U	0.33	0.96	0.0	09/13/02	09/17/02	2256499	
Thorium 231	-0.006	U	0.43	1.3	0.0	09/13/02	09/17/02	2256499	
Thorium 234	1.70	U	0.58	1.9	0.0	09/13/02	09/17/02	2256499	
Tin 113	-10.6	U	6.2	20	0.0	09/13/02	09/17/02	2256499	
Uranium 235	0.33	U	0.21	0.75	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	1.8	U	4.1	20	0.0	09/13/02	09/17/02	2256499	
--- Other Detected Radionuclides ---									
Actinium 228	1.94		0.32	0.61	0.0	09/13/02	09/17/02	2256499	
Thorium 232	1.48		0.24	0.42	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	7.44		0.55	0.84	0.51	09/16/02	09/26/02	2259564	59
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	1.30		0.13	0.01	0.004	10/09/02	10/17/02	2280439	92
Plutonium 239/40	7.03		0.67	0.01	0.004	10/09/02	10/17/02	2280439	92

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49377

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110288-005
Work Order: E73TV
Matrix: SOLID

Date Collected: 08/14/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	184		11	1	0.0	09/13/02	09/17/02	2256499	
Antimony 125	0.51	U, RS U	0.53	1.8	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	3.34		0.70	2.5	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	1.06		0.22	0.67	0.0	09/13/02	09/17/02	2256499	
Cadmium 109	5.0	U, RS U	4.0	12	0.0	09/13/02	09/17/02	2256499	
Cerium 139	-0.9	U	2.4	8.0	0.0	09/13/02	09/17/02	2256499	
Cesium 134	0.19	U	0.14	0.44	0.0	09/13/02	09/17/02	2256499	
Cesium 137	72.4		4.1	0.3	0.0	09/13/02	09/17/02	2256499	
Cobalt 60	-0.003	U, RS U	0.046	0.19	0.0	09/13/02	09/17/02	2256499	
Europium 152	0.32	U	0.24	1.0	0.0	09/13/02	09/17/02	2256499	
Europium 154	0.04	U	0.32	1.2	0.0	09/13/02	09/17/02	2256499	
Europium 155	0.03	U	0.23	0.78	0.0	09/13/02	09/17/02	2256499	
Lead 212	2.82		0.43	0.94	0.0	09/13/02	09/17/02	2256499	
Lead 214	1.03		0.22	0.79	0.0	09/13/02	09/17/02	2256499	
Mercury 203	-9500	U, RS U	6200	0.0	0.0	09/13/02	09/17/02	2256499	
Potassium 40	27.8		2.3	1.4	0.0	09/13/02	09/17/02	2256499	
Protactinium 233	-0.03	U, RS U	0.16	0.54	0.0	09/13/02	09/17/02	2256499	
Radium (226)	1.05		0.22	0.67	0.0	09/13/02	09/17/02	2256499	
Radium 228	1.00	U, RS U	0.28	1.0	0.0	09/13/02	09/17/02	2256499	
Radium 223	0.26	U	0.74	2.5	0.0	09/13/02	09/17/02	2256499	
Radium 224	10.7	U	4.8	11	0.0	09/13/02	09/17/02	2256499	
Ruthenium 106	-0.9	U	2.8	9.6	0.0	09/13/02	09/17/02	2256499	
Sodium 22	0.006	U	0.081	0.31	0.0	09/13/02	09/17/02	2256499	
Strontium 85	-760	U	300	0.0	0.0	09/13/02	09/17/02	2256499	
Thallium 208	0.79		0.26	0.75	0.0	09/13/02	09/17/02	2256499	
Thorium 227	-0.43	U, RS U	0.61	1.7	0.0	09/13/02	09/17/02	2256499	
Thorium 231	-1.10	U	0.63	2.0	0.0	09/13/02	09/17/02	2256499	
Thorium 234	1.40	U	0.79	2.5	0.0	09/13/02	09/17/02	2256499	
Tin 113	-16	U	12	41	0.0	09/13/02	09/17/02	2256499	
Uranium 235	0.36	U	0.14	1.3	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	-1.9	U	3.2	13	0.0	09/13/02	09/17/02	2256499	
--- Other Detected Radionuclides ---									
Actinium 228	1.20		0.39	0.80	0.0	09/13/02	09/17/02	2256499	
Thorium 232	1.36		0.31	0.68	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	34.5		5.2	0.7	1.0	09/16/02	09/26/02	2259564	71
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	8.74		0.82	0.004	0.0	10/09/02	10/17/02	2280439	93
Plutonium 239/40	24.1		2.2	0.004	0.0	10/09/02	10/17/02	2280439	93

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49378

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110288-006
Work Order: E73TW
Matrix: SOLID

Date Collected: 08/14/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	281		17	1	0.0	09/13/02	09/17/02	2256499	
Antimony 125	0.84	U, RS U	0.58	1.9	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	3.2	U, R11	1.1	2.5	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	0.76		0.20	0.59	0.0	09/13/02	09/17/02	2256499	
Cadmium 109	-4.2	U, RS U	3.6	12	0.0	09/13/02	09/17/02	2256499	
Cerium 139	-0.4	U	2.5	8.5	0.0	09/13/02	09/17/02	2256499	
Cesium 134	0.28	U	0.13	0.41	0.0	09/13/02	09/17/02	2256499	
Cesium 137	81.6		5.5	0.2	0.0	09/13/02	09/17/02	2256499	
Cobalt 60	-0.061	U, RS U	0.057	0.21	0.0	09/13/02	09/17/02	2256499	
Europium 152	0.19	U	0.20	0.83	0.0	09/13/02	09/17/02	2256499	
Europium 154	0.46	U	0.37	1.5	0.0	09/13/02	09/17/02	2256499	
Europium 155	0.07	U	0.25	0.84	0.0	09/13/02	09/17/02	2256499	
Lead 212	2.56		0.48	1.0	0.0	09/13/02	09/17/02	2256499	
Lead 214	0.98	U, R11	0.34	0.76	0.0	09/13/02	09/17/02	2256499	
Mercury 203	7500		6600	0.0	0.0	09/13/02	09/17/02	2256499	
Potassium 40	28.6		2.2	1	0.0	09/13/02	09/17/02	2256499	
Protactinium 233	0.05	U, RS U	0.19	0.56	0.0	09/13/02	09/17/02	2256499	
Radium (226)	0.75		0.20	0.58	0.0	09/13/02	09/17/02	2256499	
Radium 228	1.22	U, RS U	0.44	1.7	0.0	09/13/02	09/17/02	2256499	
Radium 223	-0.71	U	0.81	2.7	0.0	09/13/02	09/17/02	2256499	
Radium 224	34		11	13	0.0	09/13/02	09/17/02	2256499	
Ruthenium 106	-0.03	U, RS U	2.4	8.5	0.0	09/13/02	09/17/02	2256499	
Sodium 22	-0.043	U	0.079	0.28	0.0	09/13/02	09/17/02	2256499	
Strontium 85	-320	U	310	0.0	0.0	09/13/02	09/17/02	2256499	
Thallium 208	0.84		0.22	0.65	0.0	09/13/02	09/17/02	2256499	
Thorium 227	0.46	U, RS U	0.64	1.8	0.0	09/13/02	09/17/02	2256499	
Thorium 231	-0.08	U	0.65	2.2	0.0	09/13/02	09/17/02	2256499	
Thorium 234	1.82	U	0.78	2.7	0.0	09/13/02	09/17/02	2256499	
Tin 113	-23	U	13	43	0.0	09/13/02	09/17/02	2256499	
Uranium 235	0.66	U	0.21	1.3	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	-1.4	U	3.2	13	0.0	09/13/02	09/17/02	2256499	
--- Other Detected Radionuclides ---									
Actinium 228	2.19		0.37	0.55	0.0	09/13/02	09/17/02	2256499	
Thorium 232	1.12		0.29	0.75	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	54.6		3.4	0.8	1.2	09/16/02	09/26/02	2259564	57
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	19.2		1.8	0.01	0.007	10/09/02	10/18/02	2280439	92
Plutonium 239/40	34.9		3.3	0.01	0.005	10/09/02	10/18/02	2280439	92

LOS ALAMOS NATIONAL LABORATORY

Client Sample ID: MD21-02-49379

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2I110288-007
Work Order: E73T0
Matrix: SOLID

Date Collected: 08/15/02 0000
Date Received: 09/11/02 0900

Parameter	Result	Qual	Total Uncert. (1 σ+/-)	MDC	DLC	Prep Date	Analysis Date	Batch #	Yld %
Gamma Cs-137 & Hits by DOE RP-730 MOD				pCi/g		RP-730 MOD			
Americium 241	0.094	U, RS U	0.074	0.27	0.0	09/13/02	09/17/02	2256499	
Antimony 125	0.01	U	0.14	0.52	0.0	09/13/02	09/17/02	2256499	
Bismuth 211	3.71		0.47	1.6	0.0	09/13/02	09/17/02	2256499	
Bismuth 214	1.06		0.15	0.56	0.0	09/13/02	09/17/02	2256499	
Cadmium 109	0.9	U, RS U	2.0	7.2	0.0	09/13/02	09/17/02	2256499	
Cerium 139	1.3	U	1.0	3.8	0.0	09/13/02	09/17/02	2256499	
Cesium 134	-0.024	U	0.064	0.21	0.0	09/13/02	09/17/02	2256499	
Cesium 137	0.604		0.076	0.14	0.0	09/13/02	09/17/02	2256499	
Cobalt 60	-0.099	U, RS U	0.046	0.13	0.0	09/13/02	09/17/02	2256499	
Europium 152	-0.003	U	0.11	0.48	0.0	09/13/02	09/17/02	2256499	
Europium 154	0.48	U	0.34	1.4	0.0	09/13/02	09/17/02	2256499	
Europium 155	0.11	U	0.10	0.38	0.0	09/13/02	09/17/02	2256499	
Lead 212	3.05		0.26	0.32	0.0	09/13/02	09/17/02	2256499	
Lead 214	1.15		0.15	0.51	0.0	09/13/02	09/17/02	2256499	
Mercury 203	-2300	U, RS U	2400	0.0	0.0	09/13/02	09/17/02	2256499	
Potassium 40	30.8		2.4	1.1	0.0	09/13/02	09/17/02	2256499	
Protactinium 233	0.033	U, RS U	0.054	0.20	0.0	09/13/02	09/17/02	2256499	
Radium (226)	1.08		0.091	0.22	0.0	09/13/02	09/17/02	2256499	
Radium 228	1.72	U, RS U	0.42	1.7	0.0	09/13/02	09/17/02	2256499	
Radium 223	0.25	U	0.32	1.2	0.0	09/13/02	09/17/02	2256499	
Radium 224	3.3	U	1.2	3.4	0.0	09/13/02	09/17/02	2256499	
Ruthenium 106	1.1	U	1.2	4.8	0.0	09/13/02	09/17/02	2256499	
Sodium 22	0.070	U	0.070	0.30	0.0	09/13/02	09/17/02	2256499	
Strontium 85	-570	U	130	0.0	0.0	09/13/02	09/17/02	2256499	
Thallium 208	1.04		0.16	0.60	0.0	09/13/02	09/17/02	2256499	
Thorium 227	-0.11	U, RS U	0.20	0.61	0.0	09/13/02	09/17/02	2256499	
Thorium 231	0.43	U	0.33	1.3	0.0	09/13/02	09/17/02	2256499	
Thorium 234	0.96	U	0.41	1.6	0.0	09/13/02	09/17/02	2256499	
Tin 113	6.6	U	4.1	16	0.0	09/13/02	09/17/02	2256499	
Uranium 235	0.120	U	0.067	0.60	0.0	09/13/02	09/17/02	2256499	
Yttrium 88	3.1	U	4.3	21	0.0	09/13/02	09/17/02	2256499	
--- Other Detected Radionuclides ---									
Actinium 228	1.61		0.29	0.49	0.0	09/13/02	09/17/02	2256499	
Thorium 232	1.39		0.21	0.35	0.0	09/13/02	09/17/02	2256499	
SR-90 BY GFPC DOE 7500-SR MOD				pCi/g		7500-SR MOD			
Strontium 90	0.42	U, RS U	0.16	0.58	0.28	09/16/02	09/26/02	2259564	94
Iso PLUTONIUM (LONG CT) NAS & DOE MOD				pCi/g		3058/RP-725			
Plutonium 238	0.0082	U, RS U	0.0048	0.015	0.0092	10/09/02	10/18/02	2280439	91
Plutonium 239/40	0.867		0.088	0.004	0.0	10/09/02	10/18/02	2280439	91

CHAIN OF CUSTODY DOCUMENT NUMBER: 1182SC

Los Alamos
NATIONAL LABORATORY

REQUEST NUMBER: 1182S

ANALYSIS TYPE: RAD

ATTN: Mark Loeb
Severn Trent Laboratories, Inc., St. Louis
13715 Rider Trail N.
Earth City, MO 63045

SAMPLE ID	CONT ID	CONTAINER DESCRIPTION	ORDER TEMPLATE CODE	PRESERVATIVE	MATRIX
MD21-02-49373	2	1 L POLY	GS+ISOPU+SR90	NONE	S
MD21-02-49374	2	1 L POLY	GS+ISOPU+SR90	NONE	S
MD21-02-49375	2	1 L POLY	GS+ISOPU+SR90	NONE	S
MD21-02-49376	2	1 L POLY	GS+ISOPU+SR90	NONE	S
MD21-02-49377	2	1 L POLY	GS+ISOPU+SR90	NONE	S
MD21-02-49378	2	1 L POLY	GS+ISOPU+SR90	NONE	S
MD21-02-49379	2	1 L POLY	GS+ISOPU+SR90	NONE	S

Final Page of CHAIN OF CUSTODY DOCUMENT FOR REQUEST NUMBER 1182S

elinquished By:		Date	Time	Received By:		Date	Time
Padilla	Padilla	9/10/02	1400	CHRIS CLIFFORD		9/11/02	0900
RINTED NAME	SIGNATURE			PRINTED NAME	SIGNATURE		
RINTED NAME	SIGNATURE			PRINTED NAME	SIGNATURE		
RINTED NAME	SIGNATURE			PRINTED NAME	SIGNATURE		

eceived for DISPOSAL By:		Date	Time	Remarks:
INTED NAME	SIGNATURE			

NT# F2T110288

73116

ENVIRONMENTAL RESTORATION PROJECT

Los Alamos National Laboratory (LANL)
Environment Restoration Project (ER)
Records Processing Facility (RPF)
ER Record ID Number Barcode Label

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION
Records Processing Facility
ER Records Index Form

ER ID NO. 73116 ***Date Received:*** 6/12/2002 ***Processor:*** DSV ***Page Count:*** 1

Privileged: (Y/N) N ***Record Category:*** P

FileFolder: N/A

Correction: (Y/N) N ***Corrected No.*** 0 ***Corrected By Number:*** 0

Administrative Record: (Y/N) Y

Refilmed: (Y/N) N ***Old ER ID Number:*** 0 ***New ER ID Number:*** 0

Miscellaneous Comments:

REFERENCE CITATION

#73116

TELECOM/CONVERSATION

Washington/PMC Los Alamos Team
Los Alamos, New Mexico

CALL TO: Harvey Decker ORGANIZATION: formerly with ESH-18 Phone No.: ( ) 667-1616	DATE:6/12/02 Page 1 of 1
CALL FROM: John Crocker ORGANIZATION: PMC Phone No.: ( ) 662-1319	Time:11:00

	Banar, A.		Everett, M.		Wald-Hopkins, M.		Schultz, C.
	Benson, T.		Frank, D.		Kisiel, K.		Shepard, M.
	Calhoun, S.		Funk, A.		Law, J.		Smiroldo, C.
	Causey, L.		Gibson, M.		Lowry, B.		Steven, D.
	Cooney, R.		Gillespie, K		Martorello, D.		Toya, A.
	Crocker, J.		Germain, N.		McFadden, K.		Thompson, D
	Crowder, A.		Gomez, L.		Neeper, D.		Tucker, K.
	Dale, L.		Gray, B.		Newell, D.		Von Bargen, C.
	DeJoia, J.		Gleason, L.		Purdue, S.		Williams, D.
	Drakos, P.		Haaker, R.		Sanchez, S.		Wilson, C.
	Edmonds, R.		Haug, K		Santo, J.		
	Evans, R.		Hill, D.		Schmerber, J.		

TOPIC: PRS 21-011(k) accidental release from tank 21-113 in 2001

SUMMARY OF CONVERSATION: Contacted Mr. Decker to ask about the 2001 release from tank 21-113. He indicated that the source o the water was the TSTA Facility. He indicted that water samples from the tank were collected and rad analysis performed. The results were included in the release report. He further indicated that no soil samples were collected from below the outfall.

COMMENTS MADE/ACTION REQUIRED:

none

Received by ER-ADP
JUN 12 2002

REFERENCES (Documents, Contract, etc.)

NA

C:\Documents and Settings\mlhogg\Desktop\TELECOM_Decker.doc

73115

ENVIRONMENTAL RESTORATION PROJECT

Los Alamos National Laboratory (LANL)
Environment Restoration Project (ER)
Records Processing Facility (RPF)
ER Record ID Number Barcode Label

LOS ALAMOS NATIONAL LABORATORY
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Records Processing Facility
ER Records Index Form

ER ID NO. 73115 ***Date Received:*** 6/12/2002 ***Processor:*** DSV ***Page Count:*** 1

Privileged: (Y/N) N ***Record Category:*** P

FileFolder: N/A

Correction: (Y/N) N ***Corrected No.*** 0 ***Corrected By Number:*** 0

Administrative Record: (Y/N) Y

Refilmed: (Y/N) N ***Old ER ID Number:*** 0 ***New ER ID Number:*** 0

Miscellaneous Comments:

REFERENCE CITATION

(1) #73115

TELECOM/CONVERSATION

Washington/PMC Los Alamos Team
Los Alamos, New Mexico

CALL TO:___Marc Bailey
ORGANIZATION:_____ ESH-18
Phone No.: ( )__665-8135

DATE 5/30/02
Page ___1 of _1__

CALL FROM:_____John Crocker_
ORGANIZATION:_____PMC_____
Phone No.: ( )___662-1319___

Time:

	Banar, A.		Everett, M.		Wald-Hopkins, M.		Schultz, C.
	Benson, T.		Frank, D.		Kisiel, K.		Shepard, M.
	Calhoun, S.		Funk, A.		Law, J.		Smiroldo, C.
	Causey, L.		Gibson, M.		Lowry, B.		Steven, D.
	Cooney, R.		Gillespie, K		Martorello, D.		Toya, A.
	Crocker, J.		Germain, N.		McFadden, K.		Thompson, D
	Crowder, A.		Gomez, L.		Neeper, D.		Tucker, K.
	Dale, L.		Gray, B.		Newell, D.		Von Bargen, C.
	DeJoia, J.		Gleason, L.		Purdue, S.		Williams, D.
	Drakos, P.		Haaker, R.		Sanchez, S.		Wilson, C.
	Edmonds, R.		Haug, K		Santo, J.		
	Evans, R.		Hill, D.		Schmerber, J.		

TOPIC: PRS 21-011(k) outfall

SUMMARY OF CONVERSATION: Mr. Bailey indicated that the outfall became inactive in July of 1986. This date corresponds to the last sample collected from the outfall (also July 1986)

COMMENTS MADE/ACTION REQUIRED:

None

REFERENCES (Documents, Contract, etc.)

NA

Received by ER-RPF
JUN 12 2002

C:\Documents and Settings\mlhogg\Desktop\TELECOM_Bailey.doc

Los Alamos Environmental Restoration Records Processing Facility

ER Record I.D.# 49660

LOS ALAMOS

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ENVIRONMENTAL RESTORATION
Records Processing Facility
ER Record Index Form
RPF USE ONLY

PAGE COUNT: 10

DATE RECEIVED: 09/14/95 PROCESSOR: Dic

RECORD CATEGORY (P/R): P INITIALS: Dic

RECORD PACKAGE NO.: —

FILE FOLDER: —

CORRECTION (Y/N): — CORRECTED NO.: — CORRECTED BY: —

AR (Y/N): Yes INITIALS: Dic

AR DESCRIPTION (D/G): —

PRIVILEGED Y/N: —

ELECTRONIC INDEX INITIALS: Dic

MISCELLANEOUS: OU 1049

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. B6, PAGES 6129–6147, JUNE 10, 1988

RPF

(10)

Restoration of Compositional Zonation in the Bandelier Silicic Magma Chamber Between Two Caldera-Forming Eruptions: Geochemistry and Origin of the Cerro Toledo Rhyolite, Jemez Mountains, New Mexico

JOHN STIX,[1] FRASER GOFF,[2] MICHAEL P. GORTON,[1] GRANT HEIKEN,[2] AND SAMMY R. GARCIA[3]

The Cerro Toledo Rhyolite is a group of high-silica rhyolite domes and tephras that range in age from 1.45 to 1.12 Ma. The unit crops out in the Jemez Mountains of northern New Mexico and lies stratigraphically between the compositionally zoned upper and lower members of the Bandelier Tuff. The Cerro Toledo Rhyolite provides an exceptional opportunity to study the origin of compositional zonation in silicic magma chambers because it allows us to follow the restoration of the zonation with time between these two large caldera-forming ignimbrite eruptions. Based upon stratigraphic, geochronologic, and geochemical evidence, we have correlated different Cerro Toledo Rhyolite tephra units with groups of domes. Early Cerro Toledo Rhyolite domes appear to be located generally along the Toledo caldera ring fracture, whereas younger domes tend to cluster in the Toledo embayment. The Cerro Toledo Rhyolite appears to have tapped the most fractionated liquids at or near the top of the Bandelier magma chamber and records the restoration of compositional gradients over a period of 0.33 m.y. after the Lower Bandelier ignimbrite eruption. Cl, Rb, Cs, heavy rare earth elements, Y, Nb, Th, and U increase in concentration in progressively younger Cerro Toledo Rhyolite rocks. Because of depletions in K/Cs, Sr, Zr, Nb, and La/Yb over the same interval, we favor crystal fractionation of essentially quartz, alkali feldspar, zircon, and a light rare earth element enriched phase (probably allanite) as the primary mechanism by which the compositional gradients were reestablished. We believe diffusive processes did not play an important role because (1) certain cations of widely different valences and diffusivities are not fractionated with respect to each other and (2) the observed chemical gradients conflict with those predicted by recent experimental Soret studies.

INTRODUCTION

The Cerro Toledo Rhyolite is a group of metaluminous high-silica rhyolite domes and associated tephras that crop out in and around the Toledo and Valles calderas in the Jemez Mountains of northern New Mexico. The Toledo and Valles calderas were formed at 1.45 and 1.12 Ma, respectively [*Doell et al.*, 1968; *Smith and Bailey*, 1968; *Smith et al.*, 1970] (Figure 1). The Cerro Toledo Rhyolite consists of silicic lava domes and tephra of fallout and surge origin. The unit is situated stratigraphically between the lower and upper members of the Bandelier Tuff (LBT and UBT, respectively) and is dated at 1.47–1.20 Ma [*Izett et al.*, 1981; *Heiken et al.*, 1986].

In contrast to the LBT and UBT, which are large-volume (250–400 km³) rhyolitic ignimbrites that were erupted geologically instantaneously during caldera collapse and are compositionally zoned, the Cerro Toledo Rhyolite is a product of explosive and effusive intracaldera activity that lasted 0.27–0.33 m.y. during the period between the two cataclysmic Bandelier eruptions. The Cerro Toledo Rhyolite thus occupies the interval between the caldera-forming events and records the restoration of chemical gradients and zonation within the Bandelier magma chamber [*Smith*, 1979]. The Cerro Toledo Rhyolite deposits may represent the products of the most fractionated liquids that collected at the top of the magma chamber. Because the stratigraphy and age of the Cerro Toledo Rhyolite tephra and domes are well known [*Izett et al.*, 1981; *Goff et al.*, 1984; *Heiken et al.*, 1986], we believe these rocks provide a window through which we are able to study the reestablishment of compositional zonation in a silicic magma chamber after a caldera-forming eruption. Ignimbrites only represent snapshots of compositional gradients in a magma chamber at an instant in time; in contrast, the Cerro Toledo Rhyolite allows us to follow the establishment of the gradients over 0.3 m.y., thus providing an opportunity to place much tighter constraints on the mechanisms involved.

It is the purpose of this study to (1) correlate Cerro Toledo Rhyolite domes and tephras by means of stratigraphy, geochemistry, and geochronology, (2) document and discuss geochemical variation of the Cerro Toledo Rhyolite, and (3) discuss the petrogenesis of the Cerro Toledo Rhyolite and the evolution of compositional zonation within the Bandelier magma chamber.

GEOCHRONOLOGY, GEOLOGY, AND MINERALOGY

Toledo domes and tephra are formally named the Cerro Toledo Rhyolite and lie stratigraphically between the LBT (Otowi Member), which was erupted at 1.45 Ma during formation of the Toledo caldera, and the UBT (Tshirege Member), erupted at 1.12 Ma from Valles caldera [*Izett et al.*, 1981] (dates recalculated from *Doell et al.* [1968]). The locations of the Toledo and Valles calderas appear to be nearly coincident [*Goff et al.*, 1984], and both may have formed by asymmetric trapdoor collapse with caldera fill thickening to the east [*Nielson and Hulen*, 1984; *Heiken et al.*, 1986; *Self et al.*, 1986]. The Cerro Toledo Rhyolite domes were first recognized by *Griggs* [1964] and mapped by *Smith et al.* [1970]. The Cerro Toledo Rhyolite tuffs were noted by *Bailey et al.* [1969] and also mapped by *Smith et al.* [1970], *Izett et al.* [1981] and *Heiken*

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[3]Isotope and Nuclear Chemistry Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

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Received by EB RPF
SEP 14 1995
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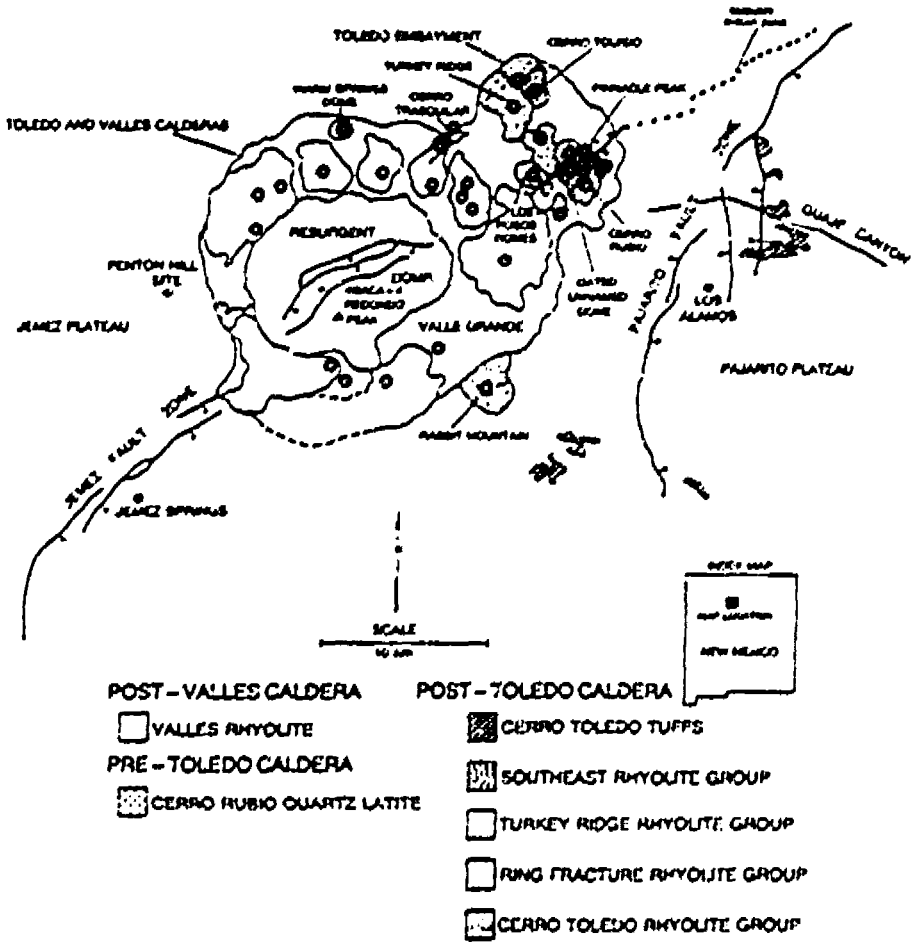


Fig. 1. Map showing the locations of Toledo and Valles calderas and Toledo embayment, Jemez Mountains, New Mexico. Cerro Toledo Rhyolite domes and lavas are shown by the stippled pattern; Cerro Toledo Rhyolite tephras are represented by the cross-hatched pattern. Locations of vents are indicated by the enclosed stars.

et al. [1986] have studied the stratigraphy, volcanology, and geochronology of the Cerro Toledo Rhyolite tephra in detail.

Domes

Cerro Toledo Rhyolite domes are conveniently divided into three groups: (1) A group of four domes, exposed within the north-northeast part of Valles caldera, forms a semicircular outcrop pattern, and is dated at 1.50–1.25 Ma [*Heiken et al.*, 1986] (Figure 1 and Table 1). These domes may represent remnants of ring fracture volcanism in Toledo caldera [*Goff et al.*, 1984; *Self et al.*, 1986] and are referred to herein as the Toledo Ring Fracture (TRF) Group. (2) The second set of domes crops out in the Toledo embayment and consists of the Cerro Toledo (CT) Group, 1.50–1.33 Ma; the Southeast Rhyolite (SR) Group, 1.20 Ma; and the Turkey Ridge (TR) Group, 1.24 Ma (Figure 1 and Table 1). (3) The third locality is Rabbit Mountain (1.47 Ma), a dome and pyroclastics situated on the southeast margin of Valles caldera (Figure 1 and Table 1). Rabbit Mountain petrographically and geochemically resembles domes of the CT and has a similar K-Ar age.

Cerro Rubio quartz latite domes also crop out in the Toledo embayment (Figure 1). These domes are considerably older (2.2–3.6 Ma) than those of the Cerro Toledo Rhyolite (Table 1). The Cerro Rubio domes appear to be part of the Tschicoma Formation, a unit which consists of intermediate-composition lavas and pyroclastics that were erupted at 3.6–6.7 Ma [*Loeffler*, 1984]. These rocks may represent parental magmas of the Cerro Toledo Rhyolite and Bandelier Tuff.

Our ongoing studies have so far shown that Cerro Toledo Rhyolite domes are composed primarily of glass (>90%), with lesser amounts of plagioclase (7–15%), hornblende (≤5%), sanidine and quartz (≤2%), biotite (<1%), and trace amounts of anorthoclase and hypersthene [*Heiken et al.*, 1986].

Tephra

Cerro Toledo Rhyolite tephra consists of Plinian pumice falls, fine-grained phreatomagmatic ash beds of fallout and surge origin that contain accretionary lapilli, and epiclastic sedimentary rocks. Individual tephra units sometimes show

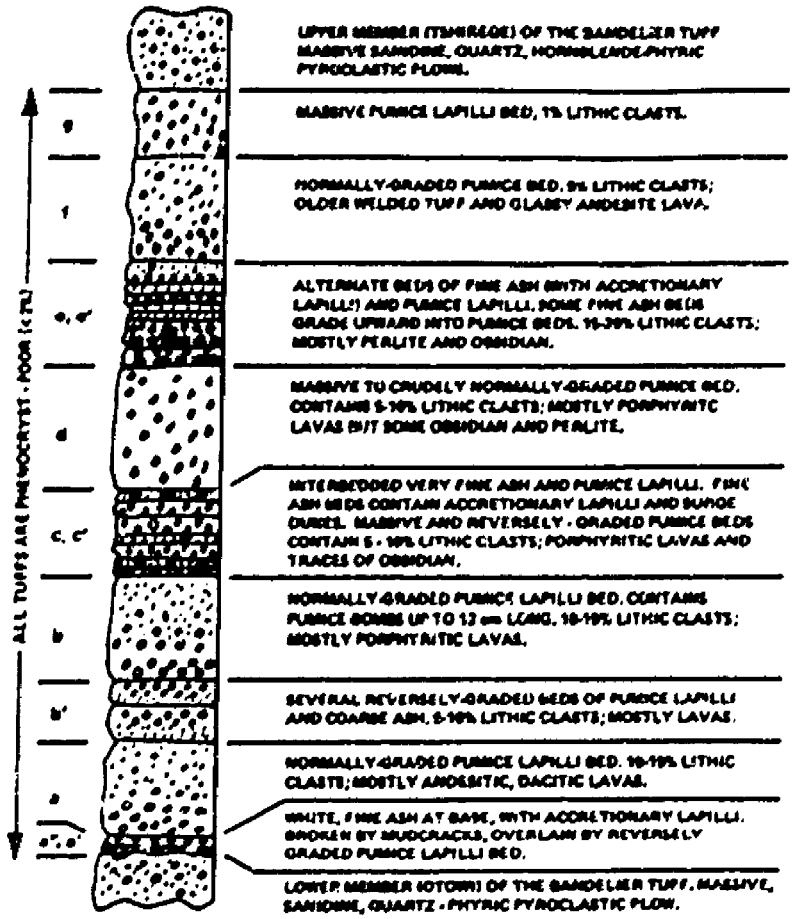
TABLE 1. Compilation of Potassium-Argon Dates From Tera Group Rhyolites and Related Rocks in the Valles Caldera, Toledo Embayment, and Pajarito Plateau, Jemez Mountains, New Mexico

Sample*	Unit	Rock Type	Material	K, %	Radiogenic ^{40}Ar, 10^{-12} mol/g	Radiogenic ^{40}Ar, %	Age,† 10^6 years	Source‡	Comments
	Upper Member, Bandelier Tuff								
	Tsankawi Pumice	pumice	sanidine				1.12 ± 0.03	I	weighted mean of three age determinations
	Cerro Toledo Rhyolite								
	Pyroclastic units								
	Fall unit D?	pumice	sanidine	4.02	12.8	54.8	1.23 ± 0.02	I	
JS 6-5	Fall unit C	pumice	glass + sanidine	3.926	5.590	13.3	1.32 ± 0.04	S	
	Fall unit B	pumice	sanidine				1.43 ± 0.11	I	mean of two fission track ages
		pumice					1.47 ± 0.04	I	isochron age from sanidine, plagioclase, and hornblende
	Cerro Toledo Rhyolite								
	Toledo Embayment domes								
FH-150	Pajarito Peak	obsidian	glass	3.74	3.797	44.3	1.20 ± 0.02	T	mean of two age determinations
PC 81 13	Turkey Ridge	rhyolite	sanidine	5.881	12.6	40.9	1.24 ± 0.03	Dr	
FH-141	Unnamed dome	obsidian	glass	3.71	8.182	20.0	1.33 ± 0.02	T	mean of two age determinations
FH 6	Rabbit Mountain	obsidian	glass + sanidine	3.682	9.135	45.6	1.43 ± 0.04	S	
FH 8	Rabbit Mountain	obsidian	glass	3.733	9.838	45.0	1.52 ± 0.06	Dr	
FH 9	Cerro Toledo	rhyolite	glass + sanidine	5.870	9.236	30.2	1.38 ± 0.05	S	
FH-144	Cerro Toledo	obsidian	glass	3.69	10.378	55.5	1.42 ± 0.02	T	mean of two age determinations
	Toledo Caldera moat domes								
	Warm Springs dome	rhyolite	sanidine	5.85	12.45	33.9	1.25 ± 0.04	Do	weighted mean of two age determinations
FH-139	Cerro Trasquilar	obsidian	glass	3.75	8.233	51.0	1.27 ± 0.03	T	mean of two age determinations
FH 12	East Los Posos dome	rhyolite	glass + sanidine	2.537	6.44	41.0	1.47 ± 0.05	S	
FH 27	West Los Posos dome	rhyolite	sanidine	5.515	14.6	45.0	1.50 ± 0.05	Dr	
	Lower Member, Bandelier Tuff								
	Guaje Pumice	pumice	sanidine				1.45 ± 0.06	I	weighted mean of three age determinations
	Cerro Rubio Quartz Latite								
614 84 8	Dome north of Cerro Rubio	dacite	plagioclase	0.428	1.618	44.1	2.18 ± 0.09	S	
FH-245	Cerro Rubio dome	dacite	plagioclase	0.353	2.20	26.4	3.59 ± 0.36	Dr	
	Pre-Bandelier Ignimbrite								
FH 10	Ignimbrite B	pumice	sanidine	4.379	21.6	67.8	2.44 ± 0.07	S	
VH-56B	Ignimbrite A	pumice	sanidine	4.60	29.06	4	3.54 ± 1.44	K	

*JS 6-5 collected by J. Stein, PC 81 13 collected by P. Carrel, 614 84 8 collected by G. Valentine, VH-56B collected by S. Self, all F samples collected by F. Goff.

†Here, $\lambda_e = 0.58 \times 10^{-10}$ yr^{-1}, $\lambda_\beta = 4.962 \times 10^{-10}$ yr^{-1}, $^{40}K/K = 1.167 \times 10^{-4}$, included of reporting error varies from lab to lab.

‡Do, Dov3 et al. [1968]; Dr, R. Drake, University of California, Berkeley; I, Izett et al. [1971]; K, D. Krummenacher, San Diego State University; S, M. Shafiqullah, University of Arizona; T, S. Tamanoyi, Geological Survey of Japan. Many dates have been previously reported by Goff et al. [1984]; Heiken et al. [1986], and Self et al. [1985].



COMPOSITE STRATIGRAPHIC SECTION, CERRO TOLEDO TUFFS.

Fig. 2. Composite stratigraphic column, Cerro Toledo Rhyolite tephra. The tephras consist of pumice falls and phreatomagmatic ash, as well as reworked volcaniclastic debris. Units c and e show rapid fluctuations between pumice falls and fine-grained phreatomagmatic deposits (c', e'). No scale is indicated because of the variable thickness of the tephra at different localities. Where they crop out, the tephras range from less than 1 m to 22 m thick.

gradation from phreatomagmatic ash at the base into coarser pumice falls upward [*Heiken et al.*, 1986]. The tephra is found in a 20-km-wide band to the east of the Toledo embayment centered near Los Alamos and in a 4-km-wide blanket from Rabbit Mountain to the southeast of Valles caldera [*Heiken et al.*, 1986] (Figure 1). A possible subsurface intracaldera facies of Cerro Toledo Rhyolite tephra is represented by the S_3 sandstone of *Nielson and Hulen* [1984] in the vicinity of the resurgent block of Valles caldera. The S_3 sandstone thickens eastward to 70 m at a depth of 1709 m in borehole B-4.

The stratigraphy of the Cerro Toledo Rhyolite tephra near Los Alamos is summarized below from *Heiken et al.* [1986]. The tephra consists of seven major units (Figure 2), beginning with units a, a', and a'' at the base, which consist of pumice falls having some fine ash with mud cracks. Above, units b and b' are Plinian fallout beds. Unit b is dated at 1.47 ± 0.04 Ma [*Izett et al.*, 1981] (Table 1). Unit c consists of fine tuff with accretionary lapilli (c') and pumice falls (c) and has an age of 1.52 ± 0.04 Ma. Unit d is dated at 1.23 ± 0.02 Ma [*Izett et al.*, 1981]. Unit d is a pumice fall, whereas unit e contains fine ash with accretionary lapilli (e') alternating with pumice beds (e). Typically, fine ash grades upward into pumice lapilli and coarse ash. Unit e is similar to c. Units f and g are both pumice falls.

Cerro Toledo Rhyolite tephra is composed predominantly of glass (>95%). Sanidine does not exceed 5% and quartz 1%, whereas the Bandelier Tuff contains 5–20% sanidine and 5–15% quartz [*Smith and Bailey*, 1966; *Heiken et al.*, 1986]. We have so far identified the following minor phases in Cerro Toledo Rhyolite tephra: plagioclase, augite, hypersthene, hornblende, biotite, Fe-Ti oxides, and traces of zircon and allanite [*Heiken et al.*, 1986]. These minerals do not exceed 1%. For example, unit b contains only 0.00014 wt % zircon [*Izett et al.*, 1981].

CORRELATION BETWEEN CERRO TOLEDO RHYOLITE DOMES AND TEPHRA

Geochemical Methods

Major elements were analyzed by X ray fluorescence (XRF) at Los Alamos following the procedures of *Valentine* [1983], except for samples 14-2, 14-4, 14-5, 14-7, 14-8, 15-1, and 15-2, which were analyzed by electron microprobe [*Heiken et al.*, 1986]. Rb, Sr, Y, Zr, and Nb were run by XRF at Toronto following *Norrish and Chappell* [1977]. Cl, Cs, Co, Sc, rare earth elements (REE), Hf, Ta, Th, and U were analyzed by instrumental neutron activation analysis (INAA) methods at Los Alamos after *Garcia et al.* [1982] and *Minor et al.* [1982]. Table 2 gives accuracy and precision for replicate analyses of NIM-G. Table 3 lists pertinent geochemical data for individual samples.

Correlations

Figure 3 shows a composite chemostratigraphy of Cerro Toledo Rhyolite tephra assembled from individual samples of five stratigraphic sections through the tuffs. We previously have correlated individual tephra units among sections by means of marker beds (e.g., units c and e) and geochemistry, as detailed by *Heiken et al.* [1986]. We discuss the correlations between domes and tephra generally in order of decreasing age and refer the reader to Figure 3 and Tables 1, 3, and 4.

Older Cerro Toledo Rhyolites

Tephra units a–a' are relatively depleted in Rb and Nb, for example, compared with the younger parts of the stratigraphy. These units do not appear to correlate with any Cerro Toledo Rhyolite domes. The oldest domes may have been obliterated or buried during subsequent explosive activity of the Cerro Toledo Rhyolite and UBT. The Los Posos domes (1.50–1.47 Ma, TRF) correlate well with tephra units b and b' (1.47 Ma) with respect to age and chemistry. For example, elements such as Rb (domes 139–145 ppm, tuffs 139–145 ppm) and Sr (domes 20–23 ppm, tuffs 21–24 ppm) bear strong resemblance. However, Zr shows somewhat poorer agreement (domes 162–168 ppm, tuffs 134–144 ppm). This may be a result of variable crystal contents between tephras and domes and/or changing zircon saturation levels between the time of tephra eruptions and emplacement of the domes, due to different amounts of water and/or different temperatures of the tephra and dome magmas [*Harrison and Watson*, 1983; *Watson and Harrison*, 1983, 1984].

Rabbit Mountain (average date 1.47 Ma) and Cerro Toledo (average 1.50 Ma, CT) have similar ages to that of units b and b'. The domes are enriched in Nb, Rb, and Y and depleted in Sr compared with the tuffs (Table 3), suggesting either that the eruptions were compositionally zoned or that the domes were not the source of the tephra units.

Middle Cerro Toledo Rhyolites

The Turkey Ridge domes (1.24 Ma, TR) appear intermediate geochemically between older TRF domes (1.50–1.47 Ma, Los Posos) and younger TRF domes (1.27–1.25 Ma, Warm Springs dome, Cerro Trasquilar). Elements such as Nb, Rb, and heavy rare earth elements (HREE) clearly display this trend (e.g., TR 85–89 ppm Nb, TRF 69–150 ppm Nb). The Turkey Ridge domes may represent the source of tephras in and/or between units d and e. This would be consistent with respect to age, because unit d is dated at 1.23 Ma [*Izett et al.*, 1981]. However, K/Cs ratios of the domes (7.7–8.4 × 10^3) favor a correlation in units c and/or d (K/Cs 8.0–8.4 × 10^3). One possible problem is that these domes carry phenocrysts, whereas the tuffs are nearly aphyric. An exact geochemical correlation is not possible in this case as with units b and b'; however, the data do suggest that the sources of units d and/or c were the Turkey Ridge domes.

TABLE 2. Precision and Accuracy for Trace Element Analyses of NIM-G by XRF and INAA

Element	n	$\bar{C}$, ppm	1σ, ppm	Accepted Values, ppm: Abbey [1983]	Accepted Values, ppm: Governdarajo [1984]
Cl	13	270	40	170*	170*
Rb	8	319	2	320	320
Cs	13	1.2	0.5	1*	1*
Sc	8	12.1	0.2	10	10
La	13	123	7	105*	109
Ce	13	222	16	200	195
Nd	13	69	10	68*	72
Sm	13	16	2	16*	15.8
Eu	13	0.5	0.3	0.4*	0.35
Dy	13	20	2	15*	17*
Yb	13	15.7	0.7	14	14.2
Lu	13	2.1	0.2	2*	2*
Y	8	137.7	0.7	145	145
Zr	8	291	1	300	300
Hf	13	13.4	0.6	12*	12*
Nb	8	54.7	0.9	53	53
Th	13	52	3	52	51
U	13	17.4	0.1	15*	15*

Younger Cerro Toledo Rhyolites

With respect to Nb, Rb, Y, Th, and U, the Southeast Rhyolite dome (1.20 Ma, SR) and welded tuffs of Pinnacle Peak show close correspondence with unit e. *Heiken et al.* [1986] have suggested that a tuff ring in which the welded tuff is found was the source of unit e. Because unit e is less than 1.23 Ma [*Izett et al.*, 1981], the geochronology is consistent between dome and tephra. Three objections to this correlation are (1) the dome carries phenocrysts, whereas the tuffs are practically aphyric, (2) the dome has very low Sr, whereas unit e has 6 ppm Sr, (3) the REE content of the domes does not match that of unit e, and (4) the K/Cs ratios of the domes (4.3–4.7 × 10^3) are lower than those of unit e (K/Cs 5.8–6.8 × 10^3). The second problem is a general one between Cerro Toledo Rhyolite domes and tephra, the third may be an analytical effect, and the fourth suggests the domes lie stratigraphically between unit f and the Tsankawi Pumice (K/Cs 5.2–2.8 × 10^3).

Warm Springs dome (1.25 Ma, TRF) and Cerro Trasquilar (1.27 Ma, TRF) are also possible sources of units e–g. Certain trace elements such as Rb, Nb, Zr, Y, and U show close agreement. However, Cerro Trasquilar also is depleted in Sr with respect to the tuffs. The K/Cs ratios of the domes (3.7–4.6 × 10^3) again indicate that the domes are situated between unit f and the Tsankawi Pumice (Table 3).

Tsankawi Pumice Bed of UBT

The Tsankawi Pumice bed represents the initial Plinian deposit from the eruption that formed Valles caldera at 1.12 Ma [*Doell et al.*, 1968]. The Tsankawi thus overlies and postdates the Cerro Toledo Rhyolite. It is therefore interesting that Warm Springs dome (1.25 Ma, TRF) has trace element con-

TABLE 3a. Geochemical Analyses

	a*	a'	a'	a	b'	b'	b'	b	b	b	c
Number*	15-8	14-8	14-7	15-9	15-10	14-5	6-1	6-2	6-3	6-4	6-5
SiO_2	...	78.1	78.0	...	...	78.1	...	...	...	...	...
TiO_2	...	0.16	0.04	...	...	0.10	...	...	...	...	...
Al_2O_3	12.1	12.2	12.1	11.6	11.9	12.1	11.3	11.9	11.9	11.8	11.4
Fe_2O_3	1.71	1.06	1.01	1.18	1.08	0.82	1.08	0.93	...	0.89	0.88
MnO	0.06	0.05	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06
MgO	...	0.02	0.04	...	...	0.04	...	...	...	...	...
CaO	0.48	0.32	0.32	0.43	...	0.37	0.51	0.39	0.47	0.34	0.46
Na_2O	3.80	3.54	3.74	3.48	3.60	3.57	3.69	3.75	3.69	3.69	3.56
K_2O	4.94	4.58	4.66	4.32	4.54	4.87	4.77	4.54	5.08	4.18	4.36
P_2O_5	...	...	...	...	...	...	...	...	...	...	...
LOI	...	...	...	...	...	...	...	...	...	...	...
Total	...	99.73	99.98	...	...	100.04	...	...	...	...	...
Cl	700	900	1000	900	1300	1300	1700	1300	1100	1200	1000
Rb	99	...	...	132	140	...	145	139	138	139	153
Cs	2.8	2.4	3.0	3.8	3.8	3.7	4.1	3.9	4.2	4.3	4.5
Sr	30	...	...	8.1	22	...	21	23	24	25	13
La	72	50	49	50	45	43	41	44	40	42	32
Ce	149	107	95	126	93	86	104	87	97	88	82
Nd	...	31	33	...	...	28	...	...	...	...	...
Sm	8.6	6.5	7.8	6.8	7.5	5.9	6.2	7.4	6.4	6.4	6.1
Eu	0.34	0.20	0.12	0.23	0.22	0.18	0.29	0.20	0.29	0.24	0.23
Dy	5.7	6.7	6.9	6.6	6.8	6.5	6.8	6.4	5.9	6.2	7.2
Yb	3.7	4.3	4.4	4.4	4.5	4.5	4.0	4.1	4.4	3.9	5.0
Lu	0.64	0.67	0.69	0.72	0.67	0.70	0.70	0.63	0.67	0.68	0.72
Y	36	...	...	43	42	...	44	42	42	42	47
Zr	309	...	...	161	140	...	144	133	136	134	135
Hf	9.6	6.0	5.4	6.4	5.2	5.5	6.2	4.9	5.3	6.0	5.9
Nb	59	...	...	63	65	...	67	64	62	63	69
Th	14	17	17	17	17	18	17	18	17	17	18
U	4.3	5.1	5.5	5.6	6.0	5.8	6.0	5.7	5.7	5.7	6.1

Analyzed samples are combined pumice lapilli that were handpicked and cleaned ultrasonically prior to being crushed.

*Tephra samples were collected from four stratigraphic sections, indicated by the prefix in the sample number. The four sections are located on the Guaje Mountain 7½-min quadrangle. Section 6, NW¼, T19N, R6E, sec 13; section 14, SW¼, T19N, R6E, sec 10; section 15, SW¼, T19N, R6E, sec 11; section 25, SW¼, T20N, R6E, sec 14.

tents remarkably similar to the basal Tsankawi Pumice (sample 6-8) that is exposed above Cerro Toledo Rhyolite tephra in the eastern Jemez Mountains (e.g., Warm Springs dome 298 ppm Rb, Tsankawi 297 ppm Rb). However, light rare earth elements (LREE) do not agree so well between these two units. Furthermore, K-Ar ages conflict, and *Self et al.* [1986] have placed the source of the Tsankawi near Redondo Peak from isopach data (Figure 1). Sample 6-8 may not represent the true base of the Tsankawi Pumice because it is not enriched in Rb, for example, compared with other samples of Tsankawi collected in the Jemez Mountains (J. Wolff, University of Texas, unpublished data, 1987). Indeed, the thickness of Tsankawi Pumice is much less to the east of Valles caldera than to the west [*Self et al.*, 1986]. Although sample 6-8 and Warm Springs dome seemingly correlate with respect to geochemistry (but not age), sample 6-8 may represent a less evolved part of the Tsankawi Pumice, erupted at 1.12 Ma, and may correspond to a certain level of compositional zonation in the Bandelier magma chamber that was also tapped by the eruption of Warm Springs dome at 1.25 Ma. This level of zonation may have been situated at a greater depth in the magma chamber at 1.12 Ma than at 1.25 Ma.

Discussion

Clearly, Cerro Toledo Rhyolite domes are the source of Cerro Toledo Rhyolite tephra and were associated with explosive volcanic activity. The eruptions appear to be a result of high water content of the magma [*Newhall and Melson*, 1983]. Certain tephra units are in part phreatomagmatic (e.g., units c' and e') (Figure 2). *Heiken et al.* [1986] suggested the tuffs erupted through a lake in the topographically low northeastern part of Valles caldera and Toledo embayment.

Because of refinements in our knowledge of Toledo caldera and Toledo embayment, the Cerro Toledo Rhyolite tephra are not merely a sequence of tuffs from most rhyolite eruptions. The above age and geochemical correlations suggest that the location of source domes for Cerro Toledo Rhyolite tephra changed, in part, from ring fracture domes in Toledo caldera in early Cerro Toledo Rhyolite time to Toledo embayment domes in middle to late Cerro Toledo Rhyolite time. The locus of explosive volcanism then changed dramatically to near Redondo Peak at 1.12 Ma during eruption of UBT [*Self et al.*, 1986]. The structural emplacement of domes in Toledo embayment is probably not coincidental because the Jemez fault zone, resurgent dome faults, Toledo embayment, and Santa Clara shear zone define the trace of the Jemez lineament, a zone of crustal weakness intermittently active from Precambrian to Quaternary time [*Aldrich*, 1986].

GEOCHEMICAL VARIATION WITHIN THE CERRO TOLEDO RHYOLITE

Domes

Younger TRF domes (Warm Springs, Cerro Trasquilar, 1.27–1.25 Ma) are depleted in LREE, Eu, and Sr and are

...la. Geochemical Analyses

	Uni...	
	b	e
	6-4	6-3
	...	...
	...	...
	11.8	11.4
	0.89	0.88
	0.06	0.06
	...	...
	0.34	0.44
	3.49	3.36
	4.18	4.36
	...	...
	...	...
	...	...
	1200	1000
	139	133
	4.3	4.3
	29	13
	42	32
	88	92
	...	...
	6.4	6.1
	0.24	0.23
	6.2	7.2
	3.9	3.0
	0.66	0.72
	42	47
	134	133
	6.0	3.9
	61	69
	17	18
	5.7	6.2

...ed.
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c'	c'	d	d*	e	e	e	e	e'	e'	f
16-4	15-3	6-6	15-11	6-7	15-1	15-7	15-12	15-2	25-1	15-6
77.9	...	...	...	...	77.8	...	...	77.7	...	...
0.11	...	...	...	...	0.02	...	...	0.06	...	...
12.0	11.2	12.1	11.6	11.5	12.2	11.6	11.7	12.2	11.3	12.1
0.99	1.04	1.10	1.07	1.12	1.11	1.18	1.16	1.00	1.12	1.19
0.01	0.07	0.06	0.07	0.07	0.06	0.07	0.07	0.11	0.07	0.08
0.4	...	...	...	...	0.04	...	...	0.02	...	...
0.37	0.31	0.42	...	0.43	0.26	...	0.28	0.25	0.46	...
3.38	3.01	3.86	3.90	3.84	3.59	3.63	3.76	3.50	2.56	3.77
5.19	4.78	4.99	4.52	4.98	4.61	4.95	5.13	5.14	5.04	4.36
...	...	...	...	...	...	...	...	...	...	
...	...	...	...	...	...	...	...	...	...	
100.01	...	...	...	...	99.69	...	...	99.98	...	...
900	1000	1400	1900	1600	1400	1500	1700	1100	1800	1700
...		150	190	197	...	200	197	...	...	202
3.8	4.2	4.9	6.0	6.1	6.2	6.3	7.3	5.5	5.1	6.9
...	...	21	5.0	5.7	...	3.1	5.0	...	...	4.4
41	38	41	34	33	33	33	35	36	38	38
101	78	59	79	80	75	86	80	81	79	78
25	26	...	...	...	24	...	...	26	27	...
8.4	7.2	7.4	7.5	8.1	6.6	7.9	7.8	5.9	7.1	8.4
0.21	0.14	0.30	0.18	0.22	...	0.08	0.21	0.12	0.12	0.18
5.6	6.7	7.9	9.2	8.9	9.2	9.4	9.3	9.6	9.3	11
4.2	4.7	4.6	6.5	6.0	6.5	6.1	7.2	5.8	6.2	7.6
0.66	0.71	0.79	0.99	1.0	0.96	1.1	1.1	0.86	0.96	1.0
		50	64	66	...	66	67	...	...	69
...	...	150	157	161	...	161	163	...	...	168
6.0	5.8	5.9	7.0	7.1	7.5	7.3	8.4	6.9	6.9	7.0
...	...	77	91	95	...	95	94	...	...	96
18	18	19	21	22	22	22	23	20	20	22
5.5	5.6	6.9	8.1	8.1	8.0	8.0	8.0	6.9	6.9	8.2

enriched in HREE, Y, Cs, Rb, Nb, Th, and U compared with the older TRF domes (Los Posos, 1.5–1.47 Ma). In contrast, CT and SR domes exhibit comparatively little chemical variation with age for many elements (e.g., Rb, Zr, Nb, Th, U), although some variability exists for REE, Y, and Cs. TR domes show generally lower concentrations of Rb, Zr, Hf, Nb, Y, and U compared with CT and SR domes (Table 3).

The above relationships suggest that the chemical compositions of Cerro Toledo Rhyolite domes are, in part, structurally controlled by the location of Toledo caldera. Intracaldera ring fracture domes (TRF) show large geochemical changes with time and thus may be connected to the main Bandelier magma chamber. Extracaldera domes (CT, SR) exhibit much more limited temporal chemical evolution and may be eruptive products of a series of smaller, isolated magma bodies in which geochemical processes operated similarly but did not enrich or deplete different elements so efficiently. As an example, Rabbit Mountain (CT) crops out on the southeast margin of Toledo caldera and is isolated from the other domes of Toledo embayment (Figure 1); however, Rabbit Mountain has many geochemical similarities to other CT and SR domes. The lower concentrations of Rb, Zr, Hf, Nb, Y, and U within TR domes, compared with CT and SR domes, may reflect a small, isolated magma chamber that evolved somewhat differently from those of CT and SR domes. Because the Jemez lineament probably controlled the ascent of magma, the TR domes may have been supplied with different amounts of magma at differing rates and times compared with the CT and SR domes.

Tephra

The relative ages of the different Cerro Toledo Rhyolite tephra units are well understood because of good time-stratigraphic control. Due to stratigraphic juxtaposition, we are able to examine temporal geochemical relationships between the LBT and UBT and the Cerro Toledo Rhyolite tephra. The tephra sequence shows systematic geochemical variations with time more clearly than do the Cerro Toledo Rhyolite domes.

Many trace elements vary systematically in concentration upsection through the Cerro Toledo Rhyolite stratigraphic column (Figures 3 and 4). Cl, Cs, Rb, Nb, Y, Th, U, and HREE are enriched upward. For example, Nb increases upward from 50 ppm at the base of the Cerro Toledo Rhyolite to 156 ppm at the Tsankawi Pumice bed. In contrast, LREE decrease irregularly in concentration upsection through most of the sequence but increase at unit e and above. Zr decreases to a minimum in the middle of the sequence, then increases upward from there. However, the Zr/Nb ratio decreases upsection. Likewise, the K/Cs and $[La/Yb]_n$ ratios systematically decrease upward (14,600–2800 and 13–3.2, respectively) (Figure 4).

Unit b displays a slight reversal of trend for elements such as Rb, Nb, and Y (Figure 3). This reversal may be the result of a relatively large eruption that tapped a slightly deeper level of the Bandelier magma chamber. Indeed, unit b is a thick (2 m at section 15) Plinian deposit when compared with other Cerro Toledo Rhyolite tephra units. We believe significant the

TABLE 3A. Geochemical Analyses for Associated Rocks

	Toledo Ring Fracture Group					Turkey Ridge Group		Cerro Toledo Group				Southeast Rhyolite Group	
	Warm Springs Dome	Cerro Trasquilar	West Los Posas	West Los Posas	East Los Posas	Indian Point	Unnamed Dome	Rabbit Mountain	Cerro Toledo	Unnamed Dome	Unnamed Dome	Unnamed Dome	Pinnacle Peak
Number	F82-9	F81-139	F81-123	F83-27	F83-26	F81-141	F83-28	F80-36	F81-145	F83-24	F83-29	F81-150	F81-159
SiO_2	75.9	75.2	74.3	76.3	76.4	77.3	76.9	76.9	77.0	76.8	77.1	77.0	74.3
TiO_2	0.05	0.08	0.12	0.12	0.12	0.09	0.08	0.08	0.08	0.07	0.08	0.08	0.07
Al_2O_3	12.6	11.9	12.4	12.8	12.5	12.2	12.2	12.1	12.2	12.0	12.2	12.2	12.2
Fe_2O_3	1.06	1.01	1.34	1.29	1.30	0.98	1.06	1.03	1.19	1.61	1.16	1.07	0.99
MnO	0.03	0.07	0.06	0.05	0.06	0.06	0.05	0.07	0.05	0.06	0.06	0.07	0.07
MgO	0.08	0.03	0.08	0.06	0.08	0.04	0.05	0.03	0.02	0.03	0.03	0.03	0.03
CaO	0.12	0.26	0.44	0.33	0.43	0.20	0.16	0.30	0.14	0.12	0.18	0.23	0.19
Na_2O	3.80	4.22	3.95	4.16	4.44	4.37	3.91	4.51	4.21	3.92	4.08	4.46	4.02
K_2O	4.94	4.49	4.62	4.54	4.40	4.57	4.54	4.42	4.47	4.43	4.53	4.43	4.40
P_2O_5	0.02	0.005	0.01	0.005	0.01	0.005	0.005	0.005	0.005	0.005	0.01	0.005	0.14
LOI	0.89	3.19	3.53	0.46	0.40	0.28	0.52	0.59	0.25	0.33	0.21	0.50	3.11
Total	100.32	100.52	100.88	100.12	100.14	100.08	99.48	100.01	99.39	99.38	99.64	100.04	99.37
Cl	900	2000	1100	200	900	600	800	2100	800	600	300	2700	2100
Rb	208	205	139	145	143	176	182	195	199	197	196	202	199
Cs	11	8.1	3.7	3.6	3.8	4.9	4.3	6.9	4.6	4.1	4.1	8.6	7.8
Sr	6.6	<1	23	20	20	<1	<1	<1	<1	<1	2.3	<1	<1
La	32	36	37	40	44	40	36	43	31	27	28	34	41
Ce	76	80	89	...	91	71	70	83	72	69	70	68	73
Nd	19	29	33	26	31	28	56	23	18	25	13	23	28
Sm	8.3	7.4	7.7	4.8	5.8	7.7	8.2	8.7	7.0	5.3	7.1	7.4	9.0
Eu	0.06	0.09	0.14	0.14	0.19	0.08	...	0.10	...	0.07	...	0.11	0.08
Dy	16	12	8.0	6.2	6.9	8.4	8.3	11	10	7.4	7.9	12	12
Yb	11	8.1	5.8	4.4	5.0	5.7	5.9	7.9	5.7	5.7	6.0	6.8	7.7
Lu	1.4	0.92	0.59	0.65	0.67	0.72	0.67	1.0	0.74	0.80	0.75	0.85	0.93
Y	106	68	45	40	44	50	54	68	50	49	60	66	67
Zr	259	164	162	163	168	142	155	173	172	168	172	169	161
Hf	13	8.8	6.3	6.2	6.0	6.7	7.2	8.9	8.6	7.7	8.4	8.5	7.5
Nb	150	98	69	69	70	85	83	97	99	99	98	130	97
Th	34	23	19	21	19	21	22	22	23	24	23	24	23
U	16	8.2	5.9	5.9	6.1	6.6	7.6	8.0	8.5	8.6	7.7	8.4	8.1

Y	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Zr	219	164	162	174	168	162	178	175	172	168	172	168	161
Hf	5.3	4.8	4.3	4.2	4.0	4.7	3.2	4.9	4.6	3.7	4.4	4.5	3.8
Nb	100	94	93	93	90	85	83	97	99	99	98	100	97
Th	34	23	19	21	19	21	22	22	23	24	23	24	23
U	14	8.2	5.9	5.9	6.1	4.6	7.6	8.0	8.5	8.6	7.7	8.4	8.1

	Cerro Rubio Group												
	Cerro Rubio		Lava Plug	Tuskahoi Pumice*				Lower Bandelier Tuff				Pre Bandelier Pumices*	
	F83-154	F83-245	F83-22	5-81	6-81	F82-94	F82-95	G-1‡	G-2‡	F82-113‡	F83-12‡	F82-91	F82-92
SiO_2	64.9	64.9	64.2	---	-	72.7	67.6	---	---	73.6	74.2	73.0	74.4
TiO_2	0.45	0.47	0.45	---	---	0.06	0.43	---	---	0.04	0.04	0.11	0.10
Al_2O_3	15.1	15.2	15.5	11.5	11.9	12.2	15.0	11.6	11.8	11.9	11.8	12.0	11.8
Fe_2O_3	3.54	3.43	3.55	1.56	2.12	1.47	3.20	1.48	1.54	1.40	1.50	1.25	1.54
MnO	0.05	0.05	0.06	0.05	0.09	0.08	0.08	0.08	0.09	0.07	0.05	0.06	0.06
MgO	1.31	1.42	1.29	---	---	0.05	1.35	---	---	0.10	0.09	0.42	0.08
CaO	3.25	3.32	3.23	-	0.59	0.33	3.19	0.41	---	0.24	0.30	0.45	0.33
Na_2O	3.70	3.60	3.96	3.95	3.53	3.08	4.86	3.54	4.25	4.36	2.86	2.90	4.00
K_2O	3.19	3.20	3.16	4.10	3.36	5.36	2.83	4.50	4.60	4.81	5.08	4.90	4.67
P_2O_5	0.14	0.15	0.16	-	-	0.005	0.16	---	---	0.005	0.005	0.005	0.005
LOI	2.01	1.37	0.27	-	-	4.01	1.42	---	---	4.26	2.95	4.30	3.35
Total	99.13	99.11	99.83	-	---	99.37	99.92	---	---	100.59	99.72	99.80	100.54
Cl	600	600	---	2500	1900	2200	1140	2400	1900	2800	900	1100	1600
Rb	52	52	53	297	251	---	131	340	344	-	184	153	153
Cs	0.9	0.9	0.8	12	10	18	4.0	11	11	10	4.4	3.9	4.1
Sr	512	537	508	5.7	9.3	---	514	11	6.1	---	6.1	12	2.1
La	37	34	35	28	53	31	37	39	44	32	45	50	39
Ce	70	68	69	120	142	117	79	112	108	109	91	111	113
Nd	19	15	24	-	---	60	38	---	---	47	42	---	30
Sm	4.3	4.4	4.7	12	11	17	5.3	11	14	14	9.7	7.2	8.0
Eu	1.2	1.1	1.2	0.12	0.46	-	0.90	---	---	2.4	---	0.33	0.16
Dy	3.1	2.6	3.2	15	14	28	5.0	17	18	18	7.1	8.4	8.0
Yb	1.8	1.6	1.4	12	9.4	15	3.0	11	12	12	5.7	4.9	5.6
Lu	0.21	0.20	0.22	1.9	1.7	1.7	0.42	1.7	1.8	1.5	0.88	0.74	0.56
Y	18	18	18	133	100	---	31	112	111	---	55	45	47
Zr	228	226	228	245	273	---	229	256	278	---	186	209	231
Hf	5.4	5.9	4.8	14	13	14	4.6	13	12	12	6.7	8.4	8.2
Nb	13	12	13	156	133	-	32	191	212	---	83	71	71
Th	5.5	4.3	4.6	32	27	43	11	40	46	---	22	21	21
U	1.2	1.2	1.1	12	9.5	12	2.7	16	17	16	14	6.8	6.7

*Analyzed samples are combined pumice lapilli that were handpicked and cleaned ultrasonically prior to being crushed.
†Samples collected from section 6.
‡Samples collected from Gauge Pumice at base of Lower Bandelier Tuff.

TABLE 4. Correlations Between Cerro Toledo Rhyolite Domes and Tephras

Dome	Tephra Unit
Warm Springs dome, Cerro Trasquilar (Southeast Rhyolite Group)	g
Warm Springs dome, Cerro Trasquilar (Southeast Rhyolite Group)	f
Southeast Rhyolite Group (Warm Springs dome, Cerro Trasquilar)	e, e'
Turkey Ridge Group	d
Turkey Ridge Group?	c, c'
Los Posos domes	b
Los Posos domes	b'

Domes in parentheses indicate a less favored, but possible correlation with the corresponding tephra unit. Question mark indicates an uncertain correlation.

fact that Rb, Nb, and Y are correlated and all show this chemical reversal.

Similarly, samples 6-8 and 6-9 show a reversal within the Tsankawi Pumice (Figures 3 and 4). The eruption that deposited the fall unit represented by sample 6-9 may have tapped deeper levels in a zoned magma chamber. Again, Rb, Nb, and Y show correlated trends. The extremely large jump in Sr content between the two units (5.7 to 93 ppm) is difficult to explain. The jump may be a manifestation of contamination and/or mixing of rhyolite magma with Tschicoma/Cerro Rubio dacite magma of high Sr content (about 507–512 ppm) [*Gardner et al.*, 1986; *Self et al.*, 1986]. However, major elements, in particular K_2O, do not support a mixing model.

Sr trends are unclear, possibly because of analytical imprecision at relatively low Sr contents. Rb/Sr increases from unit d upward (Rb/Sr 6.9–52) (Figure 4b). If unit d is incorrectly correlated and sample 15-11 is used instead of 6-6, Rb/Sr increases from 5.8 to 52. Furthermore, unit b may represent a reversal of trend, as discussed above. If so, then Rb/Sr may increase upsection from unit b' to the Tsankawi (6.9–52).

Significance

We believe the chemical gradients documented here in the Cerro Toledo Rhyolite tephra represent successive liquid compositions at or near the top of the Bandelier magma chamber between 1.45 and 1.12 Ma. Four lines of evidence support this contention.

1. Cerro Toledo Rhyolite eruptions originated from point sources and produced fallout and surge tephra without associated large-scale pyroclastic flows. These eruptions were of relatively small volume (< 1 km^3) when compared with those that produced LBT and UBT (> 250 km^3) and most likely tapped only the upper surface of the magma [*e.g., Druitt and Sparks*, 1984].

2. Trace element concentrations of the Cerro Toledo Rhyolite tephra show consistent, systematic increases and decreases with respect to stratigraphic position. If the Cerro Toledo Rhyolite eruptions had tapped various levels of the compositional zonation instead of the uppermost level, chemostratigraphic variation would be random, not systematic.

3. Cerro Toledo Rhyolite tuffs and domes are generally crystal poor, consistent with these rocks being derived from the upper part of the magma chamber [*Smith and Bailey*, 1966; *Smith*, 1979].

4. When plotted on variation diagrams (see below), Cerro Toledo Rhyolite compositions exhibit both well-defined trends and alignment with samples of the Upper and Lower Bandelier Tuff. This suggests the Cerro Toledo Rhyolite and Bandelier magmas are comagmatic and tapped the same magma chamber.

With these points in mind, we now compare enrichment trends for LBT, UBT, and the interval of time during which

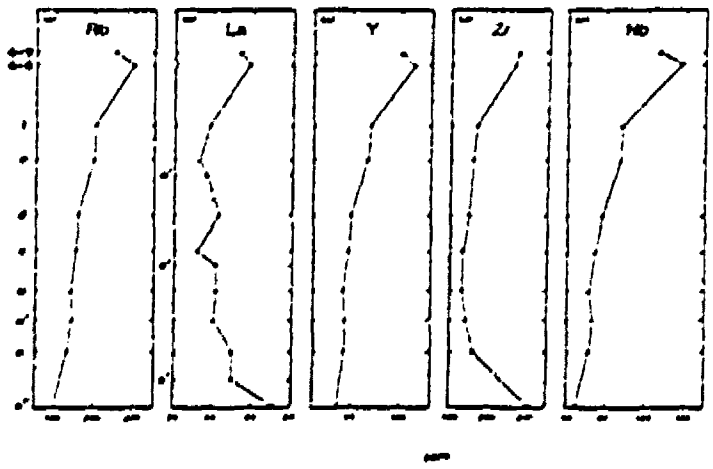


Fig. 3. Compositional variation with respect to stratigraphic height of selected trace elements within the Cerro Toledo Rhyolite tephra. The stratigraphically lowest and highest sampled units are a" and f, respectively. Units 6-8 and 6-9 refer to samples from the Tsankawi Pumice (UBT), which overlies the Cerro Toledo Rhyolite tephra. Analyzed samples of individual units are pumices except for units c' and e', which are fine-grained phenocrystic ashes. Individual units are represented by the following samples: a", 15-8; a', 14-7, 14-8; a, 15-9; b', 6-1; b, mean of 6-2, 6-3, 6-4; c, 6-5; c', 14-4, 15-3; d, 6-6; e, 6-7; e', 15-2, 25-1; f, 15-6; and Tsankawi Pumice, 6-8, 6-9. No vertical scale is shown because the tephra varies in thickness at different localities. Compare with *Smith* [1979, Figure 8] and *Mahood* [1981, Figures 4 and 5].

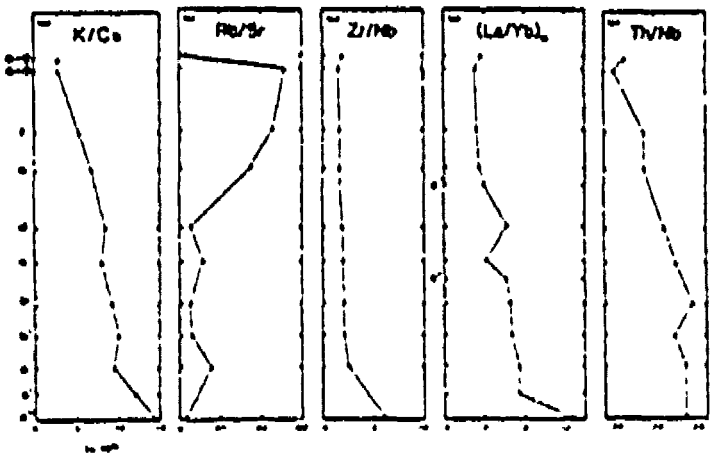


Fig. 4. Variation of major and trace element ratios with respect to stratigraphic height in the Cerro Toledo Rhyolite tephra. Unit names and sample numbers are the same as those listed in Figure 3.

the Cerro Toledo Rhyolite was erupted between the two ignimbrite sequences (Figure 5). The enrichment ratios represent the concentration of a particular element in the earliest erupted material divided by the concentration in the last-erupted deposits [cf. *Hildreth*, 1979]. We again stress the important distinction between the Cerro Toledo Rhyolite and Bandelier Tuff; whereas the Cerro Toledo Rhyolite represents small eruptions that tapped the top of the magma chamber over a period of 0.27–0.33 m.y., the LBT and UBT are the result of evacuating eruptions that sampled the chemical stratigraphy present in the magma chamber at an instant in geologic time [*Hildreth*, 1981]. The data for the interval between the LBT and UBT are taken from the stratigraphically lowest sampled Cerro Toledo Rhyolite (15-8) and basal Tsankawi unit (6-8). We have chosen the UBT sample instead of that from the stratigraphically highest Cerro Toledo Rhyolite tephra unit (unit f) for two reasons: (1) we want to document compositional changes at the top of the Bandelier magma chamber during the 0.33-m.y. period between the two caldera-forming eruptions; however, the Cerro Toledo Rhyolite tephra sequence does not fully record these changes; and (2) systematic compositional changes occur from the base of the Cerro Toledo Rhyolite tephra to the base of the UBT (Figures 3 and 4); thus we have considered sample 6-8 as a logical end-member of the Cerro Toledo Rhyolite tephra sequence.

Figure 5 shows geochemical trends for the intracaldera interval opposite to those displayed by LBT and UBT, with respect to Rb, Y, Nb, and Th. The trends suggest that chemical gradients were restored between the two ignimbrite eruptions [*Smith*, 1979]. If we take 0.33 m.y. as the age range of intracaldera volcanic activity, we can calculate the rate of restoration of compositional zonation at the top of the Bandelier magma chamber. For Rb, Y, and Nb, the rates are 0.60 ppm kyr^{-1}, 0.23 ppm kyr^{-1}, and 0.32 ppm kyr^{-1}, respectively. For comparison, Nb enrichment in Cerro Toledo Rhyolite TRF domes increased at an average rate of 0.32 ppm kyr^{-1} (Tables 1 and 2). Furthermore, *Smith* [1979, Figure 8] shows a rate of 0.35 ppm Nb kyr^{-1}, and we calculate a rate of 0.34 ppm Nb kyr^{-1} using data from *Bailey et al.* [1985] and *Kuentz et al.* [1985]. Due to stratigraphic and age uncertainties, there is a certain degree of error in these calculations. As order-of-magnitude estimates, however, we believe they are correct.

Figure 5 indicates that the magnitude of early/late intracaldera depletion of Rb, Nb, and Y resembles that of LBT enrichment much more closely than UBT. This implies that the extent of chemical zonation reestablished in intracaldera time equalled that tapped by the LBT eruption. The UBT eruption may not have tapped the zoned magma chamber to the extent that the LBT eruption did. This explanation is consistent with the smaller volume of UBT (250 km^3) compared with LBT (400 km^3) [*Bailey et al.*, 1985, 1986; *Kuentz et al.*, 1985].

PETROGENESIS

Crystal Fractionation

We believe that crystal fractionation has generated certain of the chemical gradients in the Cerro Toledo Rhyolite, as well as in the Bandelier Tuff. We present here data that support this hypothesis. We utilize two types of diagrams in the following discussion.

1. Chemostratigraphic plots that show changes in chemistry with respect to stratigraphic height and time (Figures 3 and 4).

2. Bivariant plots with Nb plotted as the abscissa (Figures 6 and 8–11). Although Nb clearly is fractionated, we justify this choice because (1) Nb appears relatively incompatible (but not to the extent of Cs; see below) in the Cerro Toledo Rhyolite and Bandelier Tuff rocks as shown in Figure 6, where Nb varies linearly with Rb, and the Rb/Nb ratio remains essentially constant at 2 above 50 ppm Nb; (2) Nb has far better relative precision than does Cs at the concentration levels encountered in these rocks (Table 2); (3) we use Nb as an index of magmatic evolution following *Smith* [1979, Figure 8]; and (4) Nb is relatively immobile [*Pearce and Norry*, 1979].

Feldspar fractionation. Figures 7 and 8 show depletions of K/Cs and Sr with increasing Cs and Nb, respectively. These are general trends for rocks of different ages but also are reflected in the Cerro Toledo Rhyolite points. The youngest Cerro Toledo Rhyolite tephras tend to be most depleted in

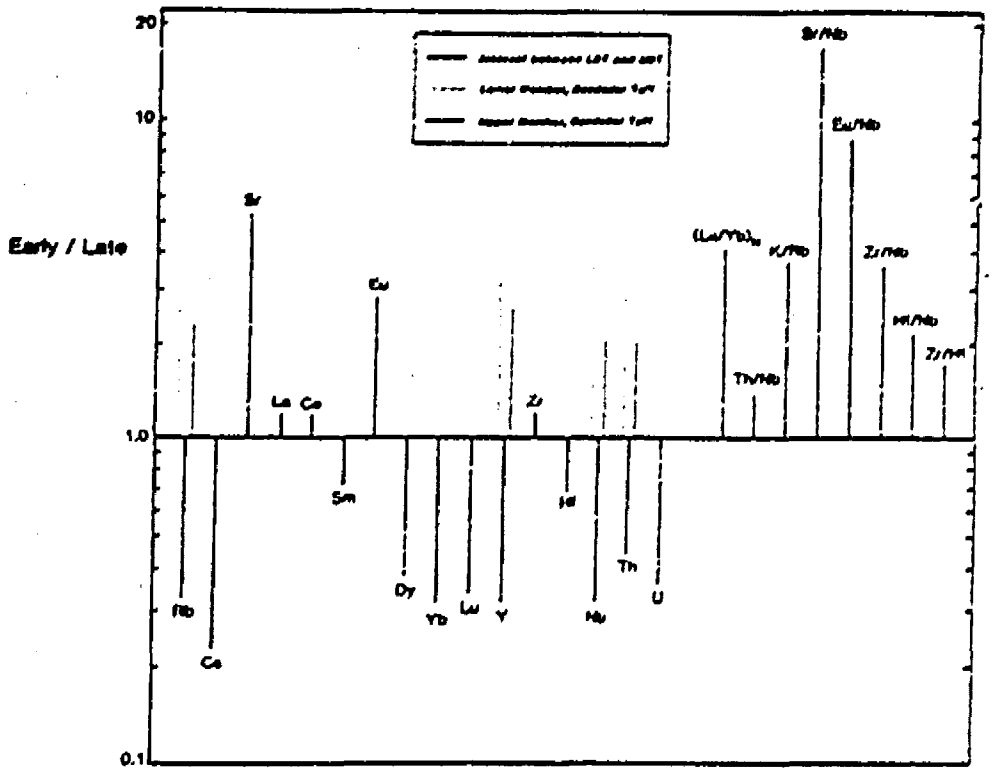


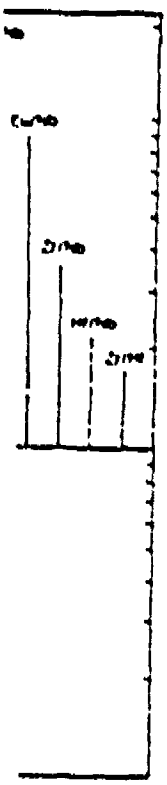
Fig. 5. Early/late enrichment-depletion trends for the interval, indicated by the solid lines, between the LST and UBT caldera-forming eruptions. The data simply represent concentrations of trace elements in unit a" (sample 15-8) at the base of the Cerro Toledo Rhyolite divided by the concentrations in the Tsankawi Pumice of the Upper Member of the Bandelier Tuff (sample 6-8) which overlies the Cerro Toledo Rhyolite tephra. In contrast to similar diagrams constructed from ignimbrite data [e.g., *Hildreth*, 1981, Figure 7], this diagram has evolutionary significance and spans approximately 0.33 m.y. [see also *Mahood*, 1981, Figure 6]. For comparison, we also have plotted on this diagram early/late enrichment factors for Rb, Y, Nb, and Th from the lower and upper members of the Bandelier Tuff [*Reisley et al.*, 1985; *Kuentz et al.*, 1985]. As stated above, these enrichment factors have no rate significance because the ignimbrites were erupted geologically instantaneously. The enrichment factors represent compositions of earliest erupted basal pumice falls from each ignimbrite cycle divided by the compositions of pumices in the last-erupted ignimbrite of the particular cycle.

K/Cs and Sr, suggesting feldspar fractionation has removed K and Sr relative to Cs and Nb in successive magmas.

Figures 4a and 4b also display these relations. K/Cs and Rb/Sr decrease and increase upsection, respectively. Changing proportions of feldspar during the crystallization process resulted in variable amounts of Sr in the residual magma as represented by the Cerro Toledo Rhyolite tephra. In spite of the large chemostratigraphic fluctuations of Sr, Rb/Sr increases upsection from 3.3 at unit a" (base of Cerro Toledo Rhyolite) to 52 at unit 6-8 (base of UBT). Because an element such as Rb is continually enriched during the crystallization process, because of its relative incompatibility, crystallization of varying amounts of feldspar will result in an increasing Rb/Sr ratio upsection. The Rb/Sr ratio will remain constant only if feldspar fractionation ceases completely so that Sr becomes incompatible to the extent of Rb.

Zircon fractionation. When plotted against Nb, Zr shows a wide scatter of points that defines no broad relationship (Figure 9a). Zr generally increases in concentration with Nb for Cerro Toledo Rhyolite tephras. In contrast, Zr/Nb is strongly depleted with increasing Nb, particularly for Cerro Toledo Rhyolite tephras in which the youngest tephras are most depleted (Figure 9b). These relations and the presence of zircon in Cerro Toledo Rhyolite tephras suggest zircon fractionation.

Chemostratigraphic diagrams show an initial decrease, followed by increase, of Zr upsection (Figure 3d). However, Zr/Nb progressively decreases upsection from 6.2 at unit a" to 1.7 at unit 6-9 (Figure 4c). This implies that zircon fractionation occurred throughout Cerro Toledo Rhyolite time from a magma that remained saturated in zircon. From unit a" to c, zircon fractionation was sufficient to deplete the residual magma of both Zr and Zr/Nb; the bulk distribution coefficient of Zr exceeded unity. From unit c upsection, Zr increases (135–273 ppm) but Zr/Nb decreases (2.0–1.7), perhaps due to less zircon fractionation. The bulk distribution coefficient of Zr may have decreased to below 1; zircon fractionation still took place, however, because the Zr/Nb ratio decreases progressively upsection. It is probable that zircon was crystallizing in different proportions in different parts of the magma chamber because (1) zircon saturation is sensitive to small changes in temperature and water content of the magma [*Watson and Harrison*, 1983, 1984] and (2) the magma chamber was zoned with respect to temperature and volatiles



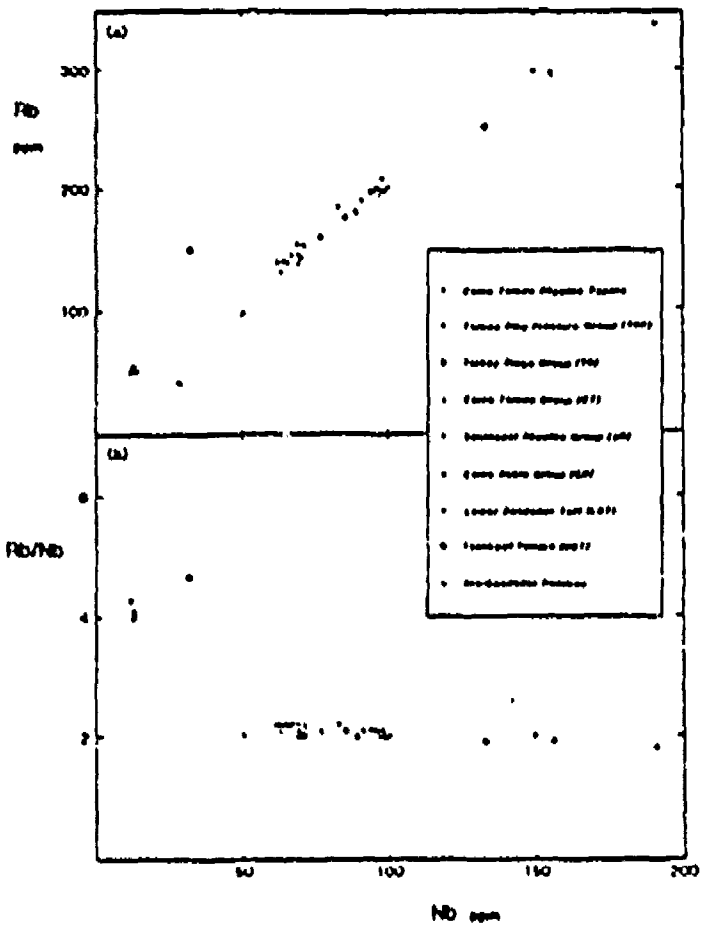


Fig. 6. (a) Nb plotted against Rb in ppm. A well-correlated linear trend is apparent. Cerro Toledo Rhyolite tephra samples that are most enriched in Nb and Rb represent the later stages of Cerro Toledo Rhyolite intracaldera explosive volcanism. Cerro Rubio Group samples are relatively depleted in Nb and Rb. (b) Nb versus Nb/Rb. The Nb/Rb ratio remains relatively constant above 50 ppm Nb. The symbols in this diagram remain the same in the following figures.

[*Smith and Bailey*, 1966; *Wörner and Smith*, 1980]. Notably, the increase in chlorine content mimics that of Zr from unit f (sample 1546) to the base of the Tsankawi Pumice (sample 631). Zr increases by 58% from 168 ppm in unit f to 265 ppm in the Tsankawi Pumice (Figure 3d), whereas Cl increases from 1700 to 2500 ppm (47%) over the same interval. If Cl contents are indicative of overall volatile concentrations in the magma chamber, these trends suggest that volatile contents (1) control, at least in part, zircon saturation in the magma and (2) increased significantly in the Bandelier magma chamber before the eruption of the Upper Member of the Bandelier Tuff.

Fractionation of an LREE-rich accessory phase. When plotted against Nb, La displays wide scatter in which Cerro Toledo Rhyolite points show La depletion with increasing Nb (Figure 10a). However, $[La/Yb]_n$ is strongly depleted with respect to Nb, particularly for the Cerro Toledo Rhyolite (Figure 10b). Although Th and Nb show a positive linear correlation, Th/Nb also decreases with Nb enrichment (Figure 11). For Cerro Toledo Rhyolite tephras, the oldest are most depleted in Th but have the highest Th/Nb values, similar to Zr relations in Figure 9. These trends contrast with those of Figure 6, in which Nb and Rb are positively correlated with essentially no change in the Rb/Nb ratio above 50 ppm Nb. These data suggest fractionation of a phase that has preferentially incorporated both Th and LREE. In metaluminous rocks, allanite is an accessory mineral that contains LREE as essential constituents [*Rapp et al.*, 1986]. Allanite is an accessory phase in unit a' of the Cerro Toledo Rhyolite tephra [*Heiken et al.*, 1986], in the Bandelier Tuff [*Kuentz*, 1986], and in the Valles Rhyolite of post-Valles caldera age (T. Spell, New Mexico Institute of Mining and Technology, personal communication, 1987). We have plotted theoretical Rayleigh fractionation trends for allanite in Figures 10 and 11 by assuming crystallization of 0.06–0.08 wt % allanite from sample 1548 as the parent. There is reasonable agreement between the theoretical and observed curves, despite mineral proportions and partition coefficients that are poorly constrained. Because allanite is so efficient at extracting LREE from the magma, however, the exact values of the partition coefficients for each

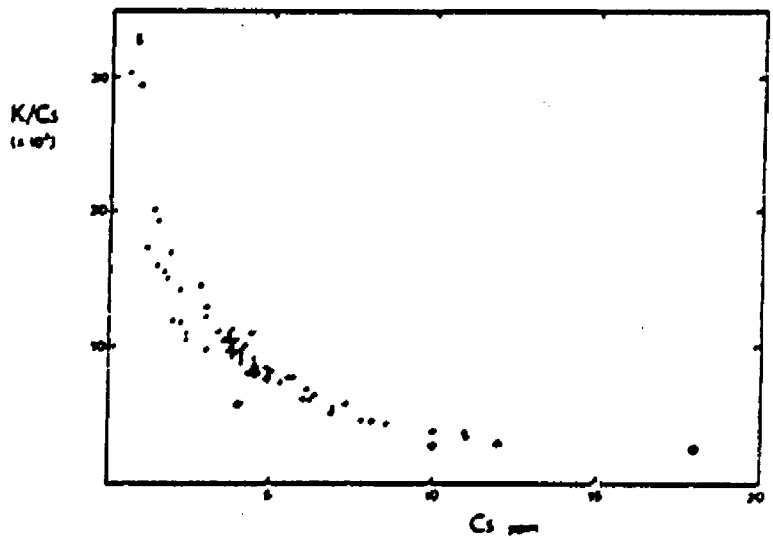


Fig. 7. Cs versus K/Cs. The data indicate decline of K/Cs with increasing Cs, both overall (K/Cs 33–2.5 × 10^3) as well as for samples of Cerro Toledo Rhyolite separa (K/Cs 15–3.2 × 10^3). Symbols as in Figure 6, except for the stars, which indicate Tschicoma Formation andesites and dacites [Langley, 1984]. These intermediate rocks, erupted at 3.7–4.7 Ma, are similar in age and composition to Cerro Rubio and may represent parental magmas of the Cerro Toledo Rhyolite and Bandelier Tuff.

element are of secondary importance. The partitioning ratios between individual REE are significant when modeling elemental ratios such as La/Yb and Th/Nb.

Chemostratigraphic data show general decreases upsection for both $[La/Yb]_n$ and Th/Nb (Figures 4d and 4e). $[La/Yb]_n$ decreases fourfold (13–3.2) from unit a" to 6–8, whereas Th/Nb decreases only 1.4 times over the same interval. $[La/Sm]_n$ shows a decrease similar to Th/Nb (1.7 times). Enhanced depletion of La compared with Th and Sm possibly results from the greater compatibility (threefold to sixfold) of La over Th and Sm into a phase such as allanite due to charge and size differences [Brooks et al., 1981; Mahood and Hildreth, 1983]. Th may be partitioned into zircon as well, but the partition coefficient is 4.6–8.8 times smaller than that of allanite in high-silica rhyolites [Mahood and Hildreth, 1983]. As with Zr, La contents increase significantly (53%) from unit f (38 ppm) to the Tsankawi Pumice (58 ppm) (Figure 3b). Chlorine contents increase 47% over the same interval, implying that volatile contents may control the solubility of LREE-enriched accessory phases in the magma.

Similar studies have shown that LREE depletion in nonperalkaline silicic magmas occurs frequently. Gromet and Silver [1983] have presented convincing evidence that the REE content of the melt in a granodiorite pluton decreased substantially during early crystallization of allanite and sphene. Miller and Mittlefehldt [1982], Mittlefehldt and Miller [1983], and Barrett [1984] have suggested that accessory phases such as monazite and allanite can effectively remove significant quantities of LREE because these elements are stoichiometric constituents of the minerals. Clearly, the ability of monazite and allanite to deplete a melt of its LREE attests to the low solubility of these accessory phases in nonperalkaline silicic melts [Rapp and Watson, 1984; Rapp et al., 1984].

Apatite fractionation. The very low P_2O_5 contents of the Cerro Toledo Rhyolite domes (generally <0.14% P_2O_5) suggest that apatite was removed from the magma [Watson, 1979; Watson and Capobianco, 1981]. Because the solubility of apatite decreases significantly (to about 0.14% P_2O_5 in rhyolite) with increasing silica content, the Cerro Toledo Rhyolite magmas clearly were once saturated in apatite and crystallized apatite [Watson and Capobianco, 1981]. However, apatite cannot have fractionated significant LREE from the melt because (1) LREE are not essential structural constituents of apatite, and thus the bulk distribution coefficients of LREE due solely to apatite are ≪1; (2) apatite does not preferentially incorporate LREE over middle rare earth elements (MREE) and HREE [Arth, 1976; Watson and Green, 1981]; and (3) P_2O_5 contents in even the least fractionated samples are so low that not much apatite crystallization is likely to have taken place (<0.3%).

"Incompatible" elements. From the evidence presented above, we believe that crystal fractionation is an important, perhaps dominant, process in the evolution of the Cerro Toledo Rhyolite and Bandelier magmas. We begin with the Rayleigh equation:

$$C_L/C_o = F^{(D-1)} \quad (1)$$

where C_o is the concentration of an element in the parental liquid, C_L the concentration of the element in the residual liquid as a result of fractional crystallization, F the amount of liquid remaining after crystallization, and D the bulk distribution coefficient. For incompatible elements, $D \ll 1$; therefore (1) can be rewritten in the form

$$C_L/C_o = F^{-1} \quad (2)$$

or

$$C_o/C_L = F \quad (3)$$

This simple inverse approach to petrogenetic modeling [Allè-

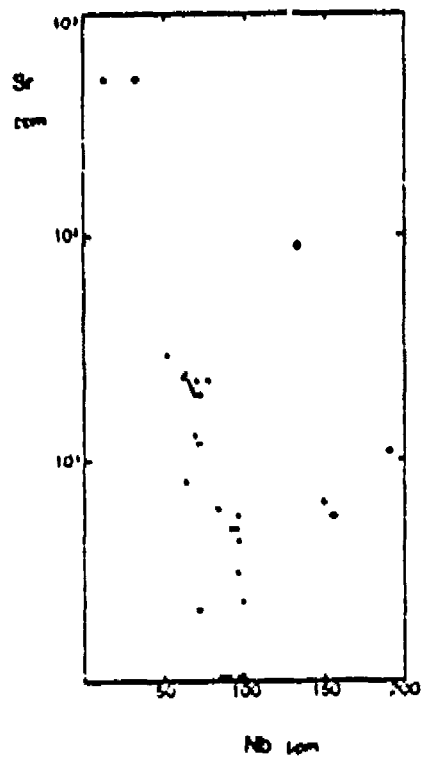


Fig. 8. Semilog plot of Nb versus Sr. The data suggest rapid depletion of Sr with increasing Nb, particularly for Cerro Toledo Rhyolite tephra. Many Cerro Toledo Rhyolite domes contain practically no Sr. Note (1) the Tsankawi Pumice sample that contains 514 ppm Sr (0.92%) plotted near the Cerro Rubio Group samples, and (2) the four points, all above 130 ppm Nb, that fall off the overall trend and are relatively enriched in Sr for such high concentrations of Nb. Only one of these points is a Cerro Toledo Rhyolite. See text for discussion. Symbols as in Figure 6.

are et al., 1977] has been used by *Ferrara and Treuil* [1974] for peralkaline systems. By assuming sample 15-8 at the base of the Cerro Toledo Rhyolite as C_0 and sample 6-8 of the Tsankawi Pumice (UBT) as C_L (Figure 3), we can calculate an apparent F using different incompatible elements (Table 5). The lowest apparent F value, 0.22 for Cs, implies that at least 78% of the magma chamber had crystallized over a period of 0.3 m.y. by fractional crystallization of essentially quartz and alkali feldspar. For comparison, *Bailey et al.* [1986] have estimated 70% crystallization occurred to produce the observed chemistry of the Lower Bandelier Tuff. Furthermore, normally incompatible elements such as HREE, Nb, and Rb have higher F values, implying that these elements are not in fact perfectly incompatible. Table 5 lists trace elements in order of increasing compatibility (increasing F values). Rb and, to a lesser extent, Cs are taken into alkali feldspar, whereas HREE, Y, Nb, Th, and U probably partition into accessory phases (e.g., zircon, allanite, apatite, and ilmenite). Nevertheless, the amounts of these accessory phases that crystallized appear to be so low that the HREE and highly charged cations were enriched, rather than depleted, in the magma as cooling and crystallization proceeded. These relations show that (1) decoupling occurs between large monovalent alkalies and more highly charged cations, (2) in spite of this decoupling, Rb and Nb are not noticeably fractionated between each other (Figure 6), and (3) the estimate of 78% crystallization from the Cs data represents a minimum figure. Although less compatible than Rb because of its large size, Cs does enter alkali feldspar to a certain degree [*Nash and Crecraft*, 1985]. Thus the amount of crystallization was probably higher.

We explore below physical processes that may or may not be capable of (1) forming the chemical gradients we have documented for the Cerro Toledo Rhyolite, (2) enriching the residual magma severalfold in incompatible trace elements [*Miller and Mittlefehldt*, 1984], and (3) generating nearly aphyric liquids as represented by the Cerro Toledo Rhyolite.

Convective fractionation. Recent experimental and theoretical work suggests that sidewall crystallization could result in the formation of a compositionally light, incompatible-element-enriched boundary layer that flows up the walls of the magma chamber to stratify at the top [*Sparks et al.*, 1984]. As well, solidification at the roof may result in a crystallization front that moves downward into the magma chamber with time [*Baker and McBirney*, 1985]. This is essentially in situ crystallization. We favor roofward crystallization over sidewall crystallization for the following reasons: (1) heat loss is greatest at the roof [*Jaeger*, 1970]; (2) stratification by roofward crystallization may be more efficient than sidewall crystallization because the light boundary layer formed by the latter process may be affected by shearing, backmixing [*McBir-*

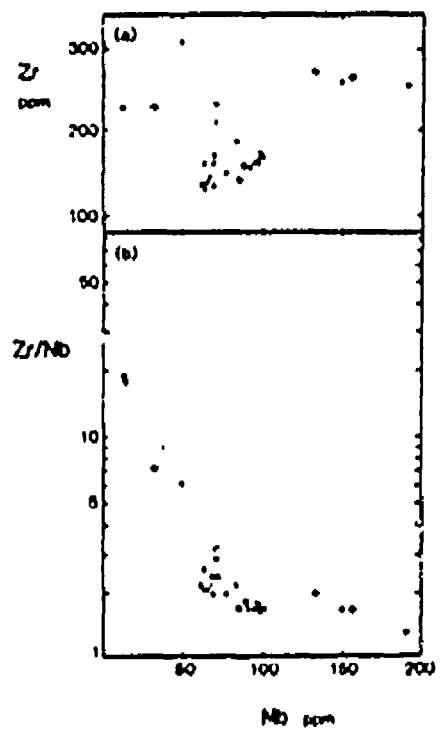


Fig. 9. (a) Nb versus Zr. A wide scatter of points is exhibited for the various groups. There is a poorly defined increase in Zr with Nb for Cerro Toledo Rhyolite tephra samples. (b) Semilog plot of Nb versus Zr/Nb. Zr/Nb decreases with increasing Nb. In contrast to Figure 9a, Cerro Toledo Rhyolite tephra samples show a general decrease in Zr/Nb with increasing Nb. The four points above 130 ppm Nb, only one of which represents the Cerro Toledo Rhyolite, fall off the trend of Zr/Nb-depletion. Symbols as in Figure 6.

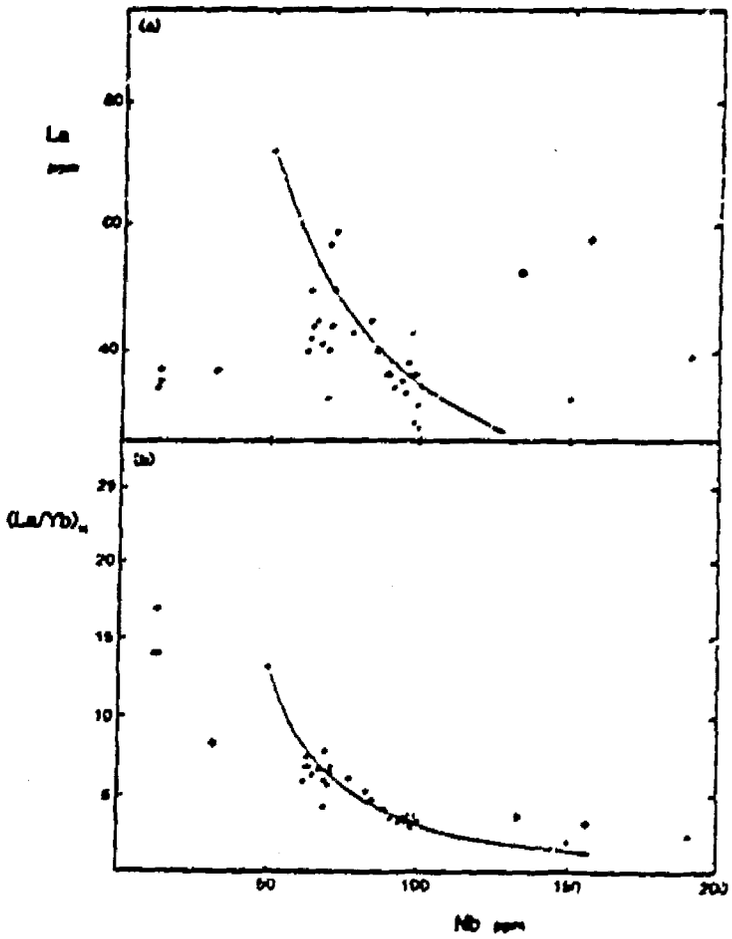


Fig. 10. (a) Nb versus La. A wide scatter of points is indicated for the different groups. (b) Nb versus $[La/Yb]_n$. $[La/Yb]_n$ is depleted with increasing Nb. A break in slope occurs above 130 ppm Nb, where four samples are relatively enriched in $[La/Yb]_n$ compared with the other data points, for the appropriate Nb concentration. Only one of these four points is a Cerro Toledo Rhyolite. The dashed lines are theoretical Rayleigh fractionation curves for allanite. Sample 15-8 just above the base of the Cerro Toledo Rhyolite represents the parental Cerro Toledo Rhyolite magma at 50 ppm Nb, and the direction of fractionation is indicated by the arrows. Our chosen theoretical values for allanite are 0.0001 weight fraction allanite, $D_{La} = 2594$, $D_{Yb} = 31$, and $D_{Nb} = 3$ [*Mahood and Hildreth*, 1983]. Symbols as in Figure 6.

ney et al., 1985], interference by growing crystals [*Huppert and Sparks*, 1984, p. 26], or other processes of disruption as it travels upward along the sidewalls before accumulating at the roof; and (3) the crystallization front at the roof remains in contact with the lightest, most fractionated liquid at the top of the magma chamber and further enriches and stratifies this liquid by continued crystallization. Thus systematic temporal changes in the erupted products (*i.e.*, the Cerro Toledo Rhyolite) may be ascribed to the changing composition with time of the most fractionated liquid at the top of the magma chamber.

Removal of crystals. The often-observed decreases of Zr and LREE in silicic magmas imply not only crystallization of zircon and LREE-enriched accessory phases but their removal from the residual liquid, as well. For a 100-μm-diameter zircon crystal to settle 500 m in silicic magma at 785°C [*Murase*, 1962] requires 1.2×10^9 years in magma with 5% H_2O ($\eta = 10^4$ P) and 1.2×10^{11} years in anhydrous magma ($\eta = 10^{13}$ P), calculated using Stokes law. Except for very wet magmas, the settling times appear unrealistic compared with the duration of Cerro Toledo Rhyolite intracaldera activity (2.7–3.3×10^5 years). Accessory phases also may be removed as inclusions in ferromagnesian phases such as biotite [*Miller and Mittlefehldt*, 1982, 1984; *Cameron and Cameron*, 1986]; however, biotite will not settle readily in silicic magma. Most logically, these crystals will be accreted to the margins of the magma chamber where heat loss is greatest, *i.e.*, the roof of the chamber.

Assimilation

Melting the roof of a magma chamber also can produce compositionally light melts that stratify at the top of the chamber. So long as heat is supplied to the liquid at the top to

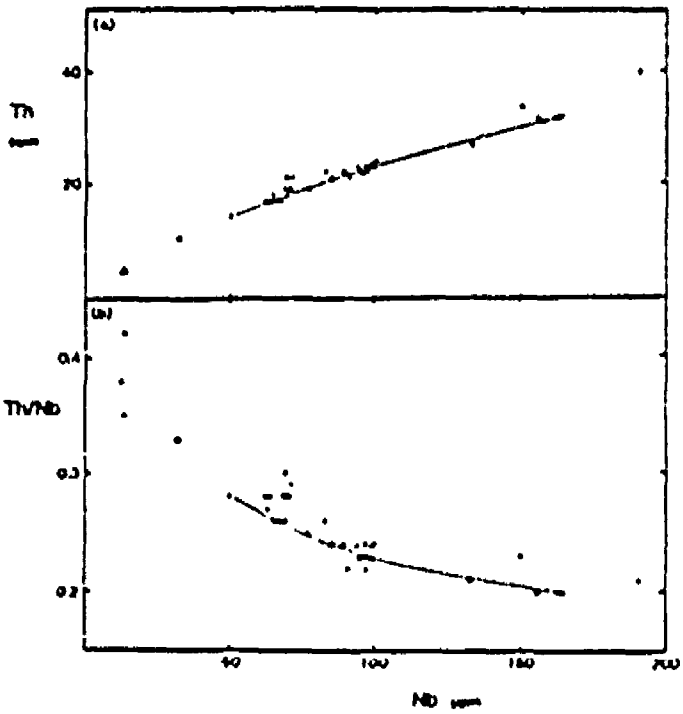


Fig. 11. (a) Nb versus Th. A well-correlated linear increase in Th with respect to Nb is indicated. (b) Nb versus Th/Nb. Th/Nb is depleted with increasing Nb. The change in slope for Cerro Toledo Rhyolite samples between Figures 11a and 11b is well illustrated. Theoretical curves are as described in Figure 10, except for 0.0026 weight fraction alkanite and D_{Th} = 4.84. The discrepancy in weight fractions between this and Figure 10 is probably due to uncertainties in the partition coefficients for La and Th. Symbols as in Figure 6.

maintain superheat and prevent crystallization, roof melting will occur if the temperature of the magma exceeds the melting point of the wall rocks [*Turner and Campbell*, 1986]. The supply of heat may come from crystallization of mafic magma at a lower level in the magma chamber [*Hildreth*, 1981]. Theoretically, roof melting provides a more efficient mechanism than sidewall crystallization to stratify liquids at the top of the chamber, and roof melting combined with subsequent fractional crystallization may be a common process [*Turner and Campbell*, 1986]. It is difficult to assess the role of roof melting for Cerro Toledo Rhyolite magmas because of a lack of isotopic data; however, the following points suggest that roof melting was not responsible for the observed chemical variations: (1) Sr contents generally are very low in Cerro Toledo Rhyolite rocks, and (2) Sr is strongly depleted with respect to Nb and follows a fractional crystallization trend (Figure 8). Fractional crystallization also may mask the effects of earlier roof melting. Isotopic data from the Bishop Tuff, a high-silica rhyolite that has many geochemical similarities with the Bandelier system, indicate that little or no melting of the roof occurred [*Halliday et al.*, 1984]. In contrast, *Noble and Hedge* [1969] have shown that the first-erupted rocks of certain ash flow sheets have higher initial strontium ratios than do the later-erupted, upper parts of the sheets, indicating that the upper parts of the magma chambers were contaminated, possibly by roof melting, stoping, and/or fluid assimilation.

TABLE 5. Apparent *F* Values

Element	*F*
Cs	0.22
Yb	0.31
Y	0.32
Nb	0.32
Rb	0.33
Lu	0.34
U	0.36
Dy	0.38
Th	0.44

F is calculated by dividing concentration of sample 15-8 (C_o) by that of 6-4 (C_f), where $F = C_o/C_f$.

Diffusive and Soret Processes

Several workers have proposed liquid-state thermodiffusive processes to explain observed major and trace element variations in ignimbrites [*e.g., Hildreth*, 1979, 1981; *Schott*, 1983]. We discuss, in turn, rates of diffusion among cations of different valencies and the Soret effect in silicic liquids.

For cations of similar ionic radius (K^+, Ba^{2+}) at 800°C, diffusivity of the 2+ cation is 3 orders of magnitude lower than that of the 1+ [*Hofmann*, 1980, Figure 7]. Similarly, for Ca^{2+} and Ce^{3+} at 800°C, diffusivity of the 3+ cation is 6 orders of magnitude lower than that of the 2+ [*Jambon*, 1982, Figure 2]. Extrapolation suggests that diffusivities for 5+ cations such as Nb are much lower still [*Jambon*, 1982, equations (13) and (14)] (Table 6). Thus if diffusion played a significant role, Rb and Nb should be very strongly fractionated with

TABLE 6. Calculated Diffusivities for Three Cations of Different Valence State

Cation	Valency	Ionic Radius Å	Activation Energy, kcal mol^{-1}	Frequency Factor, cm^2 s^{-1}	Diffusivity, cm^2 s^{-1}
Rb	+1	1.52	23.6	2.3×10^{-3}	2.4×10^{-9}
Y	+3	0.90	77.0	5.0×10^{4}	2.8×10^{-11}
Nb	+5	0.64	48.8	6.3×10^{-2}	6.3×10^{-10}

Diffusivities calculated from equations (13) and (14) of Jambon [1982] at 800°C. Ionic radii from Shannon [1976] in octahedral (VI) coordination.

respect to each other in Cerro Toledo Rhyolite and Bandelier rocks. However, Rb and Nb clearly are not fractionated (Figure 6).

Turning to the role of Soret diffusion, major and trace element fractionation in experimental felsic silicate melts by Soret processes contrasts strongly with geochemical gradients observed in certain ignimbrite sequences [*cf. Smith and Bailey*, 1966, Figure 16; *Creecraft et al.*, 1981, Figure 6; *Hildreth*, 1981, Figure 7; *Mahood*, 1981, Figure 3; this work, Figure 5]. *Lesher* [1986, Figures 4c and 4d] has shown that network-forming elements (e.g., Si) fractionate to the hot end of the laboratory Soret temperature gradient, whereas network modifiers (e.g., Ca, Mg, Fe, and most trace elements) concentrate at the cold end, for silicic melt compositions at 1300°–1670°C. *Poulsen and Mahood* [1984] have obtained similar results at temperatures more appropriate to silicic magmas (1030°C). These results conflict directly with ignimbrite data and suggest that Soret diffusion does not cause the compositional zoning documented in many silicic magma chambers.

Conclusions

We have reached four main conclusions from our study of the Cerro Toledo Rhyolite.

1. The Cerro Toledo Rhyolite tracks the restoration of compositional gradients at the top of the Bandelier magma chamber between 1.45 and 1.12 Ma.

2. Crystal fractionation was the major process by which these gradients were restored, mainly by crystallization at the roof of the magma chamber.

3. No one trace element which we have analyzed remained truly incompatible during evolution of the Cerro Toledo Rhyolite; Cs comes closest.

4. Diffusive and Soret processes did not contribute to any significant extent in forming the compositional zoning of the magma chamber.

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ASH FLOWS

By Robert L. Smith

Abstract

The ash flow is the basic unit of most pyroclastic deposits known as welded tuffs, tuff flows, pumice flows, or ignimbrites. Other useful units are the cooling unit, both simple and compound, the composite sheet, and the ash-flow field. The deposit of one ash flow is considered analogous to, but not necessarily the same as, the deposit produced by the passage of one nuée ardente. The geological evidence favors gas-emitting particulate flows as the agents of transport.

The ash-flow is an efficient heat-conserving mechanism, and, because many ash-flow fields contain cooling units believed to be derived from common magma, but clearly emplaced at different temperatures, a cooling mechanism must be invoked. Such a mechanism may be the vertical eruption column which influences the final properties of many ash flows.

Deposits are grouped in seven orders of magnitude ranging from 0.001 to 10,000 km³. Orders 1 to 3 include deposits erupted from domes. Those from craters rarely exceed 10 km³, order 4. Deposits of orders 5 to 7 are associated with subsidence structures in all examples where the source area is known. Welded tuffs occur in fields of all volumes, but they are common among the fissure-erupted deposits of larger volume. Some ash-flow fields distributed from a common source area reach areal dimensions of more than 12,000 square miles and volumes of about 800 cubic miles; some multiple-source fields are known to have volumes of more than 2000 cubic miles. Deposits of single-eruption cycles having volumes of more than a few cubic miles are thought to be related to subsidence structures.

Sorting data suggest that most welded tuffs contain more than 70 per cent by weight of materials less than 4 mm in diameter. Welding and crystallization depend largely on relative temperature and thickness of the cooling units, and most of the textures in welded ash flows can be explained in terms of these variables. Welding begins with incipient cohesion of glass shards and fragments and continues with decreasing pore space and deformation to complete welding which results in a dense black glass.

Crystallization is superimposed on the welded material at any stage, but the degree of welding may influence the type of crystallization. The degrees of welding and of crystallization are zonal and permit the distinction between simple and compound cooling. Incipient welding may take place below 535° C., but complete welding depends on load pressure and time and is thus influenced by the cooling history of individual cooling units. Deposits emplaced at low temperatures such as the Crater Lake, Oregon, "pumice flows" are essentially nonwelded in thick deposits. The high-temperature welded tuffs of southwestern Idaho are densely welded in very thin sheets. Most welded tuffs are probably emplaced at temperatures intermediate between these limits. Some deposits record a systematic change in temperature during the eruption cycle; others record a change in magmatic composition. Some ash flows are thought to be genetically related to near-surface plutons, some of which are large and complex.

Résumé

La coulée de cendres est l'élément de base de la plupart des dépôts pyroclastiques appelés tufs soudés, coulées de tufs, coulées de ponce, ou ignimbrites. D'autres éléments utiles sont le bloc de refroidissement, simple ou composé, la nappe composée, et le champ de cendres de coulées. Les dépôts d'une coulée de cendres sont considérés comme analogues, mais pas nécessairement identiques aux dépôts produits par le passage d'une seule nuée ardente. Les données géologiques sont en faveur de coulées en menues particules, et émettant des gaz, comme agents de transport.

La coulée de cendres est un mécanisme efficaces de conservation de la chaleur, et parce que beaucoup de champs de cendres contiennent des blocs en refroidissement dont on pense qu'ils dérivent d'un magma commun, mais apparemment mis en place à des températures différentes, un mécanisme de refroidissement doit entrer en jeu. Un mécanisme

de ce genre pourrait être la colonne d'éruption verticale qui influe sur les propriétés ultimes de nombreuses coulées de cendres.

Les dépôts sont groupés en 7 ordres de grandeur, de 0,001 à 10.000 km³. Les ordres de 1 à 3 comprennent les dépôts venus de dômes. Ceux originaires de cratères dépassent rarement 10 km³, ordre 4. Les dépôts des ordres 5 à 7 sont associés à des structures de subsidence dans tous les exemples dont le lieu d'origine est connu. Les tufs soudés forment des champs de tous volumes, mais ils sont communs dans les dépôts d'origine fissurale et de grand volume. Certains champs de cendres venus d'un lieu d'origine commun atteignent des surfaces de plus de 30.000 km² et des volumes de plus de 2.000 km³; des champs d'origine multiples atteignent des volumes de 8.000 km³. On pense que les dépôts de cycles à une seule éruption qui ont des volumes de plus de quelques km³ sont en relation avec des structures de subsidence.

Les données granulométriques suggèrent que la plupart des tufs soudés contiennent plus de 70% en poids de matériaux de moins de 4 mm de diamètre. L'agglomération et la cristallisation dépendent largement de la température relative et de l'épaisseur des unités en refroidissement, et la plupart des textures rencontrées dans les coulées de cendres agglomérées peuvent s'expliquer en considérant ces variables. L'agglomération commence avec la cohésion naissante d'éclats et de fragments de verre, et continue par la diminution du volume des pores, et déformation, jusqu'à soudure complète qui aboutit à un verre noir dense.

La cristallisation se surajoute à n'importe quel stade dans le matériel aggloméré, mais le degré de soudure peut influer sur le type de cristallisation. Les stades d'agglomération et de cristallisation sont en sous, et permettent de distinguer le refroidissement simple du composé. L'agglomération naissante peut avoir lieu au dessous de 535° C., mais la soudure complète dépend de la pression et de la durée, donc est influencée par l'histoire du refroidissement des blocs individuels en refroidissement.

Les matériaux mis en place à basses températures, tels que les "coulées de ponce" de Crater Lake dans l'Oregon sont en grande partie non soudés dans les dépôts épais. Les tufs soudés à haute température du sud-est de l'Idaho sont densément soudés en couches très minces. La plupart des tufs soudés sont probablement mis en place à des températures intermédiaires entre ces extrêmes. Certains dépôts montrent un changement systématique de température pendant le cycle de l'éruption, d'autres montrent un changement de composition magmatique. On pense que certaines coulées de cendres sont liées génétiquement à des plutons proches de la surface dont certains sont de grande taille et de nature complexe.

Zusammenfassung

Der Aschenstrom ist die Grundeinheit der meisten pyroklastischen Ablagerungen, die als zusammen geschweisste Tuffe ("Schmelztuff"), Tuffströme, Bimsteinströme oder Ignimbrite bekannt geworden sind. Andere anwendbare Einheiten sind die einfache und die zusammengesetzte Abkühlungseinheit, die komplexe tafelförmige Masse, und das Aschenstromfeld. Man nimmt an, dass die Ablagerung eines Aschenstroms im allgemeinen analog zu der ist, welche durch die Passage eines nuée ardente ("Glutwolke") entsteht, aber nicht unbedingt dieselbe sein muss. Die geologischen Gegebenheiten sprechen dafür, dass gasunterstützte Partikel-Ströme als Transportkräfte dienen.

Der Aschenstrom ist ein wirkungsvoller, Wärme konservierender Mechanismus. Da viele Aschenstromfelder Abkühlungseinheiten enthalten die wahrscheinlich von gewöhnlichem Magma abstammen, jedoch eindeutig bei anderen Temperaturen eingebettet worden sind nimmt man an dass ein Abkühlungsmechanismus dabei zur Hilfe gekommen sein muss. Die vertikale Eruptionssäule könnte solch ein Mechanismus sein, welcher die endgültigen Eigenschaften vieler Aschenregen beeinflusst.

Die Ablagerungen werden in sieben Grössenordnungen eingeteilt, welche von 0,001 km³ bis 10.000 km³ rangieren. Die Grössenordnungen 1 bis 3 schliessen Ablagerungen ein, die von Domen eruptiert sind. Kraterablagerungen übersteigen selten die Grössenordnung 4 (10 km³). Ablagerungen der Grössenordnungen 5 bis 7 sind in allen Fällen, wo das Ursprungsgebiet bekannt ist, mit Bodensenkungsstrukturen verbunden. Zusammen geschweisste Tuffe kommen in Feldern aller Grössenordnungen vor. Sie sind jedoch unter den aus Spalten eruptierten Ablagerungen grösseren Umfangs häufiger. Einige Aschenstromfelder, die von einem gemeinsamen Ursprungsgebiet aus verbreitet wurden, erreichen Flächendimensionen von über 30.000 km² und Volumen von etwa 2.000 km³. Es ist bekannt, dass einige Felder mit mehreren Ursprungsgebieten Volumen von über 8.000 km³ haben. Es wird angenommen, dass Ablagerungen von Einzel-Eruptions-

quen, welche ein Volumen sehr als einigen km³ haben, zu Absenkungs-Strukturen in Beziehung stehen.

Korngrössen-Analysen lassen vermuten, dass mehr als 70% des Gewichtes der meisten zusammen geschweisten Tuffe aus Materialien bestehen, die weniger als 4 mm im Durchmesser sind. Das Schweissen und Auskristallisieren hängt weitgehend von der relativen Temperatur und der Dicke der abkühlenden Einheiten ab, und die meisten Texturen in den zusammen geschweissten Aschenströmen können mit Hilfe dieser Variablen erklärt werden. Der Schweissprozess beginnt mit geringer Kohäsion von Glasscherben und -bruchstücken und verläuft weiter über abnehmenden Porenraum und Deformationen bis zu einem völligen Verschweissen, das in einem undurchsichtigen, schwarzen Glas endet.

Kristallisation kann in den geschweissten Material in jedem Stadium auftreten, aber der Grad des Zusammenschweissens kann die Art der Kristallisation beeinflussen. Die Stadien von Zusammenschweissung und Kristallisation sind zeitlich angeordnet und erlauben die Unterscheidung von einfacher und komplexer Abkühlung. Beginnende Zusammenschweissung kann unter 535° C. stattfinden, aber vollständige Zusammenschweissung hängt vom Gewichtsdruck und von der Zeitspanne ab und ist so durch den Abkühlungsverlauf der individuellen Abkühlungseinheiten beeinflusst.

Ablagerungen, welche bei niedrigen Temperaturen eingebettet wurden, wie die "Bimsströmme" am Crater Lake, Oregon, sind in dicken Lagen zusammen ungeschweisst. Die Tuffe vom südöstlichen Idaho, welche bei hohen Temperaturen zusammen geschweisst wurden, sind in undurchsichtigen und sehr dünnen Lagen zusammen geschweisst. Die meisten zusammen geschweissten Tuffe sind wahrscheinlich bei Temperaturen, die dazwischen liegen, eingebettet worden. Einige Ablagerungen weisen einen systematischen Temperaturwechsel während des Eruptionsablaufes auf, andere zeigen einen Wechsel in der magnetischen Zusammensetzung. Man nimmt an, dass einige Aschenströme genetisch mit nahe der Erdoberfläche liegenden Plutonen verwandt sind, von denen einige von grossem Ausmass und komplexer Natur sind.

ПОТОКИ ВУЛКАНИЧЕСКОГО ПЕПЛА

Роберт Л. Смит

Резюме

Потоки вулканического пепла являются основной составной частью большинства пирокластических отложений. Эти отложения представлены сварными туфами, туфовыми потоками, потоками пепла, или игнимбритами. Другими элементами пирокластических отложений являются простые и сложные залежи, образовавшиеся в результате остывания, сложные покровы и отложения раскаленных лавин пепла. Отложение потока пепла аналогично отложению образованному позже проложившим раскаленного облака. Однако это не означает, что эти отложения тождественны. Геологические данные говорят о том, что потоки мелких частиц, выделяющие газ, играют значительную роль в переносе вулканического материала.

Поток вулканического пепла хорошо сохраняет тепло. Прочее остывание играет большую роль в образовании отложений потоков, содержащих остывшие залежи. Эти залежи, очевидно, связаны с общим магматическим источником и образовались при разной температуре. Прочее остывание может начаться с образования вертикального столба извержённого материала, который влияет на конечные свойства потоков.

Отложения потоков подразделяются по размерам на семь групп и их объем колеблется от 0,001 до 10 000 кубических километров. Группы от 1 до 3 включают извержения вулканических куполов. Отложения 4-й группы приближаются пропуткам извержения кратеров и редко превышают объем 10 кубических километров. Отложения групп от 5 до 7-й ассоциируются со структурами оседания во всех случаях, когда известен источник извержённого материала. Сварежные туфы встречаются в отложениях всех объемов, но они обычны среди отложений трещинных извержений большого объема. Некоторые отложения потоков вулканического пепла, происходящие из одного источника, покрывают площадь более 30 000 квадратных километров и достигают объема около 2 000 кубических километров. Некоторые отложения, имеющие несколько источников, дос-

тигают объема более 8 000 кубических километров. Отложения одиночных потоков измеряются, имеющие объем равный нескольким кубическим километрам, вероятно связаны со структурами оседания.

По данным гранулометрического анализа большинство сваренных туфов состоят на более чем 70% по весу из материала с диаметром зерен менее 4 мм. Спайка и кристаллизация зависит, в основном, от относительной температуры и толщины остывающих залежей. Большинство структур сваренных потоков вулканического пепла зависит от температуры и толщины залежи. Спайка начинается со сваривания осколков вулканического стекла и продолжается попутно с уменьшением объема пор и с деформацией составных частей, вплоть до полного сваривания, в результате которого образуется плотное черное стекло.

Кристаллизация накладывается на сваренный материал в любой стадии развития, но степень спайки может влиять на тип кристаллизации. Степень сварки и кристаллизации имеют вольный характер и позволяют различать простой и сложный процесс остывания. Начальная спайка может происходить при температуре ниже 535° по Цельсию, но полная сварка зависит от давления вышележащего материала и от времени, и таким образом зависит от процесса остывания отдельных залежей.

Отложения, образовавшиеся при низкой температуре, такие как "потоки пепла" Кратерного Озера в Орегоне, в основном, в залежах большой мощности не сварены. Высокотемпературные сваренные туфы из юго-восточного Айдахо плотно сварены в очень тонких покровах. Большинство сваренных туфов, вероятно, отложено при средних температурах. Некоторые отложения указывают на систематическое изменение температуры во время цикла извержения, другие указывают на изменения в составе магмы. Существует мнение, что некоторые потоки вулканического пепла генетически связаны с близповерхностными плутонами, некоторые из которых имеют значительные размеры и сложный состав.

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Introduction

...evolution of thought surrounding any ...d scientific knowledge is a fascinating ..., and none more so than that leading to ...ent concepts of the recognition, origin, ...de of eruption of the rocks commonly ...welded tuffs or ignimbrites. Many keen ...ists have been troubled or even confused ...the rocks because they show characteristics ...h tuffs and lavas, but are not clearly ...able to either category.

...this group of rocks belong the "tufflavas" ...Armenia, the "piperno" of Italy, ...lavas" and "hai ishi" (ash stones) of ..., some of the "rhomb porphyry" of ...y and Sweden, and perhaps the eutaxites ...Island of Tenerife. We are also finding ...tens of thousands of square miles of ...ic rocks, formerly considered lava flows, ...clastic rocks firmly indurated by weld- ...crystallization of their glassy parts.

...se rocks are predominantly silicic— ...ites, quartz latites, rhyodacites, and ...s. Andesites and trachytes may occur ...form, but basalts of this nature are ...ngly rare. As reflected by their com- ..., these rocks are, for the most part, ...ated along the orogenic belts, and they ...throughout the geologic column.

...h few exceptions, the rocks in question ...emplaced as particulate flows or pyroclastic ...ches in contrast to fluidal lava flows ...ish-fall pyroclastic rocks. The eruptive ...ches is generally held to be the nuée- ...ty or glowing-cloud eruption in one or ...of its many forms, although some authors ...taken exception to the nuée-ardente ...as the universal agent, especially ...welded tuff sheets and "pumice flows" of ...large volume.

...study of welded tuffs and of their ...welded counterparts is still in its infancy, ...though major progress is being made, and ...can be expected as quantitative results ...detailed studies become available.

...importance of these rocks is not limited ...to petrography, petrology, or volcanology. ...extends to the mapping of certain volcanic and metamorphic terrains, with their problems of stratigraphic and structural correlation. It seriously affects the study of calderas, volcano-tectonic depressions, batholiths, and many ore deposits. The geochemist should find welded ash flows a fertile field for innumerable problems of magmatic volatiles, trace elements, and rock alteration. To the experimental geologist they offer unique materials for the study of rate processes, such as welding and deformation of glass, devitrification, diffusion, and cooling.

It would be presumptuous to attempt discussion of all the facets of the welded-tuff problem; some have recently been or will be treated in other papers, and on others little or no work has been done. In this review the writer attempts to outline some of the more promising avenues for future research, as well as to concentrate on those facets of the problem that he feels need special consideration.

The reference list contains only a selection of the available papers on the subject. Many Russian and Japanese publications which might have been included were not available in a language the author reads, and other very good papers were simply not sufficiently germane to the subjects selected for discussion. Most of these are listed in the recently published and nearly complete *Ignimbrite bibliography* by Cook (1959). In addition an excellent summary of eruptive processes and their products has been published by Williams (1957, p. 59–65); a very good summary paper covering many facets of the subject has been published by Martin (1959); and Ross and Smith (in press) present a historical review, summarize criteria for recognition, and discuss microscopic and field features and processes.

Acknowledgments

The writer gratefully acknowledges discussions with numerous colleagues mentioned in the text. Special thanks are due C. S. Ross and R. A. Bailey for reference to our unpublished joint work in the Valles Mountains, New Mexico, and to Bailey for many hours of critical discussion of ideas and facts. Special thanks are

also due P. E. Cloud, Jr., S. S. Goldich, and J. H. Mackin for critical review of the manuscript.

NOMENCLATURE

The writer recognizes that the nomenclature of these rocks is controversial. Differences on terminology are usually resolved when those most concerned reach a common level of knowledge, mutual understanding, and communication. With these thoughts in mind and with the additional thought that the "welded-tuff problem" is, in many respects, still an "infant," it does not seem profitable to discuss the relative merits of different nomenclatures. Instead, for the demands of internal consistency in this paper, the writer will present briefly the usage he has found most applicable to the greater number of deposits of welded tuffs or their nonwelded equivalents. He has no illusions that this usage will necessarily satisfy the needs and beliefs of other workers, nor does he wish to create the impression that it should.

ASH FLOW: The basic unit of ash-flow deposits is the ash flow that is analogous to, or perhaps the same as, the deposit resulting from the passage of one nuée ardente. As defined here, it consists of 50 or more weight per cent of ash and fine ash exclusive of foreign inclusions. Ash (1/16 to 4 mm) and fine ash (less than 1/16 mm) refer to the Wentworth and Williams' (1932, p. 45) size scale. Most glass shards and crystals are of ash or fine-ash size. The remaining essential materials are pumice lapilli and blocks or, in some types, scoriaceous materials, or mixtures of the two. Most welded tuffs and their nonwelded equivalents fall in this category (see discussion of sorting); however, some pyroclastic flows will not conform to the arbitrary 50 per cent minimum for essential particles less than 4 mm in diameter. For these the term lapilli-and-block flows might be used, but as this term is cumbersome, and in view of the fact that the lapilli and blocks can be separated on the basis of their pumiceous or scoriaceous nature, pumice flow or scoria flow (whichever material predominates) seems appropriate, but would call for redefinition of these terms. The term ash flow as used here includes all or, within the limits of the defined particle size, most of the deposits described under the following terms:

Tuff flow
Incandescent tuff flow
Sand flow
Pumice flow
Scoria flow
Block and ash flow (in part)
Gas and ash flow
Hot ash flow
Glowing avalanche (in part)
Deposits of the St. Vincent vertical type (in part)
Deposits of the "Nuée Ardente du katmaienne"
Deposits of the Valley of Ten Thousand Smokes type
Aso lava
Ignimbrite
"Hai ishi"
Tuff lava
Welded tuff
Welded mud lava
Schmelztuff
Piperno
"Shirasu"
Sillar

ASH-FLOW SHEET: Some ash-flow deposits have not been subdivided into well-defined units, yet they are mappable, sheetlike stratigraphic units and are of inferrable ash-flow origin. For these a nonspecific name is useful. Ash-flow sheet is used in this sense to include any unspecified sheetlike unit or group of units considered to be of ash-flow origin. If the materials of the sheet are predominantly welded tuff or if it is desirable to emphasize their welded character, the term welded tuff sheet is used.

WELDED ASH FLOW: An ash flow in which welding has produced a conspicuous zonal pattern is termed a welded ash flow.

WELDED TUFF: A welded tuff is a rock or rock body in which vitric particles have some degree of cohesion by reason of having been hot and viscous at the time of their emplacement. Incipient, partial, dense, or complete welding are indicated by these terms. The term welded tuff does not carry a stratigraphic connotation. However, a deposit of welded tuff could conceivably include an entire ash flow, and probably does in some cooling units. The term welded tuff should exclude "fused tuffs" in which reheating of vitric pyroclastic beds in proximity to hot rock bodies was responsible for their coherence. Crystallization may follow or accompany welding but, while commonplace, is not essential to that process. Some air-fall materials may be included where welding was in consequence of the inherent heat of the particles.

WELDED TUFF SHEET: A sheetlike body of rock containing conspicuous welded tuff is called a welded tuff sheet. Used loosely it

to any unit or group of units that have been specifically defined.

COOLING UNIT: A single or multiple ash-flow (Pl. 1) that can be shown to have been continuous cooling is a cooling unit. The cooling history of the unit may have been totally uniform or broken by successive movements, but not broken to the extent that part cooled completely before another was emplaced on top of it.

Simple Cooling unit is an ash flow or zone of ash flows that has had an essentially uninterrupted cooling history. Such units reveal either nonwelded and noncrystalline or cooling or form a pattern of textural zones. The zonal pattern will be consistent with the individual welding and crystallization characteristics of the unit, as determined by variables emplacement temperature, thickness, gas content, and physical and chemical composition. (See section on Zones and Zonal Sections.)

Compound Cooling unit is one that shows departures in the expectable zonation and other properties which result from simple cooling, when the intervals between ash flows were great for readjustment to a single-unit cooling gradient (Pl. 2, fig. 1).

COMPOSITE SHEET: A cooling-unit complex upgrades from one cooling unit into two or more cooling units is a composite sheet.

ASH-FLOW FIELD: Deposits of pyroclastic flows consisting preponderantly of ash flows, which are related to some specific unit of area, constitute an ash-flow field.

ASH-FLOW PROBLEM

Within the many-faceted ash-flow problem the writer stresses those deposits that contain welded tuffs, especially those that occur in great volume over large areas. The solution of many unsolved problems concerning these deposits will come about only through detailed studies. Some of these problems are minor in scope, but at least five must be considered major: (1) recognition of ash flows, (2) recognition and definition of units, (3) mode of eruption, (4) eruptive vents and source areas, and (5) origin of the magmas.

Twenty-five years ago Marshall (1935) and Marshall and Ross (1935) discussed the field and microscopic characteristics of the New Zealand "ignimbrites" and the Idaho "welded tuffs." Since that time nearly all authors who have studied welded tuffs in detail have discussed problems of recognition, and many have suggested criteria. The problem still remains, however, because the distinction between welded tuffs and lava flows on the one hand, and between ash-flow tuffs and tuffs of other origins on the other hand, is not always possible.

Recognition and definition of units within ash-flow fields is especially important where detailed structural and stratigraphic correlations are sought and where genetic problems are concerned. Deposits that were emplaced virtually "en masse" or from a very rapid sequence of eruptions are much less complex than those that contain cooling breaks or erosional disconformities.

Problems of the mode of eruption are related to the fact that no scientifically observed eruptions are known to have produced welded tuffs or deposits comparable in volume to those resulting from many prehistoric eruptions. Nearly all reasoning of the last 35 years concerning prehistoric deposits has been by analogy with the Valley of Ten Thousand Smokes whose deposits, in turn, have been explained in terms of the nuée-ardente concept developed from the observed eruptions of Pelée and La Soufrière.

The soundness of this chain of reasoning is rarely questioned, although some misinterpretation of the classical concepts have been published. Nevertheless, the eruption mechanisms before emplacement of deposits from "nuées ardentes" need investigation and clarification as does the precise meaning for the term nuée ardente, if we persist in using the term to designate the agent of emplacement of these deposits.

The most important ash-flow problem concerns the location and kind of eruptive vents and source areas which produce the sheet deposits of great volume. It seems almost incredible that, of the hundreds of occurrences of ash flows comprising tens of thousands of cubic miles of rock in the western United States, for example, the number of unequivocally known source areas is probably less than 10. In terms of published data the number is 4. These are all subsidence structures: Crater Lake caldera, Oregon; Valles caldera, New Mexico; Creede caldera, Colorado; and parts of Yellowstone National Park. On the other hand, practically all the deposits of "welded tuffs" or "pumice flows" known to have a volume of more than a few cubic miles and that have been unequivocally related to their source areas are related to subsidence structures. With this evidence favoring subsidence in the source

areas, it becomes of prime importance to locate these sources for the older deposits.

The question of origin of magma is of special interest in pyroclastic eruptions producing ash flows, because some ash-flow deposits are very large and are located in tectonic settings that suggest kinship with granitic batholiths. The problem concerns the immediate origin of the magma from "volcanic" or "plutonic" sources rather than its ultimate origin.

Mode of Eruption

General Statement

Present concepts of the mode of eruption of hot pyroclastic flows center around the nuée-ardente or glowing-avalanche eruption and depend almost entirely on the well-known published accounts of the 1902 eruptions of Mt. Pelée in Martinique (Lacroix, 1903a; 1903b; 1904; Anderson and Flett, 1903) and La Soufrière on St. Vincent (Anderson and Flett, 1903), and the eruption in 1912 near Mt. Katmai in the Valley of Ten Thousand Smokes, Alaska (Fenner, 1923). These accounts have been augmented by detailed observations of the 1929–1932 eruption of Pelée by Perret (1935) and by various eruptions of Merapi (1930–1935) in central Java (Stehn, 1936; Neumann van Padang, 1933; Van Bemmelen 1949). More recent eruptions, among which were those from Lamington (1952) in New Guinea (Fisher, 1954; Taylor, 1954; 1956) and Hibok-Hibok (1948–1953) in the Philippines (MacDonald and Alcaraz, 1953), have tended to confirm and strengthen the correctness of earlier observations.

There is thus a body of data from several competent observers which makes the "nuée ardente," in at least some of its forms, well known.

Opinion is divided, however, as to whether or not nuée-ardente mechanics are adequate to explain the eruption and emplacement of the pyroclastic materials that sometimes form welded tuffs. It may be significant, in this regard, that no observed nuée ardente has formed a recognized welded tuff. Because of the divided opinion and because some of the existing concepts of "welded-tuff" emplacement seem traceable to misconceptions regarding the classical nuées ardentes and to ambiguous usage of the term, it seems necessary to inquire briefly into the nature of the classical nuées ardentes. This is also important for understanding the development of the "pyroclastic-flow" concept.

Nuée Ardente

Lacroix (1903a) introduced nuée ardente as a geological term for the devastating eruption of Mt. Pelée on May 8, 1902, and for subsequent eruptions from Pelée. The eruption on May 7, 1902, of La Soufrière on St. Vincent also came to bear the name nuée ardente, as have many other eruptions from other volcanoes in other parts of the world, particularly Merapi in central Java.

Nuée ardente has also been used to designate eruptions which are believed to have been responsible for the great welded-tuff sheets and their nonwelded counterparts which are the main subject of this paper. This usage of nuée ardente has its origin in the studies of Fenner (1923), Lacroix (1930), and others, although Fenner sensed the fundamental difference between the deposits of the Valley of Ten Thousand Smokes and those of Pelée.

It should now be recognized that most welded ash flows cannot have had an origin from an eruption of the type that occurred at Mt. Pelée in 1902. The very size of the deposits precludes this; however, the mechanics of eruption and transport as deduced by the observers of the deposits of the eruption of Pelée and La Soufrière that took place on May 7 and 8, 1902, and observers of subsequent eruptions from Pelée, together with Fenner's interpretation of the deposits of the Valley of Ten Thousand Smokes, give us insight into a probable mechanism for eruption and transport of the ash-flow deposits of large volume.

All observers of the nuée ardente phenomenon except possibly Lacroix, agree that the nuée ardente has two parts—a basal avalanche and an overriding spectacularly expanding cloud of gas and dust (Lacroix, 1904, p. 350; Anderson and Flett, 1903, p. 447–453; Perret, 1935, p. 5; Neumann van Padang, 1933, p. 134; Van Bemmelen, 1949, p. 191–192; Taylor, 1954, p. 86; Akkersdijk, 1941, p. 63–64). The distinction between the two parts has not always been sharply drawn. These statements refer to the nuée ardente as an agent of transport of material from the vicinity of the vent to its final resting place, not to the material as it is being erupted from the vent.

Lacroix (1904, p. 350) has described the nuée ardente:

[illegible] nuée ardente est constituée [illegible]
[illegible] matériaux solides dans un mélange
[illegible] et de gaz à haute température,
[illegible] je ne reviendrai pas. La
[illegible] qu'elle présente au moment
[illegible] carapace du dôme montrent
[illegible] sous celle-ci à une compression
[illegible] bout de quelques secondes,
[illegible] supérieur de plusieurs milliers
[illegible] qu'elle possédait lors de son dé
[illegible] ... à la base, se trouve une zone
[illegible] nature, dans laquelle prédomi
[illegible] solides (blocs de toutes dim
[illegible] plus petits, cendres fines):
[illegible] ou des particules solides qui
[illegible] de la chaleur et doit être en
[illegible] sphère de gaz et de vapeur
[illegible] au début, mais se dilate
[illegible] tacte atmosphère qui, empêchant
[illegible] de se toucher, maintient l'en
[illegible] mobilité lui permettant de
[illegible], presque à la façon d'un li

[illegible] probably because of the trajec
[illegible]) nature of the May 8 nu
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[illegible] aware of but did not emph
[illegible]nche; he was, rather, pre
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[illegible] permeate the literature on
[illegible]brites. Many writers have
[illegible] as the agents of transport
[illegible]rials. This is doubly confu
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[illegible] ardentes does carry and
[illegible], although in insignifica
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[illegible]nderson and Flett (1903, p
[illegible]ing seen the trajectoral-typ
[illegible] the following account of
[illegible]ption of Pelée:

"Then in an instant a red-ho
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[illegible]ntain slopes right down to the
[illegible] and in it were brighter st
[illegible]ght were large stones, as the
[illegible] tails of yellow sparks. The
[illegible]ently rebounding when they
[illegible] ground, but never rising hi
[illegible] mass of the avalanche was
[illegible]rface was billowy like a cauc
[illegible]h. Its velocity was tremendo
[illegible] on the mountain top did n
[illegible] clearly how the fiery avalan
[illegible] a perfect view of its cours
[illegible] of the hill, and its glowing
[illegible] clearly seen. Its similarity t
[illegible]nche was complete in all re
[illegible]perature of the respective ma
[illegible]d in a minute or two, and in
[illegible] rushing forward over the sea
[illegible]g cloud, black, and filled
[illegible] straight out of the avalanc
[illegible]ly only the lighter and coole

lopment of the "pyroclastic

Nuée Ardente

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nature, dans laquelle prédominent des ma-
solides (blocs de toutes dimensions, frag-
plus petits, cendres fines); chacune des
des particules solides qui les constituent
du la chaleur et doit être entourée par une
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de se toucher, maintient l'ensemble dans un
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"Then in an instant a red-hot avalanche rose
the cleft in the hillside, and poured over the
steep slopes right down to the sea. It was dull
and in it were brighter streaks, which we
ught were large stones, as they seemed to give
ists of yellow sparks. They bowled along,
ently rebounding when they struck the surface
ground, but never rising high in the air. The
mass of the avalanche was a darker red, and
surface was billowy like a cascade in a mountain
k. Its velocity was tremendous. The mist and
on the mountain top did not allow us to see
clearly how the fiery avalanche arose, but we
a perfect view of its course over the lower
of the hill, and in a glowing undulating surface
clearly seen. Its similarity to an Alpine snow
nche was complete in all respects, except the
nature of the respective masses. The red glow
in a minute or two, and in its place we now
rushing forward over the sea, a great rounded,
g cloud, black, and filled with lightnings. It
straight out of the avalanche, of which it was
only the lighter and cooler surface, and as it
advanced it visibly swelled, getting larger and larger every minute."

Of the avalanche deposits formed from the May 7 eruption from Soufrière, Anderson and Flett (1903, p. 449) write:

"The geological evidence was not sufficient to demonstrate what form the discharge took, what was its path, and how great was its velocity when it left the crater; but by the time it reached the valleys below it was a rushing torrent of sand, stones, and hot gases, which courted along the valley bottoms, adapting itself readily to all changes in their configuration, too heavy to surmount any great height, but sweeping over the surface of the *minor ridges*, and coming gradually to rest in the deep ravines behind them. In the valleys of the Wallibu and Rabaka Dry River it filled the whole channel, and when its energy was spent it lay in banks, with irregular rounded upper surfaces, like glaciers of black sand. In the more shallow and open valley of the Wallibu Dry River it had not been confined to a narrow and steep-sided channel, but had been free to spread out laterally, and there it took the form of a broad sheet of sand with round-backed ridges, like wreaths of snow, pointing down the valley and diverging with a slightly fan-shaped arrangement."

These observations give a very clear picture of the avalanche portion of the nuée ardente. After comparing their observations at Soufrière with those at Pelée, they summarized in part that Pelean-type eruptions are characterized by avalanches of incandescent sand accompanied by a great cloud of gas and dust. The avalanche and the cloud both move at high velocity.

Anderson and Flett believed that the nuées ardentes moved under the influence of gravity, while Lacroix, although recognizing that gravity played a part, believed that a directed initial explosion was also necessary. They agreed that the extreme mobility of the mass was due to expanding gases.

The controversy was slowly resolved when, through observations of other nuée-ardente eruptions, it was realized that the position of the vent within the volcanic edifice influenced the initial behavior of the nuée ardente. It is not necessary to review the details of this evolution here; it is revealed in the works of Perret (1935), Lacroix (1908; 1930), Escher (1933a; 1933b), Stehn (1936), Grandjean (1931), Neumann van Padang (1933), Kemmerling (1932), and MacGregor (1952; 1955). MacGregor's paper is really the first detailed analysis of the problem, and in it many distinctions are clearly drawn. In particular it points up a number of common misconceptions as well as specific published errors.

Fenner (1923, p. 71–74), from his studies in the Valley of Ten Thousand Smokes, concluded that neither gravity nor violent initial explosion, alone, could explain the distribution of the "sand flow," and that a third factor was essential. He writes (p. 74):

"This, as I conceive it, is the self-explosive property inherent in the magma itself, due to the presence and evolution of dissolved gases; and this explosive evolution is not manifested immediately, but is prolonged over a considerable portion of the time during which the spreading movement continues, and gives to the material its fundamental characteristics of quasi-liquidity. Gravity plays an important part in directing the flow down mountain slopes or along topographic depressions, but it is believed that its effectiveness would be rather insignificant were it not for the peculiar properties imparted by the form of disintegration described."

We thus see Fenner as the originator of the "auto-explosive" flow concept. Lacroix, and Anderson and Flett recognized the fundamental importance of expanding gases in giving the mass its high mobility, especially over low gradients, but the delayed or continued evolution of gas has been more clearly expressed by Fenner.

Perret (1935), who witnessed more than 100 nuées ardentes from Pelée between 1929 and 1932, clearly recognized their dual character. His concept of the flowage mechanism was not essentially different from Fenner's. He stressed their wide range in intensity. Van Bemmelen (1949, p. 191–192) summarizes the nuée-ardente phenomenon based on his and other workers' observations in Indonesia, principally from the Merapi volcano in Java. He points out that the character of the eruption changes with an increase in volume of erupted material. Small-volume avalanches may be accompanied by a dust cloud, whereas larger volumes of more than a thousand, up to many hundreds of thousands of cubic meters, give rise to a nuée ardente of dual character. The "ladu" (avalanche) follows the canyons, whereas the "nuée ardente" may jump the banks and become independent of the avalanche for short distances.

The usage of the term nuée ardente is ambiguous. Within the references cited in this section it has been used for (1) the eruption which produces the laterally moving mass of fragmental material and gas, (2) the avalanche and overriding cloud as agents of transport, and (3) the cloud, exclusive of the avalanche.

Seemingly the nuée ardente as an agent of transport of volcanic materials, whatever it may be at the moment of its emergence from the vent, is, when it begins to leave a recognizable deposit, a flow of pyroclastic materials in which the fragments are hot and are emitting gas. An accompanying expanding cloud of gas emerges from the flow and carries considerable solid material, and it may become separated from the flow because of topographic diversions and run a short distance (several miles) on its own, before the gas becomes separated from the solid particles. The cloud may deposit thin beds of ash.

Any argument about the unity or separateness of the avalanche, or flow, and the cloud must center around the degree of inflation of the flow or the sharpness of transition between the flow and the cloud. Some writers have envisioned the entire nuée ardente as a "cloud" with gas suspending the solid materials, the whole having a dense base grading up to a diffuse top. Such a medium should, in spite of turbulence, leave a graded deposit either vertically, laterally, or both. To the writer's knowledge no such deposits have been described.

The eruptions discussed in this section were insignificantly small compared to ancient ash-flow eruptions. To reconcile the two we must magnify the nuées many fold or seek another explanation for the emplacement of ancient deposits.

Perhaps the significant point of difference between Pelean eruptions and eruptions that produce welded ash flows, aside from composition or the character of the vent, is that the entire mass of a Pelean nuée ardente is produced in one short burst, whereas the other type is produced by continuous evolution of material over periods of hours, days, or perhaps weeks. Fluctuations in intensity of the eruption allow diversity in ash flows not seen in Pelean deposits. The difference is probably directly related to the volume of eruptible material.

Vertical Component

The concept of formation of pyroclastic flows from vertical-eruption columns has not been given the consideration it deserves*. To

* Since this manuscript was submitted, two important papers have come to the writer's attention:

Hay, R. L., 1959, Formation of the crystal-rich glowing avalanche deposit of St. Vincent, B. W. I.: Jour. Geology, v. 67, p. 540–562

Taylor, G. A., 1958, The 1951 eruption of Mount Lamington, Papua: Australia Bur. Mineral Resources, Geology and Geophysics Bull. 38, 117 p.

Hay's findings at Soufrière are so pertinent to the discussion of the vertical component and its probable influence on cooling and sorting that the author

the concep: embodied in Lacroix's (421–472) *nuée ardente d'explosion* and the *nuée ardente du massif du* for vertical eruption, but to nearly the vertical component is just suffi- boost frothing magma to the crater's it begins its lateral journey as a ." Perhaps the most important of historical eruptions shedding light problem was that of Komagatake in (1934, p. 136) states that during part of the eruption pumice was straight up as high as 12 km. This was deposited in well-stratified beds; it was carried by the winds for more km. This air-fall pumice was followed vertical-eruption columns containing quantities of pumice erupted to lesser than the earlier materials. This later fell back on the mountain and poured the valleys to distances as great as 6 km. massive column of pumice above the together with the pumice flows pouring the mountain, may be seen in one of illustration (Kozu, 1934, Fig. 20).

(1942, p. 79) visualized conditions Lake, during the eruptions of the flows," to be much the same as at take in 1929. Similar deposits were but they are of quite different order

Komagatake "pumice flows," according (1938, p. 1851), were dry avalanches coches. Lacroix, 1930) and are not able to deposits such as the Bishop tuff. sense this may be true, but it may be that, of all pyroclastic flows produced served eruptions, the ones most closely to deposits of Crater Lake, Krakatoa, Valley of Ten Thousand Smokes are Komagatake "pumice flows." The Komaga- flows were of very small volume, erupted vertical column and hence somewhat by mixing with air before the flows were Yet fumarole temperatures as high as C. were measured in deposits averaging feet thick.

Bishop tuff is locally more than 900 feet and has a volume of more than 2400 times the Komagatake deposits. This alone is ly significant with regard to the ultimate but not with regard to mechanics of ement. Units of the Bishop tuff that are only 10 feet thick probably show no high-temperature characteristics that are not shown by the Komagatake flows, and, aside from compositional differences, the two would probably be indistinguishable. This is not to imply that the two deposits were emplaced at the same temperature, but rather that comparisons are not meaningful unless units of equal thickness are found to be different.

That the pyroclastic flow is a heat-conserving mechanism is shown by the temperature measurements on some historic deposits and by the existence of welded tuffs. Boyd (1957, Ph.D. Thesis, Harvard Univ.), in his study of the Yellowstone welded tuffs, has concluded from a careful analysis of factors causing heat loss, both during emplacement of the tuff and in the conduit, that the formation of welded tuff, from material emplaced by the "tuff-flow" mechanism, is thermodynamically feasible.

Boyd's calculations assume minimum mixing with air and indicate a temperature loss of less than 5° C., if the emplacement time was 1 hour, or less than 45° C., if the emplacement time was 10 hours. The approximate correctness of these figures, for the ideal ash flow, is suggested by the existence of certain welded-tuff sheets that are densely welded to within a few feet of their tops. Such a condition calls for very efficient heat conservation, because it means that the glassy particles must deform and weld under a very low load of less than a few pounds per square inch. Temperatures necessary to accomplish welding at such low loads are probably in excess of 800° C. (Smith, Friedman, and Long, 1958), whereas the eruption temperature of rhyolitic magma containing phenocrysts must be below about 960° C. and is probably below 900° C. for most rhyolitic pyroclastic rocks. These figures are suggested from a consideration of Tuttle and Bowen's (1958, p. 58) PT curve for the ternary minimum, and from our knowledge of minimum water contents of volcanic glass (about 0.1 per cent). There is no need to develop this argument here. It is mentioned only to show that field and experimental evidence support Boyd's conclusions that actual heat loss during flowage is small for ideal ash flows and that heat conservation is very efficient.

The ash flow seems in fact to be so efficient a heat-conserving mechanism that the writer is inclined to think that, except for eruptions from domes, the only reason ash flows containing a high proportion of glass ever escape welding is because they were cooled between the time they were erupted from the vent and

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manuscript was submitted, two im- papers came to the writer's attention: 1958, Formation of the crystal-rich deposit of St. Vincent, B. W. I.: v. 67, p. 549–562 A., 1958, The 1951 eruption of Mount Papua: Australia Bur. Mineral Re- and Geophysics Bull. 38, 117 p. pp. at footnotes are so pertinent to the the vertical component and its probable cooling and sorting that the author

recommends that Hay's paper be read by seriously interested in these facets of the problem.

the time they began their journey as pyroclastic flows. Seemingly the only significant cooling mechanism that can be invoked for this interval is mixing with air in a vertical-eruption column; the amount of mixing or degree of cooling is dependent on the height, density, and mechanics of the column, or columns.

Seeking an explanation for Lacroix's "lateral blasts" at Pelée in 1902, Jaggar (1902, p. 366) suggested that they were due to the interference between downfalling ejecta and the upblast from the crater. The interference caused the material to be deflected laterally. Anderson and Flett (1903, p. 313) discounted Jaggar's theory on the grounds that it fails to account for their observations of subsequent eruptions from Pelée. These and later observations by others at Pelée and other volcanoes support the views of Anderson and Flett, and it seems clear that Jaggar's explanation is precluded for eruptions from domes, which, because of the position of their vents, give sectoral distribution and commonly have a horizontal component. However, it is extremely doubtful whether Jaggar's or a similar explanation has been or can be disproved for the 1902 eruption from Soufrière. The important point of Jaggar's explanation is that it demands a vertical column of pyroclastic material and gas.

If the amount of solid material in the column exceeds that which can be efficiently erupted as air-fall pyroclastics, the excess must be displaced laterally as pyroclastic avalanches. Whether this laterally displaced material is influenced more by interference between upsurging and downfalling material, or whether it is related to differential velocities in the column or some other mechanism is an important point, but probably not so important as the thought that the volume of solid material in the column is a function of gas pressure, and that fluctuations or systematic changes in gas pressure might effectively control the amount of, and the emplacement-temperature characteristics of, the laterally displaced material. Such a scheme allows us to envision an eruption column which at one stage is producing air-fall pyroclastics and at another stage is simply boiling fragmental material over the lip of the vent.

Behavior of the laterally displaced material should depend on its volume, temperature, gas content, and the surrounding topography. If its volume and temperature are low, the material may accumulate to form dry avalanches, *avalanches ardentes* of Lacroix (1930, p. 466) or "hot avalanches" of Perret (1924, p. 90). If its volume is large but its temperature is low, it will perhaps form deposits like those around Crater Lake, Oregon. If its temperature is high and volume variable, it will form welded-tuff sheets, the characteristics of which will be determined by temperature, thickness, gas content, and composition.

The discussion in this section implies that the emplacement temperature of these pyroclastic flows may be controlled to much greater degree by cooling in a vertical column, before the flows form, than by a fundamental difference in magma temperature or initial gas content, and that this cooling is primarily related to the volume of materials in the column, the height of the column, and perhaps the nature of the vent. This is not to infer that the magma temperature is constant; it is not, and some deposits record a systematically changing temperature.

Emplacement by Flowage

The geologic evidence, aside from observed nuées ardentes, for the emplacement of ash flows by flowage or avalanche mechanics has been cited by authors such as Fenner (1923, p. 61–74), Anderson and Flett (1903, p. 449), Williams (1942, p. 81), and Matumoto (1943, p. 3–4). It may be summarized as follows: (1) restriction of deposits to valleys or other topographic lows in mountainous regions; (2) nearly level upper surfaces over buried topography except where compaction because of welding has caused surface irregularities; (3) lack of sorting far from vents which would suggest emplacement *en masse* rather than by air fall; (4) flowage features in some deposits; (5) retention of heat for long periods of time (years) resulting in fumarolic activity, welding, and crystallization, which appear improbable in air-fall deposits; (6) incorporation of surface debris.

TOPOGRAPHIC RESTRICTION. Restriction of ash-flow deposits to topographic lows is well illustrated by the Crater Lake "pumice flows." Williams (1942, p. 81) comments that the outstanding feature of these deposits is the manner in which they have followed the principal canyons near Crater Lake. In the Valles Mountains, New Mexico, all canyons that descend from the high-mountain source area and that are older than the Bandelier rhyolite contain welded ash flows. These flows coalesce to form continuous sheet deposits on pediment and alluvial surfaces below the canyon mouths (Ross and Smith, in press).

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...contrast to the coalesced sheets on the ...ks of the Valles Mountains, the "Aso ... (Matumoto, 1943, p. 3–4) form a con... ...field peripheral to the caldera, whereas ...r levels the field is divided into innumer... ...ches that follow the highly dissected ...phy.

...SURFACES. The nearly level upper sur... ...of ash-flow sheets whose bases may rise ... in response to changes in topography ...ll known and need no further discussion.

...OR SORTING. Lack of sorting has been ...d as a characteristic feature and criterion ...recognition of ash flows. It is generally be... ...that the lack of sorting is a result of ...ition from a turbulent flow or avalanche, ...ough some air-fall deposits in the vicinity ...ptive vents may also give rise to nonsorted ...deposits, and at times the two are indis... ...ishable (Williams, 1957, p. 64).

...ally many ash flows do show some sort... ...especially near their distal ends, where it ...be presumed that they were moving more ...ly before coming to rest. Such sorting ...s to be related directly to flowage and in ...ular to some measure of laminar flow, ...its visible traces are discussed under ...ary flow features.

...OWAGE FEATURES. Flowage features are of ... types, primary and secondary.

...mary flow features include:

...) Pumice swarms—discontinuous streaks ...ticular accumulations of pumice lapilli ... blocks in a finer matrix (Taneda, 1954, p. ...; 1957, p. 95; Taneda, Miyachi, and Nishi... ...; 1957, p. 11.).

...) Rafted pumice—top, side, and flow-front ...mulations of pumice blocks (Kuno, 1941, ...146; Ross and Smith, in press).

...) Inclusion trains—discontinuous streaks ...ticular accumulations of accidental inclu... ...s (Kuno, 1941, p. 147).

...se primary flow features appear to be ... abundant near the distal portions of ash ...s where they seem to be related to lowered ...ity movement before the ash flow comes ...st. Surface accumulations of pumice, ...ing flow tops, probably are more common ... generally recognized and may at times be ... in distinguishing individual flows in ...ly welded tuff deposits. These flow ...es may be overlooked in welded tuffs, ...se welding and crystallization tend to ...re them.

...ondary flow features are:

...) Radial stretching—shards and particu... pumice fragments may occasionally have been squeezed during compaction and welding beyond simple loss of pore space, resulting in radial stretching of the fragments. Most pumice fragments in densely welded tuffs have simply collapsed without elongation; however, if under great load or high temperature, they occasionally display abnormal elongation in cross section. Ross and Smith (in press) have suggested that secondary solution of volatiles by pumice may cause slight viscosity differences between shards and pumice fragments and may allow preferential radial elongation of pumice by differential compaction. Probably most pumice fragments in ash flows before welding are not longer than three times their smallest dimension. Taking porosity and preferred orientation into account, Ross and Smith (in press) suggest that, after dense welding, collapsed pumice fragments having a vertical dimension 3 to 20 times smaller than their long dimension are probably the result of simple loss of pore space without elongation. An elongation of 20 to 60 or more times the smaller dimension is believed to indicate stretching.

(2) Flowage deformation—the stretched pumice fragments are disclike in plan view and have random orientation. Some welded tuffs, however, contain stretched pumice that has preferred orientation, and these seem to indicate mass flowage during or after welding. In examples of this type seen by the writer the distance flowed could have been only a few inches or at most a few feet.

Secondary flowage in these rocks is of minor importance to the entire problem. It may be related to sliding off topographic highs or earth movements during welding of the tuff.

HEAT RETENTION. Retention of heat, resulting in welding and crystallization, is one of the strongest arguments for the emplacement by flowage of welded tuff deposits. Heat measurements on historic ash-flow deposits are few, but significant. Unfortunately all the temperature measurements on the "sand flow" in the Valley of Ten Thousand Smokes were of necessity made on fumaroles, rather than in the ash itself, and the first of these not until 5 years after the eruption. Fumarole temperatures, however, may approximate the internal heat of the flow, although variables such as gas reactions, localization of gas in joint cracks, depth from point of origin of the gas, and thickness of the flow all make an accurate heat analysis impossible or, at most, very undependable.

Because of the still unresolved controversy over the possibility of a deeper-seated source

for some of the fumaroles, the most significant temperature measurements in the Valley of Ten Thousand Smokes probably are those made on fumarole no. 1, near the distal end of the flow. These are also the only ones that span a 2-year period, and they give some indication of the rate of cooling and of minimum emplacement temperature. They are shown in Figure 1 along with all other temperature measurements made on fumaroles that Allen and Zies could identify in 1919 as the same ones measured in 1918 by Sapper and Hagelberger (1919, p. 262–278). All but three of these measurements show a temperature drop similar to that shown by fumarole no. 1. The three that show a rise in temperature are unexplained. The maximum temperature measured among the fumaroles was 645° C. (Allen and Zies, 1923, p. 101). If this temperature, 7 years after emplacement of the ash, is unrelated to a deeper source, it certainly must reflect a very deep layer of ash.

Also shown in Figure 1 are cooling curves drawn from measurements of both fumaroles (*S* curves) and the pumice flow deposits (*P* curves) formed during the eruption of Komagatake in 1929 (Kosu, 1934, p. 143). The curves labeled *P* are three of five very similar curves that show the rate of cooling in the pumice at a depth of 70 cm and give a minimum emplacement temperature of 385° C. The curves labeled *S* were made on fumaroles; the maximum temperature of 510° C., measured 8 to 11 days after the eruption, may be close to the maximum emplacement temperatures of the flows.

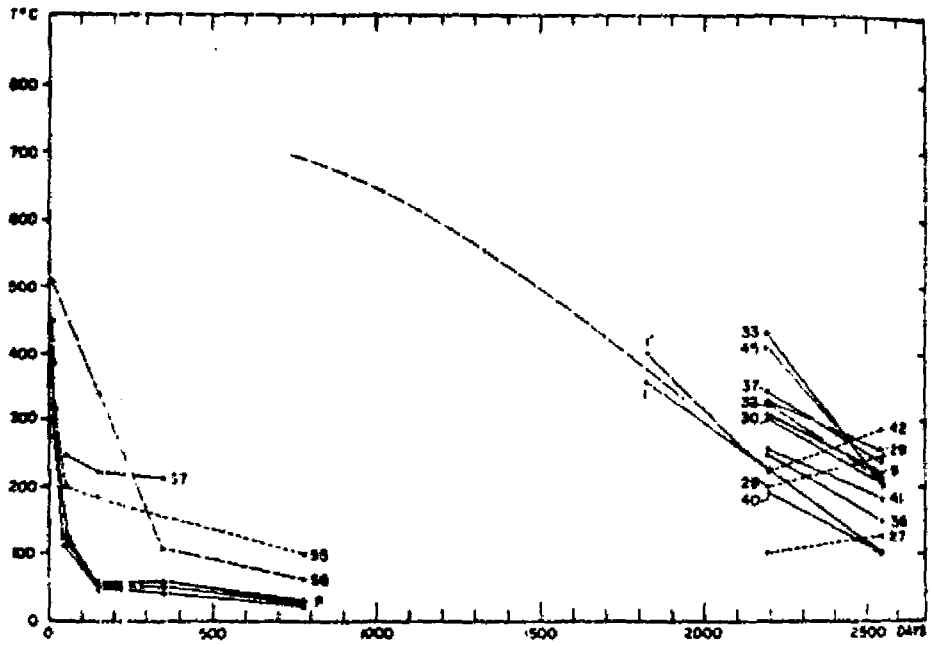
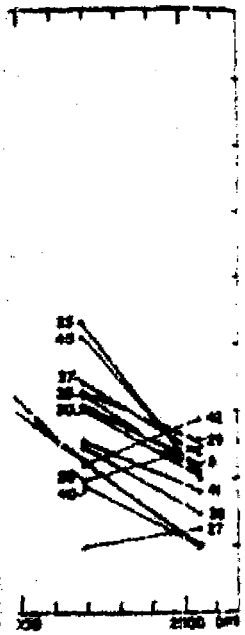


FIGURE 1.—TEMPERATURE MEASUREMENTS ON HISTORIC ASH-FLOW DEPOSITS

Komagatake pumice flows—data from Kosu (1934, p. 143): *S* curves—fumaroles, *P* curves—body of pumice. Valley of Ten Thousand Smokes ash flow—data from Allen and Zies (1923, p. 106); Zies (1929, p. 34); and Lowering (1957, p. 1590).

INCORPORATION OF SURFACE DEBRIS. It is not unusual to see in ash flows inclusions that could have been derived only from the surface over which the ash flow traveled. The inclusions range from very fine-grained material to boulders weighing tons. Some writers have observed evidence suggesting a strong erosive power of ash flows (Tsuya, 1930, p. 252). The ash flows constituting the Bandelier rhyolite tuff of New Mexico have locally swept the underlying surface clear of rock debris of all kinds and sizes up to boulders several feet in diameter, whereas elsewhere the flows have passed over bedded air-fall ash deposits seemingly without disturbing even the finest particles. In those places showing evidence of erosion the determining factor apparently was an irregular ground

f five very similar curves cooling in the pumice at give a minimum emplace- of 385° C. The curve



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ence which increased turbulence in the over- ing mass.

Particulate or Foam (Frothy) Flows

for at least some "welded tuffs" several authors have proposed mechanisms of emplacement which differ from the pyroclastic-flow concept. It has been suggested that emplacement occurred either as a mass of coherent lava which subsequently collapsed to give "welded-tuff" textures, or as a gas-charged lava which vesiculated and fragmented top and bottom while flowing, resulting in a sort of aborted "welded-tuff" deposit in which the dense interior of the flow is really a nonfragmented, but vesiculated and collapsed lava.

Kennedy casually (1955, p. 495) suggested the first mechanism for the origin of the vast welded-tuff sheets of the Yellowstone area. Boyd (1951, Ph.D. Thesis, Harvard Univ.) from field and laboratory data, believes the evidence favors the particulate-flow concept; he suggests, however, that one local unit in Yellowstone Park, the Canyon flow, may have originated as proposed by Kennedy.

Williams (1954) concluded that the Dorena "welded tuff" of western Oregon was emplaced as a vesiculating lava flow. Top and bottom of the flow were fragmented, forming what seems like typical "pumice tuff," but the interior was never disaggregated. The eutaxitic structure ("welded fusion structure"), according to Williams, was formed by "flowage along planes of minute vesicles within the partially crystallized lava." Petrofabric study of the biotite phenocrysts in the dacite "welded tuff" (Hausen, 1954, p. 212–213) shows a preferred orientation in the dense interior of the mass, but a less pronounced tendency to random distribution in upper and lower parts.

Hausel (1955, p. 142) invokes a third mechanism for explaining "welded tuffs." This mechanism involves vesiculation and fragmentation of the magma at some depth without immediate eruption, followed by regeneration ("remagmatization") to a melt, and finally by eruption as homogeneous lava flows. This interesting concept seems to be within the realm of possibility for small aberrant deposits but might be expected to obliterate the typical pyroclastic structure of welded tuffs. It might lead to a streaky, banded flow rock which would have all external characteristics of a normal lava flow. The mechanism is conceivable in view of the existence of pyroclastic dikes and the possibility that such material could have been extruded *en masse* under overpressure, conditions. The

This concept also is analogous to one held by Iddings as a mechanism for the formation of "welded pumice." Iddings (1909, p. 331) envisioned the extrusion as a lava flow of previously erupted fragmental materials that had fallen back into a vent and been reheated. He also explained flow breccia by this mechanism. Ross and Smith (in press) discuss this and other mechanisms of formation of the rocks Iddings called "welded pumice."

The controversy over the classical Armenian "tufflavas" and the Italian "piperno" has been discussed by Zavaritsky (1947, p. 15), who agrees with Paffenholz (1938) that the "tufflavas" are of pyroclastic origin, and with Dell'Erba (1892) and Zambonini (1919) that the Italian "piperno" was also a pyroclastic rock. Both "tufflavas" and "piperno" are regarded as lava flows by other authors (e.g., Levinson-Lessing, Kalkovsky, and Abich, as cited by Zavaritsky).

Summary Statement

The evidence from published studies of welded tuffs overwhelmingly favors emplacement by avalanche or flowage of fragmental material and hot gas. None of the other proposed mechanisms has been convincingly demonstrated even for a minor deposit.

The development of the alternate theories for emplacement of welded tuffs however in part probably resulted from the reluctance of geologists (Grange, 1934; Kennedy, 1955; Hausen, 1954; Hentschel, 1955) to accept the "air-borne cloud" origin. This concept was an unfortunate misinterpretation of the mode of emplacement of nuées ardentes that undoubtedly was influenced by the devastating effects of the eruptions.

During the eruption of May 8, 1902, at Pelée it was the cloud that devastated St. Pierre and left behind ash and lapilli deposits up to a few feet thick (Anderson and Flett, 1903, p. 487). The avalanche from which the cloud was derived was probably confined to the valley of the Rivière Blanche. During the eruption of May 7, 1902, at Soufrière clouds caused the death and devastation of the settlement on both sides of St. Vincent and deposited a few inches of ash (Anderson and Flett, 1903, p. 448). The avalanches from which the clouds were derived were confined largely to the Wallibo and Rabaka valleys.

It has not been shown that a welded tuff

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for all ever form from the nuée cloud. The size and temperature of Peleean type clouds are probably inadequate. However, if we assume that clouds accompanied prehistoric ash flows, as they probably did, conceivably they were at times hotter and larger and may have carried more ash. If the glassy ash could have been *emplaced* at temperatures of the order of 900° C., it would most surely develop incipient or partial welding. Complete welding would depend on the thickness of the deposit. Such welded-tuff deposits, if they exist, might have interesting distributional and textural characteristics, but would be very subordinate in volume to the total product of the eruptions which produced them.

The supporters of the particulate-flow mechanism generally agreed that the driving force of the ash flow or avalanche is gravity, aided by expanding gases. Herein lies a problem that needs solution, namely, what is the true nature of the gas-emission process, and how does it vary in different ash flows? Is total vesiculation confined to the vent, conduit, or chamber, or does some of it take place in the flow, and, if so, how much?

If we assume that some vesiculation takes place during flowage, then gas is emitted from the flow in several ways: (1) release by vesiculation during flowage, which, if explosive, gives rise to the so-called "auto-explosive" property discussed by Perret (1935, p. 22-24) and Fenner (1923, p. 74); (2) escape of gas that was trapped by the sinter bulk of the ash and pumice, but which had been released by vesiculation before the flow formed; (3) rupture during flowage of vesicles that contain partly expanded gas; and (4) diffusion from the glass shards and pumice. Process (4) should take place as long as the glass remains oversaturated with respect to the temperature and pressure of its immediate environment but would not be "auto-explosive" in the strict sense. Vesiculation, especially in the vent, probably does not reduce the glass to a state of saturation or undersaturation, and the glass may continue to lose gas even after some cooling. If the amount given off by diffusion were only a few hundredths of a per cent by weight, the volume at the eruption temperature would be impressive and would provide an adequate lubricant.

This interplay of possible mechanisms could be important in determining the physical character of the final pyroclastic material. Some insight into the problem may be gained from statistical analysis of pumice and shard types and of sorting characteristics. For example, many ash-flow deposits contain quantities of pumice crowded with long fine, parallel to subparallel, tubular vesicles, and the shards may be seen to have formed by fragmentation of such pumice. Presumably the only place such pumice could form is in the conduit, and this suggests that most, if not all, vesiculation, together with much loss of gas, took place before the ash flow was formed. The lubricating gas of the ash flow, then, must be attributed to mechanisms other than auto-explosion in the strict sense. Some ash flows, however, show a paucity of long-tube pumice, and the shards are coarse irregular fragments, many with spherical vesicles. Other deposits are mixtures of types. Quantitative studies of shard and pumice types have not been made, and such studies may reveal important clues for the solution of ash-flow problems.

Recognition and Definition of Units

General Discussion

The recognition and definition of ash-flow units pose one of the most difficult problems of pyroclastic flows, especially in deformed rocks. Perhaps the principal difficulty relates to the fact that the basic unit, one ash flow, is, in many instances, locally indistinguishable in multiple-flow cooling units. The problem is made more difficult because cooling units, or single ash-flows, may be separable in two dimensions but sometimes not in three dimensions. This is, of course, a common geological dilemma, but it has special significance for welded tuffs, because the unique properties of these rocks permit new approaches to the solution of old, as well as new, problems.

The splitting of units, and even of the basic unit, is commonly a function of the scale of mapping or of the degree of understanding one wishes to achieve. Thus, for reconnaissance mapping, a lithologic unit may be a heterogeneous volcanic field, whereas for detailed mapping a unit may be a texturally distinctive zone of one welded ash flow. The following discussion may appear to be needlessly complicated for many small ash-flow sheets and for some larger ones; for the great caldera-forming eruptions, however, the discussion is probably an oversimplification.

Flow Units

The usual concept of a flow unit, stemming as it does from our knowledge of historic

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homogeneous flow unit c

ardente eruptions, is restricted because the small size of these deposits and the fact they are confined to valleys. The flow unit avalanche is generally considered the set of one nuée ardente, and at Pelée, for ple, successive nuées ardentes were con- to the avalanche valley because they erupted from the dome through a breach in the crater rim. The resulting de- in the valley inevitably is a stack of thin or flows, separated from each other by accumulations, fine ash, materials re- by wind or water, or minor erosional discontinuities. The nature of these partings change from place to place between the flow units, and locally a parting may not readily detectable.

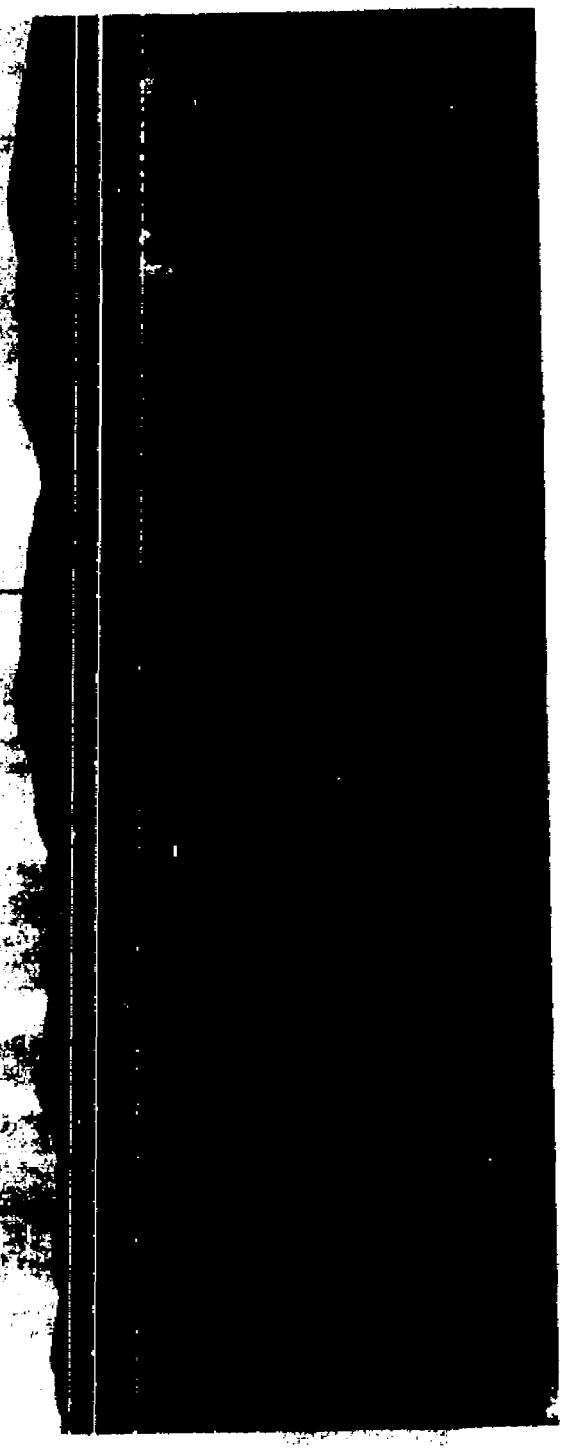
At Soufrière, because of the open crater, the distribution of the flows or avalanches was controlled largely by topography below the crater, and the materials poured down several valleys. Each of these valleys now contains a valley flow (presumably one from the May 7, eruption) which is a unit in itself, but all the valley flows are the product of a single eruption (except possibly minor material the May 9 and 18 eruption).

Let us imagine a series of successive eruptions from a volcano in an environment similar to Soufrière. The first eruption may produce a group of independent valley flows. A second eruption produces an additional flow in each valley, but some of the flows may coalesce at the mouths of the valleys. As the surrounding and valleys are buried by materials from eruptions and the terrain is leveled, flows are no longer valley units but become progressively larger, completely lobate units. Finally they may become single sheet flow units continuous through 360° around the Thus model assumes approximately radial distribution from the crater. We may conceive of an eruption giving rise a radially distributed single flow of pet- graphic homogeneity around small sources the single-vent composite cone type. From source areas and from multiple vents as those that culminate in large calderas volcano-tectonic depressions, the pattern progresses with increase in dimensions and of the source area to large and small and coalescing lobate sheet flows radially in favorable sectors relative their principal source vents. We should keep an open mind on the subject, it seems incredible that a single lithologi- homogeneous flow unit could be formed from multiple vents, or even one great fissure, to cover an area the size of, for example, the Toba field (2000 square miles). Such units probably represent something more complex than a single flow even though random sampling indicates homogeneity. On the other hand, because of the probability of the intermingling of materials from multiple vents, or continuous evolution of great volumes of material from one or more vents, our concept of a flow unit must embrace compound flows that could conceivably show nearly all possible variations seen in welded tuffs, except incompatible chemical compositions.

No description of a single flow unit in its remaining or exposed entirety has yet been published, and it is doubtful whether geologists will undertake such a task in the near future. It will thus be a long time before we penetrate the intricate maze of the large ash-flow sheets and understand their history and the history of their source areas.

Our immediate concern with the flow unit is in one- and two-dimensional vertical sections where it must be defined as the thinnest recognizable virtually nonsorted layer. Its thickness may range from inches to hundreds of feet, and it may be separated from other flows by partings of diverse characteristics (Smith, in press). The visual recognition of partings, and hence flow units, may be very difficult and locally impossible in some welded tuff sheets. Some work suggests that the magnetic properties of individual flows may be useful in distinguishing them (Hatherton, 1954a; 1954b).

The writer thinks that some of these flow units as seen in two dimensions are actually subflows that originated within the main flow itself, rather than at a common point of origin in the vicinity of the source. These subflows may result from the lateral overlapping of lobes on an irregular front or possibly by vertical overriding due to volume surges or deposition on an irregular surface. These are conjectural concepts, but the overlapping of lobes around topographic prominences can cause the appearance of two flows in vertical sections downslope from the prominence, whereas there is only one upslope from it. Whatever their origin, such units represent a physically distinct and tabular flowage mass, and we have little choice but to call them flows until detailed mapping proves otherwise.



ASH-FLOW SHEETS ON THE PAJARITO PLATEAU NEAR LOS ALAMOS, NEW MEXICO

Cooling Units

In deposits of welded ash flows the single ash flow is commonly subordinate to a unit that consists of more than one flow (Pls. 1–2). The flows, however, have been emplaced in close enough succession so that they cooled virtually simultaneously, or in continuum over an extended period of time.

These multiple-flow units may show zonal patterns of welding and crystallization indistinguishable from the pattern shown by single ash flows having approximately the same temperature and thickness characteristics. It is therefore commonly more practicable and less ambiguous to think of any zonal unit as a cooling unit: *simple* if it exhibits the zonation of a single flow unit, or *compound* if the zonal pattern deviates from that expectable in a single flow.

Because of the common difficulty of recognizing flow units within densely welded cooling units, probably many of the so-called single flows are really multiple-flow cooling units. An excellent example of this problem is shown by the "ignimbrite" sheet at Mituaeai 5, New Zealand. Marshall (1935, p. 317) writes of this "... no discontinuity could be seen in it of such a nature as to suggest that there was more than one period of deposition." R. Bailey (Oral communication), accompanied by J. Healy, has re-examined this sheet and has observed discontinuities that show that at least three flow units are represented. Hatherton (1954*b*, p. 427) distinguished three "sheets" by visual examination, whereas his measurements of remanent magnetism suggested five probable "sheets." A similar situation may exist in the Motutere section described by Marshall (1935, p. 351), as is indicated by reversals within his measured density sequence (Fig. 5).

Fenner (1923, p. 29–31 and 1948, p. 885), Gilbert (1938, p. 1836), Williams (1942, p. 82), Westerveld (1942, p. 204), and others recognized this problem, but details are lacking, especially for the more densely welded and crystallized sheets where distinctions are more obscure. Many, and perhaps most, welded tuff sheets should be re-examined with this thought in mind.

Composite Sheets

It can be demonstrated that all degrees of welding can exist at the contacts between flow units within compound cooling units. The parting between two flow units may at one place occur in densely welded tuff, whereas elsewhere it may occur in nonwelded tuff. The specific character of these contacts in any given place is related to the time interval between flows, the emplacement temperatures and thicknesses of the flows, and the number of flows that constitute the cooling unit. Some combinations of these variables will cause the formation of units that will show zonations in vertical sections ranging from the patterns of simple cooling, through degrees of compound cooling, to separate cooling units—separate, that is, in so far as we are able to detect continuous cooling in a vertical section. In complex fields of long-continuing eruptions we may expect that single cooling units in one area will grade into separate cooling units elsewhere. These may be separated by erosional disconformities.

The aggregate of cooling units joined by welding or crystallization in some areas, but grading laterally into two or more separate cooling units, is called a composite sheet (Smith, in press). Because it has not been documented by mapping, although supported by inspection in a few localities and inferred in

PLATE 1.—ASH-FLOW SHEETS ON THE PAJARITO PLATEAU NEAR LOS ALAMOS, NEW MEXICO

Two members, separated by an erosional disconformity and air-fall beds, make up the Bandelier rhyolite tuff in the photograph. The lower member is a nonwelded and vitric ash-flow unit that underlies the lower, tree-covered slopes of the mesa. The air-fall tuff and disconformity are visible at the far left, at the base of the overlying cliff-forming member. The upper member is a multiple-flow cooling unit whose partings are clearly emphasized by weathering. It is mildly welded and crystalline (vapor-phase zone) from the top of the mesa down to the middle of the lower dark band about midway up the exposed sections. The lower half of this band is a nonwelded, reddish, vitric zone. The degree of welding increases toward the mountains beyond which lies the source area. The partings between flow units become more obscure and locally invisible with increase in degree of welding. Photograph by R. A. Bailey.

112-B

FIGURE 1

FIGURE 2

VARIABLE WELDING IN THE BANDELIER RHYOLITE TUFF

LIER RHYOLITE TUFF

others, the unit is referred to as hypothetical and it can be accurately mapped. The existence such a sheet seems inevitable, and it may actually prove to be the most significant in terms of the eruptive and structural history of the source area, especially in deposits of large volume.

Additional problems of correlation may arise ash-flow fields that are separated into sectors topographic barriers. Here the composite in one sector could conceivably have ash-flow or separate cooling-unit counterparts in other sectors.

Ash-Flow Fields

An ash-flow field as here defined is the aggregate deposit of ash flows that can be related as a unit, or as a group of integral parts, to a specific source or source area. It may consist of any one or all of the other units either in single or multiple forms. The source may be any simple volcanic vent such as a dome, crater, or small fissure, whereas source area refers to calderas, volcano-tectonic grabens, or other complex vent systems. Obviously such a flexible term cannot have meaningful genetic connotations, and it is used here only in a descriptive sense to provide some measure of order to an otherwise heterogeneous complex of volcanic rock deposits. One can envision subfields, superfields, multiple fields, and so on, but such subdivisions call for data not available at present.

Ash-flow fields, in their entirety or in part, such as Toba (Westerveld, 1947), New Zealand (Marshall, 1935), Aso (Matumoto, 1943; Williams, 1941a), Chiricahua (Enlows, 1955), San Juan (Larsen and Cross, 1956; Ratte and Steven, 1959), Valles (Ross and Smith, in press), and many others, are stacks of cooling units or composite sheets with varying amounts of interbedded ash.

It is inferred that the greater the number of cooling units, and the greater the differences among them, the longer and more complex has been the eruptive history in the source areas.

Magnitude of the Deposits

Distance Traveled

The maximum distance an ash flow can travel from its source is not known. It may be of the order of 100 miles, although such a distance would be unusual in the light of existing data. Theoretically, temperature and gas content, hence the gas-emitting properties of an ash flow, appear to be the most significant variables influencing distance traveled. When actual distances traveled by specific ash flows are compared, however, gradient, topography, and especially volume appear to have exerted a greater control.

Figure 2 shows some maximum distances from known or inferred probable source areas. The most reliable figures for the greater distances are probably those given by Williams (1942, p. 79) for the "pumice flow" that can be traced down the Rogue River valley for 35 to 40 miles, and by Matumoto (1943, p. 4) who states that the farthest outcrop of the "Aso lava" is 100 km from the center of Aso caldera. The Nomlaki tuff of the northern Sacramento Valley, California (Anderson and Russell, 1939), may have traveled 50–65 miles or more from an unknown source on the eastern

PLATE 2.—VARIABLE WELDING IN THE BANDELIER RHYOLITE TUFF

FIGURE 1.—Three members of the Bandelier tuff along New Mexico Highway 4 near Totavi, New Mexico. Above a basaltic lava flow at the man's feet is a basal member of air-fall beds of lump pumice and ash of variable thickness. The nonwelded and vitric middle member (lower member in Pl. 1) underlies the tree-covered slope. The upper member is the multiple-flow cooling unit of Plate 1, crystalline and mildly welded at the base of the lower tier of columns to the top of the section. Denser welding near the top indicates prolonged cooling with a probable increase in emplacement temperature toward the top. Photograph by R. L. Bailey.

FIGURE 2.—North wall of Frijoles Canyon, Bandelier National Monument, New Mexico. Upper half of photograph equals upper member of Figure 1 of this plate. The darker layers indicate higher degrees of welding than the lighter. The lower light-colored cliffs are formed in nonwelded materials and are pocked and with wind-eroded holes. Prehistoric Pueblo Indian ruins at their base are a feature of nonwelded parts of the Bandelier ash flows in the Jemez Mountains. Photograph by George A. Grant, courtesy of the National Park Service.

side of the valley to the foothills of the western side. On the western side of the valley the tuff sheet has an outcrop area of more than 40 miles in a north-south direction.

Area

The area covered by ash-flow fields is, of course, a function of the volume of the deposit and its thickness; thus the topography sur-

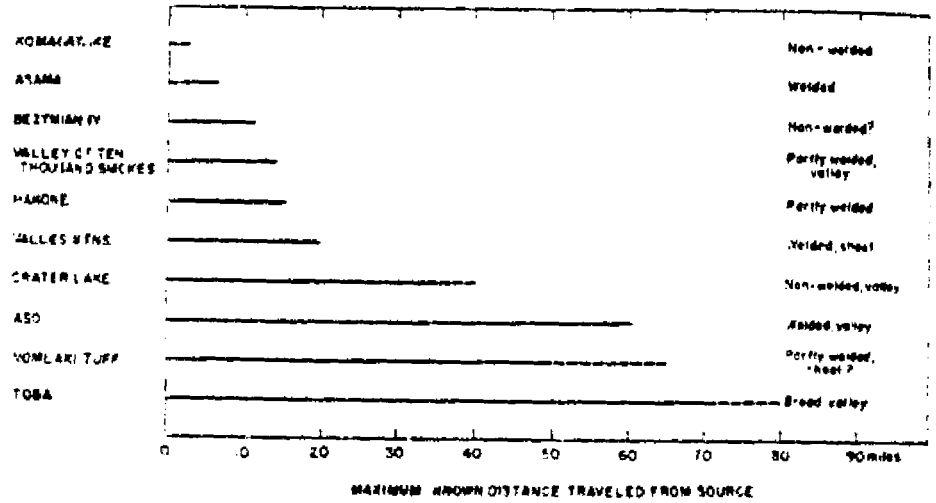


FIGURE 2.—DISTANCE TRAVELED BY ASH FLOWS FROM THEIR SOURCE

Konakatale (Kuno, 1941, p. 146); Asama (Aramaki, 1956, p. 209); Bezymianny (Gorshkov, 1959, p. 94); Valley of Ten Thousand Smokes (Griggs, 1922, p. 253); Hakone (Kuno, 1950, p. 272); Valles Mountains (Ross and Smith, in press); Crater Lake (Williams, 1942, p. 79); Aso (Matumoto, 1943, p. 4); Nomlaki Tuff (Anderson and Russell, 1939, map); Toba (Westerveld, 1947, map).

The distance of 80 miles shown for the Toba tuff represents the most distant outcrop of tuff, shown on Westerveld's (1947) map, measured from the northwest rim of the Toba depression down the L. Biang and S. Wampoa valleys. This is tentative, however, because the most distant outcrop may represent fall deposit rather than flow.

Many deposits of ash flows are continuous for more than 50 miles, but in the absence of a known source area all such distances probably represent only a partial dimension of a large sheet. Martin (1960, p. 95) and Cook (1958, p. 1543) have mentioned single welded-tuff units that extend for more than 100 miles in southwestern Utah and southeastern Nevada. If this represents distance from a source it is a prodigious figure, but if it represents diameter or long dimension of a single sheet it is large but not excessive when we consider, for example, the Toba tuff which is a continuous map unit for more than 150 miles. Admittedly this may not be a fair comparison, because the individual units of the Toba tuff have not been distinguished. However, the comparison does emphasize the large size of some welded-tuff deposits.

rounding a source area influences the thickness of the tuff, its area, and its symmetry. Figures generally quoted for area and volume are for *pyroclastic fields* which may or may not (ordinarily not) consist of one ash flow. Usually the eruptive history of any field is so complex that detailed mapping has not been done and the number and kind of units are not known.

It is therefore easy to overlook the fact that when the magnitudes of such ash-flow fields as Crater Lake and Aso are compared, they are not geologically equivalent. The Crater Lake deposits (Williams, 1942) appear to represent one catastrophic eruptive period and thus one unit, which, notwithstanding the fact that it probably consists of many ash flows, appears to have been a unit of cooling. The Aso deposits, on the other hand, comprise at least three if not five or six major cooling units and thus represent several periods of eruption separated by at least one marked disconformity (Williams, 1941a; R. A. Bailey, oral communication). Conditions similar to or more complex than those at Aso are common in a great many ash-flow fields surrounding calderas. They show the complexity of formation of these fields and associated calderas.

[illegible]e known areas and volumes of [illegible] [illegible]-flow fields have been partially tabulated by [illegible]eral writers (Westerveld, 1942; 1952; Wiley, [illegible]4; Rittmann, 1958, p. [illegible]25). Some of these [illegible]a jor volumes are incorporated in figure [illegible] [illegible] most interesting and geologically important [illegible]-flow fields cover several hundreds to thousands of square miles. Some of them contain [illegible]es of densely welded tuff throughout their [illegible]re known area. [illegible] are shown in [illegible]at detail, and many years of work [illegible] necessary to determine their volume, [illegible] number of eruptive events, and tectonic [illegible]onsmaps.

[illegible]elds most [illegible] those of the Lake [illegible] region, [illegible] of North Island, New Zealand. Here [illegible] [illegible]marison [illegible] [illegible]es [illegible] [illegible] though [illegible] [illegible] in others. [illegible] are as yet not really [illegible]ified. Toba as deduced from the writings [illegible] van Bemmelen (1949) and Westerveld (1947; 1952) appears to be enormous but not [illegible]ally complex when compared to New Zealand. The ash-flow sheets seem to have originated within a relatively short period of time [illegible] the area now occupied by the giant Toba volcano-tectonic depression. The New Zealand [illegible] ash-flow [illegible] [illegible] of a [illegible] [illegible]nence [illegible] [illegible] more complex than that of the Toba depression. [illegible]ner large fields are so little known that we [illegible] only record their existence.

YELLOWSTONE ASH-FLOW FIELD: Boyd (1957, p. [illegible]) [illegible] estimated that Yellowstone National Park [illegible]ntains 600 square miles of welded tuff exposed within the park; added to the probable western extension of the field this gives a [illegible]are of 2400 square miles. Addition of an [illegible]al area presumed to underlie the plateau [illegible]olite flows and the snake basalts gives a [illegible]al of 4000 square miles. Within the park the [illegible]ckness ranges from 300 to 1000 feet. With [illegible] feet as an average original thickness and [illegible] square miles as probable areal extent, [illegible] calculated that the volume of welded [illegible] would be on the order of 400 cubic miles. [illegible] suggests that it was all emplaced in a single [illegible]id sequence of eruptions.

[illegible]LKHORN MOUNTAINS ASH-FLOW FIELD: [illegible] of the largest ash-flow fields [illegible] [illegible] Mountains, Idaho, [illegible] [illegible] same field of Late Cretaceous age which surrounds and was intruded by the Boulder Batholith. This field appears to consist of several thick and extensive welded-tuff sheets which occupy a minimum area of 8000 square miles and have a minimum volume of 500 cubic miles, but which may have an area as great as 10,000 square miles and a maximum volume of 1000 cubic miles (Klepper and others, 1957, [illegible] and oral communication).

[illegible]AN MOUNTAINS ASH-FLOW FIELD: [illegible] the most spectacular and complex ash-flow [illegible] in the world is associated with the [illegible] Mountains volcanic [illegible] [illegible] northern New Mexico. [illegible] interest [illegible] members [illegible] Mountain, [illegible] [illegible] 250 [illegible] [illegible] geologists of the U. S. Geological Survey, including Burbank, Larsen, Luedke, Olson, Ratte, Ross, Steven, and others, and evaluation of field data over a period of [illegible] years by R. A. Bailey and the writer, [illegible] can be said that most, if not all, of the three members are silicic pyroclastic rocks, in large part welded tuff. The area covers approximately 12,000 square miles. At present only the [illegible] [illegible] (Burbank and Lasky, oral communication, 1959), are seemingly related to the giant rock [illegible] among which [illegible] flows are best known. The field should be classed as a multiple-source field; other source areas remain to be found and related to specific events of the field.

SUDBURY BASIN. On the basis of recent work in the Sudbury Basin, Ontario, Canada, Thompson (1957, p. 45) and Williams (1957, p. 69, 70) have postulated that the Sudbury "lopolith" is really a volcano-tectonic depression surrounded by a ring of eruptive centers and that the subsided basin contains no less than 300 cubic miles of "glowing-avalanche" deposits. Deposits about a mile thick are believed to occupy about 300 square miles within the basin.

BASIN AND RANGE ASH-FLOW FIELDS: Another tremendous, and probably very complex, ash-flow field occupies an area of more than 10,000 square miles in southwestern New Mexico. It comprises large parts of the Datil, Mogollon, Black, Tularosa, and other mountains and [illegible] [illegible] [illegible] than

the San Juan field. This field is a small part of the vast volcanic system of Tertiary age of the Basin and Range province of western United States and Mexico.

Welded tuffs in the Basin and Range province have long been known, although Ross (1953; 1955, p. 430–437) seems to have been the first to make a clear statement in the literature. Recently Williams (1957, p. 64) has stated that not less than 50,000 square miles of southern Nevada and southwestern Utah was buried to a maximum depth of about 8000 feet by "fissure-erupted glowing avalanches" during late Tertiary time. Mackin (1950, p. 83) has estimated the volume of silicic volcanic rocks in the Great Basin to be about 30,000 cubic miles, and this is probably conservative.

Thickness

Many figures have been published for thicknesses of "welded-tuff sheets," "ignimbrite sheets," "glowing-avalanche deposits," "tuff flows," and related rocks. What these thicknesses mean in terms of the units defined in this paper is problematical. For many general problems the lack of detail is not serious, but it is critical to many genetic problems if units of equal rank must be compared. Perhaps most published figures are for aggregate tuff deposit or deposits, and figures for "a welded-tuff sheet" or "an avalanche deposit," or "one ignimbrite" may commonly represent multiple-flow cooling units.

Marshall (1935, p. 328) found that the New Zealand "ignimbrites" range from 60 to 500 feet in thickness but stated that many are less than 100 feet thick. Some are probably single-flow units, but we now know that others are multiple-flow cooling units. Jenks and Goldich (1956, p. 162) state that locally the "white-tuff flows" are 160 feet thick, whereas three successive tuff flows composed of salmon sillar, with very little interbedded material, aggregate 500 feet.

Enlows (1955, p. 1221) gives figures ranging from 2½ to 880 feet for the seven or eight "members" of the Rhyolite Canyon formation, which he considers welded tuff. He infers (p. 1219) that each layer or "member" is the product of one "nuée ardente" or "hot-ash" eruption. Member No. 6 contains 700 feet of densely welded tuff. Manafield and Ross (1935, p. 312) found that their Idaho welded tuff ranges in thickness from 20 to 50 or more feet.

Individual pyroclastic flows evidently range from a few inches to hundreds of feet in thickness. Their individual character is probably determined primarily by their volume and by topography, although we might expect that, if volume and topography were the same, the hotter, finer-grained flows would be thinner than the colder, coarser-grained ones, although this difference might be influenced by gas content. Other variables might be considered, but at any rate we must expect that small-volume, short-burst eruptions from "Pelean" domes will result in thinner flows than will larger-volume, continuous-evolution-type eruptions from craters or fissures. Nevertheless the latter type may also result in thin flow units. Most multiple-flow cooling units probably have a similar range in thickness but have a higher average thickness than do single flow units. Exceptionally thick cooling units are known.

The thickest welded-tuff sheet that the writer would interpret as a cooling unit is the Superior dacite in the Globe-Miami-Superior area, Arizona. This welded-tuff sheet was kindly shown to him in 1956 by N. Peterson and in 1957 by D. Peterson, both of whom have studied parts of it in some detail. The Superior dacite was originally described by Ransome (1903) as a lava flow more than 1000 feet thick, and again by N. Peterson, Gilbert, and Quick (1951), who discuss the possibility of its pyroclastic origin. D. Peterson (1959, p. 1710) presents the evidence for a pyroclastic origin and suggests that the sheet, which covers at least 400 square miles and is locally as much as 1500 feet thick, "was deposited by a single huge pyroclastic eruption." The precollapsed thickness of this sheet was probably well over 2000 feet. Publication of the details about this most interesting welded-tuff sheet will add greatly to our understanding of the problems.

Thicker cooling units may exist in the San Juan Mountains of Colorado. Those currently being studied by Steven and Ratte (1959, p. 1788) in and around the Creede caldera are of special interest. Ratte and Steven (1959, p. 1785) report two major stages of ash-flow deposition: (1) a precaldera rhyolitic stage forming deposits more than 3500 feet in thickness and ranging from densely welded tuff "resembling fluidal rhyolite in the lower part to essentially nonwelded pumice breccia at the top", and (2) a caldera-subsidence stage presumably culminating in more than 4000 feet of quartz latitic welded-ash flows that are now exposed in the caldera core. Other lesser ash-flow, pyroclastic, and lava-flow units occur within the volcanic edifice.

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Volcanic Vents

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[illegible] Volcanic Vents and Source Areas

[illegible] most critical problem of ash flows, [illegible] the large-volume sheet deposits, [illegible] the location and characteristics of [illegible] source areas.

Domes

[illegible] few exceptions, historic nuées ardentes [illegible] been erupted from volcanic domes and [illegible] produced deposits of small volume and [illegible] distribution. None of the deposits [illegible] domes is known to have formed welded [illegible] although incipient welding in some of [illegible] deposits may have been overlooked. Even [illegible] future studies show that some eruptions [illegible] domes resulted in the formation of welded [illegible] this should in no way obscure the fact that [illegible] deposits will be rare, relative to welded [illegible] of other origins.

[illegible] best-known examples of nuée-ardente [illegible] from domes are the 1902 and 1929–[illegible] eruptions of Pelée, Martinique, and the [illegible] eruptions from Merapi, Central Java. [illegible] mount eruptions were Mt. Lamington, [illegible] Guinea (Taylor, 1954; 1956), Hibok-[illegible], Philippines (Macdonald and Alcaraz, [illegible]), and Bezymianny, Kamchatka (Gorsh-[illegible], 1959).

Craters

[illegible] classical example of a nuée-ardente [illegible] from an open crater is the 1902 erup-[illegible] of Soufrière, St. Vincent. The resulting [illegible]-flow deposits were seemingly unconsoli-[illegible]. Incipient welding was probably pre-[illegible], not because of too low a temperature, [illegible] because of the high-crystal, low-glass [illegible] and inadequate thickness.

[illegible] welded tuffs have been produced by historic [illegible] from open craters, although the few [illegible] are of types far removed from rocks [illegible] called welded tuffs. Aramaki (1956) [illegible] described the "Agatuma nuée ardente" [illegible] of the products of the 1783 activity of [illegible] volcano. One lobe of this flow reached [illegible] from the crater, its total area is esti-[illegible] at 18.5 km, and its volume (assuming an average thickness of 5 m) is approximately 0.1 km³. The thickness ranges from more than 10 m in the central part to less than 4 m at the edges.

Fissures

Small central vents can undoubtedly produce welded tuffs, but most recent writers believe that the large-volume ash-flow sheets (tens of cubic miles) have been erupted from fissures (Williams, 1957, p. 64; Westerveld, 1952, p. 564–568; van Bemmelen, 1949, p. 202; Ross and Smith, in press). Some writers have postulated, in the absence of positive evidence for fissures, that the fissure vents for these large-volume deposits are buried beneath the ash-flow sheets (Cotton, 1952, p. 211; Weyl, 1954, p. 25).

No evidence unequivocally supporting such a concept has been published. Several writers have found fissure dikes which they thought were feeders, but none has proved it. As indicated above, the writer is speaking of deposits with a volume in excess of several cubic miles. This would exclude the deposits of the Valley of Ten Thousand Smokes deposit which Williams, Curtis, and Juhle (1956, p. 129) now believe to have been erupted from fissures at the head of the Valley as well as from the vent now occupied by Novarupta. Fenner (1923) held much the same view, although he also suggested fissures on the Valley floor as a supplementing source. As pointed out by MacGregor (1952) Fenner has often been misquoted on this point.

The New Zealand ignimbrites are often cited as fissure-erupted materials, and the "positive" evidence seems to center around an "ignimbrite dike" which outcrops at Ongarue, and which is pictured by Cotton (1952, p. 210, Fig. 102). The writer has been skeptical of the "feeder dike" interpretation for many years and was interested to learn from Roy A. Bailey (oral communication, 1957) who has examined the outcrop in the field, that there is indeed some doubt as to the intrusive origin of the "dike". It shows a horizontal planar eutaxitic foliation just like that seen in the surrounding ignimbrite rather than the vertical lineation expected in a dike. Bailey suggests that the horizontal jointing may be related to an abnormal cooling surface such as might be found if an ash-flow filled a narrow gorge. Detailed study is needed. Aside from this one doubtful locality it would appear that no occurrence is known where pyroclastic dikes actually project into ash-flow sheets where it can be shown or rea-

sonably inferred that the dikes were actually feeders for the large-volume deposits.

The evidence for fissure feeders seems established for at least part of the Valley of Ten Thousand Smokes deposit (Williams, 1954) and for an extremely interesting occurrence in the John Day formation of Oligocene age in Oregon, kindly shown the writer by A. C. Waters. In the latter area a dike several miles long appears to change from fluidal rhyolite in its deepest exposed part to fluidal-fragmental welded tuff near the surface and merge with a densely welded tuff sheet on the surface.

Other areas where fissure feeders are suspected include the Pilemasin basin, Sumatra (van Bemmelen, 1949, p. 681), Macdoel quadrangle, California (Williams, 1949, p. 32), Sudbury, Ontario (Williams, 1957, p. 64), Independence Pass, Colorado (Burbank and Goddard, 1935), and Black Range, New Mexico (Kuellmer, 1954).

The negative evidence favoring fissure vents for the large-volume ash flow sheets is inconclusive but nevertheless more suggestive:

(1) Specific central vents as source vents seem as rare as fissures.

(2) Apparent absence of volcanic cones in association, in many areas, with ash-flow sheets.

(3) Linear arrangement, in some areas, of post-ash flow vents and intrusive rocks.

(4) Post-ash flow collapse along arcuate fractures or other linear zones of weakness producing calderas and volcano-tectonic depressions.

It is significant that nearly all ash-flow fields with a volume of more than a few cubic miles and that have been related unequivocally to source areas are associated with calderas or other depressions of subsidence. The specific vents of emission of the ash flows no longer exist at the surface; they were destroyed by the collapse after or during eruption. Those vents that were not destroyed or that may be present in the collapsed blocks are probably modified by structural readjustments, post-collapse volcanism, or intrusion, and are no longer recognizable. In deeply dissected volcanic and volcanic-plutonic structures conduits may have been obliterated by ring dikes, stocks, or other intrusive bodies.

Calderas and Volcano-Tectonic Depressions

Subsidence related to igneous activity has long been recognized, but van Bemmelen (1930) is probably to be credited with the theory of catastrophic engulfment of volcanic edifices after the eruption and draining of magma chambers of large volumes of pyroclastic material. Williams (1941a) and others have reiterated and amplified this view, calling attention to the fact that many of the pyroclastic deposits surrounding such collapse structures are of "nuée-ardente" origin, and that many of these deposits contain welded tuffs.

Specifically, when we find welded tuffs or other ash-flow deposits, where cooling units or composite sheets can be shown to have volumes of a few to many cubic miles, we may expect to find subsidence structures in the source areas. The existing positive evidence for young (Pleistocene and Recent) deposits supports this view. The characteristics of these structures may vary, but probably caldera-type structures predominate.

Figure 3 shows volumes for a selection of pyroclastic flow deposits. The logarithmic method of plotting gives undue weight to differences in the smaller deposits and suppresses more significant differences in the larger deposits, but it also allows a grouping of deposits on a small-scale plot which has geologic meaning.

This breakdown by volume is not an attempt at classification in the sense of Aramaki's (1957, p. 21–31) important three-fold classification of pyroclastic flows, but rather an attempt to generalize the interrelationship of volume of deposits with types of source areas. It is specifically designed to show that where source areas are known, and well studied, for deposits of large volume these areas are sites of volcanic or volcano-tectonic subsidence, a fact which should be of critical importance, especially to students of older rocks.

The figures for volumes shown in Figure 3 are the best available. Unfortunately it is problematical if many can be compared as equivalent entities. The figures represent units of all rank between single-flow units and complex pyroclastic fields, and are not converted to equivalent porosities. However, if we take cooling units or composite sheets as here defined as the units to be compared, it is doubtful if subdivision of the larger fields or more accurate estimates of volumes of the deposits will change the figures more than one order of magnitude.

The data suggest that the maximum volume for deposits erupted from volcanic domes, and hence Pelean-type deposits, strictly speaking, is in the fourth order of Figure 3, or somewhere between 1 and 10 km³. Most of these deposits have a volume less than 1 km³. None is known to contain welded tuffs. The term "Pelean" should probably be restricted to deposits of

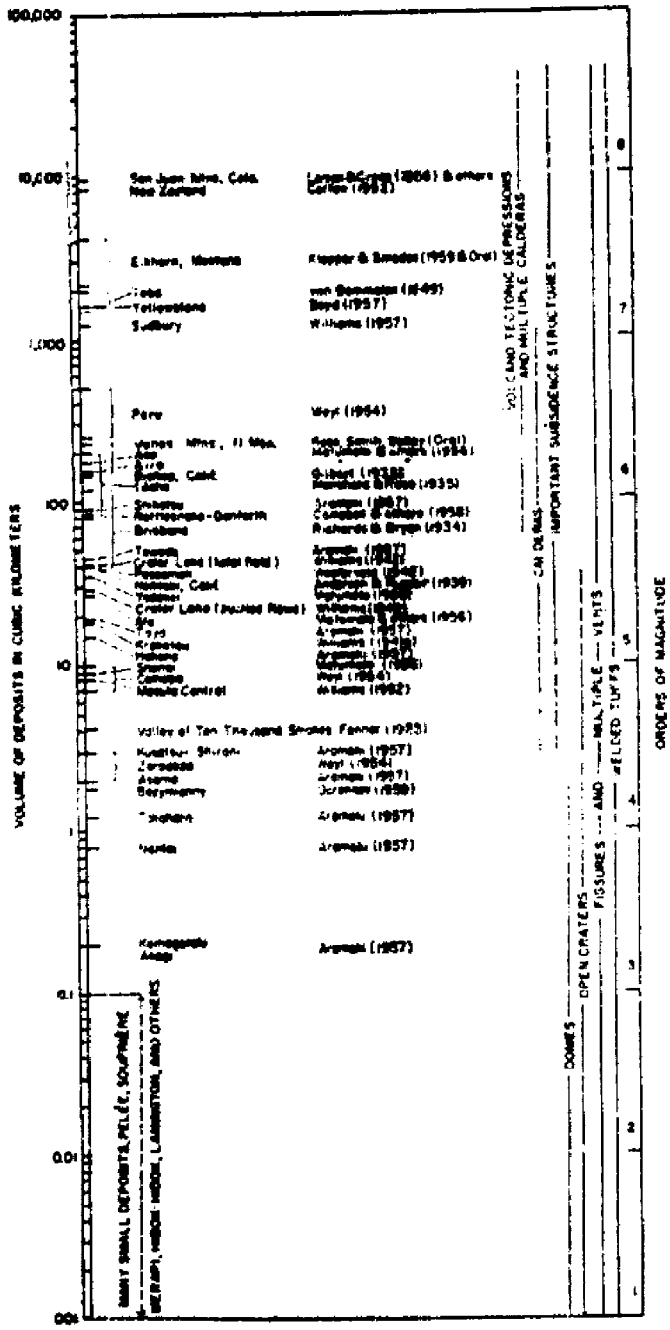

FIGURE 3.—VOLUMES OF PYROCLASTIC-FLOW FIELDS

The volumes, in km³, are plotted on five-cycle logarithmic paper and span seven orders of magnitude from [illegible] to 10,000 km³. The data show a correlation with vents and source areas.

these low orders of magnitude erupted from domes, irrespective of whether or not their emplacement mechanics are also applicable to other deposits.

The maximum probable volume from single open craters may also be in the fourth order, although the fifth cannot be ruled out. The overlapping of caldera formation obscures the nature of vents in most examples described. Deposits found around calderas which have formed in single giant cones may have been erupted from the central crater, or they may have been erupted along the boundary fractures of the subsided block or from fissure systems in the block.

All known large calderas (sixth order of Fig. 3) such as Aso and Valles, and some smaller ones such as Toya and others, are not related to single cones but rather were formed by subsidence of parts of volcanic plateaus, groups of cones, or broad volcanic shields. It is difficult to imagine single vents or even multiple vents, other than those associated with fracture (fissure) systems related to the collapse itself. The same is presumably true of many subsidence structures, both smaller and larger than those calderas associated with sixth order ash-flow deposits, which were guided by pre-existing or active tectonic trend lines and are called volcano-tectonic depressions.

Ash-flow deposits of orders 3, 6, and 7 seemingly either are associated with collapse structures or their source areas are unknown. The writer has been unable to find a well-authenticated exception in the literature. Deposits from large composite cones such as Mt. Mazama (Crater Lake) evidently reach their maximum volume in order 5. They surely do not exceed 100 km³, and probably most are smaller than 50 km³.

Of the ash-flow deposits grouped in order 6, the sources of the Brisbane tuff, the Idaho "welded tuff", and the Peruvian "sillars" are unknown, and the volume estimates are very tentative. Gilbert (1938, p. 1859–1860) suggested a possible relation between the extrusion of the Bishop tuff and faulting in Long Valley. The remaining three fields—Aso, Aira, and Valles (order 6)—are genetically related to structures of the same names which have been called the world's largest known calderas. Each exceeds 12 miles in diameter.

The ash-flow fields of order 7 have been mentioned briefly in the section on Area. Thompson (1957) and Williams (1957) consider the Sudbury basin to be a volcano-tectonic depression; Boyd (1957, Ph.D. Thesis, Harvard Univ.) noted a "tectonic basin" in Yellowstone Park and suggested a caldera origin, but he was uncertain whether subsidence was consequent on the eruption of 400 cubic miles of welded tuff or associated with 200 cubic miles of rhyolite flows that now nearly fill the basin. Toba (van Bemmelen, 1939) is the classical, and one of the largest, volcano-tectonic depressions. It is only one of several along the Barisan Mountain Range in Sumatra. The source of the Elkhorn, Montana, ash-flow field is not known and may have been totally obscured by the intrusion of the Boulder batholith: Grange (1934; 1937), Williams (1941a), and others have considered the New Zealand "ignimbrites" related to Taupo-Rotorua graben which is considered to be volcano-tectonic in origin. Within the San Juan volcanic field three giant calderas are known, but only one is known to be directly associated with the ash-flow field discussed on an earlier page and plotted on Figure 3. The volume of the field seems incompatible with a single structure, and the field should probably be classified as a multiple-caldera field.

Within the tremendous ash-flow complex of southwestern New Mexico, mentioned earlier, lie the Plains of San Augustin, a grabenlike structure probably larger than the Toba depression. It is floored with Pleistocene sediments and volcanic ash. Griggs (1954, p. [illegible]) has suggested that this "prominent closed depression" is a collapsed structure related to the eruption of the associated welded tuff. Griggs reports beds of welded tuff downfaulted to low elevations in the interior of the plains and rhyolite domes in the interior and at the margins. It may be significant that this structure lies very close to the junction of two major tectonic trends at the southeast margin of the Colorado Plateau; its long dimension lies athwart the directions of these trends.

The Deposits

Introductory Statement

As stated earlier, recognition of welded tuff still is a major problem, especially in older rocks, and in the absence of clear-cut geologic relations it is not always possible to distinguish welded tuffs from lava flows. Many writers have considered criteria for recognition of welded tuffs, notably Marshall (1935), Gilbert (1938), Weyl (1954), Enlows (1955), Ross and Smith (in press). No single criterion is in itself

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THE DEPOSITS

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sible. The ultimate criteria are those that ish that the rock is or was composed of ; at least in part, pyroclastic materials, y glass shards and pumiceous fragments, that these have been deformed and welded they were still hot. The writer has found the most pertinent observations are ly made at or near the base of the unit in tion. Here the transitions from nonwelded ly welded and from glassy to crystalline are within a few feet, and the physical ges in the fragmented materials may be y traced, in contrast to the more gradual ges in the upper part of the sheet. Even after some metamorphism, relict vitroclastic structure may still be present in what was formerly the densely welded glass zone. The base of a welded-tuff sheet does not show the basal breccia zone normally found in silicic lava flows.

Even more difficult than the distinction between some welded tuffs and lava flows is the distinction between nonwelded ash flows and tuffs of other origins. Voluminous pyroclastic fall materials, near source areas, as well as avalanches of loose accumulations of pyroclastic materials may be indistinguishable from true pyroclastic flows, although the origin of most such deposits is decipherable if they can be traced laterally.

Sorting Characteristics

Ash-flow deposits are generally nonsorted, as can be seen in any outcrops of nonwelded or poorly welded materials; fragments range in size from blocks to dust. The chief differences among deposits seem to be in the proportions of coarse to fine materials and in the relative proportions of crystals and glass. Before welding or crystallization, most ash-flow deposits are composed of (1) glass shards and glass dust, (2) pumice or scoria fragments and occasionally tube, and (3) crystals, glass generally predominates over crystalline materials. Most contain some accidental lithic fragments.

The existing data do not indicate that major sorting is ever an important phenomenon of the flow mechanism itself. Probably, however, any accidental inclusions, other than those locally derived, will decrease in size and amount from source to distal end of a given flow. The amount of fine-grained materials should probably also increase away from the source, especially in flows of low gas content.

Figure 4 shows cumulative grain-size curves for localities where size analyses are available. Although few in number, they are remarkably similar. The following localities are represented:

(1) The "Shirasu" deposits, South Kyushu, Japan (Taneda, 1954; 1957; Taneda, Miyachi, and Nishihara, 1957)

(2) Pumice deposits at Komoro on southwest foot of Asama volcano, Japan (Tsuya, Murai, and Hosoya, 1958)

(3) "Older pumice", Crater Lake (Moore, 1934)

(4) "Sand flow", Valley of Ten Thousand Smokes (Fenner, 1923)

(5) "Sillar" near Arequipa, Peru (Jenks and Goldich, 1956)

(6) Nonwelded portion of "ignimbrite", Arapuni, New Zealand (Marshall, 1935)

The "Shirasu" and the Komoro deposits are by far the best studied for their sorting. The "Shirasu" curves, Sh-35 and Sh-60, represent the highest and lowest median (size at 50 per cent) values of nine samples considered by Taneda and others to be representative of the bulk deposit. The Komoro curves, K-5 and K-8, also represent the highest and lowest median values of nine samples considered to be representative of the bulk deposit, and curve K-10 represents the fine-grained upper layer of the deposit.

The Crater Lake curves, C-34 and C-53, are the coarsest and finest of four samples but cannot be too closely compared with the others, because they do not include material larger than 64 mm in diameter. As a result their median particle sizes are larger, and their total contents of ash-size material are somewhat smaller than shown here.

The "sand-flow" and the "sillar" curves are not adequate representation of their respective deposits, but neither can they be much in error. The same may be said for the Arapuni, New Zealand, curves, which are both from the same "ignimbrite sheet", one from above and the other from below the welded zone.

The significant thing shown by these curves is the preponderance of ash and fine ash-size materials. In all the samples plotted 70 per cent of the material is smaller than 4 mm. The median sizes lie between 0.08 and 0.8 mm, or close to one order of magnitude. As mentioned above, at least some of the Crater Lake material will be generally coarser if the sizes above 64 mm were included.

The data, few as they are, are a surprisingly good representation of ash flows. The "Shirasu" is a deposit of large volume associated with the

"hai-ishi" (welded tuff) which surrounds the giant Aira caldera. The "older pumice" is a nonwelded deposit associated with the formation of Crater Lake caldera in a large composite andesitic volcano; the Komoro deposit is a contain a higher proportion of coarse blocks of pumice or scoria, and a few such as the welded tuffs from Idaho, studied by Mansfield and Ross (1935), and the Walcott tuff (Stearns and Isotoff, 1956) are probably finer-grained

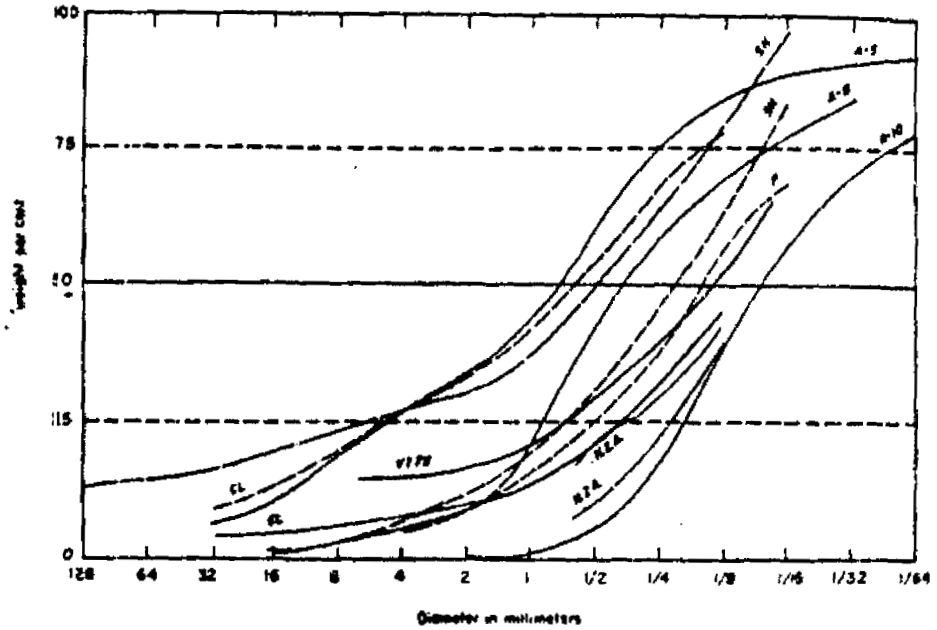

FIGURE 4.—CUMULATIVE CURVES SHOWING SORTING IN ASH FLOWS

SH curves: "Shirasu" deposits, South Kyushu, Japan (Taneda, 1954; 1957; Taneda, Miyachi, and Nishihara, 1957)

A curves: Asama volcano, Komoro deposits, Japan (Tsuya, Murai, and Hosoya, 1958)

CL curves: "Older pumice," Crater Lake, Oregon (Moore, 1934)

VTTS curve: "Sand flow," Valley of Ten Thousand Smokes, Alaska (Fenner, 1923)

P curve: "Sillar" near Arequipa, Peru (Jenks and Goldich, 1956)

N.Z.A. curve: Nonwelded portion of "ignimbrite," Arapuni, New Zealand (Marshall, 1935)

small-volume nonwelded "pumice flow" presumably from the summit crater of Asama volcano, an andesite cone. The "sand flow" of the Valley of Ten Thousand Smokes, a small-volume deposit erupted from fissures and perhaps a crater, is at least partly welded and is partly crystalline. The Peruvian "sillars" are from a large-volume deposit of unknown origin and consist of nonwelded, mildly welded, and crystalline facies. The Arapuni samples represent a finer-grained type of the fissure-erupted "ignimbrites" which form the vast tuff deposits of the North Island of New Zealand.

The writer offers with considerable confidence the opinion that *most* welded tuffs have been derived from ash flows having sorting characteristics within the range of the cumulative curves of Figure 4. Some, nevertheless, will

Seemingly there is no obvious correlation between sorting and volume of deposit, composition, type of vent, or source area. The data, therefore, do not supply criteria for separating ash flows erupted from craters from fissure eruptions. Statistical studies of a large number of deposits might show that there is a tendency for rhyolitic or fissure-erupted material to be finer-grained than *others*, but *even* this seems doubtful. The principal differences among the curves shown in Figure 4 seem to be in the variation in amount of coarse materials (pumice fragments above 4 mm) both within a single deposit and in different deposits.

The data suggest that even within the framework of the cumulative curves (Fig. 4) there is considerable room for variation, and detailed studies from many deposits should yield us-

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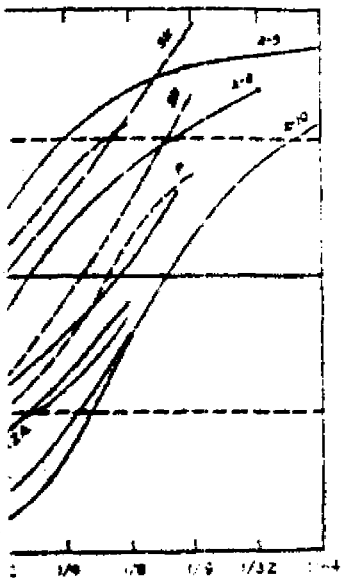

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ful data. If, for example, a variable vertical component plays a significant role in these eruptions, then we have a mechanism that can influence sorting features *before the ash flow is formed*. Crystal enrichment or, rather, fine glass shard and dust impoverishment might take place in the eruptive column giving rise to ash flows that are not strictly representative of the magma from which they were formed. Comparative studies of bulk crystal–glass ratios in the flows, and of crystal–glass ratios in the pumice fragments should be made wherever possible. Studies contrasting nonwelded ash flows with the nonwelded facies of densely welded gas-rich ash flows might supply information on the role of gases in reducing attrition and sorting during emplacement, and might also further our understanding of the pyroclastic-flow mechanism.

A few writers have considered attrition during flowage to be responsible for the high proportion of fine ash in these deposits. Whether or not this is true remains to be demonstrated. It does not seem possible that such a mass of fragmented material could flow for miles without considerable attrition (especially near the distal end), yet if attrition does take place there should be a marked increase in amount of ash and fine ash from source to distal end of the flow. There are, as yet, no really diagnostic data bearing on this facet of the problem. Although Moore's (1934, p. 365) data suggest that there is an increase in material smaller than 4 mm away from the source, in the Crater Lake pumice flows this may be due to sorting. Williams (1942, p. 82) states that the size of pumice lumps bears no relation to distance from the source although they are generally more rounded at the distal ends. Trumbein and Tisdel (1940, p. 304) have shown that the sorting characteristics of the Crater Lake "pumice flows" conform to Rosin's law of crushing, a fact which may have some bearing on our interpretation of the pyroclastic-flow mechanism. It probably remains to be determined whether explosive disintegration and attrition produce the same sorting characteristics. The sorting characteristics of lahar (volcanic mud flow) deposits are very similar to those of ash flows, but perhaps of generally finer grain.

Welding

The sticking together, cohesion, or welding of fragments of tuffaceous rocks was recognized by Fritsch and Reiss (1868, p. 414), Zirkel (1876, p. 267), and Dell'Erba (1892) long before Iddings (1899) introduced the term "welded pumice." The term "welded tuff", commonly incorrectly credited to Iddings, probably evolved from Iddings' use of "welded pumice." It was first formally introduced by Mansfield and Ross (1935), although Ross (oral communication) says that "welded tuff" was in use in the U. S. Geological Survey long before 1935. His first recollection of using the term was in 1919 in connection with rocks in the eastern San Juan Mountains near Crestone, Colorado. Their origin was then a puzzle, but we now know from re-examination that these rocks are densely welded tuffs of ash-flow origin.

The welding process as it applies to ash-flow materials promotes the union or cohesion of glassy fragments in a viscous state. The degree of welding may range from incipient stages marked by the sticking together or cohesion of glassy fragments at their points of contact to complete welding of the surfaces of glassy fragments accompanied by their deformation and by the elimination of pore space, and perhaps ultimate homogenization of the glass.

Phenocrysts and rock fragments are rarely affected by the welding process nor do they have much effect on it, except in rare instances where they are so abundant as to inhibit consolidation of the glass fragments.

Many variables affect the degree of welding; the more important ones are (1) temperature, (2) amount and composition of volatiles, (3) composition of ash, (4) lithostatic load, (5) rate of cooling, and (6) rate of crystallization. The first three control the viscosity of the glass and for purposes of discussion may be reduced to the one variable, viscosity. Lithostatic load is a function of density and depth in the deposit. The load pressure and the viscosity control the rate of loss of pore space which really is the only measure of rate of welding. We thus see that the degree of welding, in an ash flow, is dependent on three rate processes: the rates of welding, cooling, and crystallization. Crystallization is also related to the viscosity of the glass.

Of all the variables that control the cooling history of ash flows the two most important are probably emplacement temperature and the thickness of the flow or cooling unit. Because these influence all the others, or are in some way related, it is possible to interpret the observable variations in the flows in these terms. In ash flows, emplaced at approximately uniform temperature throughout, the rate of

welding will be faster at or near the base of the unit and will decrease toward the top. For this reason the transition between densely welded tuff and nonwelded tuff will invariably be much sharper in the lower part than in the upper part of a simple cooling unit. All transitions are sharper in high-temperature ash flows than in low-temperature ash flows.

In its simplest form, the welding process is the merging of viscous glass particles into a coherent mass. In very young and fresh ash flows that have not crystallized, the incipient stages of welding are marked by the first signs of coherence and brittleness in the transition from unconsolidated to obviously indurated material. In older and less fresh rocks and those which have crystallized, we must depend on visible deformation of pumice fragments or shards as a criterion for welding. From the incipient stage there is a complete gradation with progressive loss of pore space, deformation of pumice and shards, and darkening to a dense black glass. During the color change, the darkening of the pumice lumps usually precedes the darkening of the shardy matrix. The contrast emphasizes the well-known eutaxitic structure characteristic of so many welded tuffs, especially in those of low porosity (0 to 25 per cent).

The formation of a black glass appears to be the end product of the welding process; however, with aid of the microscope, an additional change becomes apparent—the gradual obliteration of vitroclastic and vesicular structures. This process begins in the collapsed pumice fragments, removing all trace of vesicular structure, and it finally extends to the shard boundaries. In some welded tuffs vesicular structure in pumice has been obliterated before the black-glass stage is reached. Elimination of all pumice structure is rare but has been noted (Ross and Smith, in press), whereas the elimination of all shard boundaries in glassy welded tuffs is not known to the writer. The elimination of all traces of shard boundaries is not achieved because of the original dusty matrix between the shards, a problem not presented by the pumice vesicles. Homogenization of all the glass shards and pumice is, then, the probable ultimate end of the welding process and will probably require an exceptionally hot, thick ash flow for its fulfillment.

Welding Temperatures Determined by Experiment

Many early workers have experimented with melting, vesiculation, and crystallization of volcanic glasses, but the first attempt to make welded tuffs by welding fragmental volcanic glass was by Boyd and Kennedy (1951, p. 327). They found that crushed rhyolitic pumice from Mono Craters, California, welded at temperatures ranging from 775° to 900° C. In later work Boyd (1957, Ph.D. Thesis, Harvard Univ.) found that the presence of water vapor effectively lowers the welding temperature. Glassy rhyolitic volcanic ash from Yellowstone Park was sealed in platinum capsules with water equivalent to 0.45 weight per cent and held for 80 hours and a pressure of 52 bars. The *minimum* welding temperature under these conditions was between 590° and 620° C. Increasing the time of the experiment to 2 weeks resulted in lowering of the welding temperature to between 550° and 590° C. Boyd found that the same ash, dehydrated and without addition of water in the experiment, showed slight welding at 690° C. after 72 hours at a pressure of 48 bars, and no welding at 655° C. From these and other experiments Boyd concluded that the minimum welding temperature in the presence of water vapor is about 600° C.

Smith, Friedman, and Long (1958, p. 532-533, and unpublished data) found very similar results. The method used differs from Boyd's in that the charge of unconsolidated ash was placed in a platinum-lined copper container which was in turn placed in a bomb fitted with an adjustable piston through its top. Load pressure was applied directly to the surface of the charge by the piston assemblage. A lever arm that applies load to the piston was attached to a recorder, and the rate of compaction was measured. Water pressure in the bomb was controlled externally, and the water content of the welded pellets was later measured directly or determined by analogy to quenching experiments made on crushed obsidian hydrated at different temperatures and pressures. The ash used in the welding experiments was from a nonwelded facies of the Bandelier rhyolite tuff, Valles Mountains, New Mexico.

The minimum temperature for incipient welding was below 535° C. and is controlled largely by temperature and water-vapor pressure, whereas complete welding is dependent on these variables plus load pressure and time. Time is limited by crystallization and cooling, but these factors have not yet been assessed. No satisfactory minimum temperature for complete welding (black glass) has yet been found, although it is below 635° C. at 528 p.s.i. load pressure, 300 p.s.i. water-vapor

ure, and 50 hours time. Fifty per cent action was reached in one run, in about s, at 535° C., 528 p.s.i. load pressure, and p.s.i. water-vapor pressure. Further, for ows of the order of 100 feet thick or less, peratures above 735° C. probably are ssary for the formation of a densely welded

nada (1957, p. 99–100) reports welding sments on the "Shirasu" (white sand), a ico-flow" deposit associated with Aira n, South Kyushu, Japan. He found that heated in an electric furnace in the perature range of 600° to 1200° C. in 1 to hours it changed color from "gray white to ish or purplish gray, a reddish tinge being ased with raising temperatures from to 1030° C." Melting began between and 920° C., and at 1200° C. melting was tially complete and the original color was ved. "Load-bearing tests of pumice" were in the temperature range 800° to 1000° C. at loads of 1, 3, and 5 kg/cm², the latter ponding to 30 m depth in a "Shirasu" bed. was concluded that the "Shirasu" would d below 920° C. to look like "Hai-iahi" ded tuff associated with "Shirasu") and t the unwelded "Shirasu" could not have n compacted above 900° C.

Because the "Shirasu" would contain little no water at the temperatures of these eriments, and because the times were very t, it is doubtful whether or not they could ly strictly to the natural materials. Probably welding would take place in "30 meter k beds" at temperatures considerably ve 900° C.

Compaction during Welding

Surprisingly few references have been made the total compaction of ash flows during ding, although compaction may reach logically significant proportions in some ligraphic sections of densely welded tuff. compactibility is related to the bulk sity and therefore to the ratio of pumice solid material. In most ash flows the initial porosity must be greater than 50 per t. This is not shown by published porosity density curves, probably because of the culty of collecting and measuring repre- tative samples of unconsolidated material, cially in older rocks.

The specific gravity and porosity curves for ded ash flows shown in Figures 5 and 6 are only ones available. In addition to these curves Weyl (1954, p. 18, 21) gives specific-gravity figures ranging from 1.28 to 2.03 for rhyodacite tuffs from the Comalpa area and from 1.21 to 1.89 for dacitic tuffs from the Zaragoza area, El Salvador. These have not been plotted in Figure 5 because the positions of the samples were not given. The figure of 1.28 for the Comalpa tuff probably represents a bulk porosity of about 50 per cent, whereas the figure of 1.21 for the Zaragoza tuff implies over 50 per cent porosity, perhaps 55 per cent to judge from Weyl's chemical analysis. These figures seem more realistic than others published for fresh unconsolidated ash-flow materials as do the figures 0.98 (specific gravity) and 60 per cent (porosity) given by Lovering (1957, p. 1587, 1593) for the Valley of Ten Thousand Smokes "sand flow." Ross and Smith (in press) found 70 per cent porosity for part of the Battleship Rock ash flow, New Mexico. Smith, Friedman, and Long (1958) found by experiment that the compaction potential of unconsolidated material, mostly less than 4 mm in size, for the Bandelier rhyolite tuff from New Mexico is approximately 50 per cent This material was used for making synthetic "welded tuffs" and represents only the finer-grained part of the Bandelier tuff, the bulk porosity of which is considerably greater than 50 per cent.

The data indicate that where measured porosity curves show maximum porosities less than 50 per cent, they should be extrapolated to at least 50 per cent if they are to be used for studies involving thicknesses of zones or cooling units, compaction, or similar problems. Pure shards or crystals probably have a bulk porosity of about 50 per cent, and most ash flows contain pumice which commonly has 70 or more per cent pore space in rhyolitic rocks. Roughly then, an ash flow containing 50 per cent by volume of pumice or pumiceous ash of 70 per cent porosity and 50 per cent shards would have a bulk porosity of 60 per cent and a specific gravity of about 0.94 if it were 100 per cent glass, or about 0.99 if it were 50 per cent crystals of sanidine and quartz. The ratio of crystals to glass will not cause significant variation in the bulk density of unconsolidated ash, except in very mafic rocks.

Because most ash flows contain some pumiceous materials but probably not more than 50 per cent we can expect that they will have initial porosities between 50 and 60 per cent. Obviously, an ash flow having 60 per cent pore space could compact to a welded tuff having less than half the original thickness. Probably very few entire sheets have undergone such

compaction. Those in which it has occurred would have been very hot, thus more thoroughly welded, or very thick allowing a thick zone of dense welding to form, or, rarely, may have had exceptionally high initial porosity. For simple cooling units that contain densely welded tuff it is possible to get an approximate figure for the thickness before welding without density or porosity measurements, if the thicknesses of the three basic zones (see section on Zones and Zonal Variations) are known. Assumption of 50 per cent initial porosity probably gives the figure closest to a minimum. The calculations: 2 times the thickness of zones of dense welding plus 1½ times the thickness of zones of partial welding plus the thickness of zones of no welding equals total thickness before welding. This method is subject to some error but is a useful approximation.

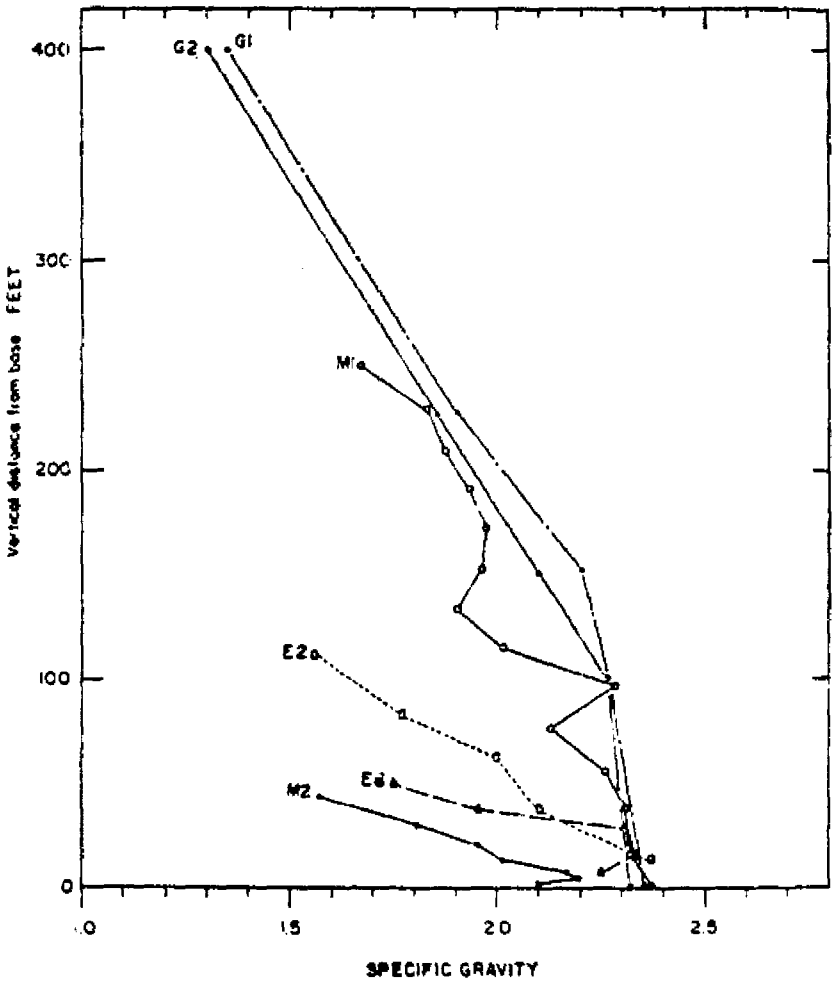

FIGURE 5.—SPECIFIC-GRAVITY CURVES FOR WELDED-TUFF SHEETS
G curves: Bishop tuff, California (Gilbert, 1938)
M1 curve: Motutere "ignimbrite," New Zealand (Marshall, 1935)
M2 curve: Arapuni "ignimbrite," New Zealand (Marshall, 1935)
E curves: Chiricahua "welded tuff," Arizona (Eakins, 1955)

Crystallization

Crystallization during cooling in pyroclastic deposits was noted by Zambonini (1919) who

described several unusual fluorine-bearing minerals from the classical Italian piperno. Fenner (1937, p. 136) found trilymite and between depth and cooling rates and the type of crystallization structures formed. Gilbert (1938, p. 1856) emphasized that crystallization

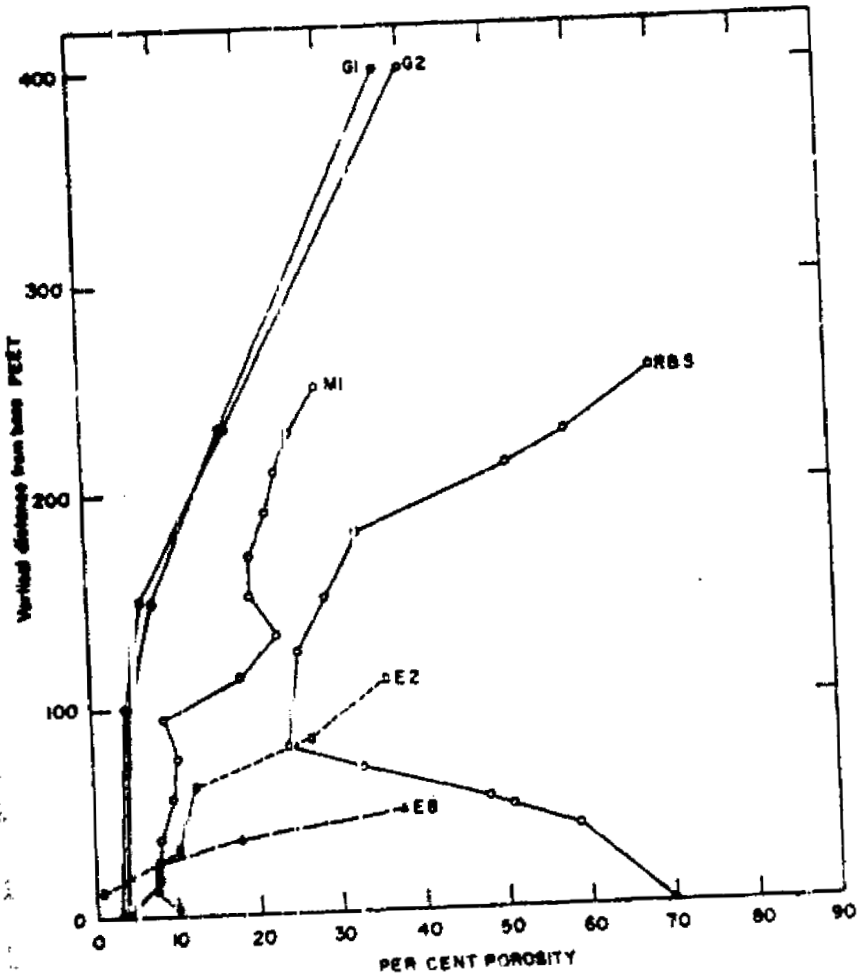

FIGURE 6.—POROSITY CURVES FOR WELDED-TUFF SHEETS

G curves: Bishop tuff, California (Gilbert, 1938)
MI curve: Motutere "ignimbrite," New Zealand (Marshall, 1935)
E curves: Chiricahua "welded tuff," Arizona (Enlows, 1955)
E8 and 3 curve: Battleship Rock "ash flow," New Mexico (Ross and Smith, in press)

"obsidian" in the Valley of Ten Thousand Smokes "sand flow." Spherulitic crystallization described by Marshall (1935, p. 347), and Mansfield and Ross (1935, p. 320) in the New Zealand ignimbrites and the Idaho welded tuffs, respectively. Marshall (1935, p. 345–350) discussed in great detail the crystallization structures and textures in the "ignimbrites" and recognized in some deposits a relationship in the upper part of the Bishop tuff sheet was influenced by rising gases. Westerveld (1942, p. 211–212) has described the effects of "pneumatolytic" crystallization in the Pasoemah tuffs, South Sumatra, and Toba tuffs (1947, p. 34), North Sumatra.

Fenner (1948, p. 883) proposed that induration in the Cordillera tuffs of Peru was due primarily to pneumatolytic "recrystallization"

rather than "softening" and union by welding, and that such tuffs should not properly be called "welded tuffs." Fenner proposed the local Peruvian name "sillar" to cover these materials. Jenks and Goldich (1956) restudied these tuffs in more detail but agreed essentially with Fenner's views. No one who has studied both the "sillar" type tuff and densely welded tuff would confuse the two in their optimum state of development or question Fenner's need for distinguishing the two, even though in some deposits they are transitional. However, we should perhaps question the reasoning that leads to the conclusion that the induration was the result of crystallization rather than welding.

We may seriously doubt that the crystallization of the vapor-phase mineral assemblages, sanidine-tridymite or sanidine-cristobalite in the "sillar" type tuffs, was *initiated* below the minimum welding temperature of the tuff (<550° C.). If this be admitted then ash flows that show crystallization must also be mildly welded if they are thick enough to show even mild deformation of pumice or shards. Some compaction could be expected without visible deformation of shards of pumice, resulting in an incipiently welded coherent rock which after crystallization would no longer show that it had once been mildly welded. However, the writer has observed that coarse vapor-phase crystallization will render an incipient to mildly welded tuff less coherent after crystallization. The comparison can be made between fresh and unaltered glassy and crystalline rocks, judged to be otherwise equivalent, in which the first visible traces of compaction foliation have appeared. The crystalline "sillar" is the more crumbly. It is also less resistant to erosion. Some specimens of Peruvian "sillar" as well as other "sillar" type tuffs show compaction foliation.

We cannot question the fact that crystallization of unconsolidated ash and pumice would result in material more coherent than it was before crystallization, but we can suggest that most completely crystalline "sillar" was a coherent, albeit porous, rock, owing to welding before it crystallized.

Ross and Smith (in press) have shown by X-ray studies that cristobalite rather than tridymite is the common form of silica, where crystallization has been confined to the glass shards or welded glass masses. Tridymite, on the other hand, is more common as discrete crystal or crystal aggregates in pore space where its crystallization is believed to be related to active vapors. Two distinct types of crystallization are suggested: (1) devitrification—characterized by intergrowths of cristobalite and alkalic feldspar, mainly in axiolitic and spherulitic growths but also in some "closed" lithophysal cavities; and (2) vapor-phase crystallization—characterized by growths of tridymite, alkalic feldspar, and other minerals in pore space. Porous axiolites and spherulites may contain tridymite, but this simply means overlapping of two processes. In general, the tendency for tridymite to form increases with the degree of porosity of the groundmass of the tuff within the crystalline portion. In some welded tuffs tridymite does not occur, yet cristobalite is common to all crystalline welded tuff sheets that have not undergone diagenetic or other metamorphic changes. In these older or altered rocks quartz replaces the other silica minerals.

Nearly all writers who have studied the products of cooling-history crystallization in welded tuffs have identified alkalic feldspar and at least one of the polymorphs of silica as the principal minerals formed.

SILICA MINERALS: Tridymite, ordinarily easily identified with the microscope, is the silica mineral most frequently mentioned, and, although it is a common mineral in many welded tuffs, it has probably been mistaken for cristobalite in many descriptions. Cristobalite has been recognized by Zavaritsky (1947), Williams (1952, p. 173), Bailey (1957), and Martin (1959, p. 404).

Enlows (1955, p. 1230) reports quartz as the common groundmass silica mineral in Member No. 6 of the Rhyolite Canyon formation, based on X-ray study. He states that tridymite was not found. The writer has been somewhat reluctant to accept most interpretations of quartz as a primary groundmass mineral in welded tuffs. It seems that it is far more common in older and more obviously altered rocks, whereas in fresh Pleistocene and Recent rocks it has not been recorded. By analogy to thick rhyolite flows it should occur in some thick sheets of welded tuff. The writer is now convinced that primary groundmass quartz should occur in any simple cooling unit of rhyolitic composition more than about 600 feet thick. The necessary thickness for the formation of quartz will no doubt vary with emplacement temperature, vapor pressure, and perhaps other factors. Enlows' Member 6 is 880 feet thick, and there seems little doubt that the quartz reported by him is primary; however, this quartz should give way at least in the upper part of the sheet to cristobalite

[illegible]: (1) devitrifica[illegible] worths of cristob[illegible] only in acidic a[illegible] so in some "dev[illegible] d (2) vapor-phase [illegible] and by growths [illegible], and other min[illegible] dity and spherul[illegible] t this simply [illegible] ses. In general, th[illegible] form increases w[illegible] the groundmass [illegible] ine portion. In so[illegible] ces not occur, y[illegible] ll crystalline weld[illegible] lerogene diagenetic[illegible] s. In these older [illegible] can the other sil[illegible]

have studied th[illegible] crystallization o[illegible] ed alkali feldspa[illegible] morphs of silica [illegible] d.

[illegible]hydrite, ordinarily [illegible] microscope, is th[illegible] uently mentioned [illegible] as mineral in many [illegible] bly been misinter[illegible] ciptions. Cristobal[illegible] Zavaritsky (1949), [illegible] Bailey (1957), and [illegible]

ports quartz as the [illegible] rimeral in Member [illegible] n formation, based [illegible] that tridymite was [illegible] been somewhat [illegible] interpretations of [illegible] chemical mineral is [illegible] t it is far more [illegible] obviously altered [illegible] tacous and Reitan [illegible] ed. By analogy to [illegible] ld occur in some [illegible] The writer is now [illegible] condensate quartz [illegible] cooling unit of [illegible] than about 400 [illegible] thickness for the [illegible] doubt very with [illegible] apor pressure, and [illegible] of Member 6 in [illegible] some little doubt [illegible] hius is primary; [illegible] give way at least [illegible] et to cristobalite.

[illegible]rhaps tridymite, unless these minerals [illegible] been replaced by secondary quartz.

[illegible]lems of this type need a much more [illegible]gh investigation before we can arrive at [illegible]nd generalizations. The writer (Smith, [illegible]) has proposed that the distribution of [illegible]ica minerals is zonal and is related to [illegible] and degree of welding within simple [illegible] units.

[illegible]ANS: Very little can be said about the [illegible]mous feldspars in crystallized welded [illegible] and systematic studies using modern [illegible] techniques have not been made. Feldspar [illegible] as discrete crystals or crystal aggre[illegible] with tridymite in the vapor-phase zones, [illegible] microscopic intergrowths with cristobal[illegible] devitrified zones, and as granophyric [illegible]wths or discrete miarolitic cavity [illegible] with quartz.

[illegible]terveld (1942, p. 211) and Martin (1959, [illegible]) reported albite; Gilbert (1938, p. 845) [illegible]lows (1955, p. 1230) reported sanidine; [illegible] (1948, p. 883), orthoclase or natro[illegible]; many other writers have reported [illegible]" or "alkali feldspar," "potassium [illegible]," or simply "feldspar."

[illegible]ably in most silicic welded tuffs the [illegible]mous alkali feldspar is a form of [illegible] that probably bears a relation to the [illegible]mposition of the host rock. It is sug[illegible] that it was formed above the solvus [illegible]ature unless it be admitted that it [illegible] form metastably, as do tridymite and [illegible]lite. This suggestion is prompted by [illegible]t that, in some thick cooling units, [illegible] crystals of sanidine have exsolved to [illegible] or microperthites.

[illegible] feldspars also probably bear a systematic [illegible]ship to their position within the cooling [illegible] Detailed studies of specific units may be [illegible] helpful in formulating a framework for [illegible] of crystallization temperatures.

[illegible]rt (1938, p. 1850) reported overgrowths [illegible]idine on sanidine phenocrysts in the [illegible] parts of the Bishop tuff where they were [illegible]ably deposited by rising gases. Similar [illegible] are found in some "vapor-phase zones" [illegible] Bandelier tuff, New Mexico.

[illegible] MINERALS: Minerals other than the [illegible]ica and silica minerals that form during [illegible]mous crystallization are not well known. [illegible] the more common are magnetite, [illegible], fayalite, and sodic amphibole. These [illegible] form deep within cooling units. Another [illegible] of near-surface and surface fumarolic [illegible], including magnetite, are known [illegible] from the work of Fenner, Allen, and Zies in the Valley of Ten Thousand Smokes, Alaska (Zies, 1929). Most of these are halides, sulfates, and sulfides of metallic elements. Magnetite has also been recorded as a fumarolic mineral by Mackin (1952, p. 1337–1338), Williams (1942, p. 86–87), and Gilbert (1938, p. 1851).

Behavior of Phenocrysts and Inclusions during Welding and Crystallization

It has not been shown that the welding process *per se* has caused changes in phenocrysts in any rocks yet described; however, crystallization processes and the rate of cooling do cause changes in *individual crystals of some* welded tuffs. Sanidine phenocrysts undergo changes in optical properties and degree of unmixing to cryptoperthites, which are related to the cooling history of given vertical sections. The catalytic effects of hot vapors may facilitate these changes. Boyd (1957 Ph.D. Thesis, Harvard Univ.) has made the only quantitative X-ray study of unmixing of sanidine which shows in the Yellowstone welded tuffs a clear-cut relationship to position in the unit. In a qualitative way the unmixing phenomena in sanidine can be observed in some welded tuffs by the change from clear "glassy" sanidines in the chilled portions of the units to chatoyant ones (moonstones) in the more slowly cooled parts. This is a common phenomena in the Bandelier tuff, Valles Mountains, New Mexico, and the writer has observed it in other sanidine-bearing welded ash flows.

Whereas unmixing is detectable in some sanidine phenocrysts under the microscope, particularly those from very thick cooling units, it does not resemble the unmixing to coarse microperthite seen in the smaller, thinner sanidine crystals formed in cavities during cooling of the same unit. An excellent example illustrating this difference in degree of unmixing is a specimen the writer collected from Bonita Canyon, Chiricahua National Monument, Arizona. These rocks were described by Enlows (1955), and the specimen is from Enlows' Member 6 for which he gives a thickness of 880 feet. Chatoyant sanidine phenocrysts show only faint visible traces of unmixing, but chatoyant tabular "sanidine" crystals from miarolitic cavities are coarse microperthite.

Biotite and hornblende, commonly green to shades of brownish green in chilled glassy parts of ash flows, are often changed to deep red brown or sometimes completely destroyed in the crystalline parts of welded ash flows.

The degree of destruction seems related to the intensity of vapor-phase activity within units of given compositions, and the thickness of the cooling unit plays a major role in controlling intensity of vapor-phase activity. This deuteric or vapor-phase alteration ranges from a very minor role in some cooling units to a major one in others. Where it was intense nearly all minerals and inclusions, except possibly zircon and similar accessory minerals, show some effects, although commonly no more than border corrosion. Specifically the writer has observed varying degrees of alteration or corrosion in phenocrystic quartz, sanidine, plagioclase, amphibole, clinopyroxene, orthopyroxene, fayalite, and sphene.

No systematic studies of these alteration effects have been made, and they are another interesting field of inquiry. Excellent examples of biotite and hornblende alterations are found in welded quartz latite ash flows throughout the Basin and Range province. Some of these from southwestern Utah and adjoining parts of eastern Nevada have been studied by Mackin (1952, p. 1338, and oral communication), and by Cook (1957, p. 57).

Zones and Zonal Variations

Nearly all workers since the 1930's who have recognized the fundamental pyroclastic nature of welded tuffs have also observed and described systematic textural changes, particularly in vertical sections, within given units. Probably all significant textural variations that occur among welded tuffs have been found and described (Marshall, 1935; Mansfield and Ross, 1935; Gilbert, 1938; Enlows, 1955). Most of these can be seen in the illustrations of Ross and Smith (in press), Smith (in press), and Martin (1959). Good illustrations of marked secondary flowage features have not yet been published.

It is improbable, but not inconceivable, that all the important known textural variations resulting from welding and crystallization could be found in the same composite sheet. Most of these are possible in simple cooling units. This fact makes it difficult to classify welded tuff sheets on a purely descriptive textural basis. Most of the available descriptions are based on one or a few vertical sections which probably only rarely characterize the three-dimensional sheet. It is true that some welded tuff sheets at first glance seem to be monotonously uniform over great areas and different enough from other welded tuffs to be considered distinct types. For example, it would be improbable for the Walcott tuff (Stearns and Isotoff, 1954, p. 23) to grade laterally as the same flow unit into a crystalline tuff of the Peruvian sillar type. However, it might merge with a cooling unit which contains crystalline sillar-type material and there lose its identity as densely welded crystalline, rather than vitric, welded tuff, without the lithophysae and spherulites that now characterize it in the section at American Falls, Idaho. Thickening of the American Falls section from 25–50 feet to 75–100 feet (as a simple cooling unit) would unquestionably have resulted in the formation of a persistent crystalline zone which might predominate over the present glassy section.

In contrast to the Walcott tuff, which shows dense welding in a 25-foot thick unit, the Battleship Rock ash flow (Ross and Smith, in press) shows no dense welding in a cooling unit about 250 feet thick, but its initial porosity of about 70 per cent has been reduced to less than 25 per cent in the zone of maximum deformation, and no crystallization has taken place during cooling. The Walcott tuff, on the other hand, shows incipient crystallization in the form of spherulites and lithophysae and clearly was emplaced at the higher temperature. Clearly the evidence presented by these two sheets, together with such data as are available from other sheets, indicates a relationship between the emplacement temperature, the degree of welding, the thickness of the sheet, and the retention of the glassy state during cooling. For any given temperature of emplacement there is apparently a corresponding maximum thickness of the simple cooling unit, below which no crystallization will take place during cooling. It is not anticipated that composition, gas content, or cooling rates in different environments will, in general, show differences great enough to invalidate this generalization for gross comparisons.

In a general way, maximum vitric cooling units emplaced at high temperature are thinner, more densely welded, and show sharper transitions between nonwelded and welded material than the maximum vitric cooling units emplaced at lower temperatures. Thicknesses greater than the maximum vitric unit for any given temperature will result in crystallization, incipient at first (Walcott tuff of American Falls, Idaho) but persistent as a continuous zone of crystallization at greater thicknesses. This zone exhibits an increasing number of facies as the unit thickens further. These different facies or zones of crystallization are

d to the degree of welding of the tuff on
they are superimposed as well as to
positions within the units and to other
s.

ith (in press) has attempted to show the
al relations between thickness, tempera-
and the formation of textural and struc-
zones by means of hypothetical diagrams.
basic zones are recognized: (1) the zone
welding, (2) the zone of partial welding,
(3) the zone of dense welding. Where
welding occurs in a unit, the other two
have upper and lower counterparts
merge with lateral thinning or near the
s of the sheet. The lower zones of no
g and partial welding are thinner than
pper ones in simple cooling units and may
ally absent owing to special or extreme
tions of temperature and pressure.
allization superimposed on the basic
may be recognized as (1) the zone of
dification, (2) the zone of vapor-phase
allization, (3) the zone of granophyric
allization, and (4) the zone of fumarolic
ation.

is scheme of representation is largely
tive, but, with the accumulation of
le measurements of the various zone
nesses and positions within a variety of
g units, it may develop into a quantitative
e leading to the solution of problems of
loss during emplacement, emplacement
peratures, rates of cooling, direction of
, and many others. In future studies
ists should, if possible, record the zonal
cteristics, especially of complete cooling-
nctions, quantitatively. The zonal patterns
mple cooling units must be understood
e we can hope to evaluate compound
g.

Deposits Emplaced at Low Temperature

flows probably can be emplaced at any
perature up to a maximum eruption
perature, perhaps of the order of 1000° C.
minimum welding temperature is taken
about 300° C., there is a wide temperature
through which endless variations can
.

e are not yet able to correlate specific ash
with specific temperatures, but a gross
tive scale is possible. Because thickness is a
important factor in controlling degree
elding, many thin ash flows emplaced
r their potential minimum welding tem-
ure do not show welding. These are ordinarily not distinguishable from deposits emplaced below their minimum welding temperature, although the presence of a red zone caused by oxidation of iron probably indicates a higher temperature. Ferromagnetic properties may be useful in distinguishing nonwelded ash flows emplaced above the minimum welding temperature which is close to the Curie point.

The designations high, low, and intermediate must be arbitrary and are only expedient subdivisions for ordered discussion.

Low-temperature deposits, then, are those in which little or no welding or crystallization is apparent in thick cooling units. These include deposits such as the Crater Lake and Krakatoan pumice deposits, the "Shirasu", and many others. Because some ash-flow fields contain units emplaced at high, low, and intermediate temperatures (Pl. 2, fig. 2), but presumably were derived from the same magma and erupted at the same temperature, the low-temperature deposits offer the best evidence for a cooling mechanism before the ash flow is formed. (*See* section on Vertical Component.)

Deposits Emplaced at High Temperature

Perhaps the best examples of high-temperature deposits are those from Idaho (Mansfield and Ross, 1935; Stearns and Isotoff, 1956). These rocks occur in sheets ranging from 15 to 50 feet thick and contain a zone of densely welded tuff to within a few feet of the surface and locally a zone of fused air-fall tuff at the base. These facts attest to their high temperature of emplacement. A high magmatic temperature is suggested by the paucity of phenocrysts. Probably these materials were derived from very hot and very dry magmas. Obsidian formed in the welded tuff from the Ammon quadrangle (Mansfield and Ross, 1935, p. 319–321; Ross and Smith, in press) has a water content of 0.15 per cent, similar to many normal obsidians of rhyolite flow or dome origin. The Walcott tuff of Stearns and Isotoff (1956), considered by Mansfield and Ross (1935, p. 310) to be equivalent to the tuffs studied by them, has been restudied by H. A. Powers (oral communication), who reports water values for the obsidian facies as low as 0.06 per cent. Water contents of this order are probably the lowest known for volcanic glasses and give further indication of the high emplacement temperature if not the low-water content of the magma.

Mansfield and Ross (1935, p. 312) considered that the tuffs described by them had been

emplaced by a great air-borne cloud of incandescent particles and cited as evidence the fact that the tuff occurred at different elevations, without significant change in thickness, over a vertical relief of over 2500 feet. The distribution of the tuff suggested that it had been sprayed or "dropped" over the irregular surface. This connotation has been widely cited in the literature and should be re-evaluated. C. S. Ross (oral communication) no longer holds this view; he now thinks these tuffs were formed from normal ash flows, and that their distribution may be explained by post-emplacement deformation.

Because these welded tuffs are an important link in the development of present-day concepts, they should be restudied. The possibility that, as normal ash flows, they were deposited with very low initial dips, probably less than 2°, might be critical to the interpretation of the geology of the very large area covered by these tuffs. Mansfield and Ross (1935, p. 311) have suggested that this might be of the order of 3000–5000 square miles. The very steep dip of 24° shown by them in one of Mansfield's (1935, p. 310) stratigraphic sections seems incompatible with a primary dip for a welded tuff sheet and suggests that at least part of the sheet has been deformed.

Deposits Emplaced at Intermediate Temperatures

Most welded ash flows are in the intermediate-temperature category. Depending on thickness, there are all degrees of welding and crystallization within this group of rocks. Thin cooling units look like low-temperature deposits, and parts of thick cooling units are not distinguishable from high-temperature deposits. Perhaps the key to relative emplacement temperature is the thickness of the upper zone of partial welding in simple cooling units. This should vary systematically between low and high temperature, but for comparisons between two units it must be equated with initial emplacement thickness or expressed as a ratio to the collapsed thickness.

On the low-temperature side of the intermediate-temperature category are the thick vitric cooling units that show moderate welding, whereas on the high-temperature side are the relatively thin cooling units that show crystallization, a zone of dense welding, and probably a weakly developed and thin vapor-phase zone. The vapor-phase zone, including the crystalline "silica," probably forms in an optimum temperature range within this intermediate category.

The vapor-phase zone requires a porous matrix for its formation (Pl. 1). At increasingly higher temperatures, the zone of dense welding would probably thicken, whereas the porous upper zones would thin, until they become a part of the "chilled" vitric mantle of the sheet, leaving no space for the formation of the vapor-phase zone. In these higher-temperature rocks the vapor-phase zone would probably give way to a zone of lithophysae in thin units or to a zone of miarolitic lenticles in thick units. Composition, however, becomes important to the problem at this point, and, in general, more basic deposits show less crystallization throughout than do the rhyolites.

Deposits that Record a Change in Temperature

Some ash-flow fields, perhaps many, record variations in emplacement temperature as shown by the different degrees of welding and of crystallization of individual flows or cooling units of equivalent thicknesses. The indicated changes in temperature are particularly significant in areas where all units have a common source. The change may be recognized within a cooling unit or in two or more units. Changes found by the writer appear to be, for the most part, systematic, indicating a general increase in emplacement temperature in successive flows.

Weyl (1954, p. 17–23) has described dacitic and rhyolitic welded tuff deposits from the Zaragoza and the Comalpa regions of El Salvador, respectively. They are of the order of 100 m thick and decrease in density from the top to the bottom. Weyl has noted the difference between these and other welded tuff sheets which increase in density toward their base. Weyl (1954, p. 27) suggests that the earlier "nuées ardentes" brought forth relatively cool material, whereas the later ones carried progressively hotter material that was more susceptible to welding.

We cannot tell, from Weyl's description, the specific type or types of units represented by either the Comalpa section which is 100 m thick or the Zaragoza section which ranges from 30 to 100 m, but the inference is that the changes he noted from top to bottom of both sections are continuous and progressive. The Comalpa section shows a range in specific gravity from 2.03 near the top to 1.28 at the base, accompanied by a change from obvious welding at the top to no welding at the base.

tematic changes of the type described by may be explained in several ways depend- the kind of units involved. If the changes related to differences in emplacement temperatures, they may represent a change in temperature as progressively lower of the magma chamber are drained during eruption, or they may represent progres- more efficient conservation of heat during formative stages of successive ash flows. detection of evidence for changes in emplacement temperature in successive units is in many deposits. Variable thicknesses units, the order in which they are and the length of time between succes- flows can create compound cooling units which systematic emplacement-temperature are not obvious and in which apparent are not real. Deposits may eventually that show an increase in density and of welding from top to bottom, but were formed by stacking of successively thinner flows.

Deposits that Record a Change in Composition

Deposits from a common source that record a in composition in successive ash flows be the most significant of all deposits logically. These changes are of three kinds: change in magma chemistry; (2) change in glass ratio; and (3) change in type of vesicular fragments. A change in chemistry is usually accompanied by physical changes of (2) and (3) and may be in one compound cooling unit.

Crater Lake field is probably the best of a change in magma chemistry yet Williams (1942, p. 18) states that volume of pyroclastic material laid during the culminating eruptions of is between 9.75 and 11.75 cubic six to 8 cubic miles of this consists of "glowing-avalanches" deposits, seven-eighths which is dacite pumice and ash; the rest is rich "basic scoria." The silica content dacite pumic ranges from 66.4 to 68.9 cent; that of the "basic scoria" from 53.9 per cent. There are no intermediate ejecta. Mineralogically the "basic differs from the dacite pumice in having ferromagnesian minerals, hornblende olivine, and more calcic feldspar, and brown glass. It also contains more lithic Most remarkable is the fact that transition between the underlying "pumice" and the later "scoria flows" takes place within a few feet (Williams, 1942, p. 83). The transition was sudden, without a detectable time break, and it must be concluded that there was an essentially continuous evolution of material. Locally the "scoria flows" have well-developed columnar structure; the "pumice flows" do not.

Commonly volcanoes that have erupted silicic magma later erupt more basic magma. In most instances we cannot evaluate the changes that took place between eruptions. At Crater Lake there was no time break, and the suddenness of the transition leads us to consider possible conditions in the magma. The continuity of the eruptions that produced the dacite pumice and "basic scoria" suggests they came from a single magma chamber where they must have existed as magmas with a sharp interface. The frequency of formation of simple calderas, like Crater Lake, in composite cones supports the single-chamber hypothesis.

The Crater Lake deposits are probably not unique. Contrasting magmas of rhyolitic and basaltic compositions are known from air-fall pyroclastic eruptions in Iceland. These are very small-volume deposits. Hekla (Thorarinsson, 1954, p. 32–45) is a notable example. In contrast to these the volume (order 5, Fig. 3) of the Crater Lake ejecta is large. The volume of pyroclastic ejecta making up the Bandelier tuff, Valles Mountains, New Mexico, is approximately 40–50 cubic miles (order 6, Fig. 3). The Bandelier ash flows record a change from early high-silica rhyolites to quartz latites at the end of the last ash-flow cycle.

The lavas that preceded the ash flows include quartz latite, rhyodacite, and more basic types.

Even the very large volume (order 7, Fig. 3) deposits may show similar trends. For example, van Bemmelen (1949, p. 694) states that the Toba eruption was preceded and succeeded by andesitic volcanism. The outburst of "granitic magma" was only an interlude in the continuous volcanic activity that normally produced "dioritic" magmas. Van Bemmelen (1949, p. 691) says that the Toba tuffs were probably produced by one, or a short succession of, cataclysmic outbursts, because no distinct stratification has been observed throughout most of the stratigraphic section. Some layering, however, is observed in the higher parts. Is it possible that a change in compositon is recorded?

Both andesitic and rhyolitic magmas were involved in the formation of the "glowing-

avalanche" deposits of the Sudbury basin (Williams, 1957, p. 69); andesitic "avalanches" followed rhyolitic eruptions.

Some ash-flow fields, composite sheets, and cooling units record a change in composition in their late stages. The frequency of such occurrences cannot be determined from published information; however, where such changes occur in young and fresh rocks, they offer an unprecedented approach to the study of problems of geochemical equilibrium in silicic magma chambers and will perhaps provide new information on the behavior of magmas. Time intervals, with their attendant possible changes, are drastically reduced or eliminated, a condition not shared by normal volcanic or intrusive sequences.

Origin of the Magmas

The evidence suggests that welded ash flows are not unique to any type of vent, source area, or composition of magma. Nevertheless they appear to be formed largely from fissures, are seemingly more common among large-volume deposits associated with subsidence structures, and more abundant among silicic magmas.

The large-volume deposits are confined to continental mountain belts or to wide island-arc systems, or in short to those environments that seem most likely to produce large volumes of granitic magma. This brings us directly to the contrasting concepts of the separateness or unity of volcanic and plutonic associations discussed by Kennedy and Anderson (1938).

Deposits of small volume, whatever their ultimate origin, have had an immediate origin within a volcanic dome or cone. Larger volumes related to caldera collapse were almost surely derived from shallow magma reservoirs having areal dimensions at least as large as the calderas, which in order 5 of Figure 3 range up to at least 20 square miles (*Crater Lake*). At depth these sites would logically be occupied by small plutons, and most are associated on the surface with more mafic volcanic rocks both older and younger than the ash-flow eruptions.

Some of the source structures associated with fields of order 5, 6, and probably 7 (Fig. 3) are true cauldron-subsidence structures, complete with ring volcanoes and a central stock; the latter is inferred from an observable uplifted central dome of pre-subsidence rocks.

Oftedahl (1957) has recently shown that the volcanic rocks of the ring structures near Oslo, Norway, long thought to be lava flows and intrusive rocks, are really welded tuffs and related effusive rocks. Buddington (1959) has recently reviewed the granite problem and has called attention to the clear-cut, volcanic-plutonic relations among the episonal plutons. Buddington (1959, p. 680) cites Billings (1943, p. 134) as having found that 11 out of 30 ring complexes reported at the time of his survey contain volcanic rocks. Probably all of these should be re-examined for welded tuffs.

The ring complexes, then, offer the best proof of a direct relationship between extrusive and plutonic rocks. Within some of these structures, ash-flow eruptions must have come directly from magma bodies that later congealed as plutons. The ring-dike complexes are commonly grouped in such a way as to suggest that they are only the upper part of a large subjacent complex (Buddington, 1959, p. 680-690; Jacobson, MacLeod, and Black, 1958).

The calderas associated with deposits of order 6 (Fig. 3) have areas of the order of 90 to 150 square miles; presumably the underlying magma bodies are at least as large and probably larger. Many ring structures are of comparable size although some ring-dike complexes are notably larger. Billings (1928, p. 86) says that the White Mountain New Hampshire "batholith" and associated volcanic rocks cover an area of 680 square miles.

Deposits of order 7 (Fig. 3) were almost necessarily derived from even larger magma bodies. The Toba volcano-tectonic depression occupies an area of approximately 1200 square miles which suggests a magma body of at least 60 miles long by about 20 miles wide or equal to the dimensions of the structure. Van Bemmelen (1939, p. 130) states that the estimated volume of pyroclastic rocks erupted approximates the volume of the Toba subsidence.

Buddington (1959, p. 681) has calculated that the 2300 cubic miles of rhyolitic volcanic rocks belonging to the Potosi volcanic series of the San Juan Mountains of Colorado (Larson and Cross, 1956, p. 94) are equivalent to a "granite batholith" 230 square miles in area and 10 miles deep.

Certainly volcanic eruptions have produced volumes of pyroclastic rocks, principally in the form of ash flows, of enormous proportions, over a short period of time. It is inferred that greater volumes of magma were not erupted, but remained behind to congeal as large plutons. The present evidence, from known volcanic fields and from plutonic complexes that contain assimilated blocks of volcanic rocks, indicates

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e immediate sources of many ash-flow es small to large granitic to dioritic ns; they are not, however, directly le to the deeper-seated great batholithic ns. Nevertheless the tectonic settings gional grouping of some ash-flow fields s common origins from deeper-seated

ddering now the immense deposits of like those of the Basin and Range prov- f western United States, perhaps the st question is whether or not the ash- lds truly represent the magmas from they were immediately derived. In other are the rhyolite ash-flow fields derived nite magma or do they represent only fferentiated part of bodies of quartz nite or granodiorite? If they represent the differentiated part, are they all or part of that fraction? At Crater Lake the ce shows that an ash-flow eruption can the entire silicic differentiate, at least on ll scale. Could this not also happen on a scale? Quartz latite and rhyodacite ash- sheets are common, in addition to the te ash flows, throughout the Basin and e province. Are these separate entities other source areas or are they related ally to the rhyolites, perhaps in a atic succession? The answers to these ions may have real significance to students deposits. It is suggested that the answers be found by careful studies of ash-flow ions from common source areas.

Geochemistry

Valley of Ten Thousand Smokes

e studies of Shipley (1920), Sayre and Harger (1919), Allen and Zies (1923), Zies (1924; 1929) in the Valley of Ten sand Smokes contain nearly all the known litative information on the geochemistry sh flows. The essentials of these studies are well known and include the tremendous nt of chlorine and fluorine given off by fumaroles; the transport in the vapor phase harge number of metallic elements and their sition in sublimate minerals around the ths of fumaroles and in fissures; the deter- n of most of these same metallic elements in mutated glassy pumice; and their release the pumice by attack of steam and acid s. The reader is referred to Zies's (1924; 9) papers for details. These studies were ng the finest of their kind, and their importance to students of ore deposits is well recognized. Especially important is the positive evidence for low-concentration, vapor-phase transport of metallic elements from seemingly ordinary magmas. Unfortunately, for students of pure magma chemistry, these deposits are formed from a mixed magma of andesite and rhyolite (Fenner, 1923, p. 38; Williams, Curtis and Juhle, 1956, p. 129).

The controversy over the source for the fumaroles has not yet been resolved. Griggs (1918, p. 97), Fenner (1923, p. 43), Allen and Zies (1923, p. 95), and Zies (1929, p. 4) have debated this point; although they recognize that some of the smaller fumaroles may have originated in the ash flow itself, they concluded that most fumaroles had a deeper-seated source.

Examination of the interiors of dissected prehistoric ash-flow deposits indicate that during cooling of many deposits vapor-phase activity was common. Moreover, a large proportion of ash flows, in particular those that crystallized during cooling, gave off vapors at their surface for many years.

This geologic evidence supports the belief that the "sand flow" generated a large proportion of its own fumaroles with some help from surface waters converted into steam by contact with the hot ash. Indeed, Williams (1954, p. 58) says, "Fumarole cracks gradually disappear downward within the avalance deposits; hence the ore-minerals were sublimated by gases given off by the fragmental ejecta and not by a deeper body of magma." The data published by the early workers at the Valley of Ten Thousand Smokes, however, suggest that many of the fumaroles rising from the "sand flow" in the vicinity of Novarupta, Falling, Broken, and Cerberus mountains are related to, or contaminated by, a deeper source. Allen and Zies (1923, p. 105) say, "The hottest areas (in 1918) are in the central part of the main Valley opposite Knife Creek Valley, in the Novarupta Basin, in Broken Mountain Valley and at a few points at either end of Knife Creek Valley. They all fall in a nearly circular but not continuous zone, with a salient extending out from Broken Mountain into the middle Valley." All the incrustations analyzed by Zies (1929, p. 41) containing more than 0.1 per cent boron were found in this same area, and fumarolic activity persisted here locally at least as late as 1952 (Muller and others, 1954, p. 66).

Lovering (1957, p. 1587–1588) has discussed the evidence (from the earlier papers of Shipley, 1930; Allen and Zies, 1923; and Zies, 1929) bearing on the geographic control of sulfur-acid

gases and carbon dioxide and concludes that these too existed in higher concentrations in the same general area mentioned above. These facts indicate that not all of the "Ten Thousand Smokes" were from the "sand flow", and we may infer that an area of about a 3- or 4-mile radius centering on Novarupta was subject, in addition to "sand-flow" gases, to gases from a source beneath the ash flow. Contamination of ash-flow fumaroles farther down the valley by ground-water transport of the deeper-seated materials seems a distinct possibility.

On the other hand, Leverberg's (1957, p. 1587) conclusion that some source of acid gas was tapped in addition to that originally "imprisoned" in the ash flow seems based, in part, on the assumption that all the gas given off by the ash flow itself was present in void space at the time of emplacement of the ash. A more voluminous source of HF and HCl must have been the gas in solution in the glass fraction of the ash flow—conservatively, about 80 per cent of the solid material of the flow. A large proportion of the HF and HCl may have been released on crystallization of the glass. Some crystallization had taken place by 1919 (Fenner, 1937, p. 236). We may presume that crystallization was continuing in 1919. It may well be that this was the major source of the HCl and HF reported by Allen and Zies (1923, p. 143) and by Zies (1929, p. 61–66); it could have exceeded by several or many times the volume of free gas that could be entrapped in the voids at the high temperature of emplacement of the ash flow.

Most of the gas released during initial vesiculation of the magma was certainly lost before the ash flow formed, and most of the rest was lost before final emplacement or during or shortly after the initial stages of compaction and welding, *before crystallization began*. Great quantities of the juvenile gases coming from the "sand flow" itself, 5–6 years after the eruption were probably being released by crystallization of the glass and had little physical relation to the entrapped gas released by vesiculation.

The rate of crystallization in volcanic glass is not well known, but temperature, composition, volatile content, and time are important variables. Some ash-flow cooling units 250–300 feet thick show marked but not dense welding and have remained white after cooling. Others may be only 50 feet thick, yet show dense welding and have a persistent crystalline zone. Clearly the latter had a shorter cooling history than the former in spite of its higher initial temperature. The "sand flow" over most of its area seems to fit somewhere between the above examples both in thickness and in crystallinity, as well as presumably, in time for cooling. The maximum thickness of the "sand flow" is not known, but Zies (1929, p. 4) states that it is at least 100 feet thick, and this was the thickness used for volume calculation. At least mild welding and crystallization are indicated from Fenner's (1923; 1937, p. 236) allusions to indurated material, reactions with inclusions, concavity of the surface of the flow, presence of tridymite and sanidine in some of the materials, and from illustrations in Griggs's (1922) and Fenner's (1923) papers, especially those showing crude columnar structure and fallen blocks of coherent material.

In essence, the evidence forcefully implies that the time of release of gas by crystallization varies considerably in different deposits and even in the same deposit where cooling gradients differ. The "sand flow" probably underwent a period of dormancy, for release of juvenile gas, between the time of welding and compaction when most of the trapped gas was released and the time the glass began to crystallize. This time could have been 2–3 years during which fumarolic activity, if any, may have been largely supported by reheated ground water. The validity of this reasoning depends on whether or not the glass of the "sand flow" could remain oversaturated in volatiles from the time of its eruption and throughout the period ending with crystallization. In all probability it could not. However, Kozu (1934, p. 164–165) reports that, of the two types of pumice from the 1929 eruption of Komagatake, the "pumice-flow" type retained more HCl and gave it off at lower temperature (when reheated) than the air-fall type did. These specimens presumably were collected within the first year after the eruption.

The "sand flow" was formed in 1912, discovered in 1915, and the first studies of temperature and fumarolic products were during the period 1917–1919.

If the line of reasoning leading to the suggestion of a period of "dormancy" during the early years of the "sand flow" has merit, then extrapolation of amounts of volatiles given off, beyond the period of observation of the fumaroles, must be severely restricted.

Ancient Deposits

Many of us have been fascinated with the thought of finding fumarolic mineral deposits,

to those described from the "sand flow", ...ost ash-flow deposits. Traces of former ...ic activity in the tops of some sheets ...s, 1952, p. 1337–1338 and oral com-...tion; Gilbert, 1938, p. 1851–1851; Wil-...1942, p. 86–87; 1952, p. 156) and thick ...of vapor-phase crystallization in others ...It seem likely that many ancient sheets ...e "sand flow" had parallel histories. ...r, many ancient deposits show evidence ...ing had far more intense vapor-phase ...y than did the "sand flow."

...(1929, p. 18–19) has emphasized the ...al nature of the "sand-flow" sublimate ...s and has stressed the importance of ... temperature and steam dynamics. ...lly important is the absence of magne-...d other minerals when the temperature ...fumarole falls to the point when steam ...ses. The minerals are then dissolved by ...m acids and water. The persistence of ...deposits can probably be ruled out for ... cooling units on the assumption that ...would have conformed closely to the ...n set by the "sand flow."

...pound cooling units in ancient deposits ...common. This leads us to wonder what ... happen to the fumaroles and their ...ts in a sheet at the stage of cooling of ...sand flow" during the period 1917–1919 ...ther ash flow were emplaced on top of it. ...ps much would depend on the chara...ics of the second flow, which, if it were hot ...quickly welded, might effectively seal in ...maroles in the lower flow. Ultimately, ...ding factors would probably be ground ... and permeability. The suggestion is ... that these compound cooling units that ...evidence of marked breaks in their cooling ...y should be examined very carefully for ...fumaroles and traces of their former ...ts.

...y chemical analyses of rocks now known ... of ash-flow origin have been published. ...record compositions ranging from basalt ...alite and trachyte, but show no notable ...ences as a group from normal lavas of ...r compositions. The same statement ..., in so far as is known at present, to ...elements.

...ts and Goldich (1956, p. 168–169) found ...the "salmon pillar" from the Arequipa ..., Peru, contained small amounts of ...ic salts (chloride and sulfate), and halite ...determined by X ray. They attributed ...ts introduction by "ground water, which ...lly saline owing to leaching of volcanic deposits." This study suggests examination of vapor-phase zones in ancient deposits for water soluble salts, if suitable deposits could be found, located above present and past water tables.

Systematic geochemical studies of welded ash flows are needed. We are now in a position to make such studies of *limited* scope. They should be made, in the beginning, on the youngest possible fresh rocks. Probably some sheets will be essentially homogeneous chemically, and others not. We need to know the differences and their orders of magnitude.

Geochemical studies must consider the degrees of welding and types and degrees of crystallization. Major and minor elements should be determined in relation to the zonation in simple cooling units, preferably in single flows. Great care must be taken to evaluate contamination by inclusions, and in the selection of suitable samples. J. H. Mackin (oral communication, 1957) has arrived at similar ideas based on his preliminary work in southeastern Nevada.

Concluding Remarks

The problem of ash flows is in a formative stage, and a great deal of study is needed, especially to supply quantitative data. Rocks and rock bodies of ash-flow origin are now known to be so common that their recognition is no longer surprising, as it was only a decade ago. It no longer seems necessary to recapitulate the arguments or early history of development of concepts.

The importance now of recognizing these rocks, aside from pure knowledge, is because they are useful tools for the understanding of other geologic processes. Here their usefulness may be many fold, but much will depend on the accumulation of quantitative information from entire pyroclastic fields, composite sheets, or cooling units.

The important use of widespread ash-flow deposits for correlation of stratigraphic sequences, although recognized 20 years ago by Anderson and Russell (1939), is now being more fully explored and holds great promise. Many, if not all, ash-flows fields are associated with extensive air-fall beds. In and adjacent to the post-Cretaceous continental orogenic systems, we should be able to establish eventually a "tephrachronology" for the entire Cenozoic that may transcend anything envisioned today.

Detailed studies of the cooling characteristics of simple ash-flow sheets and the application

of the information to more complex sheets and to entire fields could eventually lead to concepts of eruption intervals, depositional time spans of certain rock units, and other time concepts that we do not now have.

Some of these great sheets surely represent magmas which, if intrusive, would have produced, or caused production of certain types of ore deposits. They, together with associated air-fall pyroclastic rocks, represent perhaps the closest possible approach to arrested equilibria in silicate melts that it is possible to attain in nature. In effect they may represent a quenched inverted sample of differentiating silicate magma throughout a depth of at least the upper several thousand feet in many magma chambers. To be sure most of their volatile constituents have been lost, especially those first released, but others are retained in glass, or their passage is recorded in crystallized welded tuffs. The phenocrysts remain, however, and detailed geochemical and petrologic studies of them and their relationship to their glass matrix should be made. The significance of such studies will depend on the extent to which they are guided by careful investigations of the pyroclastic fields in their entirety and should eventually encompass a variety of petrographic provinces, compositions, and fields of different volumes. Presumably the most useful data will come from those materials that represent the widest variation in composition within a single eruption cycle. All these pyroclastic deposits probably record some kind of differentiation, ranging from the extremes of a basalt-rhyolite relationship to changes in the crystal-liquid chemistry of crystallizing granite magmas.

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Zones and Zonal Variations in Welded Ash Flows

By ROBERT L. SMITH

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 354-F

A concept of zonation in ash flows based on degree of welding and type of crystallization

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PLATE 21. Diagrams showing zones of some ash-flow cooling units ..... At end of text

21. Zones of no welding, partial welding, and dense welding, and their approximate crystalline equivalents ..... Facing page 152

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

ZONES AND ZONAL VARIATIONS IN WELDED ASH FLOWS

By Robert L. Smith

ABSTRACT

Welded tuffs are recognized as special parts of ash flows, other pyroclastic flows, or, more rarely, air-fall deposits. Ash flows may be emplaced at any temperature below a maximum eruption temperature. Those emplaced above a minimum welding temperature may show any and all degrees of welding and crystallization.

Three basic zones are recognized, the *zone of no welding*, *partial welding*, and *dense welding*. In sheets where the zone of dense welding occurs, the zones of no welding and partial welding will have upper and lower counterparts.

Cooling of welded ash flows may result in sheets that range from completely glassy (except for phenocrysts and inclusions) to mostly crystalline.

Crystallization superimposed on the zonal patterns produced by welding results in another set of zones that is controlled in part by degree of welding.

Three principal types of crystallization that take place during the cooling history are recognized. These, in order of frequency of occurrence, are devitrification, vapor-phase crystallization, and granophyric crystallization. The *zone of devitrification* is common to most crystallized welded tuffs and frequently occupies most of the zones of dense welding and partial welding. The *zone of vapor-phase crystallization*, where present, occupies the porous parts of the welded tuff sheets and reaches its maximum development in the upper zone of partial welding where it overlaps the zone of devitrification. The *zone of granophyric crystallization* is probably confined to cooling units several hundreds of feet thick where it will divide the devitrified zone into upper and lower parts. Fumarolic alteration may be found in the upper zone of no welding.

Single ash flows may cool with the formation of a basic pattern of zones. This pattern is illustrated and described both for those sheets which remain glassy and for those in which crystallization has occurred. These flows are called *simple cooling units*.

Successive ash flows, emplaced quickly enough to bridge the cooling gap between flows, will form a stack of flows that may also cool to form the zonal pattern of a simple cooling unit. The gaps or hiatuses, here called partings, may contain or consist of lump pumice layers, flow surfaces reworked by wind or water, airfall pyroclastic material, other deposits, or minor erosional unconformities.

Compound cooling units consist of multiple flow units with or without visible partings and which show zonal patterns that depart from the patterns of the simple cooling units. Horizontal separation of compound cooling units into separate cooling units suggests the existence of a hypothetical unit, the *composite sheet*, which could have time-stratigraphic significance.

Buried topography can have a profound influence on the zonation of certain ash-flow cooling units. Very hot ones, because of their high compactability potential, will show less zonal change than colder ones, although they will show greater surface expression of the buried topography. Abrupt changes in relief, especially if the buried topographic high rises to the top of the zone of dense welding, can cause horizontal changes, in a short distance, that may be difficult to interpret.

INTRODUCTION

In this report, welded tuffs are considered to be special parts of ash flows, other pyroclastic flows, or more rarely, air-fall deposits (not to be confused with fused tuffs, p. 155). Most students of welded tuffs have recognized vertical variations of texture, specific gravity, color, mineralogy, and other properties within the deposits. Horizontal variations are rarely emphasized because complete ash-flow sheets have not been mapped, particularly in detail. Mapping of complete sheets has not been done because of the generally large areal extent of the sheets, they may be of only casual interest to the mapping problem, or because erosion, and cover by younger rocks, limits their area of exposure.

The uniform and unsorted character of ash-flow deposits has been cited as a criterion for their recognition. Although this is generally true, the complex emplacement and cooling history of many such deposits may produce various textural and mineralogical facies that bear little or no resemblance to the original materials of the ash flows. These variations are zonal and normally show a consistant pattern of transitions both vertically and horizontally in uniform ash flows which have had an unimpeded cooling history. Once this zonal pattern is clearly understood for simple cooling units, progress can be made in interpreting aberrant patterns in more complex deposits.

The purpose of this report is to describe the zones and the simple zonal patterns by means of 4 simplified diagrams (pl. 20 *A–D*) and a brief text. The diagrams are not intended to represent specific welded ash flows but are simply hypothetical models. They were constructed to illustrate, in part, the writer's concept of simple ash-flow cooling units. The scales used give an order-of-magnitude relation among the different zones that is probably realistic for some natural sheets. The most difficult characteristics to generalize are the horizontal changes, because a cooling unit may range from less than a mile to many tens of miles in length, or from less than a square mile to hundreds and perhaps thousands of square miles in area. The true nature of the distal ends is generally problematical. They are rarely preserved or recognized in prehistoric sheets and there appears to be a wide variation in historic "nuée ardente" deposits, from "snub noses" to thin tapered ends often measurable in inches.

The diagrams were constructed based on the assumption that some cooling took place in the direction of thinning. Although this is probably a common condition it is by no means necessarily true for all flows. Some widespread ash-flow cooling units show only slight effect of cooling or thinning over tens of miles whereas others show marked effects in only a few miles. The direction of thinning may be related to the surface underlying the flow or it may reflect a change away from the source area. These facts, among others, indicate the need for a critical examination of accepted concepts on the mechanics of eruption and emplacement of ash flows.

The use of welded tuffs for correlation purposes presents many pitfalls to the geologist, but with careful work a high degree of success should be achieved. The potential importance of these rocks as stratigraphic marker beds cannot be overemphasized, considering their possible long-distance continuity in terrane where lensing and facies changes, in sedimentary and other volcanic deposits, are common.

The presentation of hypothetical diagrams without documentation leaves much to be desired. Also much of this report may seem academic concerning very young and undeformed welded ash flows. However, this study should have practical merit where applied to mapping and interpreting problems in highly deformed areas. It should also be useful in regions where ash-flow sheets from different sources overlap, and in the vicinity of some ore deposits where the geologist must locate relative spatial position within a rock body. In the vicinity of most ore deposits, alteration of different types will further complicate matters, but this difficulty may be overcome if the geologist has a clear understanding of the normal characteristics of the unaltered rocks. The zonal patterns will be extremely important for detailed geochemical studies.

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The writer is indebted to Clarence S. Ross with whom he has studied welded tuffs for many years and with whom he has written a more comprehensive report (Ross and Smith, 1960). Much of the material in the present report is an outgrowth of this earlier study, although the writer is solely responsible for the organization of the data and theory as presented here. The writer is especially indebted to Roy A. Bailey, also a close working companion of many years, who has been a most helpful critic. Of the many other Geological Survey colleagues who have aided the writer's studies special thanks are due C. A. Anderson and Harry W. Smedes for their constructive criticisms.

ERUPTION AND EMPLACEMENT

Much could be written about the eruption of pyroclastic materials that are emplaced as hot sheetlike bodies and whose slow cooling may result in deposits that show striking physical and chemical differences from the initially erupted material. However, the main purpose of this report is to discuss the more obvious characteristics of the deposits after they have cooled. It is well recognized that these deposits were, for the most part, emplaced as hot avalanchelike masses or particulate flows, many if not all of which contained hot gas and many of which were autoexplosive. The evidence for flowage as the principal mechanism for emplacement of these deposits has been cited by many authors; the most fundamental papers are those by Fenner (1923), Marshall (1935), and Gilbert (1938). In the present report, the basic unit of most of these deposits is referred to as an ash flow.

Ash flows can probably be emplaced at any temperature below a maximum eruption temperature. However, there will be a temperature of emplacement below which no visible physical or chemical changes will take place during cooling. This temperature may be referred to as the minimum welding temperature and will vary from place to place with changes in the variables that control the lower limit of the softening range of the glass.

Nonwelded ash flows are important, but those emplaced at temperatures above their minimum welding temperatures are of greater interest.

A single ash flow may be the only unit of cooling, or two or more ash flows, with or without intercalated air-fall beds or other partings, may combine to form

the cooling unit. A deposit that can be shown to be a *cooling unit* in one place, may by division horizontally, become two or more cooling units, separated by chill zones, air-fall pyroclastic rocks, sedimentary deposits, erosional unconformities, or lava flows. The writer will refer to this complex rock body as the *composite sheet*. The complexities inherent in such a scheme are infinite and the geologic implications will be obvious.

WELDING

The welding process must begin immediately after emplacement if the ash flow or any part of it, comes to rest above its minimum welding temperature. Welding continues until it is complete or until the process is stopped by cooling or crystallization of the glass.

In the present report welding is briefly defined as that process which promotes the union or cohesion of glassy fragments. The degree of welding may range from incipient stages marked by the sticking together or cohesion of glassy fragments at their points of contact and within the softening range of the glass to complete welding marked by the cohesion of the surfaces of glassy fragments accompanied by their deformation and the elimination of pore space, and perhaps ultimate homogenization of the glass.

Incipient welding may be recognized in some very young and fresh glassy tuffs by brittle rather than crumbly fracture, although the rock is very porous. However, this criterion is not entirely dependable because other types of induration may cause the rock to break in a similar manner.

Where the distinction between nonwelded and incipiently welded tuff is necessary, the boundary should be placed at, or close to, that point where deformation of glassy fragments becomes visible. Deformation of pumiceous fragments and shards is the only positive criterion of welding in the tuffs which have crystallized, particularly in older rocks.

Incipient welding presumably takes place in most welded tuffs before the deformation of glass fragments becomes visible, because the deformation accompanying welding is related primarily to lithostatic load pressure, especially at the lower temperatures. In practice the transition between visible deformation and obviously nonwelded tuff can be located in most tuffs within a few feet or at most a few tens of feet.

Even the sillars (Fenner, 1948, p. 883), those columnar-jointed, largely crystalline, but very porous tuffs, which are believed to be indurated by crystallization rather than by welding (Fenner, 1948, p. 883; Jenks and Goldich, 1956, p. 157), were probably incipiently welded before they crystallized. Specimens of salmon and white sillars kindly given to C. S. Ross and the writer by Fenner, are interpreted by the writer to be incipiently welded. Some of the specimens of salmon sillar show practically no crystallization but are firmly coherent. They show slight deformation of shards in thin sections and incipient compaction foliation in hand specimens. The white sillar, on the other hand, is completely crystalline and could represent salmon sillar that has crystallized in the vapor-phase zone of a cooling unit.

The sillar-type tuffs were probably emplaced at temperatures as high as that of many densely welded tuffs but the load pressure within the deposits was insufficient to cause obvious visible deformation of the glass before crystallization (white sillar) or cooling below the minimum welding temperature (salmon sillar) began. If these tuffs could be traced horizontally into thicker cooling units, the degree of welding would increase greatly.

The transition from incipient to complete welding is one of progressive loss of pore space accompanied by an increase in deformation of the shards and pumiceous fragments (pl. 21A–F). The progressive flattening of shards and pumice produces the streaky foliate structure long known as eutaxitic structure, which can be seen in outcrop, hand specimen, and under the microscope.

In most welded tuffs complete welding is probably achieved by simple load deformation, without stretching of particles, other than that necessary for local accommodation to available space. Crinkling or crenulation around crystal or rock fragments is common, and in many pumice-rich or inclusion-rich tuffs wavy eutaxitic foliation is normal.

Flattened pumiceous fragments, depending on their primary shape, are normally disclike in the plane of flattening. However, in some tuffs, usually in the lower part of the cooling unit, the fragments are elongate rather than disclike and show a preferred orientation. In most such examples probably some mass flowage has taken place in the sheet during welding. In welded tuffs of this kind observed by the writer, the stretching could have been accomplished by mass movement of from less than a few inches to a maximum of a few feet. Such mass flowage might be related to buried topography, earth movements during welding, or other factors, and more rarely, might be of greater magnitude.

CRYSTALLIZATION

Crystallization of the glass takes place in many ash flows subsequent to, or perhaps in part synchronous

with, the welding process. Physically and (or) chemically different environments within the cooling unit may give rise to different types of crystallization. These may, depending on the degree of their development, be recognized as distinct, although overlapping, entities, and together with the degree of welding, can be potential guides to relative position within a deposit.

Three principal categories of crystallization which may take place during cooling are recognized by the writer. In order of frequency of occurrence, these are devitrification, vapor-phase crystallization, and granophyric crystallization. Throughout the report the term "cooling-history crystallization" refers to these three types, and to fumarolic alteration unless otherwise specified. The principal categories of cooling-history crystallization may be defined as follows:

Devitrification.—Crystallization of glass to form spherulitic and axiolitic intergrowths and aggregates, chiefly of cristobalite and feldspar. This crystallization is confined within glass fragments or massive glass. It is common to all crystallized silicic welded tuffs.

Vapor-phase crystallization.—The growth of crystals, from a vapor phase, in pore spaces. Vapor-phase crystallization is, in general, a coarser grained crystallization than devitrification, and is commonly manifest in the porous upper parts of welded ash flows where it is contemporary with, or follows, devitrification. In rhyolitic ash flows the predominant vapor-phase minerals are alkalic feldspar, tridymite, and cristobalite.

Granophyric crystallization.—In silicic welded tuffs granophyric crystallization is characterized by groundmass quartz intergrown with, or as blebs associated with, alkalic feldspar and minor accessory minerals. The aggregate shows granophyric or micrographic textures similar to those shown by many slowly cooled rhyolitic flows, domes, and shallow intrusive rocks.

Granophyric crystallization (quartz) has never been seen by the writer in fresh unaltered welded tuffs that were less than about 600 feet thick. However, many older deposits and ultimately all deposits will probably contain quartz as the groundmass silica mineral, through conversion of cristobalite and tridymite.

A fourth category of cooling-history crystallization or, probably more precisely, alteration, should be rec-

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EXPLANATION OF PLATE 21

ZONES OF NO WELDING, PARTIAL WELDING, AND DENSE WELDING, AND THEIR APPROXIMATE CRYSTALLINE EQUIVALENTS

Specimens *A–F* show transition from zone of no welding to zone of dense welding. Specimens *G–L* show approximate crystalline equivalents in zones of partial welding and dense welding. *A–E*, from Battleship Rock, Jemez Springs quadrangle; *G–L*, from the Bandelier rhyolite tuff (Smith, 1938), Jemez Mountains, N. Mex.

A. Zone of no welding. Pumice blocks and lapilli in an unconsolidated ashy matrix. Some accidental rock fragments.

B. Zone of partial welding (upper part of upper zone). Shows incipient compaction foliation. Fracture takes place through, rather than around pumice fragments. Matrix ash more gray than in *A*.

C. Zone of partial welding (upper zone). Compaction foliation well developed, pumice fragments darker with less pore space and more vitreous luster than in *B*. By contrast, the ashy matrix still has a dull luster and hackly fracture.

D. Zone of partial welding (lower part of upper zone). Collapsed pumice lenticles and matrix ash have vitreous luster and conchoidal fracture although pore space is still about 20 percent.

E. Zone of partial welding (near transition to zone of dense welding). Collapsed pumice lenticles obsidianlike without pores although traces of former vesicles can still be seen in thin section.

F. Zone of dense welding. Dense black obsidianlike glass of virtually zero porosity. Collapsed pumice fragments only faintly visible in hand specimen. Their boundaries are visible in thin section but former vesicular structures have been partly to completely homogenized by welding. From km 153, Taxco Highway, Central Mexico. Collected by Carl Fries, Jr.

G. Vapor-phase zone (upper part of upper zone of partial welding). Slight compaction foliation, completely devitrified. Pumice fragments crystallized into drusy growths of tridymite and alkalic feldspar and some cristobalite. The pumice-tube structure is well preserved. Approximate crystalline equivalent to *H*. Very similar, except for fragment size, to white sillar described by Fenner.

H. Vapor-phase zone (upper zone of partial welding). Compaction foliation well developed. Pumice-tube structure not as well preserved in this plane, but very obvious in the plane of flattening. Approximate crystalline equivalent to *C*.

I. Devitrified zone (zone of dense welding). Some collapsed pumice fragments visible. In thin section this specimen shows coarse axiolitic devitrification.

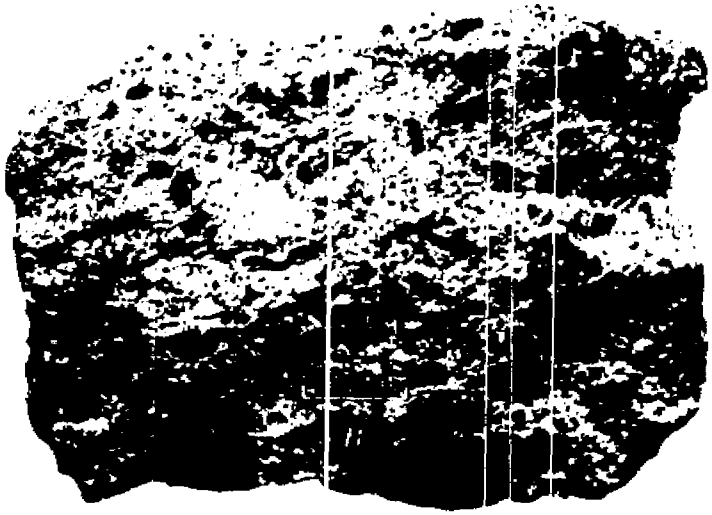
J. Devitrified zone near base (zone of dense welding). Fine-grained devitrification of a dense black glass. Only faint traces of original pyroclastic character preserved in hand specimen. Perfect preservation of shards and flattened pumice fragments in thin section. Crystalline equivalent to *F*. Matahina ash flow, Rangitaiki Gorge, North Island, New Zealand. Collected by R. A. Bailey.

K. Specimen showing the effect of gas trapped during welding. The rock belongs in the zone of dense welding but the collapsed pumice fragments are miarolitic and coarsely crystalline. From the lower part of Enlows' (1955) member 6, Rhyolite Canyon formation, Bonita Canyon, Chiricahua National Monument, Ariz.

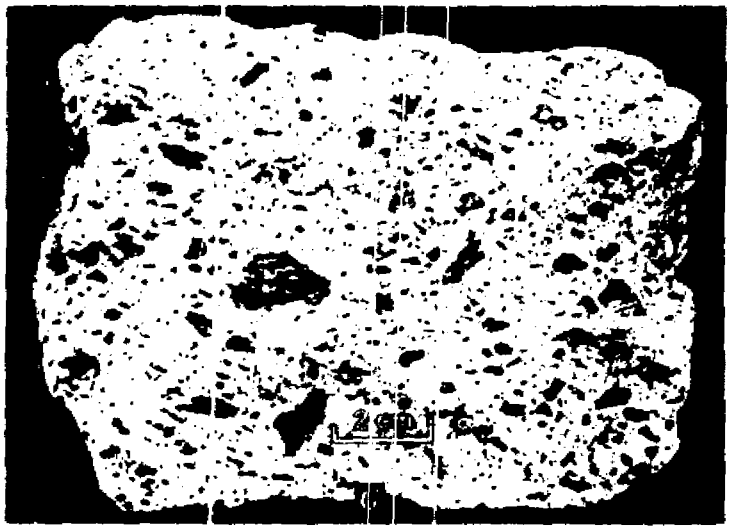
L. Lithophysal cavities in the devitrified zone of dense welding. This rock is composed of fine-grained pyroclastic materials which probably caused lithophysae to form instead of miarolitic cavities in pumice fragments. From the Ammon quadrangle, Idaho.

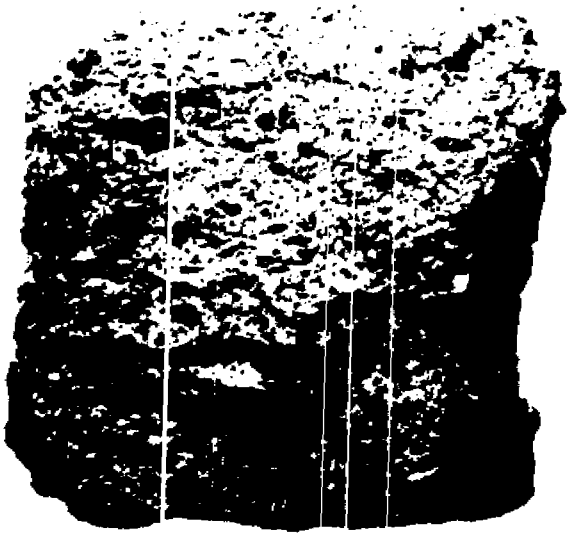
PLATE 21

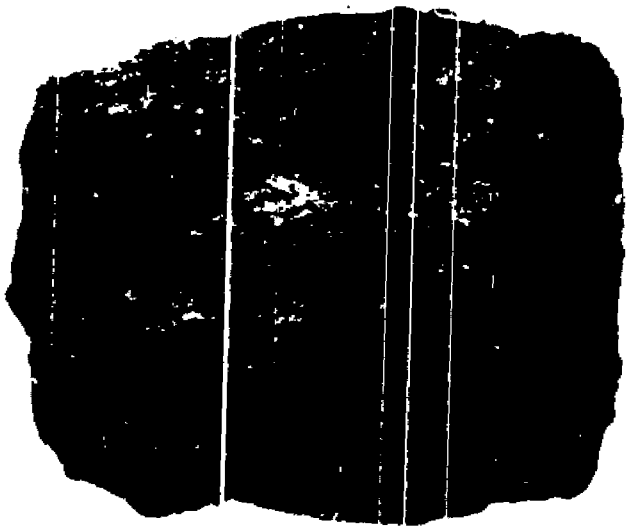
2 cm
D



2 cm
E







ognizable in many deposits. This little-studied and generally unrecognized (in older deposits) process is fumarolic alteration. Some geologists may argue that this process is not basically different from vapor-phase crystallization, but the products are notably different and, generally belong to lower temperature and pressure environments.

Devitrification of the glass after initial cooling, and other forms of low-grade alteration need much discussion, but these should be considered in well-documented papers. Correct interpretation of cooling-history processes is obstructed by post-cooling history, hydration, devitrification or other alteration of glass, oxidation of iron, and conversion of tridymite and cristobalite to opal, chalcedony, or quartz, and related processes. Some of these processes take place during as well as after cooling, and the knowledge necessary to always distinguish between the two has not yet been acquired. In Pleistocene and Recent rocks the problems are minor or nonexistent, but in some Pliocene and in most Miocene and older formations many physical and chemical properties of the rocks seem to have been affected by processes that occurred after cooling. Depth of burial and ground-water conditions are extremely important factors. Many geologists consider these altered rocks to be fresh and unaltered.

These alteration effects are often of regional extent and can best be interpreted as low-grade metamorphic reactions.

THE ZONES

All ash flows in which welding or crystallization have taken place show zonal variations in texture, color, or other features. These variations are dependent upon such factors as temperature, thickness of the deposit, composition of the ash, amount and composition of volatile constituents, and the ratio of pumice fragments to shards.

Any system that includes several variables where one variable can change the entire appearance of a rock body, or any part of it, is a very flexible system, and must be treated as such. The chance that two or more welded ash flows will show no differences as a whole is extremely slight. On the other hand, the close similarities that commonly exist between some welded ash flows may be confusing and it may be impossible to distinguish between their equivalent zonal facies. Differentiation may then be dependent upon detailed petrographic studies of phenocrystic minerals coupled with careful field study.

The zones shown in plate 20 are those which can be easily recognized or inferred in the field. Recognition of minor zones depends on the microscopic study; they are briefly mentioned in the following discussions of the individual major zones. All zone boundaries are transitional, some more abruptly than others. In general the boundaries of the basal zones are more sharply defined than those of the upper zones.

The ordered sequence of overlapping zones is best visualized by examining first the zones formed during the welding process without crystallization upon cooling. If welding proceeds to completion in any part of an ash flow, three distinct zones will be formed. These are the *zone of no welding*, the *zone of partial welding*, and the *zone of dense welding* (pl. 20 *A,B*). The *upper* zones of no welding and partial welding will be separated from the *lower* zones of no welding and partial welding by the zone of dense welding. Where sufficient lateral thinning of the ash flow occurs, such as the normal distal ends and margins, points will be reached where the upper and lower zones of partial welding will merge and grade into the nonwelded mantle of the deposit.

This simple pattern of zones is illustrated in plate 20*A* and *B*. Plate 20*B* shows the zonal relations in an extremely hot and moderately thin ash flow whereas plate 20*A* shows the zonal relations in a thicker ash flow emplaced at much lower temperature. Plate 20*B* also shows an additional zone which represents an early stage of crystallization. This additional zone in no way affects the comparison of the other zones illustrated in plate 20*A* and *B*. An ash flow emplaced at a temperature too low for welding is not shown, but is represented by the nonwelded mantle (pl. 20*A*). All transitions between this low-temperature extreme and the hot, densely welded type shown in plate 20*B* can occur. However, as temperature and thickness are increased together, a point will be reached where crystallization begins; thus the type of tuff illustrated in plate 20*B* can never reach great thickness and remain glassy throughout during cooling.

The glass of densely welded tuff that is of the order of thickness shown in plate 20*A* and *B* will probably be charged with spherulites or lithophysae or both, although these may vary in number and character with the initial gas content.

Crystallization usually follows, but may in part, accompany the welding process. This crystallization may occur in a narrow zone confined to the deep interior of the cooling unit or as a broad zone which may overlap, horizontally at least, all other zones formed during welding. All transitions between the two extremes may occur.

The character of crystallization is strongly influenced by the degree of welding of that part of the tuff upon which it is superimposed, the rate of cooling of the ash flow, and the amount and composition of vola-

tile materials that it contains. Differences in character of crystallization, then, add another set of zones controlled in part by the zones already formed during welding, and in part by other factors.

ZONE OF NO WELDING

The *zone of no welding* is that part of an ash flow in which no welding has taken place (pl. 21*A*). This zone may comprise the entire ash flow or only a small part. Most single ash-flow cooling units have a nonwelded top and bottom (pl. 20*A*), although in some of the very hot flows the nonwelded bottom may not be present under the entire sheet (pl. 20*B* and *C*). In these very hot ash flows densely or partly welded tuff may extend to the base of the unit, especially near the source area.

The nonwelded zone will probably contain some incipiently welded tuff, especially in the crystalline units, because as mentioned on page 151, the only practical way to locate the zone boundary is by megascopic detection of deformation or compaction foliation. Incipient welding occurs at some point before this.

The nonwelded zone is commonly the least spectacular part of a welded ash flow, but is probably the most important zone because it is the only one that shows the original character of the erupted materials. Its preservation is necessary to such measurements as initial density and porosity, size analyses, and to the nature of the primary glass. For the most accurate characterization of the magma, chemical analyses should be made of pumice from this zone (pl. 21*A*), providing that the rocks are fresh and the pumice is not foreign material. Most middle to early Tertiary and apparently all known pre-Cretaceous ash-flow tuffs show some alteration in this zone beyond simple hydration of the glass and are not too helpful in understanding the chemistry of the primary magma.

ZONE OF PARTIAL WELDING

The *zone of partial welding* includes all material ranging from that which shows incipient welding to that which has lost virtually all its pore space (pl. 21*B*–*E*). This zone shows a greater diversity of textures than any of the other zones because of the wide range in porosity and degree of deformation of its glassy parts. The boundary between the zones of partial and dense welding is discussed below.

Further subdivision of the zone might have practical application in some welded ash flows. For example, a measure of the degree of collapse of pumice fragments can be an important factor in determining the relative vertical position of material in the sheet.

In some cooling units the upper zone of partial welding may extend horizontally for many miles without much apparent change in thickness as long as it is underlain by a zone of dense welding.

The zone of partial welding is best developed in colder ash flows (pl. 20*A*) and is poorly developed in very hot ash flows (pl. 20*B*). The thickness of this zone is therefore, in a general way, an index of the emplacement temperature of the ash flows.

ZONE OF DENSE WELDING

Ideally the *zone of dense welding* should be defined as that zone in which complete coalescence of the glassy fragments has resulted in the elimination of all pore space. A dense black glass or vitrophyre is the normal product of this process (pl. 21*F*). Actually it will be a rare welded tuff that is completely pore free, exclusive of the *vitrophyre zone* in some sheets, because of processes other than welding that help determine the final character of the rock. Entrapped or exsolved gas, for example, causing the formation of lithophysal (pl. 21*L*) or other types of cavities, may inhibit complete loss of pore space in this zone during welding. However, in the groundmass surrounding these porous areas, complete welding of the shards will show that the rock is in the zone of dense welding. The boundary between the zone of dense welding and the upper zone of partial welding marks a plane below which the rock is pore free, or potentially pore free were it not for entrapped gas, and above which the rock would be porous, with or without gas entrapment. Crystallization of a pore-free glass may result in a slightly porous rock. All these factors must be considered in distinguishing the zone of dense welding from the zone of partial welding.

If the welded tuff remains glassy upon cooling, all the zones and zonal transitions are generally well defined and simple, although in the simple cooling units the transitions above the zone of dense welding are less sharply defined than those below. However, when crystallization takes place, the upper transitions may become obscure, and the exact location of the zone boundaries in some sheets will be largely subjective, particularly in crystal-rich quartz latites and rhyodacites.

The transition from partial to dense welding in glassy welded tuffs is best shown by changes in the pumice fragments present in most ash flows. In fresh rocks and those that have had a simple cooling history, the pumiceous fragments and blocks change by decreasing porosity and a general darkening of color until they become black and obsidianlike (pl. 21*A*–*F*).

The darkening of the pumiceous fragments precedes the darkening of the shardy matrix. For field purposes the end stage of the welding process is a dense black glass in which the pumiceous fragments and the matrix are megascopically indistinguishable.

Complete welding is not achieved until the pumiceous fragments, shards, and glass dust are homogenized; all grain boundaries disappear and, exclusive of crystals and inclusions, a completely homogenous glass is formed. This *zone of homogenization* can only be proven by microscopic study in conjunction with field study, and will be found only rarely, probably for the following reasons: (a) In ash flows initially thin enough or cold enough to remain uncrystallized after cooling, temperatures and pressures high enough to cause homogenization of the glass particles are rare; (b) in thick cooling units where a zone of complete homogenization might occur, this zone will likely crystallize on cooling and may be indistinguishable from nonhomogenized welded tuff whose vitroclastic structure has been obliterated by crystallization. Partial homogenization of tube structures in pumice fragments is common in some glassy welded tuffs but complete homogenization is rare. Tube structures refer to tubular vesicles which are more common than spherical vesicles in pumice from tuffs of silicic composition. These tubes are sometimes so fine that they present a fibrous appearance and cause the pumice to have a silky luster. The writer has never seen complete obliteration of shard boundaries in glassy rocks but it will no doubt be found, and it is for this reason that the point of homogenization is emphasized.

The vitrophyre zone generally shows a transition downward through a partly welded zone to a nonwelded base which may range from almost zero to many feet in thickness. However, some flows were emplaced at such high temperature that the vitrophyre zone extends to the base of the cooling unit and, in some vertical sections, may extend below the base of the unit as a fused zone in underlying glassy pyroclastic deposits (pl. 20*D*). This fused selvage will probably never be more than a few feet thick. If the underlying material is bedded ash, the bedding may still be preserved in the vitrophyre. An excellent example of this basal fusion has been described by Boyd.[1]

The vitrophyre zone (pl. 20*C* and *D*) is often the most useful part of a cooling unit for mapping purposes, especially in complexly faulted rocks, as it provides a useful marker unit.

[1] Boyd, F. R., 1957, Geology of the Yellowstone rhyolite plateau: Ph. D. thesis, Harvard Univ., 134 p.

ZONES OF CRYSTALLIZATION

A large proportion of welded ash flows have crystallized to some degree upon cooling. Crystallization may be incipient or intensely pervasive. Incipient crystallization may be marked by growths of minute spherulites in the zone of dense welding, or by the presence of vapor-phase or fumarolic minerals in scattered fine-grained growths in the upper porous zones. Crystallization may also be so extensive throughout the cooling unit that only a very thin chilled base, top, and distal end of the unit will remain glassy after cooling. Crystallization in most welded ash flows will fall somewhere between the two extremes (pl. 20*C*).

Devitrification is the most common crystallization process and in most cooling units the products of devitrification will be present throughout the entire crystalline zone. However, in some porous rocks these products will be subordinate to those of vapor-phase crystallization because of intense vapor-phase activity.

In rhyolitic tuffs, devitrification consists of the simultaneous crystallization of cristobalite and alkalic feldspar to form submicroscopic spherulitic and axiolitic intergrowths of these minerals plus minor accessory minerals. This devitrification process is confined within shards or glass masses, whereas crystallization by growth of crystals into pore spaces is a different process related to the movement of vapors and transfer of material. Without pore space, vapor-phase crystallization cannot take place. Thus in densely welded tuff that has not entrapped large quantities of gas, devitrification is the dominant and commonly the only process of crystallization. For this reason the writer refers to the crystallized part of the zone of dense welding as the *devitrified zone* (pl. 21*I* and *J*). The crystalline porous zone is referred to as the *vapor-phase zone* (pl. 21*G* and *H*), if it contains crystal growths in the pore spaces, or if it is probable that it had crystal growths in the pore spaces.

The ideal boundary between that part of the zone of devitrification that contains the vapor-phase zone, and that part in which the vapor phase does not occur is the boundary between the zone of dense welding and the upper zone of partial welding (pl. 20*C*). The abrupt appearance of the lower boundary of the vapor-phase zone will depend on the sharpness of transition between the glassy zones before crystallization. In some tuffs this transition may take place within a few feet, whereas in others it may be so broad that it may be difficult to detect at all.

Some of the features that may mark this transition are: (a) The upward appearance of vapor-phase minerals; (b) a visible upward increase in porosity; (c)

a downward change in color or shading of color from light to dark; (d) a downward change from coarse to fine joint spacing; and (e) the zone of dense welding is usually a better cliff former in crystalline tuffs.

Curves derived from density or porosity measurements of vertical sections of simple cooling units may sometimes show that a porosity gradient exists in the zone of dense welding. Ideally the porosity of a vertical section of a cooling unit should show no change in the zone of dense welding. However, the ideal is not usually achieved except in the vitrophyre zone or in the basal part of some devitrified zones. Thus in some cooling units, there is a slight, perhaps irregular, but steady increase in porosity upward from a point near the base of the devitrified zone to the top of the zone of dense welding. Above this point the porosity increases more rapidly and the transition is marked on porosity curves by a change in slope of the curve. The writer suggests that where this porosity gradient does exist in the zone of dense welding, it reflects a lithostatic pressure gradient, but exists owing to the direct or indirect effects of entrapped gas that acted as a deterrent to uniform completion of the welding process.

Thick hot gas-rich ash flows may weld so fast that gas is entrapped throughout all but a relatively thin basal zone. Pumice fragments commonly serve as loci for the entrapped gas, and crystallization of these gives rise to streaky eutaxitic folia, some of which are cavernous and more coarsely crystalline than the densely welded groundmass shards surrounding them (pl. 21*K*). Unless these tuffs are very young and fresh, it may be difficult or impossible to differentiate between the vapor-phase crystallization around the entrapped-gas cavities and the true continuous vapor-phase zone above the zone of dense welding. Thus in some ash-flow cooling units recognition of the vapor-phase zone may be of questionable importance. However, in others differentiation of the vapor-phaze zone, from vapor-phase crystallization in lenticular or lithophysal cavities in the zone of dense welding, may be highly important for the following reasons: (a) Stratigraphic significance: (b) petrologic and mineralogic interest; (c) because this zone is one of active rising vapors and it is here that changes may take place in chemical composition due to vapor-phase transfer of materials. Preliminary investigations indicate that appreciable chemical differences (in both major and minor elements) may be found between this and other zones.

Mafic phenocrysts, especially biotite, hornblende, and orthopyroxene, are commonly in part or wholly destroyed by the crystallization processes. Their former presence may be confirmed by the distribution of opaque oxides, relicts, and their existence in the vitric zones. In extreme examples a new generation of mafic minerals may be formed (biotite, amphibole, fayalite, and others).

In fresh rhyolitic rocks the appearance of tridymite with drusy feldspar usually indicates the presence of a vapor-phase zone (pl. 21*G* and *H*). Commonly these crystal druses are localized in pumice fragments and show varying degrees of lenticularity depending on the amount of flattening of the pumice fragment during welding. The former pumice-tube structures are often preserved in these crystal aggregates and can be seen in the field by the unaided eye. In older or less fresh rocks (middle Tertiary and older) these vapor-phase crystals have commonly been replaced by opal, chalcedony, quartz or other minerals and their original structure may no longer be recognizable.

The writer believes that most of the groundmass quartz that is seen in some welded tuffs is probably secondary, having formed through the conversion of cristobalite or tridymite by diagenetic or low-grade metamorphic processes. However, sometimes quartz is seen deep in the interior of the devitrified zone of very thick ash-flow cooling units, where it is probably primary in the sense that it formed during the cooling history of the cooling unit. The textures formed are similar to those seen in granophyric rocks. Conditions might exist within very hot thick ash flows where quartz would form in preference to cristobalite as the groundmass silica mineral, or early formed cristobalite might be converted to quartz during later stages of cooling. This would give rise to a *zone of granophyric crystallization* separating the devitrified zone into upper and lower parts.

Poor preservation or complete obliteration of vitroclastic textures might be expected in very thick cooling units. Several variables are involved hence the minimum thickness of tuff necessary for the formation of this zone is problematical. The writer has never seen what he would interpret to be primary groundmass quartz in any welded tuff unit less than about 600 feet thick.

Speculation on the probable nature of a very hot gas-rich cooling unit that is 2,000 feet or more thick seems warranted. No doubt thicknesses of this magnitude will be found. Welding would be almost instantaneous throughout most of the sheet and much gas would be entrapped. Slow cooling could be expected and a long stage of deuteric activity would produce a granophyric groundmass in which former pyroclastic textures could be completely destroyed.

Without excellent exposures to reveal the contact relations, such a rock body could easily be interpreted

as an intrusive mass. Even the contacts might be expected to show injection phenomena. Some ash flows are hot enough to cause fusion of underlying glassy ash or to weld almost completely against low porosity rocks that are relatively fast heat conductors. Such welded material under high load could inject cracks and crevices. Crystallization might also extend to the base of such a rock body. The zone of granophyric crystallization might then occupy a large proportion of the cooling unit.

Any ash flow that contains hot gas or is emplaced at a temperature high enough to crystallize on cooling should give off gas at its surface. The amount, composition, and temperature of this gas, along with other factors, will determine the degree of alteration of the surface and upper parts of the deposit including joint cracks. By this reasoning, and by analogy with historic ash-flow deposits such as the Valley of Ten Thousand Smokes (Zies, 1929, p. 1–79) and the Komagatake deposits (Kozu, 1934, p. 164–174), many ash flows should show a *zone of fumarolic alteration* transitional with the vapor-phase zone and with, perhaps, more intense alteration localized by deep joints. Surface sublimates and some near-surface alteration products are probably rapidly reworked by water entering the deposits. Some are no doubt removed entirely, but others are probably lodged in the soft tops of the cooling units.

Where these ash-flow tops are preserved in rocks of silicic composition, pale but decidedly variegated color patterns may indicate the presence of former fumarolic activity. These color patterns are in contrast to the uniform chalky white, gray, pink, lavendar, red, brown, or purplish groundmass colors of the vapor-phase zone. Mild fumarolic alteration has been recognized in prehistoric deposits by Gilbert (1938, p. 1851–1854), Williams (1942, p. 86–87), and Mackin (1952, p. 1337–1338).

COOLING UNIT

Unimpeded cooling of ash flows emplaced above the minimum welding temperature results in a deposit that shows a pattern of zones resembling closely (a) plate 20*A*, *B*, or *C*; (b) some intermediate stage between the diagrams; or (c) a vertical segment of these diagrams or intermediate stages. Such deposits may be called *simple cooling units*. Multiple flow units may also form a simple cooling unit provided they are emplaced in such rapid succession that there is no hiatus in cooling which cannot be bridged by successive flows (pl. 20*D*).

In a given vertical section of a simple cooling unit it may be impossible to distinguish between flow units, and the recognition of partings between them may only be possible because of horizontal changes in the sheet. Partings that exist in the nonwelded and partly welded zones will probably be easily seen. However, those occurring in the densely welded zone, especially after crystallization, may be invisible for many miles, depending on the characteristics of the partings.

Partings between successive ash flows within a single cooling unit may be marked by the following: (a) Concentrations of lump pumice; (b) fine- to coarse-bedded air-fall ash, lapilli, or blocks; (c) bedded ash from a reworking of the surface of the ash flow by wind or water; and (d) minor erosional unconformities. In the absence of these criteria, the ash flows may in places be distinguished on the basis of abrupt changes in their physical or chemical makeup. Such properties as grain size, phenocryst ratios, chemical or mineralogical composition, color and inclusions should be considered. In some densely welded tuffs where partings between ash flows are obscure, preferential weathering or slight irregularities in density or porosity may suggest their presence. Any, all, or none of these highly variable factors may be significant in a simple cooling unit.

Pronounced deviations in the pattern of zones as outlined for simple cooling units seem to indicate breaks in the cooling history of given cooling units and suggest compound cooling. These *compound cooling units* can show infinite variation between simple cooling units and separate cooling units. In other words, a simple cooling unit may, by horizontal gradation, become a compound cooling unit which, in turn, may grade into two or more simple or compound cooling units.

A few of the more obvious features that suggest compound cooling are: (a) Reversal of relative thickness of upper and lower zone of partial welding; (b) extensive development of vapor-phase zone below a devitrified zone of dense welding with a transitional contact between the two zones; (c) basal nonwelded zone which is many times thicker than overlying zones; (d) visible reversals in density or porosity within the zones of welding exclusive of those related to differing mineral facies; (e) extensive development of columnar joints below a zone of dense welding.

Some of the factors contributing to compound cooling are: (a) Unequal areal distribution of individual ash flows; (b) degree of development of some of the phenomena which cause the partings listed above; (c) successive emplacement of ash flows of radically different temperatures; and (d) periodicity of eruptions.

The cooling unit, either simple or compound, is probably the logical map unit in most unmetamorphosed

rocks. It is a closely limited time unit as well as a genetic rock unit. Distinguishing between individual flow units is generally not practical and is impossible in many situations. In many areas, mapping of at least the more spectacular zones of the cooling unit is practical, and in detailed studies, recognition and mapping of the zones as integral parts of a unit may help solve many problems of structure and stratigraphy.

COMPOSITE SHEET

A hypothetical unit, the *composite sheet*, is discussed because its existence seems inevitable now that many of the diverse characteristics of the cooling units are known. The writer has examined ash-flow deposits which can be explained only on the assumption that they are part of a unit of higher rank than the cooling units. The evidence consists of observed horizontal change of compound cooling units into separate cooling units. That is, the composite sheet is composed of cooling units that may range horizontally through any or every stage from a single- or multiple-flow simple cooling unit, multiple-flow compound cooling unit, to cooling units that are separated by erosional unconformities, other volcanic or sedimentary deposits, or local hiatuses in time sufficient to allow cooling of one unit before another is emplaced on top of it. Detailed mapping for documentation of this concept is necessary.

At any given time during its emplacement cycle the composite sheet is visualized as undergoing continuous cooling throughout some of its few tens to few thousands of square miles of area. The *merging or overlap* of composite sheets or cooling units from different source areas would give rise to many complexities. The time-stratigraphic importance of such a relation might be very great, especially if air-fall deposits can be related to the ash-flow sheets.

INFLUENCE OF BURIED TOPOGRAPHY

The zonal variations expected to occur where a simple cooling unit is superimposed on a high or low feature in the underlying topography are shown in plate 20*D*. The effects are the same as would be expected from normal horizontal thinning or thickening, but the changes are more abrupt.

The changes due to buried topography may be striking in regions of high relief, but in regions of low relief they are more subtle. For example, the distribution of outcrops of a persistent dense glass zone may suddenly become erratic. One explanation might be that the cooling unit was emplaced on an irregular surface such that the tops of the buried topographic high areas were roughly coincident with the level in the cooling unit that marks the transition from the zone of dense welding to the upper zone of partial welding. A dense black glass could not form over any topographic high that reached this transition level. In sheets of this type, buried topography will also be reflected by gentle irregularities in the surface of the cooling unit.

Other variables being equal, the thickness of the cooling unit (producing load pressure) at any point controls the amount and degree of welding at that point. Thus the percent of total compaction will be greater in the thicker parts of the unit, and it is this differential compaction that results in surface expression of buried topography. If two cooling units of equal emplacement thickness are of different compactability, the one with the higher compactability will show the more irregular surface over equivalent buried topography.

By careful consideration of plate 20*D*, the effect of buried topography can be predicted for other zones and different topographic environments. The extreme abruptness of changes in the cooling-unit surface and the zones as shown in plate 20*D* is due to the vertical exaggeration of the projection.

Some cooling units (map units) can change abruptly over a buried escarpment, resulting in thick welded tuff on one side and a thinner nonwelded or only partly welded tuff on the other. As shown in plate 20*D*, the thick side of the buried escarpment contains a vitrophyre zone and a devitrified zone of dense welding, whereas the other side is predominantly a "sillar" type of tuff (*p.* 151). If such a situation as this were to be found in deformed and eroded terrane, with poor exposures, the chances of correct interpretation would probably be small even for experienced geologists. It would present difficulties even under ideal field conditions. Infinite variation is possible, especially if compound cooling or composite sheet effects are involved.

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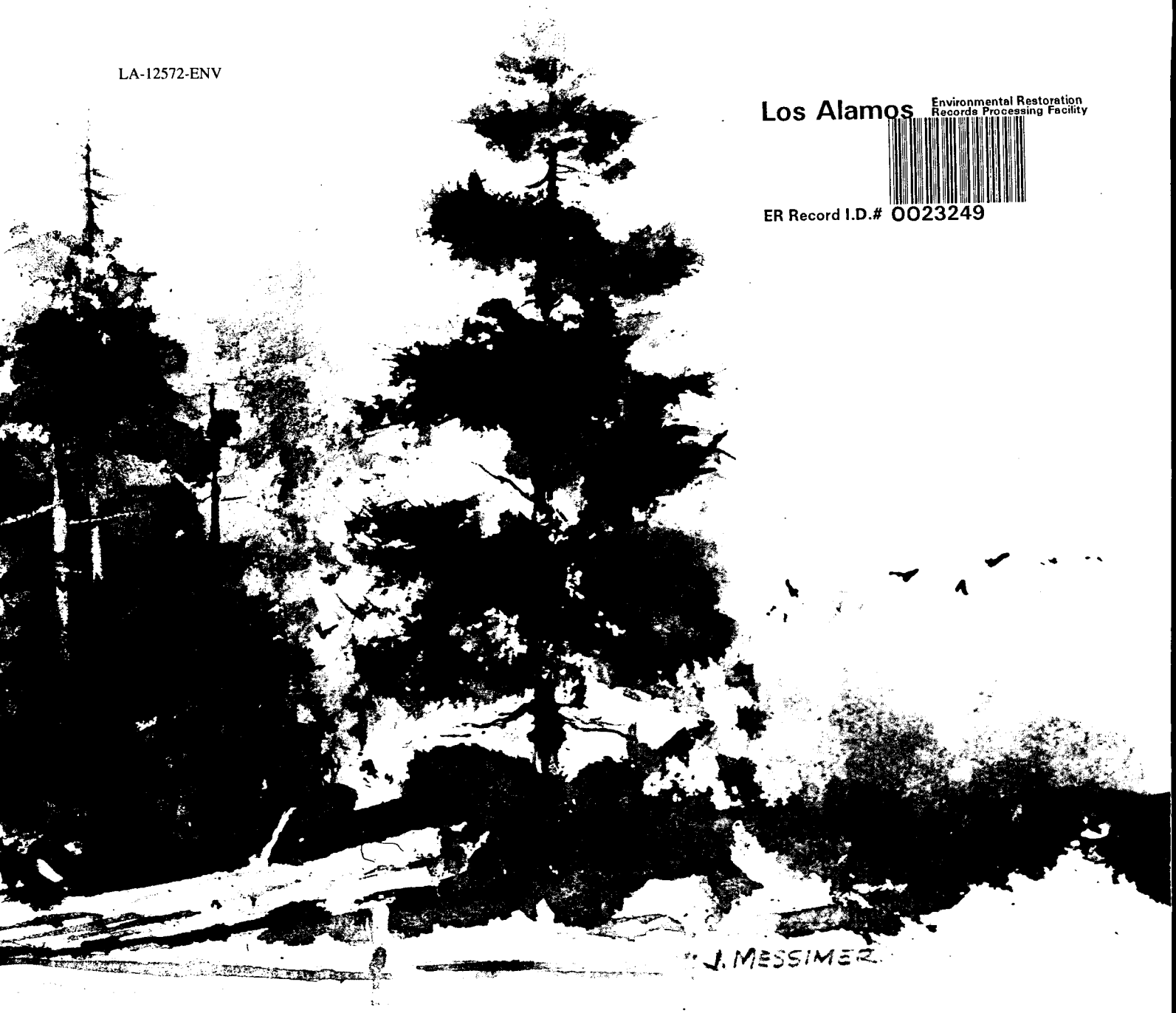

Environmental Surveillance at Los Alamos during 1991

Los Alamos
NATIONAL LABORATORY

Aerial view looking westward toward the Valle Grande in the Jemez Mountains. Extending eastward from the mountains, the Pajarito Plateau is cut into numerous narrow mesas divided by southeast-trending canyons. The Los Alamos townsite is on the mesas in the right half of the photograph and Los Alamos National Laboratory is on those in the left. The Laboratory's main technical area (TA-3) is in the top center, at the foot of the mountains, and the Los Alamos Meson Physics Facility (LAMPF) is in the lower center.

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Environmental Protection Group

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Department of Energy
Albuquerque Operations
Los Alamos Area Office
Los Alamos, New Mexico 87544

APR 27 1993

To the Reader:

Enclosed is your copy of the Environmental Surveillance Report for the Los Alamos National Laboratory (the Laboratory). This report summarizes the Laboratory's 1991 environmental surveillance program. This program is carried out to assess compliance with environmental standards, to identify at early stages any undesirable environmental trends, and to inform the public about the Laboratory's impact on the environment.

The report was prepared by the Laboratory's Environmental Management Division and Health & Safety Division for the Department of Energy. Since this is an annual report for an ongoing program, we would appreciate your comments or suggestions for improving both the report and the program. My office will continue to work with you to improve the timeliness, quality, and usefulness of this report.

If you are not currently on the mailing list for this report, or if personnel changes in your organization have resulted in a need for us to update our mailing list for next year's report, please contact Joseph Vozella of the Environment, Safety, and Health Branch at the address provided above, or by telephone at (505) 665-5027. I hope you will find this document useful and informative.

Sincerely,

Jerry L. Bellows
Area Manager

Enclosure

ENVIRONMENTAL SURVEILLANCE AT LOS ALAMOS DURING 1991

ENVIRONMENTAL PROTECTION GROUP

ABSTRACT

This report describes the environmental surveillance program conducted by Los Alamos National Laboratory during 1991. Routine monitoring for radiation and for radioactive and chemical materials is conducted on the Laboratory site as well as in the surrounding region. Monitoring results are used to determine compliance with appropriate standards and to permit early identification of potentially undesirable trends. Results and interpretation of data for 1991 cover external penetrating radiation; quantities of airborne emissions and effluents; concentrations of chemicals and radionuclides in ambient air, surface waters and groundwaters, municipal water supply, soils and sediments, and foodstuffs; and environmental compliance. Comparisons with appropriate standards, regulations, and background levels provide the basis for concluding that environmental effects from Laboratory operations are small and do not pose a threat to the public, Laboratory employees, or the environment.

FOREWORD

Suggestions on How to Read This Report

This report is written for both the lay person and the scientist. Each reader may have limited or comprehensive interest in this report. We have tried to make it accessible to all without compromising its scientific integrity. Following are directions advising each audience on how best to use this document.

1. Lay Person with Limited Interest. Read Section I, the Executive Summary, which describes the Laboratory's environmental monitoring operations for this year. Emphasis is on the significance of findings and environmental regulatory compliance. A glossary and a list of acronyms and abbreviations in the back of the report describe pertinent terms and acronyms.

2. Lay Person with Comprehensive Interest. Follow directions for the "Lay Person with Limited Interest" given above. Also, summaries of each section of the report are in boldface type and precede the technical text. Read summaries of those sections that interest you. Further details are in the text following each summary. Appendix A, Standards for Environmental Contaminants; Appendix B, Units of Measurement; and Appendix C, Description of Technical Areas and Their Associated Programs, may also be helpful.

3. Scientists with Limited Interest. Read Section I, the Executive Summary, to determine the parts of the Laboratory's environmental program that interest you. You may then read summaries and technical details of these parts in the body of the report. 1991 publications and references are presented in Sections IX and X.

4. Scientists with Comprehensive Interest. Read Section I, the Executive Summary, which describes the Laboratory's environmental programs this year. Read each major subdivision of this report; detailed data tables are included in each section. Appendix D contains detailed environmental background data.

For further information about this report, contact the Los Alamos National Laboratory's Environmental Protection Group (EM-8):

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I. EXECUTIVE SUMMARY

A. Introduction

It is the policy of the Los Alamos National Laboratory (LANL or the Laboratory) to provide a safe and healthful working environment for its employees, the employees of its subcontractors, participating guests, and visitors and to prevent any harm to these individuals, the public, or the environment as a result of the Laboratory's activities. The Laboratory began as Project Y of the Manhattan Engineer District during World War II with the specific responsibility of developing the world's first nuclear weapon. The Laboratory is managed by the University of California for the Department of Energy (DOE).

The primary mission of the Laboratory today continues to be nuclear weapons research, development, and testing to help ensure the nation's nuclear deterrent. Programs include weapons development, nuclear fission and fusion research, nuclear safeguards and security, and verification and control technologies. Basic research in physics, chemistry, mathematics, engineering, and materials science is integral to Laboratory activities. Research on peaceful uses of nuclear energy has included space applications, power reactor programs, magnetic and inertial fusion, radiobiology, and medicine. Other programs ongoing at the Laboratory include astrophysics, earth sciences, lasers, computer sciences, solar energy, geothermal energy, biomedical and environmental research, and nuclear waste management research.

"Environmental Surveillance at Los Alamos during 1991" presents the annual summary of the ongoing environmental protection program conducted by the Laboratory. The report includes descriptions of the Laboratory and its mission and programs, the site and the surrounding area, the status of the Laboratory's compliance with environmental regulations and requirements, and the surveillance program of the ambient environment. Radiological and nonradiological constituents are routinely monitored in air, surface water, groundwater, soil, and sediments. The surveillance activities document compliance with appropriate standards and permit limits, identify trends, provide information to the public, and contribute to a better understanding of the Laboratory's impact on the environment.

The format of this year's report has been revised to more closely incorporate the guidance of DOE Order 5400.1 based on a 1991 Tiger Team finding. Readers who have read previous editions of the surveillance report may find the new organization different when attempting to compare analytical results from previous years. Please refer to the Contents and lists of Figures and Tables to locate items of specific interest.

Comprehensive information about compliance status and the monitoring activities is presented in the main body of the report, which includes detailed environmental tables of 1991 analytical results and trends. Methods and procedures for acquiring, analyzing, and recording data, as well as quality assurance procedures, are presented in Section VIII, Quality Assurance and Sampling Procedures. Environmental regulatory standards and background data are presented in Appendices A–D. A Glossary and lists of Acronyms and Scientific Symbols are also included.

B. Environmental Compliance Activities

1. Resource Conservation and Recovery Act.

This act regulates hazardous wastes from generation to ultimate disposal. The Environmental Protection Agency (EPA) has given full authority for administering the Resource Conservation and Recovery Act (RCRA), with the exception of the Hazardous and Solid Waste Amendments (HSWA) of 1984, to the New Mexico Environment Department (NMED). NMED conducted a hazardous waste compliance inspection at the Laboratory on April 29 through May 3, 1991. Nine violations were noted, and a Notice of Violation was issued by the NMED on May 14, 1991. The alleged violations consisted of failure to conduct or maintain adequate inspection records, to label containers properly, to use a satellite storage area properly, to exceed waste storage time limits, and to classify waste properly. These alleged violations presented no threat to human health or to the environment. All alleged violations were corrected within the 30 days allowed by

The Laboratory's response, sent to NMED in June 1991, was found adequate.

Laboratory hazardous waste operations, which will ultimately be closed under RCRA regulations, continued at Technical Area (TA) 35, Waste Oil Storage Pits; TA-40, Scrap Detonation Site; TA-54, Waste Oil Storage Tanks; and TA-16, Landfill at Area P. Six underground storage tanks in need of upgrades were removed during 1991. Laboratory policy is to remove underground storage tanks when user groups determine that the tanks are no longer needed and as funding permits.

The Laboratory's Environmental Restoration program submitted its first site-specific work plan under HWSA in May 1991 and updated the programmatic plan in November. The Laboratory is out of compliance with RCRA requirements related to storage of certain hazardous and mixed wastes subject to the land-disposal restrictions and is utilizing a National Capacity Variance to store mixed waste on site. DOE applied for another variance and worked on statutory changes to address the problems associated with the lack of available or adequate treatment capacity for LDR mixed waste.

2. Clean Water Act.

Regulations under the Clean Water Act (CWA) set water quality standards and effluent limitations. The two primary programs at the Laboratory established to comply with the CWA are the National Pollutant Discharge Elimination System (NPDES) program and the Spill Prevention Control and Countermeasure (SPCC) program.

The CWA, under the NPDES, requires permits for point-source discharges. A single NPDES permit for the Laboratory authorizes effluent discharges from 130 industrial outfalls and 9 sanitary sewage treatment outfalls. The Laboratory submitted a NPDES permit reapplication in September 1990; the existing permit is being administratively continued under 40 CFR 122.6, pending issuance of the new permit. The Laboratory was in compliance with the NPDES permit in 99.0% of the analyses done on samples at sanitary waste discharges and 98.8% at the industrial waste discharges in calendar year (CY) 91. Noncompliant discharges are being addressed under an EPA/DOE Federal Facilities Compliance Agreement (FFCA). For example, the Sanitary Wastewater Systems Consolidation project is designed to eliminate NPDES violations by construction of a new, centralized sanitary wastewater treatment plant at TA-46. In addition, NPDES corrective activities are listed in DOE's "Environmental Restoration and Waste Management Five-Year Plan."

Another NPDES permit authorizes liquid effluent discharge from the Fenton Hill Geothermal Project. The permit is for a single outfall and was issued to regulate the discharge of mineral-laden water from the recycle loop of the geothermal wells. No discharges occurred from this outfall in 1991.

The Laboratory has an SPCC Plan, as required by the CWA in 40 CFR 112. The plan is implemented by providing secondary containment for large tanks and other containers to control accidental oil spills and prevent them from entering a watercourse. The plan also provides for spill control and clean-up training. Approximately 32 major containment structures are presently in use at the Laboratory for spill control. During 1991, eight chemical storage lockers and two containment pallets were purchased.

3. National Environmental Policy Act.

In accordance with the National Environmental Policy Act (NEPA) of 1969, federal agencies must consider the potential environmental impacts of proposed activities during the planning stage so that decisions reflect environmental values, as well as cost and mission. Proposed activities at the Laboratory are reviewed by Environmental Protection Group (EM-8) staff to identify those that could adversely impact the human environment, including environmentally sensitive areas in need of special protection, such as archaeological resources, floodplains, wetlands, and the habitat of threatened or endangered species. The staff provides DOE with information on potential environmental impacts of proposed activities, including the results of surveys of environmentally sensitive areas. No action can go beyond the planning stage, nor can reasonable alternatives be precluded, until DOE approves the NEPA documentation for that action.

In 1991, EM-8 reviewed 614 actions proposed to be undertaken at the Laboratory for NEPA applicability. Seventy-eight DOE Environmental Checklists (DECs) were submitted to DOE on 90 of these projects. In addition to the 78 DECs submitted to DOE on 1991 projects, 21 DECs were submitted during 1991 on projects reviewed through the Environment, Safety, and

Health Questionnaire process during 1990, and decisions were still pending at DOE on 21 DECs submitted during 1990. Of the 120 DECs submitted to DOE for decisions, 62 were categorically excluded from additional NEPA documentation, Environmental Assessments (EAs) were required on 12, prior NEPA documentation covered 2, and no decision had been made on the remaining 44 by the end of 1991. EAs were written on five of the proposed projects.

4. Federal Clean Air Act and New Mexico Air Quality Control Act.

Regulations under these acts set ambient air quality standards, require the permitting of new sources, and set acceptable emission limits. During 1991, all of the Laboratory's existing operations remained in compliance with air quality regulations for nonradioactive emissions.

- Monitoring demonstrated compliance with all ambient air quality standards except the state ozone standard.
- All construction projects at the Laboratory were reviewed, and air emissions were estimated to determine whether air permits or construction approvals were required.
- One sample that exceeded the opacity limits was recorded.

The state ozone standard is exceeded in many areas of the state. The cause of these exceedences is unknown; they may result from transport from urban areas or may be generated by local sources. Because the New Mexico Air Quality Act does not specifically require compliance with state standards, there are no enforcement actions associated with these exceedences. Instead, the state uses these standards as guidelines in setting allowable emission limits for regulated sources, based on modeling results. At present, LANL is not affected by these emission limits.

During 1991, no Laboratory asbestos renovation or demolition operation produced visible asbestos emissions to the environment. Johnson Controls Inc. removed approximately 2,095 lin ft of friable asbestos, including 110 lin ft of potentially radioactive contaminated friable material from small jobs. Approximately 193 sq ft of friable insulation were removed from vessels and other facility components, and 330 sq ft of nonfriable vinyl-asbestos floor tile were removed. A total of 1,640 lin ft of friable asbestos was removed through large job work.

The Laboratory identified a beryllium cutting operation at TA-55-4 in August 1991 which may require a permit under the requirements of New Mexico Air Quality Control Regulation 702 - Permits. Following discussions with the NMED, DOE officially notified NMED on October 9, 1991, of the operations. Beryllium cutting operations were suspended and a commitment was made to file an air quality permit application with NMED. The NMED issued a Notice of Violation (NOV) for the beryllium cutting operation on October 16, 1991. Negotiations for settling this NOV are continuing between Laboratory, DOE, and NMED personnel.

The EPA regulates radioactive air emissions from DOE facilities under the Clean Air Act. During 1991, the Laboratory remained in compliance with the EPA standard that limits the effective dose equivalent to a member of the public from airborne radioactive emissions to less than 10 mrem/yr. However, the Laboratory cannot yet demonstrate compliance with all of EPA's radioactive emission monitoring requirements, and DOE received a Notice of Noncompliance from EPA on November 27, 1991. A draft FFCA to address bringing the emission monitoring program into compliance with the regulations was submitted by DOE to the EPA on March 12, 1992.

5. Safe Drinking Water Act.

The municipal and industrial water supplies for the Laboratory and community are from 16 deep wells owned by DOE and one gallery (collection system fed by a spring in Water Canyon). The wells range in depth from 265 to 942 m (869 to 3,090 ft). In 1991, the chemical quality of the water met federal and state primary and secondary drinking water standards.

6. Federal Insecticide, Fungicide, and Rodenticide Act.

This act regulates the manufacturing of pesticides, with requirements on registration, labeling, packaging, enforcement, recordkeeping, distribution, worker protection, certification, experimental use, and tolerances in foods and feeds. An annual inspection conducted in 1991 by the U.S. Department of Agriculture found no deficiencies in the Laboratory's pesticide application program or certified application equipment. In 1991,

approximately 27.5 lb of herbicides and 287.5 gal. of pesticides were applied at the Laboratory.

7. National Historic Preservation Act.

As required by Section 106 of the National Historic Preservation Act of 1966, which was implemented by 36 CFR 800, "Protection of Historic Properties," Laboratory activities are evaluated in consultation with the State Historic Preservation Officer for possible effects to cultural or historic resources. During 1991, Laboratory archaeologists evaluated 1,110 undertakings (an undertaking is an activity that has the potential to affect a cultural/historic resource), conducted 51 field surveys, recorded 161 new archaeological sites, and updated the site records for 20 previously recorded sites.

8. Endangered/Threatened/Protected Species.

The DOE and the Laboratory must comply with the Endangered Species Act of 1973, as amended. Compliance under NEPA requires review of projects for potential environmental impact on critical habitats. During 1991, EM-8 reviewed 614 actions proposed to be undertaken at the Laboratory and identified 40 projects as needing reconnaissance surveys, 15 proposed actions as needing quantitative surveys, and 8 projects as requiring intensive surveys to determine the presence or absence of a species at the project site.

9. Floodplain/Wetland Protection.

The Laboratory must comply with Executive Order (EO) 11988, "Floodplain Management," and EO 11990, "Protection of Wetlands." Compliance with NEPA also requires review of projects for potential environmental impact on floodplains and wetlands. During 1991, 416 proposed actions were reviewed for impact to floodplains and wetlands. All projects reviewed were outside floodplain/wetland boundaries.

10. Comprehensive Environmental Response, Compensation, and Liability Act/Superfund Amendments and Reauthorization Act.

Clean-up of toxic and hazardous contaminants at closed and abandoned hazardous waste sites was mandated by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The Superfund Amendments and Reauthorization Act (SARA) of 1986 extensively amended CERCLA. Investigations and any required remedial actions at Los Alamos will be completed as part of DOE's Environmental Restoration program in conjunction with RCRA corrective actions.

11. Emergency Planning and Community Right-to-Know Act.

The University of California, as operator of the Laboratory, is required to report under Title III Section 313 of SARA if: (1) the Laboratory uses a listed toxic chemical above a specified threshold, and (2) the use of the chemical comes under the Standard Industrial Classification (SIC) Codes 20-39. All research operations at the Laboratory are exempt under other provisions of the regulation. Only pilot plants and specialty chemical production or manufacturing facilities at the Laboratory which fall under (1) above must report their releases.

The only facility of the Laboratory which could be considered to be within SIC codes 20-39 and therefore required to report under Section 313 is TA-55-4, the Plutonium Processing Facility. Reporting the chemical use and emissions for TA-55 has been the Laboratory's decision because of the special materials processing done at the facility. The only regulated chemical used at the Plutonium Processing Facility in amounts greater than the Section 313 reporting thresholds is nitric acid.

The Laboratory submitted its Section 313 report to EPA in July 1991. This report covered the releases of nitric acid during 1990. About 24,320 kg (53,500 lb) of nitric acid were used for plutonium processing with releases to the air of approximately 468.7 kg (1,031 lb). Atmospheric releases were calculated using data obtained from a study which measured the air emissions from the facility. All other nitric acid that was not consumed in chemical reactions was completely neutralized during wastewater treatment operations. Only the air releases required reporting in 1990. Data on releases for CY91 will be reported under Section 313 in July 1992.

12. Toxic Substances Control Act.

This act regulates the manufacture, processing, distribution, use, storage, and labeling of all chemical substances, including polychlorinated biphenyls (PCBs). The Laboratory has EPA authorization to dispose of PCB-contaminated equipment and soil at its low-level radioactive waste landfill (TA-54, Area G). However,

off site for disposal: 25,306 kg (55,673 lb) liquid PCB oil that included some 50-499 ppm PCB oil; 4,502 kg (9,904 lb) contaminated debris; 3,114 kg (6,851 lb) contaminated water; 64,621 kg (142,166 lb) from 39 transformers; and 6,622 kg (14,568 lb) from capacitors. In addition, 31,496 kg (69,291 lb) of PCB-contaminated soil, debris, and equipment were disposed of at TA-54, Area G. Of the 31 PCB transformers being retrofilled within the last two years, 11 were reclassified to non–PCB status at the end of 1991, and most of the rest were reclassified to PCB-contaminated status. The DOE Tiger Teams audited and inspected the Laboratory's PCB program in 1991. No audits or inspections of the Laboratory's PCB activities were conducted by the EPA or NMED in 1991.

C. Unplanned Releases

1. Airborne Radionuclide Releases.

On February 1, 1991, 2,800 Ci of elemental tritium were released at TA-41. Less than 0.1% of the tritium was present as tritiated water. The effective dose equivalent (50-yr dose commitment) to a member of the public was calculated to be 0.03 mrem. This dose occurred 7 km east of TA-41, where Los Alamos Canyon reaches State Road 4. The dose estimate conservatively assumed that 1% of the tritium was oxidized before reaching the receptor location. The dose is 0.03% of DOE's public dose limit (PDL) of 100 mrem/yr from all pathways and 0.3% of the EPA's 10 mrem/yr limit for the air pathway.

On March 28, 1991, 0.40 Ci of tritiated water vapor were released from TA-21 as tritium oxide. The effective dose equivalent to a member of the public was calculated to be 0.01 mrem. The dose is 0.01% of DOE's PDL from all pathways and 0.1% of the EPA's limit for the air pathway.

On April 17, 1991, 0.1550 Ci of tritiated water vapor were released from TA-3-16. A slow leak was discovered at the Van de Graaff accelerator. The effective dose equivalent to a member of the public was calculated to be 0.006 mrem. The dose is 0.006% of DOE's PDL and 0.06% of the EPA limit.

2. Airborne Nonradiological Releases.

No unplanned airborne nonradiological releases were reported during 1991.

3. Radioactive Liquid Releases.

On January 2, 1991, a discharge was discovered at TA-54, Area G. A plumbing joint on an eye wash/safety shower located inside Building 33 froze and burst sometime between December 21, 1990, and January 1, 1991, when the Laboratory was closed for the winter holidays. The amount of discharge was estimated to be 18,000 gal. Analyses were conducted on the frozen water and soil; gross alpha, beta, and gamma were found to be within background levels. Samples analyzed for tritium averaged 0.29 μCi/L, approximately 15% of the DOE Derived Concentration Guide for off-site tritium releases (2.0 μCi/L). Removal of the frozen water below Building 33 was not required because of the slow rate of melting during which the water either evaporates or enters the subsurface rather than producing a definitive runoff into Cañada del Buey.

On February 21, 1991, 0.2 μCi of plutonium and americium were released at TA-50 from a leaking pipe near the Size Reduction Facility. The spill was confined to a small area. The leak was repaired, and the spill was cleaned up to applicable standards.

4. Nonradioactive Liquid Releases.

On September 25, 1991, an underground diesel fuel transfer line broke during start-up of the TA-3 power plant's backup fuel system. Approximately 100-200 gal. of diesel fuel oil surfaced and was discharged across the ground to a storm water channel, where it drained into a tributary to Sandia Canyon. The discharge was immediately reported to EPA and NMED. Corrective actions included immediate shutdown of the fuel line. The diesel spill was contained in the water course within minutes using absorbent booms and pillows. Pools of diesel fuel and water were removed using a wet/dry vacuum and absorbents. The contaminated soil was sampled, removed, and disposed of at the Los Alamos County landfill.

During 1991, 56 other releases of nonradioactive liquids occurred at the Laboratory and were reported to the EPA and NMED. Each of these discharges was minor in nature and was contained on Laboratory property. None was found to be of any threat to health or to the environment. Sampling and clean-up were completed. Over 60% of these unplanned releases were either potable water or steam condensate originating from the Laboratory's utility system.

D. Monitoring Operations

1. Introduction.

The Laboratory supports an ongoing environmental surveillance program as required by DOE Orders 5400.1 and 5484.1. The surveillance program includes routine monitoring for radiation, radioactive materials, and hazardous chemical substances on the Laboratory site and in the surrounding region. These activities document compliance with appropriate standards, identify trends, provide information for the public, and contribute to general environmental knowledge. The environmental program also includes an assessment of the Laboratory's impact on the surrounding environment. Detailed, supplemental environmental studies also are carried out to determine the extent of potential problems, to provide a basis for any remedial actions, and to gather further information on the surrounding environment.

Monitoring and sampling locations for various types of environmental measurements are organized into three groups:

- Regional stations are located within the five counties surrounding Los Alamos County at distances up to 80 km (50 mi) from the Laboratory. They provide a basis for determining conditions beyond the range of potential influence from normal Laboratory operations.
- Perimeter stations are located within about 4 km (2.5 mi) of the Laboratory boundary, and many are in residential and community areas. They document conditions in areas regularly occupied by the public and potentially affected by Laboratory operations.
- On-site stations are within the Laboratory boundary, and most are in areas accessible only to employees during normal working hours.

They document environmental conditions at the Laboratory where public access is limited. Approximately 130,000 analyses for chemical and radiochemical constituents were carried out for more than 6,200 environmental samples during 1991.

2. External Penetrating Radiation.

Levels of external penetrating radiation (including x and gamma rays and charged particle contributions from cosmic, terrestrial, and manmade sources) around the Los Alamos area are monitored with thermoluminescent dosimeters (TLDs) at 150 locations.

Annual averages for the TLDs were generally the same in 1991 as in 1990, consistent with the variability in natural background observed at these stations. The network at Los Alamos Meson Physics Facility (LAMPF) did not record any radiation measurement above its 3.0 mrem/yr detection limit during 1991 because of reduced operations at the facility.

Radiation levels (including natural background radiation from cosmic and terrestrial sources) are also measured at regional, perimeter, and on-site locations in the environmental TLD network. Some measurements at on-site stations were above background levels, as expected, reflecting ongoing research activities at, or past releases from, Laboratory facilities.

3. Air Monitoring.

a. Radioactive. The sampling network for ambient airborne radioactivity consists of 36 continuously operating air sampling stations. Total radioactive airborne emissions decreased substantially from those in 1990. This was primarily due to a 48% decrease in releases of airborne activation products from LAMPF.

Ambient air is routinely sampled for tritium, uranium, plutonium, americium, and gross beta activity. Measurements of radioactivity in the air are compared with DOE's derived concentration guides.

Tritium was the primary radionuclide with air concentrations that showed levels indicating any measurable impact from radionuclide releases caused by Laboratory operations. Annual average concentrations of tritium continued to be much less than 0.1% of DOE's guides at all stations and posed no environmental or health problems in 1991. Annual average concentrations of all other radionuclides in air during 1991 were also much less than 0.1% of the guides.

b. Nonradioactive. The Laboratory operates monitors to routinely measure primary (or "criteria") pollutants, beryllium, acid precipitation, and visibility. In 1991, the Laboratory also monitored toxic air pollutants as part of a short-term study. Levels of pollutants in the ambient environment are extremely low and are in compliance with all applicable standards, except the state ozone standard.

4. Surface Water and Groundwater Monitoring.

Surface waters and groundwaters are monitored to detect potential dispersion of radionuclides and hazardous chemicals from Laboratory operations. Surface waters and shallow groundwaters in existing and former liquid effluent release areas contained radioactivity in concentrations that were above natural terrestrial and worldwide fallout levels. These waters are not a source of industrial or municipal water supplies. The quality of water from regional, perimeter, and on-site areas that have received no direct discharge showed no significant effects from Laboratory releases. Samples from deep test wells and water supply wells continued to show no radioactive or chemical contamination in the main aquifer. The top of the main aquifer occurs 180 to 360 m (600 to 1,200 ft) beneath the Pajarito Plateau. Liquid effluents containing low levels of radioactivity are routinely released from one waste treatment plant.

5. Soils and Sediments Monitoring.

Measurements of radioactivity and chemicals in samples of soils and sediments provide data on less direct pathways of exposure. These measurements are useful for understanding hydrological transport of radioactivity in intermittent stream channels near low-level radioactive waste management areas. Areas within Pueblo, Los Alamos, and Mortandad Canyons all had concentrations of radioactivity in sediments at levels higher than those attributable to natural terrestrial sources or worldwide fallout. Cesium, plutonium, and strontium in Mortandad Canyon result from effluents from a liquid waste treatment plant. No runoff or sediment transport has occurred beyond the Laboratory boundary in Mortandad Canyon since effluent release into the canyon started. However, some radioactivity in sediments in Pueblo Canyon (from pre-1964 effluents) and Los Alamos Canyon (from post-1952 treated effluents) has been transported to the Rio Grande. Theoretical estimates, confirmed by measurements, show that the incremental effect on Rio Grande sediments is a small percentage of the background concentrations attributable to worldwide fallout in soils and sediments.

Surface runoff has transported some low-level contamination from the active waste disposal area and several of the inactive areas into controlled-access canyons. Analyses of toxic metals in surface sediments indicate that no constituents in excess of EPA threshold criteria for determining hazardous waste are present in these canyons.

6. Monitoring of the Water Distribution System.

Samples are collected and analyzed from the Los Alamos County water distribution system on a routine basis in order to determine the levels of organic and inorganic chemical constituents and radioactive constituents in the local drinking water. During 1991, all water samples collected were found to be in compliance with the maximum contaminant levels established by federal regulation and New Mexico Water Supply Regulations.

7. Foodstuffs Monitoring.

Most fruit, vegetable, fish, bee, and honey samples from perimeter locations showed no radioactivity distinguishable from that attributable to natural sources or worldwide fallout. Some produce, bee, and honey samples from on-site locations had elevated tritium (H^3) concentrations at levels <1% of DOE's guides for tritium in water (there are no concentration guides for produce). The range in H^3 values in produce samples collected from Laboratory lands ranged in concentration from 0.7 to 8.1 pCi/mL. These values are higher than those in 1990 samples.

One fruit sample collected from the townsite area (the former TA-1 site) contained elevated levels of H^3 (16 pCi/mL) and $^{239,240}Pu$ (0.02 pCi/dry g). Plutonium levels, in particular, were about 100 times the levels found in fruit samples collected from other trees in the area. The amount of Pu in this fruit does not pose a health hazard; the total dose as a result of all radionuclides that could be obtained from ingesting all of the fruit from this tree (estimated to be about 50 lb) was only 0.3 mrem/yr.

E. Estimated Doses and Risks from Radiation Exposure

1. Radiation Doses.

Estimated individual radiation doses to the public attributable to Laboratory operations are compared with applicable standards in this report. Doses are expressed as percentages of DOE's public dose limit. The PDL excludes exposures from natural background, fallout, and radioactive consumer products. Estimated doses

are believed to be potential doses to individuals under realistic conditions of exposure.

In 1991, the estimated maximum individual effective dose was 4.4 mrem, or 4.4% of DOE's 100 mrem/yr standard for all pathways. It is 44% of EPA's 10 mrem/yr standard for the air pathway alone. This dose resulted mostly from external radiation from short-lived, airborne emissions from a linear particle accelerator at LAMPF. Another perspective is gained by comparing these estimated doses with the estimated effective dose attributable to background radiation. The estimated maximum effective dose from Laboratory operations is about 1.0% of the 339 mrem received from background radiation and radioactivity in Los Alamos during 1991. The average effective dose to residents in the Los Alamos townsite and to residents in White Rock are 0.05 mrem and 0.03 mrem, respectively.

2. Risk Estimates.

Estimates of the added risk of cancer were calculated to provide a perspective for comparing the significance of radiation exposures. Based on the average effective dose, incremental cancer risk to residents of Los Alamos townsite caused by 1991 Laboratory operations was estimated to be 1 chance in 47,000,000 and 1 chance in 68,000,000 for residents of White Rock. This risk is compared to the 1 chance in 8,000 for cancer from natural background radiation and the 1 chance in 43,000 for cancer from medical radiation.

The Laboratory's potential contribution to cancer risk is small when compared with overall cancer risks. The overall lifetime risk in the United States of contracting some form of cancer is 1 chance in 4. The lifetime risk of cancer mortality is 1 chance in 5.

II. INTRODUCTION

A. Los Alamos National Laboratory

In March 1943, a small group of scientists came to the Los Alamos Ranch School, located on a remote mesa high above the Rio Grande, northwest of Santa Fe. Project Y of the Manhattan Engineer District was charged with the specific responsibility of developing the world's first nuclear weapon. Originally, it was expected that the task could be completed by a hundred scientists. By 1945, when the first nuclear bomb was tested at Trinity Site in southern New Mexico, more than three thousand civilian and military personnel were working at Los Alamos National Laboratory (LANL or the Laboratory).

After the end of World War II, LANL became a permanent institution that is recognized as one of the finest scientific research laboratories in the world. A key factor in the Laboratory's excellence has been its management, since 1943, by the University of California. The University has maintained the tradition of free inquiry and debate that is essential to excellence in any scientific undertaking.

Today, the Laboratory is a vertically integrated research and development (R&D) institution of the Department of Energy (DOE). Vertical integration means the "research-to-retirement" responsibility that the weapons laboratories are assigned for nuclear warheads. The Laboratory works with the production plants to ensure that designs can be manufactured and with the armed services to ensure that the weapons are safe, secure, and reliable during their life cycle. The nuclear weapons program has provided challenge, flexibility, and a breadth of science and technology that has allowed LANL to contribute to many problems of national importance, developing expertise in solving large, complex technological problems for the nation and demonstrating that science makes a difference.

The overriding importance of the nuclear deterrence mission, plus the DOE's success in carrying it out, has encouraged the federal government over the years to invest resources in the Laboratory. The estimated operating cost of the Laboratory for fiscal year 1991 is $964 million, supported by close to $87 million in construction and capital equipment funds. Currently 57% of the operating budget supports broad DOE defense activities; 18% Department of Defense projects; and 25% civilian R&D, predominantly research and technology development and programs supported by the nondefense programs of DOE (Fig. II-1).

The Laboratory is the largest employer in northern New Mexico with about 7,550 full-time-equivalent employees. More than 3,000 of these employees are technical staff members, more than 2,000 are technicians, and the remainder are administrative and general support personnel.

In addition to University of California employees, over 2,000 more people are employed by contractors providing support services, protective force services, specialized scientific and technical services, and student researchers.

The primary mission of the Laboratory is nuclear weapons research, development, and testing to help ensure the nation's nuclear deterrence. As a multiprogram laboratory, it also serves the nation by using core competencies to make special contributions in such areas as

- technical assistance to the DOE weapons complex,
- energy and environmental technologies with an emphasis on working with U.S. industry,
- basic research to underpin the Laboratory's programs and support the DOE research mission, and
- work for other federal agencies, including defense and intelligence.

In performing its mission, the Laboratory has received a number of specific R&D assignments, including

- research, design, development, engineering, and testing of nuclear warhead concepts and new weapons capabilities, maintenance and enhancement of the technology base that is the

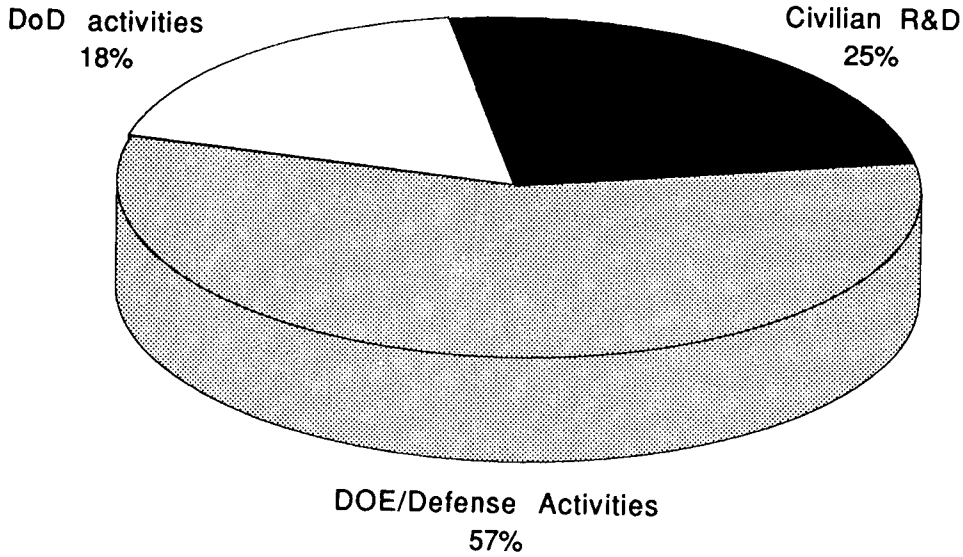


Fig. II-1. FY91 actual operating costs by percentage of allocation to programs.

foundation of the weapons program, and maintenance of the Laboratory's capabilities for nuclear tests and the execution of such tests;

- research, development, and testing support for advanced nuclear directed-energy concepts;
- R&D on inertial confinement fusion, including fusion target physics, laser-target interaction experiments, target design and fabrication, and high-energy laser development;
- nuclear materials R&D directly related to the nuclear weapons program, including research in materials science and materials development, process and fabrication development, and transfer of technology to the DOE production complex;
- non-nuclear materials R&D activities, including the neutral particle beam, free-electron laser, sensors, battle management, communication, command and control, high-velocity projectiles, advanced lasers, acquisition and tracking of targets, optics, beam propagation, and high-power microwaves;
- advanced conventional munitions, including computer code development and simulations, energetic and nonenergetic materials R&D, applications to armor/anti-armor, counter terrorism, and counter narcotics, and operations research and systems analysis;
- verification and safeguards R&D, including domestic and international safeguards, satellite- and earth-based detection and monitoring of nuclear tests, earth-based monitoring of nuclear weapons, and verification of chemical and biological warfare treaties;
- intelligence activities sponsored by national intelligence organizations involving the areas of hardware, analysis, international technology transfer and technology security, and Laboratory intelligence support;
- systems studies in the areas of strategic and tactical nuclear weapons, directed-energy weapons, non-nuclear weapons, energy technology, and supporting technologies;
- environmental R&D, including storing and managing radioactive waste, handling hazardous

waste, investigating new technologies to address problems associated with waste characterization and clean-up, environmental control technologies, global climate change, ozone depletion, clean air, and basic environmental science;

- non-nuclear energy activities, including renewable energy, conservation, and fossil energy;
- nondefense advanced technology that focuses on aerospace technology, biotechnology, artificial intelligence, and robotics;
- human genome studies, including informatics, research, and associated technology;
- research on the health consequences associated with the production and use of energy and national security materials, including radioisotope medicine, research on Acquired Immune Deficiency Syndrome, structural biology, and the use of lasers in medicine; and
- basic research in defense- and energy-related disciplines, including atomic and molecular physics, bioscience, chemistry, computational science and applied mathematics, geoscience, space science, astrophysics, materials science, nuclear and particle physics, plasma physics, fluids, particle beams, and applied science and engineering.

B. Geographic Setting

The Laboratory and the associated residential areas of Los Alamos and White Rock are located in Los Alamos County, in north central New Mexico, approximately 100 km (60 mi) north-northeast of Albuquerque and 40 km (25 mi) northwest of Santa Fe (Fig. II-2). The 111 km^2 (43 mi^2) Laboratory site and adjacent communities are situated on Pajarito Plateau, which consists of a series of finger-like mesas separated by deep east-to-west oriented canyons cut by intermittent streams (Fig. II-3). Mesa tops range in elevation from approximately 2,400 m (7,800 ft) on the flanks of the Jemez Mountains to about 1,900 m (6,200 ft) at their eastern termination above the Rio Grande Valley.

Most Laboratory and community developments are confined to mesa tops (see the inside front cover). The surrounding land is largely undeveloped, with large tracts of land north, west, and south of the Laboratory site being held by the Santa Fe National Forest, Bureau of Land Management, Bandelier National Monument, General Services Administration, and Los Alamos County (see the inside back cover). San Ildefonso Pueblo borders the Laboratory to the east.

Laboratory land is used for building sites, experimental areas, waste disposal locations, roads, and utility rights-of-way (see Fig. II-4 and Appendix C). However, these uses account for only a small part of the total land area. Most land provides isolation for security and safety and is a reserve for future structure locations.

The DOE controls the area within Laboratory boundaries and has the option to completely restrict access. Limited access by the public is allowed in certain areas of the Laboratory reservation. An area north of Ancho Canyon (Fig. II-5) between the Rio Grande and State Road 4 is open to hikers, rafters, and hunters, but woodcutting and vehicles are prohibited. Portions of Mortandad and Pueblo Canyons are also open to the public. An archaeological site (Otowi Tract), northwest of State Road 502 near the White Rock Y, and the cave kiva in Mortandad Canyon are open to the public subject to restrictions of cultural resource protection regulations.

In August 1977, the Laboratory site was dedicated as a National Environmental Research Park. The ultimate goal of programs associated with this regional facility is to encourage environmental research that will contribute to understanding how people can best live in balance with nature while enjoying the benefits of technology. Park resources are available to individuals and organizations outside of the Laboratory to facilitate self-supported research on these subjects deemed compatible with the Laboratory programmatic mission (DOE 1979).

A final Environmental Impact Statement (DOE 1979) that assessed potential cumulative environmental impacts associated with then, known future, and continuing activities at the Laboratory was completed in 1979. The report provided environmental input for decisions regarding continuing activities at the Laboratory. It also provided more detailed information on the environment of the Los Alamos area.

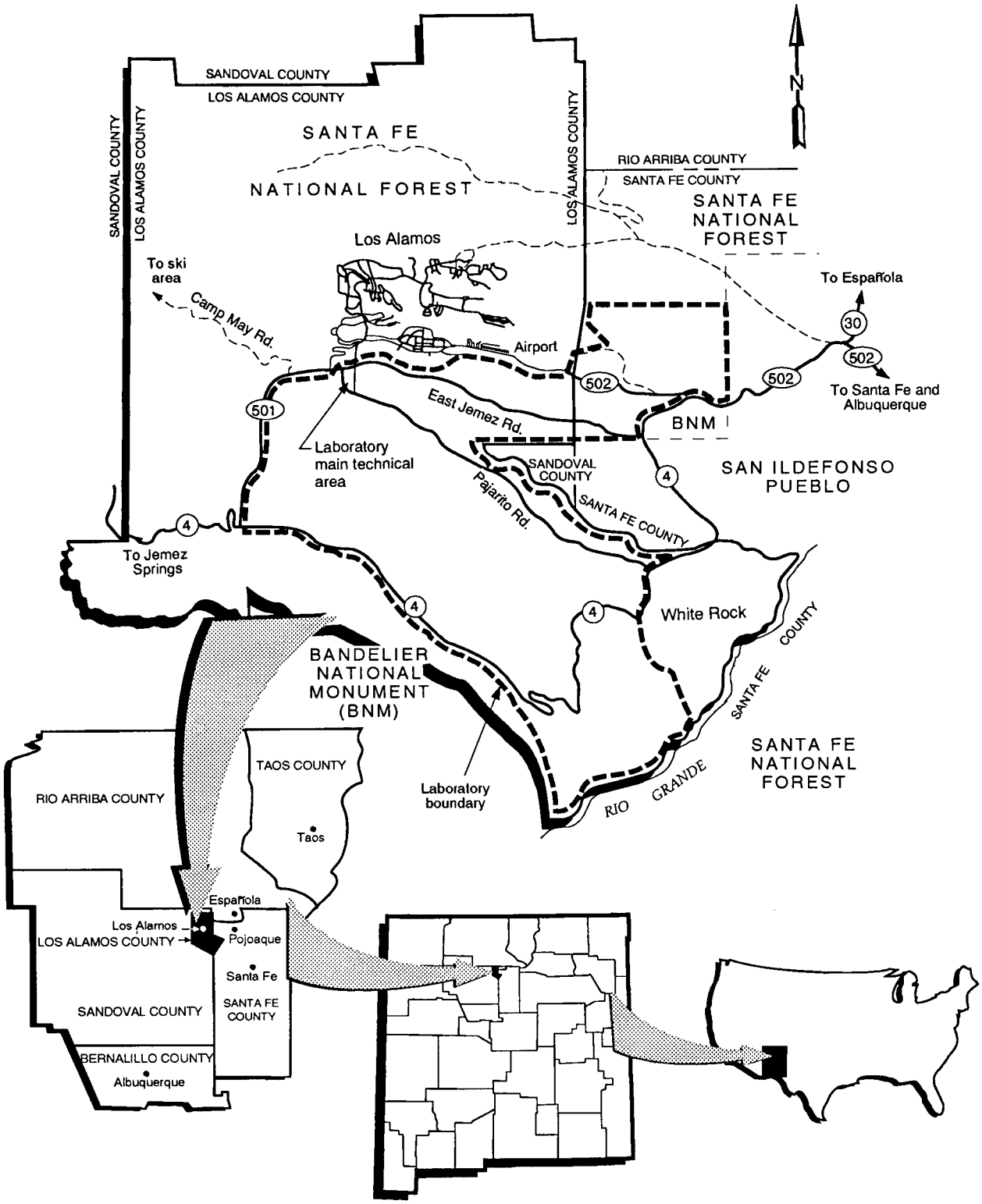


Fig II-2. Regional location of Los Alamos.

C. Geology-Hydrology

Most of the finger-like mesas in the Laboratory area are found in Bandelier Tuff (Fig. II-6). Ash fall, ash fall pumice, and rhyolite tuff form the surface of Pajarito Plateau. The tuff, ranging from nonwelded to welded, is over 300 m (1,000 ft) thick in the western part of the plateau and thins to about 80 m (260 ft) eastward above the Rio Grande. It was deposited as a result of a major eruption of a volcano in the Jemez Mountains about 1.1 to 1.4 million years ago.

The tuffs overlap onto the Tschicoma Formation, which consists of older volcanics that form the Jemez Mountains. The tuff is underlain by the conglomerate of the Puye Formation (Fig. II-6) in the central and eastern edge along the Rio Grande. Chino Mesa basalts interfinger with the conglomerate along the river. These formations overlay the sediments of the Tesuque Formation, which extends across the Rio Grande Valley and is in excess of 1,000 m (3,300 ft) thick. The Laboratory is bordered on the east by the Rio Grande, within the Rio Grande Rift. Because the rift is slowly widening, the area experiences frequent but minor seismic disturbances.

Los Alamos area surface water occurs primarily as intermittent streams. Springs on the flanks of the Jemez Mountains supply base flow into upper reaches of some canyons, but the amount is insufficient to maintain surface flows across the Laboratory site before it is depleted by evaporation, transpiration, and infiltration. Runoff from heavy thunderstorms or heavy snowmelt reaches the Rio Grande several times a year in some drainages. Effluents from sanitary sewage, industrial waste treatment plants, and cooling-tower blowdown are released into some canyons at rates sufficient to maintain surface flows for varying distances.

Groundwater occurs in three modes in the Los Alamos area: (1) water in shallow alluvium in canyons, (2) perched water (a groundwater body above an impermeable layer that separates it from the underlying main body of groundwater by an unsaturated zone), and (3) the main aquifer of the Los Alamos area.

Intermittent stream flows in canyons of the plateau have deposited alluvium that ranges from less than 1 m

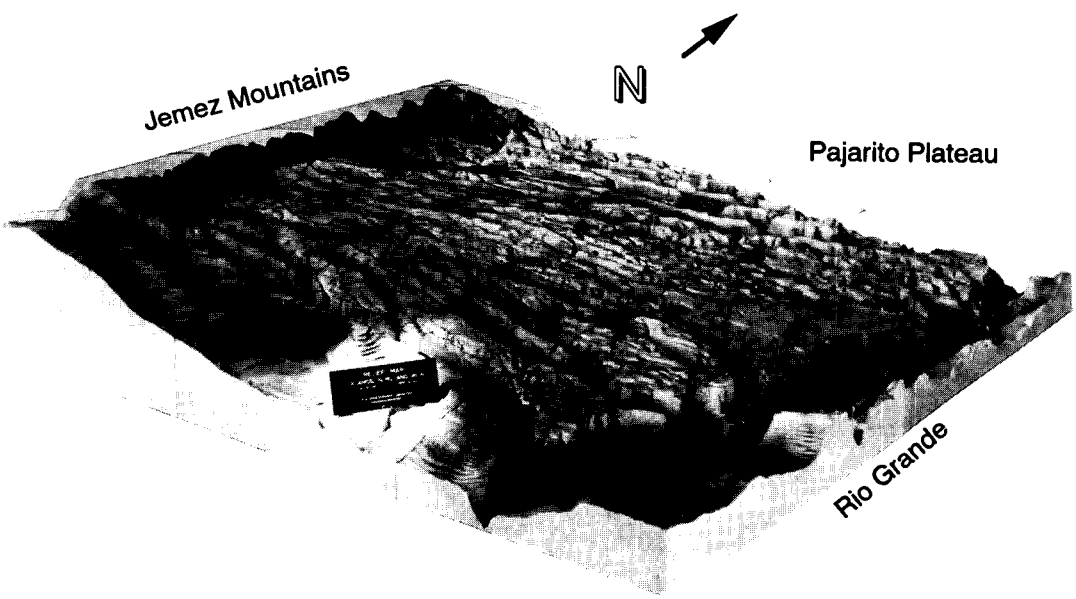


Fig. II-3. Topography of the Los Alamos area.

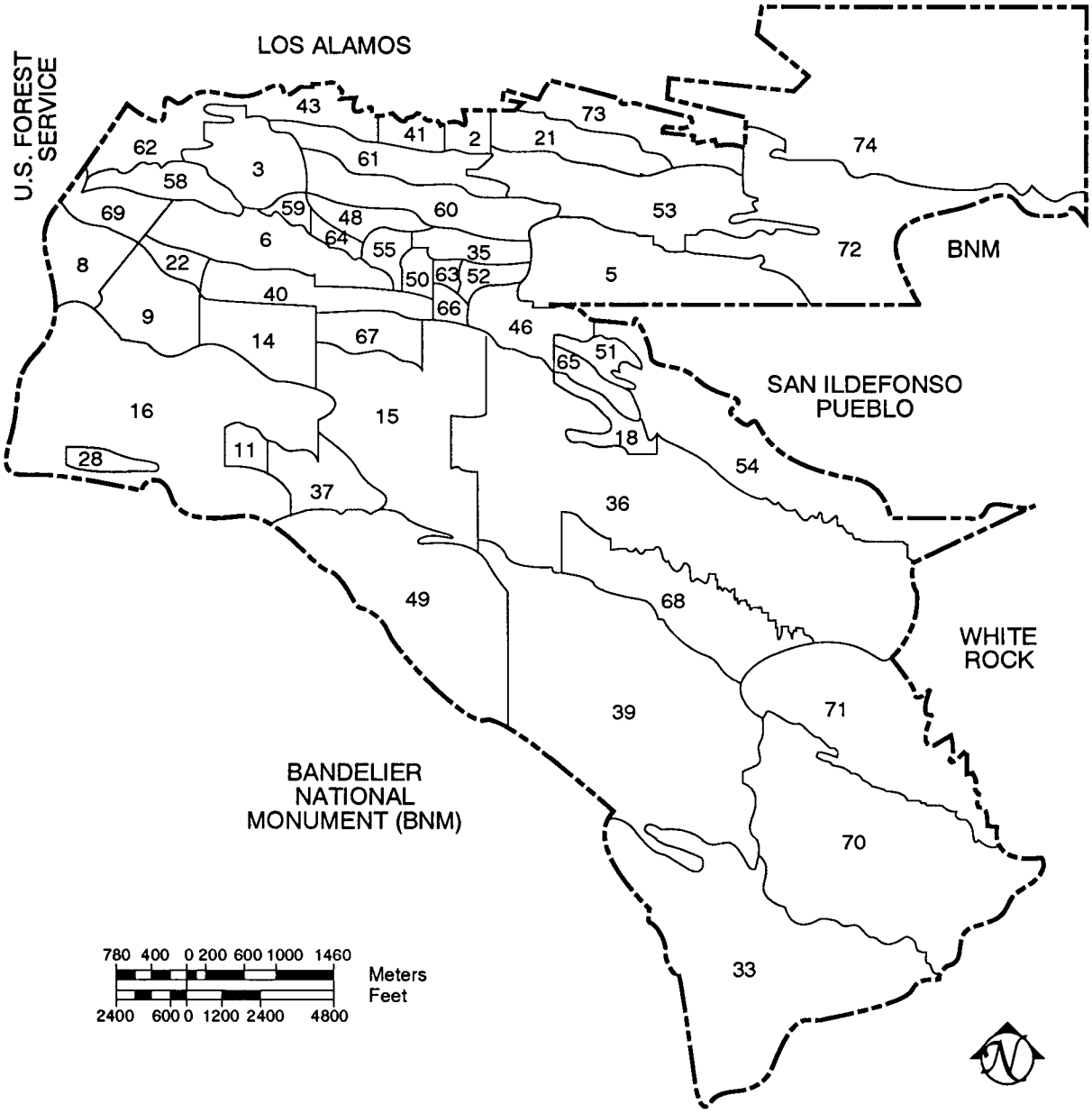
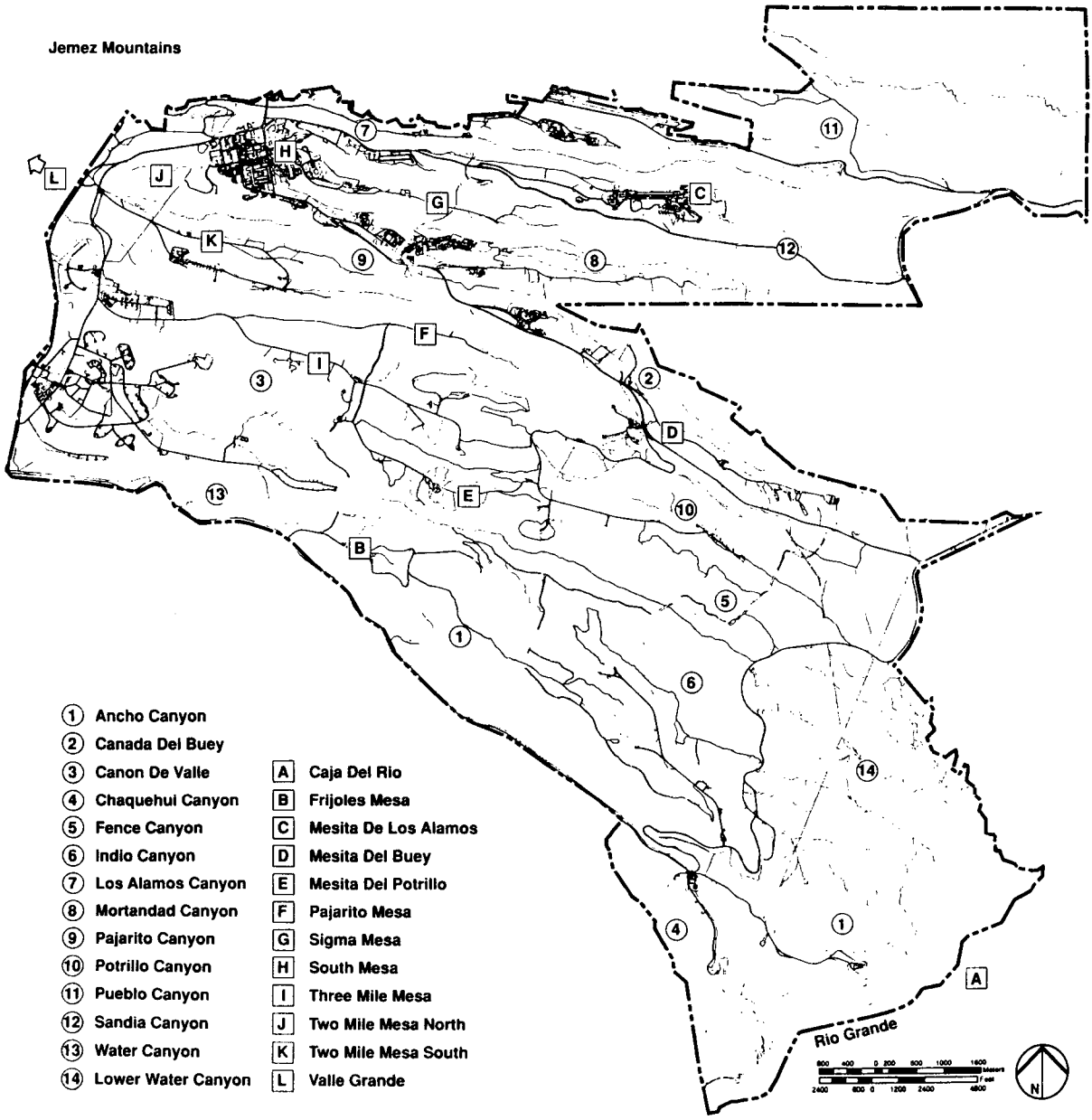


Fig. II-4. Technical areas (TAs) of Los Alamos National Laboratory in relation to surrounding landholdings.



General Site Description

1990 Los Alamos National Laboratory Site Development Plan

Fig. II-5. Major canyons and mesas.

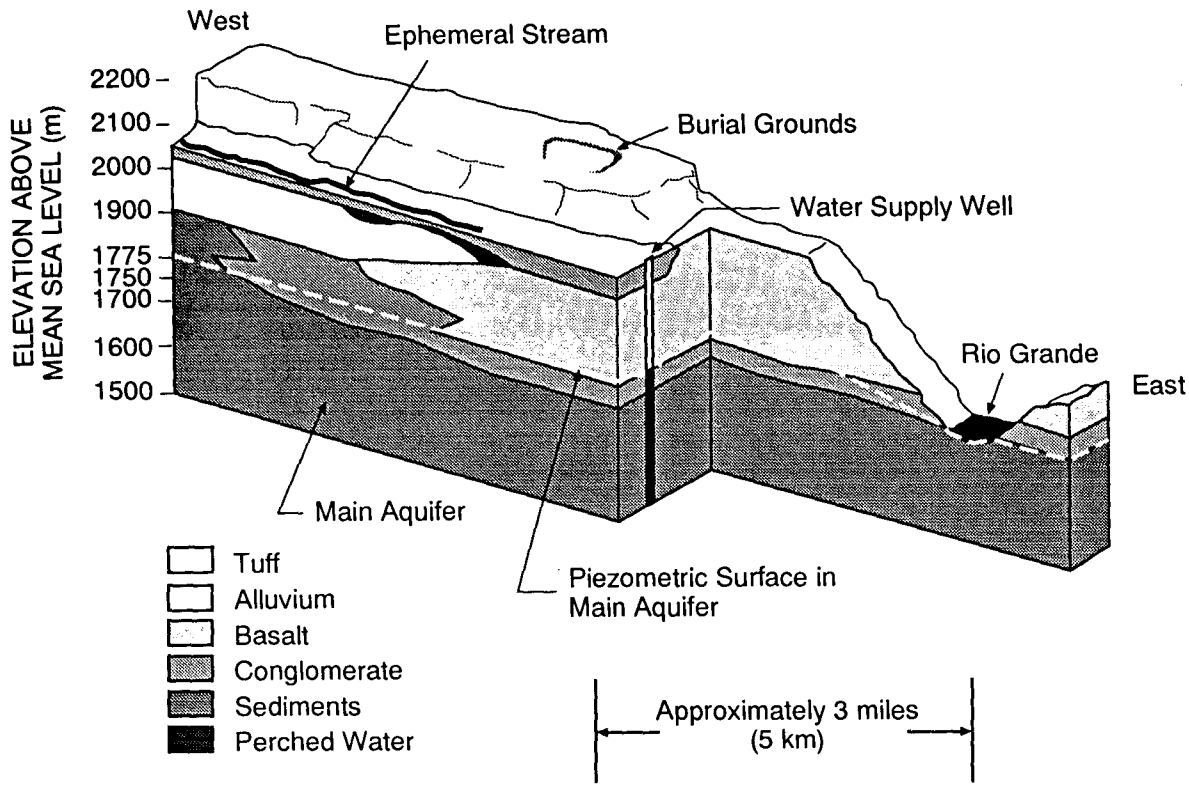


Fig. II-6. Conceptual illustration of geologic-hydrologic relationship in Los Alamos area.

(3 ft) to as much as 30 m (100 ft) in thickness. The alluvium is permeable, in contrast to the underlying volcanic tuff and sediments. Intermittent runoff in canyons infiltrates the alluvium until its downward movement is impeded by the less permeable tuff and volcanic sediment. This results in a shallow alluvial groundwater body that moves down gradient within the alluvium. As water in the alluvium moves down gradient, it is depleted by evapotranspiration and movement into underlying volcanics (Purtymun 1977).

Perched water occurs in conglomerate and basalts beneath the alluvium in portions of Pueblo, Los Alamos, and Sandia Canyons. It has been encountered at depths of about 37 m (120 ft) in the midreach of Pueblo Canyon, about 45 to 60 m (150 to 200 ft) beneath the surface in lower Pueblo and Los Alamos Canyons near their confluence, mainly in basalts in Los Alamos Canyon at 61-76 m (200-250 ft) (Fig. II-6), and in Sandia Canyon near the eastern Laboratory boundary at a depth of about 137 m (450 ft). Perched water has one discharge point at Basalt Spring in Los Alamos Canyon.

The main aquifer of the Los Alamos area is the only aquifer in the area capable of serving as a municipal water supply. The surface of the aquifer rises westward from the Rio Grande within the Tesuque Formation into the lower part of the Puye Formation beneath the central and western part of the plateau. Depth to the aquifer ranges from 360 m (1,200 ft) along the western margin of the plateau to about 180 m (600 ft) at the eastern margin. The main aquifer is isolated from alluvial and perched waters by about 110 to 190 m (350 to 620 ft) of dry tuff and volcanic sediments. Thus, there is little hydrologic connection or potential for recharge to the main aquifer from alluvial or perched water.

Water in the main aquifer is under artesian conditions in the eastern part and along the Rio Grande (Purtymun 1974b). Major recharge to the main aquifer is inferred to be from the west because of the slope of the piezometric surface. The main aquifer discharges into the Rio Grande through springs in White Rock

Canyon. The 18.5 km (11.5 mi) reach of the river in White Rock Canyon between Otowi Bridge and the mouth of Rito de Frijoles receives an estimated 5.3 to 6.8×10^6 m^3 (4,300 to 5,500 ac-ft) annually from the aquifer.

D. Climatology

Los Alamos has a semiarid, temperate mountain climate. Average annual precipitation is nearly 47 cm (19 in.). Thirty-six percent of the annual precipitation normally occurs during July and August from thundershowers. Winter precipitation falls primarily as snow, with accumulations of about 150 cm (59 in.) annually. Snowstorms with accumulations exceeding 10 cm (4 in.) are common in Los Alamos. Some storms can be associated with strong winds, frigid air, and dangerous wind chills.

Summers are generally sunny with moderate, warm days and cool nights. Maximum daily temperatures are usually below 32°C (90°F). Brief afternoon and evening thundershowers are common, especially in July and August. High altitude, light winds, clear skies, and dry atmosphere allow night temperatures to drop below 15°C (59°F) after even the warmest day. Winter temperatures typically range from about –9°C to –4°C (15°F to 25°F) during the night and from –1°C to 10°C (30°F to 50°F) during the day. Occasionally, temperatures drop to –18°C (0°F) or below. Many winter days are clear with light winds, so strong sunshine can make conditions comfortable even when air temperatures are cold.

Average wind speed and direction frequencies at four sites are plotted for daytime, night-time, and total time (Figs. II-7 to II-9). The frequencies are presented as wind roses, which are circles with lines extending from the center representing the direction *from* which the wind blows. The length of each line is proportional to the frequency at which the wind blows from the indicated direction. Each direction is 1 of 16 primary compass points (for example, N and NNE) and is centered on a 22.5° sector. Each spoke consists of different widths representing different wind speed classes. The frequency of calm winds (winds with speed less than 1 mph [0.5 m/s]) is given in the circle's center. Day and night are defined by sunrise and sunset times.

Because of complex terrain, surface winds in Los Alamos often vary greatly with time of day and location. With light, large-scale winds and clear skies, daytime winds are predominantly south to south-southwest as winds flow up the Rio Grande Valley. Thermally driven upslope winds from the southeast and east are also common toward the Jemez Mountains. At night, a shallow drainage wind often flows from the west and northwest high on the Pajarito Plateau. Night-time winds become more parallel to the Valley (south-southwest and north-northeast) both above the drainage winds over the Western Plateau (about 30-40 m [~100-130 ft] above ground level [AGL]) and at the surface toward the Valley. Predominant winds are west to west-northwesterly at the west end of the plateau to south-southwesterly at the east end.

Historically, no tornadoes have been reported to have touched down in Los Alamos County. Strong dust devils can produce winds up to 34 m/s (75 mph) at isolated spots in the County, especially at lower elevations.

Lightning is common over the Pajarito Plateau. There are 58 thunderstorm days during an average year, with most occurring during the summer. Lightning protection is an important design factor for most facilities at the Laboratory. Hail damage can also occur. Hailstones with diameters up to 0.64 cm (0.25 in.) are common; 1.3-cm- (0.5-in.-) diameter hailstones are less common.

The irregular terrain at Los Alamos affects the atmospheric turbulence and dispersion, sometimes favorably and sometimes unfavorably. Enhanced dispersion promotes greater dilution of contaminants released into the atmosphere. The complex terrain and forests create an aerodynamically rough surface, forcing increased horizontal and vertical dispersion. Dispersion generally decreases at lower elevations where the terrain becomes smoother and less vegetated. The frequent clear skies and light, large-scale winds cause good vertical, daytime dispersion, especially during the warm season. Strong daytime heating during the summer can force vertical mixing up to 1–2 km (3,000–6,000 ft) AGL, but the generally light winds are limited in diluting contaminants horizontally.

Clear skies and light winds have a negative effect on night-time dispersion, causing strong, shallow surface inversions to form. These inversions can severely restrict near-surface vertical and horizontal dispersion. Inversions are especially strong during the winter. Shallow drainage winds can fill lower areas with cold air, thereby creating deeper inversions, common toward the valley (White Rock) on clear nights with light

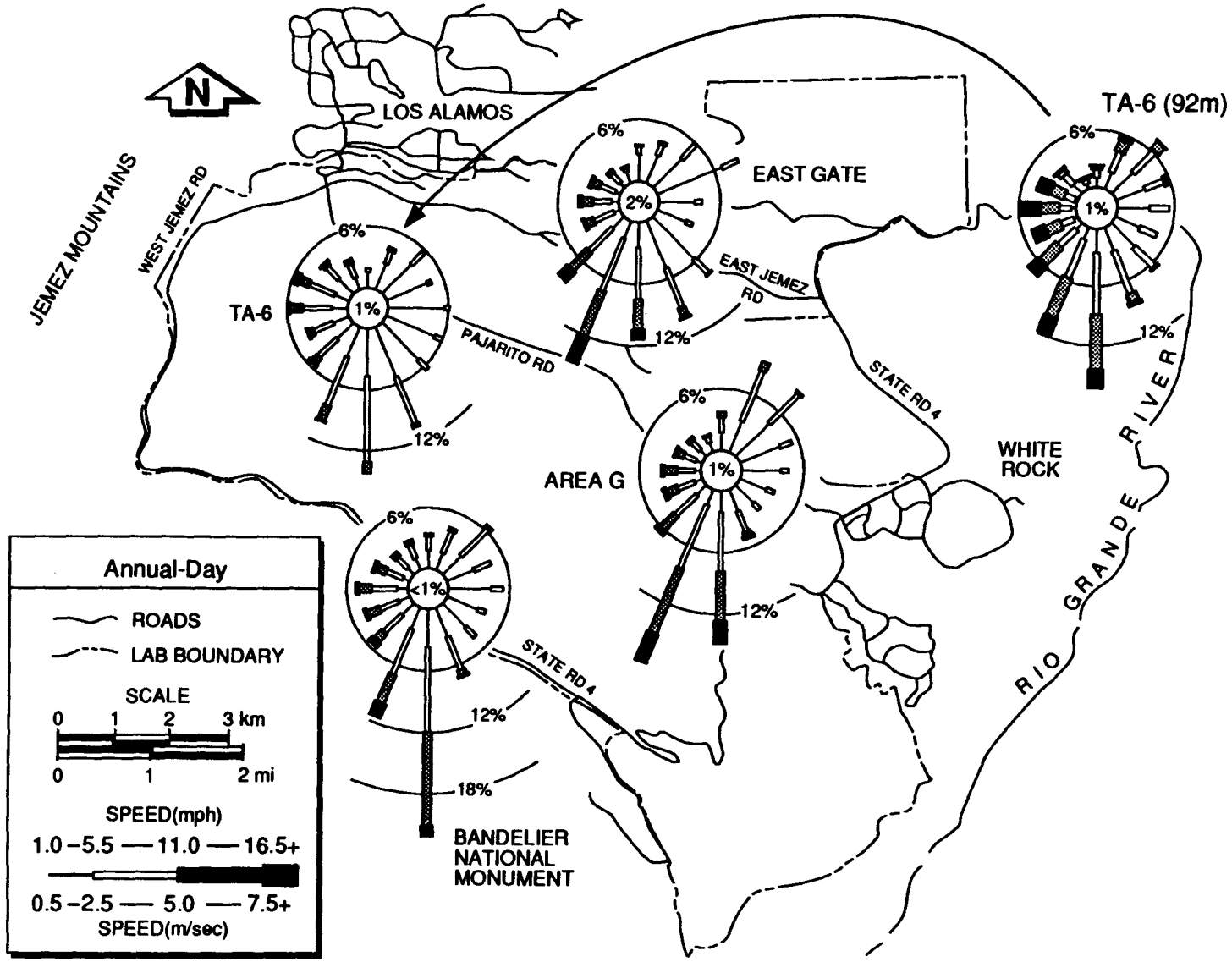


Fig. II-7. Average daytime wind roses at Laboratory stations. Surface winds are represented at TA-6 (upper left) clockwise to East Gate, Area G, and Bandelier. TA-6 winds at the 92 m (300 ft) level are also shown.

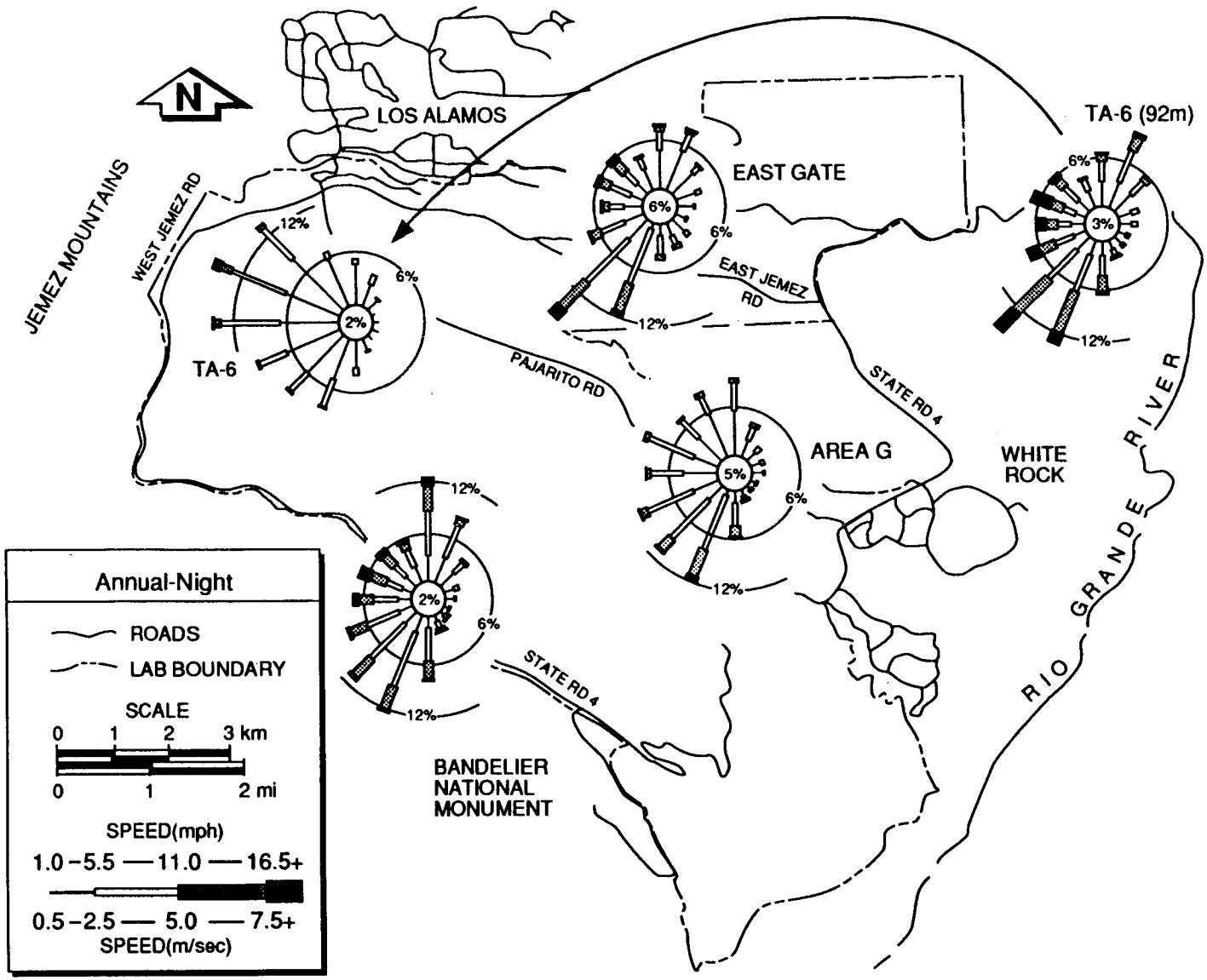


Fig. II-8. Average night-time wind roses at Laboratory stations. Surface winds are represented at TA-6 (upper left) clockwise to East Gate, Area G, and Bandelier. TA-6 winds at the 92 m (300 ft) level are also shown.

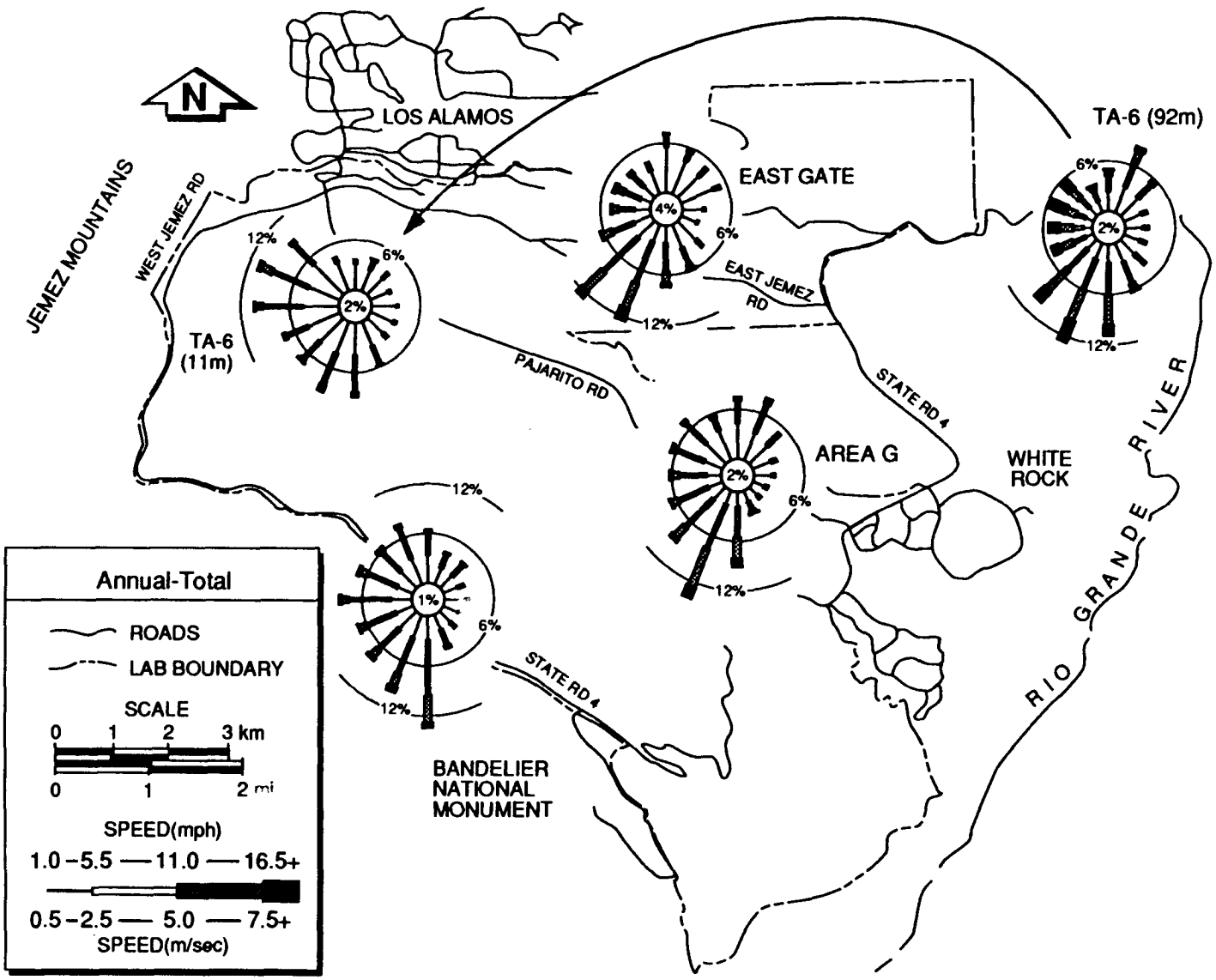


Fig. II-9. Average total wind roses at Laboratory stations. Surface winds are represented at TA-6 (upper left) clockwise to East Gate, Area G, and Bandelier. TA-6 winds at the 92 m (300 ft) level are also shown.

winds. Canyons can also limit dispersion by channeling air flow. Strong, large-scale inversions during the winter can limit vertical mixing to under 1 km (3,000 ft) AGL.

Dispersion is generally greatest during the spring when winds are strongest. However, deep vertical mixing is greatest during the summer. Low-level dispersion is generally the least during summer and autumn when winds are light. Even though low-level, winter dispersion is generally greater, intense surface inversions can cause the least dispersive conditions during the night and early morning.

The frequencies of atmospheric dispersive capability are 52% unstable (stability classes *A–C*), 21% neutral (*D*), and 27% stable (*E–F*) during the winter at TA-59. The frequencies are 44%, 22%, and 34%, respectively, during the summer. These stability category frequencies are based on measured vertical wind variations. Stability generally increases (becomes less dispersive) toward the valley.

E. Ecology

The diversity of ecosystems in the Los Alamos area is due partly to the dramatic 1,500 m (5,000 ft) elevation gradient from the Rio Grande on the east to the Jemez Mountains 20 km (12 mi) to the west and partly to the many canyons with abrupt surface slope changes that dissect the area. Six major vegetative complexes or community types are found in Los Alamos County. These are juniper-grassland, piñon-juniper, ponderosa pine, mixed conifer, spruce-fir, and subalpine grassland. The juniper-grassland is found along the Rio Grande on the eastern border of the plateau and extends upward on the south-facing sides of canyons, at 1,700 to 1,900 m (5,600–6,200 ft). The piñon-juniper, generally in the 1,900 to 2,100 m (6,200–6,900 ft) elevation range, includes large portions of the mesa tops and north-facing slopes at the lower elevations. Ponderosa pine is found in the western portion of the plateau in the 2,100 to 2,300 m (6,900–7,500 ft) elevation range. These three types predominate, each occupying about one-third of the Laboratory site. The mixed conifer, at an elevation of 2,300 to 2,900 m (7,500–9,500 ft), interfaces with the ponderosa pine in the deeper canyons and north slopes and extends to the west from the higher mesas on the slopes of the Jemez Mountains. The subalpine grasslands are mixed with the spruce-fir communities at higher elevations of 2,900 to 3,200 m (9,500–10,500 ft).

Because of the variety of complex interlocking ecotones in the Los Alamos area, there is no single ecological structure of food webs that can characterize the associations of flora and fauna in the area. Food web relations for the biota of the Laboratory environs have been studied only enough to provide general descriptions and expectations.

Generally, the larger mammals and the birds are wide-ranging and occupy commensurately large habitats, from the dry mesa-canyon country at lower elevations to the high mountain tops west of the Laboratory. The smaller mammals, reptiles, invertebrates, and vegetation are more sensitive to the variations in elevation and thus are confined to generally smaller habitats.

As a result of past and present human use of the Laboratory's environs, areas of vegetation are undergoing secondary succession. This process has had, and will continue to have, important consequences to the natural systems. Farming by prehistoric Indians and by Spanish and Anglo settlers before the Laboratory's establishment in 1943 created open grassy areas on the mesas that have not completely returned to climax plant communities. These areas afford suitable feeding areas for herbivores, especially the deer and elk, with adjacent timbered canyon slopes providing cover for these species. The food web relationships of the mesa areas are related to those of the canyons to some degree.

F. Cultural Resources

Approximately 60% of DOE land in Los Alamos County has been surveyed for prehistoric and historic cultural resources, and close to 1,000 have been recorded. Over 95% of these ruins date from the fourteenth and fifteenth centuries. Most of the sites are found in the piñon-juniper vegetation zone, with 80% lying between 5,800 and 7,100 ft in elevation. Almost three-quarters of all ruins are found on mesa tops, which are the preferred locations for development at the Laboratory today.

G. Population Distribution

Los Alamos County had an estimated 1991 population of approximately 18,200 (based on the 1990 U.S. Census, adjusted to July 1, 1991) (USBC 1991). Two residential and related commercial areas exist in the

County (Fig. II-2). The Los Alamos townsite (the original area of development, now including residential areas known as Eastern Area, Western Area, North Community, Barranca Mesa, and North Mesa) has an estimated population of 11,400. The White Rock area (including the residential areas of White Rock, La Senda, and Pajarito Acres) has about 6,800 residents. About 40% of the people employed in Los Alamos commute from other counties. Population estimates for 1991 place about 218,000 persons within an 80 km (50 mi) radius of Los Alamos (Table II-1).

Table II-1. 1991 Population within 80 km of Los Alamos[a,b]

	Distance from TA-53 (km)								
Direction	**1–2**	**2–4**	**4–8**	**8–15**	**15–20**	**20–30**	**30–40**	**40–60**	**60–80**
N	1	0	0	0	0	0	1,152	0	373
NNE	0	0	0	574	0	550	1,756	1,824	224
NE	1	0	0	0	322	15,606	1,024	1,153	3,905
ENE	0	0	0	1,985	1,586	2,780	2,778	1,205	2,241
E	0	0	85	26	569	1,172	712	0	1,412
ESE	0	0	0	0	0	299	23,695	1,079	1,493
SE	0	0	6,776	0	0	0	54,778	2,500	8
SSE	0	0	0	0	0	0	436	4,449	97
S	0	0	0	50	0	333	642	7,069	0
SSW	0	0	0	20	0	854	210	8,609	34,996
SW	0	0	0	0	0	0	329	4,345	0
WSW	0	0	0	0	0	329	327	2,660	216
W	0	0	0	0	0	0	0	171	138
WNW	0	1,439	6,553	0	0	0	0	0	3,220
NW	0	525	1,726	0	0	0	0	1,459	0
NNW	0	580	581	0	0	0	0	65	63
1991 Pop. Distribution	2	2,544	15,721	2,655	2,477	21,923	87,839	36,588	48,386

[a]Total population within 80 km of Los Alamos is 218,135.

[b]Please see Fig. II-2 for more information on the location of the population.

III. COMPLIANCE SUMMARY

Los Alamos National Laboratory (LANL or the Laboratory) operates under multiple federal and state environmental regulations and permits which mandate compliance standards for environmental qualities.

LANL had frequent interactions with federal and state Resource Conservation and Recovery Act (RCRA) personnel during 1991. Six underground storage tanks were removed during the year. The Laboratory is not able to comply with RCRA requirements related to storage of mixed waste and certain hazardous waste subject to the land-disposal restrictions because of the lack of adequate or available treatment capacity. A National Capacity Variance allows the storage of some of these wastes.

The Laboratory was in compliance with its liquid discharge permit in 99.0% of samples from its sanitary effluent outfalls and in 98.8% of its industrial effluent outfall samples in 1991. Under a Federal Facilities Compliance Agreement (FFCA) with the Environmental Protection Agency (EPA), sanitary waste treatment facilities are being upgraded to improve compliance.

During 1991, 614 actions proposed to be undertaken at the Laboratory were reviewed for National Environmental Policy Act (NEPA) applicability, and 78 Department of Energy (DOE) Environmental Checklists (DECs) were submitted to DOE on 90 of these projects.

The Laboratory is in compliance with all federal nonradiological ambient air quality standards. As a result of the review of nonradiological emissions from new and modified operations, one air quality permit and three source registrations will be submitted to the New Mexico Environment Department (NMED) in 1992. The Laboratory remained in compliance with EPA standards which limit the effective dose equivalent to members of the public from airborne radioactive emissions to less than 10 mrem/yr. The maximum off-site dose calculated for 1991 was 4.4 mrem with building shielding and occupancy being considered. DOE received a Notice of Noncompliance from EPA and is currently negotiating an FFCA on stack monitoring protocols.

Concentrations of constituents in the drinking water distribution system remained within federal and state water supply standards during 1991. An annual inspection conducted by the U.S. Department of Agriculture found no deficiencies in the Laboratory's pesticide application program.

During 1991, Laboratory archaeologists evaluated 1,110 proposed actions for possible effects on cultural resources which required 51 intensive field surveys. Laboratory biologists reviewed 614 proposed actions for potential impacts on threatened and endangered species; 63 actions required additional study. All of the proposed actions reviewed were outside floodplain/wetland boundaries.

A. Introduction

It is the policy of the Los Alamos National Laboratory to provide a safe and healthful working environment for its employees, the employees of its subcontractors, participating guests, and visitors and to prevent any harm to these individuals, the public, or the environment as a result of the Laboratory's activities.

Many of the activities and operations at the Laboratory involve or produce liquids, solids, and gases

that contain radioactive, nonradioactive but potentially hazardous materials, and combinations of the two. The Environmental Protection Program at the Laboratory monitors for contaminants and pollutants that may result from these operations. The program is under the jurisdiction of a variety of federal and state agencies to ensure that environmental regulations and standards are met. Federal agencies include the EPA and the DOE. The primary state agency involved is the NMED.

In accordance with the policy of the DOE, the Laboratory must comply with federal and state environmental requirements. These requirements address handling, transport, release, and disposal of contaminants and pollutants, as well as protection of ecological, archaeological, historic, atmospheric, and aquatic resources. Regulations specify generic requirements and standards to ensure maintenance of environmental qualities. Table III-1 presents a list of the major environmental legislation which governs the activities of the Laboratory. Environmental permits are issued under the auspices of specific legislation and are site and/or operation specific. A list of the environmental permits which applied to the Laboratory in 1991 is presented in Table III-2.

This summary presents the Laboratory's compliance status with environmental regulations and permits. A description of the applicable laws and/or permits, as well as the results of the monitoring program for 1991 and the first quarter of CY 1992, can be found in specific subsections which follow. The summary includes information on current issues and actions such as the status of the FFCAs, Notices of Violation (NOVs), significant accomplishments in achieving regulatory compliance, and DOE audits and appraisals.

B. Compliance Status

1. Resource Conservation and Recovery Act.

a. Introduction. The RCRA, as amended by the Hazardous and Solid Waste Amendments (HSWA) of 1984, mandates a comprehensive program to regulate hazardous wastes, from generation to ultimate disposal. A major emphasis of the amendments is to reduce hazardous waste volume and toxicity and to minimize land disposal of hazardous waste. EPA grants RCRA permits to specifically regulate hazardous waste and the hazardous component of radioactive mixed waste.

A RCRA Part A permit application identifies (1) facility location, (2) owner and operator, (3) hazardous or mixed wastes to be managed, and (4) hazardous waste management methods. A facility that has submitted a RCRA Part A permit application is allowed to manage hazardous or mixed wastes under transitional regulations known as the Interim Status Requirements pending issuance of a RCRA Operating Permit. The RCRA Part B permit application consists of a detailed narrative description of all facilities and procedures related to hazardous or mixed waste management.

The EPA has granted RCRA authorization to New Mexico, transferring regulatory control of hazardous wastes to the NMED. State authority for hazardous waste regulation is the Hazardous Waste Act (HWA) and Hazardous Waste Management Regulation (HWMR). However, NMED has not yet obtained authorization for implementing the majority of the 1984 HSWA. HWMR adopted the federal codification for generating and managing hazardous waste. Although this adoption makes the state regulations more consistent with federal regulations and easier to interpret, some confusion will continue because only those federal regulations in effect on July 1, 1990, were adopted. The State of New Mexico's Hazardous Waste Program was delegated authority for mixed waste by the EPA in July 1990. A Part A Permit was submitted on January 25, 1991, within the required six month period for mixed waste storage and treatment units throughout the Laboratory. A schedule is being negotiated for submittal of the Part B application.

The Laboratory is currently out of compliance with RCRA requirements related to storage of certain hazardous and mixed waste subject to the land-disposal restrictions (LDRs). These include solvents; dioxins/furans; California list; and the first, second, and third groups of scheduled wastes. No treatment alternative has been available for these wastes. The National Capacity Variance on storage of scheduled mixed waste expires on May 8, 1992. DOE Headquarters (HQ) and EPA have been negotiating an extension of the Variance. The Laboratory will begin negotiating an FFCA with EPA Region 6 to develop a schedule to bring all waste subject to LDRs into compliance.

The Laboratory produces a wide variety of hazardous wastes. Small volumes of all chemicals listed under 40 CFR 261.33 could exist at the Laboratory as a result of ongoing research. Process

Table III-1. Major Environmental Regulations under which the Laboratory Operated in 1991

Regulation	Regulatory Citation	Responsible Agency	Related Legislation
Resource Conservation and Recovery Act	RCRA, 40 CFR 260-268, 270-272, 280, and 281	EPA/NMED	Hazardous Waste Facility Permit (RCRA Operating Permit) regulates treatment, storage, and disposal of hazardous wastes. Hazardous and Solid Waste Amendments (HSWA Permit) address releases of hazardous constituents. NM Hazardous Waste Act NM Hazardous Waste Management Regulations NM Solid Waste Regulations NM Underground Storage Tank Regulations
Clean Water Act	CWA 40 CFR 122	EPA/NMED	National Pollutant Discharge Elimination System (NPDES) (40 CFR 122): two permits mandate specific monitoring and reporting conditions along with setting standards for effluent quality for Laboratory discharges to the environment. NM Water Quality Control Commission Regulations NM Liquid Waste Disposal Regulations NM Oil Conservation Division - Groundwater discharge plan, Fenton Hill
National Environmental Policy Act	NEPA, 40 CFR 1500-1508, 10 CFR 1021	Council on Environmental Quality	
Federal Clean Air Act	CAA 40 CFR 50-99	EPA/NMED	National Emission Standards for Hazardous Air Pollutants (NESHAP) for **Radionuclides** (40 CFR 61, Subpart H) requires that no member of the public receive more than 10 mrem/yr (effective dose equivalent), **Asbestos** (40 CFR 61, Subpart M) requires no visible asbestos emissions to the environment, and **Beryllium** (40 CFR 61, Subpart C) requires notification, emission limits, and stack performance testing. Ambient Air Quality Standards NM Air Quality Control Regulations

Table III-1 (Cont.)

Regulation	Regulatory Citation	Responsible Agency	Related Legislation
Safe Drinking Water Act	SDWA 40 CFR 141-148	EPA/NMED	NM Water Supply Regulations
Federal Insecticide, Fungicide, and Rodenticide Act	FIFRA	U.S. Department of Agriculture	NM Pest Control Act
National Historic Preservation Act	NHPA Section 106	State Historic Preservation Officer	
Endangered Species Act	Public Law 93-205	U.S. Fish and Wildlife	
Floodplain Management	Executive Order 11988	U.S. Corps of Engineers	
Protection of Wetlands	Executive Order 11990	U.S. Corps of Engineers	
Comprehensive Environmental Response, Compensation, and Liability Act	CERCLA 40 CFR 300 and 302	EPA	Superfund Amendments and Reauthorization Act (SARA) – Title III Sec. 313: Emergency Planning and Community Right-to-Know Act.
Toxic Substances Control Act	TSCA 40 CFR 761, 762, and 792	EPA	Polychlorinated biphenyls (PCBs) (40 CFR 461)
Atomic Energy Act		Nuclear Regulatory Commission/DOE/EPA	

Table III-2. Environmental Permits under which the Laboratory Operated in 1991

Permit Type	Permitted Activity	Issue Date	Expiration Date	Administering Agency
RCRA hazardous waste facility	Hazardous waste storage, treatment, and disposal	November 1989	November 1999	NMED
	Postclosure care	Application submitted September 1988		EPA
	RCRA Mixed Waste	Part A application submitted January 1991		EPA
HSWA	RCRA Corrective Activities	March 1990	December 1999	EPA
NPDES,[a] Los Alamos	Discharge of industrial and sanitary liquid effluents	Modified permit January 30, 1990	March 1, 1991 [b]	EPA
NPDES, Fenton Hill	Discharge of industrial liquid effluents	October 15, 1979	June 30, 1983 [b]	EPA
NMLWD Regulations[c]	Discharge of sanitary effluents from septic tank systems into soil	[d]	—	NMED
Groundwater discharge plan, Fenton Hill	Discharge to groundwater	July 9, 1990	June 5, 1995	NMOCD [e]
Air Quality (NESHAP)[f]	Construction and operation of four beryllium facilities	December 26, 1985; March 19, 1986; September 8, 1987; April 26, 1989	—	NMED
Open Burning (AQCR 301)	Burning of jet fuel for ordnance testing, TA-11	August 30, 1991	After four tests	NMED
Open Burning (AQCR 301)	Burning of scrap wood from experiments, TA-36	October 10, 1991	October 10, 1992	NMED
PCBs[g]	Disposal of PCBs at TA-54, Area G	June 5, 1980	—	EPA
PCB oil	Incineration of PCB oils [h]	May 21, 1979	—	EPA

[a]National Pollutant Discharge Elimination System.
[b]Permit administratively extended while new permit is pending.
[c]New Mexico Liquid Waste Disposal Regulations.
[d]Dates vary depending on individual permits.
[e]New Mexico Oil Conservation Division.
[f]National Emission Standards for Hazardous Air Pollutants.
[g]Polychlorinated biphenyls.
[h]No incineration occurred during 1991 even though the activity was permitted.

wastes, such as liquid wastes from circuit board preparation and lithium hydride scrap from metal machining, are generated from ongoing manufacturing operations that support research. Although they occur in larger volumes than discarded laboratory chemicals, process wastes are few in number, are well defined, and are not acutely toxic. High-explosive (HE) wastes include small pieces of explosives and contaminated sludges and liquids that are thermally treated on site.

Table III-3 presents a list of the significant RCRA-related interactions the Laboratory had with EPA and NMED in 1991 and the first quarter of 1992.

Table III-3. Resource Conservation and Recovery Act Interactions among the Laboratory, the U.S. Environmental Protection Agency, and the New Mexico Environment Department[a] in 1991 and First Quarter of 1992

January 8, 1991	New Mexico Environmental Improvement Division (NMEID) issues letter withdrawing the 12/14/90 NOV agreeing there was some justification for misunderstanding; however, the required reports are to be submitted by the deadline in the NOV letter.
January 16, 1991	LANL submits the required reports (first three quarters) and a fourth as per Permit Attachment I.
January 25, 1991	LANL/DOE submits Part A application for continued operation of mixed waste units to NMEID.
February 26, 1991	LANL/DOE submits a 7-day notification to NMEID that soil contaminated by diesel fuel was discovered during the closure of Underground Storage Tanks (USTs) Technical Area (TA) 64-RC-73.
March 18, 1991	A letter dated March 6, 1991, is received from NMED informing LANL/DOE that no additional work is required at UST TA-3-36-3. This letter is NMED's version of a closure notification.
March 26, 1991	LANL/DOE submits a 30-day letter to NMED for UST TA-64-RC-73.
March 29, 1991	LANL/DOE submits a 7-day notification to NMED that soil contaminated by dielectric oil was discovered during the closure of two USTs (TA-35-TSL-188-1 & TA-35-TSL-188-2).
April 5, 1991	A letter dated March 26, 1991, is received from NMED informing LANL/DOE that no additional work is required at UST TA-55-15. This letter is NMED's version of a closure notification.
	A letter dated March 26, 1991, is received from NMED informing LANL/DOE that no additional work is required at UST site TA-55-16. This letter is NMED's version of a closure notification.
April 8, 1991	LANL/DOE submits a 45-day letter to NMED for UST TA-64-RC-73.
April 24, 1991	LANL/DOE submits a 30-day letter to NMED for USTs TA-35-188-1 & 2.
April 29, 1991	NMED conducts the annual RCRA compliance inspection from 4/29/91 through 5/3/91. Seven violations were noted in the close-out briefing on 5/3/91.
May 7, 1991	LANL/DOE submits a 45-day letter to NMED for USTs TA-35-TSL-188-1 & 2.
May 24, 1991	DOE/LANL receives NOV from NMED for violations of the New Mexico HWMRs. The letter reports nine violations (i.e., two were added after close-out).

Table III-3 (Cont.)

June 27, 1991	LANL notifies NMED that UST TA-3-191 was being removed on 6/28/91. However, the UST was removed by Johnson Controls (JCI) on 6/27/91.
June 28, 1991	DOE/LANL responds to NMED's RCRA notice of violation letter.
	Representatives from NMED and LANL meet to evaluate the UST TA-3-191 excavation. Soil contaminated with gasoline is discovered at this time. Representatives from LANL and the DOE Los Alamos Area Office (LAAO) meet with NMED to discuss findings at the TA-53 mixed waste lagoons (e.g., potential leakage) and plans of action.
July 11, 1991	LANL/DOE submits a 7-day notification to NMED that soil contaminated by gasoline was discovered during the closure of UST TA-3-191 located at TA-3 SM-16.
July 25, 1991	LANL delivers mixed waste Part B application for TA-53 surface impoundments to NMED.
July 29, 1991	Representatives of NMED's UST Bureau visit several UST sites at LANL. Sites visited include TA-64, TA-35, TA-54 Area J, TA-3 Building SM-16, TA-16 UST storage area. No problems are found.
August 13, 1991	LANL transmits the 7-day notification report for the petroleum release at the TA-60 Tank Farm to DOE for processing and submittal to the State.
August 21, 1991	LANL/DOE submits a 45-day letter to NMED for UST TA-3-191.
August 31, 1991	LANL/DOE submits a 30-day letter to NMED for a petroleum release at TA-60 Tank Farm, fuel loading station.
September 13, 1991	LANL submits draft Exposure Information Report to LAAO for review.
September 18, 1991	LANL/DOE submits a 45-day letter to NMED for a petroleum release at TA-60 Tank Farm, fuel loading station.
November 25, 1991	LANL makes the required 48-hour notification to NMED about a planned site investigation at TA-60 Tank Farm.
December 9, 1991	LANL receives information from NMED's UST Bureau that the state received authorization to implement and enforce the federal UST Program in October 1990.
December 10, 1991	LANL receives NMED close-out letter for UST site TA-64-RC-73. The close-out letter is dated December 9, 1991.
January 16, 1992	Meet with NMED and tour TA-55 Treatment, Storage, and Disposal (TSD) units and generating processes.
January 21, 1992	The Laboratory received approval from EPA of the RCRA Facility Investigation (RFI) Work Plan for TA-21.
March 3, 1992	Notice of Deficiency letter from NMED on TA-35-125 surface impoundment.
March 11, 1992	DOE and the Laboratory received a written request from EPA to initiate modifications to the HSWA Permit.
March 26, 1992	Meet with NMED about the closure of TA-35-125 and analytical parameters for TA-53 impoundments.

[a]NMEID became NMED in March 1991.

Solid Waste Disposal. On February 15, 1991, LANL submitted the annual solid waste management report to the State of New Mexico Solid Waste Bureau. By 1991, all nonradioactive asbestos was being shipped off site to an approved commercial disposal site. Suspect and radioactive asbestos continued to be disposed into a monofill constructed at TA-54, Area G.

In the spring of 1991, the Waste Management Group (EM-7) excavated two new cells within TA-54, Area J for disposal of administratively-controlled solid waste. This new activity was a continuation of activities identified in a 1989 Notice of Intent (NOI) to Continue to Operate to the State of New Mexico. In addition, LANL continued to dispose of sanitary solid wastes and rubble at the sanitary solid waste and rubble landfill on East Jemez Road. LANL contributed approximately 38% of the total volume disposed at this site during 1991 with the remainder contributed by Los Alamos County residents. Development of a proposed replacement of the East Jemez Road site has been delayed due to funding constraints.

In 1991, JCI salvaged 1,169,000 lb of scrap metal, 360 tons of paper, 4,000 lb of scrap nonhazardous photographic film, and a few thousand truck and automobile tires from the General Services Administration (GSA) motor pool.

No data for the first quarter 1992 are available.

b. RCRA Closure Activities. The status of Laboratory hazardous waste operations to be closed under RCRA regulations is given below:

TA-35, Waste Oil Storage Pits. Closure plans for the two waste oil pits associated with Buildings 85 and 125 at TA-35 were submitted in October 1988, and verbal approval to proceed with closure activities was subsequently received from the state. All contents of the pits and underlying soil were removed and disposed of as hazardous waste. Sampling to verify the removal of contaminants from the area was completed in October of 1989. Preliminary results of the sampling effort revealed that the criteria for clean closure had been met. The pits were backfilled and revegetated at that time. Upon receipt of the final analytical results, it was noted that the allowed sample holding times were exceeded. Because of this problem, it was determined that the data could not be defended as correct. The closure plan was modified to reflect the events of the field work that occurred and to include bore sampling to be used as the final verification of clean closure. Bore sampling was performed in December of 1990 to confirm the removal of all hazardous constituents from the area. It was determined that there were minimal amounts of contaminates left in place. The levels of contamination found to remain after this clean-up effort did not exceed the EPA's health risk based clean-up levels. By achieving these clean-up levels, the Laboratory could still achieve clean closure status for these two units and no post-closure care would be necessary. The NMED is currently reviewing the final closure reports for these units.

TA-40, Scrap Detonation Site. On September 13, 1991, the NMED notified the Laboratory that the closure plans for the TA-40 Scrap Detonation Site had been approved. The plans received no comments from the public. The start date of the closure plan was September 30, 1991. The closure plan called for a phased sampling approach including surface sampling, core sampling, and sampling of an old burn cage and disposal pit. Sampling was done during the week of January 20, 1992. Preliminary results of the sampling revealed no radiological activity, pesticides, herbicides, PCBs, organic compounds, or metals above background and/or RCRA hazardous waste action levels. The final closure report will be submitted to NMED upon receipt of the final analytical results.

TA-54, Waste Oil Storage Tanks. After discovering hazardous waste in six above ground waste oil storage tanks, the Laboratory pumped and disposed of the contents as hazardous waste. The tanks were moved to Area G to make room for needed facilities at Area L. In April of 1990 the Laboratory elected to proceed with the closure of these vessels before receiving an approved closure plan. After several cleanings of the tanks, the final decontamination was accomplished in August. A final closure plan/report that reflected the actual closure process of these units was submitted in June 1991. The process will have to be approved by the state before the disposal or salvaging of the tanks.

TA-16, Landfill at Area P. Closure and post-closure-care plans for the Area P landfill were submitted on November 25, 1985. In late 1987 these plans were modified to include standards that this unit would be subject to once the Laboratory received its RCRA permit. Since that time, the Environmental Restoration (ER) Program Office has come into existence and the

Laboratory has received the HSWA requirements of the RCRA permit. Currently negotiations with the state are under way to extend the closure deadlines for this and other units that appear within the HSWA Module of the RCRA permit. An extension of the closure window would allow the ER program to incorporate the results of the RFI/Corrective Measures Study into the closure process.

c. Underground Storage Tanks. Six USTs in need of upgrades were removed during 1991. A 3,000 gal. diesel fuel UST at TA-3 (TA-3-36-3) was removed and was not replaced. A 200 gal. gasoline tank (TA-3-191) was removed and will be replaced with another tank in FY92. Two USTs, which contained dielectric oil and had a 6,000 gal. fuel capacity each, were removed at TA-35 (TA-35-188 1 & 2). Replacements for these tanks are pending. A diesel fuel UST (TA-64-RC-73) with a 1,000 gal. fuel capacity was removed from the Central Guard Station. Replacement of this UST is scheduled for FY92. The final UST (TA-55-16) removed was a 560 gal. diesel tank, located at TA-55. Replacement of this tank is also scheduled for FY92.

No data for the first quarter of 1992 are available.

d. Other RCRA Activities. Areas L and G, located at TA-54 on Mesita del Buey, have been used for disposal of hazardous and mixed wastes and are subject to RCRA regulation. Information on a groundwater monitoring waiver for both Areas L and G has been submitted to NMED. Vadose zone (the subsurface above the main aquifer) monitoring is being conducted quarterly throughout Areas L and G to identify any releases from the disposal units. This type of monitoring is used to detect the presence of organic vapor in the vadose zone. A total of 27 monitoring systems have been emplaced, one during the past year.

Table D-1 lists hazardous waste management facilities at the Laboratory. In FY89, the TA-40 scrap detonation pit used for destroying HE scrap was closed to waste detonation. All scrap is now handled at other detonation and open-burning sites included in the Part B permit. A closure plan for the TA-40 facility was submitted to NMED and was approved in 1991.

A RCRA-permitted controlled air incinerator (CAI) for treating hazardous waste is located at TA-50-37. A trial burn was conducted in October 1986. The raw data were submitted to NMED in December 1986, and a final report for the test burn was submitted on March 5, 1987. These data and the report were used to support the Laboratory's application for a hazardous waste permit for this facility. The permit was issued in November 1989. The CAI is currently closed for upgrades and modifications to improve reliability to allow the burning of waste on a routine basis.

e. RCRA Compliance Inspection. NMED conducted a hazardous waste inspection at LANL on April 29 through May 3, 1991 (Table III-4). On May 24, 1991, NMED sent DOE an NOV letter alleging violations of the New Mexico Hazardous Waste Management Regulations (HWMR-6). The alleged violations consisted of failure to conduct or maintain adequate inspection records, to properly label containers, to use a satellite storage area properly to meet waste storage time limits, and to properly classify waste. These alleged violations presented no threat to human health or to the environment. All violations were corrected within the 30 days allowed by state statute. The Laboratory's response, sent to NMED in June 1991, was found adequate, as stated in a letter from NMED dated July 12, 1991.

f. RCRA Personnel Training. The Laboratory provides training to generators of hazardous waste and to workers assigned to support the permitted hazardous waste management facilities. This training is based on the general requirements of RCRA (40 CFR Parts 262.34 and 265.16) and Appendix C of the Part B Operating Permit.

The two-hour training covers the following topics:

- identification of factors that determine if a waste is hazardous,
- determination of the need for permits and controls,
- waste reduction,
- preparation of waste for transport,
- waste sampling protocols,
- waste disposal documentation, and
- emergency response.

By September 30, 1991, more than 4,400 LANL employees and contractors had attended a Waste Generator Training course required, by Laboratory policy, for anyone generating solid, hazardous, or radioactive waste. Training continued through

Table III-4. Environmental Inspections and Audits Conducted at the Laboratory in 1991 and the First Quarter of 1992

Date	Purpose	Performing Agency
January–June, 1991	Compliance Program	DOE/LAAO
January 23–24, 1991	Inspection of Permitted Beryllium Operations Machining	NMEID[a]
February 21, 1991	Site Visit & Meetings with Region II	NMEID
February 28–March 1, 1991	Site Visit & Meeting with NPDES Enforcement	EPA
April 28–May 3, 1991	RCRA Compliance Inspection of Hazardous Waste Management Activities	NMED
May 15, 1991	Inspection of Permitted Beryllium Operations Machining	NMED
May 31, 1991	Storm Water/Water Course Inspection	NMED
June 3, 1991	NPDES Quality Assurance Inspection	DOE/LAAO
June 4–6, 1991	Site Visit & Meeting with TSCA Permit Writer	EPA
August 29–30, 1991	O & M Inspection of Sanitary Waste Treatment Facilities	NMED
September 23–November 10, 1991	Tiger Team Audit	DOE
November 14, 1991	Site Visit & Meetings with NPDES Permit Writer	EPA
November 19–20, 1991	NPDES Compliance Evaluation Inspection	EPA
December 11, 1991	Sampling Inspection of TA-53 Sanitary Lagoons	NMED
January 29–30, 1992	Inspection of Permitted Beryllium Machining Operations	NMED
February 7, 1992	TA-53 Waste Stream Characterization Inspection	NMED
February 30, 1992	Inspection of Otowi Well #4 Construction Project	NMED
March 17, 1992	Spill Cleanup Inspection	DOE/LAAO
March 17, 1992	TSCA Inspection	EPA

[a]NMEID became NMED in March 1991.

December 31 and into 1992. Updates and continuing training will be offered in a video training program available in late 1992. This course discusses LANL waste management procedures, laws affecting management of wastes, proper identification of wastes, and how to fill out waste identification forms.

In addition, Waste Management Coordinators receive training designed for their specific job responsibilities. Each participant receives an eight-hour overview including sessions in waste minimization, waste management terms, and legal/regulatory authorities. Participants are encouraged to attend additional sessions dealing with specific kinds of waste.

Workers assigned to support hazardous waste management facilities listed in the Part B Operating Permit are required to attend various training courses or review on-the-job instructions including the annual eight-hour Occupational Safety and Health Administration (OSHA) refresher, spill prevention and control techniques, and site contingency plans.

No data for the first quarter of 1992 are available.

g. Waste Minimization. Subtitle A of RCRA states that the generation of hazardous waste is to be reduced or eliminated as soon as possible. All hazardous waste must be handled minimizing the present and future threat to human health and the environment. The act promotes recovery, recycling, and treatment as alternatives to land disposal of hazardous wastes.

Every two years the Laboratory submits a report on waste minimization by waste streams to NMED. In 1991, 13 streams reported minimized waste.

h. HSWA Compliance Activities. In January 1991, the Laboratory submitted Part A of the RCRA permit application for mixed waste to the NMED. A schedule is being negotiated for submittal of the Part B portion of the application.

The Laboratory submitted its first site-specific work plan under the HSWA requirements in May 1991. The work plan addresses characterization activities at TA-21, which will begin in 1992. This technical area is one of the oldest TAs still active and contains over 100 solid waste management units (SWMUs) regulated under HSWA. These units contain residual concentrations of radionuclides, organic chemicals, and metals released during nearly 50 years of operation. The Part B permit application for TA-53 Surface Impoundments was submitted on July 25, 1992, to NMED. The programmatic plan for environmental restoration at the Laboratory was updated in November 1991. During 1991, the Laboratory drafted new work plans to investigate eight new areas, including the Los Alamos townsite. These plans are due to EPA in May 1992.

Interim Action Assessments for Environmental Restoration. An interim action is the recourse taken to evaluate a SWMU or other area of concern before the normal RCRA corrective action. Most interim actions, therefore, are associated with institutional needs, i.e., construction projects, routine maintenance, and other activities that impact SWMUs.

The main objectives of an interim action are to determine (1) the impact on the health and safety of construction workers, (2) whether construction workers will be generating hazardous waste subject to the RCRA HWMRs, including land disposal restrictions or radioactive waste subject to DOE regulation, and (3) whether the project will have an adverse impact on the ER program's final remedy (corrective action) for the SWMU. A SWMU Interim Action Technical Team (the Waste Site Studies Section) was established in Group EM-8 to conduct reconnaissance sampling to determine the nature and extent of contamination, if any. During 1991 the Waste Site Studies Section completed approximately 30 interim action assessments. The Section completed seven interim action assessments during the first quarter of 1992.

One-hundred-year Floodplain Study. Under the existing HSWA permit requirements, the EPA stipulates that regulated hazardous waste treatment, storage, and disposal facilities must delineate all 100-year floodplain elevations within their boundaries. At the Laboratory, these floodplains are located within ungaged watersheds that drain approximately 43 square miles on the Pajarito Plateau. These floodplains were mapped in 1990 using a combined graphic information system and computer modeling (GIS-HEC) approach. These maps are maintained on file by the Facilities Engineering Planning Group (ENG-2) and satisfy the RCRA/HSWA permit condition requiring floodplain definition.

Wetland Characterization Studies. As part of the DOE/Laboratory RCRA permit's HSWA Module, in coordination with the United States Fish and Wildlife (USFW) Service, all wetlands greater than one acre within the Laboratory boundaries were mapped in 1990. The mapping was part of the USFW National

Wetland Inventory (NWI). The NWI mapping used aerial mapping and a hierarchical classification based on ecological, hydrological, and soil characteristics.

Field studies to characterize wetlands identified by NWI and to identify additional wetlands not identified by the NWI have been undertaken. During 1991 wetland studies in two palustrine (marsh) wetlands (Pajarito and Sandia Canyons) were initiated and springs and associated wetlands within Ancho, Chaquehui (Doe Springs) and White Rock Canyons (6A, 9, and 9A as noted on Fig. III-1) were characterized. The purpose of the study was fourfold:

- to define the presence of wetland indicators: hydrology, hydrophytic vegetation, and hydric soils;
- to characterize the use of the springs and associated wetlands by reptiles, amphibians, small mammals, and aquatic invertebrates;
- to determine present and future impacts and threats to these wetlands; and
- to determine the presence of threatened or endangered species.

Vegetative transects, capture/release studies for small mammals, trapping of ground dwelling insects, and sampling of aquatic invertebrates were done for the perennial stream originating with the spring in Ancho Canyon. Vegetative transects and sampling of aquatic invertebrates were done for springs in Chaquehui and White Rock Canyons.

Trespassing cattle were found to present the largest impact to the spring and perennial stream habitats within Ancho, Chaquehui, and White Rock Canyons. Considerable overgrazing and degradation of the stream have occurred because of the cattle. Additionally, a strip of land approximately 150 ft above the water level of the Rio Grande has been degraded by high water levels from Cochiti Lake in the mid-1980s. All trees within this zone are dead; the stream channel has become silted and channelized.

2. Clean Water Act.

a. National Pollutant Discharge Elimination System. The primary goal of the Clean Water Act (CWA) (33 U.S.C. 446 *et seq.*) is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The act established the NPDES that requires permitting of all point-source effluent discharges to the nation's waters. The NPDES permits establish specific chemical, physical, and biological criteria that an effluent must meet before it is discharged. Although most of the Laboratory's effluent is discharged to normally dry arroyos, the Laboratory is required to meet effluent limitations under the NPDES permit program.

The DOE has two NPDES permits, one covering the effluent discharges at Los Alamos and one covering the hot dry rock geothermal facility located 50 km (30 mi) west of Los Alamos at Fenton Hill (Table III-2). The University of California (UC) is a co-permittee with DOE on the permit covering Los Alamos. Both permits are issued and enforced by EPA Region 6 in Dallas, Texas. However, through a joint federal and state agreement, NMED performs some compliance evaluation inspections and monitoring for EPA.

An NPDES application for a new permit was submitted by the Laboratory to EPA on September 4, 1990, in order to meet the 180 day submittal requirement before the old permit expired. The Laboratory's NPDES Permit No. NM0028355 expired on March 1, 1991, and is being administratively continued under 40 CFR 122.6. On May 11, 1991, EPA issued a public notice, fact sheet, and draft NPDES Permit to LANL. On August 8, 1991, the Laboratory submitted comments on the draft permit to EPA. On August 9, 1991, the NMED denied certification of the draft permit. On September 4, 1991, the NMED sent a letter to EPA Region 6 requesting that LANL be allowed to continue its discharge under administrative continuance of the expired permit. A revised draft permit is expected to be issued to LANL in May 1992.

At the present time, the Laboratory's NPDES permit for Los Alamos includes 9 sanitary wastewater treatment facilities and 130 industrial outfalls. A summary of these outfalls is included in Table D-2. The NPDES permit for the geothermal facility at Fenton Hill includes only one industrial outfall.

Under the Laboratory's existing NPDES Permit for Los Alamos, samples are collected for analysis on a weekly basis and results are reported each month to the EPA and NMED. During 1991 effluent limits were exceeded 3 times out of 297 samples collected from the sanitary wastewater facilities. Effluent limits were exceeded 21 times out of 1,799 samples collected from the industrial outfalls. As shown in Fig. III-2 and Tables D-3–D-6, overall compliance for the sanitary

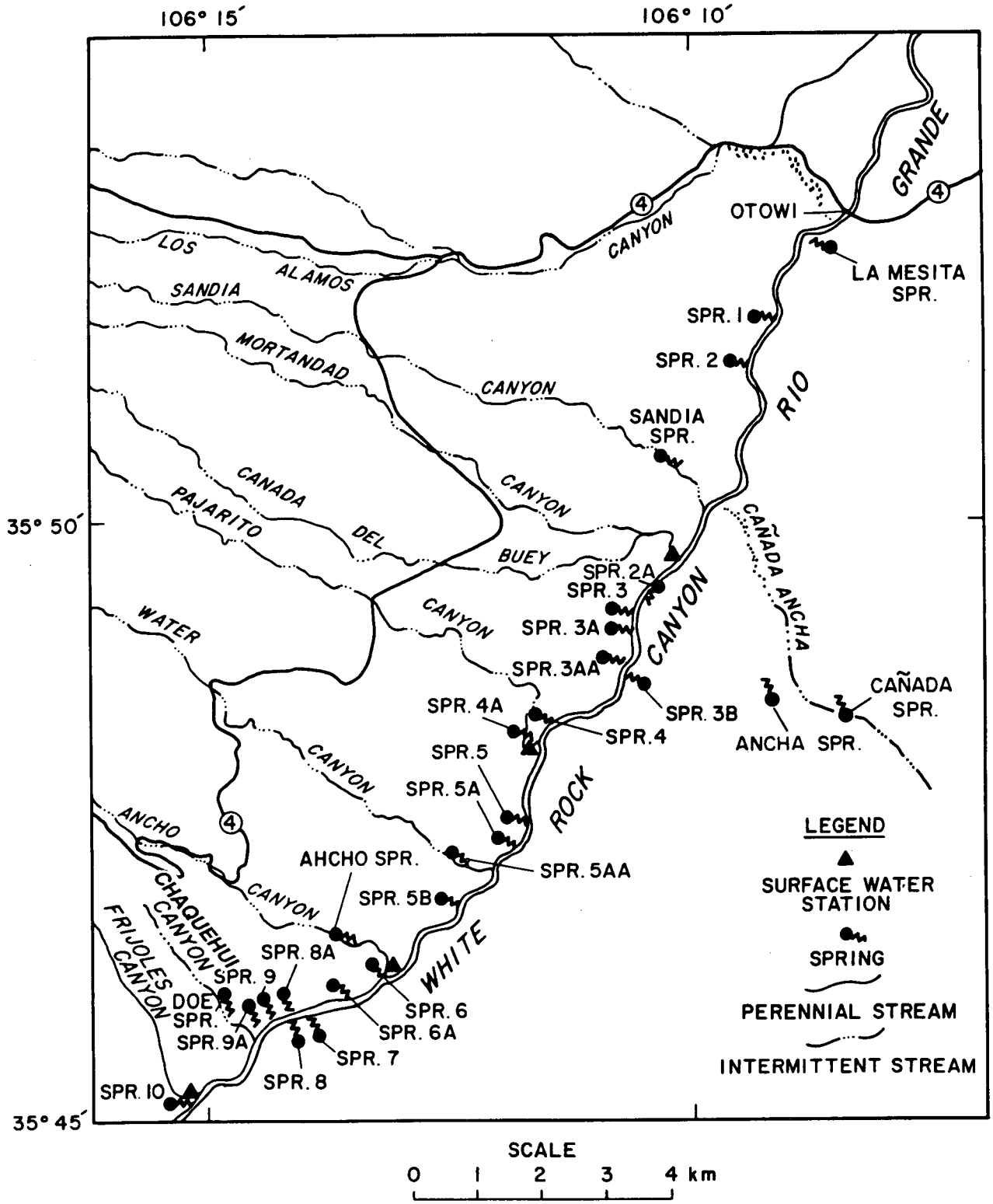


Figure III-1. Generalized location of springs in White Rock Canyon.

and industrial discharges during 1991 was 99.0% and 98.8% respectively. There was no discharge from the industrial outfall at the geothermal facility at Fenton Hill during 1991.

During the first quarter of 1992, none of the 56 samples collected from the sanitary wastewater facilities exceeded effluent limits. Effluent limits were exceeded two times out of 286 samples collected from the industrial outfalls. As shown in Fig. III-3, overall compliance for the sanitary and industrial discharges during the first quarter of 1992 was 100% and 99.3% respectively. There was no discharge for the industrial outfall at the geothermal facility at Fenton Hill during the first quarter of 1992.

Group EM-8 continued the waste stream identification and characterization program during 1991 and the first quarter of 1992 in order to verify that each waste stream is properly monitored under the outfall category in which it is permitted. These studies consist of dye testing, interviews with user groups, and coordination with other Laboratory organizations to determine sources, concentrations, and volumes of pollutants that enter waste streams, receive treatment, and are discharged to the environment.

b. Compliance Evaluation Inspection. On November 19 and 20, 1991, the EPA Region 6, Water Management Division's Enforcement Branch performed a Compliance Evaluation Inspection (CEI) on the Laboratory's NPDES self-monitoring program (Table III-4).

Following the inspection, EPA issued a Notice of Deficiency to UC and the DOE/LAAO for laboratory analytical procedures and recordkeeping for flow recorders. These items were corrected.

On February 19, 1992, EPA mailed a written report of the CEI findings to LANL and DOE. The Laboratory's written response to the CEI report was submitted to EPA on March 24, 1992.

c. Spill Prevention Control. The Laboratory has a Spill Prevention Control and Countermeasure (SPCC) Plan, as required by the CWA in accordance with 40 CFR 112. This plan requires that secondary containment be provided for all above ground storage tanks. There are approximately 40 major containment structures at the Laboratory. The plan also provides for spill control on drum and container storage, chemical storage, and equipment containing oil. Training is provided for the user group's designated Spill Coordinator on the requirements of the SPCC Plan and emergency response. The Spill Coordinator plays the major role in implementation of the SPCC Plan at the group level. During 1991, funding was allocated to various user groups for the purchase and installation of chemical storage lockers for drum storage. Eight chemical lockers and two containment pallets were purchased. The SPCC Plan is scheduled for its third revision, which will begin in early 1992.

d. Storm Water Discharges. On November 16, 1990, the EPA promulgated the final rule for NPDES Regulations for Storm Water Discharges and modified 40 CFR 122, 123, and 124. This rule was required to implement Section 402(p) of the CWA (added by Section 405 of the Water Quality Act of 1987).

Federal facilities are required to submit a permit application if they are engaged in a defined industrial activity. To date, LANL has identified approximately 100 outfalls that will require storm water permit applications. Additionally, the Laboratory will be required to submit storm water permit applications for SWMUs.

Regulations for NPDES General Permits and reporting requirements for storm water discharges associated with industrial activity are expected to be finalized in April 1992. LANL will submit NOIs for general permits for most of the outfalls requiring permitting.

Twenty-five sites were selected for storm water monitoring, and runoff from 18 of these sites was sampled during storm events during July through September 1991. Samples were collected and analyzed in accordance with EPA procedures for all required EPA Form 2F pollutants, all the priority pollutants, total alpha radioactivity, total beta radioactivity, radium 228, and radium 226. This data will be submitted to EPA with LANL storm water permit applications.

3. National Environmental Policy Act.

a. Introduction. NEPA mandates that federal agencies consider the environmental impact of their actions prior to final decision making. NEPA establishes the national policy of creating and maintaining conditions under which man and nature can exist in harmony and fulfill the social, economic, and other requirements of present and future generations.

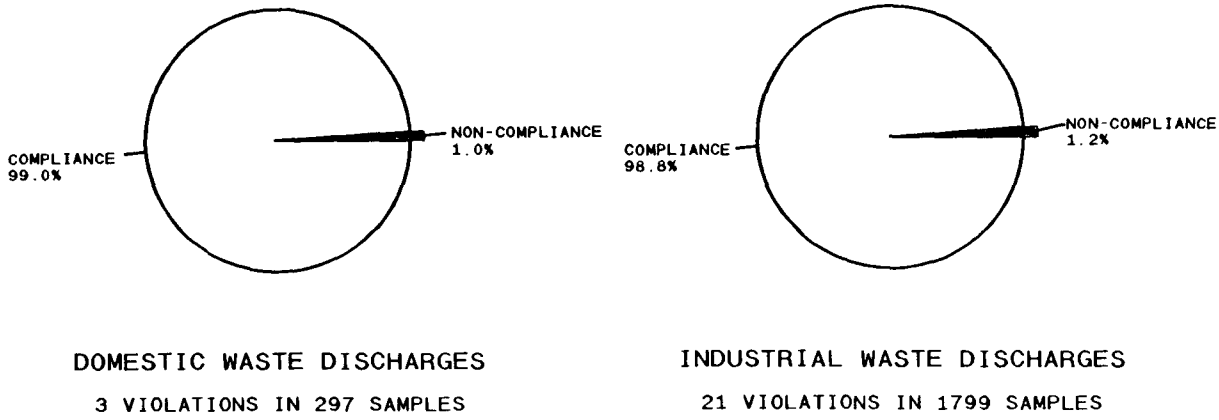


Fig. III-2. Summary of Clean Water Act Compliance in 1991, NPDES Permit NM0028355.

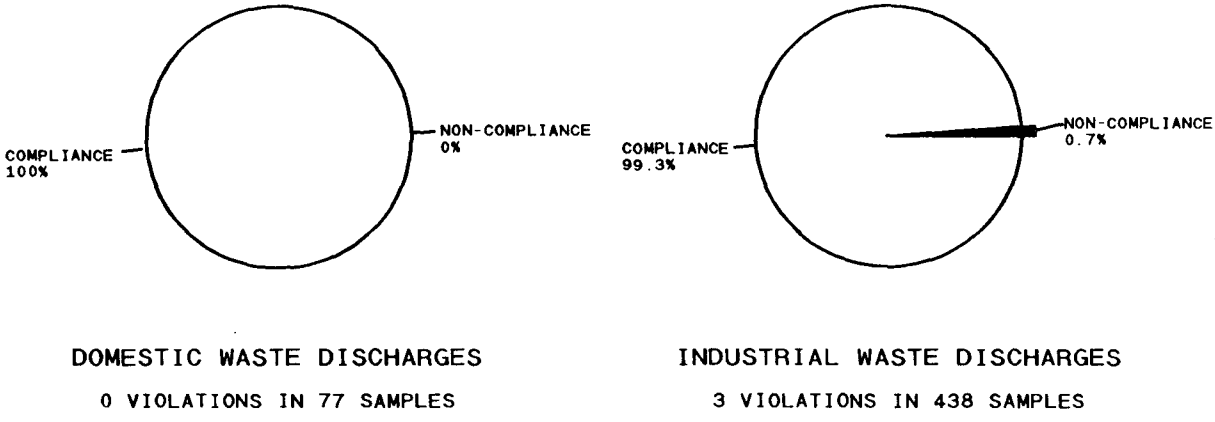


Fig. III-3. Summary of Clean Water Act Compliance in the first quarter of 1992, NPDES Permit NM0028355.

Proposed activities are evaluated to determine whether they have the potential to affect the environment. The sponsoring agency, DOE for LANL activities, is responsible for preparation of NEPA documents, which include the following:

- a categorical exclusion, applied to specific types of activities that have been determined to have no adverse environmental impacts;
- an Environmental Assessment (EA), evaluating environmental impacts, leading to either a finding of no significant impact (FONSI) if the impacts are indeed found to be not significant, or an Environmental Impact Statement (EIS) if the impacts are significant; and
- an EIS, in which impacts of proposed and alternative actions are evaluated and mitigation measures proposed, leading to a record of decision in which the agency discusses a decision on proceeding with the project.

NEPA provides specific protection to areas defined as unique resources (sensitive areas). Under NEPA review, proposed projects are evaluated for possible effects on cultural resources (archaeological sites or historic buildings) in accordance with the National Historic Preservation Act of 1966. In addition, proposed projects are evaluated for potential impact on threatened, endangered or sensitive species, in accordance with the Threatened and Endangered Species Act, and on floodplains or wetlands, in accordance with relevant executive orders (EOs). A proposed project, otherwise eligible for a categorical exclusion, cannot be approved for that NEPA determination if these sensitive areas would be adversely affected.

b. Compliance Actions. During 1991, the Environmental Protection Group (EM-8) reviewed 614 actions proposed to be undertaken at the Laboratory for NEPA applicability, including impacts on sensitive areas. Of these, about one-third were reviewed through the Environment, Safety, and Health (ES&H) Questionnaire system, which provides detailed descriptions of proposed activities. The remainder had no potential environmental, safety, or health issues, e.g., design studies, road signs, etc., and were not reviewed through the ES&H Questionnaire system. Seventy-eight DOE DECs were submitted to DOE on 90 of these projects; some DECs cover more than one related project.

In addition to the 78 DECs submitted to DOE on 1991 projects, 21 DECs were submitted during 1991 on projects reviewed through the ES&H Questionnaire process during 1990 and decisions were still pending at DOE on 21 DECs submitted during 1990. Of these 120 DECs submitted to DOE for decisions, 62 were categorically excluded from additional NEPA documentation, EAs were required on 12, two were covered by prior NEPA determinations, and no decision had been made on the remaining 44 by the end of 1991.

Based on submitted DECs, EAs were required on 12 proposed projects. Five of those EAs were prepared and submitted to DOE and were in review at the end of the year. An additional EA was required and submitted on a project for which no DEC had been prepared because the activity had been initiated at another DOE facility. A FONSI was signed in August for this project. Of the five EAs in review at the end of 1990, FONSIs were signed for three during 1991 and two were still in review at the end of 1991. This information is summarized in Tables III-5 and III-6. Copies of final EAs and FONSIs are available to the public through the Los Alamos Area Office of DOE.

During the first quarter of 1992 (January through March), EM-8 has reviewed 255 proposed actions for NEPA applicability. Of this group, 80 projects have been identified as having possible effects on the environment. Seventeen DECs were submitted covering seventeen proposed actions. Other DECs are in preparation. In addition, umbrella DECs, which cover groups of similar activities, were submitted on anticipated routine maintenance activities, minor modifications for increased workplace habitability, environmental and safety modifications, building and equipment instrumentation, and construction and operation of small support structures.

During the first quarter of 1992, DOE issued categorical exclusions on seven of the outstanding DECs and required EAs on three. Decisions on other submitted DECs are pending. A FONSI was signed January 31, 1992, for an EA on the Relocation of Superconducting Ceramics, Filament Winding, and Mechanical Characteristics Operations, which had been submitted to DOE in December 1990.

Table III-5. Environmental Assessments Submitted to DOE during 1991

Date Submitted	Title
February 4	General Purpose Heat Source Fabrication[a]
April 26	Sorbent Reactivity Study
May 24	Advanced Free Electron Laser
August 13	Transuranic (TRU) Waste Compactor[b]
August 13	Drum Storage Facility[b]
December 23	Expansion of Area G, TA-54

[a] Subsequently combined with an EA for project work at the Savannah River Plant and retitled Radioisotope Heat Source Fuel Processing and Fabrication.
[b] Subsequently combined into a single EA for the TRU Waste Compactor and Drum Storage Facility.

Table III-6. Environmental Assessments that Received Findings of No Significant Impact during 1991

Date Submitted	Title	FONSI Date
March 16, 1990	Weapons Engineering Tritium Facility	March 22, 1991
June 29, 1990	Material Science Laboratory	May 14, 1991
December 18, 1990	New Production Reactor-Modular High Temperature Gas-Cooled Reactor Experiments	October 10, 1991
February 4, 1991	General Purpose Heat Source Fabrication[a]	August 19, 1991

[a]Subsequently combined with an EA for Savannah River Plant and retitled Radioisotope Heat Source Fuel Processing and Fabrication.

c. Types of Activities Reviewed. The 78 DECs submitted during 1991 can be categorized by type of project as follows (some DECs include more than one activity):

- 22 addressed construction projects including transportables;
- 18 addressed waste management/environmental restoration projects;
- 6 addressed energy research projects;
- 11 addressed routine maintenance projects;
- 6 addressed PCB removal projects;
- 1 addressed a decontamination and decommissioning (D&D) project; and
- 14 addressed other research projects.

4. Federal Clean Air Act and the New Mexico Air Quality Control Act.

a. Federal Regulations. The Laboratory is subject to a number of federal air quality regulations. These include

- NESHAP;
- National Ambient Air Quality Standards (NAAQS); and
- New Source Performance Standards (NSPS).

However, all of the above requirements, except the NESHAP for radionuclides and wood stoves, have been adopted by the State of New Mexico as part of its State Implementation Plan. Because the Laboratory does not operate wood stoves, the NESHAP for this source does not apply. Therefore, all of these regulations except the radionuclide NESHAP are discussed in Subsection b. State Regulations.

Radionuclide NESHAP. Under 40 CFR 61, Subpart H, the EPA limits the effective dose equivalent to any member of the public from radioactive airborne releases from DOE facilities, including LANL, to 10 mrem/yr. For 1991, the maximum dose to a member of the public from airborne releases was calculated using the EPA-approved computer program CAP-88 to be 4.4 mrem, or 44% of the EPA NESHAP. This dose is lower than the dose calculated for 1990 airborne emissions principally because beam line modifications and a reduced operating schedule at the Los Alamos Meson Physics Facility (LAMPF) lowered airborne radioactive emissions during 1991.

While the Laboratory is in compliance with the 10 mrem/yr dose standard, the Laboratory cannot yet demonstrate compliance with the radioactive air effluent monitoring requirements found in 40 CFR 61, Subpart H. The EPA has been notified by LAAO and the Laboratory of the status of LANL's airborne effluent monitoring system. Meetings were held with the EPA on August 21, 1991, and November 14, 1991, to discuss these issues and to propose remedial actions. On November 27, 1991, the EPA issued DOE a Notice of Noncompliance. A draft FFCA to address bringing the effluent monitoring program into compliance with the regulations was submitted by LAAO to the EPA on March 12, 1992 (see Section III.c.1.b for a discussion of the FFCA).

In October 1991 funding was received from the DOE to begin construction of a new stack for LAMPF. This stack will include a long delay line allowing increased radioactive decay of LAMPF effluent before it is released, consequently further reducing LAMPF emissions.

In addition to the existing federal programs, the Clean Air Act Amendments (CAAA) of 1990 mandate new programs which may affect the Laboratory. The new requirements include control technology for hazardous air pollutants, prevention of accidental releases, operating permits, and chlorofluorocarbon replacement. The Laboratory will track new regulations written to implement the act, determine their effects on Laboratory operations, and implement programs as needed.

b. State Regulations. The NMED preserves air quality through a series of Air Quality Control Regulations (AQCRs). Each AQCR relevant to Laboratory operations is discussed below.

AQCR 201 - National Ambient Air Quality Standards. As part of the federal Clean Air Act of 1977, the EPA established ambient air quality standards for certain types of pollutants, usually referred to as "criteria" pollutants, to protect human health and welfare. Compliance with these standards in areas of high pollutant emissions is determined through sampling the ambient air. States can adopt standards that are more restrictive than the federal ambient air quality standards but cannot adopt standards that are weaker. New Mexico has chosen to set more restrictive standards for

several pollutants, as well as setting ambient standards for some pollutants that are not addressed under the federal regulations. Both the federal and state standards are shown in Table A-3.

Criteria pollutants are measured at a background monitoring site on Laboratory property near Bandelier National Monument. Measurements are made of sulfur dioxide, nitrogen dioxide, ozone, and particulate matter. The data collected during 1991 are shown in Table III-7. As this table shows, air quality at the Laboratory site is much better than the ambient air quality standards. Measured ozone concentrations do not exceed the federal primary or secondary standard. However, the maximum hourly concentration exceeded the New Mexico ambient standard.

No data for the first quarter 1992 are available.

AQCR 301 - Regulation to Control Open Burning. AQCR 301 regulates the open burning of materials. Under this regulation, open burning of explosive materials is permitted when transport of these materials to other facilities may be dangerous. Provisions of this regulation allow DOE and the Laboratory to burn waste explosives and explosive-contaminated wastes. Civil defense-related research projects require open burning permits. In 1991, the Laboratory filed and received extensions on two open burning permits: one for the open burning of jet fuel for ordnance testing at TA-11, Site K, and the other for burning explosive-contaminated wood at TA-36 (Table III-2).

AQCR 401 - Regulations to Control Smoke and Visible Emissions. AQCR 401 regulates the visible emissions allowed from the Laboratory boilers to less than 20 percent opacity. Opacity is the degree to which emissions reduce the transmission of light and obscure the view of a background object. Because the Laboratory boilers are fueled by clean-burning natural gas, exceeding of this standard is unlikely. It may, however, occur during start up with oil, the backup fuel for the boilers. Although oil is used infrequently, the boilers must be periodically switched to oil to ensure that the backup system is operating properly. In 1991, the Laboratory recorded one incident where the opacity limit was exceeded. This occurred at the TA-16

Table III-7. Nonradiological Ambient Air Monitoring Results for 1991

Pollutant	Averaging Time	Unit	New Mexico Standard	Federal Standards Primary	Federal Standards Secondary	Measured Concentrations
Sulfur dioxide[a]	Annual arithmetic mean	ppm	0.02	0.03		0.001
	24 hours	ppm	0.10	0.14		
	3 hours	ppm			0.5	
	1 hour	ppm				0.008
PM_{10}[a]	Annual arithmetic mean	$\mu g/m^3$		50	50	7
	24 hours	$\mu g/m^3$		150	150	15
Ozone[a]	1 hour	ppm	0.06	0.12	0.12	0.087
Nitrogen dioxide[a]	Annual arithmetic mean	ppm	0.05	0.053	0.053	0.003
	24 hours	ppm	0.10			
	1 hour	ppm				0.01
Beryllium[b]	Calendar quarter	ng/m^3				0.06
	30 day	ng/m^3	10			

[a]Measurements made at Bandelier Monitoring Compound.

[b]Measurement made at TA-52.

incinerator when the secondary chamber encountered temperature control problems and shut down. Repairs to the incinerator restored normal operations and compliance.

AQCR 501 - Asphalt Process Equipment. Provisions of AQCR 501 set emission standards according to process rate and require the control of emissions from asphalt-processing equipment. The asphalt concrete plant operated by JCI is subject to this regulation. The plant, which has a 75,000 kg/h (75 ton/h) capacity, is required to meet an emission limit of 16 kg (35 lb) of particulate matter per hour. A stack test of the asphalt plant in 1977 indicated an average emission rate of 0.8 kg/h (1.8 lb/h) and a maximum rate of 1.0 kg/h (2.2 lb/h) over three tests (Kramer 1977). Although the plant is old and is not required to, it meets NSPS stack emission limits for asphalt plants (Kramer 1977).

AQCR 507 - Oil Burning Equipment - Particulate Matter. This regulation applies to an oil burning unit having a rated heat capacity greater than 250 million British Thermal Units (Btu) per hour. Oil burning equipment of this capacity must emit less than 0.03 lb per million Btu of particulate. Although the Laboratory boilers utilize oil as a backup fuel, all have maximum rated heat capacities below this level; consequently, this regulation does not apply. The TA-3 Cogeneration Facility operates the three highest heat capacity boilers, each having a maximum rated heat capacity of 188 million Btu per hour.

AQCR 604 - Gas Burning Equipment - Nitrogen Dioxide. Provisions of AQCR 604 require gas-burning equipment built before January 10, 1972, to meet an emission standard for NO_x of 0.3 lb/10^6 Btu when natural gas consumption exceeds 10^{12} Btu/yr/unit. The TA-3 power plant's boilers have the potential to operate at heat inputs that exceed the 10^{12} Btu/yr/unit, but they have not been operated beyond this limit. Therefore, these boilers have not been subject to this regulation. However, the TA-3 power plant meets the emission standard. The emission standard is equivalent to a flue gas concentration of 248 ppm; the measured flue gas concentrations of the TA-3 boilers ranged from 20 to 22 ppm in 1991.

AQCR 605 - Oil Burning Equipment - Sulfur Dioxide. This regulation applies to oil burning equipment having a heat input of greater than 1×10^{12} Btu/yr. Although the Laboratory utilizes oil as a backup fuel, none of the equipment utilizes it at this high a rate. Therefore, this regulation did not apply during 1991 to the Laboratory fuel burning equipment. Should such equipment operate above the heat input limit, emissions of sulfur dioxide would be required to be less than 0.34 lb per million Btu.

AQCR 606 - Oil Burning Equipment - Nitrogen Dioxide. This regulation applies to oil burning equipment having a heat input of greater than 1×10^{12} Btu/yr. None of the Laboratory boilers utilize oil (their backup fuel) at this rate. Therefore this regulation did not apply during 1991 to the Laboratory fuel burning equipment. Should such equipment operate above the heat input limit, emissions of nitrogen dioxide would be required to be less than 0.3 lb per million Btu.

AQCR 702 - Permits. Provisions of AQCR 702 require permitting of any new or modified sources of potentially harmful emissions if they exceed threshold emission rates. More than 500 toxic air pollutants are regulated, and each chemical's threshold hourly emission rate is based on its toxicity. The Laboratory reviews each new and modified source and makes conservative estimates of maximum hourly chemical usage and emissions. These estimates are compared with the applicable AQCR 702 limits to determine if additional permits are required. During 1991, over 200 source reviews were conducted. None of these sources required permits under AQCR 702.

AQCR 707 - Prevention of Significant Deterioration. These regulations have stringent requirements that must be addressed before the construction of any new, large stationary source can begin. Under this regulation, wildernesses, national parks, and national monuments receive special protection. For the Laboratory, this mainly impacts Bandelier National Monument's Wilderness Area. Each new or modified source at the Laboratory is reviewed to determine whether this regulation applies. However, due to the small size of air pollutant emissions at the Laboratory, DOE and the Laboratory have not yet been required to submit a permit under this regulation.

AQCR 751 - Emission Standards for Hazardous Air Pollutants. In this regulation, NMED adopts by reference all of the federal National Emission

Standards for Hazardous Air Pollutants, except for radionuclides and new residential wood heaters. The impact of each applicable NESHAP is discussed below.

Asbestos. Under the NESHAP for asbestos, the Laboratory must assure that no visible asbestos emissions to the atmosphere are produced by asbestos removal operations at the Laboratory. During 1991, no Laboratory operation produced visible asbestos emissions.

In addition, the Laboratory is required to notify the NMED of asbestos removal and disposal activities. Renovation projects removing less than 160 sq ft or 260 lin ft are covered by an annual small job notification to NMED. For projects removing greater than these amounts of asbestos, notification of NMED is required in advance of the work. The Laboratory received one Notice of Violation on October 17, 1991, related to asbestos notification, because LANL staff notified NMED of a delay in the start of a job on the day the job was supposed to start, rather than on the day before it was to start.

During 1991, JCI removed approximately 2,095 lin ft of friable asbestos, including 110 lin ft of potentially radioactively contaminated friable material, from small jobs covered by the annual notification. Approximately 193 sq ft of friable insulation was removed from vessels and other facility components, and 330 sq ft of nonfriable vinyl-asbestos floor tile was removed. Of the floor tile, approximately 48 sq ft was disposed of as potentially radioactively contaminated material. A total of 1,640 lin ft of friable asbestos material was removed through large, job specific notification work.

Asbestos wastes potentially contaminated with radionuclides are disposed on site at TA-54 in accordance with required disposal practices. Nonradioactive asbestos is disposed off site in a certified landfill.

The NMED is notified of the disposal of friable asbestos. Ten Hazard Waste Manifests documenting the off-site disposal of nonradioactively contaminated friable asbestos were reported to NMED during 1991. An additional 13 manifests were reported for radioactively contaminated friable asbestos disposed at TA-54. The Laboratory has 14 manifests for nonfriable asbestos disposal during 1991 (11 nonradioactive, 3 radioactive) for which NMED does not require documentation.

Beryllium. The beryllium NESHAP includes requirements for notification, emission limits, and stack performance testing for beryllium sources. The four beryllium facilities at the Laboratory operate under state air quality permits containing these requirements. The Laboratory obtained a permit for a fifth beryllium processing operation to be located in TA-3-35; this facility has not yet been constructed so the permit is not active.

Beryllium machining operations are located in Shop 4 at TA-3-39, in Shop 13 at TA-3-102, the beryllium Shop at TA-35-213, and the beryllium processing facility at TA-3-141. Exhaust air from each of these operations passes through air pollution control equipment before exiting from a stack. A fabric filter controls emissions from Shop 4. The other operations use high-efficiency particle-attenuation (HEPA) filters to control emissions, with a removal efficiency of more than 99.95%. Source tests have demonstrated that all beryllium operations meet the emission limits established by NESHAP and that emissions are so low that there is negligible impact on ambient air quality.

The Laboratory identified a beryllium cutting operation at TA-55-4 in August 1991 which may require a permit under the requirements of New Mexico Air Quality Control Regulation 702 - Permits. Following discussions with the NMED, DOE officially notified NMED on October 9, 1991, of the operations. Beryllium cutting operations were suspended and a commitment was made to file an air quality permit application with NMED. The NMED issued a Notice of Violation for the beryllium cutting operation on October 16, 1991. Negotiations for settling this NOV are continuing between Laboratory, DOE, and NMED personnel.

To support a new weapons program, additional beryllium machining operations will be located in TA-55-4. The Laboratory has prepared an air quality permit application to include the existing and modified sources, which will be submitted to the NMED in early 1992. The beryllium machining operations to be located in TA-55-4 will be controlled by a series of HEPA filters with removal efficiencies of at least 99.95% each.

During 1991, three existing beryllium machining operations (located at TA-3-66 and TA-16-450) were identified for which no records are available to confirm that they were registered with NMED or EPA. Because these operations were in existence prior to the adoption of the federal NESHAP, only registration is required.

Registration information for these operations will be submitted to NMED in April 1992.

AQCR 752 - Registration of Existing Toxic Air Pollution Sources. Provisions of this regulation required a one-time registration of all sources emitting toxic air pollutants in amounts in excess of a specified annual emission limit. Complying with this regulation required the Laboratory to estimate emissions on a building-by-building basis for more than 500 chemicals. To calculate these emissions, a computerized data base has been developed that includes usage, products, and wastes for each regulated chemical. In response to the anticipated requirements of the Environmental Oversight Agreement between DOE and New Mexico, this data base is being updated. In general, air emissions are very low because the Laboratory is primarily a research facility and chemical usage is small.

5. Safe Drinking Water Act, Municipal and Industrial Water Supplies.

This program includes sampling from various points in the Laboratory and County water distribution systems to ensure compliance with the Safe Drinking Water Act (SDWA) (40 CFR 141). The EPA has established maximum contaminant levels for microbiologic, organic, and inorganic constituents and radioactivity in drinking water. Most of these standards have been adopted by the State of New Mexico and are included in the New Mexico Water Supply Regulations. The NMED has been authorized by EPA to administer and enforce federal drinking water regulations and standards in New Mexico.

Compliance samples are analyzed for organic and inorganic constituents and for radioactivity at the New Mexico Health Department's Scientific Laboratory Division (SLD) in Albuquerque. The SLD reports the analytical results directly to NMED. The JCI Environmental Laboratory also collects samples throughout the Laboratory and County distribution systems and tests them for microbiological contamination, as required under the SDWA. The JCI Environmental Laboratory is certified by SLD for microbiological testing of drinking water.

During 1991, all water samples collected under the SDWA program at Los Alamos and tested by SLD in Albuquerque and by the JCI Laboratory were found to be in compliance with the maximum contaminant levels established by regulation. A summary of the results is presented in Tables III-8, III-9, III-10, and III-11. There were no violations nor any fines levied on the Laboratory's municipal and industrial water supplies during 1991.

Each month during 1991 an average of 46 samples was collected throughout the Laboratory and County water distribution systems to determine the free chlorine residual available for disinfection and the microbiological quality of the distribution systems. These samples were collected by JCI Environmental Section personnel and analyzed in the JCI-certified laboratory for the presence of coliform bacteria, which is an indicator used to determine if harmful bacteria could be present. During 1991, no coliform bacteria were found. Sixty-five of the microbiological samples (approximately 12%) collected were found to have some noncoliform bacteria present. Although the presence of noncoliform bacteria is not a violation of SDWA, it does indicate stagnant water or biofilm growth in the distribution lines. A summary of the analytical results is found in Table III-12.

Chemical and microbiological data are available for the first quarter of 1992 and indicate full compliance with standards (Tables III-9 and III-12).

6. Federal Insecticide, Fungicide, and Rodenticide Act.

This act regulates the manufacturing of pesticides, with requirements on registration, labeling, packaging, recordkeeping, distribution, worker protection, certification, experimental use, and tolerances in foods and feeds. Sections of this act that are applicable to the Laboratory include recommended procedures for storage and disposal, and requirements for certification of applicators. The Laboratory is also regulated by the New Mexico Pest Control Act. The application, storage, disposal, and certification of these chemicals are conducted in compliance with these regulations. The Laboratory's maintenance subcontractor, JCI, conducts the application of pesticides under the direction of the Laboratory's Pest Control Program Administrator. A Laboratory Pest Control Policy, which includes management programs for vegetation, insects, and small animals, was established in 1984 and is being revised by the Pest Control Oversight Committee (PCOC). This committee was established to review and recommend policy changes in the overall pest management program at the Laboratory.

Table III-8. Volatile Organic Constituents in the Water Distribution System in 1991 (μg/L)

Contaminant	Composite Samples A	B	C
VOC Group I			
63 Compounds	0.00 N	0.00 N	0.00 N
VOC Group II			
1,2-Dibromoethane (EDB)	0.00 N	0.00 N	0.00 N
1,2-Dibromo-3-chloropropane (DBCP)	0.00 N	0.00 N	0.00 N

MDL = (Minimal detection limit) 1.00 μg/L for VOC Group I.
MDL = 0.04 μg/L for VOC Group II.
N = None detected above detection limit.
*Composite Samples A = Guaje wells #1, 1A, 2
B = Guaje wells #4, 5, 6
C = Pajarito Mesa wells #1, 2, 3, 5

Table III-9. Total Trihalomethane Concentrations in the Water Distribution System (μg/L)

Sampling Location	1991 Quarters First	Second	Third	Fourth	1992 Quarters First
Los Alamos Airport	1.20	4.60	7.80	3.10	0.00
White Rock Fire Station	0.20	0.00	0.00	0.30	0.00
North Community Fire Station	1.40	1.20	1.00	0.00	0.00
S-Site Fire Station	0.50	0.00	2.00	0.50	0.00
Barranca School	1.60	0.00	0.50	0.50	0.00
TA-33, Bldg. 114	—	—	—	4.40	2.70

The maximum contaminant level is 100 μg/L under both the SDWA and the New Mexico Water Supply Regulations.

Table III-10. Inorganic Constituents in the Water Distribution System in 1991 (mg/L)

Sampling Location	As	Ba	Cd	Cr	F	Pb	Hg	Nitrate (as N)	Se	Ag
Los Alamos Airport	0.012	0.2	<0.001	0.01	0.49	<0.005	<0.0005	0.38	<0.005	<0.001
North Community Fire Station	0.015	0.1	<0.001	0.01	0.52	<0.005	<0.0005	0.37	<0.005	<0.001
Barranca School	0.014	0.1	<0.010	0.01	0.57	<0.005	<0.0005	0.36	<0.005	<0.001
MCL[a]	0.050	1.0	0.010	0.05	4.00	0.050	0.0020	10.00	0.010	0.05

[a]The maximum contaminant level under both the SDWA and the New Mexico Water Supply Regulations.

Table III-11. Radioactivity in the Water Distribution System

Analysis	Standard for Calibration	Radioactivity in Sample December 18, 1991 (pCi/L)	
Los Alamos Airport			
Gross alpha[a]	^{241}Am	1.00	(0.30)[b]
	Natural uranium	1.20	(0.40)
Gross beta[c]	^{137}Cs	3.10	(0.60)
	^{90}Sr, ^{90}Y	3.10	(0.60)
North Community Fire Station			
Gross alpha	^{241}Am	0.00	(0.30)
	Natural uranium	0.00	(0.40)
Gross beta	^{137}Cs	1.80	(0.70)
	^{90}Sr, ^{90}Y	1.80	(0.70)
Barranca School			
Gross alpha	^{241}Am	0.60	(0.30)
	Natural uranium	0.70	(0.40)
Gross beta	^{137}Cs	3.80	(0.70)
	^{90}Sr, ^{90}Y	3.90	(0.70)

[a]The gross alpha maximum contaminant level is 15 pCi/L under both the SDWA and the New Mexico Supply Regulations.

[b]Uncertainties are in parentheses.

[c]The gross beta maximum contaminant level is 50 pCi/L under both the SDWA and the New Mexico Supply Regulations.

An annual inspection conducted by the United States Department of Agriculture found no deficiencies in the Laboratory's pesticide application program and certified application equipment. In 1991, approximately 27.5 lb of herbicides and 287.5 gal. of pesticides were applied at the Laboratory. Data for the first quarter of 1992 are not available.

7. National Historic Preservation Act.

As required by Section 106 of the National Historic Preservation Act of 1966, Laboratory activities are evaluated in consultation with the State Historic Preservation Officer (SHPO) for possible effects on cultural resources. During 1991, Laboratory archaeologists evaluated 1,110 actions, which resulted in 51 intensive field surveys.

Although only 7 of the 51 field surveys were conducted for the ER program, these 7 surveys covered close to 3,000 acres on DOE, Forest Service, GSA, and Indian land. A total of 161 new archaeological sites were recorded, and the site records were updated for 20 previously recorded sites.

A data recovery plan for mitigation of adverse effects to seven Anasazi pueblos was approved by the SHPO. These ruins will be impacted by the proposed expansion of waste disposal facilities at TA-54. A copy of this plan was sent to San Ildefonso Pueblo for comments. At the Pueblo's request, the Pueblo Council was given a tour of these ruins and the nearby ruin of Tsirege, which is ancestral to San Ildefonso Pueblo. Discussions during this tour have resulted in an informal agreement to draft a Memorandum of Understanding between San Ildefonso, DOE, and LANL. This document will specify the procedures for avoiding sacred and traditional places as required by the American Indian Religious Freedom Act of 1978 and

Table III-12. Microbiological Testing of the Water Distribution System

Month	No. of Tests Conducted	No. of Tests with Bacteria Present	
		Coliform[a]	Noncoliform
1991			
January	49	0	0
February	44	0	1
March	54	0	5
April	48	0	2
May	46	0	2
June	41	0	4
July	49	0	12
August	43	0	9
September	40	0	6
October	46	0	9
November	47	0	9
December	47	0	6
Total 1991	554	0	65
1992			
January	49	1	3
February	47	0	3
March	47	0	6
Total 1992	143	1	12

[a]The EPA total coliform maximum contaminant level for a system which collects over 40 samples per month is no more than two samples with coliforms present per month.

the procedures for the return of Native American funerary remains and other sacred objects as required by the Native American Graves Protection and Repatriation Act of 1990.

In the first quarter of 1992, EM-8 reviewed 268 Laboratory actions for possible effects to cultural resources and continued ongoing field surveys for the ER program. Four cultural resource survey reports were submitted to the SHPO for review and concurrence.

8. Endangered/Threatened/Protected Species.

a. Threatened and Endangered Species. The DOE and the Laboratory must comply with the Endangered Species Act of 1973, as amended. During 1991, EM-8 reviewed 614 actions proposed to be undertaken at the Laboratory for potential impact on threatened and endangered species. Of these, 211 were reviewed through the ES&H Questionnaire system. The Biological Resource Evaluations Team (BRET) of EM-8 identified 40 projects as needing reconnaissance surveys. These surveys are designed to evaluate the amount of previous development or disturbance at the site and if any physical characteristics required by a threatened or endangered species are present. BRET also identified 15 projects as needing quantitative surveys to determine if the appropriate habitat types were present to support any threatened or endangered species. In addition, BRET identified eight projects (Table III-13) requiring an intensive survey which is designed to determine the presence or absence of a species at the project site. The Laboratory adhered to protocols and

permit requirements of the New Mexico State Game and Fish Department.

Of the surveys conducted, only the peregrine falcon (*Falco peregrinus*) and the bald eagle (*Haliaeetus leucocephalus*) were confirmed within a project site. Biological evaluations are being prepared for the projects and consultation with U.S. Fish and Wildlife will be undertaken. The meadow jumping mouse (*Zapus hudsonius*) and spotted bat (*Euderma maculatum*) were not found in any of the surveys.

An additional listed species, Jemez Mountain salamander (*Plethodon neomexicanus*), was encountered adjacent to an area of the Seismic Trench Study. The Jemez Mountain salamander was not found within the project impact area itself. The Seismic Trench Study was a Laboratory project that occurred partly on U.S. Forest Service property. The U.S. Forest Service conducted the appropriate consultation with New Mexico State Game and Fish.

During the first quarter of 1992, 98 proposed actions were reviewed for their potential impact on threatened and endangered species. Eight projects will require additional investigation.

b. Biological Surveys. Monitoring of selected biota and sensitive habitats to provide long-term data in accordance with NEPA, DOE Order 5400.1, Endangered Species Act and Floodplain/Wetland Executive Order was begun during 1990. Monitoring studies on raptors, reptiles and amphibians, small mammals and birds continued during 1991. Additionally, wetland and adjacent upland habitats within Pajarito and Sandia Canyons were monitored. A second year of data was collected for various trophic levels of biota within Cañada del Buey. Several new surveys were initiated to obtain inventory data on groups of organisms not previously studied.

Wildlife watering. A preliminary survey (conducted July through October 1991) of 135 of 140 NPDES outfalls indicated that approximately 50% of the outfalls are used or potentially can be used by macrofauna such as deer and elk. Additionally, one-third of the outfalls have potential wetland characteristics as evidenced by hydrophytic vegetation.

Observations indicated a number of aquatic invertebrates within effluent discharge waters. Cursory wildlife observations provided a list of 35 mammal, bird, amphibian, and reptile species (evidenced from visual sightings, scat, tracks, and bedding) in the vicinity of the outfalls. These and other nonmacrofaunal species could potentially use waters from the

Table III-13. Projects Requiring a Species Specific Survey in 1991.

Project Name	Species Surveyed
Emergency Gas Line Replacement	Meadow Jumping Mouse Jemez Mountain Salamander
Sanitary Waste Consolidation System	Jemez Mountain Salamander
Seismic Trench Study	Meadow Jumping Mouse Jemez Mountain Salamander
Site Characterization, OU 1106	Peregrine Falcon
Site Characterization, OU 1071	Meadow Jumping Mouse Peregrine Falcon
Site Characterization, OU 1078	Meadow Jumping Mouse Jemez Mountain Salamander
Site Characterization, OU 1079	Peregrine Falcon
Site Characterization, OU 1122	Meadow Jumping Mouse Spotted Bat Bald Eagle Peregrine Falcon

discharges. To determine the use and level of use of discharges by small and medium-sized mammals and amphibians, further studies will be conducted. Studies on the macroinvertebrate assemblages will continue.

9. Floodplain/Wetland Protection.

Los Alamos National Laboratory must comply with EO 11988, Floodplain Management and EO 11990, Protection of Wetlands (EPA 1989a). During 1991, 416 actions proposed to be undertaken at the Laboratory were reviewed for impact to floodplains and wetlands. All projects reviewed in 1991 were outside floodplain/wetland boundaries.

During the first quarter of 1992, 98 proposed actions were reviewed for impact to floodplains and wetlands. Seven projects may be within floodplain/wetland boundaries and will require further review.

10. Comprehensive Environmental Response, Compensation, and Liability Act.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and the Superfund Amendments and Reauthorization Act (SARA) of 1986 mandate cleanup of toxic and hazardous contaminants at closed and abandoned hazardous waste sites. The CERCLA/SARA-related actions for potential release sites at the Laboratory are being addressed under the DOE's Environmental Restoration Program (Section IV.I.6) in conjunction with RCRA corrective actions (Section III.B.1.h).

11. Emergency Planning and Community Right-to-Know Act.

Title III Section 313 of SARA exempts DOE facilities from reporting requirements. However, it is DOE policy that this exemption not be exercised and that the Laboratory report its releases under the remaining provisions of Section 313. However, all research operations at the Laboratory are also exempt under other provisions of the regulation and only pilot plants and specialty chemical production facilities at the Laboratory must report their releases. As a result, the Plutonium Processing Facility is the only operation at the Laboratory that is covered by Section 313. The only regulated chemical that is used at the Plutonium Processing Facility in amounts greater than the Section 313 reporting thresholds is nitric acid.

The Laboratory submitted the required Section 313 report to EPA in July of 1991. This report covered the releases of nitric acid during 1990. About 24,320 kg (53,500 lb) of nitric acid were used for plutonium processing with releases to the air of approximately 468.7 kg (1,031 lb). The amount of nitric acid released to the atmosphere was calculated using data obtained from a study that measured the air emissions from the facility. The remaining nitric acid was either consumed in chemical reactions or was completely neutralized in the wastewater treatment operations. Only the air releases required reporting for 1990. Data on releases for CY91 will be reported under Section 313 in July 1992.

Data for the first quarter of 1992 are not available.

12. Toxic Substances Control Act

The Toxic Substances Control Act (TSCA 15 U.S.C. *et seq.*) is administered by the EPA which has authority to conduct premanufacture reviews of new chemicals prior to their introduction into the marketplace, require testing of chemicals which may present a significant risk to humans and the environment, and require recordkeeping and reporting requirements for new information regarding adverse health and environmental effects associated with chemicals. The EPA governs the manufacture, use, storage, handling, and disposal of PCB equipment and sets standards for PCB spill cleanups under TSCA. Because the Laboratory's activities are in the realm of research and development, the PCB regulations (40 CFR 761) have been the Laboratory's main concern under TSCA. Substances that are regulated by the PCB regulations include, but are not limited to, dielectric fluids, contaminated solvents, oils, waste oils, heat transfer fluids, hydraulic fluids, paints, slurries, dredge spoils, soils, and materials contaminated as a result of spills. Most of the provisions of the regulations apply to transformers and capacitors and PCB concentrations above a specified level. For example, the regulations regarding storage and disposal of PCBs generally apply to items whose concentrations are 50 ppm and above. At the Laboratory, equipment and materials containing greater than 500 ppm PCBs are transported off site for treatment and disposal, and those containing 50 to 500 ppm PCBs are incinerated off site or disposed of at TA-54, Area G. This area is approved by the EPA for disposal of PCB-contaminated solid materials.

Efforts continued toward the replacement, reclassification, and disposal of PCB equipment at the Laboratory. During 1991, the following PCB waste was sent off site for disposal: 25,306 kg (55,673 lb)

liquid PCB oil that included some 50-499 ppm oil; 4,502 kg (9,904 lb) contaminated debris; 3,114 kg (6,851 lb) contaminated water; 64,621 kg (142,166 lb) from 39 transformers; and 6,622 kg (14,568 lb) from capacitors. In addition, 31,496 kg (69,291 lb) of PCB-contaminated soil, debris, and equipment were disposed of at TA-54, Area G. Of the 31 PCB transformers that have been undergoing the retrofill process, 11 were reclassified to non–PCB status and most of the rest were reclassified to PCB-contaminated status. DOE Tiger Teams audited and inspected the Laboratory's PCB program in 1991. No other audits or inspections were conducted during 1991. In addition, a program to identify and recall PCB-contaminated equipment which was loaned to universities and other institutions prior to adoption of PCB regulations was initiated in 1991.

During the first quarter of 1992, a TSCA inspection was completed at the Laboratory by the EPA. Handling and storage of PCBs were found to be in substantial compliance with regulatory requirements. Replacement of PCB-contaminated equipment continued during the first quarter of 1992.

C. Current Issues and Actions

1. Compliance Agreements.

a. NPDES Federal Facilities Compliance Agreement and Administrative Orders. On May 31, 1991, EPA Region 6 served an Administrative Order (AO), Docket No. VI-91-273 on LANL. This AO listed 10 violations of the Laboratory's NPDES permit during November 1990 to March 1991. The AO also stated that the previous AO Docket No. VI-90-1263 was violated in that LANL had failed to comply with the specified construction schedule for Outfall 09S. The AO required the Laboratory to take corrective actions necessary to eliminate and prevent recurrence of the effluent violations cited. In addition, the Laboratory was required to submit a report detailing the specific corrective actions. For any corrective actions exceeding 30 days, EPA required LANL to submit a plan for the elimination and prevention of the listed violations. On July 8, 1991, the Laboratory submitted a response to EPA, including corrective actions taken and proposed schedules necessary to achieve compliance with the AO.

AO Docket No. VI-91-1329 was issued by the EPA to UC on August 29, 1991. Federal Facilities Compliance Agreement (FFCA) Docket No. VI-91-1328 was issued by EPA on August 29, 1991, and signed by LAAO on November 22, 1991. Included in the above AO and FFCA were interim effluent limits and compliance schedules for Outfalls 03A, 03A-023, 04S, 05S, 07S, 09S, 10S, and 12S. All sanitary discharges are scheduled to be in compliance with NPDES Permit limits by July 1992. A waste stream characterization schedule was also included in the AO and FFCA.

On December 24, 1991, the EPA issued an Order for Information, Docket No. VI-92-1130, to LANL. The Order for Information required the Laboratory to submit all information available from January 1989 to the present time concerning the radioactivity present in effluent and storm water discharges at the Laboratory. On January 29, 1992, LANL submitted a response to EPA for the Order for Information, providing all available information requested by EPA. The EPA is expected to include radioactivity limits in a draft NPDES permit to be issued in May 1992.

On February 10, 1992, the Laboratory requested that the final compliance schedules for the sanitary discharges in the AO and FFCA be revised due to delays in the construction schedules of collection lines and the TA-53 lagoon elimination project. The requested final compliance date is December 1992. The Laboratory also requested a revision to the waste stream characterization schedule and the addition of reporting procedures to provide regulatory coverage for potentially unpermitted outfalls or sources discovered while conducting the waste stream characterization to achieve compliance. The current and proposed schedules for completing projects required under the AO and FFCA are presented in Table D-7.

b. NESHAP Federal Facilities Compliance Agreement. The radioactive air emissions at the Laboratory have been evaluated against DOE/EH-0173T, Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance, and 40 CFR Part 61, Subpart H, National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities. Based on off-site environmental monitoring results and on doses calculated from measured stack emissions, the off-site doses are less than 10 mrem/yr, which is the standard given in 40 CFR 61.92.

On July 17, 1990, Los Alamos National Laboratory notified the DOE that the Laboratory met the 10 mrem/yr standard, but did not meet the monitoring

requirements (40 CFR 61.93) with its current sampling program. On November 27, 1991, EPA Region 6 issued DOE a Notice of Noncompliance with 40 CFR 61 Subpart H, specifically:

1. Every release source from an operation which used radionuclides has not been evaluated using the approved EPA computer model to determine a dose received by the public as required by 40 CFR 61.93(a).
2. DOE has failed to comply with 40 CFR 61.93(b)(4) because it has not determined each release point that has the potential to deliver more than 1% of the effective dose equivalent standard.
3. The facility currently has not installed stack monitoring equipment on all its regulated point sources in accordance with the above analysis and 40 CFR 61.93(b)(2)(ii) and (iii).
4. The facility has not conducted, and is not in compliance with, the appropriate quality assurance programs pursuant to 40 CFR 61.93(b)(2)(iv).
5. The facility is in violation of 40 CFR 61.94, Compliance and Reporting, because it has not calculated the highest effective dose equivalent in accordance with the regulations cited above.

As a result of the Notice of Noncompliance, the DOE is currently negotiating an FFCA with EPA Region 6. The FFCA will include schedules which the Laboratory will follow to come into compliance with the 1990 Clean Air Act. A draft FFCA was submitted by DOE/LAAO to the EPA on March 12, 1992.

c. Environmental Oversight and Monitoring Agreement. The Environmental Oversight and Monitoring Agreement between DOE and the State of New Mexico provides technical and financial support by DOE for state activities in environmental oversight, monitoring, access, and emergency response to ensure compliance with applicable federal, state, and local laws. The Agreement was signed in October 1990. The Agreement covers Los Alamos and Sandia National Laboratories, the Waste Isolation Pilot Project, and the Inhalation Toxicology Research Institute.

The Agreement requires the following actions on the part of DOE facilities.

- *Waste Minimization Plan:* a plan and schedule to describe how to reduce or eliminate the use and volume of existing solid, hazardous, mixed, and radioactive materials;
- *Source Reduction Study:* a study of available and appropriate methods to reduce or eliminate discharges and emissions of contaminants to the environment;
- *Waste Characterization Plan:* detailed information on the nature, quantities, and hazards associated with all hazardous, mixed, and radioactive waste produced, stored, or disposed at the facility or to be transported to the facility;
- *Site Characterization Studies:* studies to describe the background condition of surface water, groundwater, and soils on and around the facility;
- *Environmental Monitoring and Review Documents:* reports detailing environmental concerns, overviews, and monitoring at the facility;
- *Information on Environment Releases and Emissions:* information on known past releases of hazardous substances or radioactive materials above applicable standards which had not been previously reported to the state; 48-hour notification of any current releases that exceed applicable requirements or create a danger to human health or the environment; and a semiannual report on all hazardous, mixed, and radioactive waste emissions;
- *DOE Compliance Assessments:* comprehensive appraisals and audits of all activities at the site for compliance with regulatory requirements; access to all DOE Orders and Secretarial Notices on compliance assessments; and a description of all site activities that affect environmental quality, safety, and health that DOE regulates;
- *Incineration Data:* access to all information concerning the operation of any incinerator at the facility;
- *NEPA Documents:* a list of all NEPA documents submitted to DOE by the facility, to be

updated monthly; and copies of NEPA documents, as requested by the state;

- *Materials Reports:* access to the DOE Radioactive Waste Management Information System and the Industrial Waste Management Information System; identification of spent or irradiated reactor fuel, other radioactive, mixed, hazardous, or toxic wastes to be transported to the facility; and attendance by a state representative at off-site waste acceptance criteria committees;
- *Emergency Response:* notification to the state whenever there are any changes in facility operations which may have an impact on the state's emergency response program;
- *Access by State Representatives:* State representatives with the necessary security clearance will be granted access, without prior announcement and consistent with normal security procedures and safety precautions, to the facilities and facility records to carry out the provisions of the Agreement and other monitoring, inspections, and oversight activities that the state may conduct under its authority;
- *Security Clearance:* DOE will expedite the processing of security clearance applications for state representatives who will carry out the provisions of the Agreement and other monitoring, inspection, and oversight activities that the state may conduct under its authority;
- *Office for State Representatives:* Office space and telephone facilities will be provided for daily use by state representatives to carry out the provisions of the Agreement and other activities that the state may conduct under its authority; and
- *Public Participation:* provisions for public participation in the facility's Five-Year Planning Process.

Two meetings to discuss how each of these requirements affect each site were held in 1991. An addendum to the Agreement is being negotiated which will clarify requirements and schedules. Site-specific protocols are also being developed. The Laboratory expects that the Agreement will be implemented during 1992.

2. Corrective Activities.

The Corrective Activities (CA) Program is managed by EM-8 personnel under the overall DOE guidance of EM-30. Funding is provided through the Five-Year Plan. The CA Program includes those activities designed to bring active or standby facilities into compliance with ambient air, water, and solid waste regulations and/or agreements.

CA projects which demonstrate efforts toward regulatory compliance include the following:

- *Hazardous Waste Treatment Facility.* This facility, currently in the design phase, will consolidate all existing on-site hazardous waste treatment processes, upgrade existing waste treatment facilities to comply with regulations, and provide treatment for hazardous mixed wastes that are now being accumulated and stored. The facility, to be located at TA-50, is scheduled for completion in FY94 and will allow the Laboratory to achieve compliance with RCRA regulations and the RCRA Part B Operating Permit.
- *High-Explosive Wastewater Treatment System.* This project consists of two HE wastewater treatment facilities and a collection piping system to transfer HE-contaminated fluids from existing building sumps to treatment facilities. Conceptual design for the system is complete; construction is planned for FY96. This project will allow compliance with proposed toxicity (biomonitoring) requirements of the Laboratory's NPDES permit and RCRA regulations. It is anticipated that upgrading the HE wastewater facilities will be required under the Laboratory's NPDES AO and the FFCA.
- *Sanitary Wastewater Systems Consolidation.* This project consists of a new sanitary wastewater treatment plant and a new collection system which will replace 7 existing wastewater treatment plants and approximately 30 septic tanks. The project is under construction and will be fully operational during FY92. This project is required by the Laboratory's NPDES AO and the FFCA.
- *Stack Modifications at TA-53.* This project consists of modifications of the existing stack and the air quality treatment system at LAMPF at

TA-53. This stack will include a long delay line allowing increased radioactive decay of the effluent before it is released, consequently further reducing LAMPF emissions. Title I design for this project is scheduled to begin in the fourth quarter of FY92. Construction is scheduled to be completed in the fourth quarter of FY94. Funding for the continued operation of LAMPF has been allocated for FY92 and FY93. A study is now being completed concerning the decommissioning of LAMPF in FY94. If funding is not available for the continued operation of LAMPF in FY94, Title III construction will not be initiated.

- *PCB Transformers and Capacitors.* This project consists of replacing and retrofilling PCB-contaminated transformers and disposal of PCB-contaminated capacitors and other equipment. This is an ongoing activity and is required to insure compliance with the Toxic Substances Control Act.

Several other Corrective Activities projects are designed to achieve compliance with the CWA NPDES permit and the FFCA and AO requirements for effluent discharges. This work includes waste stream characterization to verify that waste streams are properly segregated and monitored, development of permits for storm water discharges and sludge disposal, implementation of toxicity testing (biomonitoring) of effluent discharges, improvements to prevent wastewater overflows and releases, upgrades to septic tank systems, and implementation of Spill Prevention Control & Countermeasures Plan requirements. In 1991 the last of 30 major secondary containment structures was completed. All major outdoor storage tanks are now equipped with secondary containment to prevent spills.

3. Unplanned Releases.

a. Airborne Radionuclide Releases. On February 1, 1991, 2,800 Ci of elemental tritium were released at TA-41. Less than 0.1% of the tritium was present as tritiated water. The effective dose equivalent (50-year dose commitment) to a member of the public was calculated to be 0.03 mrem. This dose occurred 7 km east of TA-41, where Los Alamos Canyon opens out onto State Road 4. The dose estimate conservatively assumed that 1% of the tritium was oxidized before reaching the receptor location. The dose is 0.03% of DOE's Public Dose Limit (PDL) of 100 mrem/yr from all pathways, and 0.3% of the EPA's 10 mrem/yr limit for the air pathway.

On March 28, 1991, 0.4 Ci of tritiated water vapor were released from TA-21 as tritium oxide. The effective dose equivalent (50-year dose commitment) to a member of the public was calculated to be 0.01 mrem. The dose is 0.01% of DOE's PDL of 100 mrem/yr from all pathways, and 0.1% of the EPA's 10 mrem/yr limit for the air pathway.

On April 17, 1991, 0.1550 Ci of tritiated water vapor were released from TA-3-16. A slow leak was discovered at the Van de Graaff accelerator. The effective dose equivalent (50-year dose commitment) to a member of the public was calculated to be 0.006 mrem. The dose is 0.006% of DOE's PDL of 100 mrem/yr from all pathways, and 0.06% of the EPA's 10 mrem/yr limit for the air pathway.

On March 25, 1992, 0.045 μCi of ^{242}Pu were released at TA-55. The effective dose equivalent (50-yr dose commitment) to a member of the public during passage of the puff was calculated to be 0.0001 mrem.

b. Airborne Nonradiological Releases. No unplanned airborne nonradiological releases were reported during 1991 or the first quarter of CY92.

c. Radioactive Liquid Releases. On January 2, 1991, a discharge was discovered at TA-54 Area G. A plumbing joint on an eye wash/safety shower located inside Building 33 froze and burst sometime between December 21, 1990, and January 1, 1991, when the Laboratory was closed for the winter holidays. The amount of discharge was estimated to be 18,000 gal. Analyses were conducted on the frozen water and soil; gross alpha, beta, and gamma were found to be within background levels. Samples analyzed for tritium averaged 0.29 μCi/L, approximately 15% of the DOE Derived Concentration Guide for off-site tritium releases (2.0 μCi/L). Removal of the frozen water below Building 33 was not required because of the slow rate of melting during which the water either evaporates or enters the subsurface rather than producing a definitive runoff in Cañada del Buey.

On February 21, 1991, 0.2 μCi of plutonium and americium were released at TA-50 from a leaking pipe near the Size Reduction Facility. The spill was confined to a small area. The leak was repaired, and the spill was cleaned up to applicable standards. The

contaminated soil was disposed of according to applicable standards.

d. Nonradioactive Liquid Releases. On September 25, 1991, an underground diesel fuel transfer line broke during start-up of the TA-3 Power Plant's back-up fuel system. Approximately 100-200 gal. of diesel fuel oil surfaced and was discharged across the ground to a storm water channel, where it drained into a tributary to Sandia Canyon. The discharge was immediately reported to EPA and NMED. Spill notifications were required pursuant to Paragraph G of the Laboratory's NPDES Permit and Section 1-203 of the Water Quality Control Commission Regulations, which require reporting, within 24 hours, of any discharge that may endanger health or the environment. Corrective actions included operators at the Power Plant shutting down the fuel line immediately upon discovery and clean-up of the diesel fuel. The diesel spill was contained in the water course within minutes using absorbent booms and pillows. Pools of diesel and water were removed using a wet/dry vacuum and absorbents. The contaminated soil was sampled, removed, and disposed of at the Los Alamos County Landfill.

During 1991 and the first quarter of 1992, 57 other releases of nonradioactive liquids occurred at the Laboratory and were reported to the EPA and NMED. The NMED Surface Water Bureau has requested that all liquid releases be reported regardless of any potential impact on the environment. Each of these discharges was minor in nature and was contained on Laboratory property. None was found to be of any threat to health or the environment. Sampling and clean-up were completed, as appropriate to confirm the presence or absence of pollutants and to prevent further migration. Over 60% of these unplanned releases were either potable water or steam condensate originating from the Laboratory's utility systems.

The following is a summary of these 57 unplanned releases:

- 23 releases of potable water which originated from water line breaks and other sources in the Los Alamos water supply system;
- 13 releases of steam condensate originating from condensate return line breaks and other sources in the Laboratory's steam system;
- 11 releases of sanitary sewage (less than 1,000 gal. each) from the Laboratory's wastewater treatment plant collection systems;
- 5 unplanned releases of cooling water or chiller water including: 2,000 gal. at TA-21, Bldg. 3 on November 10, 1991; 1,000 gal. at TA-21, Bldg. 149 on July 11, 1991; 30,000–40,000 gal. at TA-21, Bldg. 114 on February 15, 1991; 2,800 gal. at TA-21, Bldg. 144 on February 14, 1991; and 10 gal. per minute for an unknown period of time at TA-3, Bldg. 148 on September 4, 1991;
- 500–1,000 gal. of storm water and residual oil from fuel storage tanks at TA-60 Sigma Mesa on November 15, 1991;
- 3 gal. of ethylene glycol at TA-55, PF8 on May 19, 1991;
- residual oil in the parking lot caused a sheen in the storm drain near TA-3, Bldg. 105 on August 1, 1991;
- foam noted in storm drain near TA-3, Bldg. 105 on August 28, 1991, was a result of car washing activities in the area. Less than 1 quart of a detergent and water mixture was released into storm drain; and
- a discharge of hydraulic fluid (3-4 quarts) from a JCI street sweeper at TA-3, Bldg. 2001 ACI on February 11, 1992.

EM-8 prepared a generalized NOI to Discharge for the discharge of potable water from the Los Alamos water supply system, including production wells, transmission lines, storage tanks, booster pump stations, and other related facilities. The generalized NOI was submitted to NMED on October 31, 1991. The NOI provides the Laboratory with regulatory coverage for releases of potable water from the water supply system that are not considered hazardous to public health and are not covered under the NPDES permit. EM-8 also prepared a generalized NOI for the release of steam condensate from the Laboratory's steam distribution and condensate return systems.

4. Waiver or Variance Requests.

Groundwater monitoring is required for all RCRA surface impoundments, landfills, waste piles, and treatment units. This requirement may be waived if it

can be demonstrated that there is low or no potential for a release from the units to migrate to the uppermost aquifer. This demonstration has been developed for several units located at TA-16, TA-35, TA-53, and TA-54. All but the demonstration at TA-53 have been provided to the State of New Mexico's Hazardous Waste Program for review.

5. Significant Accomplishments.

On September 30, 1991, LANL became the first DOE site to have a DOE imposed waste shipment moratorium for hazardous and PCB wastes lifted. It was demonstrated that an effective program of waste characterization, waste management, and quality assurance exists on site, which prevents inadvertent shipment of radioactively contaminated waste off site.

LANL completed an extensive solid waste stream characterization study mandated by the hazardous waste permit. Although the permit deadline is March 1993, it was completed one year ahead of schedule. This study included site visits and personnel interviews throughout the Laboratory. More than 22,000 waste streams were identified.

The Water Quality and Toxics Section of EM-8 implemented a program in FY91 to identify all waste streams entering NPDES outfalls and to verify that each is included in the proper outfall category. Implementation of this program has allowed the Laboratory an opportunity to achieve compliance with its NPDES Permit under the current AO.

During 1991, a DEC was prepared to cover many routine maintenance activities at LANL. This DEC was given a categorical exclusion from the need for further NEPA documentation by DOE on October 1, 1991. The Laboratory was able to apply the categorical exclusion to 69 routine maintenance activities, without preparing further documentation on each one.

6. Significant Problems.

a. Lawsuits. In 1991 a lawsuit, Lujan v. Regents of the University of California, was filed against the Laboratory. Plaintiffs claim that they were injured by exposure to discharges and emissions of radioactive and hazardous materials from past operations of the Laboratory. Plaintiffs are seeking compensatory and punitive damages, as well as injunctive relief against certain ongoing operations of the Laboratory.

In February 1992, a lawsuit, Truelock v. Regents of the University of California, was filed against the Laboratory. Plaintiffs claim that they were injured by exposure to discharges and emissions of radioactive materials from past operations of the Laboratory. Plaintiffs are seeking compensatory and punitive damages, as well as injunctive relief against certain ongoing operations of the Laboratory.

On March 31, 1992, DOE and the University were notified that Concerned Citizens for Nuclear Safety intend to file a citizen suit pursuant to Section 7604 of the Clean Air Act. According to the notice letter, the suit will allege, among other things, that the Laboratory is not in compliance with the monitoring requirements for radionuclides found in 40 CFR, Part 61, Subpart H and will ask for an injunction against continued operation of all sources.

b. Notices of Violation. The Laboratory received a Notice of Violation from the NMED on January 18, 1991, concerning the discharge of potable water from a broken eye wash/safety shower at TA-54, Area G due to a frozen pipe. The NOV also addressed the discharge of steam condensate from a broken condensate return line from TA-43. The Laboratory completed a response to this NOV on February 7, 1991, including a corrective action plan. Corrective actions were completed and no further enforcement action was taken by the NMED.

The Laboratory received a Notice of Violation letter, dated May 24, 1991, citing nine violations noted during the April/May 1991 RCRA compliance inspection. The violations were corrected, and the NMED was notified within the 30 days required by state law. The Laboratory's response, sent to NMED in June 1991, was found adequate as stated in a letter from NMED dated July 12, 1991.

The Laboratory identified a site where asbestos-containing rubble waste piles had been placed in temporary storage. The site is adjacent to the sanitary landfill on East Jemez Road and was reported to state authorities in July 1991. Based on analysis of the rubble, the presence of asbestos was confined to nonfriable asbestos tiles and asbestos-embedded concrete. A Notice of Violation was received from the State of New Mexico on October 17, 1991, for failing to notify the state of a revised start-up date for clean-up prior to the originally scheduled date. This violation was a one-time occurrence, and the Laboratory's response to NMED included provisions for preventing similar occurrences in the future.

The Laboratory identified a beryllium cutting operation at TA-55-4 in August 1991 which may require a permit under the requirements of New Mexico Air Quality Control Regulation 702 - Permits. Following discussions with the New Mexico Environment Department (NMED), DOE officially notified NMED on October 9, 1991, of the operations. Beryllium cutting operations were suspended and a commitment was made to file an air quality permit application with NMED. The NMED issued a Notice of Violation for the beryllium cutting operation on October 16, 1991. The NMED proposed an out-of-court settlement on January 21, 1992. The Laboratory and DOE are negotiating the specific provisions of the agreement with NMED. The air quality permit application for beryllium cutting operations was submitted to NMED in April 1992.

7. Tiger Team Assessment.

The Tiger Team Assessment was conducted at LANL from September 23 to November 8, 1991, under the auspices of the Office of Special Projects, Office of the Assistant Secretary for Environment, Safety and Health, Headquarters, DOE. The objectives of the Environmental Subteam of the Tiger Team were to assess the effectiveness of environmental programs and program management at Los Alamos as well as to assess conformance with applicable regulations and best management practices within specific technical disciplines.

The Tiger Team did not identify any environmental deficiencies which could be considered an immediate danger to worker or public health and safety. The Tiger Team identified individual findings within nine technical disciplines. These individual findings were evaluated to determine four key findings–findings which summarize the most significant environmental program deficiencies. The key findings are

- inadequate site-wide programs for the management of wastes,
- inadequate identification, monitoring, and control of effluent releases,
- inadequate regulatory permit strategy and management, and
- lack of oversight of environmental activities.

The Tiger Team also identified some positive aspects of Laboratory environmental programs. In particular, the Tiger Team identified the high quality of environmental professionals at the Laboratory and their dedicated efforts to provide adequate and defensible programs and to meet regulatory requirements.

The Laboratory has prepared action plans to address all of the environmental deficiencies identified by the Tiger Team. These plans were submitted, as part of the Laboratory Draft Action Plan, for DOE review and approval on March 31, 1992. This Draft Action Plan, when fully executed, goes well beyond mere compliance. The Laboratory is committed to implement a comprehensive and coordinated environmental management program.

8. DOE/HQ Audits and Assessments.

The DOE Field Office, Albuquerque prepares an Annual Summary Appraisal Report of Los Alamos at the end of each fiscal year. The FY91 report concluded that LANL has made generally satisfactory progress in addressing environmental concerns and risks at LANL identified in the 1987 DOE Headquarters Environmental Survey (ES). A total of 46 of the 59 findings from this survey are now considered closed. LANL has completed corrective actions for specific findings and has programs in place to correct and track progress on long-term generic findings such as corrective actions for Inactive Waste Sites and contaminated areas.

LANL will continue to address open ES findings in a root cause/self-assessment mode to assure that all environmental risks identified in the 1987 ES are adequately incorporated into environmental programs at LANL, and that corrective actions are scheduled and tracked accordingly.

IV. ENVIRONMENTAL PROGRAM INFORMATION

The Los Alamos National Laboratory (LANL or the Laboratory) supports an ongoing environmental surveillance program which includes routine monitoring for radiation, radioactive materials, and hazardous chemical substances on the Laboratory site and in the surrounding area. Over 400 sampling locations are utilized for routine monitoring of the environment.

During 1991, the average levels of external penetrating radiation (including x and gamma rays and charged-particle contributions from cosmic, terrestrial, and manmade sources) were generally the same as in 1990, showing no statistically discernible increase in radiation levels attributable to Laboratory operations.

Airborne radioactive emissions were monitored at 88 Laboratory release points. The largest airborne release was 57,431 Ci of short-lived (8-s to 20-min half-lives) air activation products from the Los Alamos Meson Physics Facility (LAMPF). Airborne radioactive effluents decreased in 1991 from 1990 totals. Air is also sampled for tritium, uranium, and plutonium; the highest measured annual average concentrations all corresponded to less than 0.3% of the Department of Energy's (DOE's) public dose limits (PDLs).

Surface water, soils, and sediments were sampled and analyzed to monitor the impact of Laboratory operations. Surface waters and shallow alluvial groundwaters in present and former radioactive liquid effluent areas contain radioactivity in concentrations greater than natural terrestrial and worldwide fallout levels; nonradioactive constituents are also present in greater concentrations than natural waters. Radionuclides and chemical concentrations in waters from areas where there has been no direct release of treated effluents evidenced no observable effects caused by Laboratory operations. Most regional and perimeter soil and sediment stations contained radioactivity at or near background levels; concentrations of plutonium in sediments from regional reservoirs on the Rio Chama and Rio Grande reflected worldwide fallout. During 1991, all drinking water samples were in compliance with the maximum contaminant levels established by regulation.

Concentrations of radionuclides in foodstuffs (produce, honey, and fish) collected from Laboratory areas were compared to levels of radionuclides in samples collected from perimeter and regional (background) locations to determine the impact of Laboratory operations. With the exception of tritium, all other radionuclides in produce collected on site were within background concentrations. Fish from Cochiti Dam (downstream from the Laboratory) had slightly higher levels of uranium than fish from Abiquiu Dam (upstream from Laboratory operations). No radioactive contribution in foodstuffs posed a threat to the health or safety of the public.

In addition to environmental surveillance activities, the Laboratory carried out a number of special studies during 1991 which provide valuable supplementary environmental information.

A. Introduction

This section provides a summary of all of the Laboratory's environmental activities performed to comply with laws and regulations, to enhance environmental quality, and to improve understanding of the effects of environmental pollutants from site operations.

The Laboratory supports an ongoing environmental surveillance program as required by U.S. Department of Energy (DOE) Orders 5400.1 (DOE 1988a) and

5484.1 (DOE 1981a). The surveillance program includes routine monitoring for radiation, radioactive materials, and hazardous chemical substances on the Laboratory site and in the surrounding region. These activities document compliance with appropriate standards, identify trends, provide information for the public, and contribute to general environmental knowledge. Detailed, supplemental environmental studies also are carried out to determine the extent of potential problems, to provide a basis for any remedial actions, and to gather further information on the surrounding environment.

The monitoring program supports the Laboratory's policy to protect the public, employees, and environment from harm that could be caused by Laboratory activities and to reduce environmental impacts to the greatest degree practicable. Environmental monitoring information complements data on specific releases, such as those from radioactive liquid waste treatment plants and stacks at nuclear research facilities.

Monitoring and sampling locations for various types of environmental measurements are organized into three groups:

- Regional stations are located within the five counties surrounding Los Alamos County (Fig. II-2) at distances up to 80 km (50 mi) from the Laboratory. They provide a basis for determining conditions beyond the range of potential influence from normal Laboratory operations.
- Perimeter stations are located within about 4 km (2.5 mi) of the Laboratory boundary, and many are in residential and community areas. They document conditions in areas regularly occupied by the public and potentially affected by Laboratory operations.
- On-site stations are within the Laboratory boundary, and most are in areas accessible only to employees during normal working hours. They document environmental conditions at the Laboratory where public access is limited.

Samples of air particles and gases, water, soils, sediments, and foodstuffs are routinely collected at these stations for subsequent analyses. External penetrating radiation from cosmic, terrestrial, and Laboratory sources is also measured. Over 400 sampling locations are utilized for routine monitoring of the environment (Table IV-1).

Additional samples are collected and analyzed to gain information about particular events, such as major surface runoff events, nonroutine releases, or special studies. Approximately 130,000 analyses for chemical and radiochemical constituents were carried out for more than 6,200 environmental samples during 1991. Resulting data were used for dose calculations, for comparisons with standards and background levels, and for interpretation of the relative risks associated with Laboratory operations.

Methods and procedures for acquiring, analyzing, and recording data are presented in Section VIII, Quality Assurance and Sampling Procedures. Comprehensive information about environmental regulatory standards is presented in Appendix A. Detailed environmental data tables are given in Appendix D. Results are discussed in the body of the report.

Table IV-1. Number of Sampling Locations for Routine Monitoring of the Ambient Environment

Type of Monitoring	Regional	Perimeter	On-Site	Total
External radiation	3	12	135	150
Air	3	14	19	36
Surface waters[a]	6	10	12	28
Groundwaters[a]	0	48	29	77
Soils and sediments	18	28	36	82
Foodstuffs	10	8	11	29

[a]Samples from an additional 17 special surface water and groundwater stations related to the Fenton Hill Geothermal Program were also collected and analyzed as part of the monitoring program.

B. Measurement of External Penetrating Radiation

1. Introduction.

Natural external penetrating radiation comes from terrestrial and cosmic sources. The natural terrestrial component results primarily from the decay of ^{40}K and of radionuclides in the decay chains of ^{232}Th, ^{235}U, and ^{238}U. Natural terrestrial radiation in the Los Alamos area is highly variable with time and location. During any year, external radiation levels can vary from 15% to 25% at any location because of changes in soil moisture and snow cover (NCRP 1975b). There is also spatial variation because of different topographies and soil and rock types from area to area (ESG 1978).

The cosmic source of natural ionizing radiation increases with elevation because of reduced shielding by the atmosphere. At sea level, it produces measurements between 25 and 30 mrem/yr. Los Alamos, with a mean elevation of about 2.2 km (1.4 mi), receives about 60 mrem/yr from the cosmic component. However, regional locations range in elevation from about 1.7 km (1.1 mi) at Española to 2.7 km (1.7 mi) at Fenton Hill, resulting in a corresponding range between 45 and 90 mrem/yr for the cosmic component. This component can vary ±5% because of solar modulations (NCRP 1975b).

Fluctuations in natural background ionizing radiation make it difficult to detect an increase in radiation levels from manmade sources. This is especially true when the size of the increase is small relative to the magnitude of natural fluctuations. Therefore, to measure contributions to external radiation from the operation of LAMPF, arrays with 48 thermoluminescent dosimeters (TLDs) (12 stations, 4 TLDs per station) for each array have been deployed near LAMPF and in background areas.

2. Monitoring Network and Results.

Levels of external penetrating radiation (including X and gamma rays and charged-particle contributions from cosmic, terrestrial, and manmade sources) in the Los Alamos area are measured with TLDs in three independent networks. These networks are used to measure radiation levels (1) at the Laboratory and regional areas, (2) at the Laboratory boundary north of LAMPF, and (3) at low-level radioactive waste management areas.

a. Laboratory and Regional Areas. The environmental network consists of 38 stations divided into three groups. The regional group consists of three locations, 28 to 44 km (17 to 27 mi) from the Laboratory boundary in the neighboring communities of Española, Pojoaque, and Santa Fe. The Pojoaque station was removed during the fourth quarter of 1991. The off-site perimeter group consists of 12 stations within 4 km (2.5 mi) of the boundary and the on-site, or within the Laboratory, group is composed of 23 locations (Fig. IV-1, Table IV-2). Details of the sampling methodology for the TLD network are found in Section VIII.C.1.

Annual averages for the groups were generally the same in 1991 as in 1990 (Fig. IV-2), close to the averages observed in 1989, and consistent with the variability in natural background observed at these stations. An increase in the TLD reading during the second quarter of 1991 for four perimeter stations was noted and compared to independent dosimeters located at the same stations. The independent dosimeters did not reflect this increase, and it was attributed to the calibration/reading process. Data were reported as measured. Regional and perimeter stations showed no statistically discernible increase in radiation levels attributable to Laboratory operations (Table IV-2). Annual measurements at off-site stations ranged from 88 to 144 mrem.

Some comparisons provide a useful perspective for evaluating these measurements. For instance, the average person in the United States receives about 53 mrem/yr of radiation from medical diagnostic procedures (NCRP 1987a). The DOE's PDL is 100-mrem/yr effective dose received from all pathways, and the dose received by air is restricted by the Environmental Protection Agency's (EPA's) (effective dose) standard of 10 mrem/yr (Appendix A). These values are in addition to those from normal background, consumer products, and medical sources. The standards apply to locations of maximum probable exposure to an individual in an off-site, uncontrolled area.

b. TA-53 Network. This network monitors external radiation from airborne activation products (gases, particles, and vapors) released by LAMPF, Technical Area (TA) 53. The prevailing winds are from the south and southwest (Section II). Twelve TLD sites are located downwind at the Laboratory boundary north of LAMPF along 800 m (0.5 mi) of canyon rim. Twelve background TLD sites are about 9 km (5.5 mi) from the facility along a canyon rim near the southern boundary of the Laboratory (Fig. IV-1).

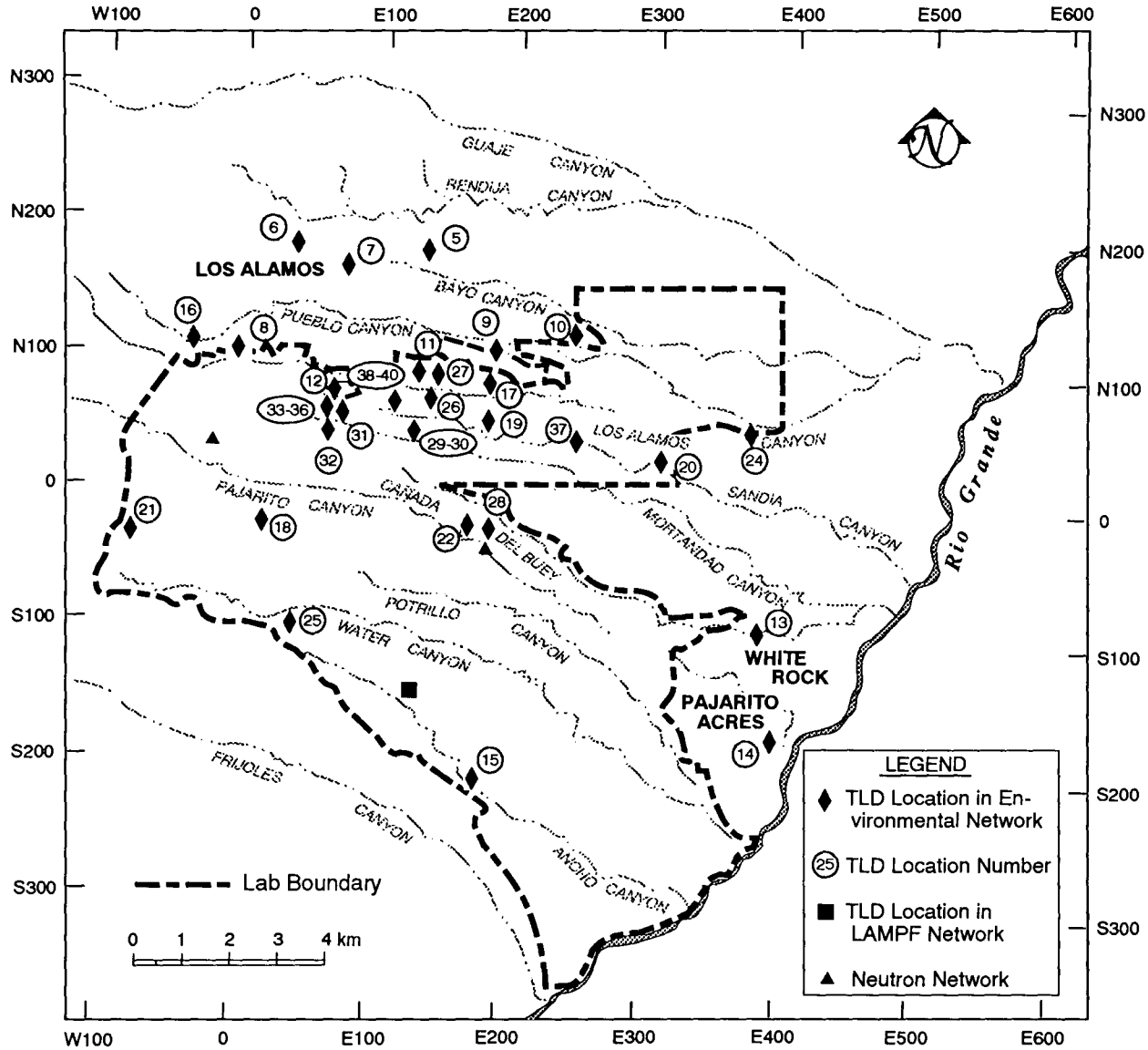


Fig. IV-1. Approximate thermoluminescent dosimeter (TLD) locations on or near the Laboratory site. Does not show Regional Stations.

This background location is not influenced by any Laboratory external radiation sources.

The TLDs at the 24 sites are changed each calendar quarter or more often if LAMPF's operating schedule indicates the need (start-up or shutdown of the accelerator for extended periods midway in a calendar quarter). No radiation measurement statistically above background was noted in this network during 1991 (Fig. IV-3). This conclusion was reached by subtracting the annual measurement taken at the background sites from the annual measurement taken at the Laboratory's boundary north of LAMPF (Section V.C.2.b). The difference was less than one mrem and within the errors of the two networks. The annual emissions of mixed activation products from LAMPF also decreased (Table IV-3) and is reflected in the boundary measurements.

No above-background increase in external radiation from Laboratory operations was measured above TLD detection limits in off-site areas by the TLD monitoring network during 1991. As a result, the effective dose to the maximum exposed individual from 1991 Laboratory operations was determined using the environmental model CAP-88, rather than by measurement as had been done in previous years. Please see Section V.C.3.b for discussion.

Table IV-2. Thermoluminescent Dosimeter Measurements

Station Location	Annual Measurement Coordinates		1991 Dose (mrem)
Uncontrolled Areas (Off Site)			
Regional Stations (28–44 km)			
1. Española	—		88[b]
2. Pojoaque	—		104[c]
3. Santa Fe	—		102
Perimeter Stations (0–4 km)[a]			
5. Barranca School	N180	E130	129
6. Arkansas Avenue	N170	E030	114
7. Cumbres School	N150	E090	102
8. 48th Street	N110	W010	107
9. Los Alamos Airport	N110	E170	121
10. Bayo Canyon	N120	E250	144
11. Shell Station	N090	E120	144
12. Royal Crest Trailer Court	N080	E080	118
13. White Rock	S080	E420	129
14. Pajarito Acres	S210	E380	104
15. Bandelier Lookout Station	S280	E200	111
16. Pajarito Ski Area	N150	W200	126
Controlled Areas (On Site)			
On-Site Stations[a]			
17. TA-21 (DP West)	N095	E140	111
18. TA-6 (Two Mile Mesa)	N025	E030	114
19. TA-53 (LAMPF)	N070	E090	118
20. Well PM-1	N030	E305	117
21. TA-16 (S Site)	S035	W025	127
22. Booster P-2	S030	E220	119
23. Discontinued	S075	E300	—
24. State Highway 4	N070	E350	138
25. Frijoles Mesa	S165	E085	109
26. TA-2 (Omega Stack)	N075	E120	123
27. TA-2 (Omega Canyon)	N085	E121	155
28. TA-18 (Pajarito Site)	S040	E205	139
29. TA-35 (Ten Site A)	N040	E105	137
30. TA-35 (Ten Site B)	N040	E110	124
31. TA-59 (Occupational Health Lab)	N050	E040	139
32. TA-3 (Van de Graaff)	N050	E020	133
33. TA-3 (Guard Station)	N050	E020	136
34. TA-3 (Alarm Building)	N050	E020	136
35. TA-3 (Guard Building)	N050	E020	125
36. TA-3 (Shop)	N050	E020	121
37. Pistol Range	N040	E240	101
38. TA-55 (Plutonium Facility South)	N040	E240	118
39. TA-55 (Plutonium Facility West)	N040	E080	132
40. TA-55 (Plutonium Facility North)	N040	E080	144

[a]See Fig. IV-1.

[b]Measurement (95% confidence increments).

[c]Station removed during fourth quarter and not replaced until 1992.

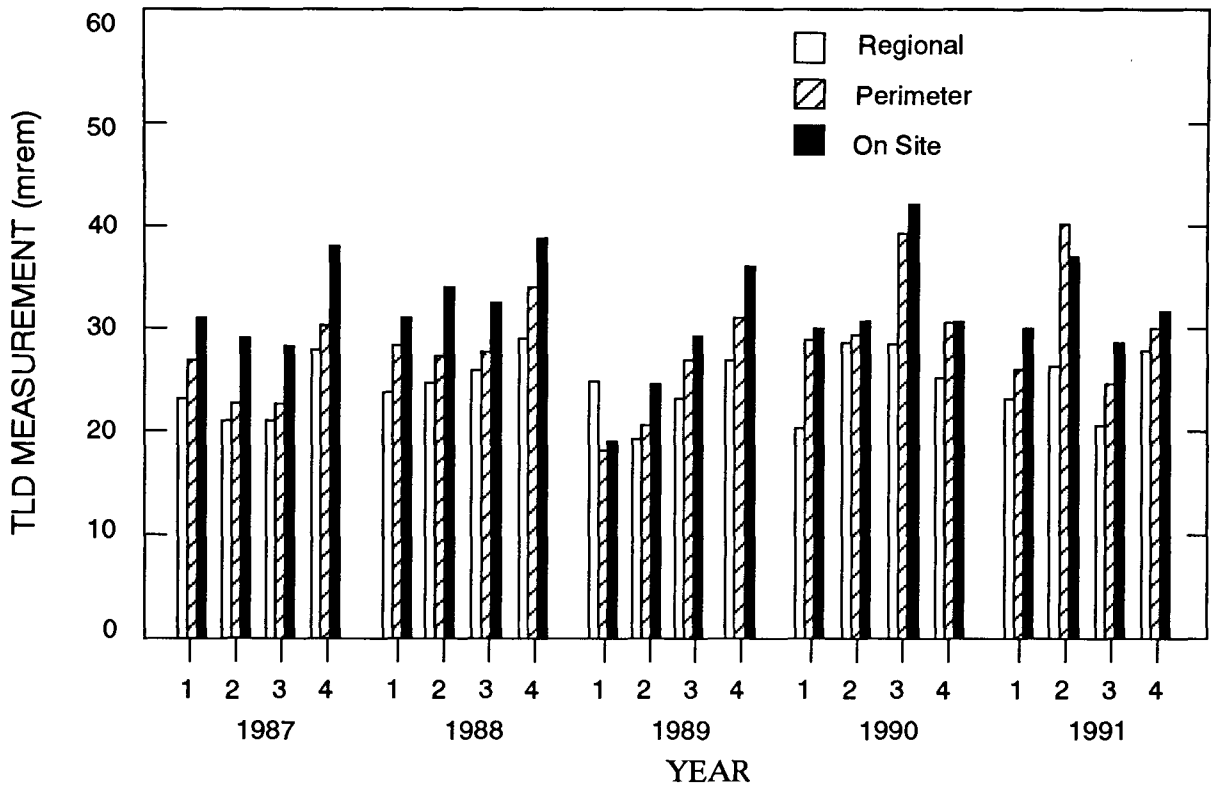


Fig. IV-2. Thermoluminescent dosimeter (TLD) measurements (including contributions from cosmic, terrestrial, and Laboratory radiation sources).

c. Low-Level Radioactive Waste Management Areas Network. This network of 88 locations monitors radiation levels at one active and nine inactive low-level radioactive waste management areas.

These waste management areas are controlled-access areas and thus are not accessible to the general public. Active and inactive waste areas are monitored for external penetrating radiation with arrays of TLDs (Table IV-4). Averages at all sites were higher than the average for the perimeter network. However, the range of values at most sites largely overlapped those found at perimeter and regional stations (Tables IV-2 and IV-4). The extremes at Area G (the active radioactive waste area) and Area T (an inactive waste area) have been noted in previous years. These data reflect the results of past and present radioactive waste management activities.

C. Air Monitoring

1. Airborne Radioactivity.

a. Introduction. Natural atmospheric and fallout radioactivity levels fluctuate and affect measurements made during the Laboratory's air sampling program. Worldwide background airborne radioactivity is largely composed of fallout from past atmospheric nuclear weapons tests, natural radioactive constituents from the decay chains of thorium and uranium attached to dust particles, and materials resulting from interactions with cosmic radiation (for example, natural tritiated water vapor produced by interactions of cosmic radiation and stable water). Background radioactivity concentrations in the atmosphere are summarized in Table IV-5 and are useful in interpreting air sampling data.

Particulate matter in the atmosphere is primarily caused by the resuspension of soil that is dependent on current meteorological conditions. Windy, dry days can increase the soil resuspension, whereas precipitation (rain or snow) can wash out particulate matter in the atmosphere. Consequently, there are often large daily and seasonal fluctuations in airborne radioactivity concentrations caused by changing meteorological conditions.

b. Monitoring Network. The sampling network for ambient airborne radioactivity consists of 36 continuously operating air sampling stations

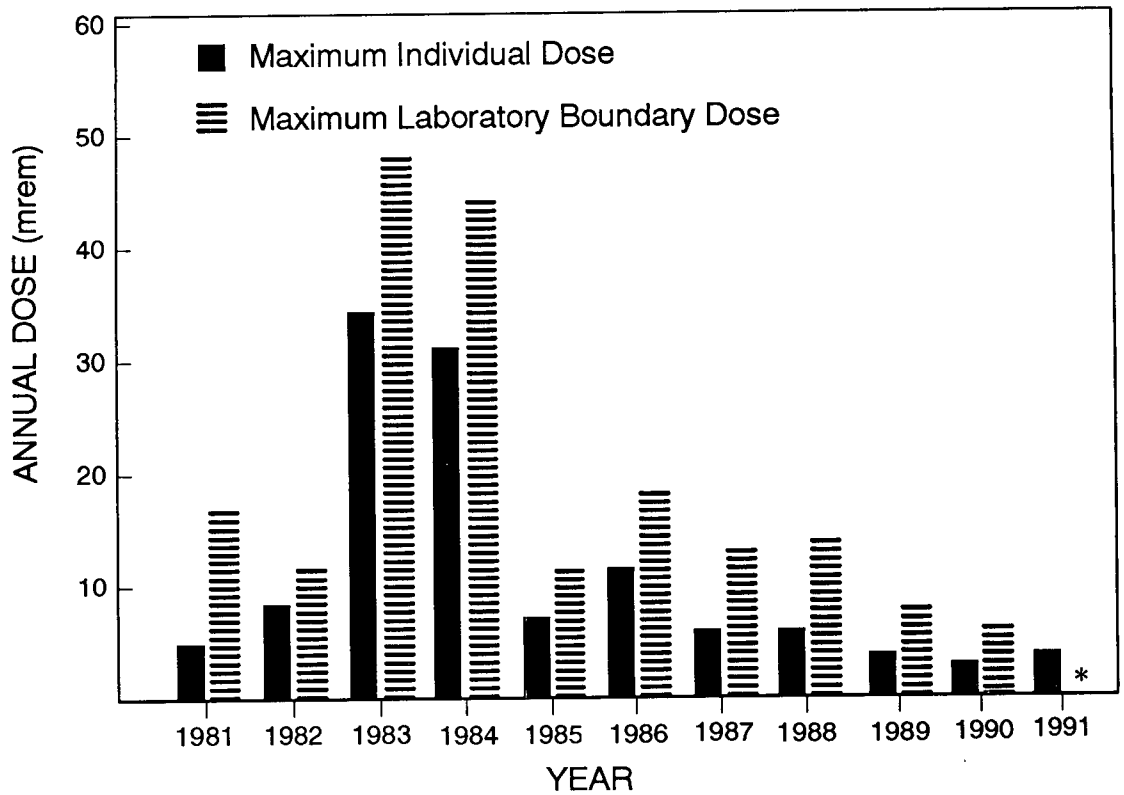


Fig. IV-3. Summary of estimated maximum individual and maximum Laboratory boundary doses from Laboratory operations (excluding contributions from cosmic, terrestrial, and medical diagnostic sources).

* No above-background Laboratory boundary doses, as measured by TLDs, were recorded during 1991. See Section IV.B.2 for discussion.

including 3 regional, 14 perimeter, 14 on site, and 5 waste site stations. In addition, two quality control stations are located next to existing locations. The regional monitoring stations, 28 to 44 km (18 to 28 mi) from the Laboratory, are located at Española, Pojoaque, and Santa Fe. The data from these stations are used as reference points for determining regional background levels of atmospheric radioactivity. The 14 perimeter stations are within 4 km (2.5 mi) of the Laboratory boundary. One perimeter station was added in 1991, and one station was changed from an on-site station in 1990 to a perimeter station in 1991. Fourteen on-site stations are within the Laboratory boundary (Fig. IV-4, Table D-8).

In addition to Station 27 at TA-54, which is part of the routine air sampling network, four additional stations are located at an active waste disposal site, Area G, TA-54, and one station at the inactive waste disposal site, Area AB, TA-49. In the past these additional stations were not identified as part of the airnet system, and the data collected from these stations were reported in a separate document (Soholt 1990).

The airnet monitoring network experienced approximately 15% station downtime during 1991. Samples were unavailable because of vacuum pump failures, power failures, and vandalism. The majority of these problems has been corrected.

c. Analytical Results.

Gross Beta Radioactivity. Gross beta analyses help in evaluating general radiological air quality. Beta activity for any single radionuclide cannot be present in greater quantity than the total gross beta concentration. If gross beta activity in a sample is consistent with past observations and background, special analysis for specific radionuclides is not required. If the sample analytical results appear to be elevated, then

Table IV-3. Comparison of 1990 and 1991 Releases of Radionuclides from Laboratory Operations[a]

Airborne Emissions

Radionuclide	Units	Activity Released 1990	Activity Released 1991	Ratio 1991:1990
H^3	Ci	6,400	4,716	0.7
^{32}P	μCi	9	17	1.9
Uranium	μCi	240	336	1.4
Plutonium	μCi	26	37	1.4
Gaseous mixed activation products	Ci	123,560	57,431	0.5
Mixed fission products	μCi	1,085	1,096	1.0
Particulate/vapor activation products	Ci	0.08	0.21	2.6
Spallation Products	Ci	2	<0.1	<0.1
Rounded Total	Ci	131,322	63,633	0.5

Liquid Effluents

Radionuclide	Activity Released (mCi) 1990	Activity Released (mCi) 1991	Ratio 1991:1990
H^3	12,000	10,600	0.9
$^{82,85,89,90}Sr$	253	124	0.5
^{137}Cs	21	67	3.2
^{234}U	0.07	0.07	1.0
$^{238,239,240}Pu$	0.8	1.3	1.6
^{241}Am	2.7	1.1	0.4
Other	574.6	52.5	0.09
Rounded Total	13,000	10,800	0.8

[a]Detailed data are presented in Tables V-1 and V-2 for airborne emissions and Table IV-26 for liquid effluents.

analysis for specific radionuclides is required to confirm or deny a problem such as an unplanned release.

Tritium. In 1991, the regional mean concentration of tritium as tritiated water in air (0.04[±0.9] × 10^{-12} μCi/mL) was lower than the perimeter annual mean (2.0 [±0.9] × 10^{-12} μCi/mL) and the on-site annual mean (4.6[±1.1] × 10^{-12} μCi/mL). The waste site's annual mean (97.0 [±160.0] × 10^{-12} μCi/mL was 21 times the on-site annual mean. The elevated concentrations observed in the waste sites are at TA-54, Area G, an area where tritium contaminated waste is disposed. The highest concentration observed in any month was also at TA-54, Area G (890.0 [±270.0] × 10^{-12} μCi/mL). These tritium concentrations are <0.1% of the concentration guide in air, based on DOE's derived air concentrations for uncontrolled areas. Table IV-6 presents complete monitoring data.

Tritium in rainwater was also analyzed by the Geology and Geochemistry Group (EES-1) of the Laboratory's Earth and Environmental Sciences Division, as reported in Section IV.I.2. The analytical results demonstrate elevated levels of tritium in rainwater in the Los Alamos area (>20 tritium units [TUs]) samples compared to the expected worldwide average concentration of 10 to 20 TUs. One tritium unit is equal to 3.2 pCi/L of water.

Plutonium and Americium. Of the 92 air sample analyses performed in 1991 for ^{238}Pu from locations outside of the waste sites, only two samples were above the minimum detectable limit of 4 × 10^{-18} μCi/mL. The highest concentration was observed at a perimeter station located at East Gate. Other sampling locations near this station did not indicate any elevations in sample results. No explanation

Table IV-4. Doses Measured by TLDs at On-Site Waste Disposal Areas during 1991

Area	Number of TLDs	Doses (mrem) Mean	Minimum	Maximum
A	5	122	119	125
B	14	128	111	144
C	10	125	115	145
E	4	126	123	130
F	4	123	112	133
G	26	162	119	569
T	7	141	115	251
U	4	124	121	130
V	4	138	127	145
AB	10	120	109	136

Table IV-5. Average Background Concentrations of Radioactivity in the Regional Atmosphere

Radioactive Constituent[a]	Units	EPA[b] 1987–1989	Laboratory[c] 1991	DOE Guide for Uncontrolled Area[d]
Gross beta	10^{-15} µCi/mL	10.0 (0.0)[e]	7.8 (2.7)	9,000
H^3	10^{-12} µCi/mL	—	1.0 (0.9)	200,000
Uranium (natural)	pg/m^3	33.0 (9.0)	96.6 (9.6)	100,000
^{238}Pu	10^{-18} µCi/mL	1.2 (0.1)	0.7 (0.6)	30,000
^{239,240}Pu	10^{-18} µCi/mL	0.7 (0.1)	0.9 (0.5)	20,000
^{241}Am	10^{-18} µCi/mL	—	2.9 (0.9)	20,000

[a]See Appendix D, Table D-38 for detection limits.

[b]EPA (1987–1989), Reports 49 through 58. Data are from the Santa Fe, New Mexico, sampling location and were taken from January 1987 through May 1989. Data for 1991 not available at time of publication.

[c]Data are annual averages from the regional stations (Española, Pojoaque, Santa Fe) and were taken during calendar year 1991

[d]See Appendix A. These values are presented for comparison.

[e]Uncertainties are in parentheses.

can be offered for this single anomalous observation of 3.25[±0.36] × 10^{-16} μCi/mL. However, all mean air concentrations of ^{238}Pu were less than 0.3% of the DOE's derived air concentration guide for uncontrolled area, 3 × 10^{-14} μ/Ci/mL.

Fifteen samples from the waste sites were analyzed for ^{238}Pu. The highest observation was 9.6 [±1.2] × 10^{-18} μCi/mL, which is less than 0.1% of the DOE's derived air concentration guide.

The 1991 annual means for ^{239,240}Pu air concentrations for the regional (0.8 [±0.5] × 10^{-18} μCi/mL), perimeter (0.7 [±0.6] × 10^{-18} μCi/mL), on site (2.4 [±0.7] × 10^{-18} μCi/mL) and waste site stations were all less than 0.1% of the DOE derived air concentration guide for controlled and uncontrolled areas. The maximum concentration observed was (31.4 [±2.6] × 10^{-18} μCi/mL) at the on site TA-54, Area G sampler. The sampler is located in a controlled area where contaminated waste is stored and disposed. Tables IV-7 and IV-8 present complete monitoring data.

Measured ^{241}Am concentrations were all less than 0.1% of the DOE's derived air concentration guides for

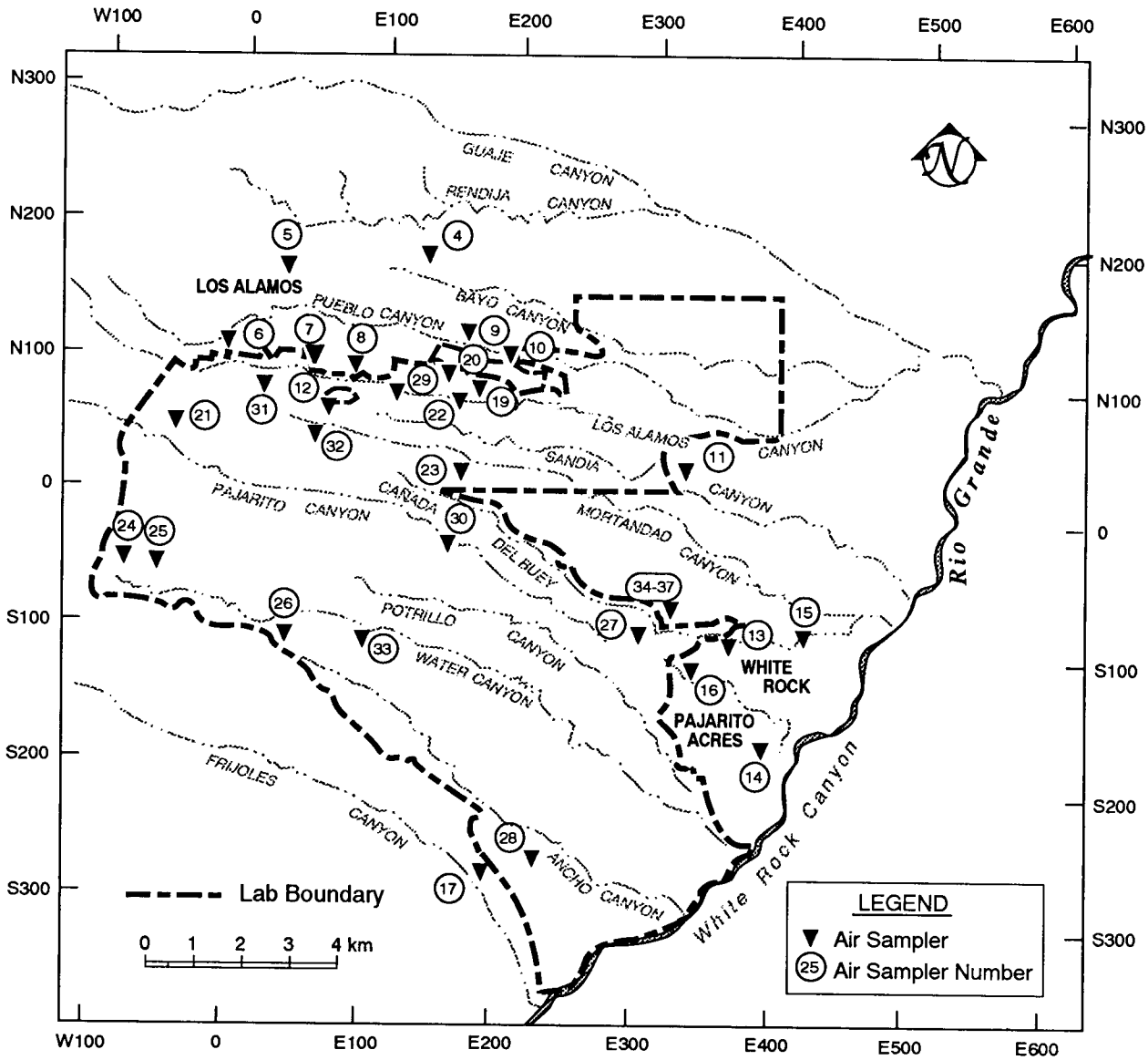


Fig. IV-4. Approximate locations on or near the Laboratory site for sampling airborne radionuclides. (Does not show Regional Stations; specific locations are presented in Table D-8.)

Table IV-6. Airborne Tritium as Tritiated Water Concentrations for 1991

Station Location[a]	Total Air Volume (m^3)	No. of Monthly Samples	No. of Samples <MDL[b]	Concentrations (pCi/m^3 [10^{-12} $\mu Ci/mL$]) Maximum[c]	Minimum[c]	Mean[c]	Mean as a Percentage of Guide[d]
Regional Stations (28–44 km), Uncontrolled Areas (Off Site)							
1. Española	119	10	10	2.8 (0.9)	−3.2 (1.7)	−0.1 (0.9)	<0.1
2. Pojoaque	34	4	2	6.3 (1.2)	−0.7 (1.3)	2.9 (1.0)	<0.1
3. Santa Fe	82	8	7	3.8 (1.5)	−3.5 (−2.0)	−0.3 (0.8)	<0.1
Group Summary		22	19	6.3 (1.2)	−3.5 (−2.0)	0.4 (0.9)	<0.1
Perimeter Stations (0–4 km), Uncontrolled Areas (Off Site)							
4. Barranca School	84	6	6	1.2 (0.6)	−0.7 (2.0)	0.1 (0.8)	<0.1
5. Arkansas Avenue	34	2	2	0.5 (0.4)	0.3 (0.4)	0.4 (0.4)	<0.1
6. 48th Street	107	10	8	28.6 (0.8)	−0.5 (1.1)	4.4 (2.8)	<0.1
7. Shell Station	63	7	6	4.9 (1.2)	−2.5 (−3.5)	1.0(−0.0)	<0.1
8. McDonald's	137	9	3	6.5 (1.3)	0.9 (0.2)	3.9 (0.7)	<0.1
9. Los Alamos Airport	61	5	5	0.8 (0.5)	−0.2 (0.3)	0.3 (0.2)	<0.1
10. East Gate	96	9	6	12.6 (1.7)	0.3 (1.2)	3.8 (1.0)	<0.1
11. Well PM-1	72	8	7	3.6 (1.0)	−0.5 (1.1)	1.0 (0.7)	<0.1
12. Royal Crest Trailer Park	182	9	5	3.9 (1.1)	0.2 (0.1)	2.3 (0.7)	<0.1
13. White Rock, Piñon School	34	5	3	6.8 (1.6)	−1.1 (1.5)	2.4 (1.2)	<0.1
14. Pajarito Acres	79	9	7	4.6 (1.2)	−1.7 (1.5)	1.0 (1.6)	<0.1
15. White Rock Fire Station	81	8	8	1.6 (0.8)	−0.4 (0.3)	0.4 (0.4)	<0.1
16. White Rock Nazarene	113	9	8	3.1 (0.6)	0.0 (0.9)	1.1 (0.5)	<0.1
17. Bandelier	64	9	8	21.4 (2.5)	−0.6 (0.6)	2.8 (0.7)	<0.1
Group Summary		105	82	28.6 (0.8)	−2.5 (−3.5)	2.0 (0.9)	<0.1
On-Site Stations, Controlled Areas							
19. TA-21, DP Site	100	9	1	20.6 (2.6)	2.6 (0.4)	11.9 (1.6)	<0.1
20. TA-21, Area B	27	4	1	8.1 (1.7)	3.0 (1.2)	5.0 (1.6)	<0.1
21. TA-6	104	9	8	9.2 (1.4)	−1.1 (1.0)	1.6 (0.9)	<0.1
22. TA-53 (LAMPF)	57	7	6	4.2 (1.0)	0.0 (2.3)	1.1 (0.8)	<0.1
23. TA-52, Beta Site	194	9	5	13.2 (2.0)	−0.4 (0.5)	3.7 (1.0)	<0.1
24. TA-16, S-Site	103	9	8	4.3 (1.2)	−2.3 (1.0)	0.4 (0.9)	<0.1
25. TA-16-450	68	5	5	2.2 (1.4)	−0.8 (1.2)	0.6 (0.9)	<0.1
26. TA-49	82	8	7	3.3 (0.7)	0.0 (0.1)	0.9 (0.3)	<0.1
27. TA-54	96	8	2	26.4 (2.8)	−0.2 (0.3)	11.5 (1.4)	<0.1
28. TA-33	34	4	2	5.4 (1.0)	0.2 (0.5)	3.2 (1.0)	<0.1
29. TA-2 (Omega)	62	6	1	10.3 (1.8)	0.8 (0.2)	5.2 (1.0)	<0.1
30. Booster P-2	86	8	6	8.7 (2.7)	−0.3 (0.4)	2.7 (1.3)	<0.1
31. TA-3	51	5	0	33.6 (5.8)	9.8 (1.5)	15.3 (2.4)	<0.1
32. TA-48	12	2	2	2.9 (2.6)	−2.7 (−1.6)	0.1 (0.5)	<0.1
Group Summary		93	54	33.6 (5.8)	−2.7 (−1.6)	4.6 (1.1)	<0.1

Table IV-6 (Cont.)

Station Location[a]	Total Air Volume (m^3)	No. of Monthly Samples	No. of Samples <MDL[b]	Concentrations (pCi/m^3 [10^{-12} $\mu Ci/mL$]) Maximum[c]	Minimum[c]	Mean[c]	Mean as a Percentage of Guide[d]
Waste Site Stations, Controlled Areas							
33. Area AB	84	8	7	3.6 (0.9)	-0.4 (-0.1)	0.9(1.0)	<0.1
34. Area G-1 NE Corner	75	8	3	52.0 (6.6)	0.4 (0.2)	22.7(2.6)	<0.1
35. Area G-2 South Fence	93	10	4	890.0 (270.0)	16.0 (4.9)	360.0(110.0)	<0.1
36. Area G-3 Gate	55	6	5	5.9 (1.7)	-1.2 (1.3)	1.3(0.7)	<0.1
37. Area G-4 H_20 Tank	64	3	1	14.0 (1.8)	1.8 (0.2)	8.6(1.2)	<0.1
Group Summary		34	20	890.0 (270.0)	-1.2 (1.3)	97.0(160.0)	<0.1

[a]See Fig. IV-4 for map of local stations.

[b]Minimum detectable limit = 2×10^{-12} $\mu Ci/mL$.

[c]Uncertainties are in parentheses.

[d]Controlled area DOE Derived Air Concentration = 2×10^{-5} $\mu Ci/mL$; uncontrolled area Derived Concentration Guide = 1×10^{-7} $\mu Ci/mL$.

controlled and uncontrolled areas. The perimeter mean (0.8 [±0.4] × 10^{-18} $\mu Ci/mL$) and the on-site mean (2.2 [±0.6] × 10^{-18} $\mu Ci/mL$) were not significantly greater than the regional mean (2.0[±0.9] × 10^{-18} $\mu Ci/mL$). The station with the highest observed concentration (14.5[±1.5] × 10^{-18} $\mu Ci/mL$) was the on-site location TA-54, Area G. Table IV-9 presents complete monitoring data for americium.

Uranium. Because uranium is a naturally occurring radionuclide in soil, it is found in airborne soil particles that have been resuspended by wind or mechanical forces (for example, vehicle or construction activity). As a result, uranium concentrations in air are heavily dependent on the immediate environment of the air sampling station. Stations with relatively higher annual averages or maximums are in dusty areas, such as Santa Fe, Pojoaque, and Española, where heavier accumulation of dust on filters results in increased amounts of natural uranium in the samples. This accounts for the larger uranium concentrations at regional stations.

The 1991 annual means for uranium concentrations in air for regional, perimeter, on site and waste sites were 108.8 (± 10.9) pg/m^3, 39.2 (± 3.9) pg/m^3, 50.5 (± 5.1) pg/m^3, and 45.8 (± 4.6) pg/m^3, respectively. All measured annual means were <0.1% of the DOE's concentration guides for uranium in air for controlled and uncontrolled areas. No effects attributable to Laboratory operations were observed. See Table IV-10 for 1991 uranium monitoring data.

d. Air Monitoring at Area G and Area AB.

In addition to the routine air monitoring performed for the environmental surveillance program, four additional air samplers are operated within the Area G controlled area at TA-54 as part of a program monitoring on-site conditions at radioactive waste management areas. A fifth air sampler is operated at Area AB at TA-49 as part of the same program.

These samplers measure air concentrations of H^3, total uranium, ^{238}Pu, $^{239,240}Pu$, and ^{241}Am. The Area G samplers are located near active waste disposal operations areas, and the measured air concentrations reflect these operations. The air sampling results for 1991 are given in Tables IV-6 to IV-10. All measured air concentrations are less than 0.1% of the DOE's

radioactivity concentration guides (Derived Air Concentrations) for on-site areas. Although the radioactivity concentration guides for off-site areas (Derived Concentration Guides [DCG]) do not apply to these on-site areas, the annual average air concentrations measured during 1991 also are less than 0.1% of these more restrictive DCGs.

Air concentrations measured by the samplers at Area G are slightly elevated above background but are less than 0.1% of the concentration guides. The ^{238}Pu air concentration at sampler G-1 was measured during 1991 to be 5.8 aCi/m^3 (5.8 × 10^{-18} μCi/mL), which is less than 0.1% of the DOE concentration guide for on-site areas. The highest annual average concentration observed at this location was 1.5 fCi/m^3, measured during 1988, also less than 0.1% of the DOE concentration guide for on-site areas. The highest single sample was 326 aCi/m^3. Measurements from the other air samplers at Area G indicated that the source of the increased concentration was a small localized area close to the G-1 air sampler. A small area that was

Table IV-7. Airborne ^{238}Pu Concentrations for 1991

Station Location[a]	Total Air Volume (m^3)	No. of Quarterly Samples	No. of Samples <MDL[b]	Concentrations (aCi/m^3 [10^{-18} μCi/mL]) Maximum[c]	Minimum[c]	Mean[c]	Mean as a Percentage of Guide[d]
Regional Stations (28–44 km), Uncontrolled Areas							
1. Española	68,005	3	3	0.0 (0.0)	−0.3 (0.4)	−0.1 (0.5)	<0.1
2. Pojoaque	16,685	1	1	0.7 (1.0)	0.7 (1.0)	0.7 (1.0)	<0.1
3. Santa Fe	80,627	4	4	1.3 (0.9)	−0.3 (0.3)	0.4 (0.6)	<0.1
Group Summary		8	8	1.3 (0.9)	−0.3 (0.4)	0.3 (0.6)	<0.1
Perimeter Stations (0–4 km), Uncontrolled Areas							
4. Barranca School	74,783	3	3	0.2 (0.2)	−0.6 (0.6)	−0.1 (0.4)	<0.1
5. Arkansas Avenue	29,241	1	1	0.0 (0.0)	−0.3 (0.2)	−0.3 (0.2)	<0.1
6. 48th Street	96,046	4	4	0.4 (0.6)	−0.4 (0.4)	0.1 (0.5)	<0.1
7. Shell Station	93,948	4	4	1.8 (1.1)	−0.2 (0.4)	0.8 (0.6)	<0.1
8. McDonald's	92,392	4	4	1.1 (1.2)	0.0 (0.4)	0.7 (0.7)	<0.1
9. Los Alamos Airport	43,065	2	2	0.7 (0.7)	0.4 (0.9)	0.6 (0.8)	<0.1
10. East Gate	100,833	4	3	325.9 (36.5)	−0.2 (0.4)	81.7 (9.5)	<0.3
11. Well PM-1	101,572	4	4	0.4 (0.5)	−0.4 (0.5)	−0.1 (0.4)	<0.1
12. Royal Crest Trailer Park	69,245	3	3	1.9 (0.8)	0.0 (0.4)	0.7 (0.6)	<0.1
13. White Rock, Piñon School	43,721	2	2	0.9 (0.9)	0.3 (0.3)	0.6 (0.6)	<0.1
14. Pajarito Acres	70,949	3	3	0.5 (0.3)	0.1 (0.1)	0.3 (0.4)	<0.1
15. White Rock Fire Station	71,810	3	3	0.5 (0.5)	0.0 (0.5)	0.2 (0.5)	<0.1
16. White Rock Nazarene	101,544	4	4	0.6 (0.6)	0.0 (0.4)	0.2 (0.4)	<0.1
17. Bandelier	63,776	3	3	1.5 (0.5)	0.2 (0.5)	0.8 (0.5)	<0.1
Group Summary		44	43	325.9 (36.5)	−0.6 (0.6)	7.8 (1.3)	<0.1

Table IV-7 (Cont.)

Station Location[a]	Total Air Volume (m^3)	No. of Monthly Samples	No. of Samples <MDL[b]	Concentrations (aCi/m^3 [10^{-18} μCi/mL]) Maximum[c]	Minimum[c]	Mean[c]	Mean as a Percentage of Guide[d]
On-Site Stations, Controlled Areas							
19. TA-21, DP Site	99,917	4	4	1.5 (0.6)	0.2 (0.6)	0.8 (0.5)	<0.1
20 TA-21, Area B	9,602	1	1	0.0 (0.0)	0.0 (1.0)	0.0 (1.0)	<0.1
21. TA-6	77,254	4	4	0.4 (0.7)	-0.8 (0.7)	0.0 (0.8)	<0.1
22. TA-53 (LAMPF)	69,279	3	3	0.6 (0.5)	0.2 (0.2)	0.4 (0.4)	<0.1
23. TA-52, Beta Site	98,083	4	4	1.0 (0.6)	-0.2 (0.4)	0.3 (0.5)	<0.1
24. TA-16, S-Site	101,140	4	4	1.4 (0.7)	-0.7 (0.7)	0.2 (0.5)	<0.1
25. TA-16-450	28,566	1	1	0.7 (0.6)	0.7 (0.6)	0.7 (0.6)	<0.1
26. TA-49	101,596	4	4	0.2 (0.5)	-0.3 (0.5)	-0.1 (0.5)	<0.1
27. TA-54	74,297	3	3	2.5 (0.9)	0.4 (0.5)	1.4 (0.6)	<0.1
28. TA-33	46,522	2	2	0.0 (0.0)	-1.2 (1.2)	-0.6 (0.8)	<0.1
29. TA-2 (Omega)	71,968	4	4	1.1 (1.5)	-0.4 (0.4)	0.3 (0.8)	<0.1
30. Booster P-2	65,812	3	3	1.1 (1.0)	0.3 (0.6)	0.7 (0.7)	<0.1
31. TA-3	39,586	2	1	3.7 (0.9)	1.7 (0.9)	2.7 (0.9)	<0.1
32. TA-48	16,175	1	1	0.0 (0.0)	0.0 (0.6)	0.0 (0.6)	<0.1
Group Summary		40	39	3.7 (0.9)	-1.2 (1.2)	0.5 (0.6)	<0.1
Waste Site Stations, Controlled Areas							
33. Area AB	103,066	4	4	0.6 (0.5)	-0.9 (1.1)	-0.0 (0.6)	<0.1
34. Area G-1 NE Corner	100,459	4	2	9.6 (1.2)	1.6 (0.5)	5.8 (1.2)	<0.1
35. Area G-2 South Fence	97,618	4	4	1.9 (1.0)	0.2 (0.5)	0.8 (0.6)	<0.1
36. Area G-3 Gate	24,100	1	1	1.0 (0.6)	1.0 (0.6)	1.0 (0.6)	<0.1
37. Area G-4 H_20 Tank	49,124	2	2	1.3 (0.6)	0.5 (0.6)	0.9 (0.56	<0.1
Group Summary		15	13	9.6(1.2)	-0.9 (1.1)	1.9 (0.7)	<0.1

[a]See Fig. IV-4 for map of on-site and perimeter stations.

[b]Minimum detectable limit = 4×10^{-18} μCi/mL.

[c]Uncertainties are in parentheses.

[d]Controlled area DOE Derived Air Concentration = 2×10^{-12} μCi/mL; uncontrolled area Derived Concentration Guide = 3×10^{-14} μCi/mL.

Table IV-8. Airborne $^{239,240}Pu$ Concentrations for 1991

Station Location[a]	Total Air Volume (m^3)	No. of Quarterly Samples	No. of Samples <MDL[b]	Concentrations (aCi/m^3 [10^{-18} $\mu Ci/mL$]) Maximum[c]	Minimum[c]	Mean[c]	Mean as a Percentage of Guide[d]
Regional Stations (28–44 km), Uncontrolled Areas							
1. Española	68,005	3	3	0.3 (0.4)	–0.2 (0.3)	0.1 (0.3)	<0.1
2. Pojoaque	16,685	1	1	2.6 (1.1)	2.6 (1.1)	2.6 (1.1)	<0.1
3. Santa Fe	80,627	4	4	1.6 (0.7)	0.2 (0.4)	0.9 (0.5)	<0.1
Group Summary		8	19	2.6 (1.1)	0.2 (0.3)	0.8 (0.5)	<0.1
Perimeter Stations (0–4 km), Uncontrolled Areas							
4. Barranca School	74,783	3	3	0.7 (0.6)	–0.2 (0.2)	0.3 (0.4)	<0.1
5. Arkansas Avenue	29,241	1	1	0.1 (0.3)	0.1 (0.3)	0.1 (0.3)	<0.1
6. 48th Street	96,046	4	4	0.2 (0.3)	–0.2 (0.4)	0.1 (0.4)	<0.1
7. Shell Station	93,948	4	4	1.8 (1.4)	0.2 (0.5)	1.0 (0.7)	<0.1
8. McDonald's	93,392	4	4	1.6 (0.8)	–0.4 (0.4)	0.8 (0.6)	<0.1
9. Los Alamos Airport	43,065	2	2	0.9 (0.5)	0.4 (0.4)	0.7 (0.5)	<0.1
10. East Gate	100,833	3	3	6.1 (5.4)	0.8 (0.4)	2.5 (1.8)	<0.1
11. Well PM-1	101,572	4	4	0.6 (0.4)	–0.2 (0.3)	0.2 (0.4)	<0.1
12. Royal Crest Trailer Park	69,245	3	3	0.8 (0.6)	0.0 (0.4)	0.3 (0.5)	<0.1
13. White Rock, Piñon School	43,721	2	2	1.3 (0.7)	1.2 (0.5)	1.3 (0.6)	<0.1
14. Pajarito Acres	70,949	3	3	0.2 (0.2)	0.0 (0.4)	0.1 (0.4)	<0.1
15. White Rock Fire Station	71,810	3	3	0.7 (0.3)	0.4 (0.5)	0.6 (0.4)	<0.1
16. White Rock Nazarene	101,544	4	4	1.3 (0.6)	0.0 (0.4)	0.7 (0.4)	<0.1
17. Bandelier	63,776	3	3	0.6 (0.4)	0.0 (0.6)	0.3 (0.5)	<0.1
Group Summary		44	43	6.1 (5.4)	-0.4 (0.4)	0.7 (0.6)	<0.1
On-Site Stations, Controlled Areas							
19. TA-21, DP Site	99,917	4	3	3.4 (0.8)	0.4 (0.3)	1.3 (0.5)	<0.1
20. TA-21, Area B	9,602	1	1	2.5 (1.0)	2.5 (1.0)	2.5 (1.0)	<0.1
21. TA-6	77,254	4	4	1.5 (0.5)	0.5 (0.4)	1.0 (0.6)	<0.1
22. TA-53 (LAMPF)	69,279	3	2	6.4 (1.2)	0.9 (0.4)	3.0 (0.7)	<0.1
23. TA-52, Beta Site	98,083	4	4	1.4 (0.5)	0.2 (0.5)	0.7 (0.4)	<0.1
24. TA-16, S Site	101,140	4	4	1.2 (0.4)	–0.5 (0.3)	0.7 (0.6)	<0.1
25. TA-16-450	28,566	1	1	1.3 (0.5)	1.3 (0.5)	1.3 (0.5)	<0.1
26. TA-49	101,596	4	3	4.3 (1.1)	0.8 (0.5)	1.7 (0.6)	<0.1
27. TA-54	74,297	3	1	31.4 (2.6)	1.6 (0.7)	18.2 (1.7)	<0.1
28. TA-33	46,522	2	2	1.2 (1.2)	0.2 (0.3)	0.7 (0.7)	<0.1
29. TA-2 (Omega)	71,968	4	4	1.5 (1.8)	–0.3 (0.3)	0.5 (0.8)	<0.1
30. Booster P-2	65,812	4	3	1.0 (0.7)	0.0 (0.6)	0.5 (0.6)	<0.1
31. TA-3	39,586	2	2	1.4 (0.6)	1.0 (0.5)	1.2 (0.6)	<0.1
32. TA-48	16,175	1	1	0.6 (0.9)	0.6 (0.9)	0.6 (0.9)	<0.1
Group Summary		40	35	31.4 (2.6)	–0.5 (0.3)	2.4 (0.7)	<0.1

Table IV-8 (Cont.)

Station Location[a]	Total Air Volume (m^3)	No. of Monthly Samples	No. of Samples <MDL[b]	Concentrations (aCi/m^3 [10^{-18} μCi/mL]) Maximum[c]	Minimum[c]	Mean[c]	Mean as a Percentage of Guide[d]
Waste Site Stations, Controlled Areas							
33. Area AB	103,066	4	4	0.7 (0.3)	-0.5 (0.1)	0.1 (0.3)	<0.1
34. Area G-1 NE Corner	100,459	4	2	13.4 (1.5)	1.3 (0.9)	5.0 (1.0)	<0.1
35. Area G-2 South Fence	97,618	4	4	1.3 (0.6)	0.3 (0.5)	0.8 (0.5)	<0.1
36. Area G-3 Gate	24,100	1	1	2.7 (0.7)	2.7 (0.7)	2.7 (0.7)	<0.1
37. Area G-4 H_20 Tank	49,124	2	2	1.5 (0.6)	0.7 (0.4)	1.1 (0.5)	<0.1
Group Summary		15	13	13.4 (1.5)	-0.5 (0.1)	1.9 (0.6)	<0.1

[a]See Fig. IV-4 for map of local stations.

[b]Minimum detectable limit = 3×10^{-18} μCi/mL.

[c]Uncertainties are in parentheses.

[d]Controlled area DOE Derived Air Concentration = 2×10^{-12} μCi/mL; uncontrolled area Derived Concentration Guide = 2×10^{-14} μCi/mL.

used for equipment storage located 40 m southwest of G-1; it had ^{238}Pu soil concentrations of up to 40 pCi/g. This area was remediated in 1990, and air concentrations at G-1 decreased to present levels. No increases in any of the off-site air concentrations were observed in the ambient air sampling network during this time period.

Air concentrations of H^3 were observed to be elevated at air sampler G-2. The 1991 average air concentration was measured to be 360.0 (± 110.0) pCi/m^3 (360.0 [± 110.0] × 10^{-12} μCi/mL). This concentration is less than 0.1% of the on-site concentration guide. All other air samplers at Area G measured H^3 concentrations within the range of those observed elsewhere. The G-2 air sampler is located from 7 to 50 m south of shafts used to dispose of higher level waste containing tritium and reflects the air concentrations close to these shafts.

Other radionuclide air concentrations were also small percentages of the concentration guides and reflected ongoing operations at Area G during 1991. The total effective dose to a member of the public from all Area G operations during 1991 was estimated using CAP-88 to be 0.009 mrem/yr (1991), or less than 1% of the EPA radiation limit. These doses are similar to doses estimated for operations in previous years. These estimates are confirmed by routine environmental monitoring in off-site areas. All measured air concentrations in off-site areas were less than 0.1% of the DOE concentration guides.

The measured air concentrations at the TA-49 air sampler showed no increase above background levels. TA-49 is an area along the southern boundary of the Laboratory where below ground experiments were performed with fissionable material (plutonium and enriched uranium) during 1959-1960.

2. Nonradioactive Air Quality.

a. Introduction. In addition to the radiological monitoring network, the Laboratory operates a network of nonradiological ambient air monitors. Because the Los Alamos area lies in a remote area far from large metropolitan areas and major sources of air pollution, extensive monitoring has not been conducted. The

Table IV-9. Airborne ^{241}Am Concentrations for 1991

Station Location[a]	Total Air Volume (m^3)	No. of Quarterly Samples	No. of Samples <MDL[b]	Concentrations (aCi/m^3 [10^{-18} $\mu Ci/mL$]) Max[c]	Min[c]	Mean[c]	Mean as a Percentage of Guide[d]
Regional Station (44 km), Uncontrolled Area							
3. Santa Fe	80,627	4	2	2.9 (0.9)	1.4 (0.9)	2.0 (0.9)	<0.1
Group Summary		4	2	2.9 (0.9)	1.4 (0.9)	2.0 (0.9)	<0.1
Perimeter Stations (0–4 km), Uncontrolled Areas							
9. Los Alamos Airport	43,065	2	1	2.1 (1.0)	1.7 (0.7)	1.9 (0.8)	<0.1
10. East Gate	100,833	4	4	1.7 (0.8)	0.0 (0.4)	0.8 (0.5)	<0.1
13. White Rock, Piñon School	43,721	2	2	1.1 (0.5)	0.0 (0.0)	0.5 (1.3)	<0.1
15. White Rock Fire Station	71,810	3	3	1.1 (0.5)	0.0 (0.0)	0.6 (0.3)	<0.1
16. White Rock Nazarene	73,472	3	3	0.9 (0.4)	0.0 (0.0)	0.5 (0.3)	<0.1
Group Summary		14	13	2.1 (1.0)	0.0 (0.4)	0.8 (0.4)	<0.1
On-Site Stations, Controlled Areas							
20. TA-21, Area B	9,602	1	1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	<0.1
21. TA-6	77,254	4	4	1.7 (0.8)	0.0 (0.0)	0.9 (0.5)	<0.1
22. TA-53 (LAMPF)	69,279	3	3	1.6 (0.7)	0.0 (0.0)	0.7 (0.4)	<0.1
24. TA-16, S Site	101,140	4	4	1.7 (0.7)	0.2 (0.3)	1.2 (0.6)	<0.1
26. TA-49	101,596	4	4	1.6 (0.7)	0.6 (0.6)	1.1 (0.6)	<0.1
27. TA-54, Area G	74,297	3	0	14.5 (1.5)	3.4 (1.0)	10.8 (1.4)	<0.1
30. Booster P-2	65,812	3	2	2.2 (0.9)	0.0 (0.4)	1.0 (0.7)	<0.1
31. TA 3	39,586	2	2	1.6 (0.8)	1.3 (0.5)	1.5 (0.7)	<0.1
Group Summary		24	20	14.5 (1.5)	0.0 (0.0)	2.2 (0.6)	<0.1
Waste Site Stations, Controlled Areas							
34. Area G-1 NE Corner	46,025	2	1	8.5 (1.5)	1.1 (0.8)	5.8 (1.2)	<0.1
35. Area G-2 South Fence	47,422	2	2	0.9 (0.8)	0.8 (0.5)	0.9 (0.6)	<0.1
36. Area G-3 Gate	24,100	1	1	2.0 (0.9)	2.0 (0.9)	2.0 (0.9)	<0.1
37. Area G-4 H_20 Tank	23,906	1	1	0.9 (0.7)	0.9 (0.7)	0.9 (0.7)	<0.1
Group Summary		6	5	8.5(1.5)	0.8 (0.5)	2.4 (0.9)	<0.1

[a]See Fig. IV-4 for map of station locations.
[b]Minimum detectable limit = 2×10^{-18} $\mu Ci/mL$.
[c]Uncertainties are in parentheses.
[d]Controlled area DOE Derived Air Concentration = 2×10^{-12} $\mu Ci/mL$; uncontrolled area Derived Concentration Guide = 2×10^{-14} $\mu Ci/mL$.
NOTE: Only those Airnet stations listed in this table are sampled for ^{241}Am.

Table IV-10. Airborne Uranium Concentrations for 1991

Station Location[a]	Total Air Volume (m^3)	No. of Quarterly Samples	No. of Samples <MDL[b]	Concentrations (pg/m^3) Maximum[c]	Minimum[c]	Mean[c]	Mean as a Percentage of Guide[d]
Regional Stations (28–44 km), Uncontrolled Areas							
1. Española	68,005	3	0	98.7 (9.8)	35.5(3.5)	60.8(6.1)	<0.1
2. Pojoaque	16,685	1	0	157.4 (15.7)	157.4(15.7)	157.4(15.7)	<0.1
3. Santa Fe	80,627	4	0	116.3 (11.6)	103.7(10.4)	108.3(10.8)	<0.1
Group Summary		8	0	157.4 (15.7)	35.5(3.5)	108.8(10.9)	<0.1
Perimeter Stations (0–4 km), Uncontrolled Areas							
4. Barranca School	74,783	3	0	92.1 (9.2)	32.5(3.2)	58.9(5.9)	<0.1
5. Arkansas Avenue	29,241	1	0	39.5 (3.9)	39.5(3.9)	39.5(3.9)	<0.1
6. 48th Street	96,046	4	0	66.2 (6.6)	22.4(2.2)	36.6(3.7)	<0.1
7. Shell Station	93,948	4	0	86.6 (8.6)	24.9(2.5)	51.9(5.2)	<0.1
8. McDonald's	92,392	4	0	109.2 (11.0)	18.3(1.8)	53.5(5.3)	<0.1
9. Los Alamos Airport	43,065	2	0	89.5 (8.9)	81.1(8.1)	85.3(8.5)	<0.1
10. East Gate	100,833	4	0	61.5 (6.2)	26.7(2.7)	42.9(4.3)	<0.1
11. Well PM-1	101,572	4	0	58.2 (5.8)	13.3(1.3)	30.4(3.0)	<0.1
12. Royal Crest Trailer Park	69,245	3	0	38.5 (3.8)	19.9(1.9)	28.6(2.8)	<0.1
13. White Rock Piñon School	43,721	2	0	17.4 (1.8)	13.2(1.3)	15.3(1.6)	<0.1
14. Pajarito Acres	52,932	2	0	37.0 (3.7)	14.5(1.5)	25.8(2.6)	<0.1
15. White Rock Fire Station	71,810	3	0	45.7 (4.6)	17.6(1.7)	34.7(3.5)	<0.1
16. White Rock Nazarene	101,544	4	0	51.4 (5.1)	11.4(1.2)	25.3(2.5)	<0.1
17. Bandelier	63,776	3	0	25.3 (2.5)	14.1(1.4)	20.5(2.0)	<0.1
Group Summary		43	0	109.2 (11.0)	11.4(1.2)	39.2(3.9)	<0.1
On-Site Stations, Controlled Areas							
19. TA-21, DP Site	99,917	4	0	98.2 (9.9)	23.5(2.3)	64.5(6.5)	<0.1
20. TA-21, Area B	9,602	1	0	44.4 (4.4)	44.4(4.4)	44.4(4.4)	<0.1
21. TA-6	77,254	4	0	83.3 (8.4)	32.0(3.2)	53.5(5.4)	<0.1
22. TA-53 (LAMPF)	69,279	3	0	62.3 (6.3)	22.5(2.2)	39.1(3.9)	<0.1
23. TA-52, Beta Site	98,083	4	0	128.5 (12.8)	20.0(2.0)	55.5(5.5)	<0.1
24. TA-16, S Site	101,140	4	0	62.2 (6.3)	24.7(2.5)	44.0(4.4)	<0.1
25. TA-16-450	28,566	1	0	35.1 (3.5)	35.1(3.5)	35.1(3.5)	<0.1
26. TA-49	101,596	4	0	39.7 (4.0)	11.4(1.2)	23.3(2.3)	<0.1
27. TA-54	74,297	3	0	100.4 (10.0)	34.7(3.4)	61.2(6.1)	<0.1
28. TA-33	46,522	2	0	18.6 (1.8)	6.2(0.6)	12.4(1.2)	<0.1
29. TA-2 (Omega)	71,968	4	0	67.8 (6.8)	25.5(2.5)	48.1(4.8)	<0.1
30. Booster P-2	65,812	3	0	66.5 (6.7)	35.0(3.5)	51.8(5.2)	<0.1
31. TA-3	39,568	2	0	79.3 (7.9)	40.6(4.0)	59.9(6.0)	<0.1
32. TA-48	16,175	1	0	113.9 (11.4)	113.9(11.4)	113.9(11.4)	<0.1
Group Summary		40	0	128.5 (12.8)	6.2 (0.6)	50.5(5.1)	<0.1

Table IV-10 (Cont.)

Station Location[a]	Total Air Volume (m^3)	No. of Quarterly Samples	No. of Samples <MDL[b]	Concentrations (pg/m^3) Maximum[c]	Minimum[c]	Mean[c]	Mean as a Percentage of Guide[d]
Waste Site Stations, Controlled Areas							
33. Area AB	103,066	4	0	82.2 (8.2)	20.9(2.0)	50.7(5.1)	<0.1
34. Area G-1 NE Corner	100,459	4	0	83.8 (8.4)	27.8(2.8)	48.7(4.9)	<0.1
35. Area G-2 South Fence	97,618	4	0	83.2 (8.3)	30.3(3.0)	46.4(4.7)	<0.1
36. Area G-3 Gate	24,100	1	0	34.1 (3.4)	34.1(3.4)	34.1(3.4)	<0.1
37. Area G-4 H_20 Tank	49,124	2	0	88.2 (8.8)	10.3(1.0)	49.2(4.9)	<0.1
Group Summary		17	0	88.2(8.8)	10.3(1.0)	45.8(4.6)	<0.1

[a]See Fig. IV-4 for map of local stations.

[b]Minimum detectable limit = 1 pg/m^3.

[c]Uncertainties are in parentheses.

[d]Controlled area DOE Derived Air Concentration = 2×10^8 pg/m^3; uncontrolled area Derived Concentration Guide = 1×10^5 pg/m^3.

Laboratory operates monitors to routinely measure primary (or "criteria") pollutants, National Emission Standards for Hazardous Air Pollutants (NESHAP) for beryllium, acid precipitation, and visibility. In 1991, the Laboratory also monitored toxic air pollutants (TAPs) as part of a short-term study.

b. Monitoring Network. The nonradiological monitoring network consists of a variety of monitoring stations: one criteria pollutant monitor, nine beryllium monitors, one acid rain monitor, and one visibility monitoring station. For the 1991 TAP study, five additional monitoring sites were used.

c. Primary Pollutants. Although it is Laboratory owned, the New Mexico Environment Department (NMED) operates the criteria pollutant monitoring station south of TA-49, adjacent to Bandelier National Monument. This station, which began operation in the second quarter of 1990, continuously monitors air concentrations of nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2). Filters to trap small particulate matter (less than 10 microns in diameter – PM_{10}) are collected every 6 days and weighed. The NMED analyzes all results and provides the results to the Laboratory. Measured ozone concentrations do not exceed the federal primary or secondary standard. However, the maximum hourly concentration exceeded the New Mexico ambient standard.

d. NESHAP (Beryllium). The Laboratory conducts beryllium monitoring at nine monitoring stations; one regional station (28-44 km), four perimeter stations (0-4 km), and four on-site stations. Quarterly samples are taken and analyzed. Table IV-11 presents the results for 1991. All concentrations were well below the New Mexico ambient air standards.

e. Acid Precipitation. The Environmental Protection Group (EM-8) operates a wet deposition station that is part of the National Atmospheric Deposition Program (NADP) network. The station is located at the Bandelier National Monument. The corrected 1990 and 1991 annual and quarterly deposition rates are presented in Table IV-12.

Table IV-11. Airborne Beryllium Concentrations for 1991

Station Location[a]	Total Air Volume (m^3)	No. of Quarterly Samples	Concentrations (ng/m^3) Maximum[b]	Minimum[b]	Mean[b]
Regional Stations (28–44 km), Uncontrolled Areas					
Pojoaque	22,288	2	0.04 (0.02)	0.03 (0.02)	0.04 (0.02)
Group Summary		2	0.04 (0.02)	0.03 (0.02)	0.04 (0.02)
Perimeter Stations (0–4 km), Uncontrolled Areas					
Barranca School	60,004	3	0.02 (0.01)	0.02 (0.00)	0.02 (0.01)
Los Alamos, 48th Street	70,737	3	0.02 (0.01)	0.01 (0.00)	0.01 (0.01)
Shell Station	67,584	3	0.04 (0.00)	0.01 (0.00)	0.02 (0.00)
Pajarito Acres	70,949	3	0.02 (0.01)	0.01 (0.00)	0.01 (0.00)
Bandelier	37,528	2	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
Group Summary		14	0.04 (0.01)	0.01 (0.00)	0.02 (0.00)
On-Site Stations, Controlled Areas					
TA-52 Beta Site	69,689	3	0.06 (0.01)	0.01 (0.00)	0.03 (0.00)
TA-16 S-Site	74,668	3	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
TA-16-450	43,139	2	0.01 (0.00)	0.01 (0.01)	0.01 (0.00)
TA-54, Area G by QA	28,872	1	0.04 (0.01)	0.04 (0.01)	0.04 (0.01)
TA-3	39,586	2	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
Group Summary		11	0.06 (0.01)	0.01 (0.01)	0.02 (0.00)

[a]See Figure IV-4 for map of on-site and perimeter stations.
[b]Uncertainties are in parentheses.

Deposition rates for the various ionic species vary widely and are somewhat dependent on precipitation. The highest deposition rates usually coincide with high precipitation. The lowest rates normally occur in the winter, probably reflecting the decrease in wind-blown dust. The ions in the rainwater are from both nearby and distant anthropogenic and natural sources. High nitrate and sulfate deposition may be caused by anthropogenic sources, such as motor vehicles, copper smelters, and power plants.

The natural pH of rainfall, without anthropogenic contributions, is unknown. Because of the contribution from entrained alkaline soil particles in the southwest, natural pH may be higher than 5.6, the pH of rainwater in equilibrium with atmospheric carbon dioxide. Some studies indicate that there may be an inverse relationship between elevation and pH effect that lowers the pH of samples measured in the field.

f. Visibility. The Laboratory operates one transmissometer to measure visibility, adjacent to Bandelier National Monument. As shown in Table IV-13, typical visibility is high in the area, with median visibilities of almost 130 km (82 mi). Summers show the lowest visibility, due to high humidity associated with common afternoon thunderstorms. About 10% of the time the visibility exceeded 190 km (118 mi) with the maximum visibility exceeding 223 km (140 mi). These visibilities are characteristic of clean air areas in relatively arid climates. Visibility results also are provided to the National Park Service for publication.

g. Toxic Air Pollutants. During January 1991, the Laboratory conducted a short-term, intensive air monitoring program to estimate the impact of chemical emissions on the ambient air environment. Sampling and analysis of indicator chemicals required an

Table IV-12. Annual and Quarterly Wet Deposition Statistics for 1990 and 1991

1990[a]	Quarter				
	First	Second	Third	Fourth	Total
Field pH (standard units)					
Mean	4.9	4.9	4.9	5.2	4.9
Minimum	4.4	4.4	4.6	4.8	4.4
Maximum	6.0	5.6	5.6	5.6	6.0
Precipitation (in.)	2.2	1.8	4.8	3.3	12.1
Deposition (microequivalents per square meter)					
Ca	5,218	1,208	1,196	440	8,064
Mg	196	164	186	69	615
K	43	50	48	26	168
Na	363	202	209	131	905
NH_4	857	839	1,924	507	4,127
NO_3	862	998	2,439	675	4,975
Cl	215	243	394	125	976
SO_4	1,520	1,379	2,462	1,272	6,633
PO_4	44	51	112	25	233
H	720	650	1,430	910	3,710

1991	Quarter				
	First	Second	Third	Fourth	Total
Field pH (standard units)					
Mean	5.4	4.7	4.9	5.0	5.0
Minimum	4.7	4.5	4.7	4.8	4.5
Maximum	6.7	4.8	5.1	5.1	6.7
Precipitation (in.)	2.2	2.2	11.1	5.2	20.8
Deposition (microequivalents per square meter)					
Ca	1,494	2,010	1,619	529	5,653
Mg	160	364	257	90	872
K	47	129	91	24	291
Na	218	413	331	206	1,168
NH_4	317	1,542	1,718	463	4,039
NO_3	680	1,686	3,573	784	6,722
Cl	179	398	493	168	1,237
SO_4	576	2,501	3,353	1,692	8,121
PO_4	0	9	8	0	17
H	230	640	3,260	840	4,970

[a]Calendar year 1989 data were presented in the "Environmental Surveillance at Los Alamos during 1990," and were mistakenly identified as 1990 data.

Table IV-13. Median Visibility Measured at Bandelier National Monument in 1991

Season	Median Visibility km	(mi)
Winter (12/90–2/91)	160	(100)
Spring (3/91–5/91)	132	(82)
Summer (6/91–8/91)	120	(75)
Fall (9/91–11/91)	107	(66)

innovative and high-sensitivity strategy in order to detect chemicals at very low concentrations in the ambient air as well as to address the complex terrain and meteorology of the area and potential interferences from Los Alamos community emissions. The indicator chemicals were chosen from a list of more than 600 potential air contaminants regulated by the State of New Mexico. An inventory prepared in 1988 showed that the Laboratory emitted 50 of these regulated air contaminants in amounts greater than 10 lb/yr. Of these 50 compounds, certain compounds were identified as traceable only to Laboratory operations since no other nearby sources of these chemicals likely exist, for example, acetone and 2-butanone. Other chemicals were chosen that would be traceable to non-Laboratory sources. For instance, chemicals indicative of automobile emissions were targeted. Overall, 20 organic vapors, 6 metals, and 5 inorganic acid vapors were chosen as target compounds. These were measured at five sites around the Laboratory over seven consecutive days in January 1991. The sites were selected based on several criteria, including proximity to LANL's areas of highest emissions, historical wind direction patterns, utility in estimation, the impact of LANL emissions on the Los Alamos community, and (in some cases) proximity to electrical power.

The results of the sampling program are summarized in Tables IV-14–IV-16. All three target chemical groups were sampled at TA-3 (Sites A and B) and the background monitor located near Bandelier National Monument. The background monitor, located upwind of the Laboratory, was included to measure ambient chemical concentrations not associated with LANL. Acids were the only chemicals sampled by the monitors located at TA-55 and TA-59. These monitors were sited specifically to measure acid concentrations, because acids are the primary chemical emissions from each of these areas. These tables also show the occupational health standards (TLV-PEL) set by the National Institute for Occupational Safety and Health of the American Conference of Governmental Industrial Hygienists. These standards are set to protect healthy workers exposed during a 40-hour work week. To protect sensitive individuals potentially exposed more than 40 hours weekly, NMED divides these standards by 100. As the tables show, levels of these pollutants in the ambient air surrounding the Laboratory are so low that they are an order of magnitude lower than the TLV-PEL divided by 100.

D. Surface Water Monitoring

1. Introduction.

Surface waters from regional, perimeter, and on-site stations are monitored to provide routine surveillance of environmental effects of Laboratory operations. As described in Section II.C, Geology-Hydrology, there are no perennial surface water flows that extend completely across the Laboratory in any of the canyons. Spring-fed flow originating on the flanks of the Jemez Mountains in Los Alamos Canyon maintains a flow into the Los Alamos Reservoir that continues onto the western portion of the Laboratory. Two have spring-fed flows over short distances east of the Laboratory in White Rock Canyon. These are Pajarito Canyon (on Los Alamos County land) and Ancho Canyon (on DOE land). Periodic natural surface runoff occurs in two modes: 1) spring snowmelt runoff occurs over highly variable periods of time (days to weeks) at a low discharge rate and sediment load, and 2) summer runoff from thunderstorms occurs over a short period of time (hours) at a high discharge rate and sediment load. None of these surface waters within the Laboratory are a source of municipal, industrial, or irrigation water supply. The waters are utilized by wildlife.

Most canyons receive discharges from some of the approximately 140 National Pollutant Discharge Elimination System (NPDES) permitted industrial and sanitary effluent outfalls. These effluents support flows for varying distances in some of the canyons. The largest effluent-supported flow is in Sandia Canyon from the TA-3 Sanitary Sewage Plant. In 1991, treated radioactive liquid waste effluents containing residual radioactivity were released only from the central

Table IV-14. Summary of Acid Data for Seven-Day Sampling Period for All Five Sites for 1991

Station	Minimum $\mu g/m^3$	Maximum $\mu g/m^3$	TLV-PEL[a] $\mu g/m^3$
TA-3 Site (A)			
Hydrochloric Acid	ND (<0.1)[b]	ND (<0.1)	7500[c]
Hydrofluoric Acid	ND (<0.07)	ND (<0.07)	2600[c]
Nitric Acid	0.29	0.47	5200[d]
Phosphoric Acid	ND (<0.5)	ND (<0.5)	1000
Sulfuric Acid	0.2	1.8	1000
TA-3 Site (B)			
Hydrochloric Acid	ND (<0.1)	0.2	7500[c]
Hydrofluoric Acid	ND (<0.07)	ND (<0.07)	2600[c]
Nitric Acid	0.34	0.67	5200[d]
Phosphoric Acid	ND (<0.5)	ND (<0.5)	1000
Sulfuric Acid	0.3	1.8	1000
TA-55			
Hydrochloric Acid	ND (<0.1)	0.2	7500[c]
Hydrofluoric Acid	ND (<0.07)	ND (<0.07)	2600[c]
Nitric Acid	0.34	0.71	5200[d]
Phosphoric Acid	ND (<0.5)	ND (<0.5)	1000
Sulfuric Acid	0.3	3.3	1000
TA-59			
Hydrochloric Acid	0.1	0.6	7500[c]
Hydrofluoric Acid	ND (<0.07)	ND (<0.07)	2600[c]
Nitric Acid	0.31	0.78	5200[d]
Phosphoric Acid	ND (<0.5)	ND (<0.5)	1000
Sulfuric Acid	0.5	2.7	1000
Background			
Hydrochloric Acid	ND (<0.1)	0.2	7500[c]
Hydrofluoric Acid	ND (<0.07)	ND (<0.07)	2600[c]
Nitric Acid	0.34	0.92	5200[d]
Phosphoric Acid	ND (<0.5)	ND (<0.5)	1000
Sulfuric Acid	ND (0.2)	0.2	1000

[a]This concentration is the occupational exposure standard.

[b]ND = None detected; number in parentheses is the detection level.

[c]This is a ceiling value, a concentration never to be exceeded.

[d]HNO_3 Limit of Detection (LOD) = 0.03 $\mu g/m^3$; H_2SO_4 LOD = 0.2 $\mu g/m^3$.

Table IV-15. Summary of Metals Data for Seven-Day Sampling Period for Three Sites for 1991

Station	Minimum $\mu g/m^3$	Maximum $\mu g/m^3$	TLV-PEL[a] $\mu g/m^3$
TA-3 Site (A)			
Beryllium	ND (<0.01)[b]	ND (<0.01)	2[c]
Cadmium	ND (<0.02)	ND (<0.02)	10[c]
Chromium	ND (<0.03)	ND (<0.03)	500
Lead	0.01	0.04	50[d]
Silver	ND (<0.05)	ND (<0.05)	10
Uranium	ND (<0.1)	ND (<0.1)	50
TA-3 Site (B)			
Beryllium	ND (<0.01)	ND (<0.01)	2[c]
Cadmium	ND (<0.02)	ND (<0.02)	10[c]
Chromium	ND (<0.03)	ND (<0.03)	500
Lead	0.01	0.03	50[d]
Silver	ND (<0.05)	ND (<0.05)	10
Uranium	ND (<0.1)	ND (<0.1)	50
Background			
Beryllium	ND (<0.01)	ND (<0.01)	2[c]
Cadmium	ND (<0.02)	ND (<0.02)	10[c]
Chromium	ND (<0.03)	ND (<0.03)	500
Lead	0.01	0.01	50[d]
Silver	ND (<0.05)	ND (<0.05)	10
Uranium	ND (<0.1)	ND (<0.1)	50

[a]This concentration is the occupational exposure standard.

[b]ND = None detected; number in parentheses is the detection level.

[c]Human carcinogen.

[d]Limit of detection (LOD) for lead = 0.01 $\mu g/m^3$

Table IV-16. Summary of Organics Data for Seven-Day Sampling Period for Three Sites for 1991

Station	Minimum µg/m³	Maximum µg/m³	TLV-PEL[a] µg/m³
TA-3 Site (A)			
Acetone	1.2	43.3	1,780,000
Benzene	0.8	5.8	32,000[b]
2-Butanone	ND (<1.5)[c]	5.3	590,000
Cyclohexane	ND (<1.0)	139.2	1,030,000
Ethylbenzene	ND (<0.4)	2.4	434,000
n-Hexane	1.1	3.6	176,000
Methanol	ND (<1.5)	12.7	262,000
Methylene chloride	ND (<0.2)	6.1	174,000[b]
Toluene	2.5	15.9	377,000
1,1,1-Trichloroethane	0.7	11.1	1,910,000
o,m,p-Xylenes	0.8	10.8	434,000
TNMHC[d]	69.9	393.0	
Halogenated TNMHC	3.7	19.0	
TA-3 Site (B)			
Acetone	1.8	30.0	1,780,000
Benzene	1.1	4.1	32,000[b]
2-Butanone	ND (<1.5)	10.7	590,000
Cyclohexane	ND (<1.0)	137.7	1,030,000
Ethylbenzene	ND (<0.4)	1.7	434,000
n-Hexane	1.0	2.9	176,000
Methanol	ND (<1.5)	92.0	262,000
Methylene chloride	ND (<0.2)	4.5	174,000[b]
Toluene	4.1	14.4	377,000
1,1,1-Trichloroethane	0.7	16.4	1,910,000
o,m,p-Xylenes	0.8	7.4	434,000
TNMHC[d]	94.2	482.0	
Halogenated TNMHC	3.6	15.6	
Background			
Acetone	ND (<0.7)	7.6	1,780,000
Benzene	ND (<0.4)	1.0	32,000[b]
2-Butanone	ND (<1.5)	2.5	590,000
Cyclohexane	ND (<3.4)	810.0	1,030,000
Ethylbenzene	ND (<0.4)	ND (<0.4)	434,000
n-Hexane	ND (<1.0)	1.5	176,000
Methanol	ND (<1.5)	21.0	262,000
Methylene chloride	ND (<0.2)	1.0	174,000[b]
Toluene	1.7	19.1	377,000
1,1,1-Trichloroethane	0.5	73.5	1,910,000
o,m,p-Xylenes	ND (<0.4)	1.4	434,000
TNMHC[d]	67.2	1,060.0	
Halogenated TNMHC	3.6	86.0	

[a]This concentration is the occupational exposure standard.
[b]Human carcinogen.
[c]ND = None detected; number in parentheses is the detection level.
[d]Total nonmethane hydrocarbons.

Radioactive Liquid Waste Treatment Plant at TA-50 into the Mortandad Canyon drainage. In the past, Pueblo and Los Alamos Canyons also received effluents containing radioactivity.

Concentrations of radionuclides in environmental water samples, whether within the DOE site boundary or off site, are compared with the ingested water derived concentration guides for members of the public. (See Section V.C.2, Methods for Dose Calculations for further explanation.) Routine chemical analyses of water samples have been carried out for many constituents over a number of years to monitor general water quality. For the stream channels that cross the DOE Laboratory lands, results of analyses of surface water samples from the on-site and downstream off-site locations for nonradioactive chemical quality analyses are compared with NMED Livestock and Wildlife Watering standards as these are the most likely potential water use (NMWQCC 1991). No attempt is made to evaluate water quality in the regional rivers or entirely off-site perennial streams.

2. Monitoring Network.

The locations of surface water monitoring stations are shown in Figs. IV-5 and IV-6 and are listed in Table D-9.

a. Regional Stations. Regional surface water samples were collected within 75 km (47 mi) of the Laboratory from six stations on the Rio Grande, the Rio Chama, and Jemez River. The six water sampling stations are located at current or former U.S. Geological Survey (USGS) gaging stations. These waters provide baseline data for radiochemical and chemical analyses in areas beyond the Laboratory boundary. Stations on the Rio Grande were at Embudo, Otowi, Cochiti, and Bernalillo (a former gaging station).

The Rio Grande at Otowi, just east of Los Alamos, has a drainage area of 37,000 km^2 (14,300 mi^2) in southern Colorado and northern New Mexico. Discharge for the periods of record (1895–1905 and 1909–1990) has ranged from a minimum of 1.7 m^3/s (60 ft^3/s) in 1902 to 691 m^3/s (24,400 ft^3/s) in 1920. The discharge for water year 1990 (October 1989 through September 1990) ranged from 15.7 m^3/s (555 ft^3/s) in October to 242 m^3/s (8,560 ft^3/s) in May (USGS 1992).

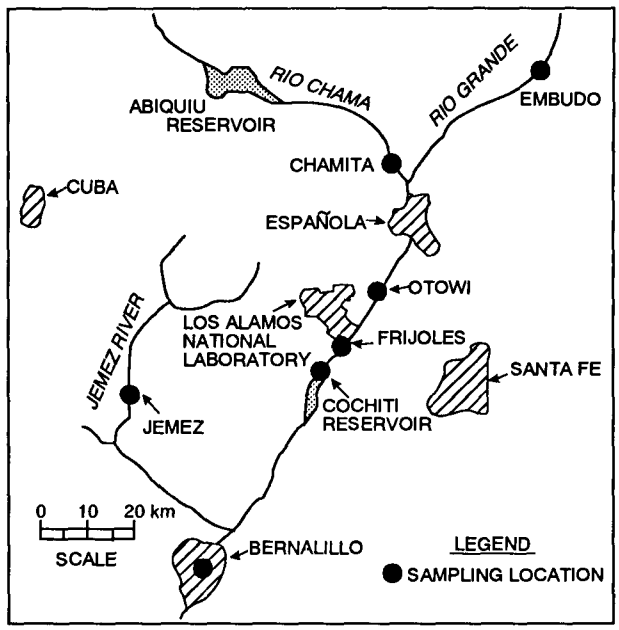


Fig. IV-5. Regional surface water, sediment, and soil sampling locations. (Map denotes general locations only; see Table D-9 for specific locations.)

The Rio Chama is a tributary to the Rio Grande upstream from Los Alamos. At Chamita on the Rio Chama, the drainage area above the station is 8,143 km^2 (3,143 mi^2) in northern New Mexico, together with a small area in southern Colorado. Since 1971, some flow has resulted from transmountain diversion water from the San Juan drainage. Flow at the Chamita gage is governed by release from several reservoirs. Discharge at Chamita during water year 1990 ranged from 1.4 m^3/s (51 ft^3/s) in January to 108 m^3/s (3,820 ft^3/s) in June.

The station at Jemez on the Jemez River drains an area of the Jemez Mountains west of Los Alamos. The Fenton Hill Hot Dry Rock Geothermal Facility (TA-57) is located within this drainage. The drainage area is small, about 1,220 km^2 (471 mi^2). During water year 1990, discharge ranged from 0.4 m^3/s (14 ft^3/s) in December to 30.3 m^3/s (1,070 ft^3/s) in April. The river is a tributary to the Rio Grande downstream from Los Alamos.

Surface waters from the Rio Grande, the Rio Chama, and Jemez River are used for irrigation of crops in the

valleys, both upstream and downstream from Los Alamos. These rivers run through recreational areas on state and federal lands.

b. Perimeter (Off-Site) Stations.

Radioactive Effluent Areas. Effluent-associated radionuclides occur off site in Pueblo and Los Alamos Canyons. The residual contaminants are from past discharges and are predominantly associated with sediments in the canyons. (See Section IV.E, Sediment and Soil Monitoring, for further information.) Some resuspension and redissolution occurs when surface flows move across these sediments, resulting in measurable concentrations in the surface waters.

Acid Canyon, a small tributary of Pueblo Canyon, is a former on-site release area for industrial effluents. Acid Canyon and the upper portion of Pueblo Canyon are now on Los Alamos County land about 1,190 m (3,900 ft) west of the Los Alamos-Santa Fe County Line. Acid-Pueblo Canyon received untreated and treated industrial effluent containing residual

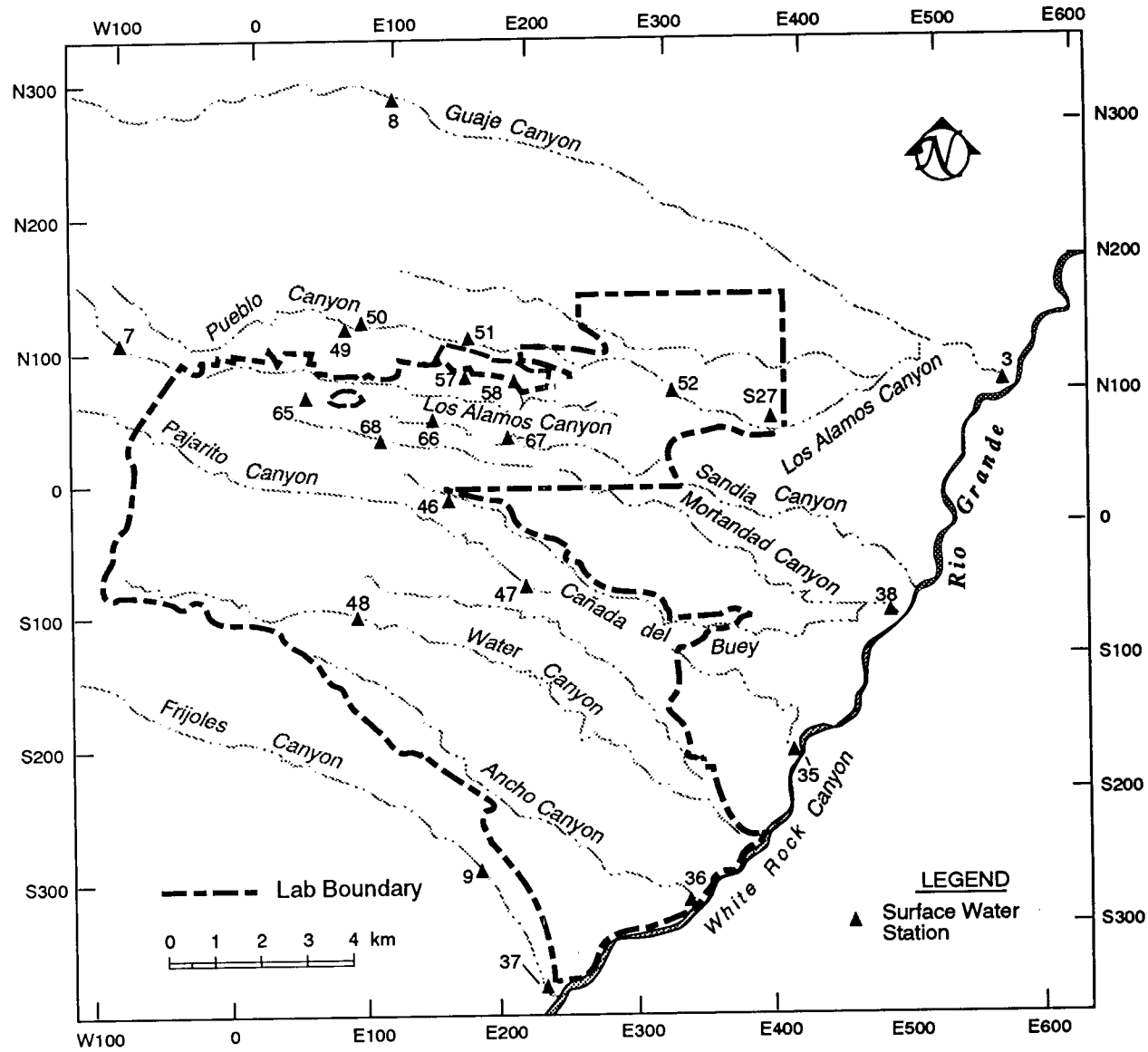


Fig. IV-6. Surface water sampling locations on and near the Laboratory site. (Map denotes general locations only; see Table D-9 for specific locations.)

radionuclides from 1944 to 1964 (ESG 1981). Most of the residual radioactivity from these historic releases are now associated with the sediments in Pueblo Canyon with an estimated total inventory of about 600 mCi of plutonium (ESG 1981). About two-thirds (400 mCi) of this total are on the DOE-owned portion of lower Pueblo Canyon. Pueblo Canyon presently receives treated sanitary effluent from the Los Alamos County Bayo sewage treatment plant in the middle reach of Pueblo Canyon. Increased discharge of sanitary effluent from the County treatment plant starting in 1990 resulted in nearly perennial flow during most days of all months except June and July in the lower reach of Pueblo Canyon, across the DOE land and into the off-site lower reach of Los Alamos Canyon on San Ildefonso Pueblo.

This effluent flow from Pueblo Canyon into Los Alamos Canyon typically extends to a location between Wells LA-6 and LA-2 in Los Alamos Canyon. During the peak irrigating season (mid-June through early August), the reduction in treatment plant discharge because of effluent diversion for golf course irrigation and higher evapotranspiration eliminates flow from Pueblo Canyon into Los Alamos Canyon.

The off-site surface water sampling stations are at Acid Weir (where Acid Canyon joins the main channel of Pueblo Canyon), Pueblo 1, and Pueblo 2. Flow is irregular at these locations, dependent mainly on snowmelt and thunderstorm runoff and return flow from the shallow alluvium. In the past, discharges from the Los Alamos County Pueblo sanitary sewage plant upstream from the confluence with Acid Canyon maintained more regular flow; however, operation of this plant has been discontinued except for short periods in the summer when it is operated primarily to provide irrigation water for the County golf course. In lower Los Alamos Canyon, off-site surface water samples are collected at its confluence with the Rio Grande.

Other Areas. Off-site perimeter stations within about 4 km (2.5 mi) of the Laboratory boundary include surface water stations at Los Alamos Reservoir, Guaje Canyon, and Frijoles Canyon. Los Alamos Reservoir, in upper Los Alamos Canyon on the flanks of the mountains west of Los Alamos, has a capacity of 51,000 m^3 (41 ac-ft) and a drainage area of 17 km^2 (6.4 mi^2) above the intake. The reservoir is used for recreation and storage for limited landscape irrigation in the townsite.

The station in Guaje Canyon is below Guaje Reservoir, which is located in upper Guaje Canyon and has a capacity of 900 m^3 (0.7 ac-ft) and a drainage area above the intake of about 14 km^2 (5.6 mi^2). Flow into the reservoir is maintained by perennial springs. The stream and reservoir are used for recreation and diversion of water for landscape irrigation in the townsite.

Surface water flow in Frijoles Canyon is sampled at Bandelier National Monument Headquarters. Flow in the canyon is from spring discharge in the upper reach of the canyon. The drainage area above the monument headquarters is about 45 km^2 (17 mi^2) (Purtymun 1980a). Surface flow in Frijoles Canyon is also sampled at the confluence with the Rio Grande.

There are four other perimeter stations in White Rock Canyon along the Rio Grande just east of the Laboratory; two are off site and two are on site. Included in this group are the streams in Pajarito (off site), Water, and Ancho Canyons (both on site), which are fed from Group I springs. (See Section VII, Groundwater Protection Management Program, for additional information.) Treated sanitary effluent from the community of White Rock is sampled in Mortandad Canyon (off site) at its confluence with the Rio Grande.

c. On-Site Stations.

Radioactive Effluent Areas. On-site effluent release areas are canyons that receive, or have received, effluents containing radioactivity, including Pueblo, DP, Los Alamos, and Mortandad Canyons.

As noted above in the section describing off-site radioactive effluent areas, the portion of lower Pueblo Canyon presently on DOE lands contains sediments contaminated with residuals from past discharges into Acid Canyon. (See Section IV.E for related information.) Surface flow is presently maintained across the DOE land in Pueblo Canyon by discharge of effluent from the Los Alamos County Bayo sanitary sewage treatment plant located just west of the County-DOE boundary. Some of this effluent flow infiltrates and maintains a shallow body of perched alluvial water. (See Section VII for further information.) Pueblo Canyon discharges into Los Alamos Canyon at State Road 502 near the eastern Laboratory boundary. Surface water is sampled at Pueblo 3 and at State Road 502 (Fig. IV-6).

DP Canyon, a small tributary of Los Alamos Canyon, received treated radioactive liquid waste

effluents between 1952 and 1984. Some residuals remain, primarily associated with sediments, that are subject to resuspension and redissolution in surface flow. DP Canyon presently receives some sanitary effluent from the treatment plant at TA-21. Sampling stations consist of two surface water stations in DP Canyon, DPS-1 and DPS-4.

In the upper reach of Los Alamos Canyon (above Station LAO-1), there were releases of treated and untreated radioactive effluents during the earliest years of operations at TA-1 (late 1940s) and some release of cooling water from the research reactor at TA-2. The Los Alamos Canyon drainage also received discharge containing some radioactivity in previous years from the sanitary sewage lagoon system at LAMPF (TA-53). In 1989, the low-level radioactive waste stream was separated from the sanitary system at TA-53 and directed into a total retention, evaporative lagoon. There is normally some surface flow in the westernmost portion of Los Alamos Canyon within the Laboratory which is maintained by discharge from the Los Alamos Reservoir. This flow generally infiltrates the shallow alluvium in the canyon and is depleted before reaching the eastern margin of the Laboratory at State Road 4. Water quality in this portion of Los Alamos Canyon is monitored by samples of the alluvial water. (See Section VII for further information.) Snowmelt will often saturate the alluvium sufficiently to result in some surface flow beyond State Road 4 for varying periods in the spring. In the fall of 1991, the USGS, under contract to the Laboratory, resumed continuous operation of a streamflow gaging station a short distance upstream from State Road 4.

Mortandad Canyon has a small drainage area that heads at TA-3. Industrial liquid wastes containing radionuclides are collected and processed at the industrial waste treatment plant at TA-50 which started operation in 1963. After treatment the effluents are released into Mortandad Canyon. Most of the residuals are now associated with the sediments in the canyon. The inventory of transuranic contaminants is about 400 mCi, entirely contained on site (Stoker 1991). Hydrologic studies in the canyon were initiated by the USGS in 1960. Since that time, there has been no surface water flow beyond the Laboratory's boundary because the small drainage area in the upper part of the canyon results in limited runoff and because a thick section of unsaturated alluvium in the lower canyon allows rapid infiltration and storage of runoff when it does occur. One surface water station, Gaging Station 1 (GS-1) is located a short distance downstream from the effluent release point. Most water quality observations in Mortandad Canyon are made on the alluvial water. (See Section VII for further information.) Three sediment traps are located about 3 km (2 mi) downstream from the effluent discharge in Mortandad Canyon to dissipate the energy of major thunderstorm runoff events and settle out transported sediments. It is approximately another 1.5 km (1 mi) to the Laboratory boundary with San Ildefonso Pueblo.

Other Areas. Sandia Canyon has a small drainage area that heads on Pajarito Plateau at TA-3. The canyon receives cooling tower blowdown from the TA-3 power plant and treated sanitary effluents from TA-3. Treated effluents from the TA-3 sanitary treatment plant form a perennial stream in a short reach of the upper canyon. Only during summer thundershowers does stream flow reach the Laboratory boundary at State Road 4. Only during periods of heavy thunderstorms or snowmelt does surface flow from Sandia Canyon extend beyond Laboratory boundaries or reach the Rio Grande. Three surface water sampling stations, SCS-1, SCS-2, and SCS-3, are located in the reach of the canyon containing perennial flow maintained by the effluents.

Surface water samples are collected in three other on-site canyons: Cañada del Buey, Pajarito, and Water (at Beta Hole). The flows at these locations are primarily maintained by effluents but do include some natural flows. Spring supported flows in Water and Ancho Canyons are sampled at the DOE boundary where these streams join the Rio Grande.

3. Analytical Results.

a. Radiochemical Analyses. The results of radiochemical analyses of surface water samples for 1991 are listed in Table IV-17. All results are below the DOE Derived Concentration Guides that limit potential exposure to the public from ingestion of water to levels below the DOE public dose limit (see Appendix A.). The majority of the results are near or below analytical method detection limits. Of the few at or above detection limits, most are from locations with previously known contamination: the Acid-Pueblo Canyon and the Mortandad Canyon locations. The plutonium analyses for the Jemez River and the Frijoles Stream at Bandelier National Monument Headquarters sample are just at the detection limit, but because they

Table IV-17. Radiochemical Analyses of Surface Waters

Location	H^3 (pCi/L)	^{90}S (nCi/L)	^{137}Cs (pCi/L)	Uranium (µg/L)	^{238}Pu (pCi/L)	^{239}Pu (pCi/L)	Gross Gamma (Counts/min/L)
REGIONAL STATIONS							
Rio Chama at Chamita	0.0 (0.3)[a]	N/A	114.00 (82.00)	1.3 (0.1)	0.000 (0.010)	0.004 (0.009)	20 (70)
Rio Grande at Embudo	0.3 (0.3)	N/A	96.00 (237.00)	1.1 (0.1)	0.012 (0.017)	0.000 (0.010)	-10 (70)
Rio Grande at Otowi	0.2 (0.3)	N/A	101.00 (88.00)	1.5 (0.2)	0.010 (0.020)	0.005 (0.011)	-10 (70)
Rio Grande at Cochiti	0.5 (0.3)	N/A	175.00 (135.00)	1.6 (0.1)	0.004 (0.004)	0.000 (0.010)	60 (80)
Rio Grande at Bernalillo	0.1 (0.3)	N/A	151.00 (126.00)	1.9 (0.1)	0.004 (0.004)	0.013 (0.007)	-30 (70)
Jemez River	0.3 (0.3)	N/A	74.00 (88.00)	0.6 (0.1)	0.022 (0.010)	0.022 (0.012)	-180 (80)
PERIMETER STATIONS (OFF SITE)							
Radioactive Effluent Release Areas							
Acid-Pueblo Canyons							
Acid Weir	0.4 (0.3)	N/A	186.00 (122.00)	0.2 (0.1)	-0.005 (0.009)	0.025 (0.013)	190 (80)
Pueblo 1	1.9 (0.3)	N/A	324.00 (131.00)	0.1 (0.1)	-0.005 (0.005)	0.014 (0.008)	140 (70)
Pueblo 2		Dry in 1991					
Los Alamos Canyon							
Los Alamos at Rio Grande		See Section IV.E.5.a[b]					
Other Areas							
Guaje at Rio Grande	0.3 (0.3)	N/A	103.00 (124.00)	0.1 (0.1)	0.020 (0.014)	0.008 (0.010)	20 (70)
Los Alamos Reservoir	0.2 (0.3)	N/A	-23.00 (74.30)	<0.1 (0.0)	0.012 (0.012)	0.004 (0.007)	-190 (70)
Mortandad at Rio Grande	0.4 (0.3)	0.5 (0.6)	89.70 (66.00)	0.8 (0.5)	0.013 (0.015)	0.008 (0.008)	
Pajarito at Rio Grande	0.0 (0.3)	0.1 (0.6)	11.50 (63.20)	<0.8 (0.5)	0.004 (0.007)	0.000 (0.010)	
Frijoles at Park Headquarters	1.7 (0.3)	N/A	93.30 (123.00)	0.3 (0.1)	0.024 (0.017)	0.006 (0.010)	
Frijoles at Rio Grande	0.1 (0.3)	0.5 (0.6)	94.80 (68.80)	<0.5 (0.0)	0.008 (0.008)	0.000 (0.010)	-80 (7)
ON-SITE STATIONS							
Radioactive Effluent Release Areas							
Acid-Pueblo Canyons							
Pueblo 3	1.5 (0.3)	N/A	6.53 (9.31)	0.8 (0.1)	0.015 (0.041)	0.046 (0.046)	110 (70)
Pueblo at SR 502		See Section IV.E.5.a[b]					

Table IV-17 (Cont.)

Location	H^3 (pCi/L)	^{90}S (nCi/L)	^{137}Cs (pCi/L)	Uranium (μg/L)	^{238}Pu (pCi/L)	^{239}Pu (pCi/L)	Gross Gamma (Counts/min/L)
DP--Los Alamos Canyons							
DPS-1		Dry in 1991					
DPS-4		Dry in 1991					
Mortandad Canyon							
GS-1		See Section VII.C.1[c]					
Other Areas							
Cañada del Buey	0.5 (0.3)	N/A	10.10 (85.00)	0.3 (0.1)	0.000 (0.010)	0.010 (0.010)	120 (70)
Pajarito Canyon	0.1 (0.3)	N/A	334.00 (131.00)	0.1 (0.0)	0.004 (0.007)	0.013 (0.007)	90 (70)
Water Canyon at Beta	0.3 (0.3)	N/A	53.60 (67.70)	0.3 (0.0)	-0.004 (0.004)	0.004 (0.004)	10 (80)
Ancho at Rio Grande	0.0 (0.3)	0.7 (0.6)	-3.82 (73.20)	0.6 (0.5)	0.004 (0.004)	0.004 (0.004)	
Sandia Canyon							
SCS-1	0.2 (0.3)	N/A	88.00 (93.00)	1.0 (0.1)	0.005 (0.008)	0.009 (0.007)	110 (70)
SCS-2	0.5 (0.3)	N/A	273.00 (121.00)	0.9 (0.1)	0.013 (0.009)	0.008 (0.010)	50 (70)
SCS-3	0.4 (0.3)	N/A	N/A	0.8 (0.1)	0.000 (0.010)	0.000 (0.010)	200 (80)
Limits of Detection[d]	0.4	3	40	1	0.02	0.02	50
DCG for Public Dose[e]	2000	1000	3000	800	40	60	—

[a]Radioactivity counting uncertainties (±1 standard deviation) are shown in parentheses.
[b]See special study on transport of radioactivity on sediments in Pueblo and Los Alamos Canyons in Section IV.E.5.a of the Sediments and Soils Monitoring for sampling results.
[c]Individual result not available this year, see radiochemical results discussion in Section VII.C.1 for range of values.
[d]See Section VIII.D.
[e]See Appendix A.

are not in the expected ratio for worldwide fallout ($^{239,240}Pu$ about 20 times ^{238}Pu), it is unlikely the ^{238}Pu values are representative. The tritium level in the sample of Frijoles Stream at Bandelier Headquarters is higher than seen previously or than expected for regional waters; however, the sample at Frijoles taken further downstream at the Rio Grande does not show any detectable tritium. Most of the cesium analyses appear to be above the detection limits, but even the largest is about 10% of the DOE guide. Because the individual measurement uncertainties are so large (most more than half of the reported value and ranging up to almost 20 times) and are generally inconsistent with the gross gamma measurements, it is not likely that they represent real values. Improvements are being made to the cesium counting procedure and equipment for 1992 that are expected to result in more confidence in the measurements.

Multiple measurements of radioactivity on sediments transported in Pueblo and Los Alamos Canyons are presented and discussed in Sediment and Soils, Section IV.E.5.a.

b. Nonradioactive Analyses. The results of major chemical parameters in surface water samples for 1991 are listed in Table IV-18. The results are consistent with those observed in previous years, showing some expected variability. The measurements in waters from areas receiving effluents show some effect from these effluents. None of the measurements exceed any limits for drinking water systems even though such standards are not applicable to these surface waters.

The results of metal analyses on surface water samples for 1991 are listed in Table IV-19. The levels are generally consistent with previous observations in the effluent release areas. Most of the measurements were made for the first time this year (Regional and Perimeter-Other) and will serve as a base for future comparisons. The only levels above the Livestock and Wildlife Watering standards include the aluminum and selenium levels at the GS-1 location in Mortandad Canyon. One other selenium level, the sample from Water Canyon, is just below the standard. However, this second level is only slightly above the analytical method detection limit, which is 80% of the standard. An effort will be made in 1992 to obtain a lower selenium detection limit for more confidence in comparisons with standards.

Analyses for organics were performed on some surface waters this year. The analyses included the volatile, semivolatile, and PCB analyses (see Section VIII.D for detailed listings of parameters). None of the analyses detected the presence of any of the compounds. The sources sampled included Acid Weir, Pueblo 1, Pueblo 2, and Pueblo 3 in the Pueblo Canyon; DPS-1 and DPS-4 in Los Alamos Canyon; and SCS-1, SCS-2, SCS-3 in Sandia Canyon.

4. Long-Term Trends.

Long-term trends of dissolved radionuclide concentrations in surface water in Pueblo Canyon (a former release area) are depicted in Fig. IV-7. These measurements were made on samples collected at Station Pueblo 3, which is a short distance upstream of the confluence of Pueblo and Los Alamos Canyons. This is representative of the surface water flow that moves off site into the lower reach of Los Alamos Canyon on San Ildefonso Pueblo. In general, there has been a decrease in combined ^{238}Pu and $^{239,240}Pu$ (in solution) over three and a half decades, to the point where most recent measurements are below detection limits. The tritium concentrations peaked in 1982 and have decreased over the last 10 years to values typically observed in regional surface waters and very near the detection limit of the methods of analysis. More transport of radioactivity occurs as sediments are suspended and moved by the surface water flow. This aspect of off-site transport from Pueblo Canyon into Los Alamos Canyon is described in the following section, Sediment and Soil Monitoring.

E. Sediment and Soil Monitoring

1. Introduction.

Sediments and soils from regional, perimeter, and on-site locations are monitored to provide routine surveillance of environmental effects of Laboratory operations. One major mechanism of transport of contaminants is the hydrologic cycle, principally in surface water, as sheet erosion of soil, and subsequently as suspended sediment or bedload in surface runoff in canyons. Many contaminants have an affinity for attachment to soil or sediment particles by adsorption or ion exchange. Thus contaminants from airborne deposition, effluent discharges, or unplanned releases usually become associated with soils or sediments.

Table IV-18. Chemical Quality of Surface Waters (mg/L)

Station	SiO_2	Ca	Mg	K	Na	Cl	F	CO_3	HCO_3	PO_4-P	SO_4	NO_3-N	CN	TDS[a]	Total Hardness	pH[b]	Conductivity (µmho/em)
REGIONAL STATIONS																	
Rio Chama at Chamita	15	51	9.4	2.3	19	3	0.2	<5	78	0.2	112	<0.04	<0.01	722	168	8.0	320
Rio Grande at Embudo	21	31	5.2	2.4	12	3	0.3	<5	70	0.2	33	0.5	<0.01	148	101	8.0	181
Rio Grande at Otowi	20	43	7.2	2.4	17	4	0.3	<5	81	0.2	69	0.1	<0.01	106	139	8.0	257
Rio Grande at Cochiti	19	45	7.1	2.8	18	4	0.3	<5	80	0.1	64	0.1	<0.01	197	142	8.0	225
Rio Grande at Bernalillo	19	45	7.3	3.2	25	12	0.4	<5	89	0.2	72	0.1	<0.01	86	143	7.9	284
Jemez River	27	33	3.2	4.3	18	19	0.4	<5	67	0.1	13	0.0	<0.01	192	96	7.9	207
PERIMETER STATIONS (OFF SITE)																	
Radioactive Effluent Release Areas																	
Acid-Pueblo Canyons																	
Acid Weir	17	29	3.2	7.0	81	212	0.3	<2	35	0.3	12	0.7	<0.01	362	95	6.8	631
Pueblo 1	24	31	5.2	8.7	65	162	0.3	<2	53	0.7	18	0.3	<0.01	322	99	7.3	562
Pueblo 2		Dry in 1991															
Other Areas																	
Guaje Canyon	55	10	2.4	2.9	10	1	0.3	<5	39	0.3	5	0.0	0.01	176	35	7.4	89
Los Alamos Reservoir	32	9	2.7	2.2	9	9	0.2	<5	24	0.1	4	0.0	0.01	66	35	7.2	80
Mortandad at Rio Grande	89	26	7.7	14.0	80	49	1.1	12	119	8.2	35	8.7	<0.01	432	96	8.6	569
Pajarito at Rio Grande	70	20	4.8	2.2	12	6	0.4	<5	83	0.3	5	0.7	<0.01	198	69	8.3	177
Frijoles at Park Headquarters	49	10	2.8	2.0	11	4	0.2	<5	33	0.3	5	0.0	0.01	90	37	7.5	89
Frijoles at Rio Grande	59	10	3.3	2.6	10	3	<0.2	<5	55	0.3	3	<0.04	<0.01	144	38	7.3	98
ON-SITE STATIONS																	
Radioactive Effluent Release Areas																	
Acid-Pueblo Canyons																	
Pueblo 3	72	24	3.3	14.9	79	51	0.9	<2	118	8.9	38	13.4	0.040	414	75	7.4	316
Mortandad Canyon																	
GS-1	39	190	33.0	43.0	180	7	0.3	<5	70	0.2	5	3.2	0.014	248	610	7.5	138
DP--Los Alamos Canyons																	
DPS-1			Dry in 1991														
DPS-4			Dry in 1991														

Table IV-18. (Cont.)

Station	SiO_2	Ca	Mg	K	Na	Cl	F	CO_3	HCO_3	PO_4-P	SO_4	NO_3-N	CN	TDS	Total Hardness	pH	Conductivity (µmho/em)
Other Areas																	
Cañada del Buey	33	16	3.3	3.3	34	57	0.6	<2	<2	0.2	62	6.0	<0.01	220	55	3.6	320
Pajarito Canyon	33	30	7.3	4.5	31	62	<0.2	<2	67	0.1	15	1.5	<0.01	218	105	8.0	286
Water Canyon at Beta	30	15	5.0	4.0	19	9	<0.2	<2	61	0.2	7	2.7	<0.01	168	58	6.8	172
Ancho at Rio Grande	75	13	3.4	2.4	11	2	0.4	<5	62	0.3	2	<0.04	<0.01	94	48	8.9	109
Sandia Canyon																	
SCS-1	73	32	5.0	13.0	91	62	0.8	2	126	3.2	99	0.8	0.010	494	101	8.3	636
SCS-2	74	32	4.9	12.8	88	63	0.8	2	122	3.2	109	0.8	0.010	484	100	8.3	665
SCS-3	74	32	4.9	12.8	86	62	0.8	2	123	16.0	98	0.8	0.023	492	122	8.3	650
Drinking Water System Limit						250[c]	4[d]				250[c]	10[d]		500[c]		6.8-8.5[c]	
Livestock and Wildlife Watering								None in this table[e]									

[a]Total dissolved solids.
[b]Standard Units.
[c]Maximum contaminent level for secondary constituents, applicable to drinking water system, given here for comparison only, see Appendix A.
[d]Maximum contaminent level for primary constituents, applicable to drinking water system, given here for comparison only, see Appendix A.
[e]New Mexico Water Quality Standards applicable to streams for designated uses, given here for comparison only, see Appendix A.

Table IV-19. Trace Metals in Surface Waters (mg/L)

Location	Ag	Al	As	B	Be	Cd	Cr	Co	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
REGIONAL STATIONS																						
Rio Chama at Chamita	<0.0005[a]	0.4	<0.01	0.03	<0.001	<0.01	<0.002	N/A	<0.02	0.37	<0.0002	0.120	<0.002	<0.01	0.002	<0.0001	<0.02	N/A	0.355	0.0002	0.012	0.007
Rio Grande at Embudo	<0.0005	0.5	<0.01	0.02	<0.001	<0.01	<0.002	N/A	<0.02	0.68	<0.0002	0.240	<0.002	<0.01	0.003	0.0002	<0.02	N/A	0.161	<0.0002	0.010	0.030
Rio Grande at Otowi	0.001	0.5	0.010	0.03	<0.001	<0.01	0.002	N/A	<0.02	0.51	<0.0002	0.180	<0.002	<0.01	0.004	<0.0001	<0.02	N/A	0.252	<0.0002	0.012	0.018
Rio Grande at Cochiti	<0.0005	0.2	<0.01	0.03	<0.001	<0.01	<0.002	N/A	<0.02	0.14	<0.0002	0.002	0.003	<0.01	0.001	0.0001	<0.02	N/A	0.239	<0.0002	0.010	<0.001
Rio Grande at Bernalillo	<0.0005	0.5	<0.01	0.07	<0.001	<0.01	<0.002	N/A	<0.02	0.51	<0.0002	0.100	0.003	<0.01	0.002	<0.0001	<0.02	N/A	0.299	<0.0002	0.011	0.009
Jemez River	<0.0005	0.4	0.020	0.15	<0.001	<0.01	<0.002	N/A	<0.02	0.41	<0.0002	0.070	<0.002	<0.01	0.001	<0.0001	<0.02	N/A	0.097	<0.0002	0.007	0.006
PERIMETER STATIONS (OFF SITE)																						
Effluent Release Areas																						
Acid-Pueblo Canyons																						
Acid Weir	<0.0005	<0.02	0.002	0.00	<0.0005	<0.0003	<0.001	<0.003	<0.001	<0.004	0.0004	0.002	<0.001	<0.02	0.000	0.0002	<0.03	<0.02	0.123	0.0001	0.004	<0.0033
Pueblo 1	<0.0005	<0.02	0.003	0.04	<0.0005	<0.0003	<0.001	<0.003	0.002	0.23	0.0004	0.220	0.002	<0.02	0.001	0.0002	<0.03	<0.02	0.135	<0.0001	0.006	0.004
Other Areas																						
Guaje Canyon	0.001	0.2	<0.02	0.01	<0.001	<0.005	0.0020	N/A	<0.007	0.11	<0.0002	0.007	<0.006	<0.01	0.001	<0.0005	<0.04	N/A	0.038	<0.0001	<0.003	0.008
Los Alamos Reservoir	0.001	0.1	<0.02	0.01	<0.001	<0.005	<0.002	N/A	<0.007	0.10	<0.0002	0.014	<0.006	<0.01	0.001	<0.0005	<0.04	N/A	0.045	<0.0001	0.004	0.006
Mortandad at Rio Grande	<0.0005	0.1	0.003	0.32	<0.0005	<0.004	<0.0005	N/A	0.031	0.70	<0.0002	0.005	N/A	0.010	0.001	<0.002	<0.03	N/A	0.125	<0.0005	0.011	0.019
Frijoles at Park Headquarters	<0.0005	0.3	<0.02	0.01	<0.001	<0.005	<0.002	N/A	<0.007	0.26	<0.0002	0.021	<0.006	<0.01	0.002	<0.0005	<0.04	N/A	0.062	<0.0001	0.005	0.009
Frijoles at Rio Grande	<0.0005	0.2	0.002	0.02	<0.0005	<0.001	0.0021	N/A	0.002	0.20	<0.0002	0.007	N/A	<0.006	0.001	<0.001	<0.03	N/A	0.062	<0.0005	0.005	0.014
ON-SITE STATIONS																						
Radioactive Effluent Release Areas																						
Acid-Pueblo Canyons																						
Pueblo 3	0.002	0.5	0.013	0.32	<0.0005	<0.0003	0.0032	<0.003	0.010	0.67	0.0004	0.017	0.004	<0.02	0.001	0.0004	<0.03	<0.02	0.108	<0.0001	0.026	0.033
Mortandad Canyon																						
GS-1	<0.0005	14.0	0.004	0.29	<0.0005	<0.0005	0.0063	0.060	0.006	11.00	0.0004	0.045	0.062	0.040	0.005	<0.0005	0.670	0.130	0.080	<0.0005	0.009	0.023
Other Areas																						
Cañada del Buey	0.002	0.3	<0.0017	0.07	<0.0005	<0.0003	0.0072	<0.008	0.006	0.77	<0.0002	0.518	0.101	0.010	0.002	0.0003	<0.04	<0.01	0.076	0.0002	0.003	0.054
Pajarito Canyon	0.001	0.1	<0.0015	0.04	<0.0005	<0.0003	0.0022	<0.008	<0.001	2.40	0.0002	0.064	0.001	<0.01	0.000	0.0003	<0.04	0.010	0.147	0.0002	0.001	0.005
Water Canyon at Beta	<0.002	2.5	<0.002	0.09	<0.0003	0.0021	<0.002	<0.008	<0.002	1.10	<0.0002	0.014	<0.002	<0.015	0.002	0.0003	0.048	0.026	0.090	<0.0005	<0.002	N/A
Ancho at Rio Grande	<0.0005	0.0	0.002	0.02	<0.0005	<0.0005	0.0034	N/A	<0.002	0.05	<0.0002	0.003	N/A	<0.006	<0.0005	<0.001	<0.03	N/A	0.071	<0.0005	0.009	<0.005

Table IV-19. (Cont.)

Location	Ag	Al	As	B	Be	Cd	Cr	Co	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
Sandia Canyon																						
SCS-1	0.001	0.1	N/A	0.11	<0.0005	N/A	0.0144	<0.008	0.012	0.36	<0.0002	0.015	0.179	0.010	0.003	0.0005	<0.04	0.020	0.115	0.0002	0.011	0.030
SCS-2	0.001	0.2	N/A	0.11	<0.0005	N/A	0.0131	<0.008	0.010	0.46	<0.0002	0.008	0.176	<0.01	0.012	0.0003	<0.04	0.020	0.114	0.0002	0.011	0.031
SCS-3	0.001	0.1	N/A	0.11	<0.0005	N/A	0.0130	<0.008	0.010	0.36	<0.0002	0.007	0.180	<0.01	0.003	0.0007	<0.04	0.020	0.113	0.0002	0.011	0.037
Drinking Water System Limit	0.05[b]		0.05[b]	0		.01[b]	0.05[b]		1.0[c]	0.3[c]	0.002[b]	0.05[c]			0.05[b]		0.01[b]					5.0[c]
Livestock and Wildlife Watering Limit[d]		5.0	0.02	5.0		0.05	1.0	1.0	0.5		0.01				0.1		0.05				0.1	25

[a]Less than symbol (<) means measurement was below the specified detection limit of the analytical method.
[b]Maximum contaminent level for primary constituents, applicable to drinking water system, given here for comparison only, see Appendix A.
[c]Maximum contaminent level for secondary constituents, applicable to drinking water system, given here for comparison only, see Appendix A.
[d]New Mexico Water Quality Standards applicable to streams for designated uses, given here for comparison only, see Appendix A.

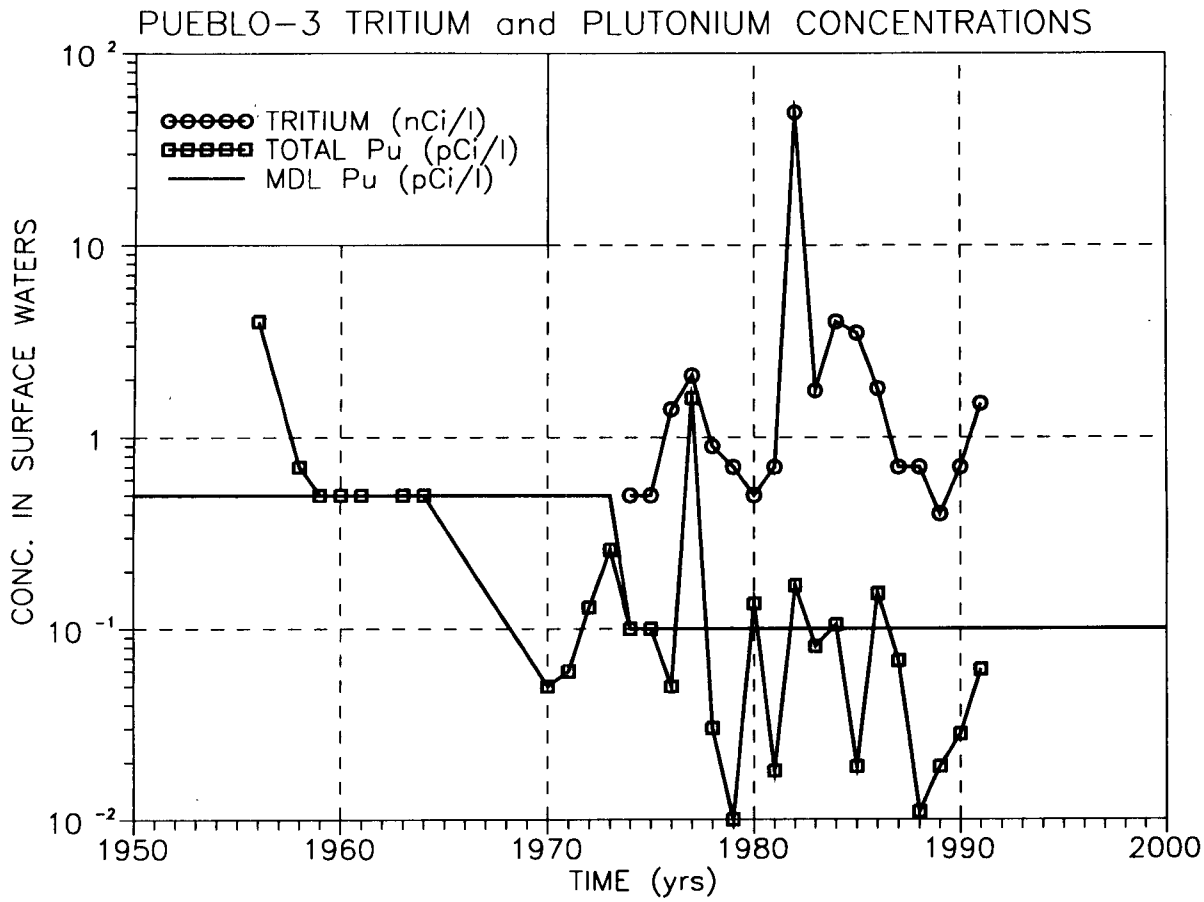


Fig. IV-7. Pueblo-3, tritium and plutonium concentrations.

Accordingly, soils are monitored at representative locations across the Laboratory, and sediments are sampled in all canyons, whether perennial or intermittent, that cross the Laboratory lands.

There are no standards directly applicable to radioactive contamination of soils or sediments; rather, the levels of contaminants on soils or sediments must be interpreted by means of pathway analyses that determine the consequences in terms of dose to humans if the contaminated particles are either ingested or inhaled. (See Section V.C.2, Methods of Dose Calculations, for further information.) As an indication of environmental contamination levels attributable to Los Alamos operations, the results of the annual sampling are compared to levels attributable to worldwide fallout or natural background. Results of analyses of radionuclides in soil and sediment samples from regional stations routinely collected from 1974 through 1986 were used to establish statistical limits for worldwide fallout levels of H^3, ^{90}Sr, ^{137}Cs, ^{238}Pu, and $^{239,240}Pu$ and natural background levels of total uranium in northern New Mexico soils and sediments (Purtymun 1987a). The average of the concentration levels in these samples plus twice the standard deviation of the mean was used to establish the upper limits of worldwide fallout or natural background concentrations.

2. Monitoring Network.

The sediment sampling locations are shown in Fig. IV-8 (Regional), Fig. IV-9 (Perimeter and On Site), and Fig. IV-10 (Solid Waste Management Areas) and are listed in Table D-10. The locations of the soil sampling locations are shown in Fig. IV-8 (Regional) and Fig. IV-11 (Perimeter and On Site), and listed in Table D-11. The sediment stations are organized in the same groupings as the surface water sampling locations discussed in the previous section, Surface Water Monitoring. That section contains the basic rationale for the groupings and related historic information. Some detail specific to sediment samples is included in the following paragraphs.

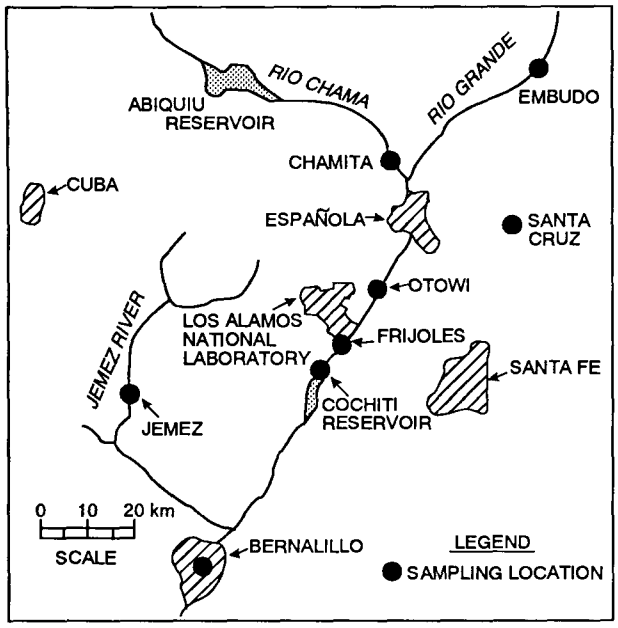


Fig. IV-8. Regional sampling locations for sediments and soil. (Four additional sediment samples are taken from the Rio Grande between Otowi and Frijoles, see Table D-10 and Fig. IV-9.)

a. Regional Stations. The regional stations for both soils and stream sediments are located in the three major drainages in northern New Mexico surrounding the Laboratory. One additional soil station is located near Santa Cruz Lake, across the Rio Grande valley to the northeast of the Laboratory.

Special samples of lake sediments are also collected from three locations in Abiquiu Reservoir on the Rio Chama upstream from Los Alamos, and three locations in Cochiti Reservoir on the Rio Grande downstream of Los Alamos. The two lakes are the nearest upstream and downstream lakes. These sediment samples are used to obtain better detection limits when analyzing for ^{238}Pu and ^{239,240}Pu by using 1 kg samples (100 times the mass usually used for analyses). Large samples increase the sensitivity of the plutonium analyses and are necessary to effectively evaluate plutonium concentrations due to worldwide fallout from atmospheric tests.

b. Perimeter (Off-Site) Stations. The Radioactive Effluent Release Area sediment stations are located to represent the off-site drainages affected by transport of residuals from past releases, as discussed in the previous section. The off-site Acid Canyon and Pueblo Canyon areas contain an estimated 150 mCi of plutonium from the 1944–1964 effluent releases into Acid Canyon (ESG 1981), the sampling station at Acid Weir at the confluence of Acid and Pueblo Canyons. The off-site portion of Los Alamos Canyon contains an estimated 30 mCi of plutonium; three stations are sampled routinely. Transport of contaminated sediments off site is discussed below. Other sediment locations are sampled in order to cover all the canyons including those without perennial flow. Several sediment samples are collected in the off-site portion of Mortandad Canyon on San Ildefonso Pueblo to document conditions downgradient from the on-site residual contamination as discussed in the previous section. Also, sediment samples are taken in the Rio Grande at confluences with major canyons that cross the Laboratory and adjacent public or San Ildefonso Pueblo lands.

The six perimeter soil stations within 4 km (2.5 mi) of the Laboratory perimeter are located to emphasize the inhabited areas to the north and east of the Laboratory.

c. On-Site Stations. The on-site sediment stations are grouped into Radioactive Effluent Release Areas, Solid Waste Management Areas, and Other Canyons.

The Radioactive Effluent Release Areas are the same as those used for the Surface Water Stations (see Section IV.D.2 for historic information). Transport of contaminated sediments off site from Pueblo Canyon is discussed below. Transport of contaminated sediments within the on-site portion of Mortandad Canyon and the sediment traps is discussed below. No off-site transport of contaminated sediments from Mortandad Canyon has occurred; no contaminated runoff has reached or extended past the Laboratory boundary since before the TA-50 treatment plant started operating in 1963.

Sediments from natural drainages around two Radioactive Solid Waste Management Areas are sampled to monitor transport of radioactivity from surface contamination. Nine sampling stations were established in 1982 outside the perimeter fence at TA-54, Area G (Fig. IV-10b), to monitor possible transport of radionuclides by sheet erosion from the active waste storage and disposal area. Some radionuclides are transported from the surface at Area G in suspended or bed sediments into channels that drain the area. This contamination is from the land surface and is not related to the buried wastes in the pits and shafts. It is

residual contamination in the land surface that occurred during earlier handling of the wastes.

From 1959 to 1961, hydronuclear experiments were conducted in underground shafts that ranged in depth from 15 to 36 m (50 to 120 ft) beneath the surface of the mesa at TA-49 (Purtymun 1987b, ESG 1988). The experiments involved a combination of conventional (chemical) high explosives, usually in a nuclear weapons configuration. The quantity of fissile material was kept far below the amount required for a nuclear explosion (Purtymun 1987b). The residuals of the experiments were confined in the shafts and left in place. The site is designated Solid Waste Management Area AB. A surface contamination incident occurred in 1960, and some erosional transport of radioactivity occurred (Purtymun 1987b, ESG 1988). Eleven sediment stations were established in 1972 to monitor surface sediments in natural drainage from the experimental area. Another station (AB-4A) was added in 1981 as the drainage changed (Fig. IV-10a).

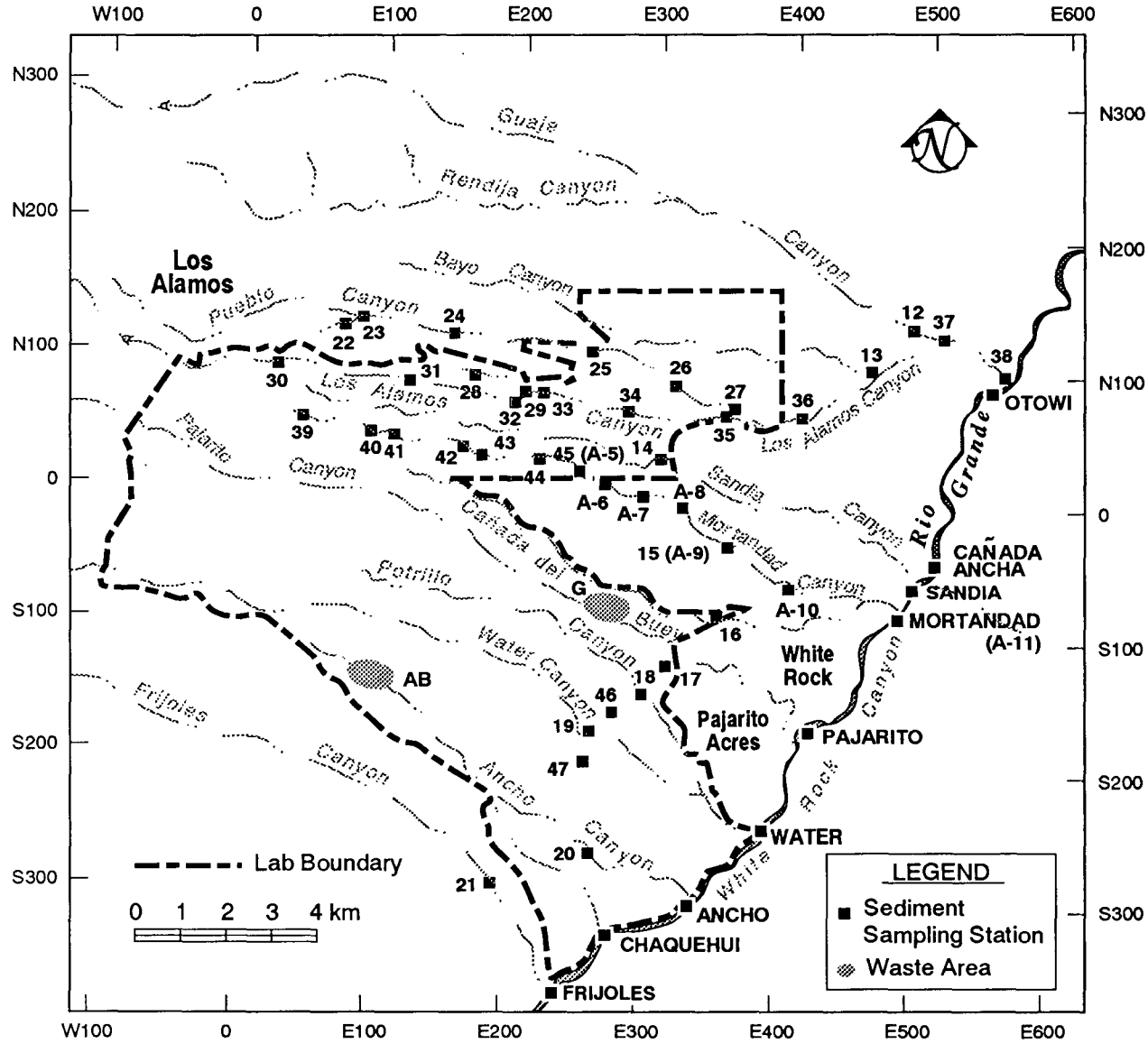
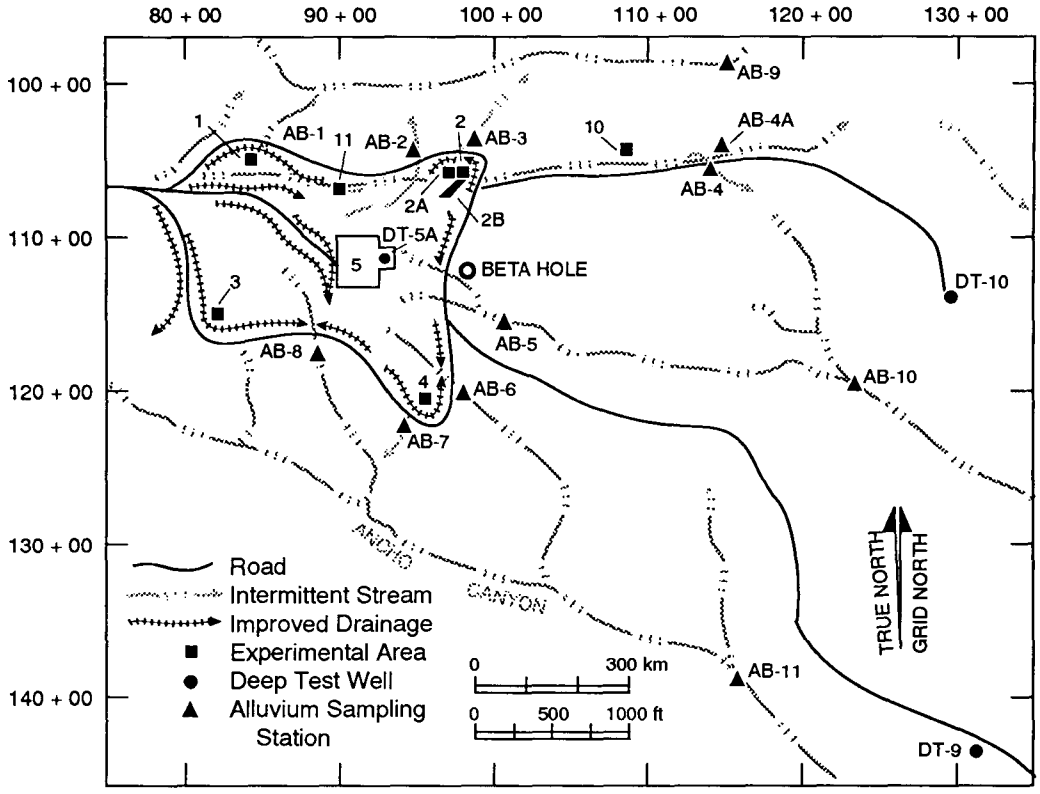


Fig. IV-9. Sediment sampling locations on and near the Laboratory site. Waste areas with multiple sampling locations are shown in Fig. IV-10. (Map denotes general locations only; see Table D-10 for specific locations.)



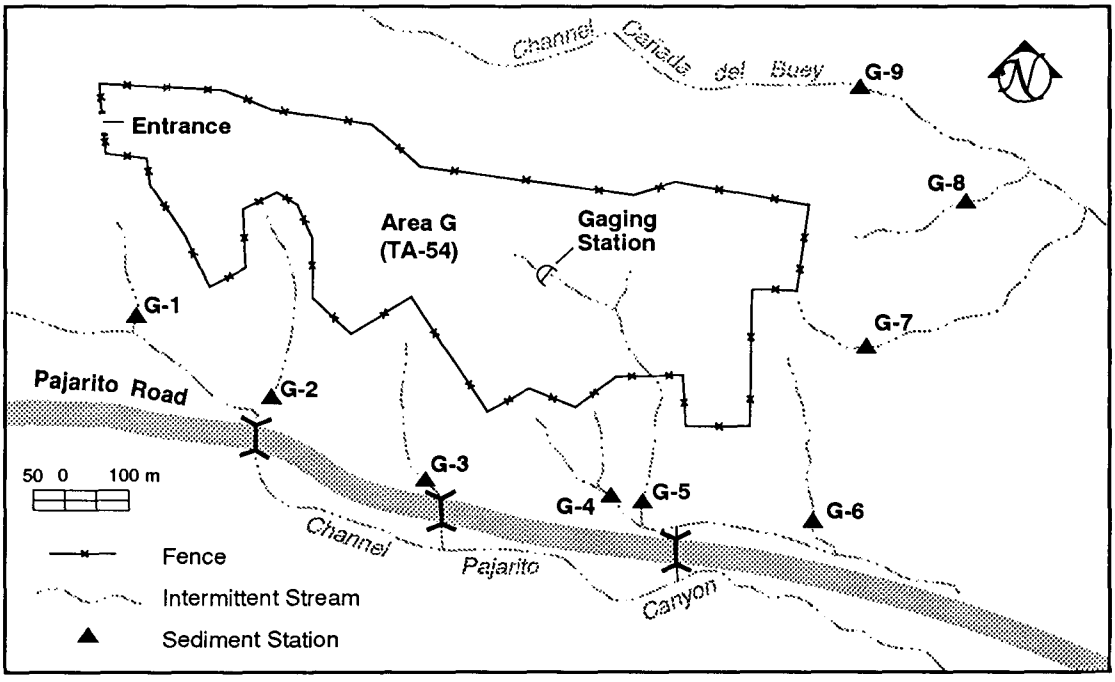


Fig. IV-10. Sediment sampling locations on and near solid waste management areas.
a. Upper map shows the location of experimental areas and sediment stations at TA-49, Area AB.
b. Bottom map shows the locations of alluvium sampling stations at TA-54, Area G.

Eight sediment sampling stations are in the Other Canyons group. These are located where the canyons intersect State Road 4 because all Laboratory facilities in or adjacent to those canyons are located upgradient of the state road.

The on-site soil sampling stations (Table D-10 and Fig. IV-11) are located near major Laboratory facilities that are principal sources of airborne emissions or could be potential contaminant sources.

3. Analytical Results.

a. Radiochemical Analyses. The results of radiochemical analyses of regional, perimeter, and on-site sediment samples for 1991 are listed in Table IV-20. The results of radiochemical analyses of radioactive solid waste area sediment samples for 1991 are listed in Table IV-21.

The results of radiochemical analyses of soil samples for 1991 are listed in Table IV-22.

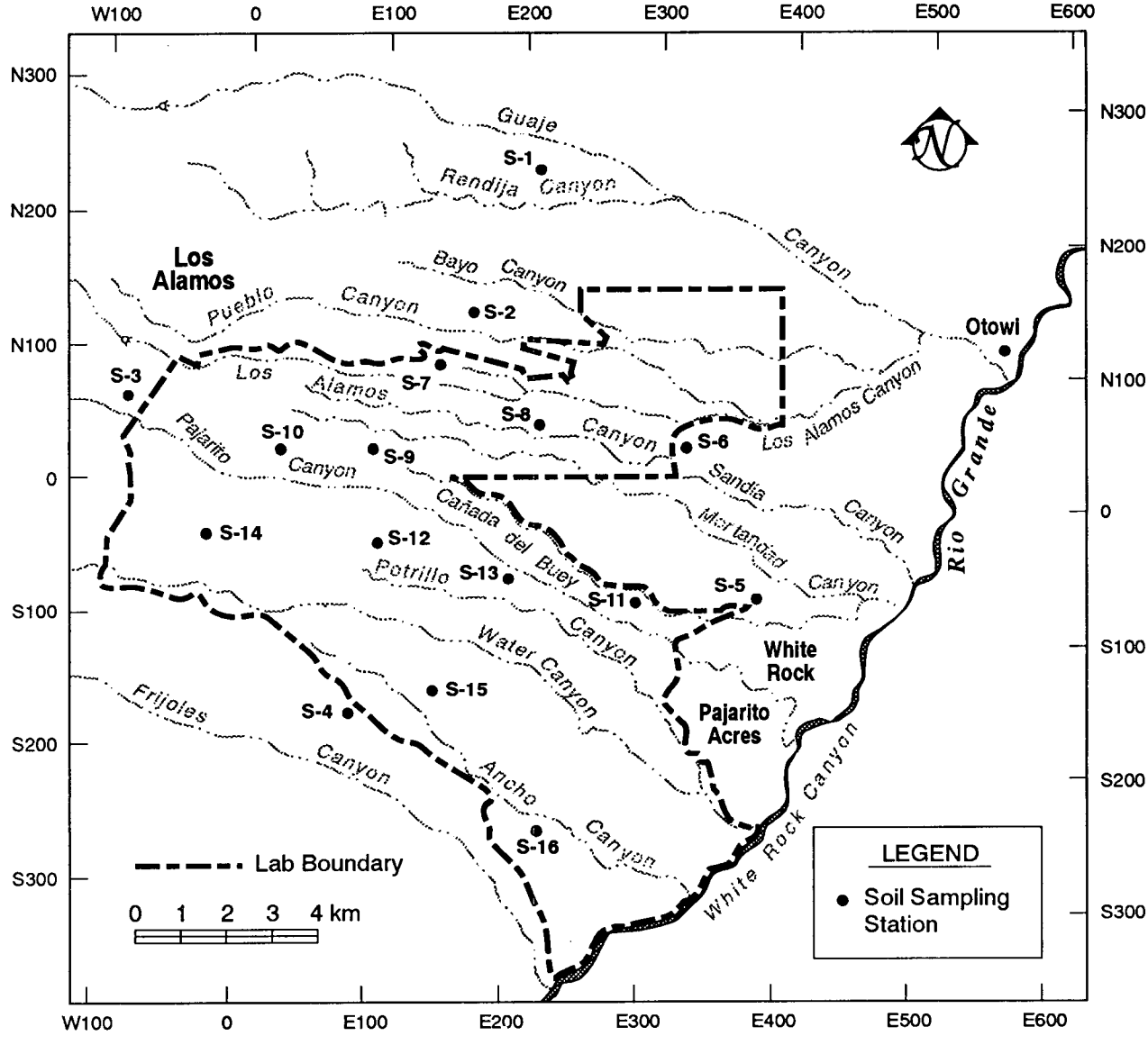


Fig. IV-11. Soil sampling locations on or near the Laboratory site. (Map denotes generalized locations only; refer to Table D-11 for specific locations.)

Table IV-20. Radiochemical Analyses of Sediments

Location	H^3 (nCi/L)[a]	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	Total Uranium (µg/g)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)	^{241}Am (pCi/g)	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Gross Gamma (counts/min/g)
REGIONAL STATIONS										
Chamita	N/A[b]	0.100 (0.200)[c]	0.1 (0.1)	2.6 (0.3)	0.001 (0.001)	0.002 (0.001)	N/A	3 (1)	3 (0)	1 (0)
Embudo	N/A	0.100 (0.200)	0.0 (0.1)	3.0 (0.3)	0.011 (0.002)	0.004 (0.001)	N/A	2 (1)	3 (0)	-0 (0)
Rio Grande at Otowi	N/A	0.200 (0.200)	0.1 (0.1)	2.4 (0.2)	0.002 (0.001)	0.002 (0.001)	N/A	3 (1)	2 (0)	1 (0)
Rio Grande at Frijoles	-0.5 (0.3)	0.000 (0.200)	0.2 (0.1)	4.1 (0.4)	0.002 (0.001)	0.004 (0.001)	N/A	3 (1)	4 (0)	2 (0)
Rio Grande at Cochiti	Channel completely scoured, no sediment in 1991									
Rio Grande at Bernalillo	N/A	0.200 (0.200)	0.1 (0.1)	1.6 (0.2)	0.002 (0.001)	0.004 (0.001)	N/A	3 (1)	2 (0)	-0 (0)
Jemez River	N/A	0.200 (0.200)	0.0 (0.1)	2.4 (0.2)	0.001 (0.001)	0.002 (0.001)	N/A	4 (1)	3 (0)	0 (0)
Rio Grande in White Rock Canyon										
Rio Grande at Sandia	-0.6 (0.3)	0.200 (0.200)	0.2 (0.1)	3.2 (0.3)	0.001 (0.001)	0.004 (0.001)	N/A	3 (1)	3 (0)	2 (0)
Rio Grande at Pajarito	-0.5 (0.3)	0.100 (0.200)	0.2 (0.1)	2.6 (0.3)	0.008 (0.002)	0.001 (0.001)	N/A	2 (1)	2 (0)	1 (0)
Rio Grande at Water Canyon	-0.3 (0.3)	0.000 (0.200)	0.2 (0.1)	2.7 (0.3)	0.001 (0.001)	0.002 (0.001)	N/A	4 (1)	4 (1)	1 (0)
Rio Grande at Ancho	-0.6 (0.3)	0.200 (0.200)	0.3 (0.1)	2.2 (0.2)	0.002 (0.001)	0.001 (0.001)	N/A	2 (1)	2 (0)	1 (0)
Rio Grande at Chaquehui	-0.4 (0.3)	0.200 (0.200)	0.0 (0.1)	2.3 (0.2)	0.001 (0.000)	0.003 (0.001)	N/A	3 (1)	3 (0)	1 (0)
PERIMETER STATIONS (OFF SITE)										
Radioactive Effluent Release Areas										
Acid-Pueblo Canyon										
Acid Weir	N/A	0.600 (0.200)	0.5 (0.1)	2.2 (0.2)	0.036 (0.006)	7.280 (0.420)	N/A	8 (2)	2 (0)	0 (0)
Pueblo 1	N/A	0.200 (0.200)	0.1 (0.1)	2.3 (0.2)	0.002 (0.001)	0.055 (0.004)	N/A	4 (1)	2 (0)	1 (0)
Pueblo 2	N/A	0.200 (0.200)	0.1 (0.1)	2.1 (0.2)	0.000 (0.002)	0.008 (0.001)	N/A	3 (1)	2 (0)	1 (0)
DP-Los Alamos Canyon										
Los Alamos at Totavi	N/A	0.100 (0.200)	0.0 (0.1)	4.2 (0.4)	0.003 (0.001)	0.003 (0.001)	N/A	2 (0)	2 (0)	2 (0)
Los Alamos at LA-2	N/A	0.300 (0.200)	-0.1 (0.1)	2.6 (0.3)	0.004 (0.001)	0.002 (0.001)	N/A	2 (1)	1 (0)	1 (0)
Los Alamos at Otowi	N/A	0.200 (0.200)	0.0 (0.1)	2.1 (0.2)	0.002 (0.002)	0.059 (0.004)	N/A	1 (0)	1 (0)	-1 (0)
Other Areas										
Guaje at SR-4	N/A	0.200 (0.200)	0.1 (0.1)	2.4 (0.2)	0.001 (0.001)	0.001 (0.001)	N/A	2 (1)	1 (0)	1 (0)
Bayo at SR-4	N/A	0.500 (0.200)	0.0 (0.1)	2.8 (0.3)	0.002 (0.001)	0.005 (0.001)	N/A	2 (1)	2 (0)	1 (0)
Sandia at Rio Grande	-0.4 (0.8)	0.000 (0.200)	0.0 (0.1)	1.7 (0.2)	0.002 (0.001)	0.001 (0.001)	N/A	3 (1)	1 (0)	1 (0)
Cañada Ancha at Rio Grande	-1.7 (0.8)	0.000 (0.200)	0.1 (0.1)	1.7 (0.2)	0.002 (0.001)	0.002 (0.001)	N/A	3 (1)	28 (3)	0 (0)

Table IV-20. (Cont.)

Location	H^3 (nCi/L)	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	Total Uranium (µg/g)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)	^{241}Am (pCi/g)	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Gross Gamma (counts/min/g)
Other Areas, Cont.										
Pajarito at Rio Grande	-0.8 (0.3)	0.200 (0.100)	0.1 (0.1)	3.2 (0.3)	0.004 (0.001)	0.010 (0.002)	N/A	4 (1)	4 (0)	1 (0)
Water Canyon at Rio Grande	-0.8 (0.3)	0.000 (0.300)	0.4 (0.1)	2.0 (0.2)	0.001 (0.001)	0.003 (0.001)	N/A	2 (1)	1 (0)	2 (0)
Ancho at Rio Grande	-0.4 (0.3)	0.200 (0.200)	0.1 (0.1)	1.3 (0.1)	0.004 (0.001)	0.003 (0.001)	N/A	2 (1)	1 (0)	0 (0)
Chaquehui at Rio Grande	28.0 (3.0)	0.200 (0.100)	0.4 (0.1)	2.4 (0.2)	0.000 (0.001)	0.004 (0.001)	N/A	3 (1)	2 (0)	1 (0)
Frijoles at National Monument Headquarters	N/A	0.000 (0.200)	0.3 (0.1)	2.3 (0.2)	0.002 (0.001)	0.004 (0.001)	N/A	2 (1)	1 (0)	1 (0)
Frijoles at Rio Grande	-0.2 (0.3)	0.100 (0.200)	0.3 (0.1)	2.8 (0.3)	0.000 (0.001)	0.002 (0.001)	N/A	2 (1)	2 (0)	2 (0)
Mortandad Canyon on San Ildefonso Lands										
Mortandad A-6	0.5 (0.3)	0.500 (0.200)	1.1 (0.2)	2.5 (0.2)	0.002 (0.001)	0.031 (0.003)	N/A	6 (1)	5 (1)	2 (0)
Mortandad A-7	0.4 (0.3)	0.300 (0.100)	0.2 (0.1)	5.4 (0.5)	0.002 (0.001)	0.020 (0.002)	N/A	5 (1)	5 (1)	4 (1)
Mortandad A-8	0.0 (0.3)	0.200 (0.200)	0.3 (0.1)	3.2 (0.3)	0.001 (0.001)	0.023 (0.002)	N/A	6 (1)	3 (0)	2 (0)
Mortandad at SR-4 (A-9)	N/A	0.200 (0.200)	-0.1 (0.1)	1.0 (0.1)	0.005 (0.004)	0.002 (0.001)	N/A	2 (1)	2 (0)	1 (0)
Mortandad A-10	0.6 (0.3)	0.000 (0.200)	0.2 (0.1)	2.3 (0.2)	0.006 (0.001)	0.003 (0.001)	N/A	3 (1)	2 (0)	2 (0)
Mortandad at Rio Grande	-0.4 (0.3)	0.300 (0.200)	0.1 (0.1)	2.8 (0.3)	0.008 (0.002)	0.001 (0.001)	N/A	3 (1)	4 (0)	2 (0)
ON SITE STATIONS										
Radioactive Effluent Release Areas										
Acid-Pueblo Canyon										
Hamilton Bend Spring	N/A	0.200 (0.200)	0.0 (0.1)	2.7 (0.3)	0.003 (0.003)	0.138 (0.007)	N/A	3 (1)	1 (0)	1 (0)
Pueblo 3	N/A	0.300 (0.200)	0.0 (0.1)	2.7 (0.3)	0.004 (0.002)	0.132 (0.006)	N/A	2 (1)	1 (0)	1 (0)
Pueblo at SR-4	N/A	0.200 (0.200)	0.2 (0.1)	1.2 (0.1)	0.003 (0.001)	0.424 (0.016)	N/A	2 (1)	1 (0)	0 (0)
DP–Los Alamos Canyon										
DPS-1	N/A	0.300 (0.200)	2.7 (0.4)	1.8 (0.2)	0.013 (0.002)	0.032 (0.003)	N/A	2 (1)	2 (0)	0 (0)
DPS-4	N/A	0.200 (0.200)	0.0 (0.1)	1.8 (0.2)	0.003 (0.001)	0.022 (0.002)	N/A	4 (1)	2 (0)	1 (0)
Los Alamos at Bridge	N/A	0.300 (0.200)	0.0 (0.1)	1.8 (0.2)	0.002 (0.001)	0.003 (0.001)	N/A	2 (1)	1 (0)	0 (0)
Los Alamos at LAO-1	N/A	0.300 (0.200)	0.0 (0.1)	2.1 (0.2)	0.001 (0.001)	0.001 (0.001)	N/A	4 (1)	2 (0)	-1 (0)
Los Alamos at GS-1	N/A	0.300 (0.200)	1.7 (0.3)	2.4 (0.2)	0.028 (0.002)	0.189 (0.008)	N/A	2 (0)	2 (0)	2 (0)
Los Alamos at LAO-3	N/A	0.200 (0.200)	1.3 (0.2)	2.0 (0.2)	0.040 (0.003)	0.148 (0.007)	N/A	2 (1)	3 (0)	1 (0)
Los Alamos at LAO4.5	N/A	0.100 (0.200)	1.5 (0.3)	1.7 (0.2)	0.028 (0.003)	0.154 (0.007)	N/A	1 (0)	2 (0)	1 (0)
Los Alamos at SR-4	N/A	0.200 (0.200)	0.6 (0.1)	2.1 (0.2)	0.016 (0.002)	0.074 (0.005)	N/A	2 (1)	2 (0)	0 (0)

Table IV-20. (Cont.)

Location	H^3 (nCi/L)	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	Total Uranium (μg/g)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)	^{241}Am (pCi/g)	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Gross Gamma (counts/min/g)
Mortandad Canyon										
Mortandad near CMR	N/A	0.100 (0.200)	0.0 (0.1)	1.5 (0.1)	0.010 (0.002)	0.004 (0.001)	N/A	2 (0)	2 (0)	-2 (0)
Mortandad west of GS-1	N/A	0.400 (0.200)	0.3 (0.1)	3.0 (0.3)	0.015 (0.002)	0.011 (0.002)	N/A	3 (1)	4 (0)	1 (0)
Mortandad at GS-1	N/A	3.900 (0.400)	106.0 (15.9)	1.9 (0.2)	2.590 (0.090)	7.950 (0.260)	N/A	23 (5)	89 (9)	43 (4)
Mortandad at MCO-5	N/A	3.400 (0.300)	35.1 (5.3)	1.5 (0.1)	4.600 (0.300)	16.700 (1.000)	N/A	36 (7)	26 (3)	18 (2)
Mortandad at MCO-7	N/A	1.100 (0.200)	23.7 (3.6)	1.6 (0.1)	3.000 (0.200)	10.700 (0.600)	N/A	28 (6)	18 (2)	12 (1)
Mortandad at MCO-9	N/A	0.400 (0.200)	0.5 (0.1)	4.8 (0.5)	0.013 (0.002)	0.023 (0.002)	N/A	6 (1)	5 (1)	5 (1)
Mortandad at MCO-13 (A-5)	N/A	0.200 (0.200)	0.6 (0.1)	1.9 (0.2)	0.003 (0.001)	0.025 (0.002)	N/A	6 (1)	4 (1)	3 (1)
Other Canyons										
Sandia at SR-4	N/A	0.200 (0.200)	0.1 (0.1)	2.3 (0.2)	0.007 (0.003)	0.005 (0.002)	N/A	2 (1)	1 (0)	1 (0)
Cañada del Buey at SR-4	N/A	0.000 (0.200)	0.1 (0.1)	1.4 (0.1)	0.005 (0.003)	0.015 (0.004)	N/A	2 (1)	2 (0)	1 (0)
Pajarito at SR-4	Channel completely scoured, no sediment in 1991									
Potrillo at SR-4	N/A	0.200 (0.200)	0.0 (0.1)	2.5 (0.2)	0.007 (0.002)	0.010 (0.002)	N/A	3 (1)	2 (0)	1 (0)
Fence at SR-4	No sample in 1991									
Water at SR-4	N/A	0.100 (0.200)	0.1 (0.1)	1.8 (0.2)	0.001 (0.001)	0.005 (0.001)	N/A	2 (1)	1 (0)	1 (0)
Indio at SR-4	No sample in 1991									
Ancho at SR-4	N/A	0.100 (0.200)	0.1 (0.1)	3.8 (0.4)	0.006 (0.001)	0.003 (0.001)	N/A	3 (1)	3 (0)	2 (0)
Background Statistical Limit[d]	—	0.87	0.44	4.4	0.006	0.023	—	—	—	7.9

[a]Tritium as tritiated water in moisture distilled from sample.
[b]N/A means analysis not performed, lost in analysis, or not completed.
[c]Radioactivity counting uncertainties (±1 standard deviation) are shown in parentheses.
[d]Average plus 2 standard deviations of measurements in regional samples 1974–1986 (Purtymun 1987a).

Table IV-21. Radiochemical Analyses of Solid Waste Area Sediment Samples

Location	H^3 (nCi/L)[a]	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	Total Uranium (μg/g)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)	^{241}Am (pCi/g)	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Gross Gamma (cpm/g)
TA-54, AREA G										
G-1	0.1 (0.3)[b]	0.1 (0.1)	0.1 (0.1)	2.3 (0.2)	0.005 (0.002)	0.005 (0.001)	N/A[c]	3 (1)	1 (0)	1 (1)
G-2	5.2 (0.6)	0.0 (0.1)	0.3 (0.1)	1.8 (0.2)	0.007 (0.003)	0.004 (0.001)	N/A	5 (1)	2 (0)	-0 (1)
G-3	6.5 (0.7)	0.3 (0.1)	0.3 (0.1)	2.3 (0.2)	0.005 (0.003)	0.012 (0.002)	N/A	6 (1)	3 (0)	2 (1)
G-4	2.8 (0.4)	0.2 (0.1)	0.4 (0.2)	3.1 (0.3)	0.002 (0.002)	0.011 (0.002)	N/A	5 (1)	3 (0)	3 (1)
G-5	2.1 (0.4)	0.1 (0.1)	0.3 (0.1)	2.4 (0.2)	0.008 (0.003)	0.089 (0.005)	N/A	13 (3)	2 (0)	3 (1)
G-6	3.2 (0.4)	0.2 (0.1)	0.2 (0.1)	2.2 (0.2)	0.002 (0.003)	0.040 (0.003)	N/A	6 (1)	2 (0)	5 (1)
G-7	0.0 (0.3)	0.1 (0.2)	0.2 (0.1)	4.0 (0.4)	0.009 (0.003)	0.022 (0.002)	N/A	5 (1)	3 (0)	7 (1)
G-8	0.3 (0.3)	0.2 (0.2)	0.5 (0.1)	3.8 (0.4)	0.014 (0.004)	0.027 (0.002)	N/A	10 (2)	3 (0)	8 (1)
G-9	-0.3 (0.3)	0.2 (0.1)	0.1 (0.1)	1.5 (0.2)	0.002 (0.003)	0.003 (0.001)	N/A	7 (1)	2 (0)	2 (1)
TA-49, AREA AB										
AB-1	0.1 (0.3)	N/A	0.4 (0.1)	4.2 (0.4)	0.002 (0.001)	0.008 (0.001)	N/A	5 (1)	6 (1)	3 (1)
AB-2	0.2 (0.3)	N/A	0.1 (0.1)	3.6 (0.4)	0.007 (0.001)	0.017 (0.002)	N/A	8 (2)	6 (1)	2 (0)
AB-3	0.1 (0.3)	N/A	0.3 (0.1)	3.3 (0.3)	0.014 (0.002)	0.594 (0.021)	N/A	4 (1)	5 (1)	3 (1)
AB-4	0.1 (0.3)	N/A	0.3 (0.1)	3.5 (0.3)	0.005 (0.001)	0.271 (0.012)	N/A	8 (2)	6 (1)	2 (0)
AB-4A	1.1 (0.3)	N/A	0.1 (0.1)	3.7 (0.4)	0.001 (0.001)	0.009 (0.001)	N/A	6 (1)	6 (1)	4 (1)
AB-5	0.2 (0.3)	N/A	0.0 (0.1)	2.2 (0.2)	0.002 (0.001)	0.002 (0.001)	N/A	4 (1)	3 (0)	3 (1)
AB-6	0.2 (0.3)	N/A	0.1 (0.1)	3.0 (0.3)	0.002 (0.001)	0.008 (0.001)	N/A	5 (1)	4 (1)	4 (1)
AB-7	0.3 (0.3)	N/A	0.9 (0.2)	3.7 (0.4)	0.002 (0.001)	0.027 (0.002)	N/A	7 (2)	7 (1)	1 (0)
AB-8	0.3 (0.3)	N/A	0.1 (0.1)	2.9 (0.3)	0.003 (0.001)	0.003 (0.001)	N/A	4 (1)	4 (1)	1 (0)
AB-9	-0.1 (0.3)	N/A	0.3 (0.1)	3.4 (0.3)	0.000 (0.001)	0.012 (0.002)	N/A	6 (1)	7 (1)	1 (0)
AB-10	0.2 (0.3)	N/A	0.0 (0.1)	2.4 (0.2)	0.001 (0.001)	0.004 (0.001)	N/A	5 (1)	3 (0)	-1 (0)
AB-11	0.1 (0.3)	N/A	0.1 (0.1)	4.2 (0.4)	0.002 (0.001)	0.006 (0.001)	N/A	6 (1)	5 (1)	1 (0)
Background Statistical Limit[d]	—	0.87	0.44	4.4	0.006	0.023	—	—	—	7.9

[a]Tritium as tritiated water in moisture distilled from sample.
[b]Radioactivity counting uncertainties (±1 standard deviation) are shown in parentheses.
[c]N/A means analysis not performed, lost in analysis, or not completed.
[d]Average plus 2 standard deviations of measurements in regional samples 1974–1986 (Purtymun 1987a).

Table IV-22. Radiochemical Analyses of Soils

Location	H^3 (nCi/L)[a]	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	Total Uranium (m g/g)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)	^{241}Am (pCi/g)	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Gross Gamma (cpm/g)
Regional Soils										
Rio Chama	0.2 (0.3)[b]	N/A[c]	0.2 (0.1)	2.2 (0.2)	0.000 (0.002)	0.001 (0.001)	N/A	10 (2)	4 (1)	2 (1)
Embudo	-0.2 (0.3)	N/A	0.8 (0.2)	2.3 (0.2)	0.001 (0.002)	0.016 (0.002)	N/A	8 (2)	17 (2)	2 (0)
Otowi	0.5 (0.3)	N/A	0.5 (0.1)	2.7 (0.3)	0.002 (0.002)	0.064 (0.008)	N/A	4 (1)	3 (0)	3 (1)
Santa Cruz	-0.2 (0.3)	N/A	1.1 (0.2)	2.9 (0.3)	0.003 (0.002)	0.042 (0.003)	N/A	12 (3)	7 (1)	4 (1)
Cochiti	0.1 (0.3)	N/A	1.7 (0.3)	2.5 (0.3)	0.001 (0.002)	0.014 (0.002)	N/A	13 (3)	4 (1)	4 (1)
Bernalillo	-0.1 (0.3)	N/A	0.3 (0.1)	1.9 (0.2)	0.001 (0.001)	0.004 (0.002)	N/A	6 (1)	3 (0)	2 (0)
Jemez	-0.1 (0.3)	N/A	0.2 (0.1)	2.3 (0.2)	0.002 (0.002)	0.003 (0.001)	N/A	110 (20)	2 (0)	2 (0)
Perimeter Soils (off site)										
Sportsman Club	0.1 (0.3)	N/A	0.3 (0.1)	3.5 (0.4)	0.003 (0.002)	0.008 (0.003)	N/A	12 (3)	6 (1)	3 (1)
North Mesa	0.9 (0.3)	N/A	0.3 (0.1)	4.2 (0.4)	0.003 (0.001)	0.017 (0.002)	N/A	11 (2)	5 (1)	3 (1)
Near TA-8/GT Site	0.2 (0.3)	N/A	1.2 (0.3)	3.1 (0.3)	0.002 (0.002)	0.048 (0.004)	N/A	6 (1)	6 (1)	2 (1)
Near TA-49	-0.1 (0.3)	N/A	1.0 (0.2)	4.0 (0.4)	0.003 (0.002)	0.034 (0.003)	N/A	9 (2)	6 (1)	4 (1)
White Rock - East	0.1 (0.3)	N/A	0.7 (0.2)	3.5 (0.4)	0.007 (0.002)	0.020 (0.002)	N/A	12 (3)	6 (1)	4 (1)
Tsankawi	0.1 (0.3)	N/A	0.7 (0.2)	4.0 (0.4)	0.003 (0.002)	0.013 (0.002)	N/A	10 (2)	5 (1)	3 (1)
On-Site Soils										
TA-21 DP Site	1.4 (0.3)	N/A	1.9 (0.3)	3.8 (0.4)	0.002 (0.001)	0.002 (0.001)	N/A	12 (3)	5 (1)	3 (1)
East of TA-53	1.2 (0.3)	N/A	0.3 (0.1)	2.4 (0.2)	0.002 (0.003)	0.010 (0.002)	N/A	11 (2)	4 (1)	3 (1)
TA-50	1.2 (0.3)	N/A	0.1 (0.1)	3.9 (0.4)	0.001 (0.002)	0.043 (0.003)	N/A	15 (3)	10 (1)	4 (1)
2-Mile Mesa	0.8 (0.3)	N/A	0.2 (0.1)	3.7 (0.4)	0.006 (0.003)	0.012 (0.003)	N/A	11 (2)	4 (1)	3 (1)
East of TA 54	0.2 (0.3)	N/A	0.2 (0.1)	3.8 (0.4)	0.001 (0.001)	0.005 (0.001)	N/A	10 (2)	4 (1)	2 (0)
R-Site-RD-East	0.8 (0.3)	N/A	0.5 (0.1)	2.4 (0.2)	0.002 (0.001)	0.017 (0.002)	N/A	8 (2)	4 (0)	2 (1)
Potrillo Drive	0.3 (0.3)	N/A	0.3 (0.1)	4.0 (0.4)	0.001 (0.001)	0.005 (0.001)	N/A	10 (2)	4 (1)	4 (1)
S-Site TA-16	0.3 (0.3)	N/A	0.2 (0.1)	3.9 (0.4)	0.000 (0.001)	0.001 (0.001)	N/A	11 (2)	3 (0)	3 (1)
DT-9	-0.3 (0.3)	N/A	0.3 (0.2)	3.0 (0.3)	0.000 (0.000)	0.000 (0.000)	N/A	10 (2)	4 (0)	3 (1)
Near TA-33	2.0 (0.4)	N/A	0.3 (0.1)	2.8 (0.3)	0.006 (0.006)	0.005 (0.002)	N/A	26 (6)	6 (1)	3 (1)
Background Statistical Limit[d]	7.2	0.88	1.09	3.4	0.005	0.025	—	—	—	6.6

[a]Tritium as tritiated water in moisture distilled from sample.
[b]Radioactivity counting uncertanties (±1 standard deviation) are shown in parentheses.
[c]N/A means analysis not performed, lost in analysis, or not completed.
[d]Average plus 2 standard deviations of measurements in regional samples 1974–1986 (Purtymun 1987a).

The majority of the sediment samples outside known radioactive effluent release areas were within the statistically derived upper limit used as a comparison for activity attributable to worldwide fallout (Purtymun 1987a). These statistical limits give a level expected to be exceeded by about 1 in 40 samples taken from the same population. In the samples from the Rio Grande (Regional and White Rock Canyon groups), only the ^{238}Pu values for the Embudo and Pajarito samples exceeded the limit. Since they are not in the expected ratio with $^{239,240}Pu$ values for those stations, which themselves were below the statistical fallout limit, it is likely that they are analytical anomalies rather than real values. Samples taken on San Ildefonso land in Mortandad Canyon are discussed in Section IV.I.5.

Many sediment samples from the known radioactive effluent release areas, both off site and on site, including Acid-Pueblo, DP-Los Alamos, and Mortandad Canyons, exceeded worldwide fallout levels, as expected. The levels observed are consistent with previous data.

Two sediment samples from the On-Site Other Canyons group, from Sandia and Potrillo Canyons, showed ^{238}Pu levels that slightly exceeded the statistical fallout limit (0.007 compared to 0.006). Since they were not in the expected worldwide fallout ratio with $^{239,240}Pu$ values for those stations, which themselves were below the statistical fallout limit, it is likely that they are analytical anomalies rather than real values.

One sediment sample from the mouth of Chaquehui Canyon in White Rock Canyon contained significantly above background tritium in moisture distilled from the sediment. That sample contained 28 nCi/L. No other samples from canyons entering the Rio Grande contained any tritium above detection limits. Because of the unexpected anomaly, the location was resampled in February 1992, as soon as weather warmed sufficiently to melt snow and permit hiking into White Rock Canyon. That second sample also showed above background tritium, about 5.4 nCi/L. The lower level is possibly attributable to dilution from precipitation and snowmelt between October and February. Four additional samples were collected farther upstream in Chaquehui Canyon, below and above inflow from Spring 9A up to a point about 100 m upstream from where Doe Spring flow enters the channel. These four sediment samples had tritium contents ranging from about 0.5 to about 1.1 nCi/L, which, while lower, are still probably above background. No obvious source could be identified. Neither Doe Spring nor Spring 9A water samples from October 1991 showed tritium levels above the normal detection limits (see Table VII-2 and also some special low-detection limit analyses reported in Section VII.E.1). A potential source could be a known tritium-contaminated soil area in TA-33, which is located about 2 miles upgradient in a side drainage to Chaquehui Canyon. However, there is no obvious mechanism to move contaminated soil that far by a runoff event that would not also dilute the tritium in moisture significantly. This area will be investigated in detail in the future under the Environmental Restoration (ER) Program Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) that includes TA-33 (see Section III.B.1.h). The RFI Workplan encompassing TA-33, submitted to EPA in May 1992, includes field sampling tasks to help determine whether TA-33 could be the source.

The results for sediment samples from the solid radioactive waste areas (Table IV-21) were consistent with previous observations. Around Area G at TA-54, the statistical fallout levels for ^{238}Pu and/or $^{239,240}Pu$ were exceeded at Stations G-2, G-5, G-6, G-7, and G-8. The levels are generally in the same range as observed in previous years with the exception of station G-5, which may be the result of higher than typical runoff during the summer of 1991.

Tritium levels in the soil samples around Area G were within the general range observed in soils and did not repeat the anomalously high levels seen in 1990.

Subsequent to the water release from TA-54 (see Section V.B.3.b. for additional information), several special samples were collected along a small drainage leading from the north edge of TA-54 down into Cañada del Buey, joining the main channel slightly upstream of Location G-9. The first set collected on January 7, 1991, showed tritium concentrations in the water or soil moisture ranging up to 0.29 μCi/L. These samples extended from a point about 10 ft north of the TA-54 fence in the release path for about 800 ft, the apparent farthest point of flow as judged from the presence of ice. A subsequent set collected on March 27, 1991, showed a decline in concentration to about 0.053 μCi/L at the same point 10 ft north of the fence line. At the point where the drainage reached the Cañada del Buey channel, the concentration was about

0.004 μCi/L. Three samples 0.1, 0.3, and 0.7 miles farther downstream in Cañada del Buey had levels of only about 0.001 μCi/L down to analytical detection limits. Thus, it appears that the tritium in the release was substantially diluted or had mostly evaporated by the end of March.

Around Area AB at TA-49, worldwide fallout levels of ^{238}Pu and/or ^{239,240}Pu were exceeded at stations AB-2, AB-3, AB-4, and AB-7. These areas have shown elevated levels in previous years and are probably associated with known surface contamination incidents related to operation of the site in 1959–1961 (Purtymun, 1987b). The ^{137}Cs concentration in the sample from location AB-7 was about twice the statistical background limit for sediments but within the background limit for soils.

Four off-site soil samples (Otowi, Santa Cruz, near TA-8, and near TA-49) and one on-site sample (TA-50) had results for ^{239,240}Pu that were 2 to 3 times the statistical worldwide fallout limits for no apparent reason. Three soil samples (White Rock, 2-Mile Mesa, and TA-33) had results for ^{239}Pu (0.006 to 0.007 pCi/g) that were slightly above the statistical fallout limit (0.006). These locations were below the limits in 1990. Four soil samples (Santa Cruz, Cochiti, TA-8, and TA-21) had ^{137}Cs levels that were just at to about twice the statistical fallout limit. They are presumed to be normal variability as they did not exceed the limits in 1990, and are within the range of levels seen at other stations in 1991 that are below the limit this year. Uranium levels in the perimeter and on-site locations contain higher concentrations of natural uranium than other regional stations in northern New Mexico because the soils are derived from the Pajarito Plateau volcanic rocks that have higher than average natural uranium contents. The uranium levels are consistent with previous observations.

b. Nonradioactive Constituents. Sediments from the known radioactive effluent release areas were analyzed for metals using the EPA Toxicity Characteristic Leaching Procedure (TCLP) method for establishing whether solid wastes exceed the toxicity criteria (first section of Table IV-23). None of the criteria levels were exceeded or even approached. Sediments from the Perimeter group locations in White Rock Canyon were analyzed for total metals (second section of Table IV-23). These analyses were made to begin establishing a data base of results comparable to those reported by other agencies such as the USGS and are more meaningful for accounting for geochemical processes.

Soil samples were analyzed for metals using the EPA TCLP method for establishing whether solid wastes exceed the toxicity criteria (Table IV-24). None of the criteria levels were exceeded or even approached.

4. Long-Term Trends.

The concentrations of radioactivity on sediments in the Acid, Pueblo, and Los Alamos Canyon drainages that involve existing and potential off-site transport of radioactive contaminants are of considerable public interest. These were studied in extensive detail about 10 years ago under the Formerly Utilized Sites Remedial Action Program and are fully documented (ESG 1981). The routine monitoring program data from selected locations in these areas is an indication of changes. The total plutonium concentrations (^{238}Pu and ^{239,240}Pu) on sediments at four indicator locations observed since 1980 are shown in Fig. IV-12. The first location is Acid Weir, the location in Acid Canyon near its confluence with Pueblo Canyon where the highest concentrations are typically observed. This location is on Los Alamos County property and effectively integrates the mobile sediments from all of Acid Canyon. The second location is Pueblo at State Road 502 (State Road 4 in previous years), just upstream of the confluence with Los Alamos Canyon. This location is on DOE land and represents levels just prior to off-site transport. The third location is Los Alamos Canyon at Totavi, located on San Ildefonso Pueblo, and represents the first off-site point. The fourth location is Los Alamos Canyon at Otowi, also located on San Ildefonso Pueblo, and represents sediment concentrations at the point where they enter the Rio Grande. The basic observation is that the levels have been relatively constant at each location since 1980.

5. Transport of Radionuclides on Sediments in Surface Runoff.

The major transport of radionuclides from canyons that have received radioactive effluents (Acid-Pueblo, DP-Los Alamos, and Mortandad Canyons) is by surface runoff. Residual radionuclides in the effluents may become adsorbed or attached to sediment particles in the stream channels. Concentrations of radioactivity in

Table IV-23. Trace Metals in Sediments

Trace Metals in Solution Extracts from Sediment (mg/L)[a]

Stations	Ag	As	Ba	Cd	Cr	Hg	Pb	Se
REGIONAL STATIONS	Not all stations were sampled for metals in 1991; see next section of table for total recoverable metals in White Rock Canyon stations.							
PERIMETER STATIONS (OFF SITE)								
Radioactive Effluent Release Areas								
Acid-Pueblo Canyon								
Acid Weir	<0.023[b]	<0.02	0.47	<0.01	0.0	<0.0006	<0.05	0.020
Pueblo 1	<0.03	<0.02	0.55	<0.01	<0.01	<0.0006	<0.05	<0.02
Pueblo 2	<0.03	<0.02	0.48	<0.01	<0.01	<0.0006	<0.05	<0.02
DP – Los Alamos Canyon								
Los Alamos at Totavi	<0.03	<0.02	0.57	<0.01	<0.01	<0.0006	<0.05	0.028
Los Alamos at LA 2	<0.03	<0.02	0.51	<0.01	<0.01	<0.0006	<0.05	0.030
Los Alamos at Otowi	<0.03	<0.02	0.42	<0.01	<0.01	<0.0006	<0.05	0.023
Other Areas	See second section of table for total recoverable metals							
ON-SITE STATIONS								
Radioactive Effluent Release Areas								
Acid Pueblo Canyon								
Hamilton Bend Spring	<0.03	<0.02	0.46	<0.01	<0.01	<0.0006	<0.05	<0.02
Pueblo 3	<0.03	<0.02	0.46	<0.01	<0.01	<0.0006	<0.05	0.023
Pueblo at SR-4	<0.03	<0.02	0.28	<0.01	<0.01	<0.0006	<0.05	<0.02
DP–Los Alamos Canyon								
DPS-1	<0.03	<0.02	0.53	<0.01	<0.01	<0.0006	<0.05	0.034
DPS-4	<0.03	<0.02	0.76	<0.01	<0.01	0.0006	<0.05	0.022
Los Alamos at Bridge	<0.03	<0.02	0.55	<0.01	<0.01	0.0006	<0.05	0.034
Los Alamos at LAO-1	<0.03	<0.02	0.33	<0.01	<0.01	0.0006	<0.05	0.026
Los Alamos at GS-1	<0.023	<0.02	0.30	<0.01	<0.01	0.0006	<0.05	<0.02
Los Alamos at LAO-3	<0.03	<0.02	0.46	<0.01	<0.01	<0.0006	<0.05	0.030
Los Alamos at LAO4.5	<0.03	<0.02	0.48	<0.01	<0.01	<0.0006	<0.05	0.030
Los Alamos at SR-4	<0.03	<0.02	0.40	<0.01	<0.01	<0.0006	<0.05	0.025
Mortandad Canyon								
Mortandad near CMR	<0.03	<0.02	0.62	0.01	<0.01	<0.0002	<0.05	0.330
Mortandad W GS-1	<0.03	<0.02	0.98	<0.01	<0.01	<0.0006	<0.05	0.034
Mortandad at GS-1	<0.023	<0.02	0.56	<0.01	<0.01	<0.0006	<0.05	0.028
Mortandad at MCO-5	<0.03	<0.02	0.62	<0.01	<0.01	<0.0006	<0.5	0.025
Mortandad at MCO-7	<0.03	<0.02	0.53	<0.01	<0.01	<0.0006	<0.05	0.030
Mortandad at MCO-9	<0.03	<0.02	0.62	<0.01	<0.01	<0.0006	<0.05	0.030
Mortandad at MCO-13	<0.03	<0.02	0.66	<0.01	<0.01	<0.0006	<0.05	0.040
Limit for EPA Toxicity Criteria	5	5	100	1	5	0.2	5	1

Table IV-23. (Cont.)

Total Recoverable Trace Metals from Sediment (μg/g[c])

Stations	Ag	As	Ba	Cd	Cr	Hg	Pb	Se
REGIONAL STATIONS								
Rio Grande in White Rock Canyon								
Rio Grande at Sandia	<2	1.150	565	1.20	5.0	<21.5	1.4	<0.4
Rio Grande at Pajarito	<2	<0.4	553	0.77	3.0	<23	0.1	<0.4
Rio Grande at Water Canyon	5	1.400	619	1.40	4.6	97	3.1	<0.4
Rio Grande at Ancho	<2	0.900	578	1.00	3.7	23	0.5	<0.4
Rio Grande at Chaquehui	<2	1.500	637	1.30	4.7	<21	4.2	<0.4
Rio Grande at Frijoles	<2	1.000	550	1.70	7.3	<20	0.1	<0.4
PERIMETER STATIONS (OFF SITE)								
Other Canyons								
Sandia at Rio Grande	8	<0.4	299	1.20	3.6	<20	3.4	<0.4
Cañada Del Ancha	<2	<0.4	600	0.70	2.0	<20	5.9	<0.4
Pajarito at Rio Grande	<2	1.100	534	1.80	7.2	<20	1.2	<0.4
Frijoles at Rio Grande	27	0.400	207	0.54	2.8	<20	6.9	<0.4
Mortandad on San Ildefonso Lands								
Mortandad at Rio Grande	<2	<0.4	521	1.71	5.5	<23	1.5	<0.4
ON-SITE STATIONS								
Other Canyons								
Water Canyon at Rio Grande	<2	0.400	247	0.70	2.0	<22.5	1.5	<0.4
Ancho at Rio Grande	<2	<0.4	319	0.40	1.4	<22.5	3.4	<0.4
Chaquehui at Rio Grande	<2.1	<0.4	320	1.30	3.6	<20	3.8	<0.4

[a] Analysis by EPA TCLP method.
[b] Less than symbol (<) means measurement was below the specified detection limit of the analytical method.
[c] Analysis by EPA Method 3051 for total metals.

Table IV-24. Trace Metals In Soils

Trace Metals in Solution Extracted from Soil Sample (mg/L)[a]

Stations	Ag	As	Ba	Cd	Cr	Hg	Pb	Se
REGIONAL STATIONS								
Rio Chama	0.030	<0.02[b]	1.00	0.01	0.01	<0.0002	<0.05	0.03
Embudo	<0.03	<0.02	0.70	0.01	<0.01	<0.0002	<0.05	0.04
Otowi	<0.03	<0.02	0.50	0.01	<0.01	<0.0002	<0.05	0.02
Santa Cruz	0.027	<0.02	2.50	0.01	0.01	<0.0002	<0.05	0.05
Cochiti	<0.03	<0.02	0.74	0.01	<0.01	<0.0002	<0.05	0.02
Bernalillo	0.032	<0.02	1.00	0.01	0.01	<0.0002	<0.05	0.04
Jemez	0.0325	<0.02	1.70	0.02	0.01	<0.0002	<0.05	0.11
Perimeter Soils								
Sportsman Club	<0.03	<0.02	0.60	0.01	0.01	<0.0002	<0.05	0.03
North Mesa	<0.03	<0.02	0.70	0.01	<0.01	<0.0005	<0.05	0.04
TA-8	<0.03	<0.02	1.40	0.01	<0.01	<0.0005	<0.05	0.02
TA-49	<0.03	<0.02	1.20	0.01	<0.01	<0.0005	<0.05	0.02
White Rock	<0.03	<0.02	0.92	0.01	<0.01	<0.0002	<0.05	0.02
Tsankawi	<0.03	<0.02	0.60	<0.01	<0.01	<0.0002	<0.05	<0.02
On-Site Soils								
TA-21	<0.03	<0.02	0.70	0.01	<0.01	<0.0002	<0.05	0.02
East of TA-53	<0.023	<0.02	1.00	<0.01	<0.01	<0.0002	<0.05	0.02
TA-50	<0.03	<0.02	1.30	0.01	<0.01	<0.0002	<0.05	0.03
Two-Mile Mesa	<0.03	<0.02	0.90	0.01	<0.01	<0.0002	<0.05	0.02
East of TA-54	<0.03	<0.02	0.53	0.01	<0.01	<0.0002	<0.05	0.02
R-Site	<0.03	<0.02	0.90	<0.01	<0.01	<0.0002	<0.05	<0.0
Potrillo Drive	<0.03	<0.02	1.00	0.01	<0.01	<0.0002	<0.05	0.04
S-Site	<0.03	<0.02	0.51	<0.01	<0.01	<0.0002	<0.05	0.02
Near Well DT-9	<0.03	<0.02	2.10	0.01	<0.01	<0.0002	<0.05	0.03
Near TA-33	<0.03	<0.02	2.30	<0.01	<0.01	<0.0002	<0.05	0.03
Limit for EPA Toxicity Criteria	5	5	100	1	5	0.2	5	1

[a] Analysis by EPA TCLP method.
[b]The less than symbol (<) means the analysis was below the specified detection limit of the analytical method.

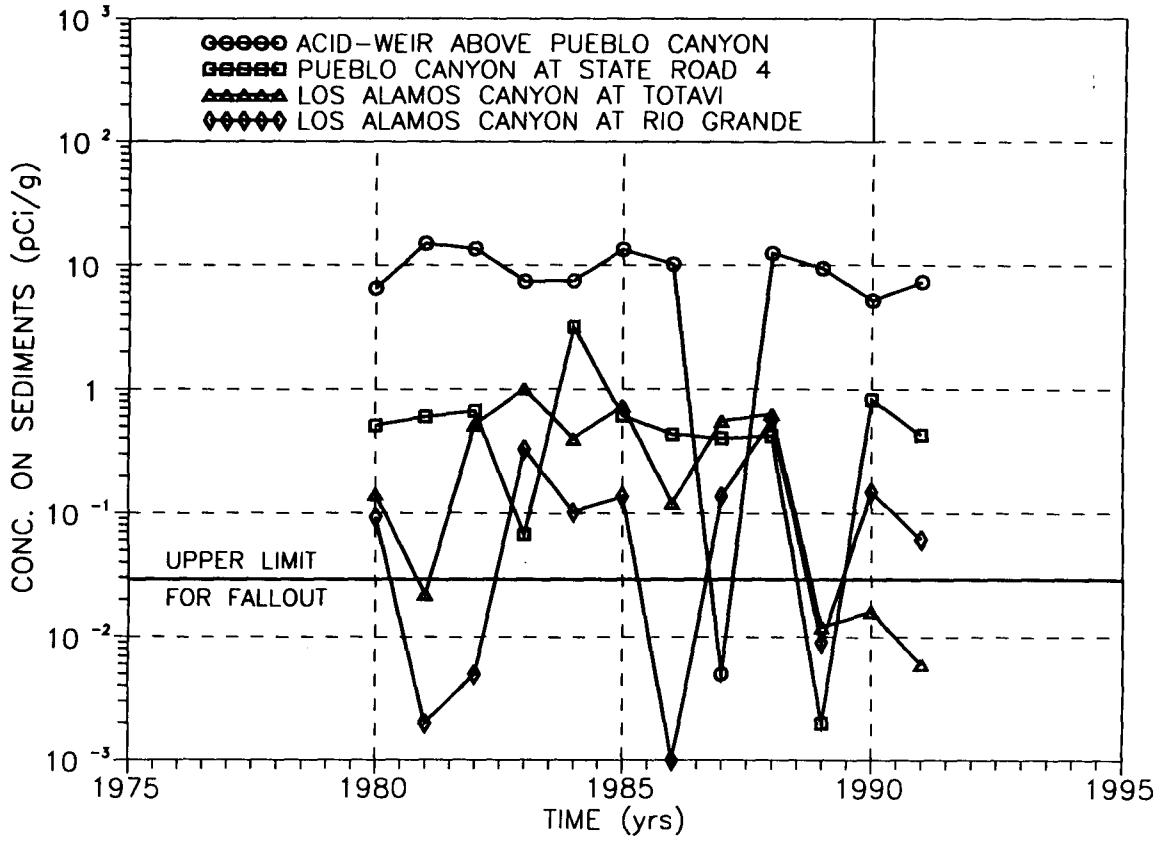


Fig. IV-12. Total plutonium concentrations on sediments.

the alluvium are generally highest near the effluent outfall and decrease downhill in the canyon as the sediments and radionuclides are transported and dispersed by other treated industrial effluents, sanitary effluents, and surface runoff.

a. Pueblo-Los Alamos Canyons. Residual radioactivity from past effluent releases into DP Canyon, upper Los Alamos Canyon, and Acid Canyon is present on sediments in those canyons and Pueblo Canyon downstream from Acid Canyon. (See Section IV.D.2 for more historic information.) Over the years some of that radioactivity has been transported off site into lower Los Alamos Canyon largely by snowmelt and thunderstorm runoff.

Starting in 1990, increased effluent flow from the Los Alamos County Bayo sanitary sewage treatment plant resulted in flow through the lower part of Pueblo Canyon and into Los Alamos Canyon during most of the year. This flow transported some of the contaminated sediments out of Pueblo Canyon and into the lower reach of Los Alamos Canyon. This effluent-induced flow from Pueblo Canyon entered Los Alamos Canyon on most days in 1991, except for the period from about mid-June to early August, and typically extended to a location between Wells LA-6 and LA-2 in Los Alamos Canyon.

Samples of effluent and runoff collected from Pueblo Canyon above the confluence with Los Alamos Canyon, near State Road 502, were analyzed for radioactivity in solution and suspended sediments. These runoff samples contained above-background amounts of cesium, strontium, and plutonium in solution, as expected from the residuals of historic releases into Pueblo Canyon. The plutonium results are shown in Table IV-25. Concentrations of plutonium on the suspended sediments were above background levels. Radioactivity in solution refers to the filtrate that passes through a 0.45-mm-pore-size filter; radioactivity in suspended sediments refers to the residue retained by the filter.

The current year measurements were combined with results of a special study, "Transport of Plutonium in

Table IV-25. Plutonium in Runoff in Pueblo and Los Alamos Canyons, 1991

Location and Date	Concentration in Solution		Concentration in Suspended Sediment		Suspended Sediment	Total in Solution and Suspended Sediment (pCi/L)		
	^{239}Pu (pCi/L)	^{238}Pu (pCi/L)	^{239}Pu (pCi/g)	^{238}Pu (pCi/g)	(gm/L)	^{239}Pu	^{238}Pu	% dissolved
Pueblo at SR 502								
2/25	0.022	0.004	4.030	0.011	0.05	0.23	0.00	11.1
3/12	0.000	0.000	4.290	0.042	0.02	0.07	0.00	0.0
8/7	0.352	0.008	14.700	0.071	3.51	51.93	0.26	0.7
8/12	0.027	0.000	1.620	0.048	1.45	2.38	0.07	1.1
8/19	0.012	0.004	0.050	0.005	14.68	0.75	0.08	1.9
9/6[a]	0.000	0.000	13.800	0.068	1.85	25.53	0.13	0.0
9/13[a]	0.023	0.054	5.650	0.062	0.44	2.53	0.08	2.9
11/26	0.049	0.000	2.380	0.120	3.84	9.19	0.46	0.5
12/19	0.082	0.017	0.948	0.006	3.50	3.40	0.04	2.9
Los Alamos at SR 4								
8/7	0.020	0.004	1.740	0.097	0.82	1.46	0.08	1.6
8/12	0.050	0.000	0.831	0.038	0.39	0.38	0.01	12.8
9/6[a]	0.027	0.014	2.930	0.465	0.52	1.54	0.25	2.3
9/13	0.017	0.000	2.070	0.094	0.06	0.15	0.01	10.9
Los Alamos at Totavi								
8/12	0.072	0.007	0.632	0.012	3.52	2.30	0.05	3.4
8/19	0.008	0.004	0.120	0.012	13.87	1.67	0.17	0.7
Los Alamos at LA-5								
9/6[a]	0.012	0.020	5.850	0.124	0.33	1.93	0.06	1.6
9/13	0.004	0.037	3.250	0.053	0.11	0.35	0.04	10.4
Los Alamos near LA-6								
2/25	0.009	0.000	1.740	0.014	6.92	12.05	0.10	0.1
3/12	0.009	0.017	1.070	0.007	10.07	10.78	0.09	0.2
Los Alamos at Rio Grande								
8/12	0.019	0.010	0.778	0.015	0.85	0.68	0.02	4.1
9/6[a]	0.029	0.000	6.900	0.170	1.36	9.38	0.23	0.3
9/13[a]	0.023	0.000	4.090	0.076	0.44	1.83	0.03	1.2
12/19	0.044	0.004	0.868	0.013	1.00	0.91	0.02	5.2
Rio Grande at Otowi								
9/6[a]	0.000	0.000	0.010	0.018	1.28	0.01	0.02	0.0
9/13	0.017	0.000	0.005	0.008	0.44	0.02	0.00	74.9

[a]Samples collected on 9/6 and 9/13 were also analyzed for plutonium on settleable solids as an estimate of bedload. These analyses showed that the total on bedload was 2 to 4 times the total in solution and suspended sediments.

Snowmelt Run-Off" (Purtymun 1990a), as the basis for estimating transport of plutonium into Los Alamos Canyon. The estimate of plutonium transported in solution and on suspended sediments from Pueblo Canyon into Los Alamos Canyon is about 1–2 mCi for 1991. By analogy with the snowmelt runoff, it is estimated that bedload sediments probably carried 2 to 3 times as much plutonium as the dissolved and suspended sediment components. Thus the total amount of plutonium transported from Pueblo Canyon into Los Alamos Canyon could be as much as 4–6 mCi.

The increased transport of contaminated sediments from Pueblo Canyon is not expected to have any significant effect on the concentrations of plutonium on sediments in lower Los Alamos Canyon (ESG 1981) which is supported by current measurements as given in Table IV-25 for locations in lower Los Alamos Canyon. Because there is an estimated inventory of about 400 mCi of plutonium in lower Pueblo Canyon, there may be periodic increases in the inventory in lower Los Alamos Canyon. Although summer thunderstorm runoff or long periods of snowmelt runoff periodically move accumulated sediments from lower Los Alamos Canyon into the Rio Grande (e.g., ESG 1981, Lane 1985), there is not likely to be any significant long-term change in the inventory in Lower Los Alamos Canyon.

The effluent-induced flow will slightly increase the rate at which contaminated sediments from historic discharges in Acid and Pueblo Canyons are moved into and through Los Alamos Canyon to the Rio Grande. Theoretical estimates (ESG 1981), confirmed by actual measurement (see Special Reservoir Sediment Studies below), show that the incremental contribution to radioactivity on sediments in Cochiti Reservoir is a small percentage (approximately 10%) of the contribution attributable to typical regional worldwide fallout levels. The resultant incremental doses through food pathways (see Section IV.G.3) are well below DOE's applicable PDLs.

b. Distribution of Radionuclides in Water and Sediment in and Adjacent to Sediment Traps in Mortandad Canyon. Residual radionuclides are released in effluent from the treatment plant at TA-50 into Mortandad Canyon (see Table IV-26). The liquid infiltrates and recharges a shallow body of groundwater in the alluvium. This shallow aquifer is of limited extent and lies completely within the Laboratory boundary (see Section IV.D.2 and Section VII.B for additional information). Most of the radionuclides in the effluent are adsorbed or bound to the sediments in the channel.

Table IV-26. Quality of Effluent Released from the TA-50 Radioactive Liquid Waste Treatment Plant in 1991

Radionuclide	Activity Released[a] (mCi)	Mean Concentration (μCi/mL)
^{3}H	10,600	4.8×10^{-4}
^{54}Mn	0	—
$^{56,57,58,60}Co$	1.0	4.6×10^{-8}
^{75}Se	6	2.7×10^{-7}
$^{83,84}Rb$	45	2.0×10^{-6}
$^{82,85,89,90}Sr$	124	5.7×10^{-6}
^{88}Y	0.6	2.9×10^{-8}
^{137}Cs	67	3.1×10^{-6}
^{234}U	0.07	3.0×10^{-9}
^{238}Pu	0.3	1.4×10^{-8}
$^{239,240}Pu$	1.0	4.4×10^{-8}
^{241}Am	1.1	4.9×10^{-8}
Total[b]	10,846	

[a]As reported on DOE Form F-5821.1.
[b]Total effluent volume 2.19×10^{7} liters.

The sediments and radionuclides in the stream channel alluvium are subject to transport when additional effluent releases or storm water runoff periodically enter the channel. The small drainage area of the canyon and the ability of the thick section of unsaturated alluvium to store runoff have prevented transport to the Laboratory boundary. To further assure containment of sediment transport by major runoff events within the Laboratory boundary, a series of canyon sediment traps was installed in the early 1970s. These traps are located in Mortandad Canyon approximately 2.3 km (1.4 mi) upstream of the eastern facility boundary. The traps are excavated below the prevailing grade of the stream channel, so runoff water flows in and is retained temporarily, letting the heavier sediments settle out. When one pond is filled up to the stream channel, the water then flows on into the next trap.

Several large thunderstorm runoff events occurred in late July and early August 1991 that filled all three sediment traps to capacity. Trap 3 overflowed on two separate occasions. An estimated 77 to 115 m^3 (20,000 to 30,000 gal.) of runoff flowed on downstream of the sediment traps during this time. The end of these flows terminated about 200 m (650 ft) east of the lowest trap.

Water samples were collected from water standing in each of the traps following the two overflows. The results of radiochemical analyses of the water and suspended sediments are presented in Table IV-27. The results are similar to values seen in previous years after major runoff events. The concentrations of suspended sediments are comparable to the maximums found on dry streambed sediments earlier in the year (see Table IV-20). The suspended sediments are predominantly smaller particles and thus exhibit somewhat higher concentrations.

After the water evaporated or infiltrated after the last runoff, sediment samples were collected from all three sediment traps (in depressions where fine grained sediments would tend to collect) and at an additional 27 locations spaced on a rectangular sample grid immediately downstream of Trap 3. This grid consisted of six channel transect lines located at approximately 30 m (100 ft) intervals below the outflow point from Trap 3. Sediment samples were collected along each transect at approximately 10 m (30 ft) intervals, with the end-point samples located outside of the visible water marks indicating where water had passed. These high-water marks consisted of sediment debris on plant leaves and plants deflected toward the direction of water flow. These water marks terminated approximately 150–250 m (500–650 ft) downstream of the outflow from Trap 3.

All sediment samples were initially scanned for gross gamma radiation. These analyses indicated that all samples contained detectable amounts of ^{241}Am, ^{137}Cs, and ^{60}Co, in addition to trace levels of other LAMPF activation products. Seven samples were selected from the 31 sample suite for quantitative gamma counting. These seven samples were selected from six locations near the outermost perimeter of the sampling grid and one location from within Trap 3. These sample results are summarized in Table IV-28. Radionuclide concentrations varied slightly above respective background values. There does not appear to be a decreasing trend in concentration levels with increasing distance downstream of the breach in Trap 3. Instead, these concentrations tend to reflect the maximum extent of sediment transport of the finest grained materials. A portion of these radionuclide concentrations is attributable to previous years when the traps were also overtopped by surface runoff. These analytical data are consistent with previous trap overflows that were reported in the 1987 and 1988 Environmental Surveillance Reports (ESG 1988, ESG 1989).

The three sediment traps will be excavated during 1992 to restore their original sediment retention volumes.

6. Special Reservoir Sediment Studies.

Results of the analyses of the special large samples collected in 1991 from Abiquiu and Cochiti Reservoirs are presented in Table IV-29. The results are similar to those from past years. The cesium concentration of 0.496 ± 0.119 pCi/g from the lower station in Abiquiu slightly exceeded the statistically established background level of 0.44 pCi/g (Purtymun 1987a). All other measurements were lower than statistical background limits.

The results are best interpreted in conjunction with information from a special study, "Plutonium Deposition and Distribution from Worldwide Fallout in Northern New Mexico and Southern Colorado," that provides a broader regional context for the reservoir sediment measurements (Purtymun 1990b). This study was based on the radiochemical analyses of large samples (1 kg) of soils and sediments collected between 1979 and 1987 from locations in northern New Mexico and southern Colorado. Data on sediments from Abiquiu and Cochiti previously published in the annual Environmental Surveillance at Los Alamos reports are included in the larger set of data. The conclusions of greatest significance to interpreting the current samples from Abiquiu and Cochiti Reservoirs are (1) the average total plutonium concentrations in Cochiti are almost identical to the concentrations found in the Rio Grande Reservoir in Colorado, (2) reservoirs on the Rio Chama exhibit slightly lower concentrations than those found in the Rio Grande Reservoir, and (3) the isotopic ratios of $^{239,240}Pu$ to ^{238}Pu are essentially the same, with nearly complete overlap of the statistical uncertainties for all of the soil and sediment samples. These findings are all consistent with the interpretation

Table IV-27. Radioactivity in Mortandad Canyon Sediment Traps

Concentrations in Solution

Location Date	H^3 (nCi/L)	^{137}Cs (pCi/L)	^{238}Pu (pCi/L)	^{239}Pu (pCi/L)	^{241}Am (pCi/L)	Gross Beta (pCi/L)
Trap 1						
7/24/91	7.2 (0.8)[a]	91 (61)	0.50 (0.05)	1.70 (0.10)	2.33 (0.12)	110 (10)
8/06/91	5.7 (0.7)	98 (66)	0.46 (0.07)	2.03 (0.28)	1.50 (0.10)	55 (5)
Trap 2						
7/24/91	7.6 (0.8)	155 (64)	0.76 (0.06)	2.08 (0.12)	3.87 (0.17)	88 (9)
8/06/91	2.0 (0.4)	80 (65)	0.35 (0.05)	1.19 (0.09)	1.21 (0.10)	51 (6)
Trap 3						
7/24/91	3.1 (0.4)	76 (56)	0.64 (0.06)	1.81 (0.11)	1.72 (0.10)	33 (3)
8/06/91	1.2 (0.3)	36 (60)	0.37 (0.08)	0.96 (0.25)	1.02 (0.09)	40 (4)

Concentrations on Suspended Sediment

	^{238}Pu (pCi/g)	^{239}Pu (pCi/g)	Suspended Sediment (g/L)
Trap 1			
7/24/91	20 (2)	61 (6)	0.80
8/06/91	37 (5)	120 (15)	0.28
Trap 2			
7/24/91	7 (3)	21 (10)	1.09
8/06/91	35 (5)	110 (15)	0.32
Trap 3			
7/24/91	12 (7)	36 (18)	1.18
8/06/91	33 (5)	102 (15)	0.41

[a]Radioactivity counting uncertainties (±1 standard deviation) are shown in parentheses.

Table IV-28. Radioactivity on Mortandad Canyon Sediments, October 18, 1991

	Analysis					
	^{241}Am (pCi/g)	^{75}Se (pCi/g)	^{137}Cs (pCi/g)	^{57}Co (pCi/g)	^{60}Co (pCi/g)	^{83}Rb (pCi/g)
Location[a]						
1	38.0 (5.72)[b]	10.9 (5.55)	282.0 (42.4)	0.232 (0.245)	3.640 (0.634)	0.714 (0.290)
2	32.2 (4.85)	3.68 (4.79)	138.0 (20.8)	0.092 (0.229)	0.319 (0.272)	0.058 (0.176)
3	28.9 (4.34)	4.06 (4.89)	173.0 (26.0)	0.007 (0.210)	0.877 (0.317)	0.043 (0.193)
4	19.4 (2.92)	11.30 (4.87)	98.0 (14.8)	0.914 (0.266)	0.120 (0.282)	0.176 (0.220)
5	36.6 (5.51)	4.58 (5.08)	225.0 (33.8)	0.681 (0.257)	0.665 (0.272)	0.041 (0.201)
6	9.2 (1.39)	8.90 (4.79)	101.0 (15.3)	0.601 (0.244)	0.050 (0.261)	0.317 (0.177)
7	10.2 (1.54)	2.29 (4.19)	11.9 (1.82)	0.172 (0.209)	0.316 (0.286)	0.247 (0.178)

[a]Sample Locations:
1 Eastern end of Trap 3; clay and fine sand.
2 Washout 120 m below outflow; 10 m north of channel.
3 Washout 120 m below outflow; 10 m south of channel.
4 Washout 150 m below outflow; 20 m north of channel.
5 Washout 150 m below outflow; in channel.
6 Washout 150 m below outflow; 20 m south of channel.
7 Washout 167 m below outflow; no channel apparent.

[b]Radioactivity counting uncertainties (±1 standard deviation) are shown in parentheses.

Table IV-29. Radiochemical Analyses of Sediments from Reservoirs on the Rio Chama and Rio Grande[a]

Location	H^3 (nCi/L)[b]	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	Total Uranium (µg/g)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)	^{241}Am (pCi/g)	Gross Gamma (counts/min/g)
Abiquiu Reservoir								
Upper	0.0 (0.2)[c]	0.2 (0.2)	0.253 (0.092)	1.89 (0.2)	0.0003 (0.0001)	0.0054 (0.0004)	0.006 (0.003)	1.8 (0.4)
Middle	0.2 (0.3)	0.2 (0.1)	0.277 (0.141)	2.51 (0.2)	0.0003 (0.0001)	0.0060 (0.0003)	0.009 (0.003)	3.2 (0.5)
Lower	0.1 (0.3)	0.2 (0.2)	0.496 (0.119)	2.2 (0.2)	0.0004 (0.0001)	0.0102 (0.0004)	0.033 (0.007)	3.0 (0.5)
Cochiti Reservoir								
Upper	−0.5 (0.5)	0.17 (0.16)	0.402 (0.106)	—[d]	0.0003 (0.0001)	0.0072 (0.0003)	N/A	1.6 (0.4)
Middle	0.3 (0.3)	0.19 (0.16)	0.245 (0.0824)	—[d]	0.0002 (0.0001)	0.0045 (0.0002)	N/A	1.4 (0.4)
Lower	−0.1 (0.3)	0.11 (0.14)	0.305 (0.108)	—[d]	0.0001 (0.0001)	0.0005 (0.0001)	N/A	5.5 (0.7)
Background (1974-1986)[e]	—	0.87	0.44	4.4	0.006	0.023	—	—

[a]Samples were collected in June 1991 at Abiquiu and July 1991 at Cochiti; counting uncertainties are in parentheses.
[b]Tritium as tritiated water in moisture distilled from sample.
[c]Radioactivity counting uncertainties(±1 standard deviation) are shown in parentheses.
[d]Sample lost in analysis.
[e]Background, upper limit (Purtymun 1987a).

that the source of the plutonium at all locations is dominantly from worldwide fallout. The data from the 1991 samples fit the longer term pattern of concentrations and isotopic ratios, as tabulated in Table IV-30. The Cochiti samples are below the long-term means for concentration and very near the mean isotope ratio; the Abiquiu samples were near the average of the concentration range and the isotopic ratio mean.

Both the 1991 data and the special study support other observations and interpretations (ESG 1981) that the contribution of total plutonium carried into the Rio Grande by current runoff through Los Alamos Canyon is small, roughly estimated at no more than 10% of that attributable to worldwide fallout on sediments in the Rio Grande (ESG 1981). The levels of plutonium on sediments in the Rio Grande in the vicinity of Los Alamos represent a variable mixing of the generally higher concentrations and isotopic ratios observed on soils and sediments farther north in the Rio Grande drainage and the generally lower concentrations and

Table IV-30. Plutonium Analyses from Sediments in Reservoirs on the Rio Chama and Rio Grande[a]

		^{238}Pu (fCi/g)	^{239,240}Pu (fCi/g)	Ratio (^{239,240}Pu/^{238}Pu) (fCi/g)
Abiquiu Reservoir				
1984	$\bar{x}$ (*s*)	0.7 (0.4)	12.7 (6.3)	18
1985	$\bar{x}$ (*s*)	0.7 (0.5)	8.8 (0.9)	12
1986	$\bar{x}$ (*s*)	0.3 (0.1)	7.5 (1.7)	25
1987	$\bar{x}$ (*s*)	0.2 (0.1)	3.8 (3.1)	19
1988	$\bar{x}$ (*s*)	0.3 (0.2)	7.5 (2.6)	25
1989	$\bar{x}$ (*s*)	0.2 (0.6)	3.7 (0.4)	18
1990	$\bar{x}$ (*s*)	0.14 (0.1)	2.6 (1.6)	19
1991	Upper	0.3 (0.1)	5.4 (0.4)	18
	Middle	0.3 (0.1)	6.0 (0.3)	20
	Lower	0.4 (0.1)	10.2 (0.4)	26
	$\bar{x}$ (*s*)	0.33 (0.1)	7.2 (2.6)	22
Cochiti Reservoir				
1984	$\bar{x}$ (*s*)	0.7 (1.1)	19.7 (14.0)	28
1985	$\bar{x}$ (*s*)	1.6 (0.6)	24.1 (7.3)	15
1986	$\bar{x}$ (*s*)	1.2 (0.5)	21.2 (6.1)	18
1987	$\bar{x}$ (*s*)	0.8 (0.7)	17.5 (13.8)	22
1988	$\bar{x}$ (*s*)	1.7 (2.3)	21.1 (2.9)	7
1989	$\bar{x}$ (*s*)	2.5 (2.3)	49.3 (7.3)	20
1990	$\bar{x}$ (*s*)	1.1 (0.5)	20.9 (10.7)	19
1991	Upper	0.3 (0.1)	7.2 (0.3)	24
	Middle	0.2 (0.1)	4.5 (0.2)	23
	Lower	0.1 (0.1)	0.5 (0.1)	5
	$\bar{x}$ (*s*)	0.2 (0.1)	4.1 (3.4)	21
Background				
(1974–1986)[b]		6.0	23.0	

[a]Samples were collected in June 1991 at Abiquiu and July 1991 at Cochiti; counting uncertainties are in parentheses.

[b]Purtymun (1987a).

lower isotopic ratios found in the Chama system reservoirs and soils of northern New Mexico. Thus, the significant variability with time and the uncertainty in measurements of at least 5-10% in even the 1 kg samples (as much as 50% in normal size samples) at the low levels combine to make it generally impossible to distinguish the contribution from current Los Alamos Canyon sediments in the Rio Grande by measuring concentrations. For similar reasons there is no distinguishable increase in $^{239,240}Pu$ to ^{238}Pu isotopic ratio as would be expected if the higher concentration, higher ratio Los Alamos Canyon sediments were making a large contribution.

7. Special Rio Grande Sediment Study.

A geomorphologic study completed in 1991, "Geomorphology of Plutonium in the Northern Rio Grande System," (Graf 1991) provides an historic perspective to evaluate the contributions of plutonium from Los Alamos to the Rio Grande. That study utilized historic aerial photography and hydrologic data to study the movement and deposition of sediments over time. Among the study's conclusions regarding a regional plutonium budget for the 1948–1985 period accounting for both worldwide fallout and input from Los Alamos Canyon for the northern Rio Grande, three are particularly relevant to interpreting the surveillance data:

- Fallout accounts for more than 90% of the plutonium in the system; Los Alamos, for slightly less than 10%.
- About half of the total plutonium (fallout plus Los Alamos) is estimated to have been stored along the river, and the remainder moved into storage in Elephant Butte Reservoir.
- Most of the Los Alamos contributions remain in storage along the river between Otowi and Peña Blanca (just downstream from Cochiti Dam); since 1973 the downstream transport of the Los Alamos contributions has terminated in Cochiti Reservoir.

The study identified locations where sediments had been deposited during specific periods. A special sediment sample was collected from a floodplain near Buckman (just south of Cañada Ancha on Fig. IV-9) that was actively deposited during the 1941–1968 period. This sample was subject to a very sensitive analysis (detection limits as little as 0.0001 pCi/gm) of plutonium isotopes by the Isotope Geochemistry Group (INC-7) at the Laboratory. This analysis showed that plutonium found at Buckman had a ratio of ^{239}Pu to ^{240}Pu consistent with about an equal mix of worldwide fallout and plutonium from the Acid-Pueblo-Los Alamos Canyon system. The total levels of ^{239}Pu to ^{240}Pu in the sample (0.017 pCi/g) were within the statistically derived fallout level (0.023 pCi/g). Only the precise and costly analysis showed that the deposit had a substantial contribution from historic flows out of Los Alamos Canyon. Such techniques may be useful for other research into the sediment transport processes.

F. Monitoring of the Water Distribution Systems

1. Introduction.

The EPA has established maximum contaminant levels for organic and inorganic constituents and radioactivity in drinking water in the Safe Drinking Water Act (SDWA). These standards have been adopted by the State of New Mexico and are included in the New Mexico Water Supply Regulations (NMEIB 1991). NMED has been authorized by EPA to administer and enforce federal drinking water regulations and standards in New Mexico.

Compliance samples are analyzed for organic and inorganic constituents and for radioactivity at the State Scientific Laboratory Division (SLD) in Albuquerque. SLD reports the analytical results directly to NMED. The Johnson Controls Inc. Environmental (JENV) Laboratory also collects samples throughout the Laboratory and County distribution systems and tests them for microbiological contamination, as required under the SDWA. The JENV Laboratory is certified by SLD for microbiological testing of drinking water.

During 1991, all water samples collected under the SDWA program at Los Alamos and tested by SLD in Albuquerque and by the JENV Laboratory were found to be in compliance with the maximum contaminant levels established by regulation.

2. Monitoring Network.

The Laboratory and County water distribution systems were sampled at three locations for inorganic and volatile organic components (VOCs) during 1991 to determine compliance with SDWA parameters. Each location is representative of one of the well fields

supplying the distribution system: Los Alamos Airport is representative of water quality in the Los Alamos Well Field; White Rock Fire Station of the Pajarito Well Field; and Barranca Mesa School of the Guaje Well Field.

3. Analytical Results.

a. Radiological Analyses of the Water Distribution Systems. The water distribution systems were sampled for radioactivity at three locations during 1991. Samples were analyzed by SLD and the results showed concentrations below the maximum contaminant level for gross alpha and gross beta. These results are summarized in Table III-11.

b. Chemical Constituent Analyses of the Water Distribution Systems. All of these results were found to be in compliance with the standards. Inorganic analyses consist of the following parameters: arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, nitrate (as N), and fluoride. VOC analyses are divided into two classes. VOC Group I consists of aromatic and halogenated purgeables to determine the presence of benzene, carbon tetrachloride, 1,1-dichloroethylene, 1,2-dichloroethane, para-dichlorobenzene, trichloroethane, trichloroethylene, and vinyl chloride plus 49 unregulated contaminants. VOC Group II consists of ethylene dibromide (EDB) and 1,2-dibromo-3-chloropropane. A summary of analytical results is included in Table III-8.

Under the SDWA, testing for total trihalomethanes is required for the Los Alamos water supply once each quarter. During 1991, samples were collected by EM-8 at five locations within the Laboratory and County water distribution systems and delivered to SLD for analysis. Results showed concentrations below the maximum contaminant level of 0.10 mg/L for total trihalomethanes. A summary of these results is included in Table III-9.

c. Microbiological Analyses of the Water Distribution Systems. Each month during 1991 an average of 46 samples was collected throughout the Laboratory and County water distribution systems to determine the free chlorine residual available for disinfection and the microbiological quality of the distribution systems. These samples were collected by personnel at the JCI Environmental Section and analyzed in the JCI certified laboratory for the presence of coliform bacteria, which is an indicator used to determine if harmful bacteria could be present. During 1991, no coliform bacteria were found. Sixty-five of the microbiological samples (approximately 12%) collected were found to have some noncoliform bacteria present. Although the presence of noncoliform bacteria is not a violation of SDWA, it does indicate stagnant water or biofilm growth in the distribution lines. A summary of the analytical results is found in Table III-12.

d. Other Environmental Activities for Protection of the Water Supply Systems. Other programs conducted to protect the water supply system include the following:

Wellhead Inspection Program. A survey of water supply wells was conducted during 1991 by the JCI Environmental Section to detect any potential sources of contamination into the system. Daily inspections of the wells were also conducted by JCI Utilities to maintain pumping equipment and to identify any problem that might lead to a potential health hazard.

Disinfection Program for New Construction. Whenever new construction or repair work is required on the distribution or supply system, the pipe must be disinfected before it is put in service. This disinfection is accomplished by flushing the pipe and adding a high-strength chlorine solution to the piping. The chlorinated water is then removed, and a sample is taken during the flushing process by the JCI Environmental Section for the presence of coliform bacteria.

G. Foodstuffs Monitoring

1. Introduction.

Concentrations of radionuclides in foodstuffs collected from Laboratory areas were compared to levels of radionuclides in foodstuffs samples collected from perimeter and regional (background) locations in an effort to monitor Laboratory operations for potential radioactive contamination. In addition, radiation dose was calculated from the data collected and compared to the radiation protection standards recommended by the International Commission on Radiological Protection (ICRP 1979) and the National Council on Radiation Protection and Measurements (NCRP 1987a), as mandated by DOE Order 5400.5 (DOE 1990a).

2. Monitoring Network.

Produce (fruits, vegetables, and grains), bee, and honey samples are collected on a yearly basis from on site (within the Laboratory boundary), perimeter (Los Alamos townsite/White Rock), and regional (Española/San Ildefonso Pueblo) locations. Regional or background samples of foodstuffs are collected upstream from the confluence of the Rio Grande and intermittent streams that cross Laboratory lands. Similarly, levels of radionuclides are determined in catfish (bottom feeders) and crappie and/or trout (surface feeders) collected from Abiquiu (a reservoir upstream from the Laboratory) and are compared to fish collected from Cochiti (a reservoir downstream from the Laboratory). Locations of produce, fish, and beehives are shown in Figs. IV-13 and IV-14 and Table D-12.

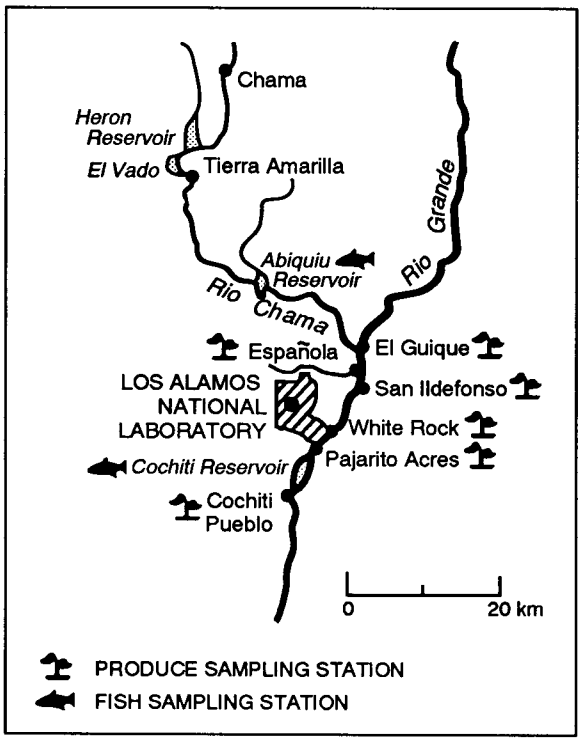


Fig. IV-13. Produce and fish sampling locations. (Map denotes general locations only.)

3. Analytical Results.

a. Produce. Concentrations of radionuclides in produce collected from on-site, perimeter and regional locations during the 1991 growing season can be found in Table IV-31. In general, most radionuclides in foodstuffs collected from on-site, perimeter, and regional locations were within a range of values reported for these areas in past years. With the exception of H^3, all radionuclides in produce collected from on-site areas were within background concentrations. The range in H^3 values in produce samples collected from on-site Laboratory lands ranged in concentration from 0.7 to 8.1 pCi/mL. These values are higher than last year's H^3 values and are probably the result of routine Laboratory operations.

With the exception of one perimeter location, no differences in H^3, ^{90}Sr, total U, $^{239,240}Pu$, and ^{137}Cs were detected between produce collected from regional areas (Española and San Ildefonso as a group mean) and produce samples collected from perimeter sampling locations.

One fruit sample collected from the former TA-1 site in the Los Alamos townsite contained elevated levels of H^3 (16 pCi/mL) and $^{239,240}Pu$ (0.02 pCi/dry g). Plutonium levels, in particular, were about 100 times the levels found in fruit samples collected from other trees in the area. The amount of Pu in this fruit does not pose a health hazard; the total dose as a result of all radionuclides that could be obtained from ingesting all of the fruit from this tree (estimated to be about 50 lb) was only 0.3 mrem/yr. This dose is less than 1% of the DOE's radiation protection standard of 100 mrem/yr for all pathways.

Subsequent sampling and analysis of air, plant branches, soil surface, and subsurface materials from around this tree and other fruit trees in the area showed that (1) the TA-1 fruit tree contained elevated levels of H^3 in fruit, branch, and subsurface soil samples as compared to plant and soil samples collected from other fruit trees growing in the area, suggesting that the TA-1 fruit tree may be transporting H^3 up through the roots to the fruit, and (2) $^{239,240}Pu$ was elevated in soil surface samples collected directly underneath the TA-1 fruit tree as compared to other soil surface samples in the area, suggesting that elevated levels of $^{239,240}Pu$ in fruit samples collected from the TA-1 tree may have been more a result of soil surface contamination (resuspension and/or sample contamination) rather than from root uptake. During the decommissioning and decontamination of the TA-1 area in the 1960s and 70s, the detection limits for clean-up activities was approximately 20 pCi/g gross alpha activity. All 1991 samples were below these limits.

Another study conducted in 1991 under the foodstuff monitoring program involved the collection

of produce samples from the Western Area community of Los Alamos. This study was initiated in response to a Los Alamos community concern about an apparently high brain cancer incidence rate in that area. Results of eight produce samples collected from the Western Area show that radionuclide contents were similar to the radionuclide contents in produce collected from the Española Valley. The total dose obtained from consuming 352 lb of Western Area produce was 0.4 mrem/yr. This dose was less than 1% of the DOE's radiation protection standard of 100 mrem/yr for all pathways for protecting members of the public. The slightly higher values of some radionuclides in produce samples collected from the Western Area as compared to background (i.e., ^{90}Sr) were believed to be a result of higher precipitation/fallout events. The total precipitation recorded in the Western Area during 1991 was twice that in Española.

In summary, Laboratory contributions to doses received from produce consumption, including that from H^3, pose no threat to the health and safety of the general public. Section V.C.3.f presents information on

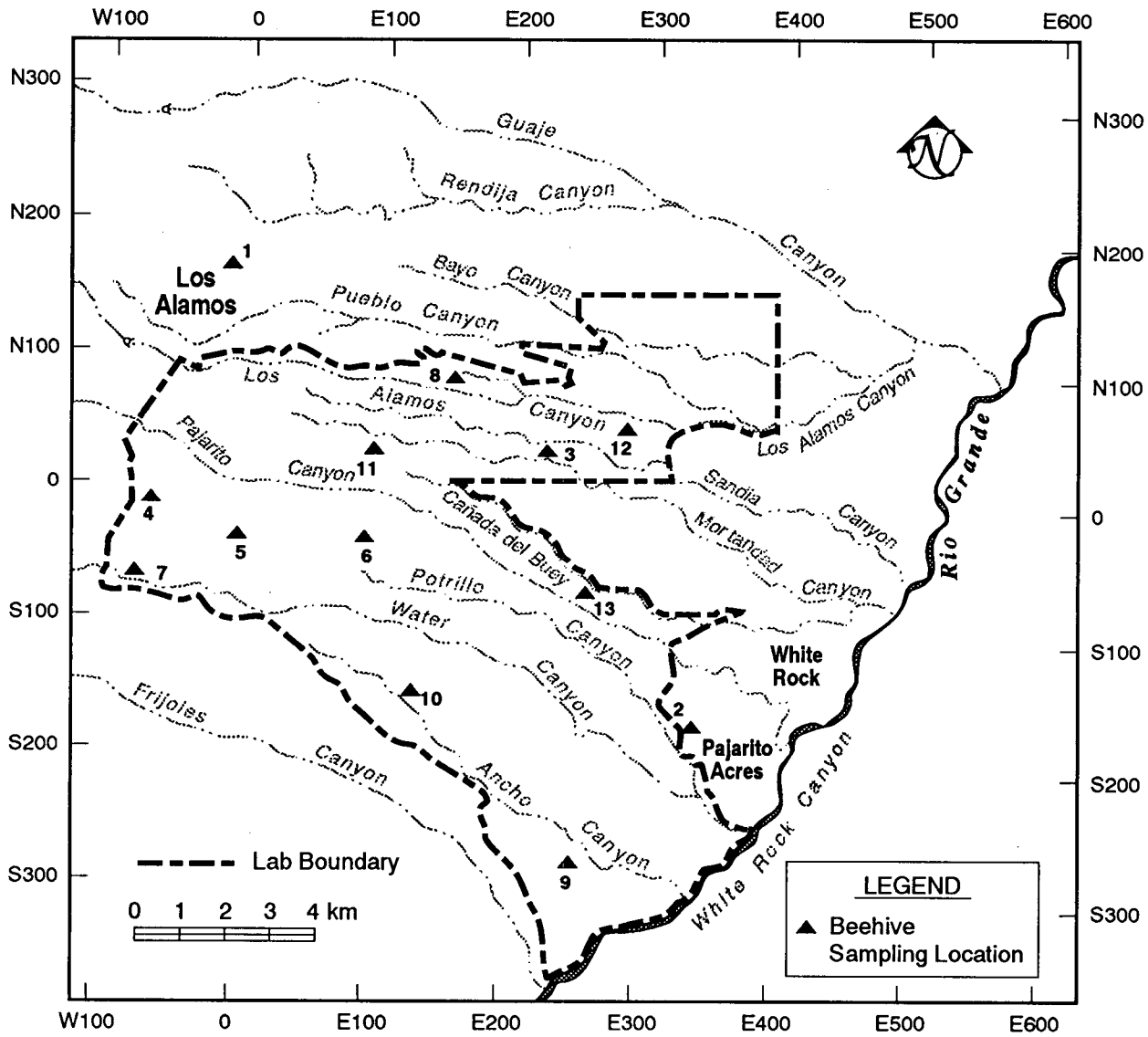


Fig. IV-14. Locations of beehives in the Los Alamos area. Regional stations are not shown. (Map denotes general locations; specific locations are presented in Table D-12.)

Table IV-31. Radionuclides in On-Site, Perimeter, and Regional Produce Collected during the 1991 Growing Season[a]

	H^3 (pCi/mL)	^{90}Sr (10^{-3} pCi/dry g)	Uranium (ng/dry g)	^{238}Pu (10^{-5} pCi/dry g)	$^{239,240}Pu$ (10^{-5} pCi/dry g)	^{137}Cs (10^{-3} pCi/dry g)
REGIONAL STATIONS						
Española						
N	10	10	10	10	10	10
Mean	0.4	45	23	−3.5	5	158
Std dev	0.2	57	15	13	15	141
Minimum	0.1 (0.3)[b]	−13.5 (−0.5)	1.5 (0.2)	−25 (1.5)	−15.1 (1.5)	−56 (61)
Maximum	0.5 (0.3)	159 (6.3)	50 (4.9)	14 (38.1)	38.0 (27)	350 (206)
San Ildefonso						
N	6	6	6	6	6	6
Mean	0.5	139	83	98	23	736
Std dev	0.4	89	103	94	44	984
Minimum	0.0 (0.3)	25 (4.2)	2 (0.2)	0.0 (3.6)	−33 (3.6)	14 (29)
Maximum	1.0 (0.3)	290 (10.5)	275 (27.5)	240 (144)	96 (93)	2,484 (1,150)
PERIMETER STATIONS (Los Alamos/White Rock)						
N	23	23	23	23	23	23
Mean	0.6	75	7	19	14	66
Std dev	0.6	173	5	28	19	287
Minimum	−0.3 (0.3)	6.6 (9.9)	1.0 (0.1)	−13.5 (3.3)	−30.8 (3.3)	−935 (62)
Maximum	2.7 (0.4)	855 (17.1)	20.8 (2.1)	123 (82.1)	60 (37)	643 (337)
ON-SITE STATIONS (Laboratory Lands)						
N	2	2	2	2	2	2
Mean	4.4	83	16	16	16	121
Std dev	5.2	14	2	9	9	172
Minimum	0.7 (0.3)	73 (9)	15 (1.5)	9.3 (9.3)	9.3 (9.3)	−0.7 (105)
Maximum	8.1 (0.5)	93 (12)	17 (1.7)	22 (14.6)	22 (15)	243 (145)

Table IV-31. (Cont.)

	H^3 (pCi/mL)	^{90}Sr (10^{-3} pCi/dry g)	Uranium (ng/dry g)	^{238}Pu (10^{-5} pCi/dry g)	$^{239,240}Pu$ (10^{-5} pCi/dry g)	^{137}Cs (10^{-3} pCi/dry g)
OTHER STATIONS (Cochiti/Santo Domingo)						
N	13	13	13	13	13	13
Mean	0.1	37	11	5	17	117
Std dev	0.4	25	9	14	19	101
Minimum	−0.6 (0.3)	5.1 (1.4)	1.5 (0.1)	−14.8 (8.6)	0.0 (5.1)	−0.6 (16)
Maximum	0.7 (0.3)	83 (14.0)	30.4 (3.1)	30.6 (30.5)	69 (43.0)	374 (189)

[a]There are no concentration guides for produce.
[b]Counting uncertainties are in parentheses.

the radiological health significance of these data (i.e., radiation dose assessments).

b. Fish. Radionuclides in fish collected from Abiquiu and Cochiti reservoirs are presented in Table IV-32. Heavy and trace metals in fish collected from these reservoirs can be found in Table IV-33. Similar types of feeders were compared using an unpaired student's t-test at the 0.05 confidence level. Concentrations of most radionuclides in bottom-feeding catfish collected from Cochiti were not statistically different than radionuclides in catfish collected from Abiquiu Dam. Total uranium was statistically different in catfish collected from Cochiti as compared to catfish collected from Abiquiu. The difference between total U in fish collected from these two reservoirs, however, was small (i.e., 4.1 ng/dry g).

Levels of ^{90}Sr, total U, and ^{238}Pu in crappie collected from Cochiti were statistically different from trout collected from Abiquiu. Although the levels of these radionuclides in fish from Cochiti were statistically higher in comparison to Abiquiu, they were within the variation exhibited by crappie in previous years. Also, the difference between the radionuclide contents detected in crappie collected from Cochiti as

Table IV-32. Radionuclides in Fish

	^{90}Sr (10^{-3} pCi/dry g)	^{137}Cs (10^{-3} pCi/dry g)	Uranium (ng/dry g)	^{238}Pu (10^{-5} pCi/dry g)	^{239}Pu (10^{-5} pCi/dry g)
BOTTOM FEEDERS (Catfish)					
Abiquiu					
N	12	12	12	12	12
Mean	26	21	5.1	1	3
Std dev	10	71	3.0	10	3
Minimum	4 (8)[a]	-17 (6)	0.7 (0.1)	-18 (2)	-5 (3)
Maximum	36 (36)	245 (36)	12.5 (1.2)	16 (18)	8 (18)
Cochiti					
N	11	11	11	11	11
Mean	17	1	9.2	4	2
Std dev	7	9	4.2	6	4
Minimum	6 (12)	-12 (9)	4.0 (0.4)	-8 (0)	-4 (3)
Maximum	27 (18)	13 (18)	16.5 (1.6)	14 (14)	7 (9)
SURFACE FEEDERS (Crappie or Trout)					
Abiquiu					
N	12	12	12	12	12
Mean	10	1	3.2	3	3
Std dev	3	16	1.0	4	4
Minimum	6 (12)	-37 (9)	1.7 (0.2)	0 (2)	-3 (2)
Maximum	16 (26)	24 (26)	5.2 (0.5)	8 (11)	10 (10)
Cochiti					
N	12	12	12	12	12
Mean	66	6	4.8	8	4
Std dev	14	21	1.0	7	8
Minimum	39 (26)	-24 (2)	3.6 (0.3)	0 (6)	-6 (3)
Maximum	90 (32)	55 (32)	6.4 (0.7)	16 (16)	16 (16)

[a]Counting uncertainties are in parentheses.

Table IV-33. Heavy and Trace Metals in Fish (μg/dry g)

	Abiquiu		Cochiti	
Element	Mean	Standard Deviation	Mean	Standard Deviation
Ag	<2.00	0.00	<2.00	0.00
Al	<2.00	0.00	<2.00	0.00
As	<0.10	0.00	<0.10	0.00
B	<2.00	0.00	<2.00	0.00
Ba	<2.00	0.00	<2.00	0.00
Be	<2.00	0.00	<2.00	0.00
Ca	85.50	20.60	378.28	440.72
Cd	<0.02	0.01	<0.02	0.00
Co	<1.00	0.00	<1.00	0.00
Cr	1.15	0.39	0.70	0.71
Cu	<2.00	0.00	<2.00	0.00
Fe	11.66	3.20	5.57	4.31
Hg	0.35	0.09	0.35	0.12
Mg	233.33	20.65	240.00	34.64
Mn	<1.00	0.00	<1.00	0.00
Mo	<2.00	0.00	<2.00	0.00
Ni	<2.00	0.00	<2.00	0.00
Pb	<0.10	0.00	<0.10	0.00
Se	0.38	0.27	0.46	0.23
Si	4.00	1.26	3.42	1.51
Sn	<2.00	0.00	<2.00	0.00
Sr	<2.00	0.00	<2.00	0.00
V	<2.00	0.00	<2.00	0.00
Zn	4.00	1.26	4.71	0.95

compared to trout collected from Abiquiu was small: ^{90}Sr was 0.056 pCi/dry g, total U was 1.6 ng/dry g, and ^{238}Pu was 0.00005 pCi/dry g. As in the past, body burdens in bottom-feeding catfish had higher levels of uranium (average was 7.1 ng/dry g) than those found in surface feeders such as crappie or trout (4.0 ng/dry g). None of the 24 heavy and trace metals analyzed, including Pb, Cd, and Hg, in fish collected from Cochiti Reservoir were significantly different from heavy and trace metal elements in fish collected from Abiquiu Reservoir.

Overall, the data indicate that Laboratory operations do not result in significant radiation doses to the general public from consuming fish from Cochiti Reservoir.

c. Bees and Honey. The most recent data (1990) for bees and honey are shown in Tables IV-34 through IV-37. In general, most radionuclide and trace metal elements were within the variation exhibited in previous years. Levels of H^3 in bees collected from Laboratory areas, in 1990, ranged in concentration from 2,400 (±400) to 760,000 (±80,000) pCi/L. The highest H^3 contents in bees collected from the Laboratory were from TA-54 (Area G) and TA-53 (LAMPF). Background levels of H^3 in bees range in concentration from 700 to 1500 (±300) pCi/L.

Tritium in honey collected from Laboratory lands in 1990 ranged from 500 (±600) to 420,000 (±40,000) pCi/L. The highest H^3 levels in honey at the Laboratory were those collected from TA-33 (HP-Site) and TA-53. Levels of H^3 in honey collected from background stations ranged in concentration from 300 (±200) to 2400 (±400) pCi/L. Honey produced by the hives on Laboratory lands is not available for consumption.

Table IV-34. Selected Radionuclides in Local and Regional Honey Collected during 1990

Station	H^3 (pCi/L)	^7Be (pCi/L)	^{22}Na (pCi/L)	^{54}Mn (pCi/L)	^{57}Co (pCi/L)	^{83}Rb (pCi/L)	^{137}Cs (pCi/L)
San Pedro	300 (200)[a]	650 (4,600)	2 (530)	9 (510)	14 (390)	18 (950)	14 (500)
Chimayo	2,400 (400)	1,900 (4,600)	–9 (530)	25 (510)	11 (390)	5 (950)	–2 (500)
San Juan	400 (200)	700 (4,600)	16 (530)	8 (510)	65 (390)	79 (950)	13 (500)
TA-5	4,900 (300)	–1,700 (4,600)	2 (530)	45 (510)	–19 (390)	11 (950)	19 (500)
TA-8	800 (300)	–2,100 (4,600)	10 (530)	7 (510)	11 (390)	110 (950)	–1 (500)
TA-9	800 (300)	2,900 (4,600)	–14 (530)	44 (510)	39 (390)	200 (950)	16 (500)
TA-15	1,000 (300)	1,700 (4,600)	204 (530)	4 (510)	4 (390)	60 (950)	–9 (500)
TA-16	500 (600)	2,500 (4,600)	60 (530)	33 (510)	–31 (390)	280 (950)	7 (500)
TA-21	110,000 (10,000)	–150 (4,600)	27 (530)	60 (510)	9 (390)	37 (950)	10 (500)
TA-33	240,000 (20,000)	–360 (4,600)	–5 (530)	35 (510)	7 (390)	–140 (950)	–30 (500)
TA-49	1,300 (300)	–900 (4,600)	2 (530)	37 (510)	13 (390)	90 (950)	55 (500)
TA-50	9,100 (1,000)	1,700 (4,600)	–3 (530)	3 (510)	–8 (390)	–6 (950)	6 (500)
TA-53	420,000 (40,000)	1,200 (4,600)	120 (530)	28 (510)	37 (390)	–24 (950)	10 (500)
TA-54	54,000 (5,000)	22 (4,600)	24 (530)	7 (510)	26 (390)	–150 (950)	49 (500)

[a]Counting uncertainties are in parentheses.

Table IV-35. Selected Trace Metals in Local and Regional Honey Collected during 1990[a]

Station	Arsenic (μg/g)	Beryllium (ng/g)	Boron (μg/g)	Cadmium (μg/g)	Chromium (μg/g)	Lead (μg/g)	Mercury (ng/g)	Selenium (μg/g)
San Pedro	0.76	<2.0	5.8	<0.01	0.03	<0.06	<25	0.90
Chimayo	0.87	<2.0	6.7	<0.01	0.04	<0.06	<25	0.85
San Juan	0.86	<2.0	6.9	<0.01	0.03	<0.06	<25	0.99
TA-5	1.10	<2.0	8.0	<0.01	0.04	0.08	<25	0.93
TA-8	0.93	<2.0	8.8	<0.01	0.04	0.06	<25	1.10
TA-9	0.97	<2.0	4.7	<0.01	0.04	<0.06	<25	0.88
TA-15	0.91	<2.0	5.2	0.02	0.04	<0.06	<25	1.20
TA-16	1.10	<2.0	7.0	<0.01	0.04	<0.06	<25	0.88
TA-21	1.00	<2.0	9.2	<0.01	0.04	<0.06	<25	1.10
TA-33	0.81	<2.0	7.5	<0.01	0.04	0.09	<25	0.92
TA-49	0.94	<2.0	5.1	<0.01	0.03	<0.06	<25	1.40
TA-50	0.82	<2.0	6.0	0.01	0.05	1.50	<25	0.90
TA-53	0.81	<2.0	5.2	<0.01	0.08	<0.06	<25	0.88
TA-54	0.94	<2.0	8.8	<0.01	0.03	<0.06	<25	1.30

[a]Uncertainty of the results is ±10%. The density of honey is about 1860 g/L.

Table IV-36. Selected Radionuclides in Local and Regional Bees Collected during 1990

Station	H^3 (pCi/L)	^7Be (pCi/g)	^{22}Na (pCi/g)	^{54}Mn (pCi/g)	^{57}Co (pCi/g)	^{83}Rb (pCi/g)	^{137}Cs (pCi/g)	Uranium (ng/g)
San Pedro	800	1.50	–0.03	0.10	0.03	0.17	0.02	288
	(300)[a]	(15.50)	(1.05)	(0.90)	(0.01)	(2.05)	(0.60)	(29)
Chimayo	1,500	1.50	–0.05	–0.05	0.05	0.10	0.03	286
	(300)	(15.50)	(1.05)	(0.90)	(0.01)	(2.05)	(0.60)	(29)
San Juan	700	2.25	0.04	–0.01	0.03	–0.07	0.00	253
	(300)	(1.00)	(1.05)	(0.90)	(0.01)	(2.05)	(0.60)	(25)
TA-5	7,200	4.06	0.04	0.02	0.00	0.00	0.00	138
	(800)	(1.15)	(1.05)	(0.90)	(0.25)	(2.05)	(0.60)	(14)
TA-8	3,500	2.45	0.02	–0.07	0.04	–0.05	–0.01	95
	(500)	(15.50)	(1.05)	(0.90)	(0.01)	(2.05)	(0.60)	(9)
TA-9	5,700	0.85	0.10	–0.04	0.06	0.11	0.02	161
	(700)	(15.50)	(1.05)	(0.90)	(0.25)	(2.05)	(0.60)	(16)
TA-15	2,400	0.65	0.03	–0.05	0.05	0.12	0.03	360
	(400)	(15.50)	(1.05)	(0.90)	(0.01)	(2.05)	(0.60)	(30)
TA-16	4,400	0.70	0.04	0.06	0.07	0.15	0.01	248
	(500)	(15.50)	(1.05)	(0.90)	(0.01)	(2.05)	(0.60)	(25)
TA-21	19,000	1.20	–0.04	–0.04	0.11	0.07	0.03	132
	(2,000)	(15.20)	(1.05)	(0.90)	(0.25)	(2.05)	(0.01)	(13)
TA-33	47,000	1.25	0.07	0.09	0.03	0.15	0.02	509
	(5,000)	(15.50)	(1.05)	(0.90)	(0.01)	(2.05)	(0.60)	(51)
TA-49	5,600	1.99	0.04	0.03	0.02	0.00	0.01	159
	(700)	(0.90)	(1.05)	(0.90)	(0.25)	(2.05)	(0.60)	(16)
TA-50	25,000	0.07	0.08	0.05	0.03	–0.09	0.03	109
	(3,000)	(15.50)	(0.03)	(0.90)	(0.01)	(2.05)	(0.60)	(11)
TA-53	55,000	0.47	1.01	0.16	0.18	0.04	0.04	147
	(6,000)	(15.50)	(0.10)	(0.90)	(0.02)	(2.05)	(0.60)	(15)
TA-54	760,000	1.77	–0.05	0.07	0.07	–0.02	0.06	81
	(80,000)	(0.80)	(1.05)	(0.90)	(0.25)	(2.05)	(0.60)	(8)

[a]Counting uncertainties are in parentheses.

Table IV-37. Selected Trace Metals in Local and Regional Bees Collected during 1990[a]

Station	Arsenic (μg/g)	Beryllium (ng/g)	Boron (μg/g)	Cadmium (μg/g)	Chromium (μg/g)	Lead (μg/g)	Mercury (ng/g)	Selenium (μg/g)
San Pedro	<0.03	8.0	7.8	0.02	0.22	0.25	<25	1.60
Chimayo	<0.03	8.0	6.0	<0.01	3.80	4.30	<25	1.70
San Juan	<0.03	20.0	6.9	0.03	0.23	0.68	<25	1.10
TA-5	<0.03	2.0	7.2	<0.01	4.00	0.16	<25	0.66
TA-8	<0.03	<2.0	4.0	0.02	0.17	0.37	<25	0.47
TA-9	<0.03	<2.0	3.9	<0.01	0.16	0.51	<25	0.68
TA-15	<0.03	<2.0	6.1	<0.01	0.26	0.52	<25	0.60
TA-16	<0.03	<2.0	3.5	0.02	0.53	0.68	<25	2.50
TA-21	<0.03	10.0	4.6	0.04	0.18	0.31	<25	0.62
TA-33	<0.03	5.0	3.9	0.04	0.33	0.85	<25	1.90
TA-49	<0.03	23.0	6.3	0.04	0.20	0.77	<25	0.51
TA-50	0.14	<2.0	3.0	0.03	0.15	0.48	<25	0.48
TA-53	0.74	<2.0	6.2	<0.01	0.46	0.21	<25	1.10
TA-54	<0.03	<2.0	0.7	<0.01	0.14	0.02	<25	<0.07

[a]Uncertainty of the results is ±10%.

H. Environmental Assessments

The National Environmental Policy Act (NEPA) mandates that federal agencies consider the environmental impact of their actions prior to final decision making. NEPA establishes the national policy of creating and maintaining conditions under which man and nature can exist in harmony and fulfill the social, economic, and other requirements of present and future generations.

NEPA documents include the following:

- a categorical exclusion, applied to specific types of activities that have been determined to have no adverse environmental impacts;
- an Environmental Assessment (EA), evaluating environmental impacts, leading to either a finding of no significant impact (FONSI) if the impacts are indeed found to be not significant, or preparation of an Environmental Impact Statement (EIS) if the impacts could be significant; and
- an EIS, in which impacts of proposed and alternative actions are evaluated and mitigation measures proposed, leading to a record of decision in which the agency discusses a decision on proceeding with the project.

The proposed activities documented in the EAs submitted to DOE during 1991 are summarized below. The DOE reviews the analysis of environmental impacts for the proposed action presented in each EA and either issues a FONSI or prepares an EIS.

Radioisotope Heat Source Fuel Processing and Fabrication. The proposed action is for the DOE to renovate and operate existing ^{238}Pu processing facilities at the Savannah River Site (SRS) and to fabricate a limited quantity of ^{238}Pu heat source units at an existing ^{238}Pu research and development facility in Building PF-4, TA-55 at LANL. The proposed action includes facilities used in ^{238}Pu fuel processing and fabrication from the point at which existing inventories of ^{238}Pu oxide can be dissolved and reblended at SRS to the point at which the fabricated ^{238}Pu fuel forms are shipped from LANL for final integration into end-use system components.

The purpose of the proposed action is to enable DOE to provide the required supplies of ^{238}Pu fuel in a fabricated form to support the National Aeronautics and Space Administration's near-term Comet Rendezvous Asteroid Flyby and Cassini missions. DOE issued a FONSI on this proposed action on August 19, 1991.

Sorbent Radioactivity Study. The proposed action is to study the adsorption and decomposition of toxic gases in contact with activated carbon filter material; theoretical studies would be conducted concurrently. The research is needed to test and improve the effectiveness of carbon sorbents used to clean toxic gases from air. One application of this research is in the design of improved respiratory protection for individuals exposed to chemical warfare agents. To date, DOE has not made a determination on this EA.

Advanced Free-Electron Laser. The proposed project is to assemble and test a laser capable of producing laser light with wavelengths in the range of 100-0.1 micrometer and to conduct experiments using the laser light. Support activities such as construction of the shielded vault, temperature controlled rooms, equipment temperature control systems, and ventilation systems also would be necessary.

Goals of the proposed program include the development of advanced components for the free-electron laser, in particular electron beam accelerators, optical systems, resonators, and wiggler magnets. DOE has issued a draft FONSI on this proposed action.

Transuranic Waste Compactor and Drum Storage Building. The proposed action consists of two activities: (1) installing a 20-ton hydraulic press in an existing laboratory area to compact approximately 500 lb/wk of TRU waste; and (2) using a prefabricated, concrete-floored, metal building for the temporary storage of drums of solid TRU waste as they await certification and transport to a longer term storage area. The proposed action would increase the efficiency of waste volume minimization and waste storage while increasing safety in process and storage areas. At DOE's request, LANL combined separate EAs for the TRU Waste Compactor and the Drum Storage Building into this EA. The combined EA was submitted to DOE, but, to date, DOE has not made a determination on these proposed activities.

Expansion of Area G. Routine activities at the Laboratory generate solid low-level wastes (LLWs) which are disposed of or stored at Area G, TA-54. For some waste types, burial is the only feasible disposal

method that is consistent with all regulations. The useful lifetime of the existing Area G 63-acre site, which is limited by the area suitable for pit construction, is estimated to be 1993. The proposed action is to expand Area G, TA-54 onto nearby acreage on Mesita del Buey in order to provide adequate area and facilities to accommodate the disposal of solid LLW after the currently active part of Area G has been filled. The Laboratory site-wide EIS (DOE 1979) designated Mesita del Buey as a dedicated waste disposal site. The EA has been revised following DOE Field Office, Albuquerque, and DOE Headquarters (HQ) comments and is currently at DOE/HQ awaiting a determination.

I. Other Significant Environmental Activities at Los Alamos

1. External Radiation Measurement Study.

In addition to the Laboratory's routine TLD monitoring of external penetrating radiation in 1991, which is described in Section IV.B, a special study was conducted from August 1990 through July 1991 to evaluate TLD measurements. This is part of a continuing study consisting of an intercomparison of Laboratory TLDs with TLDs obtained from a commercial contractor.

One phase of the study involved colocating environmental dosimeters obtained from the contractor next to Laboratory dosimeters at 29 locations in the routine environmental monitoring network. Two contractor TLDs were placed at five of these locations.

The study began in August 1990. Contractor TLDs were colocated with the Laboratory TLDs for two months of the third quarter of 1990. Both the Laboratory TLDs and the contractor TLDs were exposed for the same time period, one calendar quarter, for the fourth quarter of 1990 and the first and second quarters of 1991.

The intercomparison was a "blind" study as far as the contractor was concerned. The contractor's TLDs were set out and collected following the contractor's instructions. No information was given to the contractor concerning the nature of study. The TLDs provided to LANL were processed by the contractor as would be those from any other customer.

The preliminary measured annual average external radiation levels for the 22 stations for which data for all four quarters is available is shown in Fig. IV-15. Please note that the contractor data for the third quarter of 1990 was corrected for its shorter exposure time by scaling the measurements to a full quarter exposure.

Figure IV-15 also shows the two-standard deviation acceptance band above and below the contractor's measurements. The LANL TLD measurements appear slightly but not significantly higher than those obtained from the contractor. In general, good agreement was found between the contractor's and LANL's measurements.

2. Tritium in Precipitation in the Los Alamos Region of New Mexico. (Andrew Adams and Fraser Goff [EES-1])

In February of 1990 EES-1 commenced a study to determine the background levels of tritium in precipitation in the Los Alamos region of New Mexico. This study is part of the framework studies in support of the ER program at Los Alamos.

In Figs. IV-16–IV-18 all the collection locations and elevations are plotted with the results of the tritium analyses shown in small boxes. A Tritium Unit is about 3.2 pCi/L of water. From examination of the tritium data of this study, plus cold spring and creek data from other studies in the Jemez Mountains, it appears that any rainwater with greater than 20 TUs must be contaminated to some degree by Laboratory activities. Assuming that the maximum value of background tritium in precipitation is 20 TU, a 20 TU contour was drawn through the data points for each sampling period. The exact position of the contour is approximate, but the results are clear; activities at the Laboratory release tritium into the atmosphere. However, over the 3- to 4-month time periods represented by these samples, the average concentration is almost 2 orders of magnitude below EPA limits set for tritium in drinking water (20,000 pCi/L, which is about 6,200 TU).

Figure IV-16 shows the results of the December 1990–April 1991 collection period. Inside the Laboratory boundary, the range is from 25.5 TU at S-Site to 117 TU at the White Rock "Y". Outside the Laboratory, the tritium values range from 8.2 TU at VC-2B to 14.6 TU at the Santa Fe Ski Basin.

Figure IV-17 shows the results of the April 1991–August 1991 collection period now with 14 collectors in place. During this time period, higher than average rainfall was recorded. As a result of this, the

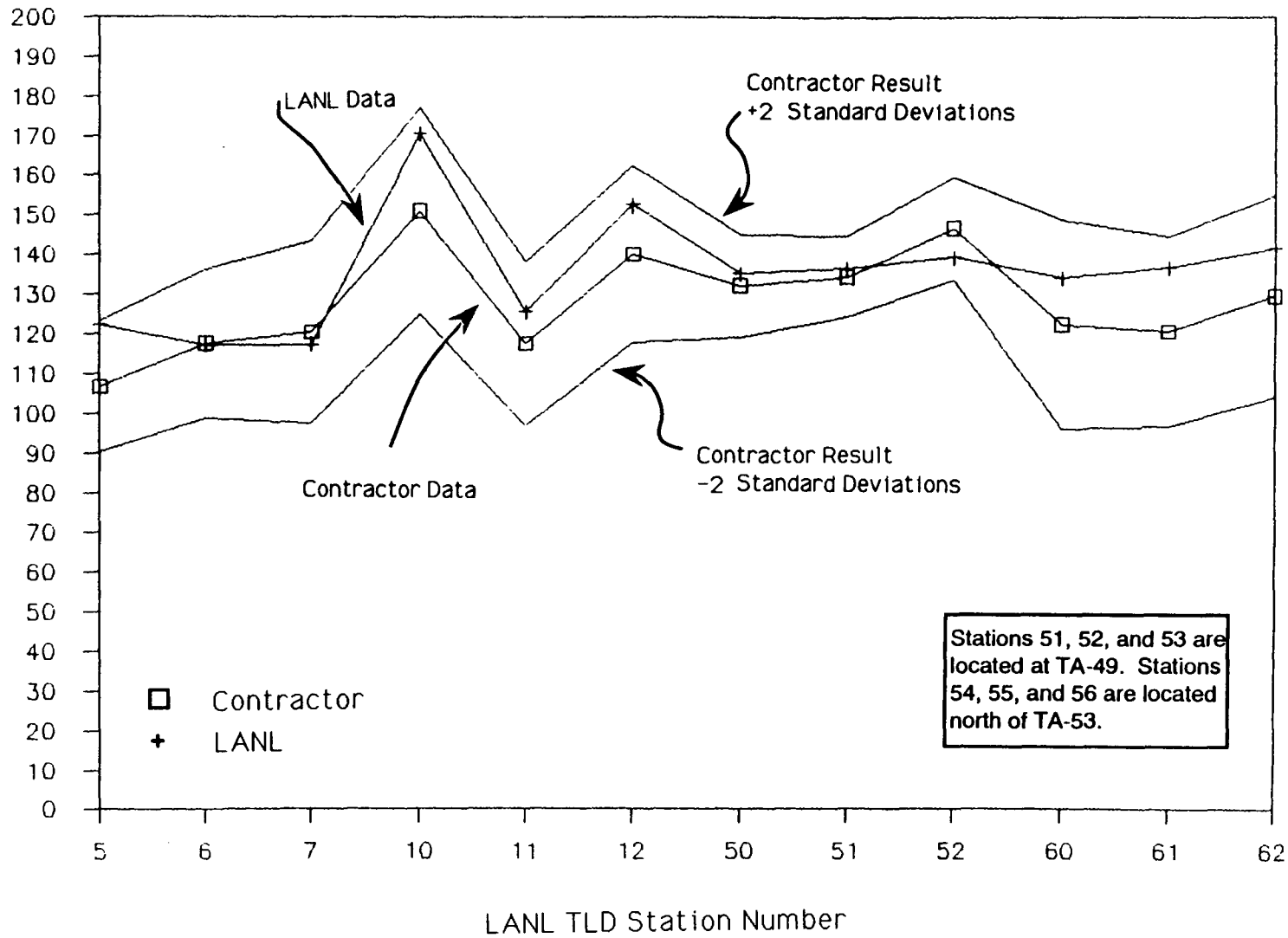


Fig. IV-15. Los Alamos National Laboratory/Contractor TLD intercomparison, July 1990 through June 1991. Please note that these data are for the period of July 1990 through June 1991 and so do not correspond to the January 1990 through December 1990 annual TLD results presented elsewhere in this report. These data are given to indicate the preliminary results of the intercomparison study.

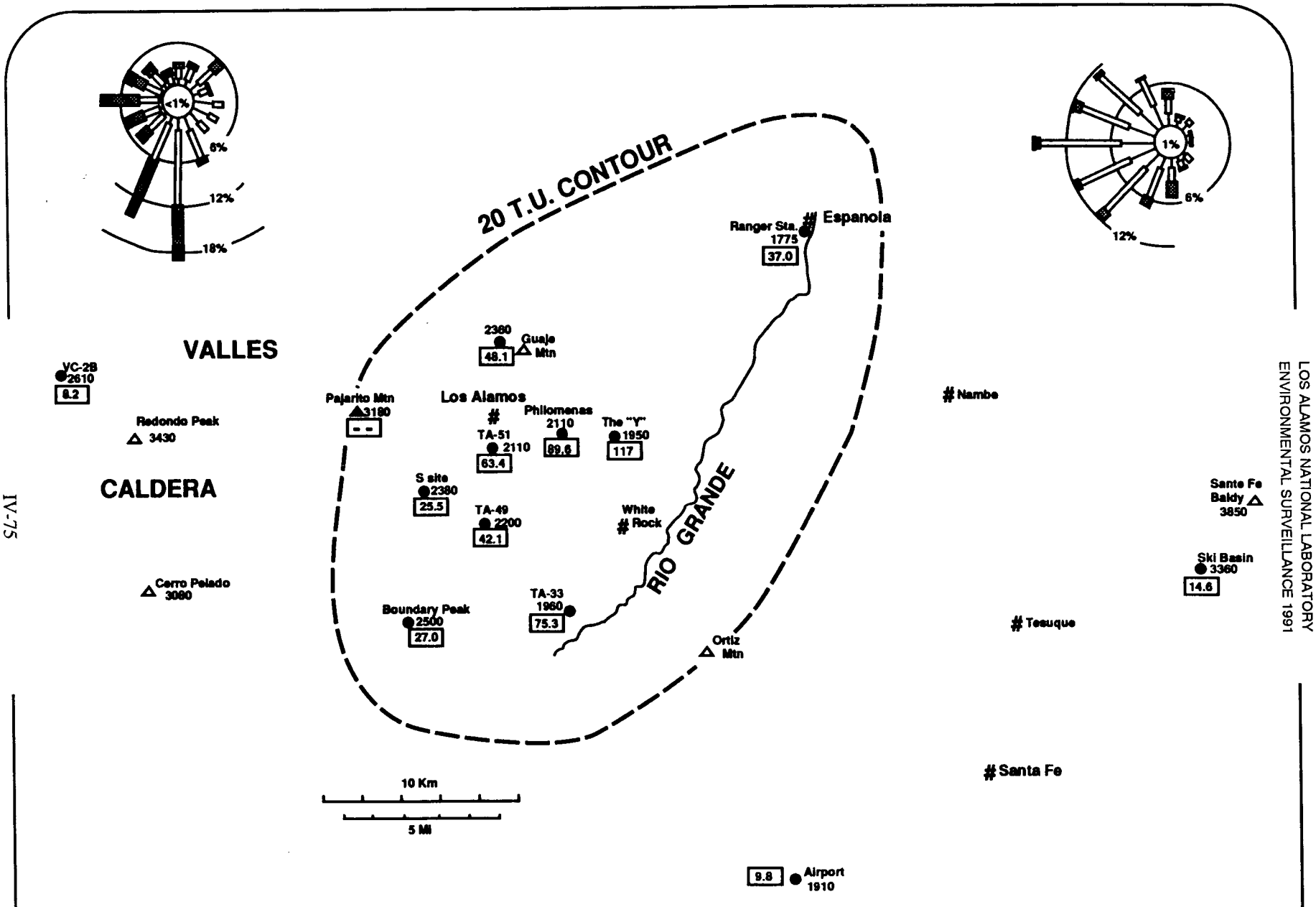


Fig. IV-16. Tritium in rainwater (collected during December 1990 - April 1991).

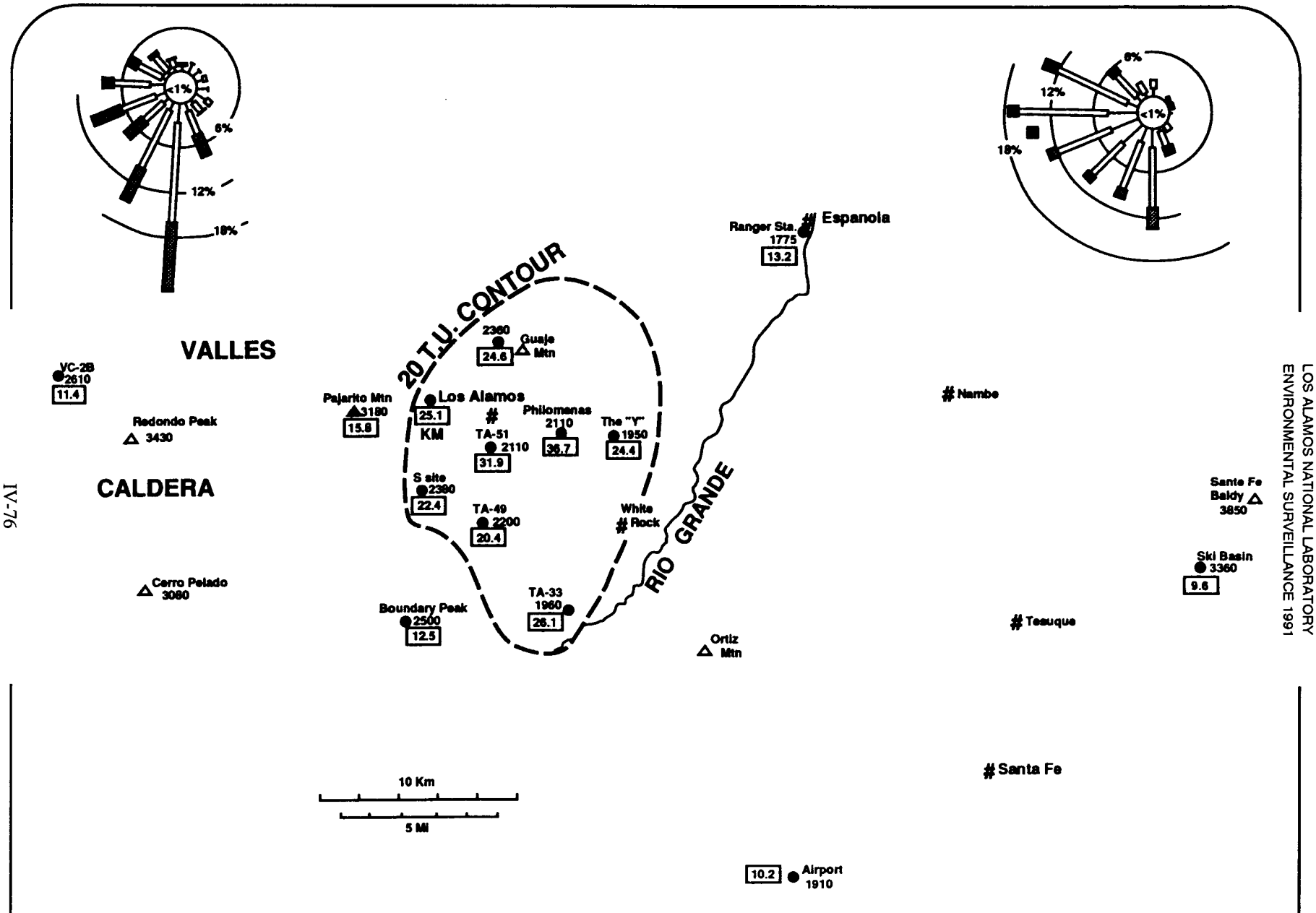


Fig. IV-17. Tritium in rainwater (collected during April 1991 - August 1991).

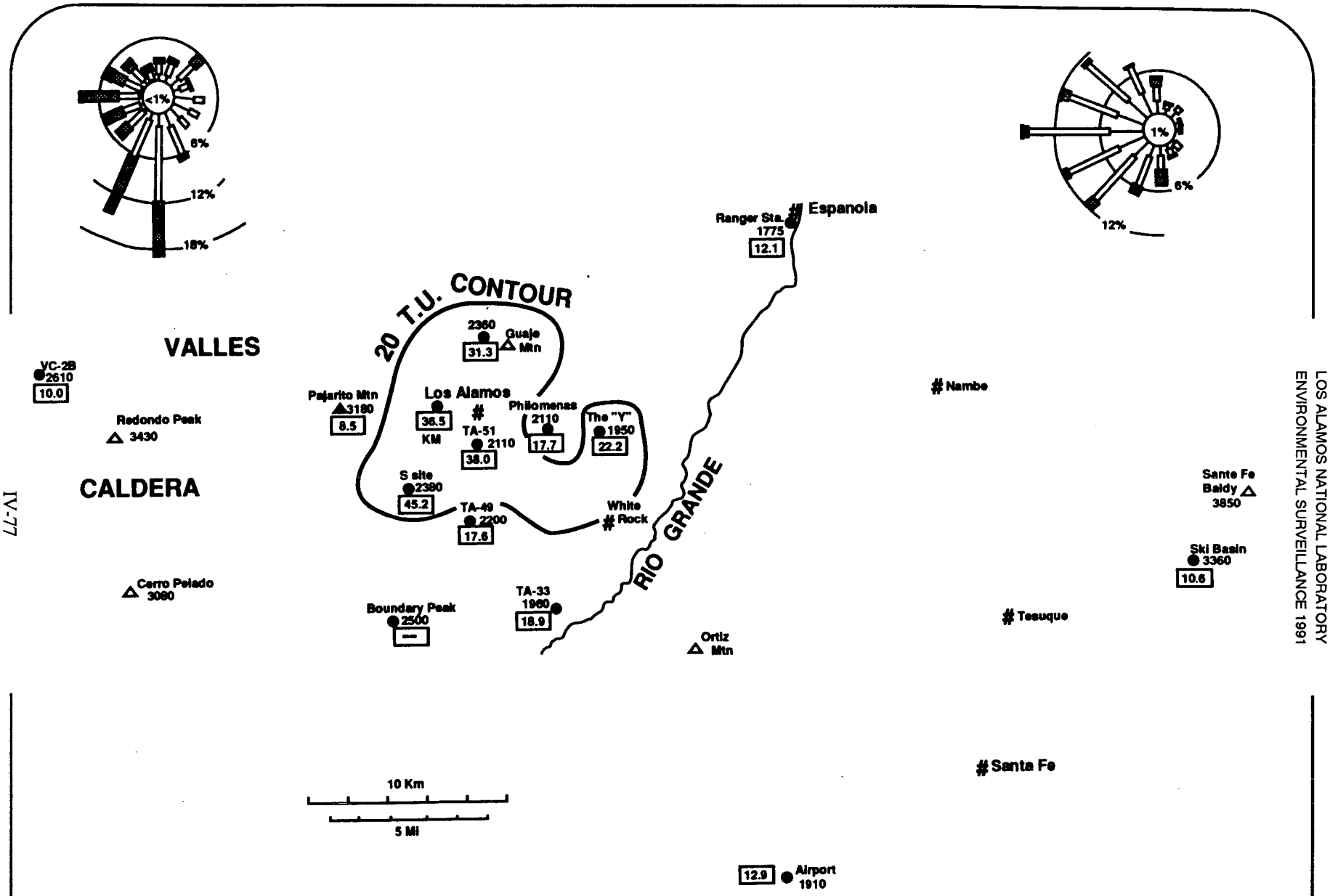


Fig. IV-18. Tritium in rainwater (collected during August 1991 - December 1991).

area within the contour shrinks due to dilution of Laboratory tritium releases by increased rain. The values inside the Laboratory range from 20.4 TU at TA-49 to 36.7 TU at East Gate. The range outside the Laboratory is 9.6 TU at the Santa Fe Ski Basin to 15.8 TU at Pajarito Mountain.

Figure IV-18 shows the results of the August 1991–December 1991 collection period. Inside the Laboratory the range is from 17.6 TU at TA-49 to 45.2 TU at S-Site. Outside the Laboratory the tritium values range from 8.2 TU at VC-2B to 14.6 TU at the Santa Fe Ski Basin.

3. Meteorological Monitoring. (Brent Bowen, Greg Stone, Bill Olsen, and Susan Kreiner)

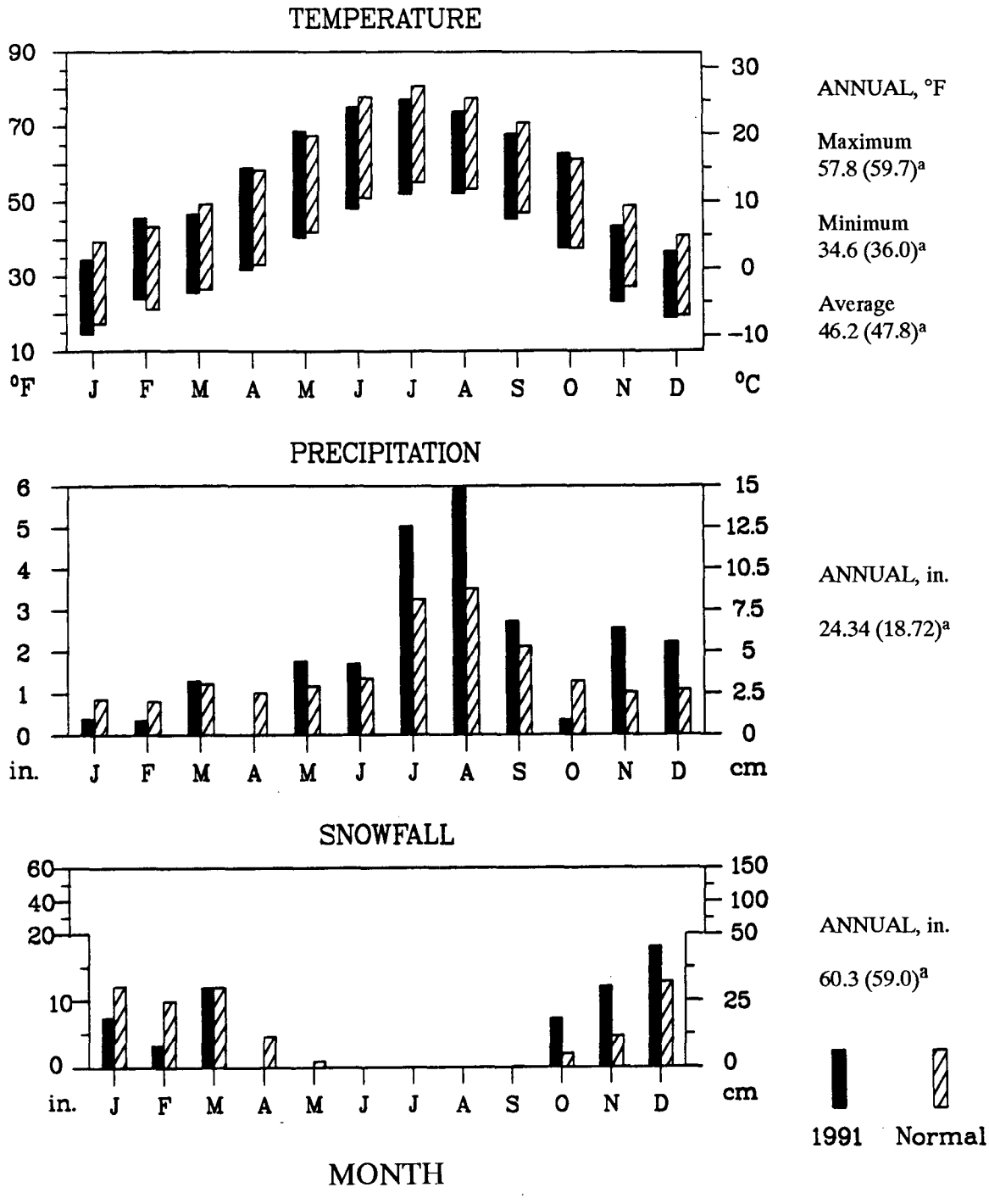
a. Weather Summary. Precipitation was heavy in Los Alamos during 1991, totaling 61.8 cm (24.34 in.), about 30% above normal. Snowfall was near normal at 153 cm (60.3 in.). Temperatures were well below normal; it was the coldest year since 1941. Unusually heavy summer rains caused some local flooding along with record cold temperatures. Unprecedented, early-season Arctic air chilled Los Alamos in late October. Heavy snowfall also fell from late October through December. The annual summary is shown in Fig. IV-19; other data are shown in Tables IV-38 and IV-39 and Tables D-13 and D-14.

The year started with dry weather in January and February. Precipitation was less than half of normal; 1.9 cm (0.73 in.) over the two months. Temperatures were quite cold in January and warm in February. Strong storms caused windier than normal conditions in March. Strong winds with peak gusts exceeding 22 m/s (50 mph) occurred on three days, with the East Gate site recording a 33 m/s (73 mph) gust on the 19th. Dry weather returned in April, with only a trace of precipitation measured during the entire month. It was the sixth April on record to report no measurable precipitation. A peak wind gust of 32 m/s (72 mph) was measured at the East Gate site on the 11th. A small rainfall on May 15 finally broke a consecutive string of 45 days without measurable precipitation.

The summer began with cool weather in June. A strong dust devil on the 18th caused considerable damage to the Los Alamos Catholic Church roof. The monsoon season began in July with heavier than normal rainfall. It was the wettest July since 1968. While official rainfall (TA-6) was over 50% above normal with 12.8 cm (5.03 in.), rainfall was even heavier at other County locations. The East Gate station recorded the greatest rainfall of 17.2 cm (6.76 in.), the second largest amount of precipitation to fall during July in Los Alamos County on record. The frequent rainfall also kept temperatures cool; it was the third coldest July on record.

Heavy thundershowers continued through August, especially at sites near the Jemez Mountains. Official rainfall was even higher in August, totaling 15.1 cm (5.93 in.), 68% above normal. It was the wettest August since 1968. The North Community site recorded 20.3 cm (7.98 in.) for the greatest rainfall in Los Alamos County. It was the highest recorded monthly precipitation to fall in Los Alamos County since the record high of 28.4 cm (11.18 in.) which fell in August of 1952. A thunderstorm on the 2nd caused local flash flooding in the SW Laboratory area with 4.5 cm (1.76 in.) falling at the Bandelier tower site. An even heavier thunderstorm occurred on the 4th, with 6.1 cm (2.40 in.) falling at the North Community rain gauge site, including 3.8 cm (1.50 in.) during a one-hour period. The heavy rains on this day falling on already saturated soil caused Los Alamos County sewer lines to be washed out in Pueblo Canyon. Widespread street and basement flooding also occurred over much of the Los Alamos townsite. More thunderstorms caused additional local flash flooding on the 6th with 4.9 cm (1.91 in.) and 4.1 cm (1.61 in.) falling at the S-Site and North Community sites, respectively. Additional heavy rains fell on the 13th and 19th. The storm on the 19th dropped 2.9 cm (1.15 in.) during a 15-minute period at the TA-6 site. The frequent and heavy rainfall made the summer the coldest on record edging out the previous coldest of 1929.

Cool and wet weather continued in September. The month became the fourth coldest September on record. Dry and mild weather prevailed through most of October. Record high temperatures were set or tied on three days in the middle of the month, including 75°F on the 17th. A record-breaking Arctic air mass descended on New Mexico at the end of the month, along with heavy snow. The low temperature reached 16°F on the 29th, setting a record for the date. The low temperature of 15°F on the 30th not only set a daily record, but also tied the record low for the entire month of October. The high temperature reached only 28°F on that day, setting a record low for the month of



[a]Normals are in parentheses.

Fig IV-19. 1991 weather summary, Los Alamos, NM.

October. Snowfall totaled 7.3 in. during the day, also a record for the date. Temperatures plunged even further, reaching a low of 9°F on the 31st which broke the record low set the previous day. While the month's precipitation was only 0.9 cm (0.35 in.), or 27% of normal, snowfall was more than 3-1/2 times the normal, totaling 18.5 cm (7.3 in.).

The cold, wet, and snowy weather from the end of October continued through much of November. Temperatures averaged 0.7°C (33.3°F) during the month or 2.6°C (4.7°F) below normal. Precipitation was 2-1/2 times the normal, totaling 6.5 cm (2.56 in.). The month became the fourth coldest and fourth wettest November on record. Record low temperatures were set on three of the four days of the month, resulting from the Arctic air mass remaining from the last few days of October. A slow-moving storm produced much of the month's precipitation, 5.1 cm (2.00 in.) on the 14–16th, including 3.5 cm (1.39 in.) on the 15th. The precipitation started out as rain; however, the rain changed to wet snow late on the 15th. Snowfall totaled about 25 cm (10 in.) by noon on the 16th. The weight of the heavy snow on the abundant amount of leaves left on deciduous trees caused wide-spread damage to trees and limbs. The month's snowfall totaled 30.7 cm (12.1 in.), or more than 2-1/2 times normal. The cold, wet, and snowy weather continued through December. Precipitation was more than twice the normal, totaling 5.7 cm (2.23 in.). Snowfall was 40% above normal at 46.0 cm (18.1 in.). Record low temperatures were set or equaled on the first three days of the month. A storm dropped 2.6 cm (1.03 in.) of precipitation on the 11th. Temperatures hovering just above freezing limited snow accumulation to 8.1 cm (3.2 in.). Another storm caused heavy snow of 27.4 cm (10.8 in.) on the 18–19th, with most falling on the 18th forcing an early shutdown of the Laboratory and other local businesses and schools.

b. Precipitation Summary. Precipitation ranged from near normal over the western parts of Los Alamos County to several inches above normal in the northeast and east. Figure IV-20 shows precipitation analyses for the summer monsoon season (July-September) and the entire year. Monthly precipitation totals are also listed in Table IV-38.

Table IV-38. Los Alamos Climatological Summary for 1991

	Temperature (°F)[a]						
	Means			Extremes			
Month	Mean Maximum	Mean Minimum	Average	High	Date	Low	Date
January	34.6	14.7	24.7	45	31	2	22
February	45.8	23.9	34.8	54	21,23	12	19
March	46.9	25.5	36.2	59	24	14	8
April	59.1	31.9	45.5	72	6	19	14
May	68.8	40.6	54.7	78	18	28	1,5
June	75.2	48.3	61.7	88	26	37	1
July	77.2	52.2	64.7	88	7	46	26
August	74.0	52.3	63.2	80	21	48	7
September	68.0	45.5	56.7	78	2	37	23
October	62.9	37.6	50.3	75	11,17	9	31
November	43.4	23.2	33.3	59	6	9	1
December	36.6	18.8	27.7	46	6,8, 9,16	5	1,2
Annual	57.8	34.6	46.2	88	6/27,7/7	2	1/22

Table IV-38. (Cont.)

Month	Precipitation (in.)[a] Water Equivalent Total	Water Equivalent Daily Maximum	Water Equivalent Date	Snow Total	Snow Daily Maximum	Snow Date	Number of Days Precip. ≥0.10 in.	Max. Temp. ≥90°F	Min. Temp. ≤32°F
January	0.39	0.21	21	7.5	5.2	21	2	0	31
February	0.34	0.20	18	3.3	2.8	18	2	0	28
March	1.30	0.37	1	12.0	4.5	16	5	0	28
April	0.00	0.00	—	0.0	0.0	—	0	0	14
May	1.77	0.97	20	0.0	0.0	—	3	0	4
June	1.71	1.00	11	0.0	0.0	—	5	0	0
July	5.03	1.52	22	0.0	0.0	—	9	0	0
August	5.93	1.20	19	0.0	0.0	—	12	0	0
September	2.73	0.71	6	0.0	0.0	—	8	0	0
October	0.35	0.33	30	7.3	7.3	30	1	0	5
November	2.56	1.39	15	12.1	6.0	16	4	0	27
December	2.23	1.03	11	18.1	8.8	18	5	0	31
Annual	24.34	1.52	7/22	60.3	8.8	12/18	56	0	168

[a]Metric conversions: 1 in. = 2.5 cm; °F = 9/5 °C + 32.

Table IV-39. Los Alamos Precipitation for 1991[a]
(in.)

	North Community (Site 1)	S-Site (Site 2)	TA-6 (Site 3)	Bandelier (Site 4)	East Gate (Site 5)	TA-54 (Area G) (Site 6)	White Rock Y (Site 7)	White Rock (Site 8)
January	0.36	0.35	0.39	0.42	0.19	0.13	0.12	0.18
February	0.34	0.51	0.34	0.54	0.21	0.27	0.27	0.56
March	1.72	1.55	1.30	1.11	0.97	0.95	1.04	1.01
April	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.02
May	2.18	2.07	1.77	1.88	1.62	1.61	1.15	1.79
June	1.34	1.61	1.71	1.98	1.25	1.09	0.96	1.66
July	4.91	5.25	5.03	5.09	6.76	4.14	5.88	4.54
August	7.89	5.10	5.93	6.57	2.70	3.44	2.90	2.53
September	2.83	4.42	2.73	2.66	2.26	2.46	1.64	1.83
October	0.57	0.42	0.35	0.27	0.23	0.20	0.28	0.58
November	3.04	3.29	2.56	2.54	2.26	2.13	2.29	2.20
December	2.19	2.27	2.23	2.17	1.75	1.68	1.55	1.75
Annual	27.38	26.85	24.34	25.23	20.20	18.11	18.08	18.65

[a]Metric conversion: 1 in. = 2.5 cm. See Fig. IV-20 for site locations.

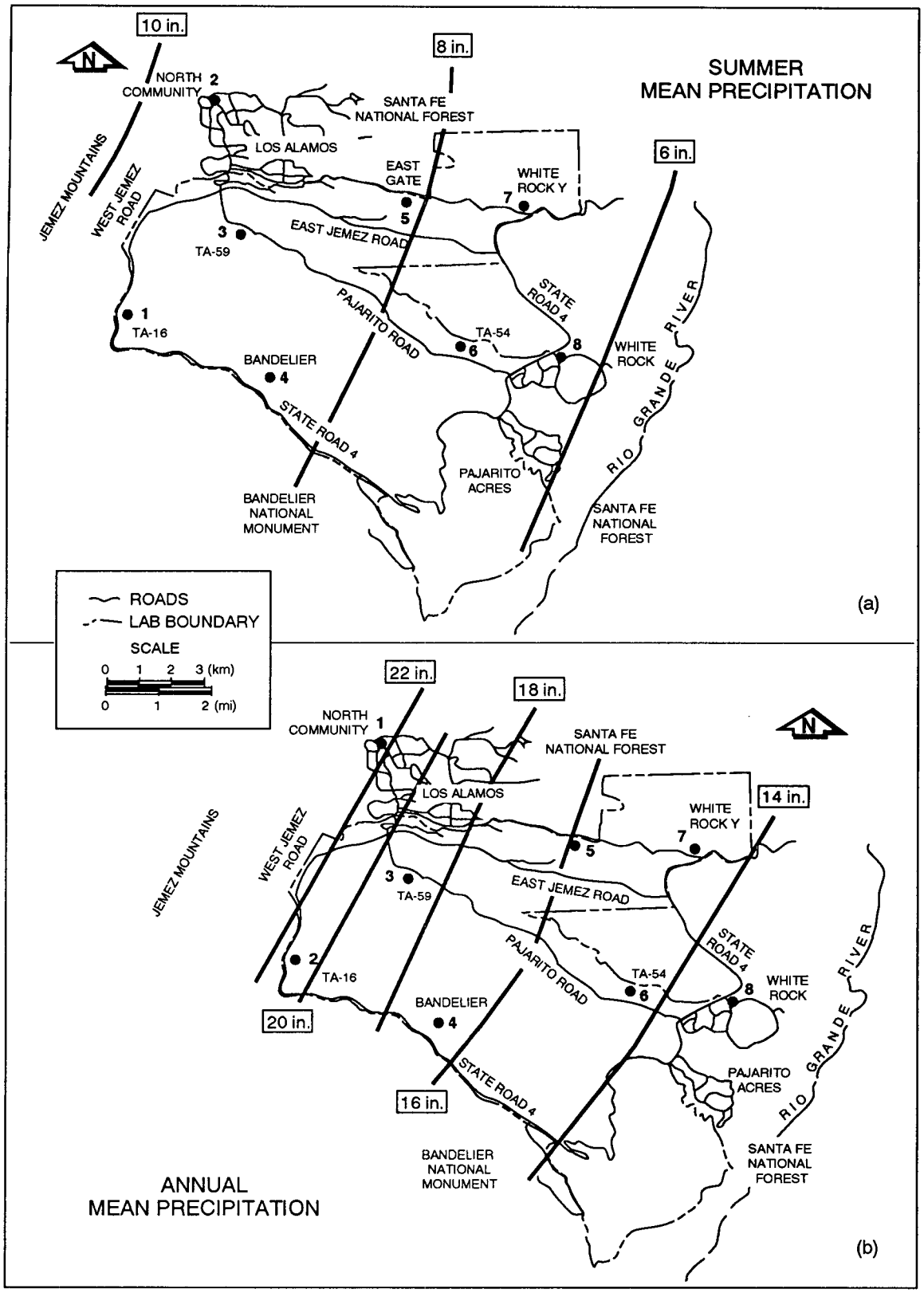


Fig. IV-20. (a) Summer monsoon (July - September) mean precipitation and (b) annual mean precipitation at Los Alamos. Isolines of precipitation are based on the eight sites shown on the maps.

Precipitation is generally greatest over and near the Jemez Mountains and decreases east-southeastward over Los Alamos County toward the Rio Grande Valley. Typically, nearly half of the annual precipitation falls during the monsoon season. The combination of a large-scale moist wind flow from the tropical Pacific Ocean and Gulf of Mexico into New Mexico, strong sunshine, warm temperatures, and elevated terrain are responsible for frequent afternoon and early evening showers and thundershowers. Monsoon rainfall was especially heavy during 1991, with rainfall ranging from 50% above normal in western locations to nearly 100% above normal at eastern locations. Precipitation also averaged above-normal during the other months, resulting in annual precipitation exceeding normal by 30-40% across the County.

4. Environmental Monitoring at the Fenton Hill Site. (Alan Stoker, Steve McLin, Max Maes, and William Purtymun).

The Laboratory operates a program to evaluate the feasibility of extracting thermal energy from the hot dry rock geothermal reservoir at the Fenton Hill Geothermal Site (TA-57), which is located about 45 km (28 mi) west of Los Alamos on the southern edge of the Valles Caldera. The hot dry rock energy concept involves drilling two deep holes, connecting these holes by hydraulic fracturing, and bringing geothermal energy to the surface by circulating water through the system. Environmental monitoring is performed adjacent to the site to assess any impacts from the geothermal operations.

The chemical quality of surface water and groundwaters in the vicinity of TA-57 (Fig. IV-21) has been monitored for use in geohydrologic and environmental studies. These water quality studies began before the construction and testing of the hot dry rock system (Purtymun 1974d).

Water samples for Fenton Hill monitoring have routinely been collected during periods of base flow (low surface water discharge) in late November or early December; in 1991 the samples were collected on December 9. The results of the general chemical parameter analyses are presented in Table IV-40, and the results of trace metal analyses and uranium tests are presented in Table IV-41. Slight variations were found in the chemical quality of surface waters and groundwaters among the individual stations when the analyses were compared with those from previous years; however, these variations are within typical seasonal fluctuations observed in the past (Purtymun 1988a). There were no significant changes in the chemical quality of surface water and groundwater at the individual stations from previous years (Purtymun 1988a).

5. Environmental Studies at the Pueblo de San Ildefonso. (Alan Stoker, Max Maes, and John Sorrell [Bureau of Indian Affairs])

To document the potential impacts of Laboratory operations on lands belonging to San Ildefonso Pueblo, the DOE entered into a memorandum of understanding (MOU) with the Pueblo and the Bureau of Indian Affairs (BIA) to conduct environmental sampling on Pueblo land. The agreement, entitled "Memorandum of Understanding Among the Bureau of Indian Affairs, the Department of Energy, and the Pueblo of San Ildefonso Regarding Testing for Radioactive and Chemical Contamination of Lands and Natural Resources Belonging to the Pueblo of San Ildefonso," No. DE-GM32-87AL37160, was concluded in June 1987. The agreement calls for both hydrologic pathway sampling (including water, soils, and sediments) and foodstuff sampling. This section deals with the hydrologic pathway. The foodstuff sampling is covered in Section IV.G of this report. During 1987, 1988, and 1989, water, soil, and sediment samples were collected in accord with the agreement (Purtymun 1988b, ESG 1989, EPG 1990).

In 1991, the formal sampling plan (Appendix A to the MOU) called for the Laboratory to collect and analyze special water samples from two stations east and two stations west of the Rio Grande (West: Station 3, Pajarito Well [both pumps]; Station 8, Halladay Well; East: Station 17 [new], Don Juan Playhouse Well; and Station 9 Eastside Artesian Well). Special sediment samples were to be collected from four locations on San Ildefonso lands in Mortandad Canyon, designated A-6, A-7, A-8, and A-10 on Fig. IV-22. Because of scheduling conflicts and postponements caused by weather, these samples were collected by Laboratory personnel on February 5, 1992, in the company of personnel from the San Ildefonso Pueblo Governor's Office and the BIA. Because of pump problems, it was not possible to sample the Pajarito Well, Pump 2, and instead, a sample was collected from the Westside Artesian Well (Station 10). The plan also specifies

collection and analysis of 9 other water samples and 11 other sediment samples that have long been included in the routine environmental sampling program, as well as special sampling of storm runoff in Los Alamos Canyon, as part of the Laboratory's routine monitoring. These locations are identified in Table IV-42 to permit cross-referencing to other sections of this report. Instead of storm runoff sampling this year, a special sampling of runoff fed by treated effluent from the Los Alamos County sewage treatment plant was conducted. Results and interpretation of this sampling are described in Section IV.E of this report.

a. Groundwater. Radiochemical analyses in 1991 of groundwater from Stations 3, 8, and 9 indicated no significant change from the analyses that were performed on wells at those locations in 1990 (Table IV-43) for all radioactive constituents except ^{137}Cs. The ^{137}Cs measurements were lower for all the

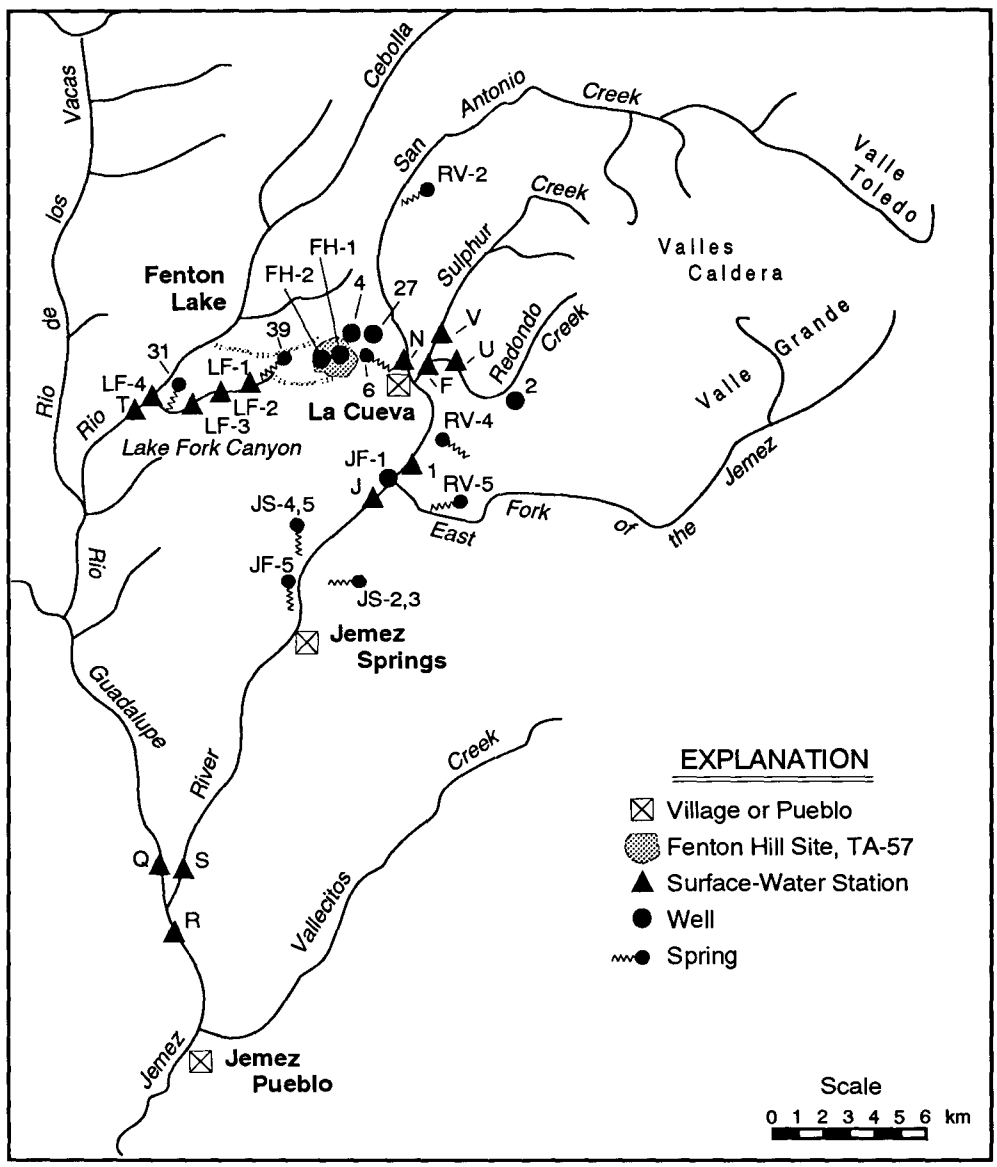


Fig. IV-21. Sampling stations for surface water and groundwater near the Fenton Hill Site (TA-57). (Map denotes general locations only.)

Table IV-40. Analyses of Surface Water and Groundwater Quality, Fenton Hill, December 9, 1991 (mg/L)

Station Location		SiO_2	Ca	Mg	K	Na	Cl	F	CO_3	HCO_3	PO_4-P	SO_4	NO_3-N	Cn	TDS[a]	Total Hardness	PH[b]	Specific Conductance µmho/cm
Surface Water																		
J	Jemez at Gage	54	13	2.5	2.0	3	4	0.7	<5	51	0.2	10	0.1	<0.01	28	42	7.9	117
N	San Antonio	38	13	2.1	2.0	12	2	0.9	<5	51	0.2	7	<0.04	<0.01	06	42	7.8	183
Q	Rio Guadalupe	25	50	5.1	1.0	11	5	0.4	<5	120	0.1	5	<0.04	<0.01	198	146	8.3	296
S	Jemez River	51	35	4.4	9.0	60	57	0.8	<5	114	0.2	68	3.2	<0.01	352	106	7.3	171
LF-1	LakeFork-1	29	29	3.9	3.0	8	3	0.4	<5	29	1.8	10	2.3	<0.01	92	88	6.2	77
LF-2	LakeFork-2	37	22	3.7	4.0	12	3	0.7	<5	13	0.2	32	0.5	<0.01	180	70	5.9	182
LF-3	LakeFork-3	66	13	2.0	2.0	12	3	1.0	<5	48	0.2	3	0.3	<0.01	86	42	7.5	112
LF-4	LakeFork-4	52	16	2.6	3.0	13	3	1.0	<5	72	0.2	4	0.1	<0.01	154	52	7.8	143
Groundwaters																		
JS-4,5	Jemez Village (spring)	86	29	4.9	4.0	50	25	1.0	<5	165	0.3	10	0.2	<0.01	290	93	7.9	399
FH-1	Fenton Hill Well	77	90	9.4	6.0	22	9	<0.2	<5	215	0.3	9	0.3	<0.01	346	264	7.8	612
JF-1	Jemez Canyon (hot spring)	49	73	18.8	50.0	468	807	1.9	<5	650	0.2	33	0.3	<0.01	1900	509	7.5	2770
JF-5	Soda Dam (hot spring)	49	29	22.6	150.0	1000	1870	2.3	<5	688	0.2	34	<0.04	<0.01	2	914	6.6	5506
Loc.4	Hofheins (well)	91	10	2.5	2.0	17	3	0.2	<5	57	0.4	3	0.3	<0.01	162	36	7.8	87
Loc.5	La Cueva (well)	77	27	6.5	3.0	18	4	0.4	<5	42	1.2	54	0.5	<0.01	182	96	6.3	233
Rv-4	Spence Spring	55	6	1.6	1.0	50	8	0.7	<5	83	0.3	28	5.6	<0.01	160	21	7.3	282
Loc.3	Cold Spring	54	20	2.7	4.0	12	3	0.9	<5	61	0.2	4	0.3	<0.01	78	61	8.0	126
Loc.39	Lf Tank	24	15	2.8	3.0	6	2	<0.2	<5	47	0.1	15	0.2	<0.01	20	50	6.7	103

[a]Total Dissolved Solids
[b]Standard Units

Table IV-41. Trace Metals in Surface Waters and Groundwaters, Fenton Hill, December 9, 1991 (mg/L)

		Ag	Al	As	B	Be	Cd	Cr	Co	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
Surface Water																							
J	Jemez River	<0.0005[a]	0.466	0.002	0.026	<0.0005	0.0101	<0.0005	<0.0005	0.003	0.410	<0.0001	0.008	0.007	<0.003	N/A	<0.0005	<0.03	<0.02	0.067	<0.0005	0.003	0.007
N	San Antonio	<0.0005	0.310	0.002	0.027	<0.0005	0.0005	<0.001	<0.0005	0.003	0.375	<0.0001	0.009	0.004	<0.003	N/A	0.001	<0.03	<0.02	0.062	<0.0005	0.003	0.010
Q	Rio Guadalupe	<0.0005	0.180	0.001	0.037	<0.0005	<0.0005	<0.0005	<0.0005	0.002	0.224	<0.0001	0.008	0.001	0.003	N/A	<0.0005	0.040	<0.02	0.179	<0.0005	0.001	0.003
S	Jemez River	<0.0005	0.390	0.058	0.656	<0.0005	<0.0005	<0.0005	<0.0005	0.002	0.390	<0.0001	0.015	0.005	0.004	N/A	0.0008	0.030	<0.02	0.155	<0.0005	0.006	0.010
LF-1	Lake Fork-1	<0.0005	5.690	0.010	0.052	0.0030	<0.0005	0.0144	0.0200	0.032	81.000	<0.0001	1.660	0.006	0.014	N/A	<0.0005	0.180	<0.02	0.186	<0.0005	0.037	0.274
LF-2	Lake Fork-2	<0.0005	0.090	<0.0005	0.018	<0.0005	<0.0005	<0.0005	0.0006	0.001	5.200	<0.0001	0.085	0.001	0.003	N/A	<0.0005	0.030	<0.02	0.095	<0.0005	0.001	0.008
LF-3	Lake Fork-3	<0.0005	<0.030	0.002	0.016	<0.0005	<0.0005	<0.0005	0.0010	0.002	0.040	<0.0001	0.002	0.002	<0.003	N/A	<0.0005	0.030	<0.02	0.061	<0.0005	0.001	0.011
LF-4	Lake Fork-4	<0.0005	0.120	0.003	0.018	<0.0005	<0.0005	0.0007	0.0010	0.003	0.250	<0.0001	0.004	0.003	<0.003	N/A	<0.0005	0.030	<0.02	0.081	<0.0005	0.001	0.007
Groundwater																							
JS-4,5	Jemez Village (spring)	<0.0005	<0.030	0.017	0.226	<0.0005	0.0011	<0.0005	<0.0005	0.006	0.010	<0.0001	0.001	0.026	<0.003	N/A	0.001	<0.03	<0.02	0.184	<0.0005	0.007	0.216
FH-1	Fenton Hill (well)	<0.0005	<0.030	0.002	0.772	<0.0005	<0.0005	0.0014	0.0010	0.006	0.200	<0.0001	0.033	0.001	0.053	N/A	<0.0005	0.050	<0.02	0.317	<0.0005	0.004	1.250
JF-1	Jemez Canyon (hot spring)	<0.0005	<0.030	<0.0005	5.480	<0.0005	<0.0005	0.0024	<0.0005	<0.001	0.161	<0.0001	<0.003	<0.0005	<0.005	N/A	0.001	0.140	<0.02	0.002	0.0015	0.003	<0.005
JF-5	Soda Dam (hot spring)	<0.0005	<0.030	1.840	13.300	<0.0005	0.0006	0.0028	0.0008	0.022	0.090	<0.0001	0.634	<0.0005	0.008	N/A	0.001	0.270	0.040	1.500	0.0015	0.036	0.013
Loc.4	LaCueva (well)	<0.0005	0.040	0.002	0.015	<0.0005	<0.0005	<0.0005	<0.0005	0.002	0.035	<0.0001	0.001	0.003	<0.003	N/A	<0.0005	0.040	<0.02	0.063	<0.0005	0.004	0.050
Loc. 5	La Cueva (well)	<0.0005	1.090	0.001	0.031	<0.0005	<0.0005	0.0041	0.0010	0.007	7.430	<0.0001	0.054	0.002	<0.003	N/A	<0.0005	0.040	<0.02	0.112	<0.0005	0.013	0.039
RV-4	Spence Spring	<0.0005	0.040	0.049	0.110	< 0.0005	<0.0005	<0.0005	0.0010	0.001	<0.003	<0.0001	<0.001	0.054	<0.003	N/A	<0.0005	<0.03	<0.02	0.028	<0.0005	0.003	0.005
Loc.3	Cold Springs	<0.0005	1.220	0.004	0.023	<0.0005	0.0021	<0.0005	<0.0005	0.005	2.200	<0.0001	0.024	0.001	<0.003	N/A	<0.0005	0.040	<0.02	0.076	<0.0005	0.001	0.007
Loc. 39	LF Tank	<0.0005	0.050	0.004	0.017	<0.0005	<0.0005	<0.0005	<0.0005	0.001	0.035	<0.0001	<0.001	0.001	<0.003	N/A	<0.0005	0.050	<0.02	0.080	<0.0005	0.001	0.003

[a] Less than symbol (<) means measurement was below the specified detection limit of the analytical method.

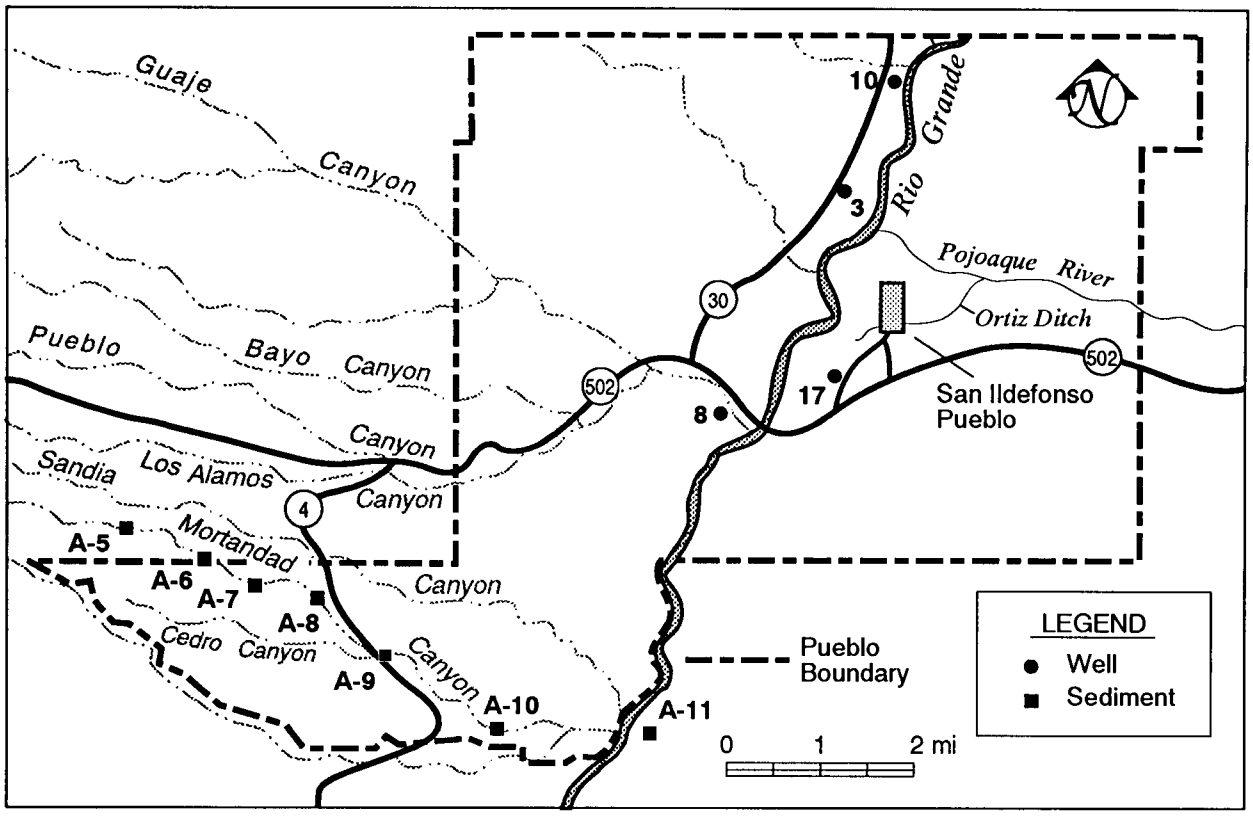


Fig. IV-22. Groundwater and sediment stations on Pueblo de San Ildefonso land. (Map denotes general locations only; see Table IV-42 for cross-referencing to specific locations.)

1991 samples, with two measurements (Stations 8 and 17) above the limit of detection by a factor of about 2, but the uncertainty in those measurements is quite high because of analytical background. It is unlikely that there is any significant cesium present. None of the measured values exceed the DOE DCG.

The maximum gross alpha activity in water was for Station 10 with 17 pCi/L. As detailed in Purtymun 1988b, the gross alpha activity in this area is due to natural uranium and not radium. The activity attributable to uranium (21.8 μg/L is equivalent to about 15 pCi/L) more than accounts for the gross alpha activity. The same pattern is true for the other wells, with natural uranium accounting for the gross alpha activity. Thus, the NMED drinking water gross alpha screening level of 5 pCi/L for radium (used for comparison only), which excludes activity from radon and uranium, is not exceeded by any of the samples. The Station 3 well showed a similar, relatively high concentration of uranium when previously sampled (Purtymun 1988b). The plutonium measurements were all below the limits of detection.

The chemical quality of the groundwater is consistent with previous observations except that standards were exceeded, as expected, for waters with such high natural dissolved solids (Table IV-44). Initial analyses of the samples showed the cadmium and lead standards were exceeded at Station 3, but analytical laboratory quality control data indicated the values were not reliable and probably high by a factor of 2 to 3. Subsequent reanalysis showed all cadmium and lead measurements to be less than the analytical detection limits. The chloride standard was exceeded slightly at Station 3 and by about a factor of 2 at Station 10. The total dissolved solids standard (500 mg/L) was exceeded, with a concentration of 1,042 mg/L at

Table IV-42. Locations on San Ildefonso Lands for Water and Sediment Sampling Included in Routine Monitoring Program

Station Identification	Map Designation	See this Table for Results
Water Sampling Locations		
Rio Grande		
Otowi	Fig. IV-6, No. 3	IV-17, -18, -19
Springs in Los Alamos Canyon		
Basalt Spring	Fig. VII-1, No. 56	VII-1, -2, -3
Indian Spring	Fig. VII-1, No. 12	VII-1, -2, -3
Spring in Canyon North of Los Alamos Canyon		
Sacred Spring	Fig. VII-1, No. 11	VII-1, -2, -3
Spring in Sandia Canyon		
Sandia Spring	Fig. VII-1, No. 13	VII-1, -2, -3
Springs in White Rock Canyon		
La Mesita Spring	Fig. VII-1, No. 10	VII-1, -2, -3
Spring 1	Fig. VII-1, No. 32	VII-1, -2, -3
Spring 2	Fig. VII-1, No. 33	VII-1, -2, -3
Sanitary Effluent Flow in Mortandad Canyon		
Mortandad at Rio Grande	Fig. VII-6, No. 38	IV-17, 18, 19
Sediment Sampling Locations		
Guaje at SR-502	Fig. IV-9, No. 12	IV-20, IV-23
Bayo at SR-502	Fig. IV-9, No. 13	IV-20, IV-23
Los Alamos Canyon		
Los Alamos at SR-4	Fig. IV-9, No. 35	IV-20, IV-23
Los Alamos at Totavi[a]	Fig. IV-9, No. 36	IV-20, IV-23
Los Alamos at LA-2[a]	Fig. IV-9, No. 37	IV-20, IV-23
Los Alamos at Otowi	Fig. IV-9, No. 38	IV-20, IV-23
Sandia Canyon		
Sandia at SR-4	Fig. IV-9, No. 38	IV-20, IV-23
Sandia at Rio Grande	Fig. IV-9, SANDIA	IV-20, IV-23
Mortandad Canyon		
Mortandad at MCO-13	Fig. IV-9, No. 45 and Fig. IV-22, A-5	IV-20, IV-23
Mortandad at SR-4	Fig. IV-9, No. 15 and Fig. IV-22, A-9	IV-20, IV-23
Mortandad at Rio Grande	Fig. IV-9, MORTANDAD	IV-20, IV-23

[a]Not required by MOU but routinely sampled and reported.

Table IV-43. Radiochemical Quality of Groundwater from Wells, Pueblo de San Ildefonso

Station Number and Well Identification	H^3 (nCi/L)	^{137}Cs (pCi/L)	Total Uranium (µg/L)	^{238}Pu (pCi/L)	$^{239,240}Pu$ (pCi/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)
3. Pajarito Well (pump 1)	0.3 (0.3)[a]	35 (43)	24 (5)	0.000 (0.010)	0.000 (0.010)	13.0 (4.0)	3.2 (5.0)
8. Halladay Well	0.5 (0.3)	80 (44)	22 (4)	0.004 (0.005)	0.000 (0.010)	1.2. (0.6)	1.2 (0.4)
9. Eastside Artesian Well	0.7 (0.3)	19 (47)	20 (4)	0.014 (0.014)	0.009 (0.013)	1.5. (0.9)	1.2 (0.4)
10. Westside Artesian Well	0.4 (0.3)	32 (47)	33 (6)	0.008 (0.012)	0.000 (0.010)	17.0 (4.0)	0.8 (0.3)
17. Don Juan Playhouse Well	–0.2 (0.3)	90 (48)	27 (5)	0.005 (0.016)	0.005 (0.005)	7.0 (2.0)	2.0 (0.4)
Summary							
Maximum concentration	0.7	90	33	0.014	0.009	17.0	3.2
Standard[b]	20[b]	120[c]	30[c]	1.6[c]	1.2[c]	15[b]	50[b]
Maximum as a percentage of standard	3.5	75	110	0.9	<0.1	113	6.4
Limits of detection	0.7	40	1	0.1	0.1	3	3

[a]Radioactivity counting uncertainties (±1 standard deviation) are shown in parentheses.

[b]Maximum contaminant level-MCL, used for comparison only (NMEIB 1991, EPA 1989b).

[c]Derived concentration guide applicable to DOE drinking water systems – used for comparison only (see Appendix A).

Table IV-44. Chemical Quality of Groundwater from Wells, Pueblo de San Ildefonso (mg/L)[a]

	Standard[b,c]	Station 3 Pajarito Well (pump 1)	Station 8 Halladay Well	Station 9 Eastside Artesian Well	Station 10 Westside Artesian Well	Station 17 Don Juan Playhouse Well	Summary: Maximum Concen-tration	Summary: Maximum Concentration as a Percentage of Standard
Chemical Constituents								
Primary[b]								
Ag	0.05	0.007	<0.005	<0.005	<0.005	<0.005	<0.007	14
As	0.05	0.005	0.006	<0.002	0.006	0.005	0.006	12
Ba	1.0	0.103	0.04	0.016	0.037	<0.005	0.103	10
Cd	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<10
Cr	0.05	<0.005	0.01	<0.005	<0.005	0.012	0.012	24
F	4.0	0.5	0.6	0.88	5.6	0.65	5.6	140
Hg	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<50
NO_3-N	10	0.1	0.5	<0.04	<0.1	1.8	1.8	18
Pb	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<2
Se	0.01	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<20
Secondary[c]								
Cl	250	268	4.4	4.1	446	3.8	446	178
Cu	1.0	0.008	<0.003	0.005	<0.005	<0.005	0.008	<1
Fe	0.3	0.2	0.1	0.1	0.3	<0.1	0.3	100
Mn	0.05	<0.005	0.002	0.01	0.010	<0.005	0.01	20
SO_4	250	52	12	11	82	14	82	33
Zn	5.0	0.036	0.013	0.023	<0.005	0.011	0.036	<1
TDS[d]	500	1,042	164	280	1,186	236	1,186	237

Table IV-44. (Cont.)

	Standard[b,c]	Station 3 Pajarito Wells (pump 1)	Station 8 Halladay Well	Station 9 Eastside Artesian Well	Station 10 Westside Artesian Well	Station 17 Don Juan Playhouse Well	Summary: Maximum Concen-tration	Summary: Maximum Concentration as a Percentage of Standard
Miscellaneous								
SiO_2	—	40	30	<5	26	27	40	—
Be	—	0.017	0.009	<0.005	<0.005	<0.005	0.017	—
Ca	—	69	4.8	2.8	15	7.2	69	—
Mg	—	6.5	0.4	0.2	0.9	0.5	6.5	—
K	—	3.9	1.4	1.2	1.9	1.4	3.9	—
Na	—	354	44	89	410	69	410	—
CO_3	—	<5	<5	34	<5	<5	34	—
HCO_3	—	553	84	185	329	137	553	—
PO_4-P	—	0.13	<0.1	<0.1	<0.1	<0.1	0.13	—
Total hardness	—	200	20	8	41	12	200	
Conductivity (μmho/cm)	—	1,436	173	385	1,540	313	1,540	—
pH (standard units)	6.8-8.5	7.3	9.1	9.7	8.1	8.9	9.7	114

[a]Units are milligrams per liter, except as noted for conductivity and pH.

[b]Maximum contaminant level for primary constituents, applicable to drinking water system, given here for camparison only, see Appendix A.

[c]New Mexico Water Quality Standards applicable to streams for designated uses, given here for comparison only, see Appendix A.

[d]Total dissolved solids.

Station 3 and 1,186 mg/L at Station 10. Other chemical constituents in water from Stations 3 and 10 and from the other three stations were at or below the standards. All these constituents are naturally occurring, and the levels are within ranges expected for the area.

Station 9 showed some significant differences in chemical quality because of recompletion of the well during 1991 by the BIA. The well was lined with new screen and casing with pressure grouting restricting the producing zone to between 115–206 m (380–680 ft) below surface to prevent uncontrolled artesian flow that had been occurring for years. Major decreases in the levels of chloride (165 in 1990, 4 this year) and silica (27 in 1990, less than 5 this year) and increases in total dissolved solids (184 in 1990, 280 this year) were noted. The chemical analyses agreed well with measurements made by the BIA immediately following the reconstruction of the well.

Special sampling and analyses were conducted during 1989 at Station 3, known as the Pajarito Wells site, to investigate what appeared to be anomalous changes in the chemical quality of water that were noted between samples collected in 1987 and those collected in 1988 (ESG 1989). This sampling determined that the difference in quality is natural and is attributable to the different location and depth of the two separate wells operated at alternate times by a controller, with no indication of a contamination problem (EPG 1990). Samples collected for 1991 from Pump 1 indicated the quality of water was within the range of values found previously.

b. Sediments. The industrial waste treatment plant at TA-50 releases treated effluent into the upper reaches of Mortandad Canyon. The effluent, containing traces of radionuclides and other chemicals, infiltrates into the underlying alluvium, forming an aquifer of limited extent perched on the underlying tuff in the upper- and midreaches of the canyon within Laboratory boundaries. A large proportion of the radionuclides in the effluent when it is first released as surface flow is adsorbed or attached to the sediments in the stream channel; thus, the principal means of transport is in surface runoff. Mortandad Canyon heads on the Pajarito Plateau at TA-3 and has a small drainage area. The alluvium thickens in the middle and lower reaches of the canyon. The small drainage area and the thick section of unsaturated alluvium in the middle reach of the canyon have retained all the runoff since 1960 when hydrologic studies began in the canyon.

During 1991, Mortandad Canyon sediments were collected and analyzed for radionuclides from seven sediment stations, one west of the Laboratory and Pueblo boundary and six within the Pueblo (Fig. IV-22). The analytical results for samples from the stations were compared with results from regional soil and sediment samples collected over many years to establish background levels for northern New Mexico (Purtymun 1987a).

Plutonium concentrations in Mortandad Canyon sediment samples taken in 1991 at and east of the Laboratory boundary to State Road 4 were near the upper end of the statistical range attributable to worldwide fallout in northern New Mexico (Table IV-45). The highest value for ^{239}Pu in 1991 was obtained at Station A-6 (on San Ildefonso property adjacent to the boundary with the Pueblo) and was slightly above the statistically derived comparison value for fallout. The levels are consistent with the range of values obtained during the last several years and do not indicate any apparent change in general conditions. In 1989 and 1990 both A-6 and A-7 had levels exceeding the statistical background limit. Samples from Station A-9 (at State Road 4) and further east had even lower levels.

The measurements are consistent with observation of the physical appearance of the stream channel at the time of collection, which gave no indication of any water runoff or transport of sediments across the Laboratory boundary. Observations during the thunderstorm season noted that no runoff from the contaminated portion of Mortandad Canyon extended near the Laboratory boundary (see related discussion in Section IV.E.5). No runoff has been observed to reach the Laboratory boundary in Mortandad Canyon since 1960 when the USGS initiated special studies there. For samples dominated by worldwide fallout at these low levels, considerable variability is expected because of different particle-size distributions in grab samples (Purtymun 1990b). Samples with a large percentage of small particles typically exhibit higher mass concentrations of plutonium because of their high adsorption capacity. The sediments in this part of Mortandad Canyon are more like soils because there has been no runoff to separate out silt and clay-size particles that typically show higher concentrations of plutonium.

Table IV-45. Radiochemical Analyses of Sediments from Mortandad Canyon

Station	Location	H^3 (nCi/L)[a]	^{137}Cs (pCi/g)	Total Uranium (µg/g)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)	Gross Gamma (counts/min/g)	^{90}Sr (pCi/g)
Sediments[b]								
(MCO-13) A-5	Laboratory	N/A[c]	0.60 (0.13)[d]	1.9 (0.2)	0.003 (0.001)	0.025 (0.002)	2.6 (0.5)	0.2(0.2)
A-6	San Ildefonso	0.5 (0.3)	1.13 (0.21)	2.5 (0.2)	0.002 (0.001)	0.031 (0.003)	1.7 (0.4)	0.5(0.2)
A-7	San Ildefonso	0.4 (0.3)	0.18 (0.06)	5.4 (0.5)	0.002 (0.001)	0.020 (0.002)	3.8 (0.5)	0.3(0.1)
A-8	San Ildefonso	0.0 (0.3)	0.29 (0.09)	3.2 (0.3)	0.001 (0.001)	0.023 (0.002)	2.3 (0.5)	0.2(0.2)
A-9	San Ildefonso	N/A	–0.07 (0.09)	1.0 (0.1)	0.005 (0.004)	0.002 (0.001)	1.3 (0.4)	0.2(0.2)
A-10	San Ildefonso	0.6 (0.3)	0.22 (0.10)	2.3 (0.2)	0.006 (0.001)	0.003 (0.001)	1.6 (0.4)	0.0(0.2)
A-11	San Ildefonso	–0.4 (0.3)	0.10 (0.10)	2.8 (0.3)	0.008 (0.002)	0.001 (0.001)	1.8 (0.4)	0.3(0.2)
Background[e]								
Sediments (1974–1986)		—	0.44	4.4	0.006	0.023	7.9	0.87
Soils (1974–1986)		7.2	1.09	3.4	0.005	0.025	6.6	0.88

[a]Tritium as tritiated water in moisture distilled from sample.

[b]Samples in Mortandad Canyon were collected from Stations A-6, A-7, A-8, and A-10 in February 1992; A-5 in June 1991; A-9 at State Road 4 in July 1991; and A-11 at the Rio Grande in October 1991.

[c]N/A means analysis not performed.

[d]Radioactivity counting uncertainities (±1 standard deviation) are in parentheses.

[e]Average plus 2 standard deviations of measurements in regional samples 1974-1986 (Purtymun 1987a).

Cesium concentrations from samples at Stations A-5, A-6, and A-7 showed minor differences from previous results. The level at A-5 was lower (by about a factor of 3), at A-6 higher (about the same as seen in 1989), and at A-7 lower (by a factor of about 2). The values overlapped the range of the statistical background comparison values for regional soils and sediments (0.44 to 1.09 pCi/g [Purtymun 1987a]).

c. Monitoring Well. A monitoring well (SIMO-1) was installed in Mortandad Canyon just east of sediment sampling station A-6 on San Ildefonso land in 1990 by BIA and Laboratory personnel under the general terms of the MOU (EPG 1992). The purpose of the monitoring well was to confirm the absence of any perched water in the alluvium of Mortandad Canyon.

No evidence of perched water was found, confirming previous inferences that no water could be moving from the Laboratory onto San Ildefonso beneath the surface. Even though the hole penetrated no saturated zones, it was completed by installing a polyvinyl chloride casing with screened sections located in two intervals that would be geologically likely locations for water to accumulate. When inspected in February 1992, the well was found to be dry.

The radiochemical analyses of the cores showed no evidence of any contaminants from the Laboratory (Tables D-15 and D-16). The plutonium measurements were all at or below detection limits. Tritium in water vapor extracted from the cores from the surface down to 4.27 m (14 ft) was all at levels within the range attributable to background expected in northern New Mexico soils (Purtymun 1987a); below 4.27 m (14 ft) the tritium measurements were all below the limits of detection. Gross gamma and ^{137}Cs in all cores were at levels within the range attributable to background expected in northern New Mexico soils (Purtymun 1987a). Uranium was measured at levels well within the ranges for naturally occurring uranium expected for the Tshirege, Tsankawi, and Otowi formations penetrated by the hole (Becker 1985 and Crowe 1978).

6. Environmental Restoration Program at Los Alamos National Laboratory.

In 1989, DOE created the Office of Environmental Restoration and Waste Management (DOE/EM). The goal of the office is to implement the DOE's policy to ensure that its past, present, and future operations do not threaten human or environmental health and safety (DOE 1990b). The DOE/EM Office implements procedures to meet these goals through three associate directorates: ER, Waste Operations, and Technology Development. The ER Program in DOE/EM is responsible for assessing, cleaning up, decontaminating, and decommissioning sites at DOE facilities and sites formerly used by DOE.

Two primary laws govern ER activities within the DOE complex: RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA [Superfund]). At the Laboratory only RCRA currently governs ER activities. The hazardous waste management provisions of RCRA, as enacted in 1976, govern the day-to-day operations of hazardous waste treatment, storage, and disposal (TSD) facilities. The law established standards for generators of hazardous waste and requires permits for TSD facilities. The Laboratory's hazardous waste treatment and storage facilities must be permitted. Section 3004(u) of RCRA as amended by the Hazardous and Solid Waste Amendments (HSWA) mandates that permits for TSD facilities include provisions for corrective action to mitigate releases from facilities currently in operation and to clean up contamination in areas designated as solid waste management units (SWMUs).

Congress conceived and passed CERCLA to clean up the nation's most hazardous abandoned waste sites. Under CERCLA, EPA ranks abandoned facilities that have hazardous waste sites according to their potential threat to human health and the environment. The high-scoring sites are listed on the National Priorities List (NPL) and are cleaned up in accordance with CERCLA regulations. When EPA ranked the Laboratory, the agency determined that current environmental conditions do not pose an imminent threat to human health. Hence, the Laboratory is not listed on the NPL and is not a Superfund site. The DOE/University of California (UC) RCRA permit includes a section called the HSWA Module, which prescribes a specific corrective action program for the Laboratory. Because the Laboratory has not been listed on the NPL, the HSWA Module provides the primary guidance for the Laboratory's ER program. The HSWA Module specifies a three-step corrective action process (Fig. IV-23):

The RCRA Facility Investigation. The goal of this step is to identify the extent of contamination at source points and environmental pathways for the

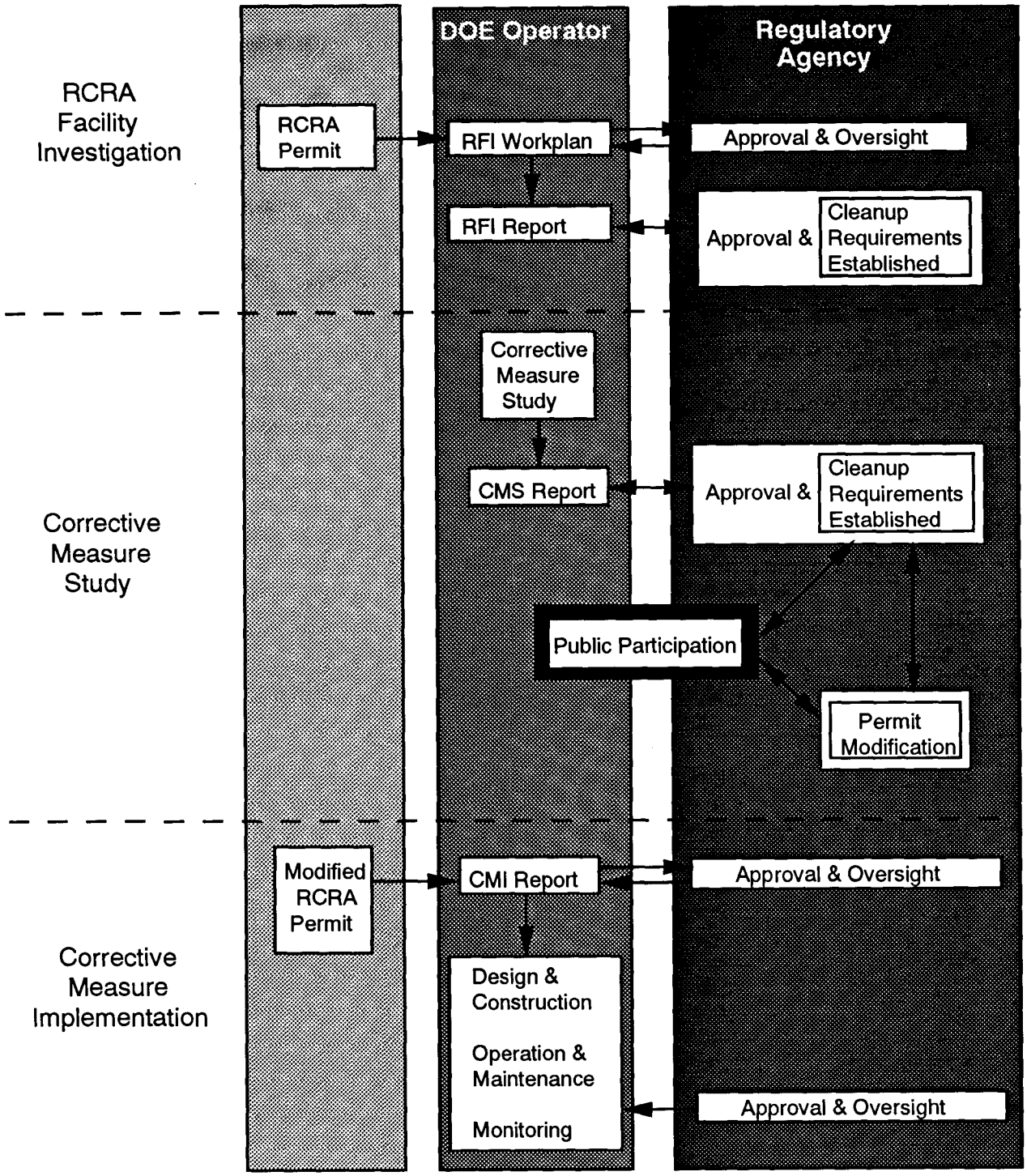


Fig. IV-23. Resource Conservation and Recovery Act corrective action process.

exposure of potential human and environmental receptors. This step will be implemented by characterizing the extent of contamination in the detail necessary to determine what corrective measures, if any, need to be taken. This approach will focus on answering only those questions relevant to deciding further actions in a cost-effective manner.

Corrective Measures Study. If characterization indicates that corrective measures may be needed, a corrective measures study (CMS) will evaluate alternatives that might be reasonably implemented. These measures will be evaluated based on their projected efficacy in reducing risks to human and environmental health and safety in a cost-effective manner.

Corrective Measures Implementation. This step implements the chosen remedy, verifies its effectiveness, and establishes ongoing control and monitoring requirements.

An ER program plan has been prepared in accordance with the HWSA Module and with proposed Subpart S, Corrective Action for Solid Waste Management Units, of 40 CFR 264 (EPA 1990a) in the regulations promulgated by EPA to implement HSWA. EPA proposed Subpart S in July 1990 to implement the clean-up program mandated in Section 3004(u) of RCRA. The plan describes how each of the three corrective action steps described above will be implemented at the Laboratory. DOE and UC propose to use the operable unit approach defined in CERCLA for organizing and managing the various SWMUs. Operable units are aggregates of SWMUs that will be addressed together. The details for each step required under the corrective action process will be presented individually for each operable unit.

The HSWA Module provides a schedule for addressing 603 SWMUs that the EPA has selected from those identified by DOE/UC. The schedule requires that all 603 SWMUs be addressed in RFI work plans by May 23, 1994, and that CMSs be complete by May 23, 2000. The work plan requirement will be met by completing work plans for 24 operable units at the Laboratory. These work plans will describe the general approach that will be applied to each operable unit. Current risks from known SWMUs are low; hence, no operable unit or set of SWMUs has a priority for action based on health or environmental concerns. The order in which operable units will be addressed is therefore designed to meet the requirements of the HSWA Module. However, DOE and UC propose to extend the RFI schedule so that the CMS process is not complete until May 23, 2002. This is necessary because of the increased number of SWMUs identified at the Laboratory and will allow effort to be spread over a period that is compatible with the availability of national resources, including funding.

Major components of the program that address the requirements of the HSWA Module are

- a technical decision making approach which identifies appropriate corrective actions and meets the requirements of the EPA;
- a strategy for the conduct of interim remedial measures;
- program management that organizes and manages the Laboratory's ER effort, including projecting schedules and costs;
- a quality assurance program that ensures a technically defensible and valid program;
- a health and safety program that ensures adequate health and safety protection during implementation of the Laboratory's ER program;
- a records management program that tracks and stores information and data throughout the ER program; and
- a community relations program that provides information to and receives recommendations from the public throughout the life of the ER program.

The HSWA Module of the RCRA permit defines the principal requirements with which DOE/UC must comply in implementing the ER Program at the Laboratory. However, RCRA does not address several issues of concern at Los Alamos. For example, source material, by-product, and special nuclear material are exempt from the RCRA definition of solid waste and are not subject to the provisions of the HSWA Module. DOE and UC recognize that these radioactive constituents are of major concern and cannot be separated from concerns about hazardous wastes. Thus, the DOE and UC ER program addresses radioactive as well as other hazardous substances not regulated by RCRA. This approach is intended to maintain a technically comprehensive program that covers

potential liabilities associated with other environmental laws, such as CERCLA.

The Laboratory submitted its first site-specific work plan under the HSWA requirements in May 1991. The work plan addresses characterization activities at TA-21, which will begin in 1992. This technical area is one of the oldest TAs still active and contains over 100 SWMUs regulated under HSWA. These units contain residual concentrations of radionuclides, organic chemicals, and metals released during nearly 50 years of operation. The programmatic plan for environmental restoration at the Laboratory was updated in November 1991. During 1991, the Laboratory drafted new work plans to investigate eight operable units, including the Los Alamos townsite. These plans are due to EPA in May 1992.

7. Performance Assessment for TA-54, Area G.

DOE Order 5820.2A, Radioactive Waste Management, became effective in September 1988. Section III of this order established policies, guidelines, minimum requirements, and performance criteria for LLW and mixed waste (LLW that also contains nonradioactive hazardous waste components) management at DOE facilities. The order applies only to LLW disposed after the order became effective. The order requires that a performance assessment (PA) of the LLW site be made to demonstrate compliance with specific performance objectives stated in the order.

A draft PA document is in preparation. It reports the results of preliminary calculations to assess the projected performance of TA-54, Area G. Area G disposes of only LLW; mixed waste is stored at the site for future disposition. Such disposition, to be determined in the future, may be on site treatment of the hazardous waste component and disposal of the resulting material as LLW on site or shipment of the mixed waste off site for treatment and subsequent disposal. The PA evaluates only the Laboratory's LLW stream; it does not consider transuranic wastes, which are not covered under Chapter III of the order.

An exposure scenario is a conceptual model that describes patterns of human activity, events, and processes that result in radiation exposure to people. Two classes of scenarios are considered in the PA: intruder scenarios and undisturbed site scenarios. Intrusion is assumed to occur after loss of institutional control at the waste site after periods of several hundreds of years. At this time, one or a few individuals are assumed to disturb the waste site, unaware of the presence of radioactive waste. Undisturbed scenarios assume that future inhabitants of the area are exposed to radioactive components of the waste that have been released from the waste site through normal environmental processes. These include possible impacts to groundwater from leaching and to surface water from erosion after long periods of time.

A variety of intruder scenarios have been defined. Inadvertent intrusion is a hypothetical event that may not occur at all. It is not possible to identify, let alone consider in the PA, all of the possible intrusion scenarios. Three hypothetical scenarios were chosen for analysis:

- Intruder-construction. A construction crew digs a pit for a basement and constructs a house at the waste site.
- Intruder-agriculture. The site is used by a farmer/gardener for the production of foodstuffs.
- Intruder-drilling. In this scenario, drilling for water, natural resources, or perhaps for site characterization causes a limited amount of deeper (shaft-disposed) wastes to be brought to the surface.

The major exposure pathways are direct exposure and inhalation. Dose limits for intruders are established in DOE Order 5820.2A, Ch. III. The annual effective dose equivalent to inadvertent intruders (after the loss of institutional control) shall not exceed 100 mrem for continuous exposure or 500 mrem for a single acute exposure.

Under current waste-stream concentrations, none of the intruder scenarios produces doses that exceed the applicable dose criteria. In the intruder-construction scenario, ^{239}Pu, ^{241}Am, and ^{238}Pu account for 44%, 25%, and 15%, respectively, of the dose to an intruder. In the intruder-agriculture scenario, ^{239}Pu, ^{241}Am, and ^{238}Pu account for 41%, 30%, and 14%, respectively, of the dose to an intruder. In the analyses to date, the only radioactive materials treated as shaft-disposed radioactive wastes are $^{90}Sr/^{90}Y$ and ^{137}Cs. In this scenario, 98% of the dose is from ^{137}Cs by external exposure. Other, minor components account for the remainder of the dose.

Although dose assessment for undisturbed site scenarios has not been completed, the depth to groundwater and the dryness of the climate are likely to reduce doses from these scenarios to insignificant levels. The migration of radionuclides by subsurface aqueous transport is always viewed as one of the critical components in assessing any waste site. Area G has the advantage of a large unsaturated zone (average distance to the saturated zone of 260 m) and low water content in the intervening material. These advantages result in delaying radionuclide migration. These advantages will be discussed in more detail in the final PA.

Waste management strategies involve maximizing distances from the source to the saturated zone while minimizing the potential for exposure by surface erosion of the mesa tops and lateral erosion of the canyon walls. The large unsaturated zone in conjunction with a retardation mechanism will allow this strategy to be effectively implemented.

8. Preoperational Studies.

Preoperational studies are required under DOE Order 5400.1 (DOE 1988a). This order requires that chemical, physical, and biological characteristics be assessed before an area is disturbed. One preoperational study was continued during 1991. Detailed results may be obtained by referring to individual preoperational reports available through EM-8.

Sanitary Wastewater Systems Consolidation (Cañada del Buey). A preoperational appraisal of the site of the Sanitary Wastewater Consolidation System (SWCS) plant has been conducted for two years. The biotic diversity of Cañada del Buey, below the SWCS site and the location of future discharges of up to 600,000 gal. of water a day, has been studied.

Activities included habitat evaluation; capture/release surveys for small mammals; point counts for birds; pellet counts for large mammals; and tracking of small, medium-sized, and large mammals. Mapping of vegetation below the plant site and monitoring of the animal populations within the canyon will be continued prior to and after the onset of discharge of water from the plant.

9. Biological Resource Evaluations.

a. Biological Surveys/Monitoring. Monitoring of selected biota and sensitive habitats to provide long-term data in accordance with NEPA, DOE Order 5400.1 (DOE 1988a), the Endangered Species Act, and the Floodplain/Wetland Executive Order was begun during 1990. Monitoring studies on raptors, reptiles and amphibians, small mammals, and birds continued during 1991. Additionally, wetland and adjacent upland habitats within Pajarito and Sandia Canyons were monitored. A second year of data was collected for various trophic levels of biota within Cañada del Buey. Several new surveys were initiated to obtain inventory data on groups of organisms not previously studied. No fish were encountered in Laboratory waters.

Raptors. Evaluation of raptor populations and raptor nest sites within Laboratory boundaries continued during 1991. Birds of concern included the zone-tail hawk (*Buteo albonotautus*), Cooper's hawk (*Accipiter cooperii*), and Northern goshawk (*Accipiter gentilis*).

Breeding birds. Breeding bird surveys were conducted by members of the Pajarito Ornithological Survey in cooperation with the Biological Resource Evaluations program for a period of five years. Data analysis and manuscript preparation was completed. Approximately 112 species of birds were found to breed within Laboratory boundaries or within Los Alamos County.

Bats. During the summer of 1991, a survey for bat species found on Laboratory land was begun by the Biological Resource Evaluations Team. The purpose of the study was two-fold: (1) to identify species of bats inhabiting Laboratory lands, and (2) to determine if the spotted bat (*Euderma maculatum*), a state endangered species, was utilizing Laboratory lands for foraging or roosting. Species identified are included in Table IV-46. No spotted bats were identified. Additional bat studies will be conducted to further define the presence or absence of this species on Laboratory lands and to further inventory the bat species using Laboratory lands for breeding, roosting, and foraging.

Table IV-46. Bat Species Found on Los Alamos National Laboratory Lands

Myotis evotis	Long-eared myotis
Myotis volans	Long-legged myotis
Lasiurus cinereus	Hoary bat
Lasionycteris noctivagans	Silver-haired bat
Eptesicus fuscus	Big brown bat
Pipistrellus hesperus	Western pipistrelle

Snails. No information on mollusk species found on the Pajarito Plateau has been compiled. Cursory surveys for land dwelling and aquatic mollusk species were conducted during the summer of 1991 in conjunction with Dr. Richard Smartt, New Mexico Museum of Natural History. Surveys were carried out in Pajarito, Los Alamos, Ancho, and Chaquehui Canyons. This preliminary survey identified 12 species of snails and bivalves on Laboratory and adjacent lands (Table IV-47). Surveys will be continued to further inventory mollusk species.

Insects. Few studies of insects or arachnids have been conducted on Laboratory lands. Two studies done prior to 1991 inventoried ants and land dwelling spiders. Trapping studies for land dwelling insects were initiated in Pajarito Canyon and in Ancho Canyon during the summer of 1991. Identification of the specimens collected is being done by various entomologists with expertise within each Order. Results have not yet been compiled.

Elk/Deer. Studies evaluating population numbers of elk and deer have not been conducted since the late 1970s. In cooperation with the New Mexico Game and Fish Department, aerial game counts were initiated in August to determine resident populations and in January 1992 for wintering populations. Counts were not successful because of altitude limitations mandated by the DOE for purposes of safety. The altitude was too high to successfully count numbers or cow/bull ratios. Other techniques are being investigated to determine the population numbers consistently from year to year.

b. Wildlife Watering. In July through October 1991, a preliminary survey of 135 of 140 NPDES outfalls was conducted to determine wildlife use. The results of the survey indicated that approximately 50% of the outfalls are used or potentially can be used by macrofauna such as deer and elk. Additionally, one-third of the outfalls have potential wetland characteristics as evidenced by hydrophytic vegetation.

Observations indicated a number of aquatic invertebrates within effluent discharge waters. Cursory wildlife observations provided a list of 35 mammal, bird, amphibian, and reptile species (evidenced from visual sightings, scat, tracts, and bedding) in the vicinity of the outfalls. These and other nonmacrofaunal species could potentially use waters from the discharges. To determine the level of use of these discharge outfalls by small and medium-sized mammals and amphibians, further studies will be conducted. Studies on the macroinvertebrate assemblages will continue.

Table IV-47. Land and Aquatic Mollusks Found on Los Alamos National Laboratory Land

Canyon	Location	Species
SNAILS		
Upper Pajarito	T19N,R6E,NW1/4, Sec. 19	*Zonitoides arboreus* *Glyphyalinia indentata* *Euconulus fulvus*
Middle Pajarito	T19N,R7E, unplatted	*Gyraulus spp.*
Lower Pajarito	T19N,47E,NE1/4,NW1/4, Sec. 10	*Physa virgata* *Oreohelix subrudis*
Los Alamos	T19N,R6E,SE1/4,NW1/4, Sec. 17	*Euconulus fulvus*
Ancho	T18N,R7E, unplatted	*Cochilicopa lubrica* *Lymnea palva* *Physa virgata*
Chaquehui	T18N,R7E, unplatted	*Physa virgata*
BIVALVES		
Ancho	T18N,R7E, unplatted	*Pisidium casertanum*

c. Wetland monitoring.

Pajarito Canyon. Monitoring of reptile, amphibian, and small mammal populations within the palustrine wetlands and adjacent uplands within Pajarito Canyon continued for a second year. Water levels within the wetlands were substantially higher due to heavy seasonal rains. Many areas that had been dry during the summer of 1990 were inundated for a period of time greater than 21 days during 1991.

Amphibian species found breeding within the wetlands included the Spadefoot toad (*Scaphlopus multiplicatus*), Red spotted toad (*Bufo punctatus*), Woodhouse's toad (*Bufo woodhousei*), Chorus frog (*Pseudacris triseriata*), and Tiger salamander (*Ambystoma tigrinum*). Tadpoles from two species were observed during the summer of 1991 that were not observed during the drier summer of 1990, the Spadefoot toad and Red spotted toad. During August, large numbers of spadefoot toads metamorphosed and were observed moving from the wetlands into the uplands.

A capture/release study of small mammals was conducted for a second year within the study area. The two most commonly captured species were the Western harvest mouse (*Reithrodontomys mealotis*) and the Deer mouse (*Peromyscus maniculatus*). Each species comprised 31.9% of the total organisms caught. Other species included Piñon mouse (*Peromyscus truei*), Brush mouse (*Peromyscus boylei*), Least chipmunk (*Eutamium minimus*), Colorado chipmunk (*Eutamius quadrivittatus*), and White throated woodrat (*Neotoma albiqua*).

Additionally, pellet transects were established in Pajarito Canyon to determine large mammal use of the wetland areas as compared to a drier canyon, Cañada del Buey. Preliminary information indicated a heavier use of the Pajarito wetland by elk and deer than the drier Cañada del Buey. These transects are monitored on a monthly basis. Pellet groups identified in Pajarito and Cañada del Buey include coyote (*Canis latrans*), elk (*Cervus canadensis*), deer (*Odocoileus hemionus*), rabbits (*Sylvilagus* spp.), and black bear (*Ursus americanus*).

Sandia Canyon. Water quality as related to the diversity and types of aquatic invertebrate assemblages has been monitored in Sandia Canyon. Water sources to the stream in Sandia Canyon include steam plant blowdown, sanitary treatment plant effluent, and other industrial waste. From the literature, there is evidence that the kinds and types of aquatic invertebrates within a stream are directly related to the quality of the waters in that stream. Initial limited data collected from Sandia Canyon suggest that aquatic assemblages do represent an ecological indication of water quality. Three sampling stations have been set up in the canyon (Fig. IV-24). The first two stations are just below industrial waste discharge points. The effluent discharges consist of sanitary waste and steam plant blowdown. The third station is approximately 0.5 m downstream from any effluent discharge. Water quality parameters such as pH, temperature, dissolved oxygen, and conductivity are measured on a monthly basis at each station. Aquatic invertebrates are also sampled. The first two stations have a limited diversity of aquatic invertebrates and tend to have those invertebrates commonly found in low oxygen environments. Water quality measurements indicate that Station 2 consistently has the lowest dissolved oxygen content (due to sanitary waste effluent). However, the third station consistently has a dissolved oxygen content near saturation and a higher degree of invertebrate diversity. The aquatic invertebrates found within Station 3 are those species thought to be sensitive to contamination and low oxygen environments. The third station appears to be in the stream recovery zone. Table IV-48 summarizes the aquatic invertebrates that have been found in Sandia Canyon.

d. Special Accomplishments.

Wildlife Observation Database. A Wildlife Observation Database was established within the Environmental Assessments and Resource Evaluations Section of EM-8. The purpose of the database is to record observations on wildlife made by Laboratory employees and field personnel. Observations are used to determine distribution and presence of species on Laboratory lands, Bandelier National Monument, and adjacent Forest Service lands. Animals observed by employees included bear, deer, elk, raccoon, fox, bald eagle, golden eagle, bobcat, coyote, peregrine falcon, chorus frogs, and a variety of birds.

Biota Databases. The Biological Resource Evaluations Program has established databases for mammals, birds, reptiles, amphibians, mollusks, insects, vascular plants, fungi, and threatened and endangered species. Historic information about species found on Laboratory and adjacent lands is being

compiled. These databases will provide information on species diversity and distribution.

10. Community Relations Program.

In 1991, community relations continued to be an important facet of LANL environmental programs. As part of the ER program, several community relations activities were accomplished. These included

- developing and distributing townsite operable unit fact sheets to the public,
- holding ER Installation Work Plan Public Information Workshops in Taos, Española, Santa Fe, and Los Alamos,
- in cooperation with DOE, mailing notifications to 350 property owners of land classified as SWMUs, and holding a public information meeting to discuss the notifications,
- holding a DOE/LANL ER and Waste Management Site-Specific Plan Public meeting, and

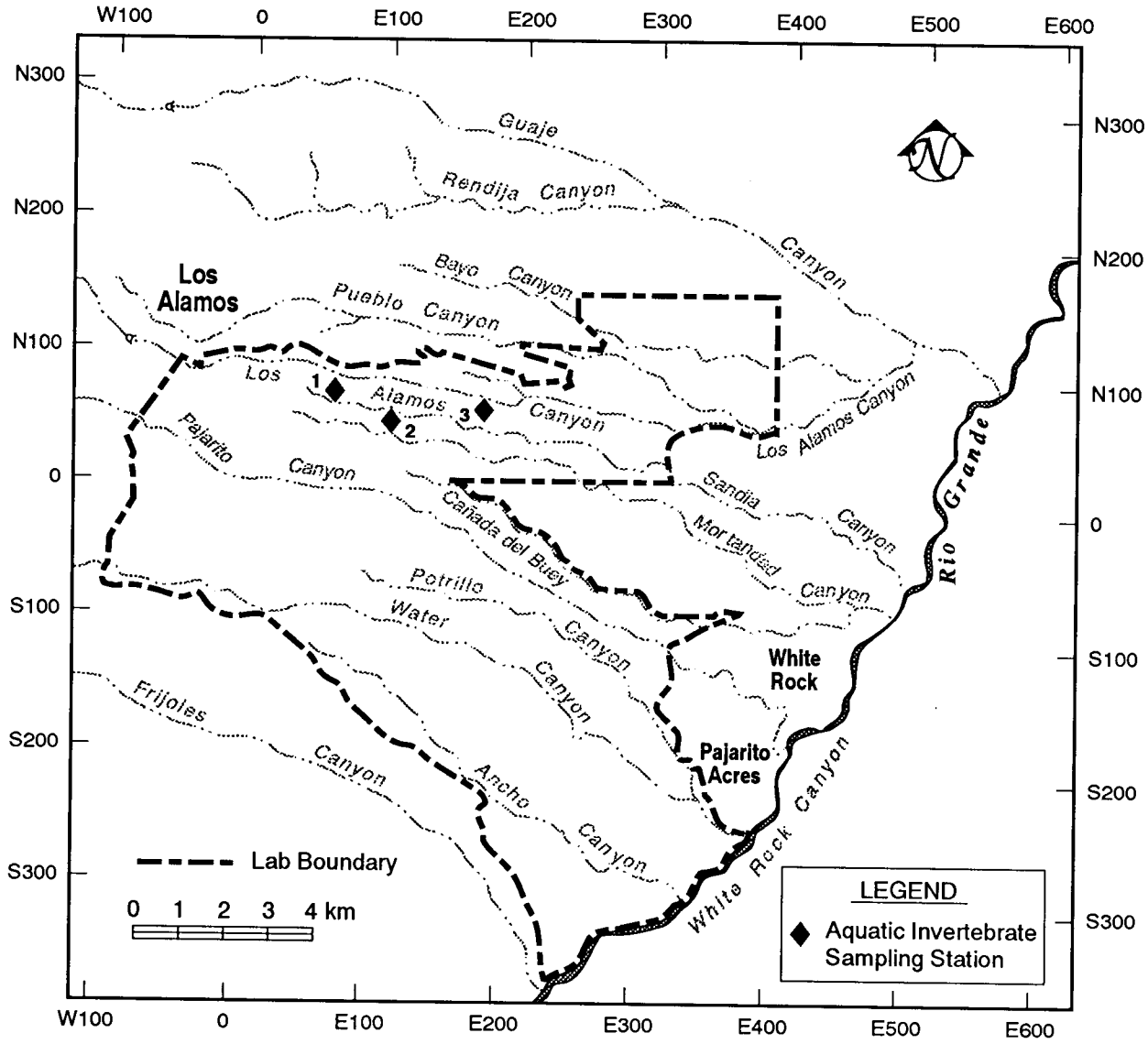


Fig. IV-24. Locations of aquatic invertebrate sampling stations in Sandia Canyon. (Map denotes general location only.)

Table IV-48. Aquatic Invertebrates Found in Sandia Canyon at Three Sampling Stations

Aquatic Invertebrate	Present at Station 1[a]	Present at Station 2[b]	Present at Station 3[c]
Order Diptera (Flies, Midges, and Mosquitoes)	Yes	Yes	Yes
Order Coleoptera (Beetles)	No	Yes	Yes
Order Ephemeroptera (Mayflies)	No	No	Yes
Order Trichoptera (Caddis Flies)	No	No	Yes
Order Hemiptera (True Bugs)	No	No	Yes
Order Plecoptera (Stoneflies)	No	No	Yes
Class Odonata (Damselfiles and Dragonflies)	No	No	Yes
Class Oligocheata (Aquatic Earthworms)	No	No	Yes
Class Gordiacea (Hairworms)	No	No	Yes
Class Nematoda (Roundworms)	Yes	Yes	No

[a]Station 1 = Immediately below steam plant effluent discharge point.
[b]Station 2 = Immediately below the sanitary waste discharge point.
[c]Station 3 = 1/2 mile down from any discharge point.

- meeting with several local neighborhood associations and the County Council to update them on current ER program activities.

In an attempt to communicate more effectively with interested and affected parties on environment, safety, and health (ES&H) issues, the Community Relations Group (PA-3) recently subscribed to Northern New Mexico Environmental Information Exchange (NENIX). NENIX is a newly initiated multiline computer bulletin board and environmental information bank.

PA-3 sponsored several events to foster dialogue between Laboratory senior management and staff and local public interest groups. Among these events were:

- Presentation to LANL staff about the Nuclear Guardianship Project by Charlotte Cook.
- Colloquium by Dr. Isadore Rosenthal and luncheon discussion among public interest groups and Laboratory representatives. Laboratory staff included members of Senior Management, Common Ground, Environmental Management Division staff, and Community Relations staff. Public interest groups included Citizens for Clean Air and Water, Trinity Forum for International Security, Concerned Citizens for Nuclear Safety, Nuclear Guardianship Project, Physicians for Social Responsibility, New Mexico Alliance, and Southwest Research and Information Center.

- Nuclear testing round table discussions among Laboratory representatives and members of Concerned Citizens for Nuclear Safety and public interest group representatives from the Livermore area.
- Seminar entitled "Public Acceptance of Science: Chernobyl and Sellafield as Competing Causes of an Environmental Emergency in England," by British scientist, Brian Wynne.
- Round table dialogue with public interest group representatives including Concerned Citizens for Nuclear Safety and People for Peace, Laboratory senior managers and John Zysman/Michael Borrus (Berkeley Round Table for the International Economy) to discuss economic conversion issues.
- Round table dialogue among public interest group representatives including People for Peace and Citizens for Clean Air and Water; Laboratory Community Relations staff; and Dixie Lee Ray, former Director of the National Regulatory Commission.

11. Waste Minimization and Pollution Prevention.

LANL's Waste Minimization and Pollution Prevention Awareness Program is a comprehensive and continual effort to systematically reduce waste generation. This program is designed to eliminate or minimize pollutant releases to the environment from all aspects of the Laboratory's operations. Included are methods of reducing hazardous chemical waste, TRU waste, low-level radioactive waste, radioactive liquid waste, mixed waste, and sanitary/industrial waste. The oversight and planning of the Waste Minimization Program is done through the LANL Waste Minimization Program Office.

The Laboratory Waste Minimization and Pollution Prevention Awareness Program is reinforced through senior management commitment. This commitment is addressed in the Laboratory Director's Policy (DP 105) which emphasizes reduction or elimination of waste whenever or wherever possible. In addition, the program uses a number of waste minimization and pollution prevention techniques to actively minimize waste and prevent pollution. These techniques include process waste assessments; site specific plans; an upper management level Waste Minimization Steering committee to facilitate waste minimization actions within the Laboratory; and an employee awareness program encompassing training, campaigns, and incentives.

The Laboratory is committed to waste minimization and pollution prevention. The program follows all applicable federal, state, and DOE requirements for waste minimization.

12. Environmental Training.

The Laboratory maintains an extensive personnel training program for ES&H courses coordinated by the Policy and Guidance Section of the Risk Management Support Group (HS-3) of the Health and Safety Division. All Laboratory employees must take the following training: General Employee Training (GET), Radiation Protection for Occupational Workers (every other year), Lockout/Tagout for Affected Workers (available in July 1992), Occupational Safety and Health Act (OSHA) Rights and Regulations, and Employee Participation Packet (yearly). The following courses are suggested for all employees: Introduction to Hazard Communication and Waste Generator Training.

All new employees, contractors, affiliates, long-term visitors, and co-op students must take the GET sessions which consist of 16 training modules:

- Facilities
- Policies
- Quality Assurance
- Security
- Safeguard Awareness
- ES&H Policy
- Employee Participation Packet
- OSHA Rights and Regulations
- Industrial Safety
- Fire Protection
- Emergency Management

- Industrial Hygiene
- Occupational Medicine
- Radiation Protection for the Occupational Worker
- Lockout/Tagout
- Environment

The Laboratory also offers specific environment-related courses for employees who work with hazardous and toxic wastes. A variety of classes designed to meet site-/job-/operation-specific training needs includes classes on Hazardous Waste Generation; Hazardous Waste Operations (which meets the OSHA training requirements as described in 29 CFR 1910.120); Packaging and Transportation of Hazardous Materials; Procedures to Implement the Spill Prevention, Control, and Countermeasures Plan; and Waste Management Coordination.

V. ENVIRONMENTAL RADIOLOGICAL PROGRAM INFORMATION

A major component of the Laboratory's Environmental Surveillance Program includes monitoring for potential exposures to the public from Laboratory-related radiation sources and assessing the risk associated with that exposure. Air is routinely sampled at locations on Laboratory property, along the Laboratory perimeter, and in more distant areas that serve as regional background stations. Atmospheric concentrations of tritium, uranium, plutonium, americium, and gross beta are measured. In 1991, total radioactive air emissions decreased by approximately 50% with gaseous mixed activation products and tritium showing the largest declines. Water effluent from the liquid waste treatment plant is sampled to determine the release of radionuclides. Total releases continued to decline in 1991. The maximum effective dose to a member of the public from 1991 Laboratory operations was 4.4 mrem. The average doses to individuals in Los Alamos and White Rock because of 1991 Laboratory activities were 0.05 and 0.03 mrem, respectively. These doses are estimated to add lifetime risks of about 1 chance in 47,000,000 in Los Alamos and 1 chance in 68,000,000 in White Rock to an individual's risk of cancer mortality.

A. Introduction

Many of the activities that take place at the Los Alamos National Laboratory (LANL or the Laboratory) involve handling radioactive materials and operating radiation-producing equipment. A major component of the Laboratory's Environmental Surveillance Program includes monitoring for potential exposures to the public from Laboratory-related radiation sources.

Radiation from radioactive materials and radiation-producing equipment is called ionizing radiation. Common types of ionizing radiation include alpha, beta, and gamma. Each type of ionizing radiation has a unique ability to penetrate or pass through materials and thereby be absorbed in living tissues causing damage from the ionization process. Alpha radiation penetrates poorly; a piece of paper or outer skin tissue can stop it. Beta radiation has low to moderate penetrating ability. X-rays and gamma radiation have much greater penetrating ability.

Radiation is released by both naturally occurring materials and by artificially produced or enhanced sources. Naturally occurring sources are called background radiation and include naturally occurring gases such as radon and naturally occurring elements such as uranium in regional rocks and soils. Ionizing radiation is also produced by medical diagnosis and treatment equipment such as x-rays, nuclear medicine procedures, and linear accelerators. Medical diagnosis and treatment account for the largest radiation dose to the American public from artificially produced sources of radiation. Tobacco products, smoke detectors, and television sets have ionizing radiation associated with them.

Other sources of ionizing radiation include occupational exposures, residual fallout from past atmospheric weapons testing, the nuclear fuel cycle, and research and scientific activities at facilities such as the Laboratory.

B. Radioactive Emissions

1. Air.

The radiological air sampling network at the Laboratory is designed to measure environmental levels of airborne radionuclides that may be released from Laboratory operations. Plutonium, americium, and uranium are released in microcurie amounts as a result of Laboratory operations. Tritium is released in curie amounts. Radioiodine and noble gases are released from facilities performing fission product chemistry, medical isotope preparation, and research reactors. The Laboratory also releases radionuclides that emit beta

and gamma radiation from the Los Alamos Meson Physics Facility (LAMPF) at TA-53 and the Omega West Reactor at TA-2.

Radioactive airborne emissions are monitored at 88 Laboratory discharge locations. These emissions consist primarily of filtered exhausts from glove boxes, experimental facilities, operational facilities (such as liquid waste treatment plants), a nuclear research reactor, and a linear particle accelerator at LAMPF. Some emissions receive appropriate treatment before discharge, such as filtration for particulate matter and catalytic conversion and adsorption for activation gases. The quantities of airborne radioactivity released depend on the type of research activities and can vary markedly from year to year (Figs. V-1 to V-3). During 1991, the most significant releases were from LAMPF. The amount released for the entire year was 57,431 Ci (2,117,029 GBq) of air activation products (gases, particles, and vapors) (Tables V-1 and V-2). This emission was about half of that in 1990 (Fig. V-3). The principal airborne activation products (half-lives in parentheses) were ^{10}C (19.5 s), ^{11}C (20 min), ^{13}N (10 min), ^{16}N (7.14 s), ^{14}O (71 s), ^{15}O (123 s), and ^{41}Ar (1.83 h). Most of the radioactivity was from these radioisotopes, whose radioactivity declines very rapidly over time. A list of selected nuclides and their half-lives is given in Table D-17.

Airborne tritium emissions continued to decrease from the 6,400 Ci (236,800 GBq) released in 1990 to 4,716 Ci (174,492 GBq) released in 1991 (Table IV-3). Release of mixed fission products remained constant in 1991, equaling levels observed prior to the 1989 unplanned release from TA-48 (1,150 μCi [42 MBq] in 1988, 435,000 μCi [16 GBq] in 1989, 1,085 μCi [40 MBq] in 1990, and 1,096 μCi [40.4 MBq] in 1991). Spallation products were observed at TA-53 and TA-48. Total activity was less than 0.1 Ci.

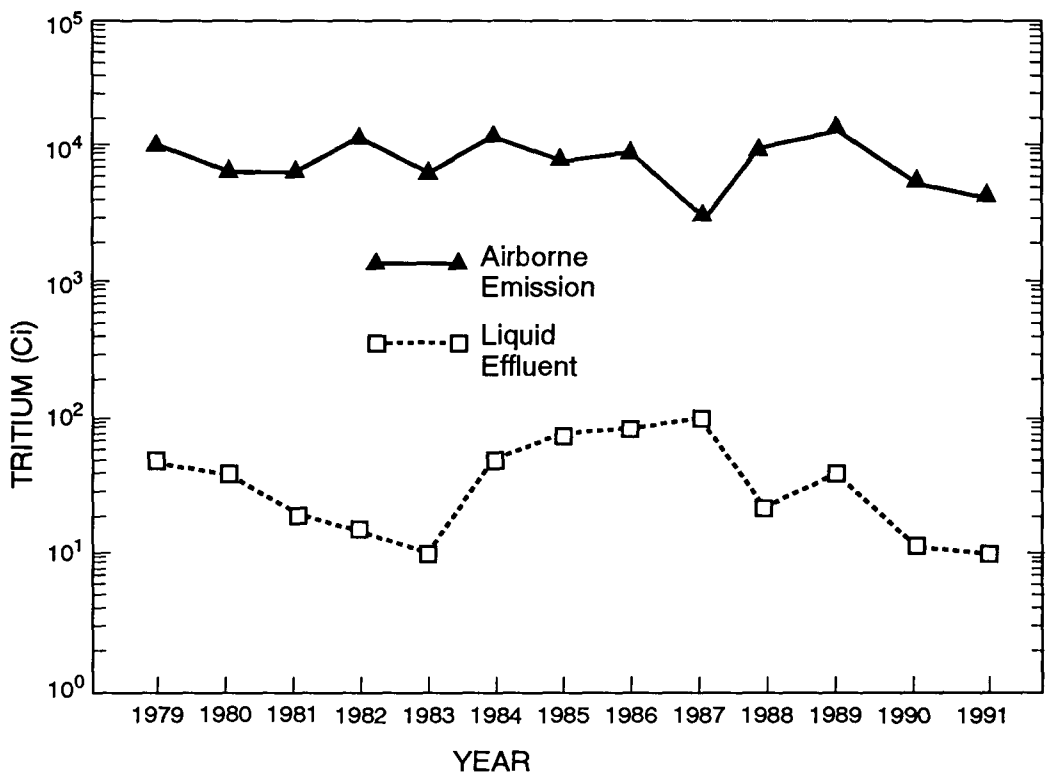


Fig. V-1. Summary of tritium releases (airborne emissions and liquid effluents).

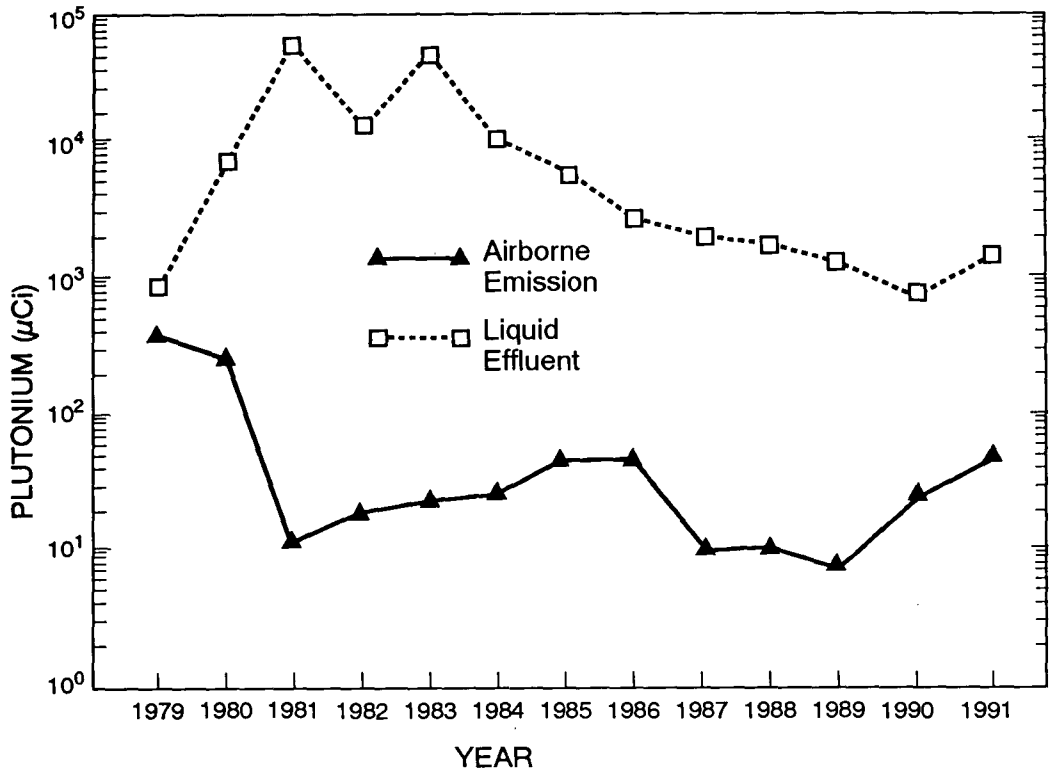


Fig. V-2. Summary of plutonium releases (airborne emissions and liquid effluents).

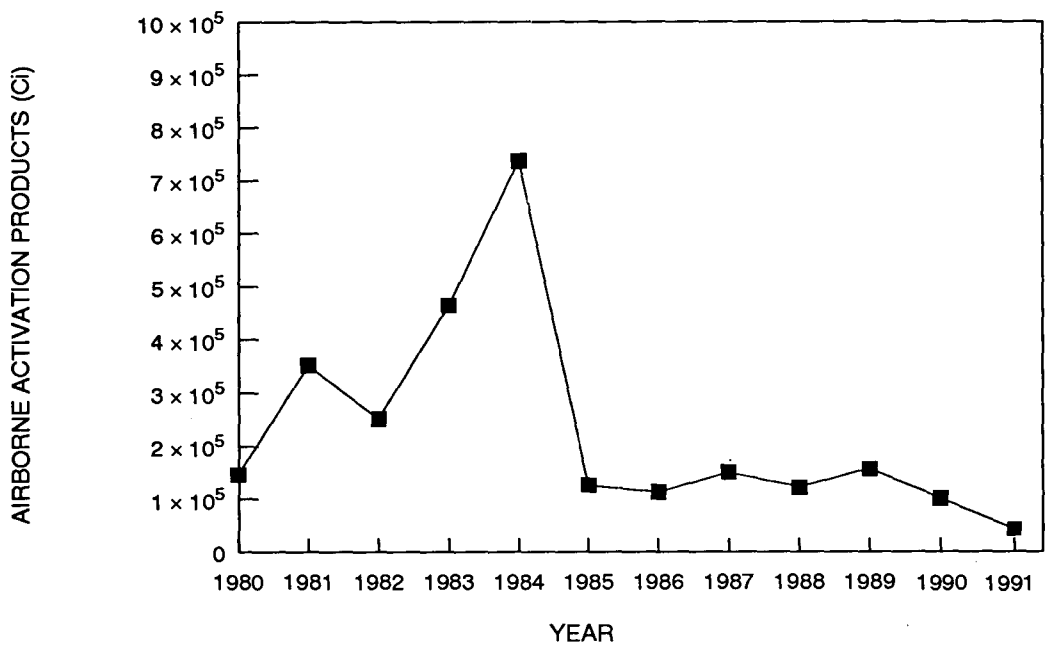


Fig. V-3. Airborne activation product emissions (principally ^{10}C, ^{11}C, ^{12}N, ^{16}N, ^{14}O, ^{15}O, ^{41}Ar) from the Los Alamos Meson Physics Facility (TA-53).

Table V-1. Airborne Radioactive Emissions from Laboratory Operations in 1991[a]

Location	H^{3}[b] (Ci)	Mixed Fission Products (μCi)	^{235}U[c] (μCi)	^{238}U (μCi)	$^{238/239/240}Pu$[d] (μCi)	^{32}P (μCi)	Summary of Activation Products (See detailed list in Table V-2) Gaseous[e] (Ci)	Particle/Vapor[f] (Ci)
TA-2	—	—	—	—	—	—	203.3	—
TA-3	205.2	14.1	164.3	79.9	30.8	—	—	—
TA-21	323.3	<0.1	92.0	—	0.8	—	—	—
TA-33	254.0	—	—	—	—	—	—	—
TA-35	—	—	—	—	1.2	—	—	—
TA-41	3,841.0	—	—	—	—	—	—	—
TA-43	—	—	—	—	—	17.0	—	—
TA-46	—	—	—	—	—	—	—	—
TA-48	—	1,078.8	—	—	0.6	—	—	<0.1
TA-50	—	3.1	—	—	1.4	—	—	—
TA-53	0.9	—	—	—	—	—	57,228.0	0.2
TA-54	—	—	—	—	<0.1	—	—	—
TA-55	91.2	—	—	—	2.0	—	—	—
Rounded Total	4,715.6	1,096.0	256.3	79.9	36.8	17.0	57,431.3	0.2

[a]As reported on DOE form F-5821.1.
[b]Includes 99.2% as H^3 (gas) and 0.2% as tritium vapor in the HTO form.
[c]Does not include aerosolized uranium from explosives testing (Table V-3).
[d]Plutonium values contain indeterminate traces of ^{241}Am, a transformation product of ^{241}Pu.
[e]Includes the following constituents: ^{16}N, ^{10}C, ^{14}O, ^{15}O, ^{13}N, ^{11}C, ^{41}Ar, (see Table V-2 for details).
[f]Includes 26 nuclides (see Table V-2 for details).

In addition to releases from facilities, some depleted uranium (uranium consisting primarily of ^{238}U) is dispersed by experiments that use conventional high explosives. About 309.2 kg (680 lb) of depleted uranium was used in such experiments in 1991 (Table V-3). This mass contains about 0.12 Ci (4,440 MBq) of radioactivity. Most of the debris from these experiments is deposited on the ground in the vicinity of the firing sites. Limited experimental data show that no more than about 10% of the depleted uranium becomes airborne (Dahl 1977). Dispersion calculations indicate that resulting airborne concentrations are in the same range as that for concentrations attributable to the natural abundance of uranium

Table V-2. Airborne Radioactive Emissions from Laboratory Operation in 1991 Detailed Listing of Mixed Activation Products: Particulate, Vapor, and Gases

Mixed Activation Products	Radionuclide	Activity in Curies		
		Location: TA-2	Location: TA-53	Location: TA-48
Particle/Vapor (P/VAP)	As-72			8.72×10^{-2}
	As-73			7.23×10^{-4}
	As-74			6.83×10^{-4}
	Be-7		1.94×10^{-2}	
	Br-76		2.00×10^{-3}	
	Br-77			2.56×10^{-3}
	Br-82		$6.01 \cdot 10^{-3}$	9.00×10^{-5}
	Cd-109			2.49×10^{-3}
	Co-57		1.13×10^{-6}	
	Co-58		7.69×10^{-6}	
	Cr-51		3.56×10^{-4}	
	Ir-192		9.67×10^{-7}	
	Mn-52		4.45×10^{-4}	
	Mn-54		1.12×10^{-5}	
	Na-22		3.11×10^{-6}	
	Na-24		5.85×10^{-3}	
	Os-185		2.83×10^{-6}	
	Rb-83		2.74×10^{-4}	
	Rb-105			1.29×10^{-3}
	Sc-46		1.95×10^{-5}	
	Sc-47		6.30×10^{-4}	
	Se-75		7.63×10^{-5}	8.30×10^{-2}
	Ta-182		1.09×10^{-4}	
	Te-132			1.08×10^{-4}
	Tl-202		5.56×10^{-5}	
	V-48		2.05×10^{-4}	
Gaseous (G/MAP)	AR-41	2.03×10^{2}	2.58×10^{2}	
	C-10		2.57×10^{3}	
	C-11		9.59×10^{3}	
	N-13		8.52×10^{3}	
	N-16		1.02×10^{3}	
	O-14		1.17×10^{3}	
	O-15		3.41×10^{4}	

Table V-3. Estimated Concentrations of Radioactive Elements Aerosolized by Dynamic Experiments

Element	1991 Total Usage (kg)	Fraction Aerosolized (%)	Annual Average Concentration ($\mu g/m^3$) (4 km)[a]	Annual Average Concentration ($\mu g/m^3$) (8 km)[a]	Applicable Standard ($\mu g/m^3$)
Uranium	309.2	10	3.0×10^{-5}	1.2×10^{-5}	9[b]

[a]Distance downwind.

[b]DOE (1981a).

that is resuspended in dust particles originating from the earth's crust.

Radioactive air emissions at the Laboratory are monitored according to DOE/EH-0173T "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance" (DOE 1991) and 40 CFR Part 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities" (EPA 1989c). Based on off-site environmental monitoring results and on doses calculated from measured stack emissions, the off-site doses are less than the 10 mrem/year standard given in 40 CFR 61.92.

On July 17, 1990, LANL notified the Department of Energy (DOE) that the Laboratory met the 10 mrem/yr standard but did not meet the monitoring requirements (40 CFR 61.93) with its existing sampling program. On November 27, 1991, Environmental Protection Agency (EPA) Region 6 issued the DOE a Notice of Noncompliance with 40 CFR 61, Subpart H, specifically:

1. Every release source from an operation which uses radionuclides has not been evaluated using the approved Environmental Protection Agency (EPA) computer model to determine a dose received by the public, as required by 40 CFR 61.93(a).
2. DOE has failed to comply with 40 CFR 61.93(b)(4) because it has not determined each release point that has the potential to deliver more than 1% of the effective dose equivalent standard.
3. The facility currently has not installed stack monitoring equipment on all its regulated point sources in accordance with the above analysis and 40 CFR 61.93 (b)(2)(ii) and (iii).
4. The facility has not conducted, and is not in compliance with, the appropriate quality assurance programs pursuant to 40 CFR 61.93 (b)(2)(iv).
5. The facility is in violation of 40 CFR 61.94 "Compliance and Reporting" because it has not calculated the highest effective dose equivalent in accordance with the regulations cited above.

As a result of the Notice of Noncompliance, the DOE is currently negotiating a Federal Facilities Compliance Agreement (FFCA) with EPA Region 6. The FFCA will include schedules which the Laboratory will follow to come into compliance with the Clean Air Act. A draft FFCA was submitted by DOE Los Alamos Area Office (LAAO) to the EPA on March 12, 1992.

2. Water.

In recent years, treated effluents containing low levels of radioactivity have been released from the central liquid waste treatment plant (TA-50), a smaller plant serving laboratories at TA-21, and a sanitary sewage lagoon system serving LAMPF at TA-53 (Tables IV-3 and IV-26 and Figs. V-1, V-2, and V-4). In 1989, the low-level radioactive waste stream was separated from the sanitary system at TA-53 and directed into a total retention, evaporative lagoon. In 1991, there were no releases from the TA-21 plant or the TA-53 total retention lagoons.

Total activity released in 1991 (about 11 Ci) was slightly less than that released in 1990 (about 13 Ci) (Table IV-3). The decrease resulted because of

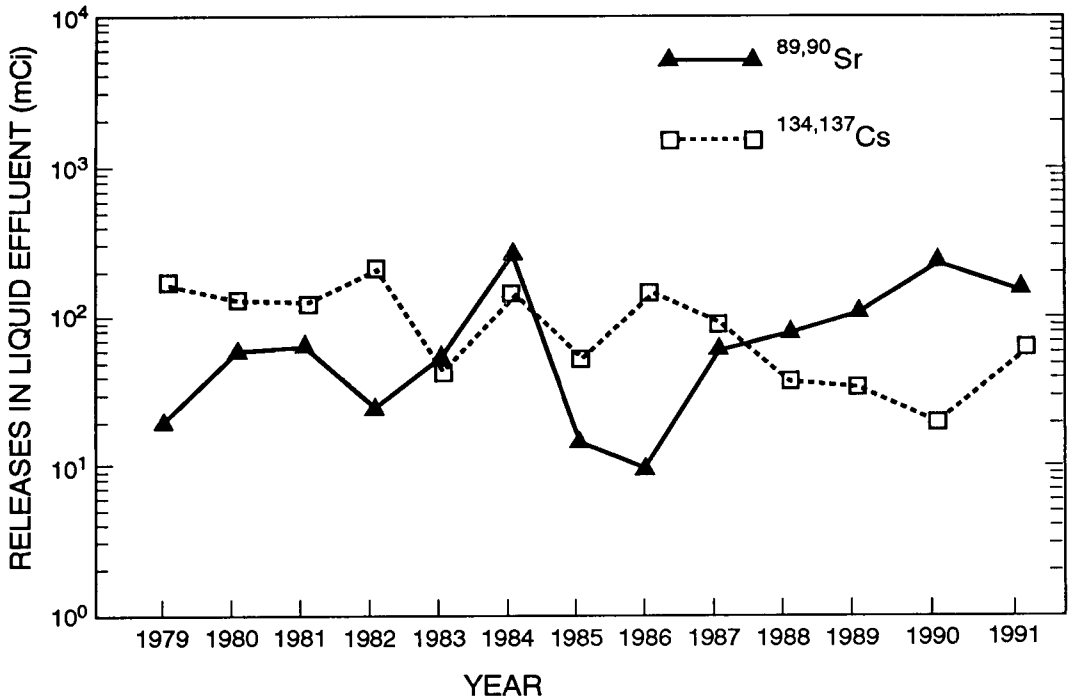


Fig. V-4. Summary of strontium and cesium liquid effluent releases.

improved treatment of the radioactive liquid waste stream. Effluents from TA-50 are discharged into the normally dry stream channel in Mortandad Canyon, where surface flow has not passed beyond the Laboratory's boundary since the plant began operation in 1963.

3. Unplanned Releases.

a. Airborne Radionuclide Releases. On February 1, 1991, 2,800 Ci of elemental tritium were released at TA-41. Less than 0.1% of the tritium was present as tritiated water. The effective dose equivalent (50-yr dose commitment) to a member of the public was calculated to be 0.03 mrem. This dose occurred 7 km (5.8 mi) east of TA-41, where Los Alamos Canyon opens out onto State Road 4. The dose estimate conservatively assumed that 1% of the tritium was oxidized before reaching the receptor location. The dose is 0.03% of DOE's Public Dose Limit (PDL) of 100 mrem/year from all pathways, and 0.3% of the EPA's 10 mrem/year limit for the air pathway. (See Appendix A for standards.)

On March 28, 1991, 0.4 Ci of tritiated water vapor were released from TA-21 as tritium oxide. The effective dose equivalent (50-yr dose commitment) to a member of the public was calculated to be 0.01 mrem. The dose is 0.01% of DOE's PDL of 100 mrem/yr (1 mSv/yr) from all pathways, and 0.1% of the EPA's 10 mrem/yr (0.1 mSv/yr) limit for the air pathway.

On April 17, 1991, 0.1550 Ci of tritiated water vapor were released from TA-3-16. A slow leak was discovered at the Van de Graaff accelerator. The effective dose equivalent (50-year dose commitment) to a member of the public was calculated to be 0.006 mrem. The dose is 0.006% of DOE's PDL of 100 mrem/yr from all pathways and 0.06% of the EPA's 10 mrem/yr limit for the air pathway.

b. Radioactive Liquid Releases. On January 2, 1991, a discharge was discovered at TA-54, Area G. A plumbing joint on an eye wash/safety shower located inside Building 33 froze and burst sometime between December 21, 1990, and January 1, 1991, when the Laboratory was closed for the winter holidays. The

amount of discharge was estimated to be 18,000 gallons. Analyses were conducted on the frozen water and soil; gross alpha, beta, and gamma were found to be within background levels. Samples analyzed for tritium averaged 0.29 μCi/L, approximately 15% of the DOE Derived Concentration Guide for off-site tritium releases (2.0 μCi/L). Removal of the frozen water below Building 33 was not required because of the slow rate of melting during which the water either evaporates or enters the subsurface, rather than producing a definitive runoff in Cañada del Buey. (See Section IV.6.3.a for data on measurements of tritiated water in sediments in Cañada del Buey.)

On February 21, 1991, 0.2 mCi of plutonium and americium isotopes were released at TA-50 from a leaking pipe near the Size Reduction Facility. The leak was repaired, and the spill was cleaned up to applicable standards.

C. Radiological Doses

1. Introduction.

Radiological doses are calculated in order to measure the health impacts of any releases of radioactivity to the public. Radiation dose refers to the quantity of radiation energy absorbed per unit mass, multiplied by adjustment factors for type of radiation. Effective dose equivalent (or simply "effective dose") is the principal measurement used in radiation protection. This term means the hypothetical whole-body dose that would give the same risk of cancer mortality and serious genetic disorder as a given exposure that may be limited to a few organs. The effective dose equivalent is equal to the sum of individual organ doses, each weighted by degree of risk that the organ dose carries. For example, a 100 mrem dose to the lung, which has a weighting factor of 0.12, gives an effective dose that is equivalent to (100 × 0.12) = 12 mrem.

Standards exist which limit the maximum effective dose to the public. DOE applies a PDL of 100 mrem/yr for all pathways. EPA limits the effective dose to a member of the public to 10 mrem/yr for the air pathway only.

2. Methods for Dose Calculations.

a. Introduction. Annual radiation doses are evaluated for three principal exposure pathways: external exposure (which includes exposure from immersion in air containing photon-emitting radionuclides and direct and scattered penetrating radiation), inhalation, and ingestion. Estimates are made of the following exposures:

- Maximum individual organ doses and effective dose equivalent to an individual at or outside the Laboratory boundary where the highest dose rate occurs and a person actually is present. It takes into account occupancy (the fraction of time that a person actually occupies that location), shielding by buildings, and self-shielding.
- Average organ doses and effective dose equivalents to nearby residents.
- Collective effective dose equivalent for the population living within an 80 km (50 mi) radius of the Laboratory.

Results of environmental measurements are used as much as possible in assessing doses to individual members of the public. Calculations based on these measurements follow procedures recommended by federal agencies to determine radiation doses (DOE 1991, NRC 1977).

If the impact of Laboratory operations is not detectable by environmental measurements, individual and population doses attributable to Laboratory activities are estimated through modeling of releases.

Dose conversion factors used for inhalation and ingestion calculations are given in Table D-18. These factors are taken from the DOE (1988b) and are based on factors in Publication 30 of the International Commission on Radiological Protection (ICRP 1979).

Dose conversion factors for inhalation assume a 1-μm activity median aerodynamic diameter, as well as the lung solubility category that will maximize the effective dose equivalent (for comparison with DOE's 100-mrem/yr PDL) if more than one category is given. Similarly, the ingestion dose conversion factors are chosen to maximize the effective dose if more than one gastrointestinal tract uptake is given (for comparison with DOE's 100-mrem/yr PDL for all pathways).

These dose conversion factors give the 50-year dose commitment for internal exposure. The 50-year dose commitment is the total dose received by an organ during the 50-year period following the intake of a radionuclide that is attributable to that intake.

External doses are calculated using the dose-rate conversion factors published by DOE (1988c) (Table D-19). These factors give the photon dose rate

in millirems per year per unit radionuclide air concentration in microcuries per cubic meter. If these factors are not available in DOE 1988c, they are calculated with the computer program DOSFACTOR II (Kocher 1981).

Annual effective dose equivalents are estimated with the CAP-88 collection of computer codes published by the EPA if impacts from Laboratory operations are so small that they are less than measurement detection limits. CAP-88 uses dose conversion factors generated by the computer program RADRISK. The 50-year dose commitment conversion factors from RADRISK were compared with the ICRP/DOE dose conversion factors and found to agree to within 5%. This agreement was judged more than adequate to justify RADRISK dose factors when CAP-88 is being used.

b. External Radiation. Environmental thermoluminescent dosimeter (TLD) measurements are used to estimate external radiation doses.

The TLD measurements are corrected for background to determine the contribution to the external radiation field from Laboratory operations. Background estimates at each site, which are based on historical data, consideration of possible nonbackground contributions, and, if possible, values measured at locations of similar geology and topography, are subtracted from each measured value. This net dose is assumed to represent the dose from Laboratory activities that would be received by an individual who spent 100% of his or her time during an entire year at the monitoring location.

The individual dose is estimated from these measurements by taking into account occupancy and shielding. At off-site locations where residences are present, an occupancy factor of 1.0 is used. Two types of shielding are considered: (1) shielding by buildings and (2) self-shielding. Each shielding type is estimated to reduce the external radiation dose by 30%.

Neutron doses from the critical assemblies at TA-18 were based on field measurements. Neutron fields were monitored principally with TLDs placed in cadmium-hooded, 23 cm (9 in.) polyethylene spheres. At on-site locations at which above background doses were measured, but at which public access is limited, dose estimates are based on a more realistic estimate of exposure time.

c. Inhalation Dose. Annual average air concentrations of H^3, total uranium, ^{238}Pu, $^{239,240}Pu$, and ^{241}Am, determined by the Laboratory's air monitoring network, are corrected for background by subtracting the average concentrations measured at regional stations. These net concentrations are then multiplied by a standard breathing rate of 8,400 m^3/yr (ICRP 1975) to determine total adjusted intake via inhalation, in microcuries per year, for each radionuclide. Each intake is multiplied by appropriate dose conversion factors to convert radionuclide intake into 50-year dose commitments. Following ICRP methods, doses are calculated for all organs that contribute more than 10% of the total effective dose equivalent for each radionuclide. The dose calculated for inhalation of H^3 is increased by 50% to account for absorption through the skin.

This procedure for dose calculation conservatively assumes that a hypothetical individual is exposed to the measured air concentration continuously throughout the entire year (8,760 hours). This assumption is made for the boundary dose, dose to the maximum exposed individual, and dose to the population living within 80 km of the site.

Organ doses and effective dose equivalent are determined at all sampling sites for each radionuclide. A final calculation estimates the total inhalation organ doses and effective dose equivalent by summing over all radionuclides.

d. Ingestion Dose. Results from foodstuffs sampling are used to calculate organ doses and effective dose equivalents from ingestion for individual members of the public. The procedure is similar to that used in the previous section. Corrections for background are made by subtracting the average concentrations from sampling stations not affected by Laboratory operations. The radionuclide concentration in a particular foodstuff is multiplied by the annual consumption rate (NRC 1977) to obtain total adjusted intake of that radionuclide. Multiplication of the adjusted intake by the radionuclide's ingestion dose conversion factor for a particular organ gives the estimated dose to the organ. Similarly, effective dose equivalent is calculated using the effective dose equivalent conversion factor (Table D-18).

Doses are evaluated for ingestion of H^3, ^{90}Sr, ^{137}Cs, total uranium, ^{238}Pu, and $^{239,240}Pu$ in fruits and

vegetables; H^3, ^7Be, ^{22}Na, ^{54}Mn, ^{57}Co, ^{83}Rb, ^{134}Cs, ^{137}Cs, and total uranium in honey; and ^{90}Sr, ^{137}Cs, total uranium, ^{238}Pu, and $^{239,240}Pu$ in fish.

3. Estimation of Radiation Doses.

a. Doses from Natural Background. Effective dose equivalents from natural background and from medical and dental uses of radiation are estimated to provide a comparison with doses resulting from Laboratory operations. Doses from global fallout are only a small fraction of total background doses (<0.3%, NCRP 1987a) and are not considered further here. Exposure to natural background radiation results principally in whole-body doses and in localized doses to the lung and other organs. These doses are divided into those resulting from exposure to radon and its decay products that mainly affect the lung and those from nonradon sources that mainly affect the whole body.

Estimates of background radiation are based on a comprehensive report by the National Council on Radiation Protection and Measurements (NCRP 1987b). The 1987 NCRP report uses 20% shielding by structures for high-energy cosmic radiation and 30% self-shielding by the body for terrestrial radiation.

Whole-body external dose is incurred from exposure to cosmic rays and to external terrestrial radiation from naturally occurring radioactivity in the earth's surface and from global fallout. Effective dose equivalents from internal radiation are due to radionuclides deposited in the body through inhalation or ingestion.

Nonradon effective dose equivalents from background radiation vary each year depending on factors such as snow cover and the solar cycle (NCRP 1975b). Estimates of background radiation in 1991 from nonradon sources are based on measured external radiation background levels of 119 mrem (1.19 mSv) in Los Alamos and 117 mrem (1.17 mSv) in White Rock caused by irradiation from charged particles, x-rays, and gamma rays. These uncorrected measured doses were adjusted for shielding by reducing the cosmic ray component (60 mrem [0.6 mSv] at Los Alamos and 52 mrem [0.52 mSv] at White Rock) by 20% to allow for shielding by structures and by reducing the terrestrial component (59 mrem [0.59 mSv] at Los Alamos and 65 mrem [0.65 mSv] at White Rock) by 30% to allow for self-shielding by the body (NCRP 1987a). To these estimates, based on measurements, were added 10 mrem (0.1 mSv) at Los Alamos and 8 mrem (0.08 mSv) at White Rock from neutron cosmic radiation (20% shielding assumed) and 40 mrem (0.4 mSv) from internal radiation (NCRP 1987a). The estimated whole body dose from background, nonradon radiation is 139 mrem (1.39 mSv) at Los Alamos and 135 mrem (1.35 mSv at White Rock.

In addition to these nonradon doses, a second component of background radiation is dose to the lung from inhalation of ^{222}Rn and its decay products. The ^{222}Rn is produced by decay of ^{226}Ra, a member of the uranium series, which is naturally present in construction materials in buildings and in the underlying soil. The effective dose equivalent from exposure to background ^{222}Rn and its decay products is taken to be equal to the national average, 200 mrem/yr (2 mSv/yr) (NCRP 1987a). This background estimate may be revised if a nationwide study of background levels of ^{222}Rn and its decay products in homes is undertaken, as recommended by the NCRP (1984, 1987a).

The total effective dose equivalent to residents is 339 mrem/yr (3.39 mSv/yr) at Los Alamos and 335 mrem (3.35 mSv) at White Rock (Table V-4), or 139 mrem/yr (1.39 mSv/yr) from nonradon sources and 200 mrem/yr (2 mSv/yr) from radon at Los Alamos and 135 mrem/yr (1.35 mSv/yr) from nonradon sources and 200 mrem/yr (2 mSv/yr) from radon at White Rock.

Medical and dental radiation in the United States accounts for an average effective dose equivalent, per person, of 53 mrem/yr (0.53 mSv/yr) (NCRP 1987a). This estimate includes doses from both x-rays and radiopharmaceuticals.

b. Doses to Individuals from External Penetrating Radiation from Airborne Emissions. The major source of external penetrating radiation from LANL operations has been airborne emissions from LAMPF. Nuclear reactions with air in the target areas at LAMPF (TA-53) cause the formation of air activation products, principally ^{11}C, ^{13}N, ^{14}O, and ^{15}O. These isotopes are all positron emitters and have 20.4-minute, 10-minute, 71-second, and 122-second half-lives, respectively. Neutron reactions with air at the Omega West Reactor (TA-2) and LAMPF also form ^{41}Ar, which has a 1.8-hour half-life.

The radioisotopes ^{11}C, ^{13}N, ^{14}O, and ^{15}O are sources of photon radiation because of the formation of two 0.511-MeV (million-electron-volt) photons through positron-electron annihilation. The ^{14}O also emits a 2.3-MeV gamma with 99% yield. The ^{41}Ar emits a 1.29-MeV gamma with 99% yield.

Table V-4. Summary of Annual Effective Dose Equivalents Attributable to 1991 Laboratory Operations

	Maximum Dose to an Individual[a]	Average Dose to Nearby Residents		Collective Dose to Population within 80 km of the Laboratory
		Los Alamos	White Rock	
Dose	4.4 mrem	0.05 mrem	0.03 mrem	1.1 person-rem
Location	Residence north of TA-53	Los Alamos	White Rock	Area within 80 km of Laboratory
DOE Public Dose Limit	100 mrem	100 mrem	100 mrem	—
Percentage of Public Dose Limit	4.4%	0.05%	0.03%	—
Background	339 mrem	339 mrem	335 mrem	71,000 person-rem
Percentage of Background	1%	0.02%	0.01%	0.002%

[a]Maximum individual dose is the dose to any individual at or outside the Laboratory where the highest dose rate occurs. Calculations take into account occupancy (the fraction of time a person is actually at that location), self-shielding, and shielding by buildings.

This dose is routinely monitored with a special TLD network in the off-site location which receives the maximum dose from LAMPF operations. During the past 5 years, this annual dose has varied between 11 mrem in 1986 to 3.1 mrem in 1990.

LAMPF airborne emissions in 1991 were 48% of the emissions in 1990. This reduction occurred primarily because of the shorter LAMPF operating schedule in 1991. As a result, the measured off-site dose during 1991 was less than the 3 mrem/yr (0.03 mSv/yr) detection limit of the LAMPF monitoring network. The maximum off-site dose was estimated using the computer model AIRDOS (CAP-88 version), which uses measured stack emissions and meteorological data to calculate off-site air concentrations and radiation doses, rather than environmental measurements. The computer model has been found in the past (see below) to slightly overestimate the dose at Los Alamos sites, principally because of the increased atmospheric mixing at Los Alamos compared to the relatively flat terrain where the model was developed. The maximum off-site effective dose from external penetrating radiation LAMPF emissions was calculated by AIRDOS to be 3.8 mrem (0.038 mSv) during 1991. This dose is 38% of the EPA's air pathway standard of 10 mrem/yr (0.1 mSv/yr), and 3.8% of the DOE's PDL of 100 mrem/yr (1 mSv/yr).

Over the past five years, the maximum annual dose calculated by AIRDOS has averaged 9.9 mrem (0.099 mSv), whereas the measured dose has averaged 6.1 mrem (0.061mSv) during the same time period. Using these averages to scale the 3.8 mrem (0.038 mSv) calculated dose to estimate what the measured dose would be yields 2.4 mrem (0.024 mSv), which is below the TLD detection limit.

c. Doses to Individuals from Direct Penetrating Radiation. No direct penetrating radiation from Laboratory operations was detected by TLD monitoring in off-site areas. On-site TLD measurements of external penetrating radiation reflected Laboratory operations and did not represent potential exposure to the public. During previous years, a potential 2- to 4-mrem/yr (0.02-to 0.04-mSv/yr) dose occurred to members of the public using the DOE-controlled road passing by TA-18. This potential dose has not occurred since 1989 because of curtailed operations at TA-18. Several programs at TA-18 restarted limited operations in the summer of 1991, but these did not include the facility with the potential for the 2- to 4-mrem (0.02- to 0.04-mSv) dose.

The on-site TLD station (Station 24, Fig. IV-1) near the northeastern Laboratory boundary recorded an above-background dose of about 139 mrem (1.39 mSv). This dose reflects direct radiation from a localized accumulation of ^{137}Cs on sediments transported from TA-21 before 1964. No one resides near this location at this time.

d. Doses to Individuals from Inhalation of Airborne Emissions. The maximum individual effective doses attributable to inhalation of airborne emissions (Table V-5) are below the EPA air pathway standard of 10 mrem/yr (1 mSv/yr).

Exposure to airborne H^3 (as tritiated water vapor), uranium, ^{238}Pu, $^{239,240}Pu$, and ^{241}Am was determined by measurement. Correction for background was made by assuming that natural radioactivity and worldwide fallout were represented by data from the three regional sampling stations at Española, Pojoaque, and Santa Fe. The highest effective dose equivalent for ^{238}Pu, $^{239,240}Pu$, and ^{241}Am was 0.3 mrem (0.003 mSv), or 0.3% of the DOE's PDL of 100 mrem/yr (1 mSv/yr), and 3% of the EPA's 10 mrem/yr (0.1 mSv/yr) standard for dose from the air pathway at the East Gate Station. Emissions of air activation products from LAMPF resulted in negligible inhalation exposures.

Exposure from all other atmospheric releases of radioactivity (Table V-2) was also evaluated by theoretical calculations of airborne dispersion. All inhalation potential doses from these releases were less than 0.5% of the DOE's PDL of 100 mrem/yr (1 mSv/yr).

e. Doses to Individuals from Treated Effluents. At this time, discharged treated effluents do not flow beyond the Laboratory boundary but are retained in the alluvium of the receiving canyons. These treated effluents are monitored at point of discharge; their behavior in the alluvium of the canyons below outfalls has been studied and is monitored annually (Hakonson 1976a, 1976b; Purtymun 1971, 1974a).

Small quantities of radioactive contaminants transported during periods of heavy runoff have been measured in canyon sediments beyond the Laboratory boundary in Los Alamos Canyon (Fig. II-5). Increased discharge from the Bayo Canyon sanitary sewage treatment plant has resulted in additional flow in Los Alamos Canyon, typically to a location between wells LA-6 and LA-2. Calculations made with radiological

Table V-5. Estimated Maximum Individual 50-Year Dose Commitments from 1991 Airborne Radioactivity[a]

Isotope	Location[b]	Estimated Dose (mrem/yr)	Percentage of Public Dose Limit
H^3	White Rock	0.004	<0.1
^{11}C, ^{13}N, ^{14}O, ^{15}O, ^{41}Ar	East Gate (Station 6)	3.8	3.8%
U, ^{238}Pu, $^{239,240}Pu$, ^{241}Am	East Gate	0.3	0.3%

[a]Estimated maximum individual dose is the dose from Laboratory operations (excluding dose contributions from cosmic, terrestrial, medical diagnostics, and other non-Laboratory sources) to an individual at or outside the Laboratory boundary where the highest dose rate occurs and where a person actually resides. It takes into account shielding and occupancy factors.

[b]See Fig. IV-4 for station locations.

data from Acid-Pueblo and Los Alamos Canyons (ESG 1981) indicate a minor exposure pathway to man from these canyon sediments. Obtaining 50% of an annual consumption of meat from a steer that drinks water from or grazes in lower Los Alamos Canyon could potentially result in a maximum committed effective dose equivalent of 0.8 mrem (0.008 mSv).

f. Doses to Individuals from Ingestion of Foodstuffs. Data from sampling of produce, fish, and honey during 1991 were used to estimate doses received from eating these foodstuffs. All calculated effective dose equivalents are <2% of DOE's 100 mrem/yr standard.

Fruit and vegetable samples were analyzed for six radionuclides (H^3, ^{137}Cs, total uranium, ^{238}Pu, and $^{239,240}Pu$). The maximum committed effective dose equivalent that would result from ingesting one-fourth of a typical annual consumption of fruits and vegetables (160 kg) with averaged radionuclide concentrations from off-site locations was 0.2 mrem (0.002 mSv). This dose, which is based on the samples collected in Los Alamos and White Rock, is 0.2% of the DOE's PDL for protecting members of the public (see Appendix A for standards). The dose calculated from the eight samples (out of the total Los Alamos County samples) collected in the Western Area of Los Alamos was 0.4 mrem (0.004 mSv). This dose was statistically indistinguishable from the dose calculated for all Los Alamos County produce samples.

Fruit from a tree in the area previously occupied by the original Los Alamos laboratory site (TA-1) was found to have elevated levels of tritium and ^{239}Pu. The estimated effective dose from consuming 5 kg (11 lbs) of fruit from this tree is 0.06 mrem, or 0.06% of the DOE's 100 mrem/yr standard. Consuming the entire 23 kg (50 lbs) annual yield from this tree corresponds to 0.3 mrem, or 0.3% of the DOE standard.

Ingestion of produce collected on site is not a significant exposure pathway because of the small amount of edible material, low radionuclide concentrations, and limited access to these foodstuffs.

Produce collected at San Ildefonso Pueblo during 1991 was found to have slightly elevated concentrations of several radionuclides. As discussed in Section IV, the produce samples were collected in an area more than 10 km beyond Laboratory facilities and upstream from the point of past Laboratory discharges into the Rio Grande. As a result, this location is not believed to be impacted by Laboratory operations. The cause of the slightly elevated radionuclide concentrations is not known, but in any case, the resulting radiation dose is low. The effective dose equivalent is calculated to be 1.5 mrem/yr (0.015 mSv/yr), which is 1.5% of the DOE's PDL of 100/mrem/yr (1 mSv/yr).

Fish samples were analyzed for ^{90}Sr, ^{137}Cs, natural uranium, ^{238}Pu, and $^{239,240}Pu$. Radionuclide concentrations in fish from Cochiti Reservoir, the sampling location downstream from the Laboratory, are compared with concentrations in fish taken from Abiquiu Reservoir upstream. The maximum effective dose equivalent to an individual eating 21 kg of fish from

Cochiti Reservoir is 0.04 mrem (0.0004 mSv), which is 0.04% of DOE's 100 mrem/yr standard (DOE 1990a).

Trace amounts of radionuclides were found on site in honey. The maximum effective dose equivalent one would get from eating 5 kg of this honey, if it were made available for consumption, would be 0.08 mrem (0.0008 mSv), which is 0.08% of DOE's 100 mrem/yr standard.

4. Total Maximum Individual Dose to a Member of the Public from 1991 Laboratory Operations.

a. Maximum Individual Dose. The maximum individual effective dose equivalent to a member of the public from 1991 Laboratory operations is estimated to be 4.4 mrem/yr (0.044 mSv/yr). This is the total effective dose equivalent from all pathways. This dose is 4.4% of the DOE's PDL of 100 mrem/yr (1 mSv/yr) effective dose equivalent from all pathways (Table V-4).

The dose occurred at East Gate (the Laboratory boundary northeast of LAMPF) and was primarily due to external penetrating radiation from air activation products released by the LAMPF accelerator. In contrast to previous years, this 1991 dose estimate is based on computer modeling rather than environmental measurements for doses from external radiation from airborne radioactivity. This is because reduced emissions from LAMPF during 1991 resulted in no measurable above-background external radiation dose in off site-areas (see Section V.C.3.b.).

The computer model CAP-88, which is discussed in more detail in the following section, was used to make the dose estimate for external radiation from airborne radioactivity. Doses from other exposure pathways were estimated using environmental monitoring results (see Sections V.C.3.d and V.C.3.f). Doses from liquid releases and direct radiation from LANL facilities did not impact this location. The maximum effective dose for external radiation from airborne emissions was estimated by CAP-88 using all measured releases from LANL facilities (Tables V-1 and V-3) and 1991 meteorological data. The dose estimate took into account shielding by buildings (30% reduction) and occupancy (100% for residences, 25% for businesses).

The average effective dose to residents in Los Alamos townsite attributable to Laboratory operation in 1991 was 0.05 mrem (0.0005 mSv). The corresponding dose to White Rock residents was 0.03 mrem (0.0003 mSv). The doses are approximately 0.05 and 0.03% of DOE's PDL of 100 mrem/yr (1.0 mSv/yr).

b. Estimate of Maximum Individual Dose from Airborne Emissions for Compliance with 40 CFR Part 61, Subpart H. As required by the EPA, compliance with regulation 40 CFR 61, Subpart H must be demonstrated with the CAP-88 version of the computer codes PREPAR2, AIRDOS2, DARTAB2, and RADRISK (EPA 1990b). These codes use measured radionuclide release rates and meteorological information to calculate transport and airborne concentrations of radionuclides released to the atmosphere. The programs estimate radiation exposures from inhalation of radioactive materials; external exposure to the radionuclides present in the atmosphere and deposited on the ground; and ingestion of radionuclides in produce, meat, and dairy products.

Calculations for Laboratory airborne releases use the radionuclide emissions given in Tables V-1 and V-3. Wind speed, wind direction, and stability class are continually measured at meteorology towers located at TA-54, TA-49, TA-6, and East Gate. Emissions were modeled with the wind information most representative of the release point.

To account for shielding by buildings, doses from external penetrating radiation were reduced by 30%, as recommended by the DOE (1988c) and the Nuclear Regulatory Commission (NRC 1977) and based on data in Report 94 of the National Council on Radiation Protection and Measurements (NCRP 1987a) for photon radiation with energies equivalent to those found in terrestrial penetrating radiation.

The maximum individual effective dose equivalent, as determined by CAP-88, was 4.0 mrem (0.040 mSv), corrected to include shielding by buildings (30% reduction) and occupancy. As expected, more than 98% of the maximum individual dose resulted from external exposure to air activation products from LAMPF. The 4.0 mrem (0.040 mSv) maximum dose, which would occur in the area just northeast of LAMPF, is 40% of the EPA's air pathway standard of 10 mrem/yr (0.1 mSv/yr) effective dose equivalent.

5. Collective Dose Equivalents.

The collective effective dose equivalent from 1991 Laboratory operations was evaluated for the area within

80 km of the Laboratory. Over 99% of this dose is expected to have resulted from airborne radioactive emissions from Laboratory programs. As a result, the collective dose was estimated by modeling 1991 radioactive air emissions, their transport off site, and the resulting radiation exposures that could occur.

The 1991 collective effective dose equivalent (in person-rem) was calculated with the CAP-88 collection of computer codes PREPAR2, AIRDOS2, and DARTAB2. These codes were also used to calculate the maximum effective dose equivalent to a member of the public as required by the EPA regulations 40 CFR Part 61 (EPA 1989c).

The collective dose calculation used the EPA's CAP-88-generated agricultural profile of the area within an 80 km radius. The same exposure pathways that were evaluated for the maximum individual dose were also evaluated for the collective dose. These pathways include inhalation of radioactive materials, external radiation from materials present in the atmosphere and deposited on the ground, and ingestion of radionuclides in meat, produce, and dairy products.

The calculations used in the 1991 population distribution, given in Table II-1 of this report, incorporate the results of the 1990 Census (USBC 1991). The population dose was calculated for the population residing within 80 km of the Laboratory.

The 1991 population collective effective dose equivalent attributable to Laboratory operations to persons living within 80 km of the Laboratory was calculated to be 1.1 person-rem (0.011 person-Sv). This dose is <0.1% of the 71,000 person-rem (710 person-Sv) exposure from natural background radiation and <0.1% of the 12,000 person-rem (120 person-Sv) exposure from medical radiation (Table V-6).

The collective dose from Laboratory operations was calculated from measured radionuclide emission rates (Table V-2), atmospheric modeling using measured meteorological data for 1991, and population data based on the Bureau of Census count (Table II-1).

The collective dose from natural background radiation was calculated using the background radiation levels given above. For the population living within the 80 km radius of the Laboratory, the dose from medical and dental radiation was calculated using a mean annual dose of 53 mrem (0.53 mSv) per capita. The population distribution in Table II-1 was used in both these calculations to obtain the total collective dose.

Table V-6. Estimated Collective Effective Dose Equivalents during 1991 (person-rem [person-Sv])

Exposure Mechanism	Los Alamos County (18,200 persons)	80 km Region (218,000 persons)[a]
Total caused by Laboratory releases	0.8 (0.008)	1.1 (0.011)
Natural background		
Nonradon[b]	2,500 (25)	27,000 (270)
Radon	3,600 (36)	44,000 (440)
Totals caused by natural sources of radiation	6,100 (61)	71,000 (710)
Diagnostic medical exposures (~53 mrem/yr/person)[c]	1,000 (10)	12,000 (120)

[a]Includes doses reported for Los Alamos County.

[b]Calculations are based on TLD measurements. They include a 20% reduction in cosmic radiation from shielding by structures and a 30% reduction in terrestrial radiation from self-shielding by the body (NCRP 1987a).

[c]NCRP (1987a).

Also shown in Table V-6 is the collective effective dose equivalent in Los Alamos County from Laboratory operations, natural background radiation, and medical and dental radiation. Approximately 70% of the total collective dose from Laboratory operations is to Los Alamos County residents. This dose is <0.1% of the collective effective dose equivalent from background and 0.2% of the collective dose from medical and dental radiation, respectively.

D. Risk to an Individual from Laboratory Releases

1. Estimating Risk.

Risk estimates of possible health effects from radiation doses to the public resulting from Laboratory operations have been made to provide a perspective in interpreting these radiation doses. These calculations, however, may overestimate actual risk for low-LET (linear energy transfer) radiation. The NCRP (1975a) has warned that "risk estimates for radiogenic cancers at low doses and low dose rates derived on the basis of linear (proportional) extrapolation from the rising portions of the dose incidence curve at high doses and high dose rates . . . cannot be expected to provide realistic estimates of the actual risks from low-level, low-LET radiation, and have such a high probability of overestimating the actual risk as to be of only marginal value, if any, for purposes of realistic risk-benefit evaluation."

Low-LET radiation, which includes gamma rays, is the principal type of environmental radiation resulting from Laboratory operations. Estimated doses from high-LET radiation, such as neutron or alpha particle radiation, are less than 3% of estimated low-LET radiation doses. Consequently, risk estimates in this report may overestimate the true risks.

Risk estimates used here are based on two recent reports by the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR IV 1988, BEIR V 1990). These reports incorporate the results of the most current research and update risk estimates in previous surveillance reports that were based on the work of the ICRP. The procedures used in this report for the risk estimates are described in more detail below.

2. Risks from Whole-Body Radiation.

Radiation exposures considered in this report are of two types: 1) whole-body exposures, and 2) individual organ exposures. The primary doses from nonradon natural background radiation and from Laboratory operations are whole-body exposures. With the exception of natural background radon exposures, discussed below, radiation doses and associated risks from those radionuclides that affect only selected body organs are a small fraction of the dose and are negligible. Risks from whole-body radiation were estimated using the factors of the BEIR V report.

Risk factors are taken from the BEIR Committee's estimate (BEIR V 1990) of the risk from a single, instantaneous, high-dose rate exposure of 10 rem. The BEIR V report states that this estimate should be reduced for an exposure distributed over time that would occur at a substantially lower dose rate. The committee discussed dose rate effectiveness factors (DREFs) ranging from 2 to 10 that should be applied to the nonleukemia part of the risk estimate.

For the risk estimates presented in this report, a DREF of 2 is used for the nonleukemia risk. Following the BEIR V report, no dose rate reduction was made for the leukemia risk. The risk is then averaged over male and female populations. The total risk estimator is 440 cancer fatalities per 10^9 person-mrem.

3. Risks from Exposure to Radon.

Radon and radon decay product exposures are an important part of natural background radiation. These exposures differ from the whole-body radiation discussed above in that they principally involve only the localized exposure of the lung and not other organs in any significant way. Consequently, the risks from radon exposure were calculated separately.

Radon (principally ^{222}Rn) and radon decay product exposure rates are usually measured with a special unit, the working level (WL); 1 WL corresponds to a liter of air containing short-lived radon decay products whose total potential alpha energy is 1.3×10^5 MeV. An atmosphere having a 100 pCi/L concentration of ^{222}Rn at equilibrium with its decay products corresponds to 1 WL. Cumulative exposure is measured in working level months (WLMs). A WLM is equal to exposure to 1 WL for 170 hours.

The estimated national average radon effective dose that was given by the NCRP is 200 mrem/yr. The NCRP derived this dose from an estimated national average radon exposure of 0.2 WLM/yr. Because the risk factors are derived in terms of WLM, for the purposes of risk calculation it is more convenient to use the radon exposure of 0.2 WLM/yr than to use the radon dose of 200 mrem/yr. Both the 0.2 WLM/yr and the 200 mrem/yr effective dose, however, correspond to the same radiation exposure.

Risks from radon were estimated using a risk factor of 350×10^{-6}/WLM. This risk factor was taken from the BEIR IV report (BEIR IV 1988).

4. Risk from Natural Background Radiation and Medical and Dental Radiation.

During 1991, persons living in Los Alamos and White Rock received an average effective dose equivalent of 139 mrem (1.39 mSv) and 135 mrem (1.35 mSv), respectively, of nonradon radiation (principally to the whole body) from natural sources (including cosmic, terrestrial, and self-irradiation sources, with allowances for shielding and cosmic neutron exposure). Thus, the added cancer mortality risk attributable to natural, whole-body radiation in 1991 was 1 chance in 16,000 in Los Alamos and 1 chance in 17,000 in White Rock.

Natural background radiation also includes exposure to the lung from ^{222}Rn and its decay products (see above) in addition to exposure to whole-body radiation. This exposure to the lung also carries a chance of cancer mortality because of natural radiation sources that were not included in the estimate for whole-body radiation. For the background effective dose equivalent of 200 mrem/yr (2 mSv/yr), the added risk because of exposure to natural ^{222}Rn and its decay products is 1 chance in 14,000.

The total cancer mortality risk from natural background radiation is 1 chance in 8,000 for Los Alamos and White Rock residents (Table V-7). The additional risk of cancer mortality from exposure to medical and dental radiation is 1 chance in 43,000.

Table V-7. Added Individual Lifetime Cancer Mortality Risks Attributable to 1991 Radiation Exposure

Exposure Source	Incremental Effective Dose Equivalent Used in Risk Estimate (mrem)	Added Risk to an Individual of Cancer Mortality (chance)
Average Exposure from Laboratory Operations		
Los Alamos townsite	0.05	1 in 47,000,000
White Rock area	0.03	1 in 68,000,000
Natural Radiation		
Cosmic, terrestrial, self irradiation, and radon exposure[a]		
Los Alamos	339	1 in 8,000[b]
White Rock	335	1 in 8,000
Medical X Rays (Diagnostic Procedures)		
Average whole-body exposure	53	1 in 43,000

[a]An effective dose equivalent of 200 mrem was used to estimate the risk from inhaling ^{222}Rn and its transformation products.

[b]The risks from natural radiation from nonradon sources were estimated to be 1 chance in 16,000 in Los Alamos and 1 chance in 17,000 for White Rock. The risk of lung cancer from radon exposure was estimated to be 1 chance in 14,000 for both locations. Risk estimates are derived from the NRC BEIR IV and BEIR V reports and the NCRP Report 93 (BEIR IV 1988, BEIR V 1990, NCRP 1987a).

5. Risk from Laboratory Operations.

The risks calculated above from natural background radiation and medical and dental radiation can be compared with the incremental risk caused by radiation from Laboratory operations. The average doses to individuals in Los Alamos and White Rock from 1991 Laboratory activities were 0.05 and 0.03 mrem (0.0005 and 0.0003 mSv), respectively. These doses are estimated to add lifetime risks of about 1 chance in 47,000,000 in Los Alamos and 1 chance in 68,000,000 in White Rock to an individual's risk of cancer mortality (Table V-7). These risks are <0.1% of the risk attributed to exposure to natural background radiation or to medical and dental radiation.

For Americans, the average lifetime risk is a 1-in-4 chance of contracting cancer and a 1-in-5 chance of dying of cancer (EPA 1979). The Los Alamos incremental risk attributable to Laboratory operations is equivalent to the additional exposure from cosmic rays a person would get from flying in a commercial jet aircraft for 27 minutes at an altitude of 9,100 m (30,000 ft) (NCRP 1987b). The exposure from Laboratory operations to Los Alamos County residents is well within variations in exposure of these people to natural cosmic and terrestrial sources and global fallout. For example, the amount of snow cover and variability of the solar sunspot cycle can explain a 10 mrem (0.1 mSv) difference from year to year (NCRP 1975b).

VI. ENVIRONMENTAL NONRADIOLOGICAL PROGRAM INFORMATION

The Laboratory quantifies and assesses nonradioactive pollutant releases to the environment by calculating and monitoring nonradioactive emissions and effluents, evaluating unplanned releases, and conducting environmental sampling. Air emissions were determined for lead pouring operations, steam and power plants, the asphalt plant, explosives detonation, removal of asbestos, and beryllium operations. All nonradioactive air emissions remained within federal and state limits during 1991. Surface water and groundwaters are monitored to determine the Los Alamos National Laboratory's (LANL's or the Laboratory's) impact on the environment; no observable effects are caused by Laboratory operations. Municipal and industrial water quality met federal and state standards during 1991.

A. Nonradioactive Emissions and Effluents Monitoring

1. Air.

a. 1990 Air Pollutant Emissions Inventory. During 1991, as part of the Environmental Oversight and Monitoring Agreement between the Department of Energy (DOE) and the New Mexico Environment Department (NMED), the Laboratory undertook an intensive effort to create a comprehensive, Laboratory-wide air pollutant emissions inventory based on 1990 chemical usages and operations. The goal of this effort was to update and expand the original emissions inventory prepared in 1987. The original inventory was performed to evaluate emissions under NMED-regulated toxic air pollutants and determine whether source registration under Air Quality Control Regulation (AQCR) 752 was required. The 1990 inventory expanded upon the 1987 work to include criteria pollutants, as well as hazardous air pollutants not currently regulated under AQCR 702 but listed in the Federal Clean Air Act.

During the 1987 survey, the Laboratory identified approximately 500 sources (specific rooms within buildings) in 44 operating groups as having the potential to emit air pollutants. For the 1990 inventory, the Laboratory evaluated approximately 1,100 emissions sources, chemical usages, and air pollutant emissions. Each emission source was described using maximum 1-hour and annual chemical usage estimates based on conservative assumptions about the operation's schedule, usage, disposal, and evaporation. Environmental Protection Agency (EPA)-published air pollutant emission factors found in AP-42: Compilation of Air Pollutant Emission Factors (EPA 1986a) or emission factors provided on the EPA Clearinghouse Inventory of Emission Factors (CHIEF) bulletin board were used to estimate emission rates. For operations containing no emission factor, material balance equations were used. The Laboratory developed an electronic database, the Regulated Air Pollutants System (RAPS), to compile, document, and store final emission estimates. Results of this study will be presented in the "Environmental Surveillance at Los Alamos during 1992" report.

b. Lead Pouring Operations. A lead pouring facility for casting lead is located at Technical Area (TA) 3-38. This facility emits particulate matter containing lead. Both federal and state ambient air quality standards for lead are 1.5 $\mu g/m^3$, averaged over a calendar quarter. Approximately 457 kg (1,000 lb) of lead were poured during 1991. The EPA emissions factors for total suspended particulate (TSP) emissions range from 0.87 lb to 0.04 lb of TSP matter and 0.01 lb of lead per ton of lead poured. There are considerable differences between the two, so both were used to provide a range of possible emissions, as shown in Table VI-1.

Table VI-1. Maximum Lead Emissions from the Lead-Pouring Facility per Quarter in 1991

	Maximum Quarterly Emissions	
Pollutant	Emissions (lb)	Concentrations ($\mu g/m^3$)
TSP matter	0.02–0.44	0.001–0.03
Lead	0.01	0.0001

The maximum quarterly ambient air quality concentrations for 1991 are also shown in the table. Air dispersion procedures recommended by the EPA (EPA 1986b) were used to estimate these concentrations on the basis of quarterly emissions from the lead pouring facility. Impacts were estimated by assuming that all of the TSP matter was lead. This approach provides a worst-case estimate of ambient lead concentration of 0.03 $\mu g/m^3$, or about 2% of the standard. If the lower lead emission factors for secondary lead processing were used, the estimated air concentrations would be only 0.0001 $\mu g/m^3$, or about 0.005% of the standard.

c. Steam Plants and Power Plant. Fuel consumption and emission estimates for the steam plants located throughout the Laboratory and the TA-3 power plant are reported in Table VI-2. The plants are sources of particulate matter, oxides of nitrogen (NO_x), carbon monoxide, and hydrocarbons. The NO_x emissions from the TA-3 power plant were estimated on the basis of boiler exhaust gas measurements. Exhaust gas measurements also indicated that sulfur oxides (SO_x) in the exhaust gases were below minimum detection levels. EPA emission factors were used in making the other emission estimates (EPA 1986a). The emissions from these plants are low, posing no threat of violating ambient air quality standards. The Western Area steam plant used as a standby plant was not operated during 1991.

d. Asphalt Plant. In addition to the power plant and steam plants at TA-3, Johnson Controls Inc. (JCI) operates an asphalt plant at TA-3. As part of its contract with the Laboratory, JCI provides annual records summarizing operations at the asphalt concrete plant. The records presented in Table VI-3 show 1991 production figures and estimates of emissions. Asphalt production has decreased steadily since 1986 because most of the asphalt used at the Laboratory has been purchased from an outside vendor. Although it is not required to, the plant meets the New Source Performance Standards stack emission limits for asphalt plants.

e. Detonation of Explosives. The Laboratory conducts explosive testing by detonating explosives at Dynamic Testing Division firing sites. The Laboratory maintains monthly shot records, including the type of explosive and weight fired at each mound to tract

Table VI-2. Emissions and Fuel Consumption during 1991 from the Steam Plants and TA-3 Power Plant

Pollutant	TA-3	TA-16	TA-21	Western Area	Total
Emissions (ton/yr)					
Particulate Matter	0.8	0.6	0.2	0.0	1.6
Oxides of Nitrogen	6.9	17.2	5.4	0.0	29.5
Carbon Monoxide	10.2	4.3	1.3	0.0	15.8
Hydrocarbons	0.4	0.7	0.2	0.0	1.3
Fuel Consumption (10^9 Btu/yr)	535	270	84	0	889

Table VI-3. Asphalt Plant Emissions in 1991

Production (ton/yr)	Particulate Matter Emissions (lb/yr)	Sulfur Dioxide Emissions (lb/yr)	Nitrogen Dioxide (lb/yr)	Carbon Monoxide (lb/yr)	Nonmethane Hydrocarbons (lb/yr)	Formaldehyde (lb/yr)
4,147	138	1,210	149	153	116	0.6

emissions from this activity. Emission rates from 1990 operations were included in the 1990 air pollutant emission inventory. Table VI-4 summarizes the explosives detonation conducted at the Laboratory during 1991.

f. Asbestos. During 1991, JCI removed approximately 2,095 lin ft of friable asbestos, including 110 lin ft of potentially radioactively contaminated friable material, from small jobs covered by the annual notification to NMED. Approximately 193 sq ft of friable insulation was removed from vessels and other facility components, and 330 sq ft of nonfriable vinyl-asbestos floor tile was removed. Of the floor tile, approximately 48 sq ft was disposed of as potentially radioactively contaminated material. A total of 1,640 lin ft of friable asbestos material was removed through large jobs.

g. Beryllium. Beryllium machining operations are located in Shop 4 at TA-3-39, in Shop 13 at TA-3-102, the beryllium shop at TA-35-213, and the beryllium processing facility at TA-3-141. Exhaust air from each of these operations passes through air pollution control equipment before exiting from a stack. Source tests have demonstrated that all beryllium operations meet the emission limits established by National Emission Standards for Hazardous Air Pollutants and that emissions are so low that there is negligible impact on ambient air quality.

2. Water.

a. Surface Water and Groundwater Monitoring. Surface waters and groundwaters are sampled and analyzed to monitor dispersion of chemicals from Laboratory operations. Chemical concentrations in water from areas where there has been no direct release of treated effluents show no observable effects caused by Laboratory operations. The chemical quality of surface waters from areas with no effluent release varied with seasonal fluctuations. The quality of off-site water in and downstream from the release areas reflects some impact from Laboratory operations, but these waters are not a source of municipal or industrial water supply. Water in Los Alamos Canyon is used by livestock.

Groundwater resource management and protection at Los Alamos is focused on the main aquifer underlying the region (see Section II.C, Geology-Hydrology). Groundwater resource monitoring routinely documents conditions of the water supply wells and the main aquifer. The long and comprehensive record of data indicates that DOE operations at the Laboratory have not resulted in any contamination of the main aquifer.

b. National Pollutant Discharge Elimination System. The DOE has two National Pollutant Discharge Elimination System (NPDES) permits. One permit covers the effluent discharges for nine sanitary wastewater treatment facilities and 130 industrial outfalls at the Laboratory. A summary of these outfalls is presented in Table D-2. The other permit covers one industrial outfall at the hot dry rock geothermal facility located 50 km (30 mi) west at Fenton Hill. Both permits are issued and enforced by EPA Region 6 in Dallas, Texas. Through a joint federal/state agreement, NMED performs some compliance evaluation inspections and monitoring for EPA.

The NPDES permit for the Laboratory expired on March 1, 1991, and is being administratively continued under 40 CFR 122.6. A revised draft permit was issued to LANL on May 16, 1992.

During 1991, effluent limits were exceeded 3 times out of 297 samples collected from the sanitary wastewater facilities. Effluent limits were exceeded 21 times out of 1,799 samples collected from the industrial outfalls. As shown in Fig. III-2, overall compliance for the sanitary and industrial discharges during 1991 was 99% and 98.8%, respectively. There was no discharge from the industrial outfall at the geothermal facility at Fenton Hill during 1991.

Table VI-4. Estimated Concentrations of Toxic Elements Aerosolized by Dynamic Experiments

Element	1991 Total Usage (kg)	Fraction Aerosolized (%)	Annual Average Concentration ($\mu g/m^3$) (4 km)[a]	Annual Average Concentration ($\mu g/m^3$) (8 km)[a]	Applicable Standard ($\mu g/m^3$)
Beryllium	2.2	2	3.0×10^{-8}	1.2×10^{-8}	0.01[b]
Lead	30.5	100[c]	3.2×10^{-5}	1.3×10^{-8}	1.5[d]
Heavy metals	113.4	100[c]	1.2×10^{-4}	4.7×10^{-5}	10[d]

[a]Distance downwind.

[b]Standard for 30-day average, New Mexico AQCR 201.

[c]No data are available; estimate was done assuming worst-case percentage was aerosolized.

[d]Standard for 3-month average (40 CFR 50.12).

The Environmental Protection Group (EM-8) continued the waste stream identification and characterization program during 1991 in order to verify that each waste stream is properly monitored under the outfall category in which it is permitted. These studies consist of dye testing; interviews with user groups; and coordination with other Laboratory organizations to determine sources, concentrations, and volumes of pollutants that enter waste streams, receive treatment, and are discharged to the environment.

TA-50 Liquid Waste Treatment Plant. In recent years, treated effluents containing constituents regulated by the NPDES permit have been released from the central liquid waste treatment plant at TA-50. Table VI-5 presents information on the quality of that effluent for 1990 and 1991. The total effluent volume increased in 1991 while the constituent levels generally decreased (see Section V.B.2 for information on radioactive constituents released from the plant). Effluents from TA-50 are discharged into the normally dry stream channel in Mortandad Canyon where surface flow has not passed beyond the Laboratory's boundary since the plant began operation in 1963.

c. Safe Drinking Water Act, Municipal and Industrial Water Supplies. This program includes sampling from various points in the Laboratory and County water distribution systems to ensure compliance with the Safe Drinking Water Act (SDWA) (40 CFR 141). The EPA has established maximum contaminant levels for microbiologic, organic, and inorganic constituents in drinking water. These standards have been adopted by the State of New Mexico and are included in the New Mexico Water Supply Regulations (NMEIB 1991). The NMED has been authorized by EPA to administer and enforce federal drinking water regulations and standards in New Mexico.

During 1991, all water samples collected under the SDWA program at Los Alamos were found to be in compliance with the maximum contaminant levels established by regulation. Summaries of the results are presented in Tables III-8, III-9, and III-10. There were no violations or fines levied on the Laboratory's municipal and industrial water supplies during 1991.

Each month during 1991, an average of 46 samples was collected throughout the Laboratory and County water distribution systems to determine the free chlorine residual available for disinfection and the microbiological quality of the distribution systems. During 1991, no coliform bacteria were found. Sixty-five of the microbiological samples (approximately 12%) collected were found to have some noncoliform bacteria present. Although the presence of noncoliform bacteria is not a violation of the SDWA, it does indicate stagnant water or biofilm growth in the distribution lines. A summary of the analytical results is found in Table III-12.

3. Superfund Amendments and Reauthorization Act: Title III Reporting.

The University of California, as operator of the Laboratory, is required to report under Title III Section 313 of SARA if: (1) the Laboratory uses a listed toxic chemical above a specified threshold, and (2) the use of the chemical comes under the Standard Industrial Classification (SIC) Codes 20-39. All research operations at the Laboratory are exempt under other provisions of the regulation. Only pilot plants and specialty chemical production or manufacturing facilities at the Laboratory which fall under (1) above must report their releases.

The only facility of the Laboratory which could be considered to be within SIC codes 20-39 and therefore required to report under Section 313 is TA-55-4, the Plutonium Processing Facility. Reporting the chemical use and emissions for TA-55 has been the Laboratory's decision because of the special materials processing done at the facility. The only regulated chemical used at the Plutonium Processing Facility in amounts greater than the Section 313 reporting thresholds is nitric acid.

The Laboratory submitted the required Section 313 report to EPA in July of 1991. This report covered the releases of nitric acid during 1990. About 24,320 kg (53,500 lb) of nitric acid were used for plutonium processing with releases to the air of approximately 468.7 kg (1,031 lb). Atmospheric releases were calculated using data obtained from a study which measured the air emissions from the facility. All other nitric acid that was not consumed in chemical reactions was completely neutralized during wastewater treatment operations. For this reason only the air releases required reporting for 1990. Data on releases for CY91 will be reported under Section 313 in July 1992.

Table VI-5. Quality of Nonradioactive Effluent Released from the TA-50 Radioactive Liquid Waste Treatment Plant in 1990 and 1991

Nonradioactive Constituents	Mean Concentration (mg/L)	
	1990	1991
Cd[a]	4.3×10^{-4}	3.3×10^{-4}
Ca	241	290
Cl	97	82
Total Cr[a]	2.5×10^{-2}	4.0×10^{-3}
Cu[a]	0.2	0.2
F	11	3.3
Hg[a]	3.6×10^{-4}	1.6×10^{-4}
Mg	6.3	0.2
Na	591	397
Pb[a]	2.1×10^{-2}	7.1×10^{-3}
Zn[a]	0.1	0.08
CN	0.2	0.2
COD[a]	33	29
NO_3-N	297	164
PO_4	0.2	0.9
TDS[b]	2,550	1,810
pH[a]	7.1–7.8	7.16–7.7
Total Effluent Volume	2.11×10^7 Liters	2.19×10^7 Liters

[a]Constituents regulated by NPDES permit.
[b]Total dissolved solids.

4. Toxic Substances Control Act.

The Toxic Substances Control Act (TSCA) (15 U.S.C. *et seq.*) is administered by EPA which has authority to conduct premanufacture reviews of new chemicals prior to their introduction into the marketplace; require testing of chemicals which may present a significant risk to humans and the environment; and require recordkeeping and reporting requirements for new information regarding adverse health and environmental effects associated with chemicals. Because the Laboratory's activities are in the realm of research and development, the PCB regulations (40 CFR 761) have been the Laboratory's main concern under TSCA which governs the manufacture, use, storage, handling, and disposal of PCB equipment and sets standards for PCB spill clean-ups.

Efforts continued toward the replacement, reclassification, and disposal of PCB equipment at the Laboratory. During 1991, the following PCB waste was sent off site for disposal: 25,306 kg (55,673 lb) liquid PCB oil that included 50-499 ppm PCB oil; 4,502 kg (9,904 lb) contaminated debris; 3,114 kg (6,851 lb) contaminated water; 64,621 kg (142,166 lb) from 39 transformers; and 6,622 kg (14,568 lb) from capacitors. In addition, 31,496 kg (69,291 lb) of PCB-contaminated soil, debris, and equipment were disposed of at TA-54, Area G, an EPA-approved area for the disposal of PCB-contaminated solid materials. Of the 31 PCB transformers that have been undergoing the retrofill process, 11 were reclassified to non-PCB status, and most of the rest were reclassified to PCB-contaminated status. DOE Tiger Teams audited and inspected the Laboratory's PCB program in 1991; no other audits or inspections were conducted in 1991. In addition, a program to identify and recall PCB equipment which was loaned to universities and other institutions prior to adoption of PCB regulations was initiated in 1991.

B. Unplanned Releases of Nonradiological Materials

1. Airborne Releases.

No airborne nonradiological unplanned releases were reported during 1991.

2. Liquid Releases.

On September 25, 1991, an underground diesel fuel transfer line broke during start-up of the TA-3 power plant's back-up fuel system. Approximately 100-200 gal. of diesel fuel oil surfaced and were discharged across the ground to a storm water channel where it drained into a tributary to Sandia Canyon. The discharge was immediately reported to EPA and NMED. Corrective actions included shutting down the fuel line immediately upon discovery and cleaning up the diesel fuel. The diesel spill was contained in the water course within minutes using absorbent booms and pillows. Pools of diesel and water were removed using a wet/dry vacuum and absorbents. The contaminated soil was sampled, removed, and disposed of at the Los Alamos County landfill.

During 1991, 56 other releases of nonradioactive liquids occurred at the Laboratory and were reported to the EPA and NMED. The NMED Surface Water Bureau has requested that all liquid releases be reported, regardless of any potential impact on the environment. Each of these discharges was minor in nature and was contained on DOE property. None were found to be of any threat to health or the environment. Sampling and clean-up were completed, as appropriate, to confirm the presence or absence of pollutants and to prevent further migration. Over 60% of these unplanned releases were either potable water or steam condensate originating from the Laboratory's utility systems.

The following is a summary of these 56 unplanned releases:

- 23 releases of potable water which originated from water line breaks and other sources in the Los Alamos water supply system;
- 13 releases of steam condensate originating from condensate return line breaks and other sources in the Laboratory's steam system;
- 11 releases of sanitary sewage (less than 1,000 gal. each) from the Laboratory's wastewater treatment plant collection system;
- 5 unplanned releases of cooling water or chiller water;

- 500-1,000 gal. of storm water and residual oil from fuel storage tanks at TA-60 Sigma Mesa, on November 15, 1991;
- 3 gal. of ethylene glycol at TA-55 PF8, on May 19, 1991;
- residual oil in the parking lot caused a sheen in the storm drain near TA-3-105 on August 1, 1991; and
- foam noted in storm drain near TA-3-105 on August 28, 1991, a result of car washing activities in the area. Less than 1 qt of a detergent and water mixture was released into the storm drain.

EM-8 prepared a generalized Notice of Intent (NOI) to Discharge for the discharge of potable water from the Los Alamos water supply system, including production wells, transmission lines, storage tanks, booster pump stations, and other related facilities. The generalized NOI was submitted to NMED on October 31, 1991. The NOI provides the Laboratory with regulatory coverage for releases of potable water from the water supply system that are not considered hazardous to public health and are not covered under the NPDES permit. EM-8 also prepared a generalized NOI for the release of steam condensate from the Laboratory's steam condensate distribution and condensate return systems.

C. Environmental Sampling for the Nonradioactive Effluent Program

1. Air.

a. Ambient Air Monitoring. The nonradiological monitoring network consists of one criteria pollutant station, nine samplers where beryllium is monitored, one acid precipitation monitoring station, and one visibility monitoring station. For the 1991 toxic air pollutant (TAP) study, five additional monitoring stations were used. Results of the 1991 ambient air monitoring program are described fully in Section IV.C.2. The special air sampling program conducted in 1991 is described below.

b. Toxic Air Pollutant Sampling Program. During January 1991, the Laboratory conducted a short-term, intensive air monitoring program to estimate the impact of chemical emissions on the ambient air environment. Sampling and analysis of indicator chemicals required an innovative and high-sensitivity strategy in order to detect chemicals at very low concentrations in the ambient air, as well as to address the complex terrain and meteorology of the area and potential interferences from Los Alamos community emissions. The indicator chemicals were chosen from a list of more than 600 potential air contaminants regulated by the State of New Mexico. An inventory prepared in 1987 showed that the Laboratory emitted 50 of these regulated air contaminants in amounts greater than 10 lb/yr. Of these 50 compounds, certain compounds were identified as traceable only to Laboratory operations since no other nearby sources of these chemicals were likely to exist (for example, acetone and 2-butanone). Other chemicals were chosen that would be traceable to non-Laboratory sources. For instance, chemicals indicative of automobile emissions were targeted. Overall, 20 organic vapors, 6 metals, and 5 inorganic acid vapors were chosen as target compounds. These were measured at five sites around the Laboratory over seven consecutive days in January 1991. Results of this sampling program are summarized in Tables IV-14 through IV-16.

2. Water.

The Laboratory maintains three separate programs which monitor water quality: the surface and groundwater monitoring programs, NPDES compliance, and SDWA compliance.

The first program includes sampling of water supply wells and special monitoring wells under the long-term environmental surveillance program. The samples are collected by EM-8 personnel and are analyzed by the Environmental Chemistry Group (EM-9) laboratory. Routine chemical analyses of water samples have been carried out for many constituents over a number of years. Although surface water and shallow groundwater are not sources of municipal or industrial water supplies, results of these analyses are compared with NMED and EPA drinking water standards (maximum concentration levels). The chemical quality of surface waters is compared to N.M. Livestock and Wildlife Watering Standards. The results of these programs are reported for nonradioactive constituents in Sections IV.D and VII of this report. A detailed description of procedures for sampling surface water and groundwater is presented in Section VIII.C.3.

Under the Laboratory's existing NPDES permit for Los Alamos, samples are collected on a weekly basis and analyzed for those chemicals listed in the permit. Results are reported each month to the EPA and NMED. See Section VIII.C.3 for more information on the NPDES compliance sampling program.

Samples collected by the Laboratory to ensure compliance with SDWA standards are analyzed for organic, inorganic, and radioactive constituents at the New Mexico Health Department's Scientific Laboratory Division (SLD) in Albuquerque. The SLD reports the analytical results directly to NMED. The JCI Environmental Laboratory (JENV) also collects samples throughout the Laboratory and County water distribution systems and tests them for microbiological contamination, as required by the SDWA. The JENV is certified by SLD for microbiological testing of drinking water. See Section VIII.C.3 for more information on the sampling program.

VII. GROUNDWATER PROTECTION MANAGEMENT PROGRAM

Efforts to monitor and protect groundwater quality in the Los Alamos area began in 1949. The long and comprehensive record of data indicates that Department of Energy (DOE) operations at Los Alamos National Laboratory (LANL or the Laboratory) have not resulted in any measurable contamination of the main aquifer. In addition, there has been no significant depletion of the main aquifer groundwater resource.

A. Introduction

Groundwater resource management and protection at the Laboratory are focused on the main aquifer underlying the region (see Section II.C of this report: Geology-Hydrology). The aquifer has been of paramount importance to Los Alamos since the days of the post-World War II Manhattan Engineer District when the Atomic Energy Commission (AEC) needed to develop a reliable water supply. The U.S. Geological Survey (USGS) was extensively involved in overseeing and conducting various studies for development of groundwater supplies starting in 1945–46. Studies specifically aimed at protecting and monitoring groundwater quality were initiated as joint efforts between the AEC, the Los Alamos Scientific Laboratory, and the USGS in about 1949.

The long and comprehensive record of data indicates that DOE operations at the Laboratory have not resulted in any measurable contamination of the main aquifer. The development and production of the water supply have not resulted in any significant depletion of the resource as there is no widespread major decline of the piezometric surface of the aquifer. Drawdowns are localized in the vicinity of the production wells; nearly complete recoveries are observed when wells are shut down for routine maintenance.

The early groundwater management efforts evolved with the growth of the Laboratory's current Groundwater Protection Management Program that addresses environmental monitoring, resource management, aquifer protection, and geohydrologic investigations. Essentially all of the action elements required by DOE Order 5400.1 (DOE 1988a) as part of the Groundwater Protection Management Program have been functioning at the Laboratory for varying lengths of time prior to issuance of the DOE order. Formal documentation for the program, the "Groundwater Protection Management Program Plan," was issued in April 1990. Several hundred reports and articles document studies and data germane to groundwater and the related Los Alamos environmental setting (Bennett 1990).

Groundwater resource monitoring routinely documents conditions of the water supply wells and the hydrologic conditions of the main aquifer as part of the overall Groundwater Protection Management Program. This information is documented in an annual series of reports providing detailed records of pumping and water level measurements. The most recent report in this series is entitled "Water Supply at Los Alamos During 1989" (Stoker 1992).

The groundwater quality monitoring described in this report is the current evolution of the program that was initiated by the USGS for the AEC in 1949. Groundwater quality monitoring addresses the main aquifer at Los Alamos; shallow alluvial groundwaters in canyons; the deeper perched systems in the basalt; the Puye conglomerate beneath parts of Pueblo, Los Alamos, and Sandia Canyons; and special studies on the vadose zone. See Section II.C for a general description of hydrogeological relationships.

Concentrations of radionuclides in environmental water samples from the main aquifer, the alluvial canyon aquifers, and the perched systems, whether

collected within the DOE site boundary or off site, may be evaluated by comparison with derived concentration guides (DCGs) for ingested water calculated from DOE's public dose limits (see Section V.C.2). Concentrations of radioactivity in samples of water from the water supply wells completed in the Los Alamos main aquifer are also compared to New Mexico Environment Department (NMED) and Environmental Protection Agency (EPA) drinking water standards or to the DOE derived concentration guides applicable to radioactivity in DOE drinking water systems, which are more restrictive in a few cases.

The concentrations of nonradioactive chemical quality parameters may be evaluated by comparing them to NMED and EPA drinking water standards (maximum concentration levels [MCLs]), even though these standards are only directly applicable to public water supply. The supply wells in the main aquifer are the source of the Los Alamos public water supply. Although not a source of municipal or industrial water supply, the shallow alluvial groundwaters that result in return flow to surface water and the various springs are used by livestock and wildlife and may be compared to the Livestock and Wildlife Watering Standards established by the New Mexico Water Quality Control Commission (NMWQCC 1991).

B. Monitoring Network

There are three principal groups of groundwater sampling locations: main aquifer, alluvial canyon aquifers, and the localized perched systems. The sampling locations are shown in Fig. VII-1 and referenced by map number in Table D-20.

Water for drinking and industrial use is also obtained from a well at the Laboratory's experimental geothermal site (Fenton Hill, Technical Area [TA] 57) about 45 km (28 mi) west of Los Alamos on Forest Service land. The well is about 133 m (436 ft) deep, completed in volcanics. Information about groundwater and other environmental monitoring at this remote technical area is presented in Section IV.J.5.

1. Main Aquifer.

Sampling locations for the main aquifer include test wells, supply wells, and springs. Seven deep test wells, completed into the main aquifer, are routinely sampled. One of the test wells is off site; the other six are within the Laboratory boundary. The off-site well, Test Well 2, drilled in 1949, is in the middle reach of Pueblo Canyon downstream from the confluence with Acid Canyon on Los Alamos County land. Depth to the top of the main aquifer in 1990 was 241 m (789 ft). Test Well 1, drilled in 1950, is in the lower reach of Pueblo Canyon near the DOE boundary with San Ildefonso Pueblo. Depth to the top of the main aquifer in 1991 was 155 m (507 ft).

Test Well 3, drilled in 1949, is in the midreach of Los Alamos Canyon just upstream from the confluence with DP Canyon. Depth to the top of the main aquifer in 1990 was 236 m (774 ft).

Test Well 8, drilled in 1960, is in the midreach of Mortandad Canyon. Depth to the top of the main aquifer in 1961 was about 295 m (968 ft).

Test Wells DT-5A, DT-9, and DT-10 (all three were drilled in 1960) are at the southern edge of the Laboratory in TA-49. Depths to the top of the main aquifer were 359 m (1.180 ft) in 1960, 332 m (1,090 ft) in 1967, and 306 m (1,006 ft) in 1982. When drilled, no perched water was observed between the surface of the mesa and the top of the main aquifer.

Samples are collected from 16 deep wells in 3 well fields that produce water for the Laboratory and community. The well fields include the Los Alamos and Guaje fields located off site in canyons east of the Laboratory and the on-site Pajarito field.

The Los Alamos Well Field is located on San Ildefonso Pueblo lands east of the Laboratory in Los Alamos Canyon. In 1991, the Los Alamos Well Field had four producing wells, including LA-1B, LA-2, LA-3, and LA-5. Wells LA-1, LA-4, and LA-6 were entirely out of service; their pump houses were demolished in 1990 as the initial steps in phasing out the Los Alamos Well Field. Most of the wells in that field have reached the limit of economically useful production (Purtymun 1988c), and reconstruction of State Road 502, which started in 1991, required discontinuance of the transmission line. The last production of water for the distribution system was in September 1991. Wells in the field range in depth from 265 m to 610 m (870 ft to 2,000 ft). Movement of water in the upper 411 m (1,350 ft) of the main aquifer in this area is eastward at about 6 m/yr (20 ft/yr) (Purtymun 1984).

The Guaje Well Field is located northeast of the Laboratory on U.S. Forest Service lands in Guaje Canyon. The Guaje Well Field contains seven wells, six in production during 1991. Wells in this field

range in depth from 463 m to 610 m (1,520 ft to 2,000 ft). Movement of water in the upper 430 m (1,410 ft) of the aquifer is southeastward at about 11 m/yr (36 ft/yr) (Purtymun 1984).

The Pajarito Well Field is located in Sandia and Pajarito Canyons and on mesa tops between those canyons. The Pajarito Well Field comprises five wells ranging in depth from 701 m to 942 m (2,300 ft to 3,090 ft). Movement of water in the upper 535 m (1,750 ft) of the aquifer is eastward at 29 m/yr (95 ft/yr) (Purtymun 1984).

Two new water supply wells were completed in 1990. These are the first wells in a new field designated as the Otowi Well Field, and the wells were designated Otowi-1 and Otowi-4. No production from these wells occurred in 1991; Otowi-4 is expected to be equipped with a pump and connected to the distribution system during 1992.

Additional wells in the aquifer in the Santa Fe Group sedimentary deposits included five San Ildefonso Pueblo wells located near the Rio Grande. These included two wells that are used for water

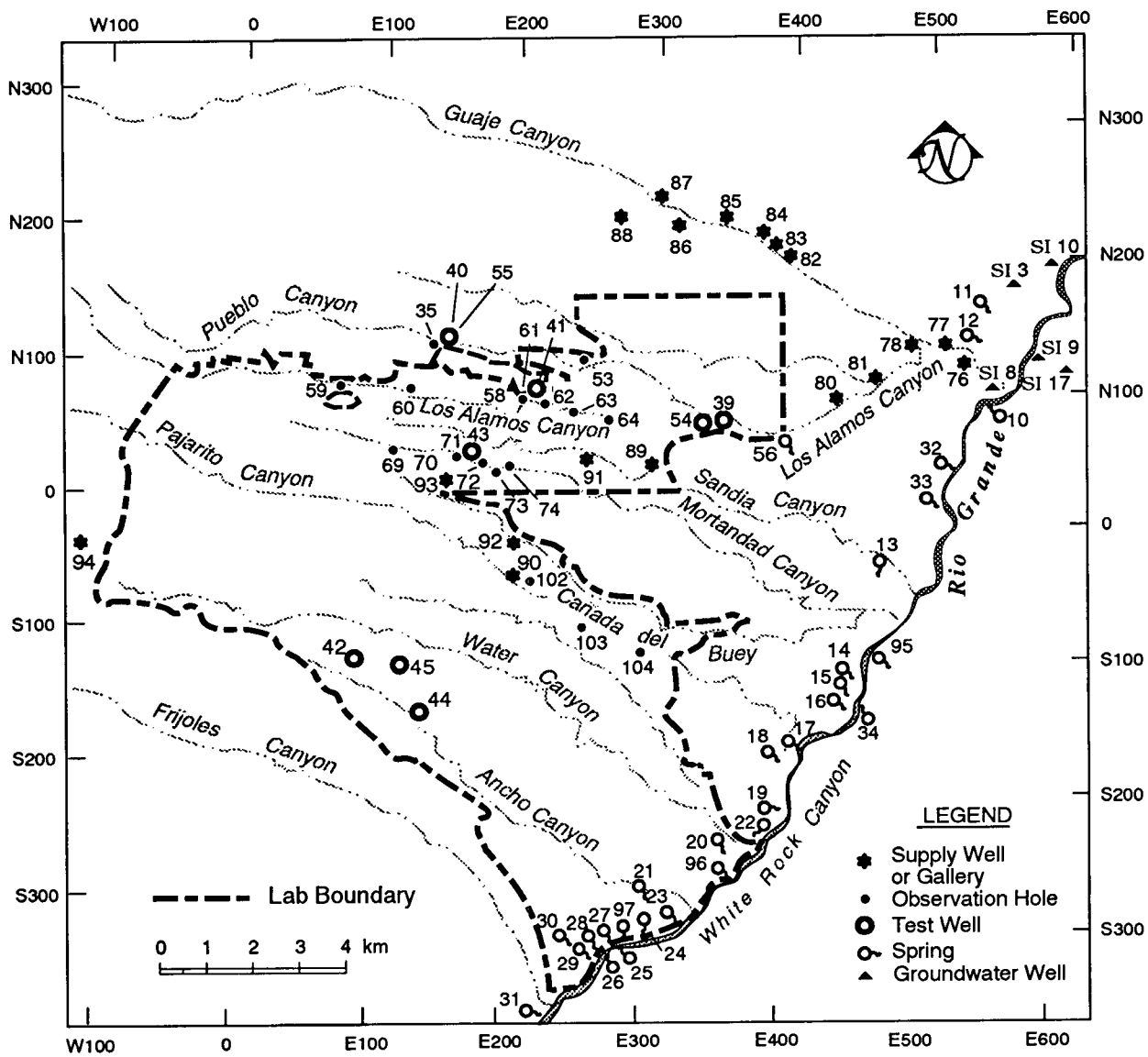


Fig. VII-1. Groundwater sampling locations on and near the Laboratory site.

supply, Pajarito Well (Pump 1) and the Halladay House Well; one that is used for irrigation, Don Juan Playhouse Well; and two artesian wells presently unused, the Eastside and Westside Artesian wells. See Section IV.I.5 for information on the Memorandum of Understanding between DOE, the Bureau of Indian Affairs, and Pueblo de San Ildefonso.

Numerous springs near the Rio Grande are sampled because they are representative of natural discharge from the main aquifer (Purtymun 1980b). See Section II.C. for information on discharge into the Rio Grande. In White Rock Canyon four groups of springs discharge from the main aquifer. Three groups (I, II, and III) have similar, aquifer-related chemical quality. Chemical quality of springs in Group IV reflect local conditions in the aquifer, probably discharging through faults in volcanics. Indian and Sacred Springs are west of the river in lower Los Alamos Canyon. These two springs discharge from faults in the siltstones and sandstones of the Tesuque Formation.

2. Alluvial Canyon Aquifers.

The alluvial canyon aquifers in four canyons are sampled by means of shallow observation wells as part of the routine monitoring program. Three of these canyons are radioactive effluent release areas: Pueblo, Los Alamos, and Mortandad Canyons. The fourth is Pajarito Canyon, immediately south of the existing solid waste management areas in TA-54 on Mesita del Buey. All of the alluvial aquifer sampling locations are on site.

Acid Canyon, a small tributary of Pueblo Canyon, received untreated and treated industrial effluent that contained residual radionuclides from 1944 to 1964 (ESG 1981). Pueblo Canyon currently receives treated sanitary effluent from Los Alamos County Bayo sewage treatment plant in the middle reach of Pueblo Canyon. Water occurs seasonally in the alluvium, depending on the volume of surface flow from snowmelt, thunderstorm runoff, and sanitary effluents. One sampling point, Hamilton Bend Spring, which in the past discharged from alluvium in the lower reach of Pueblo Canyon, has been dry since 1990, probably because there was no discharge from the older, almost abandoned Los Alamos County Pueblo sewage treatment plant. Further east, at the location of well APCO-1, the alluvium is continuously saturated, mainly because of infiltration of effluent from the Los Alamos County Bayo sanitary sewage treatment plant. At APCO-1, the alluvium is about 3.4 m (11 ft) thick and depth to water is about 1.8 m (6 ft).

The on-site reach of Los Alamos Canyon presently carries inflow from the Los Alamos Reservoir to the west of the Laboratory, as well as National Pollutant Discharge Elimination System (NPDES)-permitted effluents from TA-2, TA-53, and TA-21. In the past, the reservoir received treated and untreated industrial effluents containing some radionuclides. See Section IV.D, Surface Water Monitoring, for more information on historic releases. Infiltration of NPDES-permitted effluents and natural runoff from the stream channel maintains a shallow body of water in the alluvium of Los Alamos Canyon. Water levels are highest in late spring from snowmelt runoff and in late summer from thundershowers. Water levels decline during the winter and early summer, when storm runoff is at a minimum. Sampling stations consist of six observation wells completed into the alluvium in Los Alamos Canyon. The wells range in depth from about 6 m to about 9 m (20–30 ft). Depth to water is typically in the range of 1.5 m to 3 m (5–10 ft).

Mortandad Canyon has a small drainage area that also heads at TA-3. Its drainage area presently receives inflow from natural precipitation and a number of NPDES-permitted effluents including those from the current radioactive liquid waste treatment plant at TA-50. See Section IV.D for more information. These infiltrate the stream channel and maintain a saturated zone in the alluvium extending about 3.5 km (2.2 mi) downstream from the TA-50 outfall location. The easternmost extent of saturation is on site, about 1.6 km (1 mi) west of the Laboratory boundary with San Ildefonso Pueblo. The alluvium is less than 1.5 m (5 ft) thick in the upper reach of Mortandad Canyon and thickens to about 23 m (75 ft) at the easternmost extent of saturation. The saturated portion of the alluvium is perched on weathered and unweathered tuff and is generally no more than 3 m (10 ft) thick. There is considerable seasonal variation depending on the amount of runoff experienced in any given year (Stoker 1991). Velocity of water movement in the perched aquifer ranges from 18 m/day (59 ft/day) in the upper reach to about 2 m/day (7 ft/day) in the lower reach of the canyon (Purtymun 1974c, 1983). The top of the main aquifer is about 290 m (950 ft) below the perched aquifer. Monitoring wells that are sampled as part of

the routine monitoring program consist of six observation wells in the shallow alluvial aquifer. These wells range in depth from about 3.7 m to about 21 m (12–69 ft) with depths to water ranging from about 0.9 m to about 14 m (3–45 ft). Additional wells that have been installed in the lower reach of the canyon are dry.

In Pajarito Canyon, water in the alluvium is perched on the underlying tuff and is recharged mainly through snowmelt and thunderstorm runoff and some NPDES-permitted effluents. Three shallow observation wells were constructed in 1985 as part of a compliance agreement with the State of New Mexico to determine if technical areas in the canyon or solid waste disposal activities on the adjacent mesa were affecting the quality of shallow groundwater.

3. Perched Systems.

Perched water systems of limited extent occur in the conglomerates and basalts beneath the alluvium in portions of Pueblo, Los Alamos, and Sandia Canyons. Samples are obtained from two test wells and one spring. Test Well 2A is located in the off-site middle reach of Pueblo Canyon. Test Well 2A (drilled in 1949 to a depth of 40.5 m [133 ft]) penetrates the alluvium and Bandelier Tuff and is completed into the Puye Conglomerate. Aquifer tests indicated that the perched aquifer in the conglomerate is of limited extent. Depth to water was about 27 m (89 ft) in 1990.

Test Well 1A is located in the on-site lower reach of Pueblo Canyon. Test Well 1A (drilled in 1950 to a depth of 69 m [225 ft]) penetrates the alluvium, Puye Conglomerate, and basalt and is completed in basalts. Depth to water was about 53 m (173 ft) in 1991. Perched water in the basaltic rocks is also sampled from Basalt Spring, which is off site in lower Los Alamos Canyon on San Ildefonso Pueblo. Measurements of water levels over a period of time indicate that the perched aquifer is hydrologically connected to the stream in Pueblo Canyon. Perched water in similar stratigraphy was observed during the drilling of water supply wells Otowi-4 in Los Alamos Canyon (depth about 61 to 76 m [200–250 ft]), Otowi-1 in Pueblo Canyon (depth about 69 to 76 m [225–250 ft]), and PM-1 in Sandia Canyon (depth about 137 m [450 ft]).

Some recharge to the perched aquifer in the basalt occurs near Hamilton Bend Spring. The time for water from the recharge area near Hamilton Bend Spring to reach Test Well 1A is estimated to be 1 to 2 months, with another 2 to 3 months required to reach Basalt Spring. Recharge probably also occurs in Los Alamos Canyon.

Some perched water occurs in volcanics on the flanks of the Jemez mountains off site to the west of the Laboratory. This discharges into several springs (Armistead and American Springs) and a significant flow from the Water Canyon gallery in Water Canyon. The gallery contributed to the Los Alamos water supply for 41 years, producing 23 to 96 million gallons annually. Since 1988 it has only been used for makeup water for the steam plant at TA-16, producing about 12 million gallons in 1991.

4. Vadose Zone.

The occurrence and movement of water in unsaturated conditions has been studied in numerous locations within the Laboratory starting with special USGS studies in the 1950s (Purtymun 1990c). Knowledge of vadose zone processes is relevant to understanding the potential for downward movement of water that could constitute recharge to the main aquifer or provide a mechanism for downward migration of contaminants.

In general, the vadose zone studies show that there is consistently low moisture content (less than 10% by volume) in the tuff beneath mesa tops at depths greater than a few tens of feet, the zone affected by seasonal inputs of moisture and evapotranspiration. This carries the implication that very little, if any, recharge from the mesas is able to reach the main aquifer, which is about 305 m (1,000 ft) deep.

The canyons with alluvial aquifers are presumed to represent a greater potential for downward water movement because there is a constant driving force. Since the mid-1980s several investigations have been performed under various Resource Conservation and Recovery Act compliance requirements that have installed monitoring facilities in canyons to further define the occurrence of alluvial water or to help understand the potential for movement of water or contaminants.

In 1985, observation wells were installed in canyons adjacent to the operating solid waste management and disposal areas in TA-54. These included the three in Pajarito Canyon (south of TA-54) already described in

Section B.2 of this chapter, and four in the Cañada del Buey drainage (north of TA-54). Three of the wells were located in a side drainage of the main Cañada del Buey, west and north of Area L and penetrated to 2.4 to 3.7 m (8–12 ft) of dry alluvium. One in the main channel north of the eastern end of Area G penetrated 2.7 m (9 ft) of dry alluvium. These have remained dry on subsequent observation indicating the absence of any saturation in this reach of Cañada del Buey (Devaurs 1985).

In 1989 boreholes or monitoring wells were installed in four canyons to determine whether saturated conditions occurred in the alluvium. Two holes in Sandia Canyon, SCO-1 (near supply well PM-2) drilled to 24 m (79 ft) and SCO-2 (near supply well PM-1) drilled to 9 m (29 ft), penetrated the alluvium without encountering any saturated zone. These were completed as observation holes and have remained dry. One hole in Potrillo Canyon, PCTH-1 (about 0.3 km [1/2 mi] west of State Road 4) was drilled to 23 m (74 ft). It penetrated only dry weathered and unweathered tuff indicating no presence of past water. This hole was plugged. One hole in Fence Canyon, FCO-1 (within 0.2 km [1/4 mi] of State Road 4) was drilled to 9 m (29 ft) and completed as an observation well. It penetrated only dry weathered and unweathered tuff, indicating no past saturation. Three holes in Water Canyon, WCO-1 (about 3.2 km [2 mi] west of State Road 4) drilled 11 m (37 ft), WCO-2 (about 0.6 km [1 mi] west of State Road 4) drilled to 12 m (38 ft), and WCO-3 (within about 0.2 km [1/4 m] of State Road 4) all penetrated the alluvium without encountering saturated conditions. They were all completed as observation wells for future monitoring of potential occurrence of saturation (Purtymun 1990c).

In 1987 nine observation wells were installed in Cañon del Valle adjacent to inactive Waste Disposal Area P in TA-16. These wells, drilled on the toe of the landfill above the channel alluvium, encountered no saturation and showed no evidence of leachate or seepage from the landfill.

C. Analytical Results

1. Radiochemical Constituents.

The results of the radiochemical analyses of groundwater samples for 1991 are listed in Table VII-1. Discussion of the results will address first the main aquifer and second, the alluvial canyon aquifers.

For samples from wells or springs in the main aquifer, all results for ^{3}H, ^{90}Sr, U, ^{238}Pu, $^{239,240}Pu$, and gross beta were below the DOE Derived Concentration Guides or New Mexico Standards that would be applicable to a DOE drinking water system. Most of the results were at or below the detection limits for the analytical methods.

A few samples from wells (TW-1, PM-2, PM-4, TW-2, G-1, and LA-5) and springs (Sandia, SP-4, SP-5A, SP-9, SP-2, and Indian) had plutonium results slightly above method detection limits (up to about a factor of two). Because of inconsistency between the two types of analyses, (i.e., apparent ^{238}Pu without any corresponding $^{239,240}Pu$ or vice versa), the large counting uncertainties in the measurements (often 50% or more of the value) at the low levels near average detection limits, and, in the case of springs, the fact that such samples often must be collected in contact with surface rocks or channel sediments, none of these are believed to represent any indication of contamination in the main aquifer. Two samples from Wells G-4 and G-6 showed apparently measurable ^{239}Pu at levels of 0.669 and 0.4 pCi/L, respectively. Reanalysis of the G-6 sample was below detection limits with a value of 0.008 ± 0.006; however, there was insufficient sample from G-4 for reanalysis. The G-4 result is suspected to have been contaminated during sampling or analysis because there is no corresponding ^{238}Pu, there has never been previous confirmed contamination in the well, and none of the other wells in the field show any contamination.

One gross alpha analysis, for Well LA-1B, is above the limit that would be applicable to a drinking water distribution system. The water from that well (and Wells LA-2 and LA-3) has always contained natural uranium.

Several ^{137}Cs measurements from wells (TW-3, PM-2, PM-3, PM-4, TW-2, G-1, G-1A, G-2, G-5, LA-1B, and LA-3) and springs (SP-5A, SP-7, and SP-1) appear to be above the Derived Concentration Guide applicable to DOE Drinking Water Systems (though they are no more than 14% of the Derived Concentration Guide for Public Dose for Ingestion of Environmental Water). All of these measurements are believed to be suspect because of the large counting uncertainties (generally more than 50% of the result),

Table VII-1. Radiochemical Analyses of Groundwater Samples for 1991

Location	H^3 (nCi/L)	^{90}Sr (pCi/L)	^{137}Cs (pCi/L)	U (µg/L)	^{238}Pu (pCi/L)	$^{239,240}Pu$ (pCi/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Gross Gamma (cpm/L)
MAIN AQUIFER ON SITE									
Test Wells									
Test Well 1	1.1 (0.3)[a]	0.5 (0.6)	−169 (74)	0.0 (0.0)	0.030 (0.013)	0.004 (0.006)	0 (1)	6 (1)	−90.0 (80.0)
Test Well 3	−0.3 (0.3)	N/A[b]	158 (124)	0.8 (0.1)	0.009 (0.015)	0.000 (0.010)	−0 (1)	3 (0)	90.0 (70.0)
Test Well 8	0.0 (0.3)	0.2 (0.6)	−57 (99)	0.0 (0.0)	0.004 (0.004)	0.000 (0.010)	−0 (1)	3 (0)	−220.0 (80.0)
Test Well DT-5A	0.0 (0.3)	3.0 (0.9)	−260 (84)	0.6 (0.5)	−0.008 (0.006)	0.004 (0.007)	2 (1)	2 (0)	−130.0 (80.0)
Test Well DT-9	−0.1 (0.3)	0.7 (0.6)	19 (92)	0.0 (0.0)	−0.004 (0.010)	0.007 (0.010)	1 (1)	3 (0)	−30.0 (80.0)
Test Well DT-10	−0.2 (0.3)	0.9 (0.6)	−90 (76)	0.0 (0.0)	0.000 (0.010)	0.008 (0.006)	1 (1)	3 (0)	−100.0 (80.0)
Water Supply Wells									
Pajarito Well Field									
Well PM-1	N/A	N/A	N/A	2.2 (0.5)	N/A	N/A	N/A	N/A	N/A
Well PM-2	−0.2 (0.3)	N/A	197 (91)	0.7 (0.3)	0.017 (0.017)	0.021 (0.014)	2 (1)	2 (0)	50.0 (70.0)
Well PM-3	−0.2 (0.3)	N/A	431 (138)	1.3 (0.3)	0.005 (0.017)	0.000 (0.010)	3 (1)	4 (1)	140.0 (70.0)
Well PM-4	0.9 (0.3)	N/A	189 (120)	0.9 (0.3)	0.000 (0.010)	0.022 (0.010)	2 (1)	3 (1)	20.0 (70.0)
Well PM-5	N/A	N/A	N/A	0.9 (0.5)	N/A	N/A	N/A	N/A	N/A
MAIN AQUIFER OFF SITE									
Test Wells									
Test Well 2	1.8 (0.3)	N/A	138 (80)	0.4 (0.1)	0.031 (0.018)	0.021 (0.015)	2 (1)	4 (1)	−10.0 (70.0)
Water Supply Wells									
Guaje Well Field									
Well G-1	0.4 (0.3)	N/A	284 (121)	0.9 (0.3)	0.026 (0.014)	0.018 (0.011)	2 (1)	4 (1)	230.0 (80.0)
Well G-1A	0.4 (0.3)	N/A	188 (89)	0.9 (0.3)	−0.008 (0.008)	0.004 (0.009)	2 (1)	4 (1)	160.0 (80.0)
Well G-2	1.1 (0.3)	N/A	118 (117)	1.1 (0.3)	−0.009 (0.009)	−0.004 (0.004)	1 (1)	4 (1)	160.0 (80.0)
Well G-4	0.2 (0.3)	N/A	40 (88)	1.1 (0.3)	0.000 (0.010)	0.669 (0.069)	2 (1)	4 (1)	90.0 (70.0)
Well G-5	0.6 (0.3)	N/A	191 (118)	1.5 (0.3)	0.011 (0.017)	−0.011 (0.008)	2 (1)	3 (1)	180.0 (80.0)
Well G-6	0.0 (0.3)	N/A	−21 (86)	1.0 (0.3)	0.006 (0.009)	0.008 (0.006)	0 (1)	3 (0)	−20.0 (70.0)

Table VII-1 (Cont)

Location	H^3 (nCi/L)	^{90}Sr (pCi/L)	^{137}Cs (pCi/L)	U (µg/L)	^{238}Pu (pCi/L)	$^{239,240}Pu$ (pCi/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Gross Gamma (cpm/L)
Los Alamos Well Field									
Well LA-1B	0.2 (0.3)	N/A	229 (120)	6.0 (0.6)	0.008 (0.012)	0.008 (0.010)	30 (7)	3 (1)	-0.0 (70.0)
Well LA-2	0.1 (0.3)	N/A	40 (92)	6.1 (0.6)	0.000 (0.010)	-0.005 (0.009)	6 (2)	2 (0)	0.0 (70.0)
Well LA-3	0.3 (0.3)	N/A	223 (119)	4.2 (0.4)	0.014 (0.008)	0.019 (0.012)	3 (1)	2 (0)	-10.0 (70.0)
Well LA-5	0.2 (0.3)	N/A	74 (81)	1.0 (0.3)	0.038 (0.014)	0.010 (0.010)	0 (1)	2 (0)	80.0 (70.0)
MAIN AQUIFER SPRINGS									
White Rock Canyon Springs (Perimeter and Off Site)									
Group I									
Sandia Spring	-0.3 (0.3)	0.0 (0.6)	-40 (55)	1.6 (0.5)	0.028 (0.017)	0.004 (0.007)	1 (1)	4 (1)	-380.0 (80.0)
Spring 3	0.0 (0.3)	0.2 (0.6)	132 (66)	1.6 (0.5)	0.008 (0.008)	0.000 (0.010)	3 (1)	6 (1)	-40.0 (70.0)
Spring 3A	-0.3 (0.3)	-0.1 (0.5)	84 (61)	1.2 (0.5)	0.000 (0.010)	-0.008 (0.006)	3 (1)	5 (1)	-60.0 (70.0)
Spring 3AA	0.1 (0.3)	1.0 (0.6)	-4 (64)	2.0 (0.5)	0.004 (0.012)	0.000 (0.010)	1 (1)	5 (1)	-40.0 (70.0)
Spring 4	0.1 (0.3)	0.6 (0.6)	85 (65)	0.9 (0.5)	0.022 (0.015)	0.000 (0.010)	2 (1)	4 (1)	10.0 (70.0)
Spring 4A	0.0 (0.3)	0.0 (0.6)	64 (64)	0.7 (0.5)	0.000 (0.010)	0.008 (0.010)	1 (1)	3 (1)	-40.0 (70.0)
Spring 5	0.0 (0.3)	0.5 (0.6)	-20 (59)	0.5 (0.0)	0.008 (0.010)	0.000 (0.010)	1 (1)	3 (1)	-80.0 (70.0)
Spring 5AA	0.2 (0.3)	0.7 (0.6)	110 (69)	0.5 (0.0)	-0.004 (0.004)	0.008 (0.008)	1 (1)	4 (1)	-110.0 (70.0)
Ancho Spring	-0.1 (0.3)	0.8 (0.7)	-0 (64)	0.5 (0.0)	0.004 (0.013)	0.012 (0.007)	1 (1)	3 (0)	30.0 (70.0)
Group II									
Spring 5A	0.2 (0.3)	0.6 (0.6)	103 (68)	1.9 (0.5)	0.021 (0.011)	0.021 (0.011)	2 (1)	3 (1)	-70.0 (70.0)
Spring 6	-0.1 (0.3)	0.6 (0.6)	-1 (67)	0.5 (0.5)	0.004 (0.006)	0.004 (0.004)	1 (1)	2 (0)	-70.0 (70.0)
Spring 6A	-0.1 (0.3)	0.3 (0.6)	37 (64)	0.5 (0.0)	0.004 (0.010)	0.000 (0.010)	1 (1)	2 (0)	30.0 (70.0)
Spring 7	0.3 (0.3)	0.4 (0.6)	131 (70)	0.5 (0.5)	0.009 (0.007)	0.005 (0.008)	1 (1)	3 (0)	-20.0 (70.0)
Spring 8	0.1 (0.3)	0.4 (0.5)	71 (70)	2.1 (0.5)	0.004 (0.007)	0.000 (0.010)	2 (1)	5 (1)	10.0 (70.0)
Spring 8A	0.1 (0.3)	0.6 (0.6)	35 (60)	0.5 (0.0)	0.012 (0.013)	0.008 (0.011)	2 (1)	3 (0)	-0.0 (70.0)
Spring 9	-0.3 (0.3)	0.4 (0.6)	63 (64)	0.5 (0.0)	0.025 (0.014)	0.000 (0.010)	1 (0)	2 (0)	40.0 (70.0)
Spring 9A	0.1 (0.3)	0.3 (0.6)	65 (65)	0.5 (0.0)	0.004 (0.012)	-0.008 (0.012)	0 (0)	62 (0)	-90.0 (70.0)
Doe Spring	-0.1 (0.3)	0.5 (0.6)	-47 (65)	0.5 (0.0)	0.004 (0.007)	0.004 (0.004)	0 (0)	2 (0)	-70.0 (70.0)

Table VII-1 (Cont)

Location	H^3 (nCi/L)	^{90}Sr (pCi/L)	^{137}Cs (pCi/L)	U (µg/L)	^{238}Pu (pCi/L)	$^{239,240}Pu$ (pCi/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Gross Gamma (cpm/L)
Group III									
Spring 1	-0.1 (0.3)	0.3 (0.6)	142 (63)	3.0 (0.5)	-0.014 (0.008)	0.000 (0.010)	4 (1)	5 (1)	150.0 (70.0)
Spring 2	-0.1 (0.4)	0.8 (0.6)	-77 (57)	3.9 (0.5)	0.042 (0.017)	0.023 (0.012)	2 (1)	3 (1)	-40.0 (70.0)
Group IV									
La Mesita	-0.3 (0.3)	N/A	92 (92)	11.0 (0.6)	0.004 (0.009)	0.004 (0.004)	4 (1)	5 (1)	-100 (70.0)
Spring 3B	0.8 (0.3)	0.7 (0.6)	57 (60)	18.3 (1.8)	0.000 (0.010)	0.004 (0.010)	18 (4)	11 (1)	-30 (70.0)
Other Off-Site Springs									
Sacred Spring	0.7 (0.3)	N/A	57 (115)	1.2 (0.1)	0.009 (0.012)	0.004 (0.007)	3 (1)	4 (1)	-40 (70.0)
Indian Spring	-0.2 (0.3)	N/A	118 (88)	20.2 (1.0)	0.026 (0.017)	0.000 (0.010)	13 (4)	14 (1)	20 (70.0)
ALLUVIAL CANYON AQUIFERS									
Radioactive Effluent Release Areas									
DP-Los Alamos Canyon									
LAO-C	0.1 (0.2)	0.6 (0.6)	258 (127)	1.6 (0.3)	-0.020 (0.024)	0.010 (0.022)	8 (2)	6 (1)	0 (70.0)
LAO-1	6.2 (0.7)	14.0 (1.0)	80 (124)	0.3 (0.0)	-0.028 (0.021)	0.009 (0.016)	4 (1)	28 (3)	100 (70.0)
LAO-2	3.1 (0.4)	42.0 (2.0)	3 (9)	0.3 (0.3)	-0.011 (0.011)	0.021 (0.015)	5 (2)	74 (8)	-00 (70.0)
LAO-3	2.4 (0.4)	55.0 (2.0)	13 (9)	2.2 (0.3)	0.004 (0.011)	0.016 (0.010)	5 (2)	120 (10)	120 (70.0)
LAO-4	3.0 (0.4)	5.6 (0.8)	3 (9)	0.3 (0.0)	-0.005 (0.014)	0.005 (0.009)	3 (1)	20 (2)	160 (70.0)
LAO-4.5	2.3 (0.4)	0.5 (0.6)	234 (113)	0.3 (0.0)	0.008 (0.017)	0.230 (0.044)	3 (1)	8 (1)	50 (70.0)
Mortandad Canyon									
MCO-3	See text for discussion.[c]								
MCO-4	See text for discussion.[c]								
MCO-5	See text for discussion.[c]								
MCO-6.0	See text for discussion.[c]								
MCO-7	See text for discussion.[c]								
MCO-7.5	See text for discussion.[c]								

Table VII-1 (Cont)

Location	H^3 (nCi/L)	^{90}Sr (pCi/L)	^{137}Cs (pCi/L)	U (µg/L)	^{238}Pu (pCi/L)	$^{239,240}Pu$ (pCi/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Gross Gamma (cpm/L)
Other Areas									
Pajarito Canyon									
PCO-1	0.4 (0.3)	N/A	25 (86)	0.3 (0.3)	0.000 (0.010)	0.024 (0.017)	2 (1)	5 (1)	140.0 (70.0)
PCO-2	0.3 (0.3)	N/A	237 (135)	1.8 (0.3)	-0.011 (0.011)	0.000 (0.010)	3 (1)	6 (1)	70.0 (70.0)
PCO-3	0.8 (0.3)	N/A	140 (87)	0.3 (0.3)	0.026 (0.014)	0.005 (0.009)	6 (3)	7 (1)	60.0 (70.0)
PERCHED SYSTEM CONGLOMERATES AND BASALT									
(Pueblo/Los Alamos/Sandia Canyon Area)									
Test Well 1A	0.2 (0.3)	N/A	56 (92)	0.5 (0.1)	0.000 (0.010)	0.027 (0.018)	1 (1)	7 (1)	100.0 (70.0)
Test Well 2A	0.2 (0.3)	N/A	-10 (124)	0.2 (0.1)	0.000 (0.010)	-0.004 (0.004)	0 (1)	3 (0)	50.0 (70.0)
Basalt Spring	0.2 (0.3)	N/A	2 (9)	0.7 (0.1)	0.000 (0.010)	0.000 (0.010)	4 (2)	10 (1)	80 (70.0)
PERCHED AQUIFER IN VOLCANICS									
Water Canyon Gallery	1.0 (0.3)	N/A	151 (79)	0.4 (0.3)	0.004 (0.011)	0.004 (0.009)	1 (0)	2 (0)	340.0 (80.0)
Limits of Detection[d]	0.4	3	40	1	0.02	0.02	3	3	50
DCG for Public Dose[e]	2000	1000	3000	800	40	60	—	—	—
Drinking Water System	20[f]	8[g]	120[g]	30[g]	1.6[g]	1.2[g]	15[f]	50[f]	—

[a]Radioactivity counting uncertainties (±1 Standard Deviation) are shown in parentheses.

[b]N/A symbol means analysis not performed, lost in analysis, or not completed.

[c]Due to laboratory error in labeling, individual well sample results are not available. Range of results for Mortandad Canyon samples in 1991 were: 4.2 to 40 nCi/L for H^3, nondetectable to 25 pCi/L for ^{90}Sr, 0.004 to 0.907 pCi/L for ^{238}Pu, 0.024 to 2.43 pCi/L for $^{239,240}Pu$, and 0.462 to 45 pCi/L for ^{241}Am.

[d]Limit of valid quantification based on radioactivity counting statistics for analytical method.

[e]DOE Derived Concentration Guide to meet the Public Dose Limit applicable to water ingested, see Appendix A.

[f]Maximum Contaminant Level (MCL), See Appendix A; (NMEIB 1991 and EPA 1989b).

[g]DOE Derived Concentration Guide applicable to DOE Drinking Water System, see Appendix A.

NOTE: See Table IV-43 for radiochemical quality of groundwater from wells, Pueblo de San Ildefonso.

the lack of consistency with the gross gamma results, and the lack of consistency for groups of samples that should have similar characteristics. Accordingly the measurements are not believed to represent any real contamination. The reason for the large uncertainties is that the present counting system and procedure has a detection limit that is about one-third the DOE Derived Concentration Guide that went into effect in 1990. Good measurements would preferably have a detection limit about one-tenth of the Guide. New procedures are to be implemented for 1992 and should permit better discrimination.

The samples from the alluvial aquifer in Los Alamos Canyon show residual contamination as has been seen since the earliest days of operation at Los Alamos. None of the concentrations are above the DOE Derived Concentration Guides for Public Dose for Ingestion of Environmental Water. Tritium; ^{137}Cs; Uranium; ^{238}Pu; $^{239,240}Pu$; and gross alpha, beta, and gamma results are all within the range of values observed in recent years. Measurements of ^{90}Sr serve as a basis for observing future changes.

The Mortandad Canyon water samples (six shallow alluvial groundwaters and one surface water) were analyzed as a single batch, but an apparent error in analytical laboratory labeling resulted in the loss of individual sample identity. Many years of data have shown a consistent distinct decline in concentrations of plutonium (in particular) with distance downstream from the TA-50 liquid waste treatment plant outfall. The analytical results as reported more or less inverted that pattern, which is very unlikely from a physical process standpoint. The range of values in the data set as a group, however, is completely consistent with the ranges of values observed in previous years. Thus, there is no reason to believe that any real change in overall concentrations or physical distribution has occurred. Accordingly, the individual results are not being reported this year. The ranges of values for the principal radioactive analyses were 0.024 to 2.43 pCi/L for $^{239,240}Pu$, 0.004 to 0.907 pCi/L for ^{238}Pu, 4.2 to 40 nCi/L for H^3, 0.462 to 45 pCi/L for ^{241}Am, nondetectable to 1,730 pCi/L for ^{137}Cs, and nondetectable to 25 pCi/L for ^{90}Sr. All stations will be sampled in 1992.

The samples from Test Wells 1A and 2A in the perched zones in Pueblo Canyon were consistent with previous observations. The levels are all at or below limits of detection and indicate no measurable radioactive contamination even though the waters are known to be influenced by contaminated surface water in the canyon based on major inorganic ion measurements.

The sample from the Water Canyon Gallery was consistent with previous results, showing no evidence of contamination from Los Alamos operations.

2. Nonradioactive Constituents.

The results of major general chemical parameter analyses of groundwater samples for 1991 are listed in Table VII-2. The results are consistent with values observed in previous years, showing some expected variability.

Values for all parameters measured in the water supply wells were within drinking water limits with the exception of two pH values. These measurements at Wells G-2 and LA-5 were both 8.6, only slightly above the standard of 8.5; blending of waters in the distribution system results in compliance with standards. Alluvial canyon aquifer waters in the areas receiving effluents show levels of some parameters higher than water supply values as expected.

The results of metal analyses of groundwater samples for 1991 are listed in Table VII-3. The results are generally consistent with values observed in previous years. A few parameters from analyses of samples from the water supply wells were above drinking water limits applicable to the distribution system. Two wells in the Guaje field, G-1 and G-5, exhibited lead levels of 0.049 and 0.095, compared to the limit of 0.05. Neither well has shown excessive lead before; if the values are not due to inadvertent sample contamination and excessive levels appear in the 1992 samples, an attempt will be made to isolate the source. Blending of waters in the distribution system results in overall water system compliance.

Test Wells TW-2, TW-1A, and TW-2A had lead levels slightly above drinking water limits as has been observed previously, probably attributable to the original well construction which included lead swedging in the casings. Iron and manganese levels in several test wells exceed the EPA secondary limit, to be expected because of the steel casings.

Table VII-2. Chemical Quality of Groundwaters (mg/L)[a]

Station	SiO_2	Ca	Mg	K	Na	Cl	F	CO_3	HCO_3	PO^4-P	SO_4	NO_3-N	Cn	TDS[b]	Total Hardness	pH[c]	Conductivity (µmho/cm)
MAIN AQUIFER ON SITE																	
Test Wells																	
Test Well 1	40	45	9.3	3.8	16	39	0.4	<2[d]	99	0.2	22	5.3	<0.01	216	150	8.0	366
Test Well 3	82	23	5.9	2.4	15	4	0.5	<2	80	0.3	3	0.6	<0.01	150	82	7.9	170
Test Well 8	11	10	2.5	1.6	12	2	0.3	<1	50	0.1	1	<0.04	<0.01	36	35	8.3	80
Test Well DT-5A	73	8	2.5	1.6	11	1	0.3	<5	49	0.3	1	0.3	<0.01	138	31	7.9	74
Test Well DT-9	11	7	1.9	1.1	9	2	0.3	<2	48	0.1	1	<0.04	<0.01	20	26	8.4	91
Test Well DT-10	11	9	2.4	1.6	12	2	0.3	3	50	0.1	1	<0.04	<0.01	12	34	8.4	92
Water Supply Wells																	
Pajarito Well Field																	
Well PM-1	83	24	6.2	3.6	21	6	0.3	<5	116	0.3	4	0.4	N/A[e]	122	85	8.2	234
Well PM-2	82	13	3.4	2.2	14	2	0.3	<2	50	0.3	2	0.3	<0.01	156	46	8.0	87
Well PM-3	90	32	9.4	4.4	23	8	0.3	<2	112	0.3	5	0.4	<0.01	238	119	7.8	232
Well PM-4	89	17	5.3	2.9	19	3	0.3	<2	62	0.3	3	0.3	<0.01	188	43	7.9	115
Well PM-5	95	9	3.7	1.9	13	2	0.3	<5	65	0.3	2	0.3	N/A	240	39	8.1	91
MAIN AQUIFER OFF SITE																	
Test Wells																	
Test Well 2	17	42	7.7	4.7	28	51	0.2	<2	83	0.4	20	<0.04	<0.01	236	138	8.0	318
Water Supply Wells																	
Guaje Well Field																	
Well G-1	81	18	0.7	3.3	32	<0.5	0.6	<2	75	0.3	<1	0.4	<0.01	198	47	8.5	120
Well G-1A	72	15	0.6	3.0	41	5	0.6	<2	82	0.2	5	0.4	<0.01	196	39	8.5	172
Well G-2	30	17	0.7	3.2	45	3	0.8	<2	90	0.2	4	0.4	<0.01	190	45	8.6	184
Well G-4	58	25	4.1	2.2	18	3	0.4	<2	75	0.2	4	0.6	<0.01	168	80	8.2	149
Well G-5	59	24	4.4	2.3	17	4	0.4	<2	74	0.2	4	0.6	<0.01	144	80	8.3	140
Well G-6	52	21	2.4	2.4	24	3	0.4	<2	69	0.2	4	0.4	<0.01	162	62	8.4	138
Los Alamos Well Field																	
Well LA-1B	39	14	<0.5	3.4	192	21	2.9	11	278	0.2	41	0.5	<0.01	456	35	8.4	652
Well LA-2	33	12	<0.5	1.7	103	21	2.1	<2	132	0.1	16	0.6	<0.01	264	31	8.5	349
Well LA-3	33	20	<0.5	2.2	55	5	0.9	<2	99	0.1	8	0.5	<0.01	164	52	8.5	207
Well LA-5	40	18	<0.5	2.0	34	3	0.5	<2	70	0.1	4	0.4	<0.01	148	46	8.6	128

Table VII-2 (Cont)

Station	SiO_2	Ca	Mg	K	Na	Cl	F	CO_3	HCO_3	PO^4-P	SO_4	NO_3-N	Cn	TDS[b]	Total Hard-ness	pH[c]	Conduc-tivity (µmho/cm)
MAIN AQUIFER SPRINGS																	
White Rock Canyon Springs (Perimeter and Off Site)																	
Group I																	
Sandia Spring	47	43	3.8	3.2	17	4	0.6	<5	143	0.2	4	0.1	<0.01	172	123	8.1	287
Spring 3	52	21	1.8	3.2	16	4	0.5	<5	81	0.2	4	0.8	<0.01	160	61	8.2	141
Spring 3A	53	20	1.8	3.2	15	3	0.5	<5	79	0.2	4	0.7	<0.01	162	57	8.2	161
Spring 3AA	43	19	0.4	3.3	18	3	0.4	<5	82	0.2	3	0.7	<0.01	128	49	7.9	153
Spring 4	55	<0.003	<0.02	0.2	<0.008	7	0.5	<5	85	0.2	9	1.1	<0.01	114	<1	7.6	152
Spring 4A	54	23	4.6	2.7	14	5	0.5	<5	72	0.3	5	0.8	<0.01	186	76	8.1	150
Spring 5	69	21	4.7	2.7	14	4	0.5	<5	74	0.3	4	0.5	<0.01	158	71	7.9	155
Spring 5AA	66	39	7.8	2.9	17	6	0.6	<5	147	0.3	3	<0.04	<0.01	256	129	7.0	296
Ancho Spring	78	14	3.5	2.3	10	2	0.4	<5	62	0.3	2	0.5	<0.07	134	49	7.5	120
Group II																	
Spring 5A	60	19	5.0	2.2	12	5	0.4	<5	97	0.4	7	0.5	<0.01	160	68	8.0	194
Spring 6	76	13	3.9	2.3	11	2	0.4	<5	57	0.3	2	0.4	<0.01	114	48	7.2	115
Spring 6A	79	10	2.8	2.2	10	1	0.3	<5	47	0.3	1	0.4	<0.01	126	37	8.1	89
Spring 7	80	12	3.2	2.6	14	2	0.3	<5	64	0.3	3	0.5	<0.01	154	44	7.2	121
Spring 8	79	22	4.8	3.4	25	4	0.4	<5	100	0.4	10	0.7	<0.01	204	74	6.9	235
Spring 8A	61	11	2.9	2.5	12	2	0.4	<5	59	0.3	1	<0.04	<0.01	170	39	8.4	100
Spring 9	74	11	3.3	1.8	12	2	0.5	<5	61	0.3	2	<0.04	<0.01	148	41	8.0	103
Spring 9A	79	11	3.2	1.8	11	2	0.5	<5	63	0.3	1	0.4	<0.01	168	40	8.0	90
Doe Spring	79	13	3.5	1.8	12	2	0.5	<5	59	0.4	1	0.1	<0.01	64	46	7.9	112
Group III																	
Spring 1	29	24	1.9	3.2	33	4	0.6	<5	110	0.3	7	0.2	<0.01	106	13	8.0	186
Spring 2	42	22	1.3	1.5	66	6	1.4	<5	187	0.2	11	<0.04	<0.01	292	61	8.4	356
Group IV																	
La Mesita	30	49	1.0	3.2	37	8	0.3	<5	117	0.2	18	1.4	0.010	188	128	8.2	281
Spring 3B	47	20	1.9	4.5	121	4	0.7	<5	280	0.7	16	2.4	<0.01	346	57	7.6	592
Other Off-Site Springs																	
Sacred Spring	34	31	0.5	2.7	31	2	0.6	<5	83	0.1	13	1.5	0.010	6	79	7.3	209
Indian Spring	46	109	5.0	7.7	34	14	0.6	<5	129	3.9	19	0.5	0.120	366	294	7.2	488

Table VII-2 (Cont)

Station	SiO_2	Ca	Mg	K	Na	Cl	F	CO_3	HCO_3	PO^4-P	SO_4	NO_3-N	Cn	TDS[b]	Total Hardness	pH[c]	Conductivity (µmho/cm)
ALLUVIAL CANYON AQUIFERS																	
Radioactive Effluent Release Areas																	
DP-Los Alamos Canyon																	
LAO-C	36	13	2.5	3.0	28	45	<0.2	<2	38	1.4	4	0.4	<0.01	204	43	7.1	195
LAO-1	39	19	3.2	3.6	59	105	0.5	<2	62	0.3	8	0.1	<0.01	290	62	7.1	369
LAO-2	50	24	4.8	8.9	40	69	0.9	<2	78	0.4	11	0.5	<0.01	264	81	6.9	346
LAO-3	46	23	4.2	8.3	44	70	1.0	<2	74	0.5	11	0.4	<0.01	268	77	6.9	341
LAO-4	39	18	4.7	5.7	43	68	0.8	<2	64	0.2	13	0.0	<0.01	224	65	7.1	312
LAO-4.5	40	18	4.2	7.5	42	77	0.9	<2	5[illegible]	0.2	8	0.1	<0.01	234	63	7.0	305
Mortandad Canyon																	
MCO-3	39	19	3.2	4.2	18	7	0.3	<5	59	0.2	5	4.8	0.017	250	60	7.5	166
MCO-4	46	38	8.6	11.0	130	29	1.4	<5	140	0.5	30	34.7	0.034	500	130	7.0	566
MCO-5	47	35	7.5	11.0	120	31	1.4	<5	111	0.5	31	35.8	0.033	488	118	7.0	748
MCO-6.0	49	39	6.5	8.8	98	23	1.3	<1	<1	0.6	30	28.5	0.011	584	124	2.2	665
MCO-7	46	35	6.1	8.3	95	23	1.7	<1	152	0.6	30	26.0	0.011	444	112	6.9	621
MCO-7.5	45	33	5.7	7.3	94	23	1.2	<5	153	0.6	29	27.0	0.011	446	105	7.1	627
Other Areas																	
Pajarito Canyon																	
PCO-1	35	24	6.3	4.0	25	56	<0.2	<2	59	0.3	11	0.3	<0.01	194	146	6.9	279
PCO-2	30	26	6.8	3.1	22	59	<0.2	<2	58	0.1	15	0.0	<0.01	204	175	6.9	275
PCO-3	43	118	17.2	5.8	66	245	<0.2	<2	81	0.3	151	0.1	<0.01	622	782	6.5	999
PERCHED SYSTEM IN CONGLOMERATES AND BASALT																	
(Pueblo/Los Alamos/Sandia Canyon Area)																	
Test Well 1A	55	34	8.2	9.6	88	60	0.7	<2	157	4.1	29	2.9	<0.01	334	120	8.2	502
Test Well 2A	7	10	1.8	2.7	52	8	0.8	<2	101	0.1	10	<0.04	<0.01	184	33	8.5	210
Basalt Spring	64	26	4.2	12.3	67	45	0.8	<2	121	6.9	34	10.9	0.023	358	82	8.3	489

Table VII-2 (Cont)

Station	SiO_2	Ca	Mg	K	Na	Cl	F	CO_3	HCO_3	PO^4-P	SO_4	NO_3-N	Cn	TDS[b]	Total Hard-ness	pH[c]	Conduc-tivity (µmho/cm)
PERCHED AQUIFER IN VOLCANICS																	
Water Canyon Gallery	38	8	3.1	1.6	7	1	<0.2	<5	37	0.2	2	0.2	<0.01	100	32	7.7	83
Drinking Water System Limit						250[f]	4[g]				250[f]	10[g]		500[f]		6.8-8.5[f]	
Livestock and Wildlife Watering[h]		None in this table															

[a]Except where noted.
[b]Total dissolved solids.
[c]Standard units.
[d]Less than symbol (<) means measurement was below the specified detection limit of the analytical method.
[e]N/A means analysis not performed, lost in analysis, or not completed.
[f]Maximum contaminant level, secondary standard (EPA 1989b), see Appendix A.
[g]Maximum contaminant level, primary standard (NMEIB 1991, EPA 1989b), see Appendix A.
[h]New Mexico Stream Standards for Livestock and Wildlife Watering (NMWQCC 1991), see Appendix A.

Table VII-3. Trace Metals in Groundwaters (mg/L)

Station	Ag	Al	As	B	Be	Cd	Cr	Co	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
MAIN AQUIFER ON SITE																						
Test Wells																						
Test Well 1	<0.001[a]	0.03	0.0026	0.07	<0.0005	<0.0005	0.0012	<0.006	<0.0005	1.80	<0.0002	0.071	<0.003	<0.008	0.022	0.0085	<0.040	<0.03	0.256	<0.0005	0.002	0.691
Test Well 3	<0.0003	<0.03	0.001	0.04	<0.0005	0.0001	0.0029	<0.008	0.003	0.07	0.0002	0.005	0.003	<0.01	0.001	<0.0005	<0.04	0.020	0.076	<0.0001	0.010	0.019
Test Well 8	<0.001	0.04	0.0041	0.10	<0.0005	<0.0005	0.0086	<0.006	0.270	0.40	<0.0002	0.023	<0.003	<0.008	0.036	<0.0005	0.040	<0.03	0.045	<0.0005	0.002	1.100
Test Well DT-5A	<0.001	0.03	0.0037	0.10	<0.0005	0.0005	0.0100	<0.006	0.243	0.33	<0.0002	0.022	0.003	<0.008	0.033	<0.0005	<0.040	<0.03	0.045	<0.0005	0.001	1.050
Test Well DT-9	<0.001	<0.02	0.0038	0.08	<0.0005	<0.0005	0.0018	<0.006	0.155	0.24	<0.0002	0.020	<0.003	<0.008	0.026	0.0006	<0.040	<0.03	0.046	<0.0005	0.001	0.895
Test Well DT-10	<0.001	0.03	0.0039	0.10	<0.0005	0.0006	0.0016	<0.006	0.181	0.33	<0.0002	0.019	<0.003	<0.008	0.028	0.0010	0.040	<0.03	0.044	<0.0005	0.002	1.010
Water Supply Wells																						
Pajarito Well Field																						
Well PM-1	<0.001	<0.02	<0.0005	0.05	<0.0005	<0.0005	0.0055	N/A[b]	0.009	0.01	N/A	<0.001	<0.002	<0.008	0.002	<0.0005	<0.04	N/A	0.136	<0.0005	0.012	0.025
Well PM-2	<0.002	<0.03	<0.0015	<0.01	<0.0015	<0.002	0.0046	<0.008	<0.001	<0.003	0.0002	<0.001	0.001	<0.01	<0.001	<0.0005	<0.04	0.020	0.038	<0.0003	0.007	<0.003
Well PM-3	<0.002	0.12	<0.0015	0.05	<0.0015	<0.002	0.0044	<0.008	<0.001	<0.003	<0.0002	<0.001	<0.001	<0.01	0.002	<0.0005	<0.04	0.020	0.126	<0.0003	0.016	0.008
Well PM-4	<0.002	0.03	0.003	0.01	<0.0015	<0.002	0.0064	<0.008	<0.01	<0.003	0.0002	<0.001	0.001	<0.01	<0.001	<0.0005	<0.04	0.010	0.050	<0.0003	0.012	0.005
Well PM-5	<0.001	<0.02	<0.0005	0.01	<0.0005	<0.0005	0.0098	N/A	0.024	0.00	N/A	<0.001	0.002	<0.008	0.003	<0.0005	<0.04	N/A	0.046	<0.0005	0.008	0.030
MAIN AQUIFER OFF SITE																						
Test Wells																						
Test Well 2	<0.0003	0.04	<0.001	0.16	<0.0005	0.0079	0.0010	<0.008	0.006	1.30	0.0002	0.174	0.003	<0.01	0.053	<0.0005	<0.04	0.010	0.168	<0.0005	0.001	4.280
Water Supply Wells																						
Guaje Well Field																						
Well G-1	<0.002	<0.03	0.005	0.02	<0.0015	<0.002	0.0054	<0.008	0.006	<0.003	<0.0002	<0.001	0.002	<0.01	0.049	<0.0005	<0.04	<0.01	0.095	<0.0003	0.028	0.015
Well G-1A	<0.002	<0.03	0.013	0.03	<0.001	<0.002	0.0077	<0.008	0.002	<0.003	<0.0002	<0.001	0.004	<0.01	0.001	<0.0005	<0.04	<0.01	0.071	<0.0003	0.046	0.012
Well G-2	<0.002	<0.03	0.033	0.04	<0.0015	<0.0015	0.0087	<0.008	0.001	<0.003	<0.0002	<0.001	0.001	<0.01	<0.001	<0.0005	<0.04	<0.01	0.078	<0.0003	0.080	0.007
Well G-4	<0.002	<0.03	0.002	0.02	<0.0015	<0.0015	0.0042	<0.008	0.002	<0.003	<0.0002	0.001	0.001	<0.01	<0.001	<0.0005	<0.04	0.010	0.100	<0.0003	0.019	0.015
Well G-5	<0.002	<0.03	<0.0015	0.02	<0.0015	0.0018	0.0035	<0.008	0.051	<0.003	<0.0002	<0.001	0.001	<0.01	0.095	<0.0005	<0.04	<0.01	0.083	0.0003	0.012	0.022
Well G-6	<0.002	<0.03	0.002	0.02	<0.0015	<0.002	0.0041	<0.008	0.002	<0.003	<0.0002	0.001	0.001	<0.01	0.007	<0.0005	<0.04	<0.01	0.065	<0.0003	0.021	0.010
Los Alamos Field																						
Well LA-1B	<0.002	<0.03	0.0308	0.35	<0.0015	<0.002	0.0255	<0.008	0.0256	<0.003	<0.0002	<0.001	0.0193	<0.01	0.0011	<0.0005	<0.04	<0.01	0.164	<0.0003	0.0482	0.0044
Well LA-2	<0.002	<0.03	0.0098	0.24	<0.0015	0.0037	0.0221	<0.008	<0.001	<0.003	<0.0002	<0.001	0.0119	<0.01	0.0011	<0.0005	<0.04	0.01	0.146	<0.0003	0.0284	0.0137
Well LA-3	<0.002	<0.03	0.0042	0.06	<0.0015	<0.002	0.0085	<0.008	0.0356	<0.003	<0.0002	<0.001	0.0026	<0.01	0.01	<0.0005	<0.04	<0.01	0.191	<0.0003	0.0192	0.0399
Well LA-5	<0.002	<0.03	0.002	0.02	<0.0015	<0.002	0.0048	<0.008	<0.001	<0.003	<0.0002	<0.001	0.0017	<0.01	<0.001	<0.0005	<0.04	0.01	0.16	<0.0003	0.0206	0.0039
MAIN AQUIFER SPRINGS																						
White Rock Canyon Springs (Perimeter and Off Site)																						
Group I																						
Sandia Spring	<0.0005	0.2	0.002	0.03	<0.0005	0.0051	<0.0005	N/A	0.005	0.40	<0.0002	0.155	N/A	0.006	0.001	<0.002	<0.03	N/A	0.426	<0.0005	0.005	0.003
Spring 3	<0.0005	0.02	0.002	0.03	<0.0005	0.0050	0.0057	N/A	<0.005	0.05	<0.0002	0.003	N/A	<0.006	0.001	<0.002	<0.03	N/A	0.227	<0.0005	0.015	0.005
Spring 3A	<0.0005	0.01	0.002	0.03	<0.0005	0.0051	0.0055	N/A	<0.005	0.01	<0.0002	0.001	N/A	<0.006	0.001	<0.002	<0.03	N/A	0.220	<0.0005	0.014	0.002
Spring 3AA	<0.0005	0.08	0.001	0.03	<0.0005	<0.002	0.0044	N/A	0.005	0.12	<0.0002	0.007	N/A	<0.006	0.001	<0.002	<0.03	N/A	0.166	<0.0005	0.017	0.008
Spring 4	<0.0005	<0.008	0.002	0.00	<0.0005	<0.002	0.0055	N/A	<0.005	0.00	<0.0002	<0.0005	N/A	0.830	0.001	<0.002	<0.03	N/A	0.132	<0.0005	0.010	0.003
Spring 4A	<0.0005	0.01	0.001	0.02	<0.0005	0.0138	0.0058	N/A	<0.003	0.02	<0.0002	<0.0005	N/A	<0.006	0.001	<0.002	<0.03	N/A	0.100	<0.0005	0.008	0.042
Spring 5	<0.0005	0.03	0.003	0.03	0.0005	0.0089	0.0058	N/A	<0.006	0.03	<0.0008	0.013	N/A	<0.006	0.001	<.002	<0.03	N/A	0.093	<0.0005	<0.0092	0.005
Spring 5AA	<0.0005	0.02	0.002	0.04	<0.0005	0.0007	<0.0005	N/A	0.003	1.20	<0.0002	0.295	N/A	<0.006	<0.0005	<0.001	<0.03	N/A	0.227	<0.0005	0.001	<0.005
Ancho Spring	<0.0005	0.2	0.001	0.02	<0.0005	<0.0005	0.0033	N/A	0.004	0.11	<0.0002	0.008	N/A	<0.006	0.001	<0.001	<0.03	N/A	0.068	<0.0005	0.008	<0.005

Table VII-3 (Cont)

Station	Ag	Al	As	B	Be	Cd	Cr	Co	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
Group II																						
Spring 5A	<0.0005	0.10	0.002	0.03	<0.0005	<0.0005	0.0206	N/A	0.004	0.14	<0.0002	0.004	N/A	<0.006	0.002	<0.001	<0.03	N/A	0.189	<0.0005	0.014	<0.005
Spring 6	<0.0005	0.02	0.001	0.02	<0.0005	<0.0005	0.0049	N/A	<0.002	0.01	0.0006	0.002	N/A	0.006	0.001	<0.001	<0.03	N/A	0.063	<0.0005	0.008	0.009
Spring 6A	<0.0005	0.03	0.002	0.02	<0.0005	<0.0005	0.0030	N/A	<0.002	0.02	<0.0002	0.001	N/A	<0.006	<0.0005	<0.001	<0.03	N/A	0.049	<0.0005	0.008	<0.005
Spring 7	<0.0005	0.1	0.002	0.02	<0.0005	<0.0005	0.0025	N/A	<0.002	0.07	<0.0002	<0.001	N/A	<0.006	0.001	<0.001	<0.03	N/A	0.086	<0.0005	0.010	<0.005
Spring 8	<0.0005	<0.008	0.003	0.04	<0.0005	0.0006	0.0026	N/A	<0.002	0.01	<0.0002	<0.002	N/A	0.008	0.001	<0.001	<0.03	N/A	0.142	<0.0005	0.014	<0.005
Spring 8A	<0.0005	0.03	0.002	0.01	<0.0005	0.0005	0.0011	N/A	<0.002	0.05	<0.0002	<0.001	N/A	<0.006	<0.0005	<0.001	<0.03	N/A	0.053	<0.0005	0.011	<0.005
Spring 9	<0.0005	0.06	<0.001	0.01	<0.0005	0.0019	0.0024	N/A	<0.002	0.17	<0.0002	0.005	N/A	0.006	0.001	<0.001	<0.03	N/A	0.052	0.0005	0.009	<0.005
Spring 9A	<0.0005	0.02	0.001	0.03	<0.0005	<0.0005	0.0014	N/A	<0.002	0.02	<0.0002	<0.001	N/A	0.010	<0.0005	<0.001	<0.03	N/A	0.050	<0.0005	0.009	0.005
Doe Spring	<0.0005	0.1	0.002	0.02	<0.0005	0.0020	0.1150	N/A	<0.002	0.09	<0.0002	0.022	N/A	<0.006	0.001	<0.001	0.030	N/A	0.056	<0.0005	0.009	<0.005
Group III																						
Spring 1	<0.0005	0.6	0.003	0.05	<0.0005	0.0059	0.0094	N/A	0.024	0.90	<0.0002	0.107	N/A	0.007	0.003	<0.002	<0.03	N/A	0.240	<0.0005	0.020	0.009
Spring 2	<0.0005	0.1	0.022	0.08	<0.0005	0.0061	0.0047	N/A	0.010	0.06	<0.0002	0.006	N/A	<0.006	0.001	<0.002	<0.03	N/A	0.256	<0.0005	0.031	0.006
Group IV																						
La Mesita	<0.0005	0.03	<0.02	0.05	<0.001	<0.005	0.0020	N/A	<0.007	0.06	<0.0002	0.002	<0.006	<0.01	0.000	<0.0005	<0.04	N/A	0.734	<0.0001	0.006	0.006
Spring 3B	<0.0005	0.7	0.011	0.20	<0.0005	<0.002	0.0304	N/A	0.012	1.10	<0.0002	0.013	N/A	0.007	0.002	<0.002	<0.03	N/A	0.220	<0.0005	0.039	0.006
Other Off-Site Springs																						
Sacred Spring	<0.0005	0.1	<0.02	0.04	<0.001	<0.005	0.0050	N/A	<0.007	0.25	<0.0002	0.036	<0.006	<0.01	0.001	<0.0005	<0.04	N/A	0.450	<0.0001	0.014	0.006
Indian Spring	0.001	3.8	0.070	0.08	0.0020	0.0060	0.0260	N/A	<0.007	10.00	<0.0002	1.300	<0.006	<0.01	0.199	<0.0005	0.070	N/A	1.430	0.0012	0.150	6.500
ALLUVIAL CANYON AQUIFERS																						
Radioactive Effluent Release Areas																						
DP-Los Alamos Canyons																						
LAO-C	<0.0003	2.1	0.011	<0.02	0.0017	<0.002	0.0079	<0.003	0.013	35.00	0.0003	2.060	0.003	<0.0200	0.050	0.0010	<0.03	<0.02	0.078	0.0004	0.032	0.048
LAO-1	<0.0001	0.8	0.002	<0.02	0.0004	<0.002	0.0145	<0.003	0.005	0.82	0.0002	0.067	0.156	<0.0200	0.003	<0.0005	<0.03	<0.02	0.103	0.0003	0.006	0.262
LAO-2	<0.0003	0.7	0.002	0.27	0.0003	<0.002	0.0039	<0.003	0.011	0.69	<0.0002	0.101	0.026	<0.0200	0.005	0.0007	<0.03	<0.02	0.129	<0.0003	0.006	0.020
LAO-3	<0.0003	1.4	0.002	0.22	0.0007	<0.002	0.0057	<0.003	0.009	1.00	0.0002	0.192	0.018	<0.0200	0.011	<0.0005	<0.03	<0.02	0.109	0.0004	0.007	0.019
LAO-4	<0.0003	0.3	0.001	0.12	0.0003	0.002	0.0021	<0.003	0.003	0.28	<0.0002	0.013	0.012	<0.0200	0.001	<0.0005	<0.03	<0.02	0.097	<0.0003	0.003	0.014
LAO-4.5	0.0004	0.6	0.001	0.23	0.0004	0.002	0.0058	<0.003	0.021	0.35	<0.0002	0.064	0.002	<0.0200	0.012	<0.0005	<0.03	<0.02	0.092	<0.0003	0.004	0.037
Mortandad Canyon																						
MCO-3	<0.0005	1.0	0.002	0.03	<0.0005	<0.0005	0.0064	<0.03	0.006	0.89	<0.0002	0.044	0.059	<0.01	0.004	0.0016	0.050	<0.04	0.080	<0.0005	0.009	0.032
MCO-4	<0.0005	2.4	0.006	0.11	0.0013	0.0006	0.0122	<0.03	0.051	1.30	<0.0008	0.268	0.010	<0.01	0.016	<0.0005	0.090	<0.04	0.186	0.0005	0.022	0.070
MCO-5	<0.0005	0.2	0.006	0.10	0.0015	<0.0005	0.0122	<0.03	0.037	0.04	0.0009	0.309	0.011	<0.01	0.020	<0.0005	0.080	<0.04	0.190	<0.0007	0.023	0.063
MCO-6.0	<0.0005	3.7	0.005	0.11	0.0012	<0.002	0.0110	<0.03	0.068	3.10	0.0009	0.293	0.015	0.030	0.016	<0.0005	0.070	<0.04	0.145	<0.0005	0.018	0.089
MCO-7	0.001	3.2	0.006	0.11	0.0020	<0.002	0.0184	<0.03	0.041	2.60	0.0019	0.687	0.015	0.030	0.029	0.0021	0.070	<0.04	0.149	<0.0005	0.027	0.078
MCO-7.5	0.001	3.0	0.006	0.10	0.0015	<0.002	0.0177	<0.03	0.025	2.40	0.0010	0.290	0.014	0.030	0.017	0.0005	0.080	<0.04	0.151	<0.0005	0.023	0.058
Other Areas																						
Pajarito Canyon																						
PCO-1	0.005	0.1	0.004	0.04	N/A	0.0018	N/A	<0.008	0.004	9.50	0.0006	2.340	0.002	<0.01	0.002	<0.0005	<0.04	0.020	0.150	<0.0001	N/A	0.020
PCO-2	0.003	1.5	0.003	0.04	N/A	0.0012	N/A	<0.008	0.017	14.00	0.0005	0.707	0.004	0.010	0.032	0.0005	<0.04	0.010	0.181	0.0002	N/A	0.066
PCO-3	0.001	0.2	0.004	0.05	N/A	0.0019	N/A	<0.008	0.008	2.50	0.0003	0.632	0.002	<0.01	0.004	0.0005	<0.04	0.020	0.659	<0.0001	N/A	0.022

Table VII-3 (Cont)

Station	Ag	Al	As	B	Be	Cd	Cr	Co	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
PERCHED SYSTEM IN CONGLOMERATES AND BASALT																						
(Pueblo/Los Alamos/Sandia Canyon)																						
TW-1A	<0.0003	0.04	0.007	0.22	<0.0005	0.0004	0.0016	<0.008	0.047	4.00	0.0002	0.056	0.005	<0.01	0.090	0.1320	<0.04	0.070	0.127	<0.0001	0.005	0.140
TW-2A	<0.0003	0.04	<0.001	0.03	<0.0005	0.0103	0.0064	<0.008	0.055	0.45	0.0002	0.072	0.007	<0.01	0.089	<0.0005	<0.04	<0.01	0.033	0.0001	0.002	0.000
Basalt Spring	0.001	<0.02	0.013	0.27	<0.0005	<0.0003	0.0015	<0.003	0.004	0.12	0.0004	0.017	0.004	<0.02	0.001	0.0004	<0.03	<0.02	0.113	<0.0001	0.018	0.010
PERCHED AQUIFER IN VOLCANICS																						
Water Canyon Gallery	<0.002	0.09	0.0015	<0.01	<0.0015	<0.002	0.0053	<0.008	0.003	0.04	<0.0002	<0.001	<0.001	<0.01	<0.001	<0.0005	<0.04	<0.01	0.042	<0.0003	0.004	0.030
Drinking Water System Limit	0.05[c]		0.05[c]			0.01[c]	0.05[c]		1.0[d]	0.3[d]	0.002[c]	0.05[d]			0.5[c]		0.01[c]					5.0[d]
Livestock and Wildlife Watering Limit[e]		5.0	0.02	5.0		0.05	1.0	1.0	0.5		0.01				0.1		0.05				0.1	25

[a] Less than symbol (<) means measurement was below the specified detection limit of the analytical method.
[b] N/A means analysis not performed, lost in analysis, or not completed.
[c] Maximum contaminant level, primary standard (NMEIB 1991 EPA 1989b), see Appendix A.
[d] Maximum contaminant level, secondary standard (EPA, 1989b), see Appendix A.
[e] New Mexico Stream Standard for Livestock and Wildlife Watering (NMWQCC 1991), see Appendix A.

Samples from some of the springs in White Rock Canyon showed levels of iron and manganese that would exceed drinking water system secondary standards, but are naturally occurring levels generally consistent with those observed previously. One sample, from Doe Spring, showed a level of chromium that exceeded the drinking water system standard; this level is inconsistent with the level seen last year and is suspected of being inadvertent sample contamination. Selenium level in one spring, Indian Spring, exceeds the livestock and wildlife watering limit; however, the analytical detection limit for selenium this year is itself above the standard, and the value is less than twice the detection limit. The source will be sampled again in 1992.

Analyses for organics were performed on some groundwaters this year. The analyses included the volatile, semivolatile, and PCB analyses (see Table D-21 for detailed listings of parameters). None of the analyses detected the presence of any of the compounds. The sources sampled included Water Supply Wells G-1, G-1A, G-2, G-3, G-4, G-5, G-6, PM-2, PM-3, PM-4, LA-1B, LA-2, LA-3, and LA-5; Test Wells TW-1A and TW-2A; Basalt Spring; and the shallow alluvial groundwater observation wells in Los Alamos Canyon (LAO-1 through LAO-4.5) and Mortandad Canyon (MCO-3 through MCO-7.5).

D. Long-Term Trends

1. Main Aquifer.

The long-term trends of the water quality in the main aquifer are simple to summarize: no concentrations of radionuclides above detection limits (other than an occasional analytical statistical outlier) have been measured on water samples from the production wells or test wells that reach the main aquifer. There is no indication that any contamination of the main aquifer has occurred as a result of Laboratory operations.

In 1990 a special large volume sample (approximately 200 L) was collected for analysis of plutonium isotopes by unique extra-low-level mass spectrometric measurement facilities available in the Isotope Geochemistry Group (INC-7) at LANL. The sample was collected from one of the newly drilled production wells, Otowi-4, near the end of the aquifer pumping test in April 1990. The results showed less than 0.00008 pCi/L of ^{239}Pu, with the limit being constrained by the value of the analytical method blanks rather than any inferred actual presence of plutonium. This detection limit is about 1,000 times smaller than levels detected in routine radiochemical methods at LANL, which have a detection limit of about 0.1 pCi/L for ^{239,240}Pu. These results further confirm that operation of the Laboratory over the years has had no measurable effect on the main aquifer.

The long-term trends of water levels in the water supply and test wells in the main aquifer indicate that there is no major depletion of the resource as a result of pumping for the Los Alamos water supply. In the central part of the plateau, water levels in Test Wells 2 and 3 have declined about 1.6 to 12 m (25–40 ft) in slightly more than 50 years or less than a 0.25 m/yr. Test Well 3 is located about 1.6 km (1 mi) from the nearest supply wells (PM-5 and PM-3); Test Well 2 is about 3.0 km (2 m). Nonpumping levels in Supply Well PM-5 have declined about 10 m (32 ft) in 10 years and in PM-3 have declined about 8 m (26 ft) in 26 years. PM-3, the largest producer of all the wells, provided about 220 million gallons a year or 16% of the total water supply in the last several years. Near the southern boundary of the Laboratory, water levels were monitored in Test Well DT-9 from 1960 to 1982, when a pump was installed. The water level declined a total of about 1 m (3 ft) in the 22 years. The initial years of this decline occurred before any of the Pajarito field wells were drilled and must be attributed to a general regional trend unaffected by pumpage. Thus, the decline observed in the test wells to the north and in the pumping wells is probably partly attributable to a general trend in the regional aquifer.

In the Guaje Well Field northeast of the Laboratory, the average 1991 nonpumping water levels in the well field remained about the same when compared to the 1990 water levels. Increased or decreased pumpage in individual wells during the year resulted in slight declines or increases in water levels in that particular well. The overall nonpumping levels have declined an average of about 19 m (62 ft) for the entire field in the past 40 years.

The Los Alamos Well Field will be retired from service after 1991. The production during 1991 was from wells LA-1B, LA-2, LA-3, and LA-5. The production decreased about 62 million gallons from 187 million gallons in 1990 to 125 million gallons in 1991. The well field contributed about 9% of the total 1991

production. From 1952 to 1964 the production was high, varying from 350 million gallons in 1957 to 627 million gallons in 1964 as the Pajarito field was added to the system. The average water level in the field declined about 17 m (61 ft) from 37 m (121 ft) in 1951 to 55 m (182 ft) in 1964. Since 1965 the production from the field has generally decreased. As a result of the reduced pumpage, the water level in the field has recovered. The average water level has recovered about 21 m (68 ft) from 55 m (182 ft) in 1964 to 35 m (114 ft) in 1991. With end of production from the field there should be a general water recovery in the field.

2. Alluvial Canyon Aquifers.

Long-term trends of radionuclide concentrations in shallow alluvial groundwater in Mortandad Canyon (the current radioactive effluent release area for the waste treatment plant at TA-50) are depicted in Fig. VII-2. The samples are from Observation Well MCO-6, in the midreach of the canyon. The combined total of ^{238}Pu and $^{239,240}Pu$ concentrations (in solution) are relatively constant, fluctuating up and down in response to variations in the treatment plant effluent and storm runoff water that cause some dilution in the shallow alluvial water. The tritium concentration has fluctuated almost in direct response to the average annual concentration of tritium in the TA-50 effluent, with a time lag of about 1 year. Because of the analytical problem discussed in Section VII.C.1 and Table VII-1, the 1991 data are not shown in Fig. VII-2.

E. Special Studies

1. Main Aquifer.

a. Age of the Water. In an effort to better understand the nature of recharge to the main aquifer in the Los Alamos area, a series of special measurements has been initiated on selected water samples. This cooperative effort, involving researchers in the

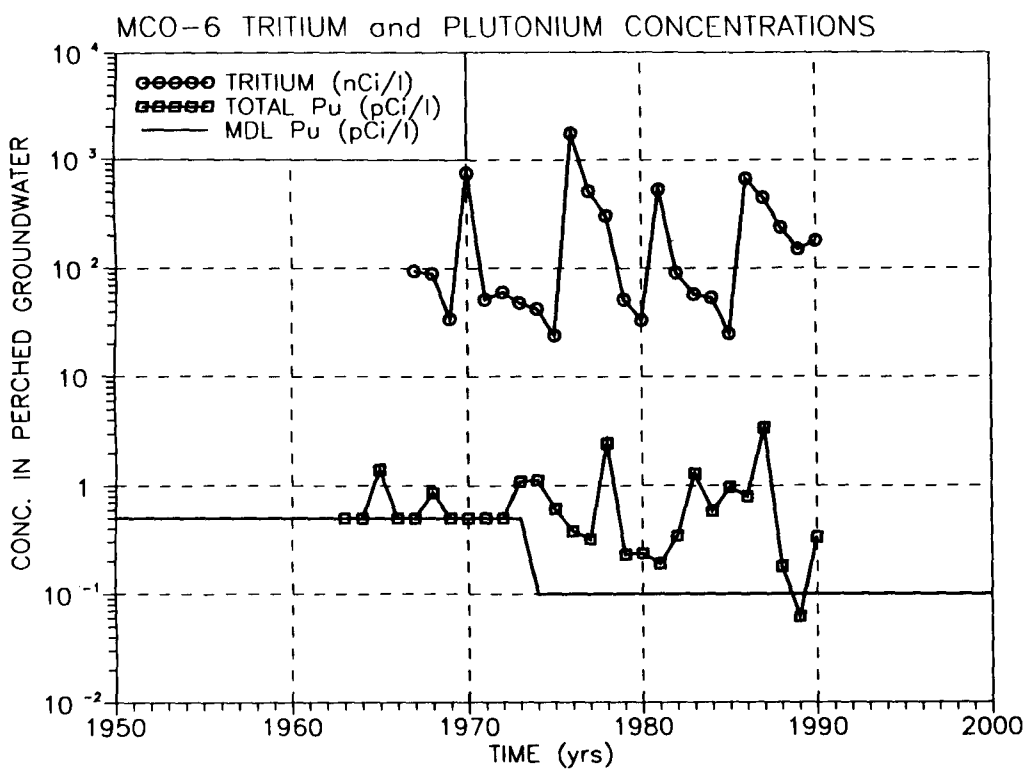


Fig. VII-2. Observation Well, MCO-6 tritium and plutonium concentrations, through 1990. (Graph does not include 1991 data because of analytical problems.)

Laboratory's Earth and Environmental Sciences and Isotope and Nuclear Chemistry Divisions and staff from another DOE installation, is attempting to apply a range of geochemical techniques based on measurements of both radioactive and stable isotopes to help identify specific sources and estimate the age of water in the main aquifer. To date, low-detection limit tritium analyses have been completed on 12 samples from springs in White Rock Canyon and 5 samples from wells into the main aquifer (Goff 1991). These data are summarized in Table VII-4.

The values for tritium in the water range from less than detectable to about 7 pCi/L, with one value about 18 pCi/L. The highest value, for Doe Spring in Chaquehui Canyon, is a sample that must be collected in a pool in the stream channel after it has flowed over a rock face for some distance and thus is subject to mixing with some contemporary precipitation or contamination in the sediments. (See also Section IV.E.3 for information on tritium in sediments in Chaquehui Canyon.) The values are all less than values for tritium in contemporary precipitation (about 30 to 60 pCi/L) and much less than the roughly 700 pCi/L that would be present now in water precipitated in northern New Mexico during the 1962–1963 period when tritium from atmospheric nuclear weapons testing was at its maximum. The conclusion is that there cannot be any significant component of recharge from

Table VII-4. Low-Level Tritium Measurements in Groundwater Samples [a]

Sample Location	Date of Sample	Tritium (as HTO)
Springs in White Rock Canyon		
Spring 2	Oct. 91	4.21 ± (0.36)
Spring 3	Oct. 91	1.65 ± (0.39)
	Sept. 90	3.40 ± (0.29)
Spring 3B	Oct. 91	0.13 ± (0.29)
	Sept. 90	0.91 ± (0.29)
Spring 4A	Oct. 91	2.40 ± (0.39)
Spring 6	Oct. 91	1.78 ± (0.32)
Spring 6A	Oct. 91	0.03 ± (0.29)
	Sept. 90	0.06 ± (0.29)
Spring 7	Oct. 91	2.10 ± (0.29)
	Sept. 90	1.46 ± (0.29)
Spring 8	Oct. 91	7.09 ± (0.55)
	Sept. 90	5.83 ± (0.29)
Spring 8B	Sept. 90	4.66 ± (0.29)
Spring 9A	Oct. 91	1.78 ± (0.29)
Ancho Spring	Oct. 91	4.21 ± (0.36)
	Sept. 90	3.40 ± (0.29)
Doe Spring	Sept. 90	17.71 ± (0.58)
Wells In Main Aquifer		
Well LA-1B	Oct. 91	0.26 ± (0.29)
Well G-5	Oct. 91	0.06 ± (0.29)
Well PM-1	Oct. 91	1.65 ± (0.32)
Well PM-5	Oct. 91	0.29 ± (0.29)
Test Well DT-5A	Oct. 91	-0.23 ± (0.29)

[a]Counting uncertainties are in parenthesis.

water precipitated during the last several decades in the water from the main aquifer. The inference is that the water is considerably older.

Preliminary interpretation of carbon-14 data for samples from the same five deep wells indicates that the water ranges in age from several thousand years to more than 10,000 years (Spangler 1992). It is anticipated that results from all the analyses will be complete in 1992, and a full interpretation will be included in "Environmental Surveillance at Los Alamos during 1992."

b. Potential Communication between Test Well 1 and Test Well 1A. A special study was initiated in 1991 to investigate the potential for communication between two test wells adjacent to each other in lower Pueblo Canyon. Test Wells TW-1 and TW-1A are located in Pueblo Canyon upstream from the Los Alamos Canyon confluence. These wells were drilled by cable tool and completed in 1949 as observation wells (Purtymun 1987a). TW-1A penetrates to a total depth of 68 m (225 ft) below land surface; this entire length is cased and the bottom 3 m (10 ft) is screened in the top of the main aquifer in the Puye Conglomerate. Two separate layers of dense basalt are located between the screened intervals in these two test wells. Between 1951 and 1991, the water levels in TW-1A have fluctuated between about 52 to 64 m (170–210 ft) below land surface. These fluctuations were in response to stream channel percolation losses, which have fluctuated widely during this period in response to variable storm water and snowmelt runoff, evapotranspiration losses, and historic (i.e., prior to 1964) Laboratory effluent releases into Pueblo Canyon.

The water levels in TW-1 have fluctuated between about 178 to 180 m (587–593 ft) below land surface between 1951 and 1966. Since 1966, however, the water levels in TW-1 have risen to approximately 153 m (506 ft) below land surface. The reason for this change is currently under investigation; however, such increases could be associated with either a leaky well casing or natural percolation through the formations surrounding the wellbore.

During late September and early October 1991, TW-1 and TW-1A were tested as follows. A recording pressure transducer was placed in TW-1A to monitor water level fluctuations while TW-1 was pump tested. TW-1 began pumping on September 23, 1991, at a constant rate of 2.35 gpm. Within several hours, the water level in TW-1 had declined by approximately 23 m (75 ft) below its static level. This pumping rate continued for approximately 15 days; however, the drawdown levels in TW-1 gradually approached a constant 24 m (80 ft). During this period, the water levels in TW-1A only responded to atmospheric pressure fluctuations; these TW-1A water level fluctuations were less than 0.3 m (1 ft) and are directly correlated with corresponding atmospheric pressure fluctuations. Eleven water samples were collected from TW-1 during this period for chemical analyses; these data are summarized in Table VII-5. When the pump at TW-1 was turned off, the water level recovered back to previous static levels within 24 hours. TW-1A was then pump tested at approximately 0.5 gpm for several days, and water levels were simultaneously recorded in TW-1. Approximately 2 m (7 ft) of total drawdown were observed in TW-1A during this period; however, no corresponding water level changes were observed in TW-1. Three water samples were collected from TW-1A for laboratory analyses during this second pump test period. Throughout the pump test periods at TW-1 and TW-1A, additional water samples were also collected at TW-2, TW-2A, APCO-1, and Basalt Springs; these data are summarized in Table VII-5.

Major ion water quality data from TW-1 and TW-1A were compared to major ion water quality data from Pueblo Canyon surface waters and shallow alluvial waters (i.e., from Observation Well APCO-1 located near the Pueblo-3 sample station). These analyses suggest that the water quality in TW-1A is practically identical to that in the surface stream (Pueblo-3 surface sample station) and in the shallow alluvium (APCO-1 sample at about 3 to 4 m [10–12 ft] below land surface) as expected. Furthermore, the relative proportions of major ions (i.e., Ca, Mg, Na, K, ^{3}CO, ^{3}HCO, Cl, and ^{4}SO) have not significantly changed over the years. However, the water quality in TW-1, as characterized by major ion concentrations, is distinctly different from TW-1A, APCO-1, or Pueblo-3 samples, as seen in the Stiff pattern diagrams shown in Fig. VII-3. The Stiff patterns for TW-1A, APCO-1, and Pueblo-3 surface waters are very similar because major ion concentrations are similar. It is apparent that TW-1A is in hydraulic communication with surface and near surface waters in Pueblo Canyon as expected. Furthermore, these Stiff pattern similarities have

Table VII-5. Water Quality in Pueblo Canyon Average Water Quality Values (conc in mg/l)[a]

Location	TW-1	TW-1A	TW-2	TW-2A	APCO-1	Basalt Springs
No. of Samples	10	3	3	3	2	2
Analysis						
Ca	45.9	24.7	6.5	33.7	21.5	22.0
K	3.4	6.9	2.0	3.4	12.0	5.0
Mg	9.7	6.9	1.7	7.1	3.7	4.9
Na	16.0	68.0	39.0	22.3	73.0	36.0
HCO^3	99.6	137.3	98.0	83.0	140.5	57.5
CO^3	4.1	5.0	5.0	5.0	5.0	5.0
Cl	40.1	52.8	4.8	47.5	45.1	31.6
NO^3-N	6.1	2.2	0.0	2.3	1.1	7.3
SO^4	23.6	28.3	1.8	22.5	29.9	45.2
PO^4-P	0.2	3.3	0.1	1.4	7.0	11.2
F	0.4	0.6	0.8	0.2	0.7	0.6
SiO^2	46.5	35.0	14.7	47.3	62.5	49.0
TDS	176.6	202.0	55.3	182.0	139.0	215.0
pH[b]	6.7	6.3	6.8	6.8	6.3	7.07
Temperature[c]	15.1	13.0	16.0	14.6	16.6	17.9
Conductivity[d]	268.7	306.0	183.7	166.7	355.0	254.0

[a]Samples collected September 23 to October 10, 1991.
[b]Standard units.
[c]Degrees Celsius.
[d]Units of μmho/cm.

remained relatively constant since at least 1981. The major ion pattern for TW-1 is distinctly different from the other samples and has maintained its current pattern over the past decade. These data suggest that TW-1 is basically isolated from surface and near surface waters in Pueblo Canyon and has been for at least the past decade.

The Stiff diagrams for TW-1 may also be showing subtle changes in water quality over the past decade (note the increases in chloride and sulfate concentrations over time) possibly reflecting slow percolation from the stream channel over decades, or they may be reflecting normal temporal variability. However, current and historical water quality data do not conclusively answer this question.

If TW-1A and TW-1 were in relatively direct hydraulic communication via a leaky wellbore, then one would also expect that rapid water level fluctuations in these wells would be correlated over time. Indeed, one might logically expect these water levels to also be in equilibrium during nonpumping periods. On the other hand, if there is a natural hydraulic communication through the formations separating the respective well screens, then one might expect lower frequency nonpumping water levels to be correlated. If these water levels are not correlated, then one would likely conclude that TW-1A and TW-1 are not in hydraulic communication. In addition, water level fluctuation data should also corroborate findings implied by major ion water quality data. Long-term, high-frequency water level fluctuations must be monitored to answer these questions conclusively. Additional study will be necessary to completely determine the significance of the higher water levels and chemical quality changes in TW-1.

c. Water Production Records. Monthly water production records are provided to the State Engineer's Office under the water rights permit held by the DOE

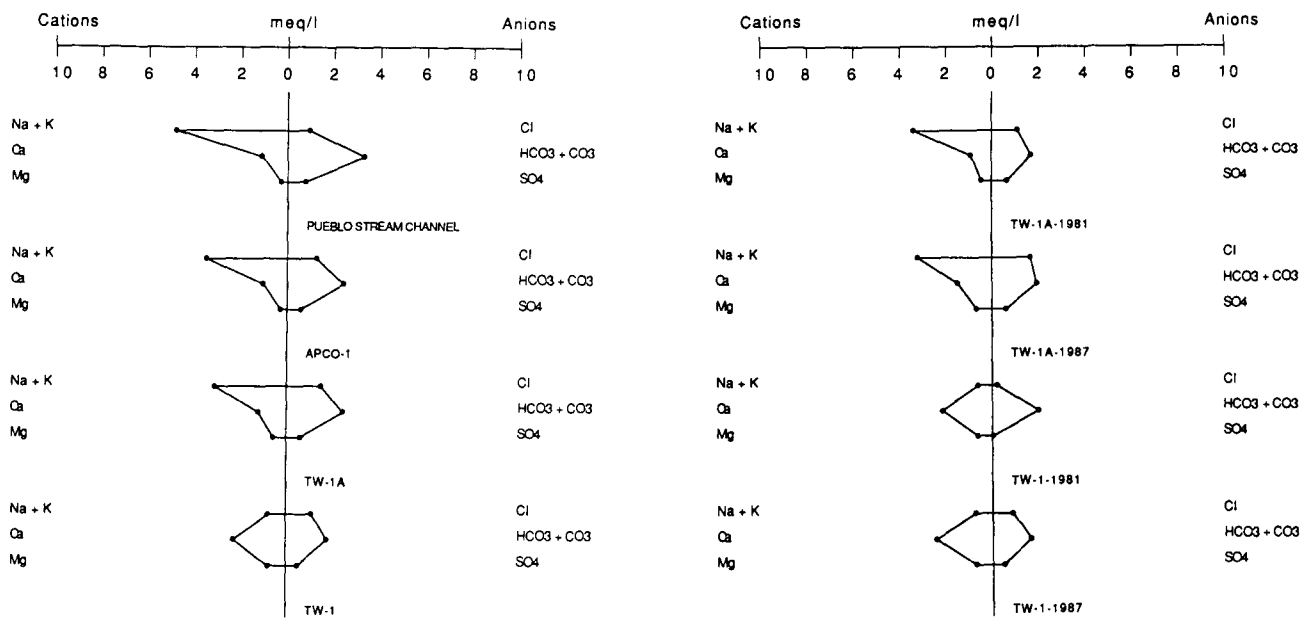


Fig. VII-3. Pueblo Canyon water quality.

for the Los Alamos water system. During 1991, total production from the wells and gallery for potable and nonpotable use was 5.55×10^6 m^3 (4,493 ac-ft). This production amounts to 81% of the total diversion right of 6.8×10^6 m^3 (5,541 ac-ft) that is available to the DOE under its permit. Details of the performance of the water supply wells (pumpage, water levels, drawdown, and specific yield) and their operation are published in a series of separate reports, the most recent of which is "Water Supply at Los Alamos During 1989" (Stoker 1992).

2. Vadose Zone.

A special study, "Extent of Saturation in Mortandad Canyon" (Stoker 1991), provides some important information on the movement of moisture and contaminants in the unsaturated tuff beneath the alluvial aquifer in that canyon. Measurements of moisture content from several core holes that penetrated the saturated portion of the alluvium all exhibited the same pattern. Data from one of the holes (MCM-5.9) are shown in Fig. VII-4 as an example. Most values for gravimetric moisture content in the Tshirege tuff beneath the alluvial aquifer ranged from 10 to 30%, corresponding to about 20 to 60% of saturation. There were one or more peaks at higher values, approaching 90% of saturation near the contact with or in the Tsankawi tuff and the fluvial Cerro Toledo rhyolite deposits on the top of the Otowi member of the tuff, at depths around 30 m (100 ft). In the Otowi tuff, the gravimetric moisture content decreased and leveled off at about 12 to 18%, which corresponds to 20 to 40% of saturation.

A similar pattern occurred in a core hole (SIMO-1) further downstream in Mortandad Canyon on San Ildefonso lands past the end of the alluvial aquifer (EPG 1992). The gravimetric moisture content was somewhat lower in the Tshirege tuff but still with some higher peaks in the vicinity of the Tsankawi, and then gradually increasing in the Otowi tuff to 10 to 20%, which corresponds to about 20 to 40% of saturation.

In other canyons the basic pattern of moisture distribution appears to be repeated. One core hole was drilled in Sandia Canyon south of TA-53 in June 1991 as part of a special investigation regarding potential leakage from the lagoons at TA-53. The hole was located in a side drainage that flows only occasionally

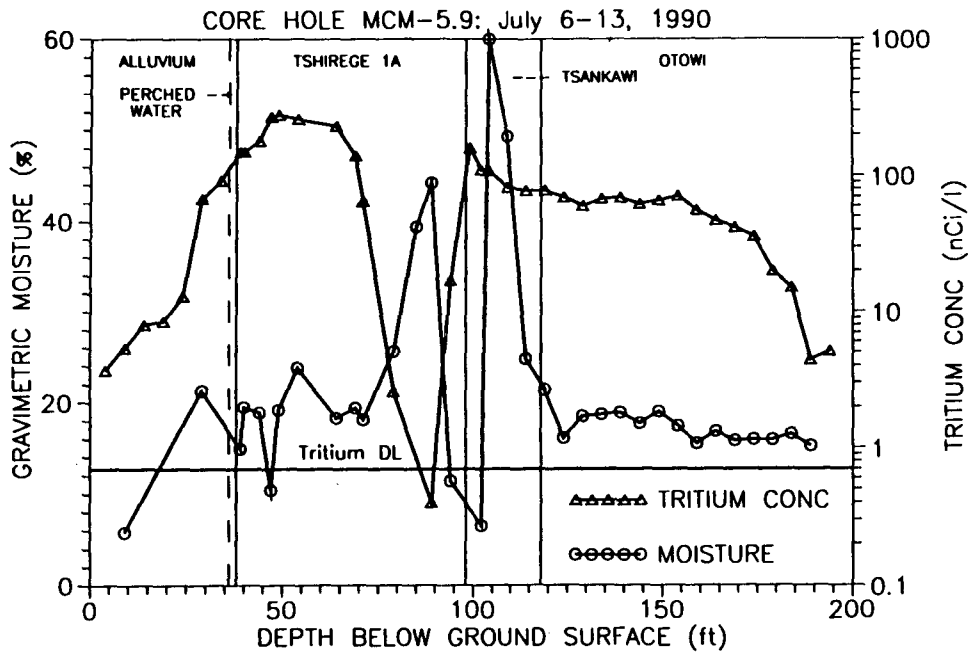


Fig. VII-4. Mortandad Canyon moisture and tritium profiles.

with natural runoff and did not penetrate any saturated zone. Data from that hole are shown in Fig. VII-5. As in Hole SIMO-1, there are peaks of moisture just above and in the Tsankawi, and then gravimetric moisture increases and levels off between 15 and 20%, which corresponds to 25 to 30% of saturation.

A core hole was drilled in Potrillo Canyon in November 1991 as part of a special uranium transport study. The hole was drilled in an area where significant volumes of natural runoff infiltrate during the rainy season but no saturation was encountered. Data from that hole is shown in Fig. VII-6. The gravimetric moisture content in the Tshirege tuff is relatively high, between 15 and 25%. In the Tsankawi the moisture content dips and peaks sharply; once into the Otowi tuff, the moisture content levels off at 10 to 11%.

The data suggest there are some complex variations in hydrologic properties in the layers from the base of the Tshirege through to the top of the Otowi tuff that significantly affect the movement of moisture in the unsaturated zone. These data also indicate that moisture conditions in the Otowi tuff become very uniform with only moderate differences in magnitude depending on whether there are saturated conditions in overlying layers. Additional field data and theoretical interpretation will be required to confirm the patterns and quantify movement.

The basic conclusions of the Mortandad study regarding the movement of radioactive contaminants below the alluvial aquifer are (1) soluble or particulate radioactive constituents have moved less than about 3 m (10 ft) into the unsaturated zone beneath the alluvial aquifer, and (2) tritium, as tritiated water (HTO), has moved at least 46 m (150 ft) below the alluvial aquifer, to a total depth of about 59 m (195 ft). The tritium data for cores from hole MCM-5.9 (the deepest corehole drilled to date in Mortandad Canyon) are shown in Fig. VII-4. Tritium concentrations decrease by a factor of about 100 between 46 and 59 m (150 and 195 ft), suggesting the possibility that tritium may not have moved much deeper in the almost 30 years since effluents were first released from the TA-50 treatment plant. However, this possible conclusion must be considered tentative until additional, deeper core holes can confirm the pattern.

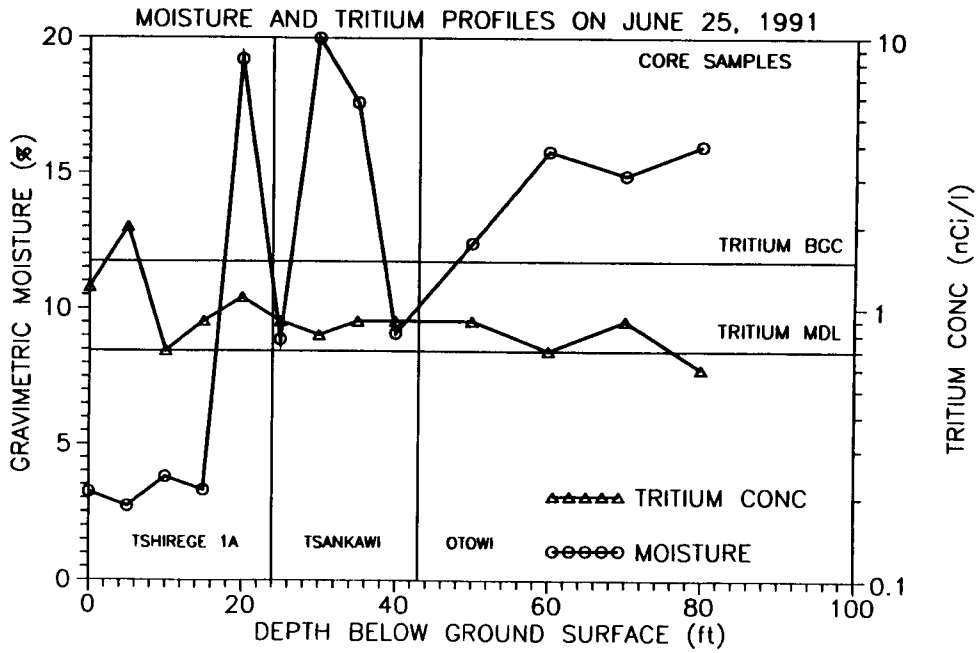


Fig. VII-5. TA-53 Surface Impoundments: Core Hole No. 7 moisture and tritium profiles on June 25, 1991.

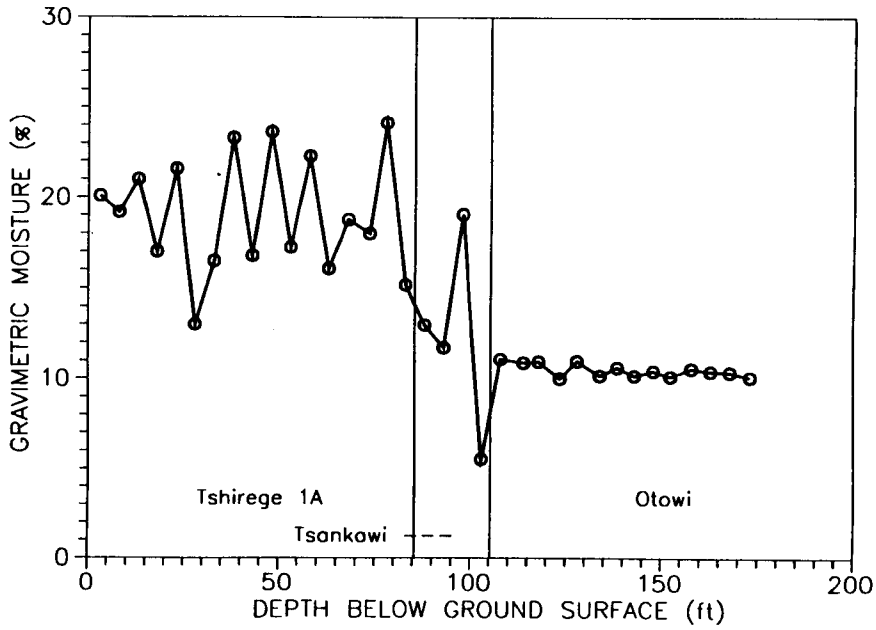


Fig. VII-6. Potrillo Canyon Core Hole No. 1 on December 12, 1991.

VIII. QUALITY ASSURANCE AND SAMPLING PROCEDURES

Quality assurance includes all of the planned and systematic actions and activities necessary to provide adequate confidence that a system or process will perform satisfactorily. Every monitoring and compliance activity sponsored by the Laboratory's Environmental Protection Group (EM-8) has its own quality assurance program with documented sampling procedures. The Environmental Chemistry Group (EM-9) also has a documented quality assurance program for sample analysis and data verification.

A. Organization

The Laboratory is managed by the University of California (UC) for the Department of Energy (DOE) and is obligated to report both to the UC and to the DOE. The Laboratory contract is administered through the DOE Los Alamos Area Office (LAAO) and the Albuquerque Operations Office (AL). The Laboratory Director is ultimately responsible for all Laboratory activities. However, technical and administrative responsibility and authority are delegated to directorates and support offices.

The Director is supported by a Deputy Director, an Executive Staff Director, eight Associate Directors, two Associate Directors at Large, the Controller, Laboratory Counsel, the Director of Human Resources, and the Office of Public Affairs.

The Environmental Management (EM) Division is the primary Laboratory support program in all environmental activities. The Division initiates and promotes a comprehensive Laboratory program for environmental protection and has primary responsibility for environmental surveillance and regulatory compliance; manages the Laboratory's waste management, corrective action, environmental chemistry, environmental protection, and environmental restoration programs; and maintains a record of Laboratory documents related to environmental matters and provides data to Laboratory managers for trend and root cause analysis. Although the Laboratory Director has primary responsibility for environment, safety, and health (ES&H) management, EM Division provides line managers with assistance in preparing and completing environmental documentation such as reports required by the National Environmental Policy Act (NEPA) of 1969 and Resource Conservation and Recovery Act (RCRA). With assistance from Laboratory Counsel, EM Division helps to define and recommend Laboratory policies with regard to applicable federal and state environmental regulations and laws and DOE orders and directives.

The EM Division organization and groups within the Division are shown in Fig. VIII-1. EM-8 assists operating groups in complying with federal, state, local, and DOE environmental requirements. This group also bears primary responsibility for monitoring the ambient environment and evaluating past, present, and future environmental impacts from Laboratory operations. EM-8 bears principal responsibility for obtaining permits and approvals from applicable environmental regulatory authorities and oversees corrective actions required in compliance orders and interagency agreements with regulators.

EM-9 provides analytical services to the Laboratory's environmental, waste management, radiation protection, and industrial hygiene operations. EM-9 is responsible for quality assurance for the health and environmental analytical work. EM-9 currently participates in the following Interlaboratory Quality Assurance Programs:

- National Institute for Occupational Safety and Health, Proficiency Analytical Testing Program;
- Environmental Monitoring and Support Laboratory, Cincinnati (EMSL-CI) Drinking Water Program;
- EMSL-CI Water Pollution Study;

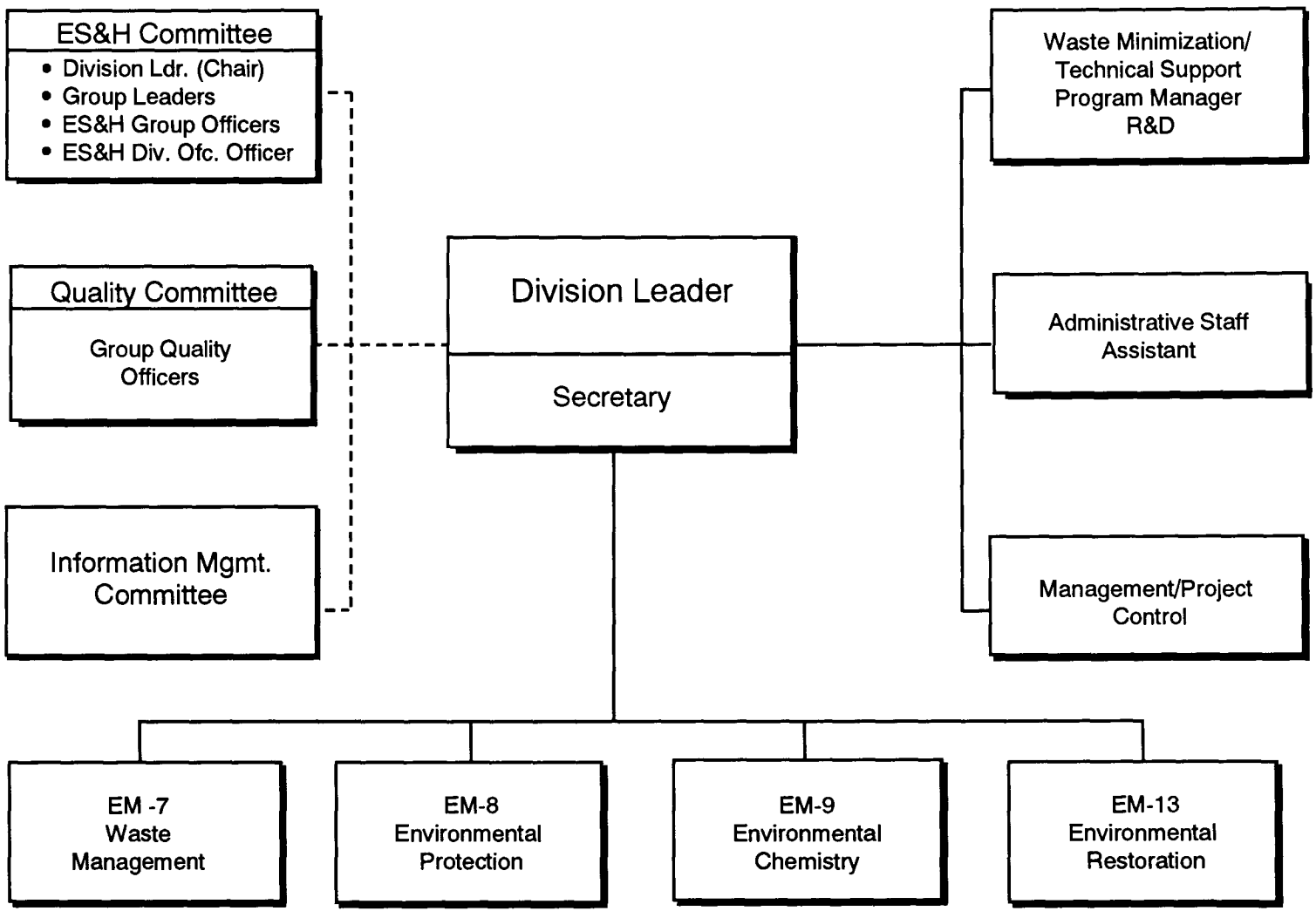


Fig. VIII-1. Organizational chart for the Environmental Management Division.

- Environmental Protection Agency (EPA) Environmental Monitoring Systems Laboratory-Las Vegas;
- Environmental Measurements Laboratory;
- National Pollutant Discharge Elimination System (NPDES); and
- DOE Beryllium Intercomparison Study.

The Waste Management Group (EM-7) manages Laboratory-generated liquid and solid wastes to reduce the impact of the release of radioactive and hazardous materials to the environment while ensuring that requirements for regulatory compliance are maintained. The group also maintains the program for monitoring the constituents of the radioactive liquid waste streams at the Laboratory. The Environmental Restoration Group (EM-13) is responsible for compliance with the Hazardous and Solid Waste Amendments (HSWAs) and Module VIII of the RCRA Operating Permit and coordinates any Comprehensive Environmental Response, Compensation, and Liability Act activities at the Laboratory. The primary objective of EM-13 is to implement assessment and remediation activities as required for potential release sites and contaminated facilities at the Laboratory.

The Health and Safety Division (HS) is also key in implementing the Laboratory's environmental program. The Health Physics Measurement Group (HS-4) and the Health Physics Policy & Programs Group (HS-12) are responsible for monitoring radiological airborne emissions from stacks around the Laboratory, for maintaining stack emission plans and quality assurance documentation, and for preparing annual reports. The Risk Management Support Group (HS-3) helps communicate environmental policies to Laboratory employees and ensures that appropriate environmental training programs are available.

Several committees provide environmental concurrence and review functions for Laboratory operations. The Laboratory's ES&H Questionnaire Review Committee provides reviews of proposed projects to ensure that appropriate environmental, as well as health and safety, issues are properly addressed. In 1991, the committee reviewed 211 questionnaires. The day-to-day questionnaire and review process is managed by HS-3. The Laboratory Environmental Review Committee reviews and concurs with NEPA documentation for projects prior to submittal to DOE. The ES&H Council provides senior management level oversight of environmental activities and policy development.

The Laboratory Assessment Office is an independent environmental appraisal and auditing program which verifies appropriate implementation of environmental requirements. The Quality Operations Office performs quality assurance (QA) and quality control (QC) audits and surveillance of Laboratory and subcontractor activities in accordance with the Quality Assurance Plan for the Laboratory and for the specific activity, if one is required. The Emergency Management Office is responsible for the Laboratory's Emergency Response Plan, which is designed for prompt mitigation of all incidents, including those with environmental impact, and provides the means for coordinating all Laboratory resources in the mitigation effort.

B. Quality Assurance Program

Quality is the extent to which an item or activity meets or exceeds requirements. QA is all of the planned and systematic actions and activities necessary to provide adequate confidence that a facility, structure, system, component, or process will perform satisfactorily in service. Each monitoring activity sponsored by EM-8 maintains its own QA program (QAP) for its activities. Programs are unique to activities but are guided by the need to establish policies, requirements, and guidelines for the effective implementation of regulatory requirements and to meet the requirements of DOE Orders 5400.1 (DOE 1988a) and 5700.6B (DOE 1989b), by the following criteria:

- Organization
- QA program
- Design control
- Procurement document control
- Plans, procedures, and drawings
- Document control
- Control of purchased items and services
- Identification and control of data, samples, and items
- Control of processes
- Inspection
- Test control
- Control of measuring and test equipment
- Handling, storage, and shipping

- Status of inspection, test, and operations
- Control of nonconforming items and activities
- Corrective action
- QA records
- Audits and surveillances

QAPs for each environmental monitoring program performed by EM-8 have been drafted for inclusion in the Environmental Monitoring Program, currently being revised. The QAPs will be revised under DOE Order 5700.6C (August 21, 1991) within three years. The Laboratory's Quality Operations Office has recently distributed guidelines for revision which indicate that the existing 18-point program used by DOE Order 5700.6B will be replaced by a 10-point program.

C. Sampling Procedures

1. Thermoluminescent Dosimeters.

Thermoluminescent dosimeters (TLDs) used at the Laboratory are lithium fluoride (LiF) chips, 6.4 mm square by 0.9 mm thick. The TLDs, after being exposed to radiation, emit light upon being heated. The amount of light is proportional to the amount of radiation to which the TLD was exposed. The TLDs used in the Laboratory's environmental monitoring program are insensitive to neutrons, so the contribution of cosmic neutrons to natural background radiation is not measured.

The chips are annealed to 400°C (752°F) for 1 hour and then cooled rapidly to room temperature. This is followed by annealing at 100°C (212°F) for 1 hour and again cooling rapidly to room temperature. For the annealing conditions to be repeatable, chips are put into rectangular borosilicate glass vials that hold 48 LiF chips each. These vials are slipped into a borosilicate glass rack so they can be placed all at once into ovens maintained at 400°C and 100°C.

Four LiF chips constitute a dosimeter. The LiF chips are contained in a two-part threaded assembly made of an opaque yellow acetate plastic. A calibration set is prepared each time chips are annealed. The calibration set is read at the start of the dosimetry cycle. The number of dosimeters and exposure levels are determined for each calibration in order to efficiently use available TLD chips and personnel. Each set contains from 20 to 50 dosimeters, which are irradiated at levels between 0 and 80 mR using an 8.5-mCi ^{137}Cs source calibrated by the National Bureau of Standards.

A factor of 1 mrem (tissue) = 1.050 mR is used in evaluating the dosimeter data. This factor is the reciprocal of the product of the roentgen-to-rad conversion factor of 0.958 for muscle for ^{137}Cs and of 0.994, which corrects for attenuation of the primary radiation beam at electronic equilibrium thickness. A rad-to-rem conversion factor of 1.0 for gamma rays is used, as recommended by the International Commission on Radiation Protection (John 1974, ICRP 1970). A method of weighted least-squares linear regression is used to determine the relationship between TLD reader response and dose (the weighting factor is the variance) (Bevington 1969).

The TLD chips used were all from the same production batch and were selected by the manufacturer so that the measured standard deviation in thermoluminescent sensitivity is 2.0% to 4.0% of the mean at a 10-R exposure. At the end of each field cycle, whether a calendar quarter or the Los Alamos Meson Physics Facility (LAMPF) operation cycle, the dose at each network location is estimated from the regression along with the regression's upper and lower 95% confidence limits at the estimated value (Natrella 1963). At the end of the calendar year, individual field cycle doses are summed for each location. Uncertainty is calculated as the summation in quadrature of the individual uncertainties (Bevington 1969).

2. Air Sampling.

a. Ambient Air. Samples are collected monthly at all but one of the 37 continuously operating stations. Samples are collected weekly from a station located on the top of the Occupational Health Laboratory (OHL) building at TA-59.

Airborne particulates are collected from the atmosphere using vacuum pumps with flow rates of 3 liters per second (approximately 6 cubic feet per minute [cfm]). The flow rates at the start and the finish of the sampling period are measured with a calibrated rotameter to determine average flow rate and are multiplied by the total run time to determine the volume of air sampled. The particulates are collected on 79 mm diameter polystyrene filters (Microsorban). Each filter is mounted on a charcoal cartridge. The charcoal cartridge is used as a quantitative determination for gaseous gamma emitters should an unplanned release occur.

The particulate filters are analyzed monthly for gross alpha and gross beta activity. Particulate filters and charcoal cartridges are also analyzed monthly using gamma ray spectrometry. The filter and cartridge collected from the OHL building at TA-59 are analyzed by the process described above on a weekly basis. Particulate filters are then composited for a quarter and analyzed for plutonium, americium, and uranium.

Part of the total airflow (1.5 to 4.0 cc/sec) from the above system is passed through a cartridge containing 200 to 300 grams of indicating silica gel. The silica gel adsorbs atmospheric water vapor to tritium analysis. Indicating silica gel is used to determine if moisture was absorbed through the entire sample during the collection period. If the sample indicates "breakthrough" has occurred, then the sample is discarded.

A calibrated rotameter is used to determine initial and final air flow to find average air flow. The total time of operation is multiplied by the average flow rate to determine the volume of air sampled. The silica gel collected monthly is heated to drive off the moisture collected from the atmosphere. The moisture is then analyzed for tritium using liquid scintillation counting.

A specific radioiodine sampling program is being developed in anticipation of the Laboratory's future participation in additional medical isotope production projects. The program was started in August with six sampling stations. The system will be modified for optimum detection as the projects near start-up. The system uses vacuum pumps with constant airflow regulators that sample at 1 cfm. Cartridges that contain activated TEDA treated charcoal are used to collect radioiodine as gas. A 47 mm micro glass borosilicate particulate filter is placed in front of the charcoal cartridge to collect any iodine in particulate form. Air volumes are determined by multiplying the constant flow rate (1 cfm) by the total time sampled. Samples are collected weekly. Filters and cartridges are qualitatively analyzed by gamma spectroscopy before being sent to the analytical laboratory for quantitative analysis. No radioiodine was detected in 1991.

Measurement of tritium in rainwater is included in this year's monitoring results. This sampling program was initiated to support the Laboratory's Environmental Restoration program and was conducted by the Geology and Geochemistry Group (ESS-1). In the laboratory, measurement of tritium in rainwater is accomplished through ultra low-level beta counting in gas proportional counters. The tritium content of the rainwater sample is enriched through electrolysis, then reduced to hydrogen gas, which is injected into the counter and measured. The sample measurement value is statistically scrutinized according to background and standards before release to the investigator. Values of tritium are given in tritium units: one TU is 3.2 pCi/L of water.

b. Radioactive Air Emissions Monitoring. Samples are collected at weekly intervals from 88 monitors. Sample collection and analysis are performed by personnel from HS-12 and HS-4.

The typical system for monitoring particulate radioactivity in stack emissions consists of one or more sampling or monitoring probes that continuously extract a representative sample from the stack exhaust stream by the use of an air sampling pump that passes the sample through a filter on which the particles are trapped. The pumps typically sample at a rate of 2 cfm. The filter with its trapped particles is analyzed for radioactivity. The filters are counted for either gross alpha or gross beta activity depending on the respective isotope(s) that are emitted from the stack. To determine the total activity released, the radioactivity on the sample filter is multiplied by the ratio of the total stack flow (in the sampling time) to the volume of air sampled by the pump during the sampling period. This total activity is expressed in microcuries or curies. The radioisotopes of plutonium are not listed separately because the analysis of the air sample filters by gross alpha count does not distinguish between the individual isotopes of plutonium. Likewise, the analysis of the air sample filters by gross beta counts does not distinguish between the individual radioisotopes in the group called "mixed fission products."

The typical system for monitoring an effluent or exhaust stream for airborne tritium in the gaseous form (HT, DT, T^2) is basically an in-line system in which one or more sampling or monitoring probes continuously extract a representative sample from the stream and direct it to remotely located tritium (H^3) measuring instruments through metal tubing (or "lines"). The instruments measure the tritium concentration and, in conjunction with the effluent exhaust rate, the total H^3 activity (in curies) released to the environment over a period of time. At LAMPF, the tritium in the form of water (HTO) is captured on silica gel, which is changed monthly to count for the H^3 activity. At other facilities such as the Tritium Systems Test Assembly (TSTA) the

effluent containing H^3 activity is captured in a bubbler system which enables analysts to distinguish between the quantity of tritium activity that is in the form of HT or HTO.

At LAMPF, the particulate/vapor activation products are captured on paper filters in the case of particulates or on charcoal filters in the case of vapor products, and total radioactivity is counted. Gaseous activation products (G/MAP) are counted in a flow-through air ionization chamber to determine total radioactivity. Isotopic ratios are measured using high purity germanium detectors. Stack flow rates are measured by Johnson Controls Inc. (JCI) using flowmeters that are calibrated at least quarterly using magnehelic gauges that are traceable to National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards) standards.

The following procedures have been documented and approved by HS-12:

- the calibration of flowmeters used in stack effluent sampling;
- traverse flow measurements;
- Sutorbilt maintenance procedures;
- assembly and service of Sutorbilt air sampling system (air sampling pumps used to collect stack air samples);
- calibration procedures of magnehelic gauges (to calibrate the flowmeters); and
- special monitoring instructions for air sampling.

The following procedures have been documented and approved by HS-4:

- instrumentation and calibration;
- instrument recall and issue;
- calibration of fixed tritium instrumentation at TSTA, TA-3-16, TA-21-209, TA-33-86, TA-35-TSL 213, TA-55-PF4, TA-16-205;
- calibration procedures for the TSTA stack bubbler;
- calibration and maintenance of the TA-55 CAM facility, TA-3-40-RM E28;
- gamma spectroscopy of LAMPF stack filters and water samples;
- operation of the IMPULSE alpha analyses system (used to transfer data from HS-4 to databank on OF-VAX computer); and
- liquid scintillation analysis.

c. Nonradioactive Air. The criteria pollutant monitoring station owned by the Laboratory is located south of TA-49, adjacent to Bandelier National Monument. This station, which began operation in the second quarter of 1990, continuously monitors air concentrations of nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2). Filters to trap small particulate matter (less than 10 microns in diameter - PM_{10}) are collected every 6 days and weighed. Once each month, the New Mexico Environment Department (NMED) audits the flow rate of the instrumentation.

Atmospheric visibility is also analyzed using a transmissometer. A 10-minute measurement is taken every hour, on a 24-hour per day basis. The visibility is measured between TA-49 and TA-33, a distance of 4.58 km (2.84 mi). Air Resources of Fort Collins, Colorado, is responsible for data quality.

Acid deposition from precipitation is measured once per week. Water samples are examined in the field for visible contamination, pH factor, and electrical conductivity. Samples are sent to Colorado State University (CSU) to be further analyzed for inorganic content and pH values. Blind samples are audited by CSU twice per year, and equipment checks are made once every three years.

Beryllium is monitored on the Continuous Ambient Air Monitors that are operated as part of the ambient radionuclide monitoring system. The samples are taken using a flow rate of 6 cfm. The flow rate is calibrated to a dry gas flow meter which is calibrated to a National Bureau of Standards spirometer. The equipment operates continuously, and samples are collected monthly. A composite of the monthly samples is generated quarterly by combining the samples into one and then analyzing it.

3. Water Sampling.

a. Surface Water and Groundwater. Surface water and groundwater sampling stations are grouped by location (regional, perimeter, on site) and hydrologic similarity. Water samples are taken once a year. Samples from wells are collected after sufficient water has been pumped or bailed to ensure that the sample is representative of the aquifer. Spring samples (groundwater) are collected at the discharge point.

The water samples are collected in 4-L polyethylene bottles for radiochemical analyses. The 4-L bottles are acidified in the field with 5 mL of concentrated nitric acid and then are returned to the laboratory within a

few hours of sample collection for filtration through a 0.45-µm membrane filter. The samples are routinely analyzed radiochemically for H^3, ^{137}Cs, total uranium, ^{238}Pu, and $^{239,240}Pu$, as well as for gross alpha, beta, and gamma activities. Selected samples are also analyzed for ^{241}Am, ^{90}Sr, and accelerator-induced activation products. Analytical methodology and its quality assurance program are discussed in Section VIII.D. Detailed container and preservation requirements of EM-9 are documented in a handbook (Williams 1990).

Water samples for inorganic and organic chemical analyses are collected at the same time. For most samples for inorganic analyses, three 1-L polyethylene bottles are collected, one with no additives, one with sulfuric acid, and one with nitric acid to provide the proper range of preservatives for the standard list of constituents. When necessary, additional containers with appropriate preservatives are collected for mercury, cyanide, and sulfide analyses. For selected samples additional glass containers are collected for organic analyses. Details of container and preservation requirements, and identification of EPA methodology for each analysis are contained in the EM-9 Handbook (Williams 1990).

Runoff samples are analyzed for radionuclides in solution and suspended sediments. The samples are filtered through a 0.45-µm filter. Solution is defined as filtrate passing through the filter; suspended sediment is defined as the residue on the filter.

b. National Pollutant Discharge Elimination System. Personnel from EM-8 complete sample collection, preservation, and field analysis of the Laboratory's National Pollutant Discharge Elimination System (NPDES) permitted industrial outfall discharges. Industrial effluent samples are collected for specific parameters at the monitoring frequencies and locations specified in the NPDES Permit. Monitoring is conducted according to EPA-approved methods documented in 40 CFR Part 136 and NPDES Permit Nos. NM0028355 and NM0028576. Chain-of-custody (COC) procedures for sample collection and analysis are conducted during NPDES industrial compliance sampling.

EM-9 performs analysis of industrial discharges for pollutants listed in the NPDES permits. Samples are tested according to EPA-approved methods documented in 40 CFR Part 136, "Guidelines Establishing Test Procedures for Analysis of Pollutants under the Clean Water Act; Final Rule and Technical Amendments" (EPA 1991) or otherwise specified in the NPDES permits.

Treated effluent samples are collected from the sanitary treatment plants by JCI Environmental (JENV) laboratory in accordance with the monitoring conditions specified in NPDES Permit NM0028355. Representative samples are collected from the monitoring points designated by the permit for each outfall. Sample collection and preservation are conducted according to test procedures approved under 40 CFR 136. Chain-of-custody procedures are used by JENV for sample collection and analysis. JENV conducts the sanitary wastewater testing for pollutants listed in the NPDES permit. Testing procedures are conducted according to the seventeenth edition of Standard Methods for the Examination of Water and Wastewater (APHA 1989) and other conditions specified by the NPDES permit.

All instruments used for sanitary and industrial field and laboratory analysis are routinely serviced and calibrated; records are properly maintained. Measurements are made in accordance with the NPDES permit quality assurance requirements, 40 CFR Section 122.41. Quality assurance procedures include the use of duplicate, replicate, and spike analyses; sample splits; outside reference samples; blanks; reagent blanks to check for sources of error; and method verification. Both JENV and the EM-9 laboratories participate in the National Discharge Monitoring Report Quality Assurance Program. EM-9 also participates in the EPA Water Pollution Study for blind spike analyses. The Laboratory's NPDES program is subject to Compliance Evaluation Inspections by EPA and NMED on an annual basis.

c. Safe Drinking Water Act. The sampling program for drinking water quality is designed to meet or exceed regulatory requirements under the Federal Safe Drinking Water Act (SDWA) and the New Mexico Environmental Improvement Act. Sampling locations, frequencies, preservation, handling, and analysis follow the requirements specified in federal and state regulations. Samples are drawn from the individual water supply well heads for volatile organic compounds and microbiology. All other types of regulatory compliance samples are drawn from the taps in the water distribution system.

Samples are drawn at taps on the individual water supply well heads for volatile organic constituents (VOCs) at least once every year. Samples are collected in 40 ml glass septum vials. Travel blanks are submitted with the well head VOC samples.

Well head samples are drawn on a monthly basis for microbiological quality including total coliforms, noncoliforms, and heterotrophic plate counts. Autoclaved 100 ml polyethylene bottles are used to collect microbiological samples.

Samples for inorganic chemicals and radiochemistry are collected annually from locations in the distribution system representative of the two currently operating well fields. The White Rock Fire Station location is representative of water originating from the Pajarito Well Field. The Barranca Mesa School and the North Community Fire Station are representative of the Guaje Well Field. Samples are collected in 1 liter polyethylene containers.

Trihalomethane (THM) samples are collected on a quarterly basis from six sampling locations which are spread throughout the distribution system. These are Barranca Mesa School, North Community Fire Station, Los Alamos Airport, White Rock Fire Station, S-Site Fire Station, and TA-33, Building 114. The sample containers are 40 ml glass septum vials. Travel blanks are submitted with the distribution system THM samples.

Microbiological samples are also collected at a network of approximately 80 locations throughout the distribution system. The sampling sites are rotated such that at least 40 samples from throughout the system are taken each month. Samples are analyzed for total coliforms, fecal coliforms, and noncoliform bacteria. Autoclaved 100 ml polyethylene bottles are used to collect microbiological samples.

Microbiological sampling and analysis are performed by personnel of the JENV which is certified by the State of New Mexico for microbiological compliance analysis. Certification requirements include proficiency samples, maintenance of an approved QA/QC program, and periodic audit by the State Scientific Laboratory Division (SLD).

Chemical and radiochemical sampling is performed by LANL staff certified by the NMED to do drinking water compliance sampling. These samples are sent to SLD in Albuquerque for analysis. The SLD QA/QC program is certified by the EPA.

4. Soil and Sediment Sampling.

The soil sampling procedure involves taking five plugs, 75 mm (3.0 in.) in diameter and 50 mm (2.0 in.) deep, at the center and corners of a 10 m (33 ft) square area. The five plugs are combined to form a single composite sample for radiochemical analysis.

Sediment samples are collected from dune buildup behind boulders in the main channels of perennially flowing streams. Samples from the beds of intermittently flowing streams are collected by scooping a line of uniform depth across the main channel. Reservoir sediments are collected from a boat, using an Eckman dredge. Bottom reservoir sediments are collected from an area 10 cm by 15 cm (4 in. by 6 in.) to a depth of 5 cm (2 in.).

Depending on the reason for taking a particular soil or sediment sample, it may be analyzed to detect any of the following: gross alpha and gross beta activities, ^{90}Sr, total uranium, ^{137}Cs, ^{238}Pu, $^{239,240}Pu$, ^{241}Am, and possibly selected accelerator-induced activation products. Moisture distilled from soil samples may be analyzed for H^3.

5. Foodstuffs Sampling.

Local and regional produce are sampled annually. Fish are sampled annually from reservoirs upstream and downstream from the Laboratory.

Produce and soil samples are collected from local gardens in the fall of each year (Salazar 1984). Each produce or soil sample is sealed in a labeled plastic bag. Samples are refrigerated until prepared for chemical analysis. Produce samples are washed, as if prepared for consumption, and quantitative wet, dry, and ash weights are determined. Soils are split and dried at 100°C (212°F) before analysis. A complete sample bank is kept until all radiochemical analyses are completed. Water is distilled from samples and submitted for tritium analysis. Produce ash and dry soil are submitted for analyses of ^{90}Sr, ^{137}Cs, total uranium, ^{238}Pu, and $^{239,240}Pu$.

At each reservoir, hook and line, trot line, or gill nets are used to capture fish (Salazar 1984). Fish, sediment, and water samples are transported under ice to the Laboratory for preparation. Sediment and water samples are submitted directly for radiochemical analysis. Fish are individually washed, as if for consumption, and dissected. Wet, dry, and ash weights are

determined, and ash is submitted for analysis of ^{90}Sr, ^{137}Cs, total uranium, ^{238}Pu, and $^{239,240}Pu$.

6. Meteorological Monitoring.

Meteorological data were continuously gathered at four instrumented towers during 1991. Data taken include wind speed and direction, standard deviations of wind speed and direction, vertical wind speed and its standard deviation, air and soil temperature, relative humidity, solar and terrestrial radiation, precipitation, and sensible and evaporative heat fluxes (vertical transport). Each variable is measured every three seconds. A Dopper Acoustic Sodar is also located at a tower site. This instrument measures wind direction and speed, vertical wind speed, horizontal and vertical wind standard deviations, and inversion information at 30 m (99 ft) levels up to 750 m (2,475 ft). Finally, four additional sites monitor precipitation; one of these sites also measures temperature and relative humidity.

The tower and sodar data are averaged or summed over 15-minute intervals. Data are transmitted by phone line to a microcomputer at the OHL at TA-59. Charts from the four precipitation stations are picked up every week. Data validation of 15-minute data is accomplished with automated and manual screening techniques. Computer codes screen incoming data for reasonableness and consistency. Invalid data are discarded. Other codes produce daily plots for each tower and the sodar. These graphics are reviewed to provide an additional check of the data. This screening helps to detect problems with the instrumentation that might develop between calibrations. Most instruments are calibrated semiannually, including a thorough audit by an outside contractor once a year. The outside audit was performed in June 1991 (META 1991).

D. Analytical Chemistry

1. Methodology.

a. Introduction. Most analytical chemistry services are provided by the Laboratory's EM-9 Group. The EM-9 Sample Management Section functions as a working interface between the group and its customers. This section provides the sample collector with presampling information in the areas of sample containers, sample volumes, and sample preservation techniques. Collection of samples for chemical and radiochemical analyses follows a set procedure to ensure proper sample collection, documentation, submittal for chemical analysis, and posting of analytical results.

Before sample collection, the Sample Management Section discusses the schedule and procedures to be followed with the sample collector. The discussion includes

- number and type of samples;
- type of analyses and required limits of detection;
- proper sample containers;
- preparation of sample containers with preservative, if needed; and
- sample schedule to ensure minimum holding time of analyses to comply with EPA criteria.

All samples are delivered to Sample Management personnel and are then scheduled and processed for proper distribution and analysis. EM-9 assigns sample numbers to samples when submitted. Each number, representing a single sample, is assigned to a particular station and is entered into the collector's log book. The processing of samples includes (1) validating all samples for sampling correctness and integrity, (2) scheduling and labeling all samples for analysis, (3) initiating internal COC procedures for all samples, and (4) arranging for the proper disposal of any unused portions of samples.

After a sample is collected, it is delivered to the EM-9 Sample Management Section, where the pertinent information is entered into the EM-9 Laboratory Information Management System and the request is given a form number. The request form number is also entered in the collector's log book opposite sample numbers submitted, along with the date the sample was delivered to EM-9. EM-9 provides COC forms for the samples once they are received if COC was not started in the field. The date, time, temperature (if water), other pertinent information, and remarks are entered opposite the sample number and station previously listed in the log book. The sample container is labeled with station name, sample number, date, and preservative, if added.

The analytical request form contains the following information related to ownership and the sample program submitted: (1) requester, i.e., sample collector; (2) program code; (3) sample owner, i.e., program manager; (4) date; and (5) total number of samples. The second part of the request form contains (1) sample

number or numbers; (2) matrix, e.g., water; (3) types of analyses, i.e., specific radionuclide and/or chemical constituents; (4) technique, i.e., analytical method to be used for individual constituents; (5) analyst, i.e., chemist to perform analyses; (6) priority of sample or samples; and (7) remarks. One copy of the form goes to the collector for filing, and the other copies follow the sample.

The analytical results are returned to the sample collector, who posts data according to sample and station taken from the log book. These data sheets are included in the report and are used to interpret data for the report.

b. Radioactive Constituents. Environmental samples are routinely analyzed for the following radioactive constituents: gross alpha, beta, and gamma; isotopic plutonium; americium; uranium; cesium; tritium; and strontium. Detailed procedures have been published in this report in previous years (EPG 1990) and in the EM-9 Analytical Methods Manual (Gautier 1986). Occasionally, other radionuclides from specific sources are determined: ^{7}Be, ^{22}Na, ^{40}K, ^{51}Cr, ^{60}Co, ^{65}Zn, ^{83}Rb, ^{106}Ru, ^{134}Cs, ^{140}Ba, ^{152}Eu, ^{154}Eu, and ^{226}Ra. All but ^{226}Ra are determined by gamma-ray spectrometry on large germanium lithide detectors. Depending on the concentration and matrix, ^{226}Ra is measured by emanation or by gamma-ray spectrometry of its ^{214}Bi decay product. Uranium isotopic ratios ($^{235}U/^{238}U$) are measured by neutron activation analysis where precisions of ±5% are adequate. More precise work requires mass spectrometry. Uranium isotopic ratios are readily determined in environmental materials with precisions of 1%–2% relative standard deviation, at considerably reduced cost relative to neutron activations by inductively coupled plasma mass spectrometry (ICPMS).

c. Stable Constituents. A number of analytical methods are used for various stable isotopes. The choice of method is based on many criteria, including the operational state of the instruments, time limitations, expected concentrations in samples, quantity of sample available, sample matrix, and EPA regulations. Instrumental techniques available include neutron activation, atomic absorption, ion chromatography, color spectrophotometry (manual and automated), potentiometry, combustion analysis, ICPMS, and inductively coupled plasma atomic emission spectrometry. Standard chemical methods are also used for many of the common water quality tests. Atomic absorption capabilities include flame, furnace, cold vapor, and hydride generation, as well as flame emission spectrophotometry. The methods used and references for determination of various chemical constituents are presented elsewhere (Gautier 1986). In 1986, the EPA Region 6 administration granted EM-9 limited approval for alternative test procedures for uranium in drinking water (delayed neutron assay) and for chloride in drinking water and wastewater (flow injection without distillation). EPA approval for other modified methods is actively being sought. EM-9 is participating in the EPA-sponsored study to evaluate ICPMS for acceptance as an EPA-approved methodology.

d. Organic Constituents. Environmental soil and water samples are analyzed using EPA procedures outlined in EPA SW-846 (EPA 1989d) or modified procedures (Gautier 1986) that meet QA criteria outlined in Chapter One of SW-846, as shown in Table VIII-1. Methods used are supported by documented spike/recovery studies, method and field blanks, matrix spikes, surrogate spikes, and blind quality control samples. Volatile organics are analyzed using method 8260, SW-846. Tables D-21 and D-22 list volatile organics on the target list for water and soil samples, respectively. Semivolatile organics are analyzed using method 8270, SW-846. Table D-23 is the target list for semivolatile organics in water. Soil-gas (pore-gas) monitoring is performed by collecting organic vapors on charcoal, extracting the charcoal with CS_2 and analyzing the CS_2 extracts using gas chromatography/mass spectrometry (GC/MS). Soil-gas target compounds are listed in Table D-24, and the Toxicity Characteristics Leaching Procedure (TCLP) target compounds are listed in Table D-25.

Instrumentation available for organic analysis includes GC/flame ionization detector, GC/electron capture detector, GC/MS, high performance liquid with ultraviolet (UV) and refractive index detectors, a Fourier transform infrared spectrometer, and a UV/visible spectrophotometer. Sample preparation methods include: Soxhlet extraction, ultrasonic extraction, continuous liquid/liquid extraction, Kuderna Danish concentration, evaporative blowdown, and gel permeation chromatography clean-up of sample extracts.

Organic mixed waste analyses are performed for samples up to 100 nCi/g (solids/sludges) or 100 nCi/L (solutions) alpha, beta, or gamma. Higher level

Table VIII-1. Method Summary (Organic Compounds)

Analyte	Matrix	Method[a]	Technique[b]
Volatile organic compounds	Air	—	GC/MS
	Soil	8,240	PAT/GC/MS
	Water	8,240	PAT/GC/MS
TCLP[c] toxicity	Soil	1,311, 8,080 8,150,8240,8270	GC/ECD
PCBs	Water	608	GC/ECD
	Soil	8,270	GC/ECD
	Oil	IH 320	GC/ECD
Semivolatile organic compounds	Soil and waste	8270	GC/MS

[a]Industrial hygiene (IH).

[b]Gas chromatography (GC), purge and trap (PAT), electron capture detection (ECD), and mass spectrometry (MS).

[c]Toxicity Characteristic Leaching Procedure (TCLP).

samples are analyzed on a case-by-case basis. New methods are being developed for routine analysis of mixed waste greater than 100 nCi/g (or nCi/L). The Laboratory's capacity for mixed waste analyses will increase in the summer of 1992 when mixed waste analytical operations move to a dedicated facility.

2. Quality Evaluation Program.

a. Introduction. Control samples are analyzed in conjunction with the normal analytical chemistry workload. Such samples consist of several general types: calibration standards, reagent blanks, process blanks, matrix blanks, duplicates, spikes, and reference materials. Analysis of control samples fills two needs in analytical work: (1) it provides quality control over analytical procedures so that problems that might occur can be identified and corrected, and (2) data obtained from analysis of control samples permit evaluation of the capabilities of a particular analytical technique to determine a given element or constituent under a certain set of circumstances.

Blind QC samples are disguised and numbered to resemble unknown samples in a set, and no attempt is made to conceal the identity of the open QC samples from the analyst. In neither case are the concentrations of the analytes of interest revealed until after the data have been formally reported.

These samples are submitted to the laboratory at regular intervals and are analyzed in association with other samples; that is, they are not handled as a unique set of samples. At least 10% of stable constituent, organic, and selected radioactive constituent analyses are run as quality control samples using the materials described above. A detailed description of EM-9's QAP and a complete listing of results have been published annually since 1976 (Gautier 1991).

b. Radioactive Constituents. In addition to those that are prepared internally, QC and QA samples for radioactive constituents are obtained from outside agencies. The Quality Assurance Division of the Environmental Monitoring Systems Laboratory (EPA, Las Vegas) provides water, milk, and air filter samples for analysis of gross alpha, gross beta, H^3, ^{40}K, ^{60}Co, ^{65}Zn, ^{90}Sr, ^{106}Ru, ^{131}I, ^{134}Cs, ^{137}Cs, ^{226}Ra, and $^{239,240}Pu$ as part of an ongoing laboratory intercomparison program. NIST provides several soil and sediment standard reference materials (SRMs) for environmental radioactivity. These SRMs are certified for ^{60}Co, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{238}Pu, ^{239}Pu, ^{241}Am, and several other

nuclides. The DOE's Environmental Measurements Laboratory also provides quality assurance samples.

Soil, rock, and ore samples obtained from the Canadian Geological Survey (CGS) are used for quality assurance of uranium and thorium determinations in silicate matrices. EM-9's own in-house standards are prepared by adding known quantities of liquid NIST radioactivity SRMs to blank matrix materials.

c. Stable Constituents. Quality assurance for the stable constituent analysis program is maintained by analysis of certified or well-characterized environmental materials. The NIST has a large set of silicate, water, and biological SRMs. The EPA distributes mineral analysis and trace analysis water standards. Rock and soil reference materials have been obtained from the CGS and the United States Geological Survey. Details of this program have been published elsewhere (Gautier 1991). Stock solutions of inorganic analytes are prepared and spiked on blank matrices by the Quality Assurance Section.

The analytical quality control program for a specific batch of samples is the combination of many factors. These include the "fit of the calibration," instrument drift, calibration of the instrument and/or reagents, recovery for SRMs, and precision of results.

d. Organic Constituents. Soil samples are received for the analysis of volatile and semivolatile organic compounds, pesticides, and herbicides for compliance work done under RCRA. Certified matrix-based reference materials were not available for these analyses, so stock solutions of the analytes were prepared and spiked directly on blank soil by the Quality Assurance Section. Because homogeneity of the sample could not be ensured, the entire sample was analyzed. Volatile organic compounds are analyzed by GC/MS and are spiked in the microgram-per-kilogram range.

The majority of water samples submitted during 1991 were environmental compliance samples for the analysis of pesticides, herbicides, volatile and semivolatile organic compounds, and PCBs. Methods were developed and refined for in-house preparation of quality control samples for volatile and semivolatile organic compounds in water.

Oil samples were received for the analysis of PCBs and organic solvents. Quality control samples for PCBs were prepared by diluting EPA standards or by preparing standards in hexane from the neat analyte. In the United States, the only PCBs that have been found in transformers have been PCBs 1242, 1254, and 1260. Samples submitted for analysis have contained only these PCBs, so they have been used to spike quality control samples. Vacuum pump oil was chosen for the oil base blank after an experiment with various brands of motor oil showed excessive matrix interferences.

3. Data Handling of Radiochemical Samples.

Measurements of radiochemical samples require that analytical or instrumental backgrounds be subtracted to obtain net values. Thus, net values that are lower than the minimum detection limit of an analytical technique are sometimes obtained. Consequently, individual measurements can result in values of positive or negative numbers. Although a negative value does not represent a physical reality, a valid long-term average of many measurements can be obtained only if the very small and negative values are included in the population calculations (Gilbert 1975).

For individual measurements, uncertainties are reported as the standard deviation. These values are associated with the estimated variance of counting and indicate the precision of the counts.

Standard deviations for the station and group (regional, perimeter, and on site) means are calculated using the following equation:

$$s = \sqrt{\frac{\sum_{i=1}^{N} \left(\bar{c} - c_i\right)^2}{(N-1)}},$$

where

c_i = sample i,

$\bar{c}$ = mean of samples from a given station or group, and

N = number of samples comprising a station or group.

This value is reported as the uncertainty for the station and group means.

4. Indicators of Accuracy and Precision of Radiochemical Samples.

Accuracy is the degree of difference between average test results and true results when the latter are known or assumed. Precision is the degree of mutual agreement among replicate measurements (frequently assessed by calculating the standard deviation of a set of data points). Accuracy and precision are evaluated from results of analysis of reference materials. These results (r) are normalized to the known quality in the reference material to permit comparison among reference materials of a similar matrix containing different concentrations of the analyte:

$$r = \frac{\text{Reported quantity}}{\text{Known quantity}}.$$

A mean value R for all normalized analyses of a given type is calculated as follows for a given matrix type (N is total number of analytical determinations):

$$R = \frac{\sum_i r_i}{N}.$$

Standard deviations of R are calculated assuming a normal distribution of the population of analytical determinations (N):

$$s = \sqrt{\frac{\sum_i (R - r_i)^2}{(N-1)}}.$$

These calculated values are presented as the EM-9 "Ratio – Std Dev" in Tables D-26 to D-36. The mean value of R is a measure of the accuracy of a procedure. Values of R greater than unity indicate a positive bias in the analysis; values less than unity, a negative bias. The standard deviation is a measure of precision. Precision is a function of the concentration of analyte; that is, as the absolute concentration approaches the limit of detection, precision deteriorates. For instance, the precision for some determinations is quite good because many standards approach the limits of detection of a measurement. We address this issue by calculating a new quality assurance parameter,

$$|\overline{X}_E - \overline{X}_C|,$$

where X_E is the experimentally determined mean elemental concentration based on N measurements, and X_c is the certified or consensus mean elemental concentration. The total standard deviation, S_T, of X_E - X_c is given by

$$S_r \sqrt{(S_E^2)\sqrt{N} + (S_C^2)},$$

where S_E is the standard deviation of a single experimentally determined measurement, and S_c is the standard deviation of the certified or consensus mean elemental concentration.

Analyses are considered under control if the absolute value of the difference between our result ($\overline{X}_E$) and the certified or consensus mean ($\overline{X}_c$) is within the propagated standard deviation of the experimental uncertainty (U_E) and of the certified mean (S_c). N is equal to the number of measurements on a sample and in our case is equal to 1. This concept is formulated in the following equation and is an adaptation of Dixon and Massey (Dixon 1969) to include the experimental uncertainty:

$$z = \frac{|\overline{X}_E - \overline{X}_c|}{\sqrt{(U_E)^2\sqrt{N} + (S_c)^2}}.$$

The test statistics used in this document are based on 5% and 0.2% levels of significance. The respective critical regions are defined using the z statistics 2 and 3. Data having a calculated z value ≤2 are accepted as in control at the 5% level of significance. Data that have a calculated z value >2 and ≤3.0 are considered at the warning level, or the 0.2% level of significance. Data

with a z value >3.0 are considered out of control. This criterion is also incorporated in the QACHECK computer program.

The percentage of the tests for each parameter where X_E - X_C fell within ≤2 S_T (under control), between $2S_T$ and $3S_T$ (warning level), or outside $>3S_T$ (out of control) is shown in Tables D-26 to D-36. A summary of the overall state of statistical control for analytical work done by EM-9 is also provided in Table VIII-2.

Table VIII-3 summarizes recovery information on organic surrogate compounds required for use in the EPA-Contract Laboratory Program protocol. Table VIII-4 summarizes EM-9's overall record of meeting EPA SW-846 holding times for EM-9 samples during 1991. The data include all samples where holding times were missed and the customer elected to either resample or accept the data as usable.

Table D-37 reports the incidence of false positive results for blank QC samples and false negative results for spiked QC samples at the 95% confidence level.

For most radiochemical and inorganic analyses, more than 90% are within <2 propagated standard deviations of the certified/consensus mean values (under control). EM-9's performance on most classes of inorganic matrices remained virtually unchanged since 1990, while improvement in radiochemical determinations in soils was observed. Unfortunately, the overall control of radiochemical analyses in biological materials declined over the 1990 record as did that of stable elements in soils. These areas will be the focus of increased QA/QC efforts in the future. Overall control on organic measurements in all materials remained at over 90% with all organic determinations being under control. Data on analytical detection limits are given in Table D-38.

Table VIII-2. Overall Summary of EM-9 Quality Assurance Tests for 1991

Analysis	No. QC with CV[a]	Under Control <2z (%)	Warning 2–3z (%)	Out of Control >3z (%)
Stable Elements				
Biological Materials	4	75	25	—
Filters	13	100	—	—
Bulk Materials	18	100	—	—
Soil	1,263	82	8	10
Water	3,400	97	2	1
Radiochemical Elements				
Biologicals	67	76	11	13
Filters	168	97	2	1
Soils	475	89	8	3
Water	988	95	4	1
Organic Compounds				
Filters	268	92	6	2
Bulk Materials	284	98	1	1
Soil	4,621	95	1	4
Charcoal Tube	897	97	1	2
Water	3,008	96	1	3

[a]Quality control tests with certified values.

Table VIII-3. Summary of EM-9 Organic Surrogate Compliance with EPA SW-846 Criteria for 1991

Analysis	EPA SW-846 Range Low	EPA SW-846 Range High	Number of Surrogates In-Range	Number of Surrogates Total	% In-Range	% of Samples Run with Surrogate
Volatile Organic Compounds						
In Soil						
1,2-Dichloroethane d4	70	121	464	536	86.6	99.1
Toluene d8	81	117	501	536	93.5	99.1
4-Bromofluorobenzene	74	121	411	536	76.7	99.1
In Water						
1,2-Dichloroethane d4	76	114	178	213	83.6	100.0
Toluene d8	88	110	180	213	84.5	100.0
4-Bromofluorobenzene	86	115	171	213	80.3	100.0
Semivolatile Organic Compounds						
In Soil						
2-Fluorophenol	25	121	331	353	93.8	97.2
Phenol d6	24	113	346	362	95.6	99.7
Nitrobenzene d5	23	120	352	362	97.2	99.7
2-Fluorobiphenyl	30	115	351	362	97.0	99.7
2,4,6-Tribromophenol	19	122	346	362	95.6	99.7
p-Terphenyl d14	18	137	324	362	89.5	99.7
In Water						
2-Fluorophenol	21	100	145	173	83.8	95.1
Phenol d6	10	94	152	173	87.9	95.1
Nitrobenzene d5	35	114	147	173	85.0	95.1
2-Fluorobiphenyl	43	116	150	173	86.7	95.1
2,4,6-Tribromophenol	10	123	161	173	93.1	95.1
p-Terphenyl d14	33	141	141	173	81.5	95.1

Table VIII-4. EPA SW-846 Holding Time Summary for 1991

Organic Analysis Type	Number Meeting EPA Criteria	Total Number Performed	% Within EPA Criteria
Extraction holding times			
Volatiles in soils	363	419	86.6
Volatiles in waters	125	141	88.7
Semivolatiles in soils	274	282	97.2
Semivolatiles in waters	111	133	83.5
Pesticides in soils	29	35	82.9
Pesticides in waters	3	3	100.0
Herbicides in waters	3	3	100.0
PCBs in soils	134	221	60.6
PCBs in waters	35	72	48.6
Instrument analysis holding times			
Volatiles in soils	419	419	100.0
Volatiles in waters	141	141	100.0
Semivolatiles in soils	282	282	100.0
Semivolatiles in waters	133	133	100.0
Pesticides in soils	35	35	100.0
Pesticides in waters	3	3	100.0
Herbicides in waters	3	3	100.0
PCBs in soils	147	221	66.5
PCBs in waters	72	72	100.0

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APPENDIX A

STANDARDS FOR ENVIRONMENTAL CONTAMINANTS

Throughout this report, concentrations of radioactive and chemical constituents in air and water samples are compared with pertinent standards and guidelines in regulations of federal and state agencies. No comparable standards for soils, sediments, and foodstuffs are available. Los Alamos National Laboratory (LANL or the Laboratory) operations are conducted in accordance with directives for compliance with environmental standards. These directives are contained in Department of Energy (DOE) Orders 5400.1, "General Environmental Program;" 5400.5, "Radiation Protection of the Public and the Environment;" 5480.1, "Environmental Protection, Safety, and Health Protection Standards;" 5480.11, "Requirements for Radiation Protection for Occupational Workers;" and 5484.1, "Environmental Radiation Protection, Safety, and Health Protection Information Reporting Requirements," Chap. III, "Effluent and Environmental Monitoring Program Requirements."

DOE regulates radiation exposure to the public and the worker by limiting the radiation dose that can be received during routine Laboratory operation. Because some radionuclides remain in the body and result in exposure long after intake, DOE requires consideration of the dose commitment caused by inhalation, ingestion, or absorption of such radionuclides. This evaluation involves integrating the dose received from radionuclides over a standard period of time. For this report, 50-year dose commitments were calculated using dose factors from Refs. A1 and A2. The dose factors adopted by DOE are based on the recommendations of Publication 30 of the International Commission on Radiological Protection (ICRP).[A3]

In 1990, DOE issued Order 5400.5 which finalized the interim radiation protection standard (RPS) for the public.[A4] Table A-1 lists currently applicable RPSs, now referred to as public dose limits (PDLs), for operations at the Laboratory. DOE's comprehensive PDL for radiation exposure limits the effective dose equivalent that a member of the public can receive from DOE operations to 100 mrem/yr. The PDLs and the information in Refs. A1 and A2 are based on recommendations of the ICRP and the National Council on Radiation Protection and Measurements.[A3,A4]

The effective dose equivalent is the hypothetical whole-body dose that would result in the same risk of radiation-induced cancer or genetic disorder as a given exposure to an individual organ. The effective dose is the sum of the individual organ doses, weighted to account for the sensitivity of each organ to radiation-induced damage. The weighting factors are taken from the recommendations of the ICRP. The effective dose equivalent includes doses from both internal and external exposure.

Radionuclide concentrations in air and water in uncontrolled areas measured by the Laboratory's surveillance program are compared with DOE's derived concentration guides (DCGs) in this report (Table A-2).[A5] These DCGs represent the smallest estimated concentrations in water or air, taken in continuously for a period of 50 years, that will result in annual effective dose equivalents equal to the PDL of 100 mrem in the 50th year of exposure.

In addition to the 100 mrem/yr effective dose PDL, exposures from the air pathway are also limited by the Environmental Protection Agency's (EPA's) 1989 standard of 10 mrem/yr (effective dose equivalent).[A6] To demonstrate compliance with these standards, doses from the air pathway are compared directly with the EPA dose limits. This dose limit of 10 mrem/yr replaced the previous EPA limits of 25 mrem/yr (whole body) and 75 mrem/yr (any organ).[A7]

Federal and state ambient air quality standards for nonradioactive pollutants are shown in Table A-3. New Mexico nonradiological standards are generally more stringent than national standards.

For chemical constituents in drinking water, standards have been promulgated by the EPA and adopted by the New Mexico Environment Department (NMED) (Table A-4).[A8] The EPA's primary maximum contaminant level (MCL) is the maximum permissible level of a contaminant in water that is delivered to the ultimate user of a public water system.[A9] The EPA's secondary water standards, which are not included in

Table A-1. DOE Public Dose Limits and Radiation Protection Standards for External and Internal Exposures

Exposure of Any Member of the Public [a]

	Effective Dose Equivalent[b] at Point of Maximum Probable Exposure
All Pathways	100 mrem/yr[c]

	Effective Dose Equivalent at Point of Maximum Probable Exposure
Air Pathway Only [d]	10 mrem/yr
Drinking Water	4 mrem/yr

Occupational Exposure [a]

Stochastic Effects	5 rem (annual effective dose equivalent[e])
Nonstochastic Effects	
Lens of eye	15 rem (annual dose equivalent[e])
Extremity	50 rem (annual dose equivalent[e])
Skin of the whole body	50 rem (annual dose equivalent[e])
Organ or tissue	50 rem (annual dose equivalent[e])
Unborn Child	
Entire gestation period	0.5 rem (annual effective dose equivalent[e])

[a]In keeping with DOE policy, exposures shall be limited to as small a fraction of the respective annual dose limits as practicable. DOE's RPS applies to exposures from routine Laboratory operation, excluding contributions from cosmic, terrestrial, and global fallout; self-irradiation; and medical diagnostic sources of radiation. Routine operation means normal, planned operation and does not include actual or potential accidental or unplanned releases. Exposure limits for any member of the general public are taken from Ref. A4. Limits for occupational exposure are taken from DOE Order 5480.11.

[b]As used by DOE, effective dose equivalent includes both the effective dose equivalent from external radiation and the committed effective dose equivalent to individual tissues from ingestion and inhalation during the calendar year.

[c]Under special circumstances and subject to approval by the DOE, this effective dose equivalent limit may be temporarily increased up to 500 mrem/yr, provided the dose averaged over a lifetime does not exceed the principal limit of 100 mrem/yr.

[d]This level is from EPA's regulations promulgated under the Clean Air Act (40 CFR 61, Subpart H).

[e]Annual effective dose equivalent is the effective dose equivalent received in a year.

Table A-2. DOE's Derived Concentration Guides (DCG) for Public Dose and Derived Air Concentrations (DAC) for Controlled Areas[a]

Nuclide	DCGs for Uncontrolled Areas (μCi/mL) Air	DCGs for Uncontrolled Areas (μCi/mL) Water	Calculated Guides for Drinking Water Systems (μCi/mL)	DACs for Controlled Areas (μCi/mL)
H^3	1×10^{-7}	2×10^{-3}	8×10^{-5}	2×10^{-5}
^7Be	4×10^{-8}	1×10^{-3}	4×10^{-5}	8×10^{-6}
^{89}Sr	3×10^{-10}	2×10^{-5}	8×10^{-7}	6×10^{-8}
^{90}Sr[b]	9×10^{-12}	1×10^{-6}	4×10^{-8}	2×10^{-9}
^{137}Cs	4×10^{-10}	3×10^{-6}	1.2×10^{-7}	7×10^{-8}
^{234}U	9×10^{-14}	5×10^{-7}	2×10^{-8}	2×10^{-11}
^{235}U	1×10^{-13}	6×10^{-7}	2.4×10^{-8}	2×10^{-11}
^{238}U	1×10^{-13}	6×10^{-7}	2.4×10^{-8}	2×10^{-11}
^{238}Pu	3×10^{-14}	4×10^{-8}	1.6×10^{-9}	3×10^{-12}
^{239}Pu[b]	2×10^{-14}	3×10^{-8}	1.2×10^{-9}	2×10^{-12}
^{240}Pu	2×10^{-14}	3×10^{-8}	1.2×10^{-9}	2×10^{-12}
^{241}Am	2×10^{-14}	3×10^{-8}	1.2×10^{-9}	2×10^{-12}
	(pg/m³)	(mg/L)	(mg/L)	(pg/m³)
Natural Uranium	1×10^{5}	8×10^{-1}	3×10^{-2}	3×10^{7}

[a]Guides for uncontrolled areas are based on DOE's Public Dose Limit (PDL) for the general public;[A4] those for controlled areas are based on occupational Radiation Protection Standards (RPSs) for DOE Order 5480.11 ("Radiation Protection for Occupational Workers," December 21, 1988). Guides apply to concentrations in excess of those occurring naturally or that are due to fallout.

[b]Guides for ^{239}Pu and ^{90}Sr are the most appropriate to use for gross alpha and gross beta, respectively.

the NMED Water Supply Regulations and are not enforceable, relate to contaminants in drinking water that primarily affect aesthetic qualities associated with public acceptance of drinking water.[A9] At considerably higher concentrations of these contaminants, health implications may arise.

Radioactivity in drinking water is regulated by EPA regulations contained in 40 CFR 141[A9] and New Mexico Water Supplies Regulations, Sections 206 and 207.[A8] These regulations provide that combined ^{226}Ra and ^{228}Ra may not exceed 5×10^{-9} μCi/mL. Gross alpha activity (including ^{226}Ra, but excluding radon and uranium) may not exceed 15×10^{-9} μCi/mL.

A screening level of 5×10^{-9} μCi/mL for gross alpha is established to determine when analysis specifically for radium isotopes is necessary. In this report, plutonium concentrations are compared with both the EPA gross alpha standard for drinking water (Table A-4) and the DOE guides calculated for the DCGs applicable to drinking water (Table A-2).

For manmade beta- and photon-emitting radionuclides, EPA drinking water standards are limited to concentrations that would result in doses not exceeding 4 mrem/yr, calculated according to a specified procedure. In addition, DOE Order 5400.5 requires that DOE-operated public water supplies not cause persons consuming the water to receive an effective dose equivalent exceeding 4 mrem/yr. Drinking water concentration guides based on this requirement are in Table A-2.

In its regulations, the EPA has established minimum concentrations of certain contaminants in water extracted from wastes that will cause the waste to be designated as hazardous by reason of toxicity.[A10] The toxicity characteristic leaching procedure (TCLP) must

follow steps outlined by the EPA in 40 CFR 261, Appendix II. In this report, the TCLP minimum concentrations (Table A-5) are used for comparison with concentrations of selected constituents in extracts from the Laboratory's active waste areas.

The NMED is now using numeric Livestock and Wildlife Watering Standards (Table A-6)[A11] to evaluate requirements for National Pollutant Discharge Elimination System (NPDES) discharges into normally dry canyons where the attainable use is only livestock and wildlife watering. In this report, surface waters and shallow alluvial water sample analyses are compared to these values as a potential actual use of the water regardless of whether the water is directly from an NPDES outfall.

Table A-3. National and New Mexico Ambient Air Quality Standards

Pollutant	Averaging Time	Unit	New Mexico Standard	Federal Standards Primary	Federal Standards Secondary
Sulfur dioxide	Annual arithmetic mean	ppm	0.02	0.03	
	24 hours[a]	ppm	0.10	0.14	
	3 hours[a]	ppm			0.5
Total suspended particulate matter	Annual geometric mean	μg/m³	60		
	30 days	μg/m³	90		
	7 days	μg/m³	110		
	24 hours[a]	μg/m³	150		
PM_{10}[b]	Annual arithmetic mean	μg/m³		50	50
	24 hours	μg/m³		150	150
Carbon monoxide	8 hours[a]	ppm	8.7	9	
	1 hour[a]	ppm	13.1	35	
Ozone	1 hour[c]	ppm	0.06	0.12	0.12
Nitrogen dioxide	Annual arithmetic mean	ppm	0.05	0.053	0.053
	24 hours[a]	ppm	0.10		
Lead	Calendar quarter	μg/m³		1.5	1.5
Beryllium	30 days	μg/m³	0.01		
Asbestos	30 days	μg/m³	0.01		
Heavy metals (total combined)	30 days	μg/m³	10		
Nonmethane hydrocarbons	3 hours	ppm	0.19		

[a]Maximum concentration, not to be exceeded more than once per year.

[b]Particles measured at an effective diameter of <10 μm.

[c]The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above the limit is ≤1.

Table A-4. Maximum Contaminant Level in the Water Supply for Inorganic Chemicals, Organic Chemicals, and Radiochemicals[a]

Inorganic Chemical Contaminant	MCL (mg/L)
Primary Standards	
Ag	0.05
As	0.05
Ba	1
Cd	0.010
Cr	0.05
F	4.0
Hg	0.002
NO_3 (as N)	10
Pb	0.05
Se	0.01
Secondary Standards	
Cl	250
Cu	1
Fe	0.3
Mn	0.05
SO_4	250
Zn	5.0
TDS[c]	500
pH	6.5–8.5

Radiochemical Contaminant	MCL
Gross alpha[b]	15×10^{-9} µCi/mL
Gross beta & photon[c]	4 mrem/yr
H^3	$20{,}000 \times 10^{-9}$ µCi/mL
^{90}Sr	8×10^{-9} µCi/mL

Organic Chemical Contaminant	MCL (mg/L)
Insecticides:	
Endrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8a-octa hydro-1,4-endo, endo-5, 8-dimethano napthalene)	0.0002
Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer)	0.004
Methoxychlor (1,1,1-Trichloro-2, 2-bis[p-methoxyphenyl] ethane)	0.1
Toxaphene ($C_{10}H_{10}C_{l8}$ - technical chlorinated camphene, 67-69 percent chlorine)	0.005
Herbicides:	
2,4-D, (2,4-Dichlorophenoxyacetic acid)	0.1
2,4,5-TP Silvex (2,4,5-Trichlorophenoxy-propionic acid)	0.01
Total trihalomethanes (TTHM)	0.10

Table A-4 (Cont.)

Other Organic Contaminants:	
Benzene	0.005
Vinyl Chloride	0.002
Carbon tetrachloride	0.005
1,2-Dichloroethane	0.005
Trichloroethylene	0.005
1,1-Dichloroethylene	0.007
1,1,1-Trichloroethane	0.20
para-Dichlorobenzene	0.075

Microbiological Contaminant	**MCL**
Total coliforms - presence	5% of samples/month
Fecal coliform or E. Coli - presence	0 sample/month

[a]Refs. A8 and A9.

[b]See text for discussion of application of gross alpha MCL and gross alpha screening level of 5×10^{-9} µCi/mL.

[c]Screening limit for gross beta activity is 50×10^{-9} µCi/mL.[A8]

[d]Ref. A8.

Table A-5. Toxicity Characteristic Leaching Procedure Levels[a,b]

Contaminant	(mg/L)
Arsenic	5.0
Barium	100.0
Benzene	0.5
Cadmium	1.0
Carbon tetrachloride	0.5
Chlordane	0.03
Chlorobenzene	100.0
Chloroform	6.0
Chromium	5.0
o-Cresol	200.0
m-Cresol	200.0
p-Cresol	200.0
Cresol	200.0
2,4-D	10.0
1,4-Dichlorobenzene	7.5
1,2-Dichloroethane	0.5
1,1-Dichloroethylene	0.7
2,4-Dinitrotoluene	0.13
Endrin	0.02
Heptachlor (and its epoxide)	0.008
Hexachlorobenzene	0.13
Hexachlorobutadiene	0.5
Hexachloroethane	3.0
Lead	5.0
Lindane	0.4
Mercury	0.2
Methoxychlor	10.0
Methyl ethyl ketone	200.0
Nitrobenzene	2.0
Pentachlorophenol	100.0
Pyridine	5.0
Selenium	1.0
Silver	5.0
Tetrachloroethylene	0.7
Toxaphene	0.5
Trichloroethylene	0.5
2,4,5-Trichlorophenol	400.0
2,4,6-Trichlorophenol	2.0
2,4,5-TP (Silvex)	1.0
Vinyl chloride	0.2

[a]Concentrations of inorganic contaminants that constitute hazardous waste.
[b]Ref. A10.

Table A-6. Wildlife Watering Standards[a]

Livestock Contaminant	Concentration (mg/L)
Dissolved Al	5.0
Dissolved As	0.02
Dissolved B	5.0
Dissolved Cd	0.05
Dissolved $Cr^{(+3, +6)}$	1.0
Dissolved Co	1.0
Dissolved Cu	0.5
Dissolved Pb	0.1
Total Hg	0.01
Dissolved Se	0.05
Dissolved V	0.1
Dissolved Zn	25.0
^{226}Ra, ^{228}Ra	30 pCi/L

[a] Ref. All

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A10. U.S. Environmental Protection Agency, "Title 40, Part 261, Identification and Listing of Hazardous Waste. Table I. Maximum Concentration of Contaminants for the Toxicity Concentrations," (July 1, 1990 edition).

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APPENDIX B

UNITS OF MEASUREMENT

Throughout this report the International System of Units (SI) or metric system of measurements has been used, with some exceptions. For units of radiation activity, exposure, and dose, U.S. Customary Units (that is, curie [Ci], roentgen [R], rad, and rem) are retained because current standards are written in terms of these units.

The equivalent SI units are the becquerel (Bq), coulomb per kilogram (C/kg), gray (Gy), and sievert (Sv), respectively. Table B-1 presents prefixes used in this report to define fractions or multiples of the base units of measurements. Table B-2 presents conversion factors for converting from SI units to U.S. Customary Units. Table B-3 presents common measurement abbreviations.

Table B-1. Prefixes Used with SI (Metric) Units

Prefix	Factor	Symbol
mega	1 000 000 or 10^6	M
kilo	1 000 or 10^3	k
centi	0.01 or 10^{-2}	c
milli	0.001 or 10^{-3}	m
micro	0.000001 or 10^{-6}	μ
nano	0.000000001 or 10^{-9}	n
pico	0.000000000001 or 10^{-12}	p
femto	0.000000000000001 or 10^{-15}	f
atto	0.000000000000000001 or 10^{-18}	a

Table B-2. Approximate Conversion Factors for Selected SI (Metric) Units

Multiply SI (Metric) Unit	By	To Obtain U.S. Customary Unit
Celsius (°C)	9/5 + 32	Fahrenheit (°F)
Centimeters (cm)	0.39	Inches (in.)
Cubic meters (m^3)	35	Cubic feet (ft^3)
Hectares (ha)	2.5	Acres
Grams (g)	0.035	Ounces (oz)
Kilograms (kg)	2.2	Pounds (lb)
Kilometers (km)	0.62	Miles (mi)
Liters (L)	0.26	Gallons (gal.)
Meters (m)	3.3	Feet (ft)
Micrograms per gram (μg/g)	1	Parts per million (ppm)
Milligrams per liter (mg/L)	1	Parts per million (ppm)
Square kilometers (km^2)	0.39	Square miles (mi^2)

Table B-3. Common Measurement Abbreviations

aCi	attocurie
Btu/yr	British thermal unit per year
cc/sec	cubic centimeters per second
cfm	cubic feet per minute
cfs	cubic feet per second
Ci	curie
cpm/L	counts per minute per liter
fCi/g	femtocurie per gram
ft	foot
ft^3/s	cubic feet per second
gal.	gallon
in.	inch
kg	kilogram
kg/h	kilogram per hour
L or l	liter
lb	pound
lb/h	pound per hour
lin ft	linear feet
m^3/s	cubic meter per second
µCi/L	microcurie per liter
µCi/mL	microcurie per milliliter
µg/g	microgram per gram
$\mu g/m^3$	microgram per cubic meter
mL or ml	milliliter
mm	millimeter
µm	micrometer
µmho/cm	micro mho per centimeter (mho is the reciprocal of ohm)
mCi	millicurie
mR	milliroentgen
mrem	millirem
nCi	nanocurie
nCi/dry g	nanocurie per dry gram
nCi/L	nanocurie per liter
ng/m^3	nanogram per cubic meter
pCi/dry g	picocurie per dry gram
pCi/g	picocurie per gram
pCi/L	picocurie per liter
pCi/m^3	picocurie per cubic meter
pCi/mL	picocurie per milliliter
pg/g	picogram per gram
pg/m^3	picogram per cubic meter
PM_{10}	small particulate matter (less than 10 microns in diameter)
sq ft (ft^2)	square feet
TU	tritium unit

APPENDIX C

DESCRIPTIONS OF TECHNICAL AREAS AND THEIR ASSOCIATED PROGRAMS

Locations of the technical areas (TAs) operated by the Laboratory in Los Alamos County are shown in Sec. II, Fig. II-4. The main programs conducted at each of the areas are listed in this Appendix.

TA-2, Omega Site: Omega West Reactor, an 8-MW nuclear research reactor, is located here. It serves as a research tool by providing a source of neutrons for fundamental studies in nuclear physics and associated fields.

TA-3, Core Area: In this main technical area of the Laboratory is the Administration Building that contains the Director's office and administrative offices and laboratories for several divisions. Other buildings house the central computing facility, materials division, science museum, chemistry and materials science laboratories, physics laboratories, technical shops, cryogenics laboratories, a Van de Graaff accelerator, the main cafeteria, and the Study Center.

TA-5, Beta Site: This site contains some physical support functions, several archaeological sites, and environmental monitoring and buffer areas.

TA-6, Two-Mile Mesa Site: This site is used in the development of special detonators to initiate high-explosive systems. Fundamental and applied research in support of this activity includes investigating phenomena associated with initiating high explosives and research in rapid shock-induced reactions.

TA-8, GT Site (or Anchor Site West): This is a dynamic testing site operated as a service facility for the entire Laboratory. It maintains capability in all modern nondestructive testing techniques for ensuring quality of material, ranging from test weapons components to high-pressure dies and molds. Principal tools include radiographic techniques (x ray machines to 1,000,000 V and a 24-MeV betatron), radioactive-isotope techniques, ultrasonic and penetrant testing, and electromagnetic test methods.

TA-9, Anchor Site East: At this site, fabrication feasibility and physical properties of explosives are explored. New organic compounds are investigated for possible use as explosives. Storage and stability problems are also studied.

TA-11, K Site: Facilities are located here for testing explosives components and systems under a variety of extreme physical environments. The facilities are arranged so that testing may be controlled and observed remotely and so that devices containing explosives or radioactive materials, as well as those containing nonhazardous materials, may be tested.

TA-14, Q Site: This dynamic testing site is used for running various tests on relatively small explosive charges and for fragment impact tests.

TA-15, R Site: This is the home of PHERMEX, a multiple-cavity electron accelerator capable of producing a very large flux of x rays for certain weapons development problems and tests. This site is also used for the investigation of weapons functioning and systems behavior in non-nuclear tests, principally by electronic recording means.

TA-16, S Site: Investigations at this site include development, engineering design, prototype manufacture, and environmental testing of nuclear weapons warhead systems. Development and testing of high explosives, plastics, and adhesives, and research on process development for manufacture of items using these and other materials are accomplished in extensive facilities.

TA-18, Pajarito Laboratory Site: The fundamental behavior of nuclear chain reactions with simple,

low-power reactors called critical assemblies is studied here. Experiments are operated by remote control and observed by closed-circuit television. The machines are housed in buildings known as kivas and are used primarily to provide a controlled means of assembling a critical amount of fissionable materials. This is done to study the effects of various shapes, sizes, and configurations. These machines are also used as a source of fission neutrons in large quantities for experimental purposes.

TA-21, DP Site: This site has two primary research areas: DP West and DP East. DP West is concerned with chemistry research; DP East is the high-temperature chemistry and tritium research site. Currently, several structures are undergoing decontamination and decommissioning. The future use of TA-21 is being studied.

TA-22, TD Site: This site is used in the development of special detonators to initiate high-explosive systems. Fundamental and applied research in support of this activity includes investigating phenomena associated with initiating high explosives and research in rapid shock-induced reactions.

TA-28, Magazine Area A: This is an explosives storage area.

TA-33, HP Site: An old high-pressure, tritium handling facility located here is being phased out. The National Radio Astronomy Observatory's Very Large Baseline Array Telescope is located at this site.

TA-35, Ten Site: Nuclear safeguards research and development, which are conducted here, are concerned with techniques for nondestructive detection, identification, and analysis of fissionable isotopes. Research in reactor safety and laser fusion is also done here.

TA-36, Kappa Site: Various explosives phenomena, such as detonation velocity, are investigated at this dynamic testing site.

TA-37, Magazine Area C: This is an explosives storage site.

TA-39, Ancho Canyon Site: Non-nuclear weapons behavior is studied here, primarily by photographic techniques. Investigations are also made into various phenomenological aspects of explosives, interactions of explosives, and explosions involving other materials.

TA-40, DF Site: This site is used in the development of special detonators to initiate high-explosive systems. Fundamental and applied research in support of this activity includes investigating phenomena associated with initiating high explosives and research in rapid shock-induced reactions.

TA-41, W Site: Personnel at this site engage primarily in engineering design and development of nuclear components, including fabrication and evaluation of test materials for weapons.

TA-43, Health Research Laboratory: Research performed at this site includes cellular radiobiology, biophysics, mammalian radiobiology, and mammalian metabolism. A large medical library; special counters used to measure radioactivity in humans and animals; and animal quarters for dogs, mice, and monkeys are also located in this building.

TA-46, WA Site: Applied photochemistry, which includes development of technology for laser isotope separation and laser enhancement of chemical processes, is investigated here. Solar energy research, particularly in the area of passive solar heating for residences, is also done at this site.

TA-48, Radiochemistry Site: Laboratory scientists and technicians at this site study nuclear properties of radioactive materials by using analytical and physical chemistry. Measurements of radioactive substances are made, and "hot cells" are used for remote handling of radioactive materials.

TA-49, Frijoles Mesa Site: This site is currently restricted to carefully selected functions because of its location near Bandelier National Monument and past use in high-explosive and radioactive materials experiments.

TA-50, Waste Management Site: Personnel at this site have responsibility for treating and disposing of most industrial liquid and radioactive liquid waste received from Laboratory technical areas, for development of improved methods of solid waste treatment, and for containment of radioactivity removed by treatment.

TA-51, Animal Exposure Facility: At this site, animals are exposed to nonradioactive toxic materials to determine biological effects of high and low exposures.

TA-52, Reactor Development Site: A wide variety of activities related to nuclear reactor performance and safety is done at this site.

TA-53, Meson Physics Facility: The Los Alamos Meson Physics Facility, a linear particle accelerator, is used to conduct research in areas of basic physics, cancer treatment, materials studies, and isotope production. The Los Alamos Neutron Scattering Center and the Proton Storage Ring are also located at this TA.

TA-54, Waste Disposal Site: The primary function of this site is radioactive solid and hazardous chemical waste management and disposal.

TA-55, Plutonium Facility Site: Processing of plutonium and research in plutonium metallurgy are done at this site.

TA-57, Fenton Hill Site: This is the location of the Laboratory's Hot Dry Rock geothermal project. Scientists at this site are studying the possibility of producing energy by circulating water through hot, dry rock located hundreds of meters below the earth's surface. The water is heated and then brought to the surface to drive electric generators.

TA-59, Occupational Health Site: Occupational health and environmental science activities are conducted at this site.

TA-60, Sigma Mesa: This area contains physical support and infrastructure facilities, including the Test Fabrication Facility.

TA-61, East Jemez Road: This site is used for physical support and infrastructure facilities, including the sanitary landfill.

TA-63: This area contains physical support facilities operated by Johnson Controls Inc.

TA-64: This is the site of the Central Guard Facility.

TA-66: This site is used for public and corporate interface functions.

TA-69: This undeveloped TA serves as an environmental buffer for the dynamic testing area.

TA-70: This undeveloped TA serves as an environmental buffer for the high-explosives test area.

TA-71: This undeveloped TA serves as an environmental buffer for the high-explosives test area.

TA-72: This is the site of the Protective Forces Training facility.

TA-73: This area is the Los Alamos Airport.

TA-74, Otowi Tract: This large area, bordering San Ildefonso Pueblo on the east, is isolated from most of the Laboratory and contains significant concentrations of archaeological sites and an endangered species breeding area.

APPENDIX D

ENVIRONMENTAL BACKGROUND INFORMATION

Table D-1. Hazardous Waste Management Facilities at Los Alamos National Laboratory.

Technical Area	Facility Type	Inclusion in Part B Permit Application or Interim Status[a]
3-29[b]	Container (2 Units)	Interim S
3-102-118A	Container	Closed
14-35	OB/OD (2 Units)[c]	Interim T
15-184[b]	OB/OD	Interim T
16, Area-P	Landfill	Under Closure
16	OB/OD (6 Units)	Interim T
16	Surface Impoundment	Under Closure
16-88[b]	Container	Interim S
16-1150	Incinerator	Interim T
21-61[b]	Container	Interim S
22-24	Container	Closed
35-85	Surface Impoundment	Under Closure
35-125	Surface Impoundment	Under Closure
36-8[b]	OB/OD	Interim T
39-6	OB/OD	Interim T
39-57	OB/OD	Interim T
40, SDS	OB/OD	Under Closure
40-2	Container	Closed
50-1-60A[b]	Container	Interim TS
50-1-60D[b]	Container	Interim S
50-1-BWTP	Above Ground Tank	Permitted TS
50-37-115[b]	Above Ground Tank (2 Units)	Interim S
50-37-115[b]	Container	Interim S
50-37-117	Container	Permitted S
50-37-117[b]	Container	Interim S
50-37-118[b]	Container	Interim S
50-37-CAI[b]	Incinerator	Interim T
50-37-CAI	Incinerator	Permitted T
50-69[b]	Container	Interim S
50-69[b]	Container	Interim S
50-114	Container	Permitted S
50-114[b]	Container	Interim S
50-137[d]	Container	Permitted S
50-138[d]	Container	Permitted S
50-139[d]	Container	Permitted S
50-140[d]	Container	Permitted S
53-166[b]	NE Surface Impoundment	Interim S
53-166[b]	NW Surface Impoundment	Interim S
53-166[b]	S Surface Impoundment	Interim S
54, Area-G Over Pit 33[b]	Container	Interim S
54, Area-G	Landfill	Under Closure

Table D-1. (Cont.)

Technical Area	Facility Type	Inclusion in Part B Permit Application or Interim Status[a]
54, Area-G Pad 1[b]	Container	Interim S
54, Area-G Pad 2[b]	Container	Interim S
54, Area-G Pad 4[b]	Container	Interim S
54, Area-H	Landfill	Under Closure
54, Area-G Over Pit 30[b]	Container	Interim S
54, Area-G Shaft 145[b]	Container	Interim S
54, Area-G Shaft 146[b]	Container	Interim S
54, Area-G Shaft 148[b]	Container	Interim S
54, Area-L Shaft 36[b]	Container	Interim S
54, Area-L Shaft 37[b]	Container	Interim S
54, Area-G Shaft 147[b]	Container	Interim S
54, Area-G Shaft 149[b]	Container	Interim S
54, Area L	Above Ground Tank (4 Tanks)	Permitted T
54, Area L Gas Cyl[b]	Container	Interim S
54, Area L Gas Cyl	Container	Permitted S
54-8[b]	Container	Interim S
54-31	Container	Permitted S
54-32	Container	Permitted S
54-33[b]	Container	Interim S
54-48[b]	Container	Interim S
54-49[b]	Container	Interim S
54-68	Container	Permitted S
54-69	Container	Permitted S
55, Near Bldg 4[b]	Container	Interim S
55-4[b]	Container (3 Units)	Interim S
55-4[b]	Tank (13 Tanks)	Interim TS
55-4[b]	Container	Interim S
55-4[b]	Container	Interim S
55-4[b]	Container	Interim TS
55-4[b]	Container	Interim S

[a]S = Storage; T = Treatment.
[b]Designates mixed waste units.
[c]OB/OD = open burning/open detonation.
[d]These units have not yet been constructed.

Table D-2. Types of Discharges and Parameters Monitored at the Laboratory under its NPDES Permit NM0028355

EPA Identification No.	Type of Discharge	Number of Outfalls	Monitoring Required	Sampling Frequency
01A	Power plant	1	Total suspended solids, free available chlorine, pH, flow	Monthly
02A	Boiler blowdown	2	pH, total suspended solids, flow, copper, iron, phosphorus, sulfite, total chromium	Weekly
03A	Treated cooling water	38	Total suspended solids, free available chlorine, phosphorus, pH, flow	Weekly
04A	Noncontact cooling water	52	pH, flow	Weekly
050 051	Radioactive waste treatment plant (TA-21 & TA-50)	2	Ammonia, chemical oxygen demand, total suspended solids, cadmium, chromium, copper, iron, lead, mercury, zinc, pH, flow	Weekly
05A	High explosives wastewater	21	Chemical oxygen demand, pH, flow, total suspended solids	Weekly
06A	Photo wastewater	13	Cyanide, silver, pH, flow	Weekly
128	Printed circuit board	1	pH, chemical oxygen demand, total suspended solids, iron, copper, silver, flow	Weekly
S	Sanitary wastewater	9	Biochemical oxygen demand, flow, pH, total suspended solids, fecal coliform bacteria	Variable frequency, from three per month to once quarterly

Table D-3. Limits Established by NPDES Permit NM0028355 for Sanitary Outfall Discharges

Discharge Category	Permit Parameter	Daily Average	Daily Maximum	Unit of Measurement
01S TA-3 Treatment Plant	BOD[a]	30.0	45.0	mg/l
		225.2	N/A	lb/day
	TSS[b]	30.0	45.0	mg/l
		225.2	N/A	lb/day
	Fecal coliform bacteria	1,000.0	2,000.0	org/100 ml
	pH	6–9	6–9	standard unit
02S TA-9 Lagoon and Sand Filters	BOD	30.0	45.0	mg/l
		0.3	N/A	lb/day
	TSS	30.0	45.0	mg/l
		0.3	N/A	lb/day
	pH	6–9	6–9	standard unit
03S TA-16 Treatment Plant	BOD	30.0	45.0	mg/l
		25.0	N/A	lb/day
	TSS	30.0	45.0	mg/l
		25.0	N/A	lb/day
	pH	6–9	6–9	standard unit
04S TA-18 Lagoons	BOD	100.0[c]	175.0[c]	mg/l
		2.5[c]	N/A	lb/day
	TSS	100.0[c]	200.0[c]	mg/l
		2.5[c]	N/A	lb/day
	pH	5.5–11.5[c]	5.5–11.5[c]	standard unit
05S TA-21 Package Plant	BOD	100.0[c]	175.0[c]	mg/l
		12.5[c]	N/A	lb/day
	TSS	150.0[c]	200.0[c]	mg/l
		12.5[c]	N/A	lb/day
	pH	5.5–11.5[c]	5.5–11.5[c]	standard unit

Table D-3. (Cont.)

Discharge Category	Permit Parameter	Daily Average	Daily Maximum	Unit of Measurement
07S TA-46N Lagoons & Sand Filters	BOD	30.0	45.0	mg/l
		1.3	N/A	lb/d
	TSS	30.0	45.0	mg/l
		1.3	N/A	lb/d
	pH	6–9	6–9	standard unit
09S TA-53 Lagoons	BOD	100.0[c]	175.0[c]	mg/l
		94.0[c]	N/A	lb/day
	TSS	150.0[c]	200.0[c]	mg/l
		94.0[c]	N/A	lb/day
	pH	5.5–11.5[c]	5.5–11.5[c]	standard unit
10S TA-35 Lagoons & Sand Filters	BOD	100.0[c]	175.0[c]	mg/l
		94.0[c]	N/A	lb/d
	TSS	150.0[c]	200.0[c]	mg/l
		94.0[c]	N/A	lb/d
	pH	5.5[c]	11.5[c]	standard unit
12S TA-46S Lagoons	BOD	100.0[c]	175.0[c]	mg/l
		2.5[c]	N/A	lb/d
	TSS	100.0[c]	200.0[c]	mg/l
		2.5[c]	N/A	lb/d
	pH	5.5–11.5[c]	5.5–11.5[c]	standard unit

[a]Biochemical oxygen demand.
[b]Total suspended solids.
[c]Interim effluent limitations in effect pursuant to FFCA dated November 22, 1991.

Table D-4. NPDES Permit Monitoring of Effluent Quality at Sanitary Sewage Treatment Outfalls

Discharge Location (Outfall)	Permit Parameters	Number of Deviations	Range of Deviation
TA-3 (01S)	BOD[a]	0	—
	TSS[b]	0	—
	Fecal coliform bacteria[c]	1	21,400
	pH[d]	0	—
	Foam	1	present/trace
	Foam	1	present/trace
TA-9 (02S)	BOD	0	—
	TSS	0	—
	pH	0	—
TA-16 (03S)	BOD	0	—
	TSS	0	—
	pH	0	—
TA-18 (04S)	BOD	0	—
	TSS (90)	0	—
	pH	0	—
TA-21 (05S)	BOD	0	—
	TSS	0	—
	pH	0	—
TA-35 (10S)	BOD	0	—
	TSS (90)	0	—
	pH	0	—
TA-41 (06S)	BOD	0	—
	TSS	0	—
	Fecal coliform bacteria	0	—
	pH	0	—
TA-46 (07S)	BOD	0	—
	TSS	0	—
	pH	0	—
TA-46 (12S)	BOD	0	—
	TSS	0	—
	pH	0	—
TA-53 (09S)	BOD	0	—
	TSS (90)	0	—
	pH	0	—

[a]Biochemical oxygen demand (BOD) permit limits are 30 mg/L (30-day average) and 45 mg/L (7-day average).

[b]Total suspended solids (TSS) permit limits are 30 mg/L (30-day average) and 45 mg/L or 90 mg/L (7-day average), dependent on the specific outfall.

[c]Fecal coliform bacteria limits are 1,000 organisms/100 mL (30-day average) and 2,000 organisms/100 mL (7-day average).

[d]Range of permit pH limits is between 6.0 and 9.0 standard units.

Table D-5. Limits Established by NPDES Permit NM0028355 for Industrial Outfall Discharges

Discharge Category	Permit Parameter	Daily Average	Daily Maximum	Unit of Measurement
01A Power plant	TSS[a]	30.0	100.0	mg/L
	Free Cl	0.2	0.5	mg/L
	pH	6–9	6–9	standard unit
02A Boiler blowdown	TSS	30	100	mg/L
	Fe	10	40	mg/L
	Cu	1	1	mg/L
	P	20	40	mg/L
	SO_3	35	70	mg/L
	Cr	Report	Report	mg/L
	pH	6–9	6–9	standard unit
03A Treated cooling water	TSS	30.0	100.0	mg/L
	Free Cl	0.2	0.5	mg/L
	P	20.0[b]	40.0[b]	mg/L
04A Noncontact cooling water	pH	6–9	6–9	standard unit
050 Radioactive waste	COD[c]	18.8	37.5	lb/day
051 treatment plants	COD[d]	94.0	156.0	lb/day
	TSS[c]	3.8	12.5	lb/day
	TSS[d]	18.8	62.6	lb/day
	Cd[c]	0.01	0.06	lb/day
	Cd[d]	0.06	0.3	lb/day
	Cr[c]	0.02	0.08	lb/day
	Cr[d]	0.19	0.38	lb/day
	Cu[c]	0.13	0.13	lb/day
	Cu[d]	0.63	0.63	lb/day
	Fe[c]	0.13	0.13	lb/day
	Fe[d]	1.0	2.0	lb/day
	Pb[c]	0.01	0.03	lb/day
	Pb[d]	0.06	0.15	lb/day
	Hg[c]	0.007	0.02	lb/day
	Hg[d]	0.003	0.09	lb/day
	Zn[c]	0.13	0.37	lb/day
	Zn[d]	0.62	1.83	lb/day
	pH[c]	6–9	6–9	standard unit
	pH[d]	6–9	6–9	standard unit

Table D-5. (Cont.)

Discharge Category	Permit Parameter	Daily Average	Daily Maximum	Unit of Measurement
05A High explosive	COD	150.0	250.0	mg/L
	TSS	30.0	45.0	mg/L
	pH	6–9	6–9	standard unit
06A Photo waste	CN	0.2	0.2	mg/L
	Ag	0.5	1.0	mg/L
	pH	6–9	6–9	standard unit
128 Printed circuit board	COD	1.9	3.8	lb/day
	TSS	1.25	2.5	lb/day
	Fe	0.05	0.1	lb/day
	Cu	0.05	0.1	lb/day
	Ag	Report	Report	lb/day
	pH	6–9	6–9	standard unit

[a]Total suspendid solids.
[b]Interim effluent limitations in effect pursuant to FFCA dated November 22, 1991.
[c]Limitations for outfall 050 located at TA-21-257; COD = chemical oxygen demand.
[d]Limitations for outfall 051 located at TA-50-1.

Table D-6. NPDES Permit Monitoring of Effluent Quality at Industrial Outfalls[a]

Discharge Category	Outfall No.	Number of Outfalls	Permit Parameter	Number of Deviations	Range of Deviations	Number of Outfalls with Deviations
Power plant	01A	1	TSS[b]	0	—	0
			Free Cl	0	—	0
			pH	2	10.4–10.9	2
Boiler blowdown	02A	2	pH	1	9.8	1
			TSS	3	451.0–1,694.0	1
			Cu	0	—	0
			Fe	0	—	0
			P	3	62.0–384.0	1
			SO_3	0	—	0
			Cr	0	—	0
			Foam	1	—	1
			Foam	1	—	1
			Floating Solids	1	present/trace	1
Treated cooling water	03A	38	TSS	2	818.0–2,072.0	1
			Free Cl	1	1.4	1
			P	1	7.26	1
			pH	1	5.4	1
			Foam	1	present/trace	1
Noncontact cooling water	04A	52	pH	0	—	0
Radioactive waste treatment plant	051 and 050	2	COD[c]	0	—	0
			TSS	0	—	0
			Cd	0	—	0
			Cr	0	—	0
			Cu	0	—	0
			Fe	0	—	0
			Pb	0	—	0
			Hg	0	—	0
			Zn	0	—	0
			pH	0	—	0
High explosive	05A	21	COD	1	1,010.0	1
			TSS	0	—	0
			pH	0	—	0

Table D-6. (Cont.)

Discharge Category	Outfall No.	Number of Outfalls	Permit Parameter	Number of Deviations	Range of Deviations	Number of Outfalls with Deviations
Photo waste	06A	13	CN	0	—	0
			Ag	0	—	0
			TSS	0	—	0
			pH	0	—	0
Printed circuit board	128	1	pH	1	9.7	1
			COD	1	3.9	1
			Ag	0	—	0
			Fe	0	—	0
			Cu	0	—	0
			TSS	0	—	0
		130				

[a]Limits set by the NPDES permit are presented in Table D-3.

[b]Total suspended solids.

[c]Chemical oxygen demand.

Table D-7. Federal Facility Compliance Agreement: Schedule for Upgrading the Laboratory's Wastewater Outfalls

Outfalls	Date	Status or Target Date
Outfall 02A (Boiler Blowdown)		
Final design complete	December 1988	Completed
Advertisement of construction contract	February 1989	Completed
Award of construction contract	April 1989	Completed
Construction completion	September 1989	Completed
In compliance with final limits	October 1989	Completed
Outfall 02A-007 (TA-16 Steam Plant)		
Final design complete	April 1991	Completed
Construction complete	September 1991	September 1992
In compliance with final limits	October 1991	October 1992
Outfall 05A (HE Wastewater Discharge)		
Final design complete	December 1988	Completed
Advertisement of construction contract	February 1989	Completed
Award of construction contract	April 1989	Completed
Construction completion	August 1989	Completed
In compliance with final limits	October 1989	Completed
Outfall 04S (TA-18 Sanitary Treatment Plant)		
Outfall 10S (TA-35 Sanitary Lagoons)		
Outfall 12S (TA-46 Sanitary Lagoons)		
Final design complete	June 1990	Completed
Advertisement of construction contract	September 1990	Completed
Award of construction contract	December 1989	Completed
Construction completion	January 1992	September 1992
Special facilities completion and facility startup	September 1992	October 1992
In compliance with final limits	October 1992	October 1992
Outfall 05S (TA-21 Sanitary Package Plant)[a]		
Final design complete	August 1990	Completed
Advertisement of construction contract	September 1990	Completed
Award of construction contract	December 1990	Completed
Construction completion	January 1992	Completed
Special facilities completion and facility startup	June 1992	Completed
In compliance with final limits	July 1992	Completed
Outfall 03A (Treated Cooling Water)		
Study complete	September 1991	Completed
Corrective actions complete	March 1992	Completed
In compliance with final limits	July 1992	Completed

Table D-7. (Cont.)

Outfalls	Date	Status or Target Date
Outfall 03A-023 (Treated Cooling Water)		
Complete waste stream characterization of storm drainage system	October 1991	Completed
Complete other corrective actions	October 1991	Completed
In compliance with final limits	January 1992	Completed
Outfall 09S (TA-53 Sanitary Lagoons)		
Final design complete	March 1991	Completed
Advertisement of construction contract	January 1992	Completed
Award of construction contract	March 1992	June 1992
Construction completion	July 1992	December 1992
Special facilities completion and facilities startup	July 1992	December 1992
In compliance with final limits	August 1992	December 1992
Waste Stream Characterization		
Start Survey	October 1991	Completed
Complete Survey	July 1993	July 1993

[a]Schedule based on Phase I (Sand Filter Addition) of the TA-21 Plant Upgrades.

Table D-8. Locations of Air Sampling Stations[a]

Station	Latitude or North-South Coordinate	Longitude or East-West Coordinate
Regional (28–44 km)		
1. Española	36°00′	106°06′
2. Pojoaque	35°52′	106°02′
3. Santa Fe	35°40′	106°56′
Perimeter (0–4 km)		
4. Barranca School	35°54′09″	106°16′55″
5. Arkansas Avenue	35°54′06″	106°19′10″
6. 48th Street	35°52′58″	106°19′43″
7. Shell Station	35°52′51″	106°18′21″
8. McDonald's	35°52′42″	106°17′57″
9. Los Alamos Airport	35°52655″	106°16′33″
10. East Gate	35°52′32″	106°15′19″
11. Well PM-1	35°51′36″	106°13′31″
12. Royal Crest Trailer Park	35°52′21″	106°18′01″
13. White Rock- Piñon School	35°49′22″	106°12′46″
14. Pajarito Acres	35°47′35″	106°12′31″
15. White Rock Fire Station	35°49′44″	106°12′20″
16. White Rock Church of the Nazarene	35°49′20″	106°13′18″
17. Bandelier National Monument	35°46′52″	106°15′57″
18. North Rim	—	(non-active)
On Site Stations, Controlled Areas		
19. TA-21 DP Site	35°52′30″	106°16′04″
20. TA-21 Area B	35°52′41″	106°16′40″
21. TA-6	35°51′	106°20′
22. TA-53 (LAMPF)	35°52′12″	106°16′00″
23. TA-52 Beta Site	35°51′30″	106°16′35″
24. TA-16 S Site	35°50′57″	106°21′28″
25. TA-16-450	35°50′46″	106°21′19″
26. TA-49	35°49′35″	106°19′08″
27. TA-54 Area G	35°49′53″	106°14′13″
28. TA-33 HP Site	35°47′02″	106°15′26″
29. TA-2 Omega Site	35°52′	106°16′
30. Booster P-2	35°50′43″	106°15′51″
31. TA-3	35°52′24″	106°19′22″
32. TA-48	35°52′42″	106°19′1.6″
Waste Site Stations, Controlled Areas		
33. Area AB	35°49′27″	106°17′55″
34. Area G-1 NE Corner	35°49′48″	106°14′13.8″
35. Area G-2 Back Fence	35°49′46″	106°14′22″
36. Area G-3 Old Office	35°50′6″	106°14′42″
37. Area G-4 H_2O Tank	35°49′49″	106°14′21″

[a]See Fig. IV-4 for station locations.

Table D-9. Locations of Surface Water Sampling Stations

Station	Latitude or North-South Coordinate	Longitude or East-West Coordinate	Map Designation[a]
REGIONAL STATIONS			
Rio Chama at Chamita	30°05″	106°07″	Chamita
Rio Grande at Embudo	36°12″	105°58″	Embudo
Rio Grande at Otowi	35°52″	106°08″	Otowi
Rio Grande at Frijoles	S375	E235	Frijoles
Rio Grande at Cochiti	35°37″	106°19″	Cochiti
Rio Grande at Bernalillo	35°17″	106°36″	Bernalillo
Jemez River	35°40″	106°44″	Jemez
PERIMETER STATIONS (OFF SITE)			
Radioactive Effluent Release Areas			
Acid-Pueblo Canyons			
Acid Weir	N125	E070	49
Pueblo 1	N130	E080	50
Pueblo 2	N120	E155	51
Los Alamos Canyon			
Los Alamos at Rio Grande	35°52″	106°08″	3
Other Areas			
Guaje Canyon	N300	E100	8
Los Alamos Reservoir	N105	W090	7
Mortandad at Rio Grande	S070	E480	38
Pajarito at Rio Grande	S180	E410	35
Frijoles at Park Headquarters	S280	E180	9
Frijoles at Rio Grande	S375	E235	37
ON-SITE STATIONS			
Radioactive Effluent Release Areas			
Acid-Pueblo Canyons			
Pueblo 3	N085	E315	52
Pueblo at SR 502	N070	E350	S27[b]
DP–Los Alamos Canyons			
DPS-1	N090	E160	57
DPS-4	N080	E200	58
Mortandad Canyon			
GS-1	N040	E100	68
Other Areas			
Cañada del Buey	N010	E150	46
Pajarito Canyon	S060	E215	47
Water Canyon at Beta	S090	E090	48
Sandia Canyon			
SCS-1	N080	E040	65
SCS-2	N060	E140	66
SCS-3	N050	E185	67
Ancho at Rio Grande	S295	E340	36

[a]Regional surface water sampling locations are given in Fig. IV-5; perimeter and on site sampling locations are given in Fig. IV-6.
[b]Same location as sediment station 27 (map designation) in Table D-10.

Table D-10. Locations of Sediment Sampling Stations

Station	Latitude or North-South Coordinate	Longitude or East-West Coordinate	Map Designation[a]
REGIONAL STATIONS			
Chamita	36°05″	106°07″	Chamita
Embudo	36°12″	106°58″	Embudo
Rio Grande at Otowi	35°52″	106°08″	Otowi
Rio Grande at Sandia	S060	E490	Sandia
Rio Grande at Pajarito	S185	E410	Pajarito
Rio Grande at Water	S237	E388	Water
Rio Grande at Ancho	S305	E335	Ancho
Rio Grande at Frijoles	S375	E235	Frijoles
Rio Grande at Cochiti	35°37″	106°19″	Cochiti
Rio Grande at Bernalillo	35°17″	106°36″	Bernalillo
Jemez River	35°40″	106°44″	Jemez
PERIMETER STATIONS (OFF-SITE)			
Radioactive Effluent Release Area			
Acid-Pueblo Canyon			
Acid Weir	N125	E070	22
Pueblo 1	N130	E085	23
Pueblo 2	N120	E145	24
DP–Los Alamos Canyon			
Los Alamos at Totavi	N065	E405	36
Los Alamos at LA-2	N125	E510	37
Los Alamos at Otowi	N100	E560	38
Other Canyons			
Guaje at SR-502	N135	E480	12
Bayo at SR-502	N100	E455	13
Sandia at Rio Grande	S060	E490	Sandia
Cañada Ancha at Rio Grande	S140	E510	Cañada Ancha
Pajarito at Rio Grande	S185	E410	Pajarito
Frijoles at National Monument Headquarters	S280	E185	21
Frijoles at Rio Grande	S375	E235	Frijoles
Mortandad Canyon on San Ildefonso Lands			
Mortandad A-6	N015	E250	A-6
Mortandad A-7	N005	E280	A-7
Mortandad A-8	N000	E320	A-8
Mortandad at SR-4 (A-9)	S030	E350	15
Mortandad A-10	S060	E430	A-10
Mortandad at Rio Grande (A-11)	S070	E480	Mortandad (A-11)

Table D-10 (Cont)

Station	Latitude or North-South Coordinate	Longitude or East-West Coordinate	Map Designation[a]
ON SITE STATIONS			
Radioactive Effluent Release Areas			
Acid-Pueblo Canyon			
Hamilton Bend Spring	N105	E255	25
Pueblo 3	N090	E315	26
Pueblo at SR-502	N070	E350	27
DP–Los Alamos Canyon			
DPS-1	N090	E160	28
DPS-4	N075	E205	29
Los Alamos at Bridge	N095	E020	30
Los Alamos at LAO-1	N080	E120	31
Los Alamos at GS-1	N075	E200	32
Los Alamos at LAO-3	N075	E215	33
Los Alamos at LAO-4.5	N065	E270	34
Los Alamos at SR-4	N065	E355	35
Mortandad Canyon			
Mortandad near CMR Building	N060	E036	39
Mortandad west of GS-1	N045	E095	40
Mortandad at GS-1	N040	E105	41
Mortandad at MCO-5	N035	E155	42
Mortandad at MCO-7	N025	E190	43
Mortandad at MCO-9	N030	E215	44
Mortandad at MCO-13 (A-5)	N015	E250	45
Other Canyons			
Sandia at SR-4[b]	N025	E315	14
Cañada del Buey at SR-4[b]	S090	E360	16
Pajarito at SR-4[b]	S105	E320	17
Potrillo at SR-4[b]	S136	E285	18
Fence at SR-4[b]	S139	E280	46
Water at SR-4[b]	S170	E260	19
Indio at SR-4[b]	S200	E260	47
Ancho at SR-4[b]	S255	E250	20
Water at Rio Grande	S237	E388	Water
Ancho at Rio Crande	S305	E335	Ancho
Chaquehiu at Rio Grande	S330	E275	Chaquehui

[a]Sediment sampling locations in Figs. IV-8 and IV-9.

[b]These sediment stations located at State Road 4 are the first points of public access as all Laboratory facilities in or adjacent to these canyons are located west of State Road 4.

Table D-11. Location and Description of Soil Sampling Stations[a]

Station	Location[b]	Map Designation[c]	Description of Nearby LANL Contaminant Sources
Regional Soils			
Rio Chama	36°05' 106°07'	Chamita	
Embudo	36°12' 105°58'	Embudo	
Otowi	35°52' 106°08'	Otowi	
Near Santa Cruz	35°59' 105°54'	Santa Cruz	
Cochiti	35°37' 106°19'	Cochiti	
Bernalillo	35°17' 106°36'	Bernalillo	
Jemez	35°40' 106°44'	Jemez	
Perimeter Soils			
L.A. Sportsman Club	N240 E215	S1	
North Mesa	N134 E168	S2	
Near TA-8 (GT Site)	N060 W075	S3	
Near TA-49	S165 E085	S4	Inactive Waste Site
White Rock (east)	S055 E385	S5	
Tsankawi	N020 E310	S6	
On-Site Soils			
TA-21 (DP Site)	N095 E140	S7	Pu/Chem. Research
East of TA-53	N051 E218	S8	LAMPF Accelerator
TA-50	N035 E095	S9	Rad. Water Treatment
Two-Mile Mesa	N025 E030	S10	Main Technical Area
East of TA-54	S080 E295	S11	Rad. Disposal Site
R-Site Road East	S042 E103	S12	PHERMEX Accelerator
Potrillo Drive	S065 E195	S13	HE Detonation
S-Site (TA-16)	S035 W025	S14	HE Res.; H^3 Facility
Near Test Well DT-9	S150 E140	S15	Inactive Waste Site
Near TA-33	S245 E225	S16	Ex H^3 Facility

[a]Soil sampling locations are given in Figs. IV-8 and IV-11.
[b]Latitude/Longitude or LANL N-S/E-W coordinates.

Table D-12. Locations of Beehives[a]

Station	North-South Coordinate	East-West Coordinate
Regional Stations (28–44 km), Uncontrolled Areas		
San Pedro	—	—
Chimayo	—	—
San Juan	—	—
Perimeter Stations (0–4 km), Uncontrolled Areas		
1. Northern Los Alamos County	N180	W020
2. White Rock/Pajarito Acres	—	—
On-Site Stations, Controlled Areas		
3. TA-5 (Lower Mortandad Canyon)	N020	E185
4. TA-8 (Anchor Site W)	S020	W065
5. TA-9 (Anchor Site E)	S005	W040
6. TA-15 (R-Site)	S020	E065
7. TA-16 (S-Site)	S055	W080
8. TA-21 (DP Canyon)	N095	E180
9. TA-33 (HP-Site)	S260	E265
10. TA-49 (Frijoles Mesa)	S160	E105
11. TA-50 (Upper Mortandad Canyon)	N040	E095
12. TA-53 (LAMPF)	N050	E220
13. TA-54 (Area G)	—	—

[a]Approximate beehive locations are presented in Fig. IV-14.

Table D-13. Los Alamos, New Mexico,[a] Climatological Summary (1911–1991), Temperature and Precipitation Means[b] and Extremes

	Temperature (°F)[c]										
	Normals			Extremes							
Month	Mean Maximum	Mean Minimum	Average	High Average	Year	Low Average	Year	High Daily Maximum	Date	Low Daily Minimum	Date
January	39.5	17.4	28.4	37.6	1986	20.9	1930	64	1/12/81	–18	1/13/63
February	43.5	21.1	32.3	37.4	1934	23.0	1939	69	2/25/86	–14	2/01/51
March	49.6	26.5	38.0	45.8	1972	32.1	1948	73	3/11/89	–3	3/11/48
April	58.4	33.3	45.8	54.3	1954	39.7	1973	80	4/23/50	5	4/09/28
May	67.6	42.0	54.8	60.5	1956	50.1	1957	89	5/29/35	24	5/01/76[d]
June	77.8	51.1	64.5	69.6	1990	60.4	1965	95	6/22/81	28	6/03/19
July	80.6	55.3	68.0	71.4	1980	63.3	1926	95	7/11/35	37	7/07/24
August	77.5	53.5	65.5	70.3	1936	60.9	1929	92	8/10/37	40	8/16/47
September	71.1	47.2	59.1	65.8	1956	56.2	1965	94	9/11/34	23	9/29/36
October	61.5	37.6	49.2	54.7	1963	42.8	1984	84	10/01/80	9	10/31/91
November	48.9	27.1	38.0	44.4	1949	30.5	1972	72	11/01/50	–14	11/28/76
December	40.8	19.4	30.1	38.4	1980	24.0	1990	64	12/27/80	–13	12/09/78
Annual	59.7	36.0	47.8	52.0	1954	46.2	1932	95	6/22/81[d]	–18	1/13/63

Table D-13. (Cont.)

Month	Precipitation (in.)[c]										Mean Number of Days Per Year		
	Precipitation[e]					Snow							
	Mean	Maximum	Year	Daily Maximum	Date	Mean	Maximum	Year	Daily Maximum	Date	Precip. ≥0.10 in.	Max. Temp. ≥90°F	Min. Temp. ≤32°F
January	0.86	6.75	1916	2.45	1/12/16	12.1	64.8	1987	22.0	1/15/87	2	0	29
February	0.80	2.78	1987	1.05	2/20/15	9.9	48.5	1987	20.0	2/19/87	2	0	27
March	1.22	4.11	1973	2.25	3/30/16	12.0	36.0	1973	18.0	3/30/16	3	0	24
April	1.01	4.64	1915	2.00	4/12/75	4.6	33.6	1958	20.0	4/12/75	3	0	14
May	1.17	4.47	1929	1.80	5/21/29	0.9	17.0	1917	12.0	5/02/78	3	0	3
June	1.36	5.67	1986	2.51	6/10/13	—	—	—	—	—	3	1	0
July	3.26	7.98	1919	2.47	7/31/68	—	—	—	—	—	8	1	—
August	3.52	11.18	1952	2.26	8/01/51	—	—	—	—	—	8	0	—
September	2.12	5.79	1941	2.21	9/22/29	0.1	6.0	1913	6.0	9/25/13	5	0	0
October	1.30	6.77	1957	3.48	10/05/11	2.0	20.0	1984	9.0	10/31/72	3	0	7
November	1.02	6.60	1978	1.77	11/25/78	4.6	34.5	1957	14.0	11/22/31	2	0	22
December	1.08	3.21	1984	1.60	12/06/78	12.8	41.3	1967	22.0	12/06/78	3	0	30
Annual	18.72	30.34	1941	3.48	10/05/11	59.0	178.4	1987	22.0	1/15/87	46	3	156
Season							153.2	1986–87		12/06/78			

[a]Latitude 35°52′ north, longitude 106°19′ west; elevation 2263 m.

[b]Means are based on standard 30-year period: 1961–1990.

[c]Metric conversions: 1 in. = 2.5 cm; °F = 9/5°C + 32.

[d]Most recent occurrence.

[e]Includes water equivalent of frozen precipitation.

Table D-14. 1991 Weather Highlights

Key for Abbreviations:

SMDH: Set maximum daily high-temperature record.
TMDH: Tied maximum daily high-temperature record.
SMDL: Set minimum daily low-temperature record.
TMDL: Tied minimum daily low-temperature record.
SMDP: Set maximum daily precipitation record.
SMDS: Set maximum daily snowfall record.

January

Cold and dry.
Mean temperature = 24.7°F (normal = 28.4°F).
Precipitation = 0.39 in. (normal = 0.86 in.).
SMDS on the 21st: 5.2 in.

February

Warm and dry.
Mean temperature = 34.8°F (normal = 32.3°F).
Precipitation = 0.34 in. (normal = 0.80 in.).
Snowfall = 3.3 in. (normal = 9.9 in.).
Strong winds with peak gust of 51 mph on the 13th.

March

Windy.
Strong winds with peak gusts of 54, 57, and 55 mph on the 11th, 26th, and 27th, respectively.
Peak gust of 73 mph at the East Gate Station on the 19th.

April

Dry - only trace of precipitation entire month.
Precipitation = 0.00 in. (normal = 1.01 in.).
Tied record for driest April; 5 previous Aprils with no precipitation; most recent: 1967.
TMDH on the 6th: 72°F.
TMDL on the 28th: 22°F.
Strong winds with peak gusts of 51 and 55 mph on the 1st and 11th, respectively.
Peak gust of 72 mph at the East Gate Station on the 11th.

May

TMDL on the 5th: 28°F.
Precipitation of 0.02 in. on the 15th ended a consecutive string of 45 days with no measurable precipitation.
SMDP on the 20th: 0.71 in.

June

Cool.
Mean temperature = 61.7°F (normal = 64.5°F).
Strong dust devil damages Los Alamos Catholic Church roof on the 18th.

July

Wet and cool.
Rainfall = 5.03 in. (normal = 3.26 in.).
Wettest July since 1968 when 6.60 in. fell.

Table D-14. (Cont.)

July (cont.)

The rainfall of 6.76 in. at the East Gate Station was second largest July precipitation ever recorded in Los Alamos County; highest was 7.98 in. during 1919.
Mean temperature = 64.7°F (normal = 68.0°F).
3rd coldest July on record and coldest since 1941.
SMDP on the 22nd: 1.52 in.
SMDL on the 26th: 46°F.
SMDL on the 27th: 47°F.

August

Wet and cool.
Rainfall = 5.93 in. (normal = 3.52 in.).
Wettest August since 1968 when 6.39 in. fell.
The rainfall of 7.98 in. at the North Community site was the largest monthly precipitation recorded in Los Alamos County since the record highest 11.18 in. fell in August of 1952.
Mean temperature = 63.2°F (normal = 65.5°F).
Rainfall of 1.76 in. at Bandelier site on the 2nd.
Flooding on the 4th with 2.40 in. at North Community, including 1.50 in. during one hour.
Los Alamos County sewer lines washed out in Pueblo Canyon; widespread street and basement flooding in Los Alamos.
Heavy thunderstorms on the 6th caused more local flooding with 1.91 in. at S-Site, 1.61 in. at North Community, and 1.11 in. at TA-6 (official station).
Heavy rainfall of 1.09 in. at Bandelier on the 13th.
Heavy rainfall of 1.20 in. at both TA-6 and North Community on the 19th; 1.15 in. fell in 15 minutes at TA-6.

Summer (June - August)

Coldest summer on record.
Mean temperature = 63.2°F (normal = 66.0°F).
Previous coldest summer: 1929, 63.3°F.
2nd coldest July-August period on record.
Mean temperature (July-August) = 63.9°F (normal = 66.7°F).
Coldest July-August period: 1929, 63.1°F.
Wettest July-August period (11.96 in.) since 1968 when 12.99 in. fell.

September

Cool and wet.
Mean temperature = 56.7°F (normal = 59.1°F).
4th coldest September on record.
Rainfall = 2.73 in. (normal = 2.12 in.).
Rainfall = 4.42 in. at S-Site.

October

Dry but snowy.
Precipitation = 0.35 in. (normal = 1.30 in.).
Snowfall = 7.3 in. (normal = 2.0 in.).
TMDH on the 15th: 72°F.
SMDH on the 17th: 75°F.

Table D-14. (Cont.)

October (cont.)

TMDH on the 18th: 74°F.
SMDL on the 29th: 16°F.
SMDL on the 30th: 15°F.
Tied record low temperature during month of October: 10/19/76.
Record lowest high temperature of 28°F on the 30th.
Tied record lowest high temperature for month of October.
SMDS on the 30th: 7.3 in.
SMDL on the 31st: 9°F.
Record lowest for month of October: previous record = 15°F on 10/30/91 and 10/19/76.
Record lowest high temperature of 25°F on the 31st.
Record lowest high temperature for month of October: previous record = 28°F on 10/30/91 and 10/12/86.

November

Cold, wet, and snowy.
Mean temperature = 33.3°F (normal = 38.0°F).
Precipitation = 2.56 in. (normal = 1.03 in.).
4th coldest and 4th wettest November on record.
Snowfall = 12.1 in. (normal = 4.6 in.).
SMDL on the 1st: 9°F.
TMDL on the 3rd: 10°F.
SMDL on the 4th: 16°F.
SMDP on the 15th: 1.39 in.
SMDS on the 15th: 4.0 in.
Extensive damage to trees and limbs early morning on the 16th resulting from wet snow accumulation.
Strong winds with peak gust = 50 mph on the 18th.

December

Cold, wet, and snowy.
Mean temperature = 27.7°F (normal = 30.1°F).
Precipitation = 2.23 in. (normal = 1.08 in.).
Snowfall = 18.1 in. (normal = 12.8 in.).
SMDL on the 1st: 5°F.
SMDL on the 2nd: 5°F.
TMDL on the 3rd: 6°F.
SMDP on the 11th: 1.03 in.
SMDP on the 18th: 0.76 in.
SMDS on the 18th: 8.8 in.

Annual

1991 mean temperature = 46.2°F (normal = 47.8°F).
5th coldest year on record and coldest since 1941.
1991 precipitation = 24.34 in. (normal = 18.72 in.).
Wettest year since 1985.
1991 snowfall = 60.3 in. (normal = 59.0 in.).
1990-1991 winter snowfall = 38.8 in.
Least seasonal snowfall since 1977-1978 when 31.8 in. fell.

Table D-15. Moisture (gravimetric) and TritiumConcentration in Moisture Extracted from Core Samples from Hole SIMO-1

Depth[a] (ft)	Moisture (% by mass)	H^{3}[b] (nCi/L)
4	4.5	1.6
9	4.0	1.4
14	8.0	1.1
19	7.7	0.4
24	5.7	0.2
29	6.1	0.6
33	5.3	0.0
39	7.0	-0.1
44	8.1	0.3
49	2.8	0.2
54	8.8	0.2
59	3.9	0.1
64	4.1	0.0
69	2.3	-0.2
74	7.9	0.1
79	7.3	-0.2
84	11.2	-0.4
89	10.3	-0.1
94	19.2	-0.2
99	9.3	0.3
104	9.4	0.0

[a] depth below surface.
[b] Detection limit 0.7 nCi/L.

Table D-16. Radiochemical Analyses of Core Samples from Hole SIMO-1

Sample depth (ft)	H^3 (nCi/L)	^{137}CS (pCi/g)	Gross Alpha (cpm/g)	^{238}PU (pCi/g)	$^{239,240}PU$ (pCi/g)	Total Uranium (ug/g)	Gross Beta (pCi/g)	Gross Gamma (pCi/g)
4	1.6 (0.3)[a]	0.043 (0.077)	2.7 (0.5)	0.001 (0.001)	0.002 (0.001)	2.2 (0.2)	3.7 (0.8)	1.4 (0.2)
9	1.4 (0.3)	0.347 (0.135)	4.0 (0.6)	0.008 (0.001)	0.003 (0.001)	2.9 (0.3)	6.0 (1.0)	2.1 (0.3)
14	1.1 (0.3)	0.124 (0.079)	4.0 (0.6)	0.000 (0.000)	0.002 (0.001)	4.6 (0.5)	14.0 (3.0)	5.5 (0.6)
19	0.4 (0.3)	0.185 (0.126)	4.4 (0.6)	0.002 (0.002)	0.001 (0.001)	4.6 (0.4)	14.0 (3.0)	5.9 (0.7)
24	0.2 (0.3)	0.161 (0.081)	4.0 (0.6)	0.000 (0.000)	0.002 (0.001)	4.1 (0.4)	10.0 (2.0)	5.4 (0.6)
29	0.6 (0.3)	0.243 (0.133)	4.0 (0.6)	0.002 (0.001)	0.003 (0.002)	3.6 (0.4)	13.0 (3.0)	5.0 (0.6)
33.5	0.0 (0.3)	0.128 (0.081)	4.8 (0.6)	0.000 (0.001)	0.006 (0.006)	3.9 (0.4)	9.0 (2.0)	4.0 (0.5)
39	–0.1 (0.3)	0.043 (0.116)	2.9 (0.5)	0.000 (0.001)	0.002 (0.001)	3.9 (0.4)	9.0 (2.0)	2.9 (0.4)
44	0.3 (0.3)	0.032 (0.085)	3.9 (0.6)	0.006 (0.006)	0.001 (0.001)	4.0 (0.4)	8.0 (2.0)	3.3 (0.4)
49	0.2 (0.3)	0.150 (0.126)	2.4 (0.5)	0.000 (0.000)	0.000 (0.001)	1.6 (0.2)	2.7 (0.6)	2.0 (0.3)
54	0.2 (0.3)	0.057 (0.079)	6.7 (0.8)	0.001 (0.000)	0.001 (0.001)	5.4 (0.5)	7.0 (2.0)	3.1 (0.4)
59	0.1 (0.3)	0.119 (0.119)	4.0 (0.6)	0.001 (0.000)	0.002 (0.001)	2.8 (0.3)	4.1 (0.9)	1.5 (0.2)
64	0.0 (0.3)	0.094 (0.078)	3.7 (0.5)	0.003 (0.001)	0.002 (0.001)	2.8 (0.3)	5.0 (1.0)	1.7 (0.2)
69	–0.2 (0.3)	0.147 (0.117)	1.8 (0.4)	0.000 (0.000)	0.001 (0.001)	1.5 (0.2)	3.0 (0.7)	1.2 (0.2)
74	0.1 (0.3)	0.107 (0.081)	7.0 (0.8)	0.001 (0.001)	0.001 (0.001)	6.7 (0.7)	8.0 (2.0)	2.7 (0.3)
79	–0.2 (0.3)	0.202 (0.132)	5.6 (0.7)	0.001 (0.000)	0.001 (0.001)	5.9 (0.6)	7.0 (1.0)	2.2 (0.3)
84	–0.4 (0.3)	–0.077 (0.080)	7.1 (0.8)	0.001 (0.000)	0.001 (0.001)	6.3 (0.6)	8.0 (2.0)	3.5 (0.4)
89	–0.1 (0.3)	0.189 (0.120)	4.1 (0.6)	0.000 (0.000)	0.001 (0.000)	3.9 (0.4)	9.0 (2.0)	3.1 (0.4)
94	–0.2 (0.3)	0.102 (0.079)	5.0 (0.6)	0.000 (0.000)	0.004 (0.001)	5.6 (0.6)	3.7 (0.8)	1.8 (0.2)
99	0.3 (0.3)	0.090 (0.118)	3.9 (0.6)	0.000 (0.010)	0.003 (0.001)	5.6 (0.6)	3.1 (0.7)	1.6 (0.2)
104	0.0 (0.3)	0.004 (0.086)	5.3 (0.7)	0.000 (0.010)	0.001 (0.001)	5.5 (0.5)	2.4 (0.6)	1.6 (0.2)

[a]Counting uncertainties are in parentheses.

Table D-17. Summary of Selected Radionuclides Half-Life Information

Nuclide	Symbol	Half-Life (years)
Tritium	H^3	12
Beryllium-7	^{7}Be	0.15
Phosphorus-32	^{32}P	0.04
Potassium-40	^{40}K	1,260,000,000
Argon-41	^{41}Ar	0.00008
Cobalt-60	^{60}Co	5.2
Strontium-85	^{85}Sr	0.18
Strontium-89	^{89}Sr	0.14
Strontium-90	^{90}Sr	27.7
Iodine-131	^{131}I	0.02
Cesium-134	^{134}Cs	2.05
Cesium-137	^{137}Cs	30
Uranium-234	^{234}U	247,000
Uranium-235	^{235}U	710,000,000
Uranium-238	^{238}U	4,510,000,000
Plutonium-238	^{238}Pu	86
Plutonium-239	^{239}Pu	24,390
Plutonium-240	^{240}Pu	6,580
Americium-241	^{241}Am	458

NOTE: For the half-life of the principal airborne activation products, see discussion on page V-2.

Table D-18. Dose Conversion Factors for Calculating Internal Doses[a] (rem/μCi Intake)

Inhalation

Radionuclide	Effective Dose
H^3	6.3×10^{-5}
^{234}U	1.3×10^{2}
^{235}U	1.2×10^{2}
^{238}U	1.2×10^{2}
^{238}Pu	4.6×10^{2}
$^{239,240}Pu$	5.1×10^{2}
^{241}Am	5.2×10^{2}

Ingestion

Radionuclide	Effective Dose
H^3	6.3×10^{-5}
^{7}Be	1.1×10^{-4}
^{90}Sr	1.3×10^{-1}
^{137}Cs	5.0×10^{-2}
^{234}U	2.6×10^{-1}
^{235}U	2.5×10^{-1}
^{238}U	2.3×10^{-1}
^{238}Pu	3.8
$^{239,240}Pu$	4.3
^{241}Am	4.5

[a]Dose conversion factors taken from DOE 1988b.

Table D-19. Dose Conversion Factors for Calculating External Doses ([mrem/yr]/[μCi/m³])

Radionuclide[a]	Effective Dose
^{10}C[b]	8,830
^{11}C	5,110
^{13}N	5,110
^{16}N	29,300
^{14}O[b]	18,900
^{15}O	5,120
^{41}A	6,630

[a]Dose conversion factors taken from DOE 1988c.

[b]Dose conversion factors for ^{10}C and ^{14}O were not given in DOE 1988c and were calculated with the computer program DOSFACTER II (Kocher 1981).

Table D-20. Locations of Groundwater Sampling Stations

Station	North-South Coordinate	East-West Coordinate	Map Designation[a]
MAIN AQUIFER ON SITE			
Test Wells			
Test Well 1	N070	E345	39
Test Well 3	N080	E215	41
Test Well 8	N035	E170	43
Test Well DT-5A	S110	E090	42
Test Well DT-9	S155	E140	44
Test Well DT-10	S120	E125	45
Water Supply Wells			
Pajarito Well Field			
Well PM-1	N030	E305	89
Well PM-2	S055	E202	90
Well PM-3	N040	E255	91
Well PM-4	S030	E205	92
Well PM-5	N015	E155	93
MAIN AQUIFER OFF SITE			
Test Wells			
Test Well 2	N120	E150	40
Water Supply Wells			
Guaje Well Field			
Well G-1	N190	E385	82
Well G-1A	N197	E380	83
Well G-2	N205	E365	84
Well G-3	N215	E350	85
Well G-4	N213	E315	86
Well G-5	N228	E295	87
Well G-6	N215	E270	88
Los Alamos Well Field			
Well LA-1B	N115	E530	76
Well LA-2	N125	E505	77
Well LA-3	N130	E490	78
Well LA-5	N076	E435	80
Well LA-6	N105	E465	81
San Ildefonso Wells			
Westside Artesian Well			SI 10
Halladay Well			SI 8
Pajarito Well (Pump 1)			SI 3
Eastside Artesian Well			SI 9
Don Juan Playhouse Well			SI 17

Table D-20. (Cont.)

Station	North-South Coordinate	East-West Coordinate	Map Designation[a]
MAIN AQUIFER SPRINGS			
White Rock Canyon Springs (Perimeter and Off-Site)			
Group I			
Sandia Spring	S030	E470	13
Spring 3	S110	E450	14
Spring 3A	S120	E445	15
Spring 3AA	S140	E440	16
Spring 4	S170	E410	17
Spring 4A	S150	E395	18
Spring 5	S220	E390	19
Spring 5AA	S240	E360	20
Ancho Spring	S280	E305	21
Group II			
Spring 5A	S230	E390	22
Spring 5B	S275	E355	96
Spring 6	S300	E330	23
Spring 6A	S310	E310	24
Spring 7	S330	E295	25
Spring 8	S335	E285	26
Spring 8A	S315	E280	27
Spring 8B	S310	E285	97
Spring 9	S320	E270	28
Spring 9A	S325	E265	29
Doe Spring	S320	E250	30
Spring 10	S370	E230	31
Group III			
Spring 1	N040	E520	32
Spring 2	N015	E505	33
Group IV			
La Mesita Spring	N080	E550	10
Spring 2A	S105	E475	95
Spring 3B	S150	E465	34
Other Off-Site Springs			
Sacred Spring	N170	E540	11
Indian Spring	N140	E530	12

Table D-20. (Cont.)

Station	North-South Coordinate	East-West Coordinate	Map Designation[a]
ALLUVIAL CANYON AQUIFERS			
Radioactive Effluent Release Areas			
Acid-Pueblo Canyons			
Hamilton Bend Spring	N110	E250	53
DP-Los Alamos Canyons			
LAO-C	N085	E070	59
LAO-1	N080	E120	60
LAO-2	N080	E210	61
LAO-3	N080	E220	62
LAO-4	N070	E245	63
LAO-4.5	N065	E270	64
Mortandad Canyon			
MCO-3	N040	E110	69
MCO-4	N035	E150	70
MCO-5	N030	E160	71
MCO-6	N030	E175	72
MCO-7	N025	E180	73
MCO-7.5	N030	E190	74
Other Areas			
Pajarito Canyon			
PCO-1	S054	E212	102
PCO-2	S081	E255	103
PCO-3	S098	E293	104
PERCHED SYSTEM IN CONGLOMERATES AND BASALT			
(Pueblo/LosAlamos/Sandia Canyon Area)			
Test Well 1A	N070	E335	54
Test Well 2A	N120	E140	55
Basalt Spring	N065	E395	56
PERCHED AQUIFER IN VOLCANICS			
Water Canyon Gallery	S040	W125	94

[a]See Fig. VII-1 for perimeter and on-site groundwater sampling locations.

Table D-21. Volatile Organic Compounds Determined in Water by PAT Analyses

Compound	CAS #	Representative Limit of Quantification[a] (µg/L)
Chloromethane	74-87-3	10
Vinyl chloride	75-01-4	10
Bromomethane	74-83-9	10
Chloroethane	75-00-3	10
Acetone	67-64-1	20
Trichlorofluoromethane	75-69-4	5
1,1-Dichloroethene	75-35-4	5
Methylene chloride	75-09-2	5
Carbon disulfide	75-15-0	5
t-1,2-Dichloroethene	156-60-5	5
1,1-Dichloroethane	75-34-3	5
c-1,2-Dichloroethene	156-59-2	5
Bromochloromethane	74-97-5	5
Chloroform	67-66-3	5
1,2-Dichloroethane	107-06-2	5
1,1-Dichloropropene	563-58-6	5
Vinyl acetate	108-05-4	10
2-Butanone	78-93-3	20
2,2-Dichloropropane	590-20-7	5
1,1,1-Trichloroethane	71-55-6	5
Carbon tetrachloride	56-23-5	5
Benzene	71-43-2	5
1,2-Dichloropropane	78-87-5	5
Trichloroethene	79-01-6	5
Dibromomethane	74-95-3	5
Bromodichloromethane	75-27-4	5
t-1,3-Dichloropropene	1006-10-26	5
c-1,3-Dichloropropene	1006-10-15	5
1,1,2-Trichloroethane	79-00-5	5
1,3-Dichloropropane	142-28-9	5
Chlorodibromomethane	124-48-1	5
Bromoform	75-25-2	5
4-Methyl-2-pentanone	10-81-1	20
Toluene	108-88-3	5
2-Hexanone	59-17-86	20
1,2-Dibromomethane	74-95-3	5
Tetrachloroethene	127-18-4	5
Chlorobenzene	108-90-7	5
1,1,1,2-Tetrachloroethane	630-20-6	5
1-Chlorohexane	544-10-5	5
Ethylbenzene	100-41-4	5
m,p-Xylene (total)	108-38-3 + 106-42-3	5
o-Xylene	95-47-6	5
Styrene	100-42-5	5

Table D-21. (Cont.)

Compound	CAS #	Representative Limit of Quantification[a] (µg/L)
1,1,2,2-Tetrachloroethane	79-34-5	5
1,2,3-Trichloropropane	96-18-4	5
Isopropylbenzene	98-82-8	5
Bromobenzene	108-86-1	5
n-Propylbenzene	103-65-1	5
2-Chlorotoluene	95-49-8	5
4-Chlorotoluene	106-43-4	5
1,3,5-Trimethylbenzene	108-67-8	5
tert-Butylbenzene	98-06-6	5
1,2,4-Trimethylbenzene	95-63-6	5
sec-Butylbenzene	135-98-8	5
1,3-Dichlorobenzene	541-73-1	5
1,4-Dichlorobenzene	106-46-7	5
p−Isopropyltoluene	99-87-6	5
1,2-Dichlorobenzene	95-50-1	5
n-Butylbenzene	104-51-8	5
1,2-Dibromo-3-chloropropane	96-12-8	10
1,2,4-Trichlorobenzene	120-82-1	N/A
Naphthalene	91-20-3	N/A
1,2,3-Trichlorobenzene	87-61-6	N/A
Hexachlorobutadiene	87-68-3	N/A
Dichlorodifluoromethane	75-71-8	10
Trichlorotrifluoroethane	76-13-1	5
Iodomethane	74-88-4	5
2-Chloroethylvinylether	110-75-8	50
Acrylonitrile	107-13-1	100
Acrolein	107-02-8	100

[a]Column: Supelco SPB-5 60 m × 0.25 mm × 1.0 µm. Limits of detection estimated by minimum signal required to yield identifiable mass spectral scan.

Table D-22. Volatile Organic Compounds Determined in Solids by SW-846 Method 8260

Compound	CAS #	Limit of Quantification[a] (mg/kg)
Chloromethane	74-87-3	10
Vinyl chloride	75-01-4	10
Bromomethane	74-83-9	10
Chloroethane	75-00-3	10
Acetone	67-64-1	20
Trichlorofluoromethane	75-69-4	5
1,1-Dichloroethene	75-35-4	5
Methylene chloride	75-09-2	5
Carbon disulfide	75-15-0	5
t-1,5-Dichloroethene	156-60-5	5
1,1-Dichloroethane	75-34-3	5
c-1,2-Dichloroethene	156-59-4	5
Bromochloromethane	74-97-5	5
Chloroform	67-66-3	5
1,2-Dichloroethane	107-06-2	5
1,1-Dichloropropene	563-58-6	5
Vinyl acetate	108-05-4	10
2-Butanone (MEK)	78-93-3	20
2,2-Dichloropropane	590-20-7	5
1,1,1-Trichloroethane	71-55-6	5
Carbon tetrachloride	56-23-5	5
Benzene	71-43-2	5
1,2-Dichloropropane	78-87-5	5
Trichloroethene	79-01-6	5
Dibromomethane	74-95-3	5
Bromodichloromethane	75-27-4	5
t-1,3-Dichloropropene	1006-10-26	5
c-1,3-Dichloropropene	1006-10-15	5
1,1,2-Trichloroethane	79-00-5	5
1,3-Dichloropropane	142-28-9	5
Chlorodibromomethane	124-48-1	5
Bromoform	75-25-2	5
4-Methyl-2-pentanone (MIK)	10-81-1	20
Toluene	108-88-3	5
2-Hexanone	59-17-86	20
1,2-Dibromomethane	74-95-3	5
Tetrachloroethene	127-18-4	5
Chlorobenzene	108-90-7	5
1,1,1,2-Tetrachloroethane	630-20-6	5
1-Chlorohexane	544-10-5	5
Ethylbenzene	100-41-4	5
Mixed Xylene (total)	1330-20-7	5
Styrene	100-42-5	5
1,1,2,2-Tetrachloroethane	79-34-5	5

Table D-22. (Cont.)

Compound	CAS #	Limit of Quantification[a] (mg/kg)
1,2,3-Trichloropropane	96-18-4	5
Isopropylbenzene	98-82-8	5
Bromobenzene	108-86-1	5
n-Propylbenzene	103-65-1	5
2-Chlorotoluene	95-49-8	5
4-Chlorotoluene	106-43-4	5
1,3,5-Trimethylbenzene	108-67-8	5
tert-Butylbenzene	98-06-6	5
1,2,4-Trimethylbenzene	98-63-6	5
sec-Butylbenzene	135-98-8	5
1,3-Dichlorobenzene	541-73-1	5
1,4-Dichlorobenzene	106-46-7	5
p-Isopropyltoluene	99-87-6	5
1,2-Dichlorobenzene	95-50-1	5
n-Butylbenzene	104-51-8	5
1,2-Dibromo-3-chloropropane	96-12-8	10
1,2,4-Trichlorobenzene	120-82-1	N/A
Naphthalene	91-20-3	N/A
1,2,3-Trichlorobenzene	87-61-6	N/A
Hexachlorobutadiene	87-68-3	N/A
Dichlorodifluoromethane	75-71-8	10
Trichlorotrifluoroethane	76-13-1	5
Iodomethane	74-88-4	5
2-Chloroethylvinylether	110-75-8	50
Acrylonitrile	107-13-1	100
Acrolein	107-02-8	100

[a]Column: 60 m × 0.32 mm SPB-5 fused silica capillary, using a methanolic partition with purge and trap. Limits of quantification are calculated from the intercept of the external calibration curve using a flame-ionization detector.

Table D-23. Semivolatile Organics in Water

Compound	CAS #	Limit of Quantification (mg/L)
N-Nitrosodimethylamine	62-75-9	10
Aniline	62-55-3	10
Phenol	108-95-2	10
bis(-2-Chloroethyl)ether	111-44-4	10
2-Chlorophenol	95-57-8	10
1,3-Dichlorobenzene	541-73-1	10
1,4-Dichlorobenzene	106-46-7	10
Benzyl alcohol	100-51-6	10
1,2-Dichlorobenzene	95-50-1	10
2-Methylphenol	95-48-7	10
bis(2-Chloroisopropyl)ether	39638-32-9	10
4-Methylphenol	106-44-5	10
N-Nitroso-di-*n*-propylamine	621-64-7	10
Hexachloroethane	67-72-1	10
Nitrobenzene	98-95-3	10
Isophorone	78-59-1	10
2-Nitrophenol	88-75-5	10
2,4-Dimethylphenol	105-67-9	10
Benzoic acid	65-85-0	10
bis(-2-Chloroethoxy)methane	111-91-1	10
2,4-Dichlorophenol	120-83-2	10
1,2,4-Trichlorobenzene	120-82-1	10
Naphthalene	91-20-3	10
4-Chloroaniline	106-47-8	10
Hexachlorobutadiene	87-68-3	10
4-Chloro-3-methylphenol	59-50-7	10
2-Methylnaphthalene	91-57-6	10
Hexachlorocyclopentadiene	77-47-4	10
2,4,6-Trichlorophenol	88-06-2	10
2,4,5-Trichlorophenol	95-95-4	10
2-Chloronaphthalene	91-58-7	10
2-Nitroaniline	88-74-4	10
Dimethyl phthalate	131-11-3	10
Acenaphthylene	208-96-8	10
3-Nitroaniline	99-09-2	10
Acenaphthene	83-32-9	10
2,4-Dinitrophenol	51-28-5	10
4-Nitrophenol	100-02-7	10
Dibenzofuran	132-64-9	10
2,4-Dinitrotoluene	121-14-2	10
2,6-Dinitrotoluene	606-20-2	10
Diethylphthalate	84-66-2	10
4-Chlorophenyl-phenylether	7005-72-3	10
Fluorene	86-73-7	10
4-Nitroaniline	100-01-6	10
4,6-Dinitro-2-methylphenol	534-52-1	10
N-Nitrosodiphenylamine	86-30-6	10

Table D-23. (Cont.)

Compound	CAS #	Limit of Quantification (mg/L)
Azobenzene	103-33-3	10
4-Bromophenyl-phenylether	101-55-3	10
Hexachlorobenzene	118-74-1	10
Pentachlorophenol	87-86-5	10
Phenanthrene	85-01-8	10
Anthracene	120-12-7	10
Di-*n*-butylphthalate	84-74-2	10
Fluoranthene	206-44-0	10
Benzidine	92-87-5	10
Pyrene	129-00-0	10
Butylbenzylphthalate	85-68-7	10
3,3ó-Dichlorobenzidine	91-94-1	10
Benzo(*a*)anthracene	56-55-3	10
bis(2-Ethylhexyl)phthalate	117-81-7	10
Chrysene	218-01-9	10
Di-*n*-octyl phthalate	117-84-0	10
Benzo(*b*)fluoranthene	205-99-2	10
Benzo(*k*)fluoranthene	207-08-9	10
Benzo(*a*)pyrene	50-32-8	10
Indeno(1,2,3-*cd*)pyrene	193-39-5	10
Dibenzo(*a,h*)anthracene	53-70-3	10
Benzo(*g,h,i*)perylene	191-24-2	10

Table D-24. Volatiles Determined in Air (Pore Gas)

Compound	CAS #	Limit of Quantification (mg/tube)
Chloroform	67-66-3	8.0
1,1,1-Trichloroethane	71-56-6	8.0
Benzene	71-43-2	8.0
Carbon tetrachloride	56-23-5	8.0
Trichloroethene	79-01-6	8.0
Toluene	108-88-3	8.0
Tetrachloroethene	127-18-4	8.0
Chlorobenzene	108-90-7	8.0
Ethylbenzene	100-41-4	8.0
o-Xylene	95-47-6	8.0
m,p-Xylene (total)	108-38-3 + 106-42-3	8.0
1,2,4-Trimethylbenzene	95-63-6	8.0
Bromobenzene	108-86-1	8.0

Table D-25. Toxicity Characteristic Leaching Procedure for Target Organic Contaminants

Contaminant	Regulatory Level (mg/L)
Compound	
Acrylonitrile	5.0
Benzene	0.07
Carbon disulfide	14.4
Carbon tetachloride	0.07
Chlorobenzene	1.4
Chloroform	0.07
1,2-Dichloroethane	0.04
1,1-Dichlorethylene	0.1
Isobutanol	25
Methylene chloride	8.6
Methy ethyl ketone	7.2
1,1,1,2-Tetrachloroethane	10.0
1,1,2,2-Tetrachloroethane	1.3
Tetachloroethylene	0.1
Toluene	14.4
1,1,1-Trichloroethane	25
1,1,2-Trichloroethane	1.2
Trichloroethylene	0.07
Vinyl chloride	0.05
o-Cresol	10.0
m-Cresol	10.0
p-Cresol	10.0
Pentachlorophenol	3.6
Phenol	14.4
2,3,4,6-Tetrachlorophenol	1.5
2,4,5-Trichlorophenol	5.8
2,4,6-Trichlorophenol	0.30
Bis(2-chloroethyl)ether	0.05
1,2-Dichlorobenzene	4.3
1,4-Dichlorobenzene	10.8
2,4-Dinitrotoluene	0.13
Hexachlorobenzene	0.13
Hexachlorobutadiene	0.72
Hexachloroethane	4.3
Nitrobenzene	0.13
Pyridine	5.0
Heptachlor	0.001
Insecticides	
Endrin	0.003
Lindane(γ-BHC)	0.06
Methoxychlor	1.4
Toxaphene	0.07
Herbicides	
2,4-D	1.4
2,3,5-TP (Silvex)	0.14

Table D-26. Summary of EM-9 Quality Assurance Tests for 1991 (Stable Element Analyses in Biologicals)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
B	2	100	—	—	0.98
Pb	2	50	50	—	0.83

Table D-27. Summary of EM-9 Quality Assurance Tests for 1991 (Stable Element Analyses in Filters)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Be	9	100	—	—	0.87 ± 0.05
Pb	4	100	—	—	1.12 ± 0.11

Table D-28. Summary of EM-9 Quality Assurance Tests for 1991 (Stable Element Analyses in Bulk Materials)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Ag	3	100	—	—	0.90 ± 0.08
As	2	100	—	—	0.80
Ba	2	100	—	—	0.83
Cd	2	100	—	—	0.85
Cr	1	100	—	—	0.96
Flashpoint	4	100	—	—	1.01 ± 0.01
Hg	1	100	—	—	1.03
Pb	1	100	—	—	0.76
Se	2	100	—	—	0.93

Table D-29. Summary of EM-9 Quality Assurance Tests for 1991 (Stable Element Analyses in Soil)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Ag	17	100	—	—	1.03 ± 0.24
Al	40	73	10	18	0.91 ± 0.26
As	30	80	13	7	1.40 ± 2.04
Au	17	100	—	—	0.94 ± 0.11
Ba	29	90	7	3	0.98 ± 0.17
Be	12	67	17	17	0.71 ± 0.22
Br	19	74	5	21	1.64 ± 2.38
Ca	40	60	15	25	0.95 ± 0.25
Cd	7	57	29	14	0.59
Ce	27	74	7	19	0.99 ± 0.14
Cl	21	90	5	5	1.04 ± 0.32
Co	35	74	17	9	1.16 ± 0.78
Cr	38	66	5	29	0.97 ± 0.35
Cs	22	95	5	—	0.93 ± 0.07
Cu	24	100	—	—	1.07
Dy	25	84	12	4	0.97 ± 0.20
Eu	25	80	8	12	0.93 ± 0.13
Fe	40	83	15	3	0.95 ± 0.14
Ga	23	96	4	—	1.12 ± 0.19
H^2O	24	100	—	—	0.93 ± 0.05
Hf	26	88	12	—	0.92 ± 0.13
Hg	24	100	—	—	1.19 ± 0.14
I	18	100	—	—	0.91
In	19	100	—	—	0.91 ± 0.07
K	40	80	3	18	0.85 ± 0.36
La	25	88	12	—	1.03 ± 0.08
Lu	24	67	29	4	1.02 ± 0.18
Mg	39	74	18	8	0.96 ± 0.54
Mn	40	78	15	8	1.01 ± 0.17
Na	40	68	10	23	0.89 ± 0.35
Nd	24	79	4	17	1.01 ± 0.28
Ni	7	71	29	—	0.68 ± 0.15

Table D-29. (Cont.)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Pb	7	71	14	14	0.66 ± 0.21
Rb	22	91	9	—	0.99 ± 0.07
Sb	29	76	10	14	0.94 ± 0.21
Sc	26	88	8	4	0.98 ± 0.06
Se	25	76	—	24	18.23 ± 78.62
Sm	25	72	—	28	0.97 ± 0.18
Sr	31	97	3	—	1.04 ± 0.22
Ta	21	76	14	10	0.89 ± 0.11
Tb	24	92	4	4	0.93 ± 0.16
Th	26	96	—	4	1.00 ± 0.12
Ti	34	97	3	—	1.07 ± 0.47
Tl	7	—	—	100	35.33 ± 49.16
V	33	76	3	21	0.90 ± 0.20
W	20	90	5	5	1.31 ± 0.39
Yb	25	72	24	4	1.04 ± 0.16
Zn	40	80	5	15	1.03 ± 0.22
Zr	27	93	7	—	1.16 ± 0.31

Table D-30. Summary of EM-9 Quality Assurance Tests for 1991 (Stable Element Analyses in Water)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Ag	299	98	2	—	1.01 ± 0.09
Al	42	100	—	—	1.03 ± 0.08
As	230	99	—	—	1.04 ± 0.17
Au	3	100	—	—	—
B	46	100	—	—	1.02 ± 0.05
Ba	208	98	1	—	1.02 ± 0.08
Be	94	98	2	—	0.93 ± 0.12
Bi	3	100	—	—	—
Br	2	100	—	—	—
Ca	49	90	10	—	1.10 ± 0.12
Cd	219	99	1	—	1.02 ± 0.08
Ce	3	100	—	—	—
Cl	44	82	18	—	1.09 ± 0.17
CN	52	94	6	—	0.85 ± 0.09
Co	32	97	3	—	1.05 ± 0.09
COD	3	100	—	—	0.98 ± 0.02
Conductivity	36	92	6	3	0.92 ± 0.09
Cr	211	98	1	—	1.04 ± 0.20
Cs	3	100	—	—	—
Cu	67	93	4	3	0.97 ± 0.10
Dy	3	100	—	—	—
Er	3	100	—	—	—
Eu	3	100	—	—	—
F	31	100	—	—	1.07 ± 0.08
Fe	54	100	—	—	1.02 ± 0.08
Ga	3	100	—	—	—
Gd	3	100	—	—	—
Ge	3	100	—	—	—
Hardness	29	93	7	—	1.15 ± 0.11
Hf	3	100	—	—	—
Hg	112	93	4	4	0.97 ± 0.15
Ho	3	100	—	—	—
In	3	100	—	—	—
Ir	3	100	—	—	—
K	47	100	—	—	1.03 ± 0.08
La	3	100	—	—	—
Li	5	80	20	—	1.39
Lu	3	100	—	—	—
Mg	54	100	—	—	1.06 ± 0.06
Mn	55	96	2	2	1.08 ± 0.18
Mo	59	95	5	—	1.09 ± 0.12

Table D-30. (Cont.)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Na	47	96	4	—	1.08 ± 0.08
Nb	3	100	—	—	—
Nd	3	100	—	—	—
NH_3-N	2	50	—	50	1.02
Ni	57	100	—	—	1.03 ± 0.06
NO_3-N	55	100	—	—	0.98 ± 0.07
Oil/grease	1	100	—	—	0.90
P	8	63	38	—	1.34 ± 0.46
Pb	236	99	—	1	1.02 ± 0.06
Pd	3	100	—	—	—
pH	37	100	—	—	1.00 ± 0.01
PO_4-P	48	100	5	—	0.99 ± 0.21
Pr	3	100	—	—	—
Pt	3	100	—	—	—
Rb	3	100	—	—	—
Rh	3	100	—	—	—
Ru	3	100	—	—	—
Sb	66	97	3	—	.95 ± 0.08
Se	206	100	—	—	1.00 ± 0.09
SiO2	56	100	—	—	1.00 ± 0.05
Sm	3	100	—	5	—
Sn	19	95	—	—	0.92 ± 0.10
SO_4	45	96	4	—	1.02 ± 0.17
Sr	59	100	1	—	1.02 ± 0.07
Ta	3	100	—	—	—
Total alkalinity	33	97	3	—	1.09 ± 0.10
Tb	3	100	—	—	—
TDS (total dissolved solids)	38	84	16	—	0.95 ± 0.15
Te	3	100	—	—	—
Th	8	100	—	—	1.01 ± 0.09
Ti	9	100	—	—	0.95 ± 0.06
Tl	75	99	1	—	1.01 ± 0.08
Tm	3	100	—	—	—
TDS (total suspended solids)	3	100	—	—	0.97 ± 0.02
V	51	96	4	—	1.01 ± 0.08
W	3	100	—	—	—
Y	4	75	—	25	—
Yb	3	100	—	—	—
Zn	61	84	16	—	0.92 ± 0.15
Zr	3	100	—	—	—

Table D-31. Summary of EM-9 Quality Assurance Tests for 1991 (Radiochemical Analyses)

Matrix	Analysis	No. QC with CV	Under Control <2σ (%)	Warning 2-3σ (%)	Out of Control >3σ (%)	EM-9 CV Ratio ± Std Dev
Biologicals						
	^{241}Am	1	100	—	—	—
	^{137}Cs	17	82	6	12	0.94 ± 0.72
	^{238}Pu	12	75	17	8	1.04 ± 0.09
	^{239}Pu	12	83	17	—	1.06 ± 0.03
	^{90}Sr	10	40	—	60	0.84 ± 0.22
	U	15	87	13	—	1.15 ± 0.09
Filters						
	Alpha	60	100	—	—	0.92 ± 0.10
	^{241}Am	9	89	11	—	0.94 ± 0.04
	Beta	60	100	—	—	0.82 ± 0.02
	^{238}Pu	9	100	—	—	1.00 ± 0.07
	^{239}Pu	9	67	22	11	0.91 ± 0.07
	U	21	100	—	—	1.09 ± 0.09
Soil						
	Alpha	8	75	25	—	0.95 ± 0.41
	^{241}Am	25	80	16	4	1.09 ± 0.25
	Beta	8	88	13	—	0.93 ± 0.17
	^{137}Cs	57	95	4	2	0.98 ± 0.22
	Gamma	43	100	—	—	0.89 ± 0.02
	^{3}H	48	73	23	4	1.03 ± 0.12
	^{238}Pu	38	92	3	5	0.99 ± 0.07
	^{239}Pu	38	87	5	8	1.08 ± 0.24
	^{90}Sr	27	67	26	7	0.89 ± 0.15
	U	155	92	6	2	0.97 ± 0.09
	$^{235/238}$U	28	96	4	—	1.03 ± 0.17
Water						
	Alpha	165	98	1	1	0.96 ± 0.35
	^{241}Am	3	100	—	—	0.90
	Beta	165	95	3	2	3.86 ±29.70
	^{137}Cs	59	100	—	—	1.10 ± 0.14
	Gamma	26	88	12	—	0.99 ± 0.19
	^{3}H	219	91	8	—	1.03 ± 0.10
	^{238}Pu	17	100	—	—	1.03 ± 0.07
	^{239}Pu	17	94	—	6	1.09 ± 0.12
	^{226}Ra	4	100	—	—	1.13 ± 0.02
	^{90}Sr	9	78	22	—	0.95 ± 0.08
	^{232}Th	1	100	—	—	1.00
	U	201	93	4	3	0.97 ± 0.10
	$^{235/238}$U	101	100	—	—	1.10 ± 0.38

Table D-32. Summary of EM-9 Quality Assurance Tests for 1991 (Organic Analyses in Filters)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Mixed-Aroclor	67	84	12	4	1.48 ± 1.63
Aroclor 1242	67	91	6	3	1.63 ± 1.66
Aroclor 1254	67	99	—	1	1.04 ± 0.31
Aroclor 1260	67	94	6	—	1.68 ± 2.11

Table D-33. Summary of EM-9 Quality Assurance Tests for 1991 (Organic Analyses in Bulk Materials)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Mixed-Aroclor	71	96	1	3	1.07 ± 0.29
Aroclor 1242	71	99	—	1	1.11 ± 0.30
Aroclor 1254	71	100	—	—	—
Aroclor 1260	71	97	1	1	1.04 ± 0.27

Table D-34. Summary of EM-9 Quality Assurance Tests for 1991 (Organic Analyses in Soil)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 CV Ratio ± Std Dev
Acenaphthene	25	96	4	—	0.62 ± 0.04
Acenaphthylene	25	100	—	—	—
Acetone	41	41	15	44	0.51 ± 0.21
Acrolein	38	100	—	—	—
Acrylonitrile	38	100	—	—	—
Aldrin	4	100	—	—	—
Aniline	25	92	—	8	0.14
Anthracene	25	100	—	—	0.86 ± 0.10
Mixed-Aroclor	43	91	7	2	1.01 ± 0.34
Aroclor 1242	41	98	2	—	0.88 ± 0.19
Aroclor 1254	41	93	5	2	0.95 ± 0.47
Aroclor 1260	41	100	—	—	1.11 ± 0.28
Azobenzene	25	100	—	—	—
alpha-BHC	4	100	—	—	0.91
beta-BHC	4	100	—	—	—
delta-BHC	4	100	—	—	—
Benzene	41	98		2	0.35
m-Benzidine	25	100	—	—	—
Benzo[*a*]anthracene	25	96	—	4	—
Benzo[*a*]pyrene	25	100	—	—	0.66
Benzo[*b*]fluoranthene	25	100	—	—	0.78 ± 0.07
Benzo[*g,h,i*]perylene	25	100	—	—	—
Benzo[*k*]fluoranthene	25	100	—	—	0.75
Benzoic acid	25	68	—	32	0.21 ± 0.05
Benzyl alcohol	25	92	—	8	0.76 ± 0.36
Bis(2-chloroethoxy)methane	25	100	—	—	—
Bis(2-chloroethyl)ether	25	100	—	—	0.76 ± 0.10
Bis(2-chloroisopropyl)ether	25	100	—	—	—
Bis(2-ethylhexyl)phthalate	25	96	—	4	—
Bromobenzene	41	98	2	—	0.92 ± 0.17
Bromochloromethane	41	100	—	—	—
Bromodichloromethane	41	98	—	2	1.03 ± 0.24
Bromoform	41	95	—	5	1.02 ± 0.28
Bromomethane	41	100	—	—	—
4-Bromophenylphenyl ether	25	96	4	—	0.67
2-Butanone	41	56	7	37	0.54 ± 0.21
Butyl benzyl phthalate	25	100	—	—	—
tert-Butylbenzene	41	100	—	—	0.71
n-Butylbenzene	41	100	—	—	—
sec-Butylbenzene	41	100	—	—	0.73
Carbon disulfide	41	80	—	20	0.37
Carbon tetrachloride	41	93	—	7	1.01 ± 0.42

Table D-34. (Cont.)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 CV Ratio ± Std Dev
Chlordane	4	100	—	—	—
4-Chloro-3-methylphenol	25	96	4	—	0.75 ± 0.13
4-Chloroaniline	25	96	—	4	0.16
Chlorobenzene	41	98	—	2	0.89 ± 0.14
Chlorodibromomethane	41	93	2	5	0.97 ± 0.21
Chloroethane	41	100	—	—	—
2-Chloroethylvinyl ether	38	100	—	—	—
Chloroform	41	98	2	—	0.87 ± 0.17
Chloromethane	41	100	—	—	—
2-Chloronaphthalene	25	84	12	4	0.59 ± 0.11
o-Chlorophenol	25	96	4	—	0.60 ± 0.08
4-Chlorophenylphenyl ether	25	100	—	—	—
p-Chlorotoluene	41	100	—	—	0.65
o-Chlorotoluene	41	93	5	2	0.79 ± 0.28
Chrysene	25	100	—	—	1.35 ± 0.52
p,p'-DDD	4	100	—	—	0.81 ± 0.20
p,p'-DDE	4	100	—	—	0.63
p,p'-DDT	4	100	—	—	0.76 ± 0.26
Di-*n*-butyl phthalate	25	92	4	4	0.67 ± 0.04
Di-*n*-octyl phthalate	25	100	—	—	1.26 ± 0.55
Dibenzo[*a*,*h*]anthracene	25	100	—	—	—
Dibenzofuran	25	100	—	—	—
1,2-Dibromo-3-chloropropane	41	100	—	—	—
1,2-Dibromoethane	41	100	—	—	—
Dibromomethane	41	100	—	—	0.88 ± 0.16
o-Dichlorobenzene (1,2)	66	100	—	—	0.95 ± 0.11
m-Dichlorobenzene (1,3)	66	100	—	—	—
p-Dichlorobenzene (1,4)	66	95	5	—	0.71 ± 0.13
3,3'-Dichlorobenzidine	25	100	—	—	—
Dichlorodifluoromethane	41	100	—	—	—
1,1-Dichloroethane	41	83	2	15	0.33 ± 0.17
1,2-Dichloroethane	41	85	—	15	0.97 ± 0.40
trans-1,2-Dichloroethene	41	100	—	—	—
1,1-Dichloroethene	41	98	—	2	—
cis-1,2-Dichloroethylene	41	100	—	—	—
2,4-Dichlorophenol	25	84	16	—	0.62 ± 0.13
1,2-Dichloropropane	41	80	—	20	0.68 ± 0.36
2,2-Dichloropropane	41	100	—	—	—
1,3-Dichloropropane	41	100	—	—	—
1,1-Dichloropropene	41	100	—	—	—
trans-1,3-Dichloropropene	41	100	—	—	—
cis-1,3-Dichloropropene	41	100	—	—	—
Dieldrin	4	100	—	—	—

Table D-34. (Cont.)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 CV Ratio ± Std Dev
Diethyl phthalate	25	96	4	—	0.65 ± 0.06
Dimethyl phthalate	25	100	—	—	—
2,4-Dimethylphenol	25	80	16	4	0.59 ± 0.09
2,4-Dinitrophenol	25	100	—	—	—
2,6-Dinitrotoluene	25	100	—	—	0.68 ± 0.02
2,4-Dinitrotoluene	25	100	—	—	—
Endosulfan I	1	100	—	—	—
Endosulfan II	1	100	—	—	—
Endosulfan sulfate	4	100	—	—	—
Endrin	4	100	—	—	0.87 ± 0.30
Endrin aldehyde	4	100	—	—	—
Esters	—	—	—	—	—
Ethylbenzene	41	83	2	15	0.71 ± 0.33
Fluoranthene	25	96	—	4	0.94 ± 0.10
Fluorene	25	100	—	—	—
Heptachlor	4	100	—	—	—
Heptachlor epoxide	4	100	—	—	0.77
Hexachlorobenzene	25	100	—	—	—
Hexachlorobutadiene	26	96	—	4	0.70 ± 0.14
Hexachlorocyclopentadiene	25	96	—	4	0.60
Hexachloroethane	25	80	4	16	0.51 ± 0.23
2-Hexanone	41	80	7	12	0.72 ± 0.18
Hexyl petyl ether	—	—	—	—	—
Indeno[1,2,3-*cd*]pyrene	25	100	—	—	—
Isophorone	25	100	—	—	—
Isopropylbenzene	41	100	—	—	—
4-Isopropyltoluene	41	100	—	—	—
Lindane	4	100	—	—	0.83 ± 0.25
Methoxychlor	4	100	—	—	0.66 ± 0.16
Methyl acetate	—	—	—	—	—
Methyl iodide	41	100	—	—	—
4-Methyl-2-pentanone	41	100	—	—	0.96 ± 0.17
2-Methyl-4,6-dinitrophenol	25	100	—	—	—
Methylene chloride	41	66	5	29	0.83 ± 0.48
2-Methylnaphthalene	25	100	—	—	—
4-Methylphenol	25	100	—	—	—
2-Methylphenol	25	100	—	—	—
Naphthalene	26	92	8	—	0.55 ± 0.04
2-Nitroaniline	25	100	—	—	—
3-Nitroaniline	25	76	—	24	0.23 ± 0.09
4-Nitroaniline	25	80	8	12	0.36 ± 0.14
Nitrobenzene	25	100	—	—	—

Table D-34. (Cont.)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 CV Ratio ± Std Dev
2-Nitrophenol	25	100	—	—	—
4-Nitrophenol	25	96	4	—	0.76 ± 0.15
N-Nitrosodi-*n*-propylamine	25	100	—		—
N-Nitrosodimethylamine	25	100	—		—
N-Nitrosodiphenylamine	25	100	—		0.71 ± 0.06
Pentachlorophenol	25	100	—	—	—
Phenanthrene	25	100	—	—	0.72
Phenol	25	100	—	—	—
Propylbenzene	41	95	2	2	0.67 ± 0.18
Pyrene	25	100	—	—	—
Saturated Hydrocarbons	—	—	—	—	—
Styrene	41	90	—	10	0.84 ± 0.21
1,1,1,2-Tetrachloroethane	41	98	2	—	0.89 ± 0.15
1,1,2,2-Tetrachloroethane	41	100	—	—	1.04 ± 0.16
Tetrachloroethylene	41	93	5	2	0.80 ± 0.26
Toluene	41	95	2	2	0.77 ± 0.21
Toxaphene	4	100	—	—	—
1,1,2-Trichloro-1,2,2-trifluorethane	41	100	—	—	—
1,2,3-Trichlorobenzene	1	100	—	—	—
1,2,4-Trichlorobenzene	26	100	—	—	—
1,1,1-Trichloroethane	41	85	—	15	0.93 ± 0.48
1,1,2-Trichloroethane	41	88	7	5	0.87 ± 0.20
Trichloroethene	41	90	2	7	0.77 ± 0.20
Trichlorofluoromethane	41	100	—	—	—
2,4,5-Trichlorophenol	25	100	—	—	—
2,4,6-Trichlorophenol	25	100	—	—	—
1,2,3-Trichloropropane	41	100	—	—	0.81 ± 0.16
1,2,4-Trimethylbenzene	41	98	2	—	0.88 ± 0.13
1,3,5-Trimethylbenzene	41	100	—	—	—
n-Undecane	—	—	—	—	—
Unknown Polynuclear Aromatic Hydrocarbons	—	—	—	—	—
Unknown organic acid	—	—	—	—	—
Unknown organic compound	—	—	—	—	—
Unsaturated Hydrocarbons	—	—	—	—	—
Vinyl acetate	41	93	—	7	0.72 ± 0.05
Vinyl chloride	41	100	—	—	—
Mixed-Xylenes ($o + m + p$)	41	98	2	—	0.86 ± 0.17

Table D-35. Summary of EM-9 Quality Assurance Tests for 1991 (Organic Analyses in Charcoal Tubes)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	EM-9 Ratio ± Std Dev
Benzene	69	100	—	—	0.84 ± 0.20
Bromobenzene	69	97	3	—	0.71 ± 0.17
Carbon tetrachloride	69	99	—	1	0.90 ± 0.21
Chlorobenzene	69	100	—	—	0.82 ± 0.14
Chloroform	69	100	—	—	0.94 ± 0.29
Ethylbenzene	69	90	—	10	0.85 ± 0.16
Tetrachloroethylene	69	100	—	—	0.94 ± 0.18
Toluene	69	100	—	—	0.86 ± 0.16
1,1,1-Trichloroethane	69	100	—	—	0.87 ± 0.16
Trichloroethene	69	100	—	—	0.97 ± 0.15
1,2,4-Trimethylbenzene	69	99	—	1	0.76 ± 0.16
o-Xylene	69	100	—	—	0.95 ± 0.13
Mixed-Xylenes ($o + m + p$)	69	83	7	10	0.81 ± 0.21

Table D-36. Summary of EM-9 Quality Assurance Tests for 1991 (Organic Analyses in Water)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	HSE-9 Ratio ± Std Dev
Acenaphthene	20	85	—	15	0.27 ± 0.10
Acenaphthylene	20	100	—	—	—
Acetone	24	46	13	42	0.54 ± 0.19
Acrolein	22	100	—	—	—
Acrylonitrile	22	100	—	—	—
Aldrin	1	100	—	—	—
Aniline	20	85	—	15	0.44
Anthracene	20	95	5	—	0.71 ± 0.07
Mixed-Aroclor	12	83	8	8	0.95 ± 0.50
Aroclor 1242	12	100	—	—	1.54 ± 0.34
Aroclor 1254	12	83	8	8	0.75 ± 0.37
Aroclor 1260	12	100	—	—	—
Azobenzene	20	100	—	—	—
alpha-BHC	1	100	—	—	—
beta-BHC	1	100	—	—	—
delta-BHC	1	100	—	—	—
Benzene	24	100	—	—	0.88
Benzenes, substituted	—	—	—	—	—
m-Benzidine	20	100	—	—	—
Benzo[*a*]anthracene	20	100	—	—	—
Benzo[*a*]pyrene	20	95	—	5	0.40
Benzo[*b*]fluoranthene	20	100	—	—	0.85
Benzo[*g,h,i*]perylene	20	100	—	—	—
Benzo[*k*]fluoranthene	20	90	—	10	0.20
Benzoic acid	20	90	—	10	0.78
Benzyl alcohol	20	100	—	—	0.85 ± 0.20
Bis(2-chloroethoxy)methane	20	100	—	—	—
Bis(2-chloroethyl)ether	20	80	10	10	0.58 ± 0.17
Bis(2-chloroisopropyl)ether	20	100	—	—	—
Bis(2-ethylhexyl)phthalate	21	90	—	10	—
Bromobenzene	24	100	—	—	0.99 ± 0.07
Bromochloromethane	24	100	—	—	—
Bromodichloromethane	24	100	—	—	1.19 ± 0.37
Bromoform	24	100	—	—	0.99 ± 0.09
Bromomethane	24	100	—	—	—
4-Bromophenylphenyl ether	20	100	—	—	0.60
2-Butanone	24	54	29	17	0.50 ± 0.11
Butyl benzyl phthalate	20	100	—	—	—
n-Butylbenzene	24	100	—	—	—
sec-Butylbenzene	24	100	—	—	—
tert-Butylbenzene	24	100	—	—	0.71 ± 0.06
Carbon disulfide	24	96	4	—	0.85 ± 0.18

Table D-36. (Cont.)
(Organic Analyses in Water)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	HSE-9 Ratio ± Std Dev
Carbon tetrachloride	24	100	—	—	0.86 ± 0.15
Chlordane	1	100	—	—	—
4-Chloro-3-methylphenol	20	90	5	5	0.67 ± 0.25
4-Chloroaniline	20	90	—	10	0.14
Chlorobenzene	24	100	—	—	0.86 ± 0.05
Chlorodibromomethane	24	100	—	—	0.97 ± 0.09
Chloroethane	24	100	—	—	—
2-Chloroethylvinyl ether	22	100	—	—	—
Chloroform	24	100	—	—	0.93 ± 0.10
Chloromethane	24	100	—	—	—
2-Chloronaphthalene	20	100	—	—	0.63
o-Chlorophenol	20	90	5	5	0.60 ± 0.13
4-Chlorophenylphenyl ether	20	100	—	—	—
o-Chlorotoluene	24	100	—	—	0.74 ± 0.10
p-Chorotoluene	24	100	—	—	—
Chrysene	20	90	—	10	0.15
2,4-D	1	100	—	—	2.07
p,p'-DDD	1	100	—	—	—
p,p'-DDE	1	—	100	—	0.46
p,p'-DDT	1	100	—	—	—
Di-*n*-butyl phthalate	20	95	—	5	0.32
Di-*n*-octyl phthalate	20	80	—	20	0.50 ± 0.26
Dibenzo[*a,h*]anthracene	20	100	—	—	—
Dibenzofuran	20	100	—	—	—
1,2-dibromo-3-Chloropropane	24	100	—	—	—
1,2-Dibromoethane	24	100	—	—	—
Dibromomethane	24	100	—	—	1.02 ± 0.11
o-Dichlorobenzene (1,2)	44	100	—	—	0.74 ± 0.06
m-Dichlorobenzene (1,3)	44	100	—	—	—
p-Dichlorobenzene (1,4)	44	95	—	5	0.69 ± 0.21
3,3'-Dichlorobenzidine	20	100	—	—	—
Dichlorodifluoromethane	24	100	—	—	—
1,2-Dichloroethane	24	100	—	—	1.18 ± 0.34
1,1-Dichloroethane	24	100	—	—	0.87 ± 0.09
1,1-Dichloroethene	24	100	—	—	—
trans-1,2-Dichloroethylene	24	100	—	—	—
cis-1,2-Dichloroethylene	24	100	—	—	—
2,4-Dichlorophenol	20	100	—	—	0.70
2,2-Dichloropropane	24	100	—	—	—
1,3-Dichloropropane	24	100	—	—	—
1,2-Dichloropropane	24	100	—	—	0.86 ± 0.13

Table D-36. (Cont.)
(Organic Analyses in Water)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	HSE-9 Ratio ± Std Dev
1,1-Dichloropropene	24	100	—	—	—
cis-1,3-Dichloropropene	24	100	—	—	—
trans-1,3-Dichloropropene	24	100	—	—	—
Dieldrin	1	100	—	—	0.71
Diethyl phthalate	20	75	—	25	0.13 ± 0.01
Dimethyl phthalate	20	100	—	—	—
N,N-Dimethylformamide	—	—	—	—	—
2,4-Dimethylphenol	20	85	5	10	0.59 ± 0.24
2,4-Dinitrophenol	20	100	—	—	—
2,4-Dinitrotoluene	20	100	—	—	—
2,6-Dinitrotoluene	20	85	5	10	0.33 ± 0.18
Endosulfan I	1	100	—	—	—
Endosulfan II	1	100	—	—	—
Endosulfan sulfate	1	100	—	—	—
Endrin	1	100	—	—	—
Endrin aldehyde	1	100	—	—	—
Ethylbenzene	24	100	—	—	0.74 ± 0.10
Fluoranthene	20	95	—	5	0.75 ± 0.19
Fluorene	20	100	—	—	—
Heptachlor	1	100	—	—	—
Heptachlor epoxide	1	100	—	—	0.85
Hexachlorobenzene	20	100	—	—	—
Hexachlorobutadiene	21	86	10	5	0.50 ± 0.06
Hexachlorocyclopentadiene	20	90	5	5	0.51 ± 0.07
Hexachloroethane	20	90	—	10	0.35
2-Hexanone	24	67	17	17	0.65 ± 0.18
Indeno[1,2,3-*cd*]pyrene	20	100	—	—	—
Isophorone	20	100	—	—	—
Isopropylbenzene	24	100	—	—	—
4-Isopropyltoluene	24	100	—	—	—
Lindane	1	100	—	—	—
Methoxychlor	1	100	—	—	1.00
Methyl iodide	24	100	—	—	—
4-methyl-2-pentanone	24	96	—	4	0.90 ± 0.15
1-Methyl-2-pyrrolidinone	—	—	—	—	—
2-Methyl-4,6-dinitrophenol	20	100	—	—	—
Methylene chloride	24	100	—	—	0.85 ± 0.17
2-Methylnaphthalene	20	100	—	—	—
2-Methylphenol	20	100	—	—	—
4-Methylphenol	20	100	—	—	—
Naphthalene	21	95	5	—	0.58
4-Nitroaniline	20	95	5	—	0.80 ± 0.15

Table D-36. (Cont.)
(Organic Analyses in Water)

Analysis	Number of QC Tests	Under Control <2σ (%)	Warning 2–3σ (%)	Out of Control >3σ (%)	HSE-9 Ratio ± Std Dev
2-Nitroaniline	20	100	—	—	—
3-Nitroaniline	20	100	—	—	0.77
Nitrobenzene	20	100	—	—	—
2-Nitrophenol	20	100	—	—	—
4-Nitrohenol	20	90	5	5	0.61 ± 0.19
N-Nitrosodi-*n*-propylamine	20	100	—	—	—
N-Nitrosodimethylamine	20	100	—	—	—
N-Nitrosodiphenylamine	20	85	5	10	0.31 ± 0.16
Pentachlorophenol	20	100	—	—	—
Phenanthrene	20	95	—	5	0.54
Phenol	20	100	—	—	0.88
Propylbenzene	24	92	—	8	0.53 ± 0.14
Pyrene	20	100	—	—	—
Styrene	24	100	—	—	0.74 ± 0.07
2,4,5-TP	1	100	—	—	1.70
1,1,1,2-Tetrachloroethane	24	100	—	—	0.91 ± 0.06
1,1,2,2-Tetrachloroethane	24	100	—	—	0.95 ± 0.03
Tetrachloroethylene	24	100	—	—	0.73 ± 0.08
2,2,4,4-Tetramethyl-3-Pentanone	—	—	—	—	—
Toluene	24	100	—	—	0.74 ± 0.05
Toxaphene	1	100	—	—	—
1,1,2-Trichloro-1,2,2-Trifluoroethane	24	100	—	—	—
1,2,4-Trichlorobenzene	21	95	—	5	0.48
1,2,3-Trichlorobenzene	1	100	—	—	—
1,1,1-Trichloroethane	24	96	—	4	0.86 ± 0.15
1,1,2-Trichloroethane	24	100	—	—	0.93 ± 0.07
Trichloroethene	24	100	—	—	0.81 ± 0.05
Trichlorofluoromethane	24	96	—	4	—
2,4,6-Trichlorophenol	20	100	—	—	—
2,4,5-Trichlorophenol	20	100	—	—	—
1,2,3-Trichloropropane	24	100	—	—	0.96 ± 0.15
1,2,4-Trimethylbenzene	24	92	—	8	0.52 ± 0.20
1,3,5-Trimethylbenzene	24	100	—	—	—
Unknown Alcohol	—	—	—	—	—
Unknown Sulfur compounds	—	—	—	—	—
Unsaturated Hydrocarbons	—	—	—	—	—
Vinyl acetate	24	88	4	8	2.35
Vinyl chloride	24	100	—	—	—
Mixed-Xylenes($o + m + p$)	24	92	8	—	0.75 ± 0.16

Table D-37. Summary of EM-9 False Positive/False Negative Occurrences for EM-8 Quality Control Samples Run in 1991

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
INORGANIC ANALYSES			
Biologicals			
B	—	—	2
Pb	—	—	2
U	—	—	15
Bulk Materials			
Ag	—	—	1
As	—	—	1
Ba	—	—	1
Cd	—	—	1
Cr	—	—	1
Flashpoint	—	—	4
Hg	—	—	1
Pb	—	—	1
Se	—	—	1
Filters			
Be	—	—	6
Pb	—	—	4
U	—	—	21
Soils			
Ag	—	—	17
Al	—	—	40
As	—	2	30
Au	—	1	17
Ba	—	2	29
Be	—	—	12
Br	—	—	19
Ca	—	1	40
Cd	—	2	7
Ce	—	1	27
Cl	1	—	21
Co	—	3	35
Cr	—	—	38
Cs	—	—	22
Cu	—	—	24
Dy	—	—	25
Eu	—	—	25
Fe	—	—	40
Ga	—	—	23
H_2O-(Unbound Water)	—	24	
Hf	—	—	26

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
INORGANIC ANALYSES (Cont.)			
Soils (Cont.)			
Hg	—	—	24
I	—	—	18
In	—	—	19
K	—	—	40
La	—	—	25
Lu	—	—	24
Mg	—	—	39
Mn	—	—	40
Na	—	1	40
Nd	—	1	24
Ni	—	—	7
Pb	—	—	7
Rb	—	—	22
Sb	—	3	29
Sc	—	—	26
Se	—	1	25
Sm	—	—	25
Sr	—	3	31
Ta	—	—	21
Tb	—	—	24
Th	—	—	26
Ti	—	—	34
Tl	—	1	7
U	—	—	155
V	—	2	33
W	—	—	20
Yb	—	—	25
Zn	—	5	40
Zr	—	2	27
Waters			
Ag	—	—	287
Al	—	—	42
As	—	—	226
Au	—	—	3
B	—	—	46
Ba	—	2	208
Be	—	—	94
Bi	—	—	3
Br	—	—	2
Ca	—	—	49
Cd	2	1	219

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
INORGANIC ANALYSES (Cont.)			
Waters (Cont.)			
Ce	—	—	3
Cl	—	—	44
Cn	—	—	41
Co	—	—	32
Chemical Oxygen Demand	—	3	
Conductivity	—	—	34
Cr	—	—	211
Cs	—	—	3
Cu	—	—	67
Dy	—	—	3
Er	—	—	3
Eu	—	—	3
F	—	—	31
Fe	—	—	54
Ga	—	—	3
Gd	—	—	3
Ge	—	—	3
Hardness	—	—	28
Hf	—	—	3
Hg	—	—	110
Ho	—	—	3
In	—	—	3
Ir	—	—	3
K	—	—	47
La	—	—	47
Li	—	—	5
Lu	—	—	3
Mg	—	—	54
Mn	—	—	55
Mo	—	—	59
Na	—	—	47
Nb	—	—	3
Nd	—	—	3
NH_3-N	—	1	2
Ni	—	—	57
NO_3-N	—	—	52
Oil/grease	—	—	1
P	—	—	5
Pb	2	1	236
Pd	—	—	3
Ph	—	—	37
PO_4-P	—	—	48

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
INORGANIC ANALYSES (Cont.)			
Waters (Cont.)			
Pr	—	—	3
Pt	—	—	3
Rb	—	—	3
Rh	—	—	3
Ru	—	—	3
Sb	—	—	66
Se	—	—	202
Si	—	—	51
Sm	—	—	3
Sn	—	—	19
SO_4	—	—	45
Sr	—	—	59
Ta	—	—	3
Total Alkalinity	—	33	
Tb	—	—	3
Total Dissolved Solids	—	38	
Te	—	—	3
Th	—	—	8
Ti	—	—	9
Tl	—	—	75
Tm	—	—	3
Total Suspended Solids	—	3	
U	—	—	196
V	—	—	51
W	—	—	3
Y	—	—	4
Yb	—	—	3
Zn	—	—	61
Zr	—	—	3
ORGANIC ANALYSES			
Bulk Materials			
Mixed-Aroclor	—	—	71
Aroclor 1242	—	—	71
Aroclor 1254	—	—	71
Aroclor 1260	—	—	71
Filters			
Mixed-Aroclor	—	1	67
Aroclor 1242	—	1	67
Aroclor 1254	—	—	67
Aroclor 1260	—	—	67

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
ORGANIC ANALYSES (Cont.)			
Soils			
Acenaphthene	—	—	54
Acenaphthylene	—	—	54
Acetone	1	1	130
Acrolein	—	—	117
Acrylonitrile	—	—	117
Aldrin	—	—	4
Aniline	—	1	54
Anthracene	—	—	54
Mixed-Aroclor	—	—	42
Aroclor 1242	—	—	41
Aroclor 1254	—	—	41
Aroclor 1260	—	—	41
Azobenzene	—	—	54
Alpha-BHC	—	—	4
Beta-BHC	—	—	4
Delta-BHC	—	—	4
Benzene	—	—	130
m-Benzidine	—	—	54
Benzo[*a*]anthracene	1	—	54
Benzo[*a*]pyrene	—	—	54
Benzo[*b*]fluoranthene	—	—	54
Benzo[*g,h,i*]perylene	—	—	54
Benzo[*k*]fluoranthene	—	—	54
Benzoic acid	2	3	54
Benzyl alcohol	—	—	54
Bis(2-chloroethoxy)methane	—	—	54
Bis(2-chloroethyl)ether	—	—	54
Bis(2-chloroisopropyl)ether	—	—	54
Bis(2-ethylhexyl)phthalate	2	—	54
Bromobenzene	—	—	130
Bromochloromethane	—	—	130
Bromodichloromethane	—	—	130
Bromoform	—	2	130
Bromomethane	—	—	130
4-Bromophenylphenyl ether	—	—	54
2-Butanone	4	2	130
Butyl benzyl phthalate	—	—	54
n-Butylbenzene	—	—	129
sec-Butylbenzene	—	—	129
tert-Butylbenzene	—	—	130
Carbon disulfide	6	4	130
Carbon tetrachloride	—	1	130
Chlordane	—	—	4

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
ORGANIC ANALYSES (Cont.)			
Soils (Cont.)			
4-Chloro-3-methylphenol	—	—	54
4-Chloroaniline	—	—	54
Chlorobenzene	—	—	130
Chlorodibromomethane	—	2	130
Chloroethane	—	—	130
2-Chloroethylvinyl ether	—	—	118
Chloroform	—	—	130
Chloromethane	—	—	130
2-Chloronaphthalene	—	—	54
o-chlorophenol	—	—	54
4-Chlorophenylphenyl ether	—	—	54
o-Chlorotoluene	—	—	130
p-Chlorotoluene	—	—	130
Chrysene	—	—	54
p,p'-DDD	—	—	4
p,p'-DDE	—	—	4
p,p'-DDT	—	—	4
Di-*n*-butyl phthalate	2	—	54
Di-*n*-octyl phthalate	—	—	54
Dibenzo[*a,h*]anthracene	—	—	54
Dibenzofuran	—	—	54
1,2-Dibromo-3-Chloropropane	—	129	
1,2-Dibromoethane	—	—	130
Dibromomethane	—	—	130
o-Dichlorobenzene(1,2)	1	—	183
m-Dichlorobenzene(1,3)	—	—	183
p-Dichlorobenzene(1,4)	—	—	183
3,3'-Dichlorobenzidine	—	—	54
Dichlorodifluoromethane	—	—	130
1,1-Dichloroethane	—	3	130
1,2-Dichloroethane	—	3	130
1,1-Dichloroethene	1	—	130
trans-1,2-Dichloroethene	—	—	130
cis-1,2-Dichloroethylene	—	—	130
2,4-Dichlorophenol	—	—	54
1,2-Dichloropropane	—	4	130
1,3-Dichloropropane	—	—	130
2,2-Dichloropropane	—	—	130
1,1-Dichloropropene	—	—	130
cis-1,3-Dichloropropene	—	—	130
trans-1,3-Dichloropropene	—	—	130
Dieldrin	—	—	4
Diethyl phthalate	—	—	54

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
ORGANIC ANALYSES (Cont.)			
Soils (Cont.)			
Dimethyl phthalate	—	—	54
2,4-Dimethylphenol	—	1	54
2,4-Dinitrophenol	—	—	54
2,4-Dinitrotoluene	—	—	54
2,6-Dinitrotoluene	—	—	54
Endosulfan I	—	—	1
Endosulfan II	—	—	1
Endosulfan sulfate	—	—	4
Endrin	—	—	4
Endrin aldehyde	—	—	4
Ethylbenzene	—	3	130
1,2-Dibromoethane	—	—	130
Fluoranthene	—	1	54
Fluorene	—	—	54
Heptachlor	—	—	4
Heptachlor epoxide	—	—	4
Hexachlorobenzene	—	—	54
Hexachlorobutadiene	—	—	59
Hexachlorocyclopentadiene	—	1	54
Hexachloroethane	—	2	54
2-Hexanone	—	4	130
Indeno[1,2,3-*cd*]pyrene	—	—	54
Isophorone	—	—	54
Isopropylbenzene	—	—	130
4-Isopropyltoluene	—	—	129
Lindane	—	—	4
Methoxychlor	—	—	4
Methyl iodide	—	—	130
4-Methyl-2-pentanone	—	—	130
2-Methyl-4,6-Dinitrophenol	—	—	54
Methylene chloride	13	1	130
2-Methylnaphthalene	—	—	54
2-Methylphenol	—	—	54
4-Methylphenol	—	—	54
Naphthalene	—	—	59
2-Nitroaniline	—	—	54
3-Nitroaniline	—	3	54
4-Nitroaniline	—	—	54
Nitrobenzene	—	—	54
2-Nitrophenol	—	—	54
4-Nitrophenol	—	—	54
N-Nitrosodi-*n*-propylamine	—	—	54

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
Organic Analyses (Cont.)			
Soils (Cont.)			
N-Nitrosodimethylamine	—	—	54
N-Nitrosodiphenylamine	—	—	54
Pentachlorophenol	—	—	54
Phenanthrene	—	—	54
Phenol	—	—	54
Propylbenzene	—	—	130
Pyrene	—	—	54
Styrene	—	2	130
1,1,1,2-Tetrachloroethane	—	—	130
1,1,2,2-Tetrachloroethane	—	—	130
Tetrachloroethylene	—	—	130
Toluene	—	—	130
Toxaphene	—	—	4
1,1,2-Trichloro-1,2,2-Trifluoroethane	1	—	130
1,2,3-Trichlorobenzene	—	—	5
1,2,4-Trichlorobenzene	—	—	59
1,1,1-Trichloroethane	2	—	130
1,1,2-Trichloroethane	—	2	130
Trichloroethene	2	—	130
Trichlorofluoromethane	1	—	130
2,4,5-Trichlorophenol	—	—	54
2,4,6-Trichlorophenol	—	—	54
1,2,3-Trichloropropane	—	—	130
1,2,4-Trimethylbenzene	—	—	130
1,3,5-Trimethylbenzene	—	—	130
Vinyl acetate	—	3	130
Vinyl chloride	—	—	130
Mixed-Xylenes ($o + m + p$)	—	—	130
Charcoal Tubes			
Benzene	—	—	98
Bromobenzene	—	—	98
Carbon tetrachloride	—	1	98
Chlorobenzene	—	—	98
Chloroform	—	—	98
Ethylbenzene	4	3	98
Tetrachloroethylene	—	—	98
Toluene	—	—	98
1,1,1-Trichloroethane	—	—	98
Trichloroethene	—	—	98
1,2,4-Trimethylbenzene	—	—	98

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
INORGANIC ANALYSES (Cont.)			
Charcoal Tubes (Cont.)			
o-Xylene	—	—	98
Mixed-Xylenes (*o* + *m* + *p*)	3	4	98
Waters			
Acenaphthene	3	—	67
Acenaphthylene	—	—	47
Acetone	1	—	63
Acrolein	—	—	56
Acrylonitrile	—	—	56
Aldrin	—	—	1
Aniline	—	2	47
Anthracene	—	1	47
Mixed-Aroclor	—	—	12
Aroclor 1242	—	—	12
Aroclor 1254	—	—	12
Aroclor 1260	—	—	12
Azobenzene	—	—	47
alpha-BHC	—	—	1
beta-BHC	—	—	1
delta-BHC	—	—	1
Benzene	—	—	63
m-Benzidine	—	—	47
Benzo[*a*]anthracene	—	—	47
Benzo[*a*]pyrene	—	—	47
Benzo[*b*]fluoranthene	—	—	47
Benzo[*g,h,i*]perylene	—	—	47
Benzo[k]fluoranthene	—	—	47
Benzoic acid	1	—	47
Benzyl alcohol	—	—	47
Bis(2-chloroethoxy)methane	—	—	47
Bis(2-chloroethyl)ether	—	1	47
Bis(2-chloroisopropyl)ether	—	—	47
Bis(2-ethylhexyl)phthalate	4	—	48
Bromobenzene	—	—	63
Bromochloromethane	—	—	63
Bromodichloromethane	—	—	63
Bromoform	—	—	63
Bromomethane	—	—	63
4-Bromophenylphenyl ether	—	—	47
2-Butanone	2	2	63
Butyl benzyl phthalate	—	—	47
n-Butylbenzene	—	—	63
sec-Butylbenzene	—	—	63

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
ORGANIC ANALYSES (Cont.)			
Waters (Cont.)			
tert-Butylbenzene	—	—	63
Carbon disulfide	1	—	63
Carbon tetrachloride	—	—	63
Chlordane	—	—	1
4-Chloro-3-methylphenol	2	—	67
4-Chloroaniline	—	1	47
Chlorobenzene	—	—	63
Chlorodibromomethane	—	—	63
Chloroethane	—	—	63
2-Chloroethylvinyl ether	—	—	56
Chloroform	—	—	63
Chloromethane	—	—	63
2-Chloronaphthalene	—	—	47
o-Chlorophenol	9	—	67
4-Chlorophenylphenyl ether	—	—	47
o-Chlorotoluene	—	—	63
p-Chlorotoluene	—	—	63
Chrysene	—	1	47
2,4-D	—	—	1
p,p'-DDD	—	—	1
p,p'-DDE	—	—	1
p,p'-DDT	—	—	1
Di-*n*-butyl phthalate	—	—	47
Di-*n*-octyl phthalate	—	—	47
Dibenzo[*a,h*]anthracene	—	—	47
Dibenzofuran	—	—	47
1,2-Dibromo-3-chloropropane	—	63	
1,2-Dibromoethane	—	—	63
Dibromomethane	—	—	63
o-Dichlorobenzene(1,2)	—	—	110
m-Dichlorobenzene(1,3)	—	—	110
p-Dichlorobenzene(1,4)	5	—	130
3,3'-Dichlorobenzidine	—	—	47
Dichlorodifluoromethane	—	—	63
1,1-Dichloroethane	—	—	63
1,2-Dichloroethane	—	—	63
1,1-Dichloroethene	—	—	63
trans-1,2-Dichloroethene	—	—	63
cis-1,2-Dichloroethylene	—	—	63
2,4-Dichlorophenol	—	—	47
1,2-Dichloropropane	—	—	63
1,3-Dichloropropane	—	—	63
2,2-Dichloropropane	—	—	63

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
ORGANIC ANALYSES (Cont.)			
Waters (Cont.)			
1,1-Dichloropropene	—	—	63
cis-1,3-Dichloropropene	—	—	63
trans-1,3-Dichloropropene	—	—	63
Dieldrin	—	—	1
Diethyl phthalate	—	2	47
Dimethyl phthalate	—	—	47
2,4-Dinethylphenol	—	—	47
2,4-Dinitrophenol	—	—	47
2,4-Dinitrotoluene	3	—	67
2,6-Dinitrotoluene	—	—	47
Endosulfan I	—	—	1
Endosulfan II	—	—	1
Endosulfan sulfate	—	—	1
Endrin	—	—	1
Endrin aldehyde	—	—	1
Ethylbenzene	—	—	63
1,2-Dibromoethane	—	—	63
Fluoranthene	—	—	47
Fluorene	—	—	47
Heptachlor	—	—	1
Heptachlor epoxide	—	—	1
Hexachlorobenzene	—	—	47
Hexachlorobutadiene	—	—	49
Hexachlorocyclopentadiene	—	—	47
Hexachloroethane	—	—	47
2-Hexanone	1	2	63
Indeno[1,2,3-*cd*]pyrene	—	—	47
Isophorone	—	—	47
Isopropylbenzene	—	—	63
4-Isopropyltoluene	—	—	63
Lindane	—	—	1
Methoxychlor	—	—	1
Methyl iodide	—	—	63
4-Methyl-2-pentanone	2	—	63
2-Methyl-4,6-dinitrophenol	—	—	47
Methylene chloride	2	—	63
2-Methylnaphthalene	—	—	47
2-Methylphenol	—	—	47
4-Methylphenol	—	—	47
Naphthalene	—	—	49
2-Nitroaniline	—	—	47
3-Nitroaniline	—	—	47
4-Nitroaniline	—	—	47

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
ORGANIC ANALYSES (Cont.)			
Waters (Cont.)			
4-Nitrophenol	3	—	67
N-Nitrosodi-*n*-propylamine	7	—	67
N-Nitrosodimethylamine	—	—	47
N-Nitrosodiphenylamine	—	—	47
Pentachlorophenol	2	—	67
Phenanthrene	—	—	47
Phenol	9	—	67
Propylbenzene	—	—	63
Pyrene	1	—	67
Styrene	—	—	63
2,4,5-TP	—	—	1
1,1,1,2-Tetrachloroethane	—	—	63
1,1,2,2-Tetrachloroethane	—	—	63
Tetrachloroethylene	—	—	63
Toluene	—	—	63
Toxaphene	—	—	1
1,1,2-Trichloro-1,2,2-Trifluoroethane	—	—	63
1,2,3-Trichlorobenzene	—	—	2
1,2,4-Trichlorobenzene	8	—	69
1,1,1-Trichloroethane	1	—	63
1,1,2-Trichloroethane	—	—	63
Trichloroethene	—	—	63
Trichlorofluoromethane	1	—	63
2,4,5-Trichlorophenol	—	—	47
2,4,6-Trichlorophenol	—	—	47
1,2,3-Trichloropropane	—	—	63
1,2,4-Trimethylbenzene	—	—	63
1,3,5-Trimethylbenzene	—	—	63
Vinyl acetate	—	2	63
Vinyl chloride	—	—	63
Mixed-Xylenes (*o* + *m* + *p*)	—	—	63

Table D-37. (Cont.)

Matrix Analyte	False Positive	False Negative	Total Quality Occurrence
RADIOCHEMICAL ANALYSES			
Biologicals			
Nitrobenzene	—	—	47
2-Nitrophenol	—	—	47
^{137}Cs	—	—	17
^{238}Pu	2	—	12
^{239}Pu	2	—	12
^{90}Sr	6	—	10
Filters			
Alpha	—	—	60
^{241}Am	—	—	9
Beta	—	—	60
^{238}Pu	—	—	9
^{239}Pu	—	—	9
Soils			
Alpha	—	—	8
^{241}Am	3	—	25
Beta	—	—	8
^{137}Cs	1	—	57
Gamma	—	—	43
^{3}H	9	—	48
^{238}Pu	3	—	38
^{239}Pu	3	—	38
^{90}Sr	1	—	27
$^{235/238}U$	—	—	28
Waters			
Alpha	1	—	165
^{241}Am	—	—	3
Beta	2	—	165
^{137}Cs	—	—	59
Gamma	—	—	26
^{3}H	9	3	219
^{238}Pu	—	—	17
^{239}Pu	1	—	17
^{226}Ra	—	—	4
^{90}Sr	—	—	9
^{232}Th	—	—	1
$^{235/238}U$	—	—	100

Table D-38. Radiochemical Detection Limits for Analyses of Typical Environmental Samples

Parameter	Approximate Sample Volume or Weight	Count Time	Detection Limit Concentration	
Air Sample				
Tritium	3 m^3	30 min	1×10^{-10}	$\mu Ci/m^3$
^{238}Pu	2.0×10^4 m^3	8×10^4 s	2×10^{-18}	$\mu Ci/m^3$
$^{239,240}Pu$	2.0×10^4 m^3	8×10^4 s	2×10^{-18}	$\mu Ci/m^3$
^{241}Am	2.0×10^4 m^3	8×10^4 s	2×10^{-18}	$\mu Ci/m^3$
Gross alpha	6.5×10^3 m^3	100 min	4×10^{-16}	$\mu Ci/m^3$
Gross beta	6.5×10^3 m^3	100 min	4×10^{-16}	$\mu Ci/m^3$
Uranium (delayed neutron)	2.0×10^4 m^3	60 s	1	pg/m^3
Water Sample				
Tritium	0.005 L	30 min	4×10^{-7}	$\mu Ci/mL$
^{90}Sr	0.5 L	200 min	3×10^{-9}	$\mu Ci/mL$
^{137}Cs	0.5 L	5×10^4 s	4×10^{-8}	$\mu Ci/mL$
^{238}Pu	0.5 L	8×10^4 s	2×10^{-11}	$\mu Ci/mL$
$^{239,240}Pu$	0.5 L	8×10^4 s	2×10^{-11}	$\mu Ci/mL$
^{241}Am	0.5 L	8×10^4 s	2×10^{-11}	$\mu Ci/mL$
Gross alpha	0.9 L	100 min	3×10^{-9}	$\mu Ci/mL$
Gross beta	0.9 L	100 min	3×10^{-9}	$\mu Ci/mL$
Soil Sample				
Tritium	1 kg	30 min	0.003	pCi/g
^{90}Sr	2 g	200 min	2	pCi/g
^{137}Cs	100 g	5×10^4 s	0.1	pCi/g
^{238}Pu	10 g	8×10^4 s	0.002	pCi/g
$^{239,240}Pu$	10 g	8×10^4 s	0.002	pCi/g
^{241}Am	10 g	8×10^4 s	0.002	pCi/g
Gross alpha	2 g	100 min	3	pCi/g
Gross beta	2 g	100 min	3	pCi/g
Uranium (delayed neutron)	2 g	20 s	0.2	$\mu g/g$

GLOSSARY OF TERMS

activation products — Radioactive products generated as a result of neutrons and other subatomic particles interacting with materials such as air, construction materials, or impurities in cooling water. These activation products are usually distinguished, for reporting purposes, from fission products.

ALARA — As low as reasonably achievable. The term that describes an approach to radiation exposure control or management whereby the exposures and resulting doses are maintained as far below the limits specified for the appropriate circumstances as economic, technical, and practical considerations permit.

alpha particle — A positively charged particle (identical to the helium nucleus) composed of two protons and two neutrons that are emitted during decay of certain radioactive atoms. Alpha particles are stopped by several centimeters of air or a sheet of paper.

ambient air — The surrounding atmosphere as it exists around people, plants, and structures. It is not considered to include the air immediately adjacent to emission sources.

aquifer — A saturated layer of rock or soil below the ground surface that can supply usable quantities of groundwater to wells and springs. Aquifers can be a source of water for domestic, agricultural, and industrial uses.

AEC — Atomic Energy Commission. A federal agency created in 1946 to manage the development, use, and control of nuclear energy for military and civilian applications. It was abolished by the Energy Reorganization Act of 1974 and was succeeded by the Energy Research and Development Administration (now part of the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission).

atom — Smallest particle of an element capable of entering into a chemical reaction.

background radiation — Ionizing radiation from sources other than the Laboratory. This radiation may include cosmic radiation; external radiation from naturally occurring radioactivity in the earth (terrestrial radiation), air, and water; internal radiation from naturally occurring radioactive elements in the human body; and radiation from medical diagnostic procedures.

beta particle — A negatively charged particle (identical to the electron) that is emitted during decay of certain radioactive atoms. Most beta particles are stopped by 0.6 cm of aluminum.

blank sample — A control sample that is identical, in principal, to the sample of interest, except that the substance being analyzed is absent. The measured value or signals in blanks for the analyte is believed to be caused by artifacts, and should be subtracted from the measured value. This process yields a net amount of the substance in the sample.

blind sample — A control sample of known concentration in which the expected values of the constituent are unknown to the analyst.

BOD — Biochemical (biological) oxygen demand. A measure of the amount of oxygen in biological processes that breaks down organic matter in water; a measure of the organic pollutant load. It is used as an indicator of water quality.

CAA — Clean Air Act. The federal law that authorizes the Environmental Protection Agency (EPA) to set air quality standards and to assist state and local governments to develop and execute air pollution prevention and control programs.

CERCLA — Comprehensive Environmental Response, Compensation, and Liability Act of 1980. Also known as Superfund, this law authorizes the federal government to respond directly to releases of hazardous substances that may endanger health or the environment. The EPA is responsible for managing Superfund.

CFR — Code of Federal Regulations. A codification of all regulations developed and finalized by federal government agencies in the *Federal Register*.

COC — Chain-of-Custody. A method for documenting the history and possession of a sample from the time of collection, through analysis and data reporting, to its final disposition.

contamination — The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or personnel.

controlled area — Any Laboratory area to which access is controlled to protect individuals from exposure to radiation and radioactive materials.

Ci — Curie. Unit of radioactivity. One Ci equals 3.70×10^{10} nuclear transformations per second.

cosmic radiation High-energy particulate and electromagnetic radiations that originate outside the earth's atmosphere. Cosmic radiation is part of natural background radiation.

DCG Derived Concentration Guide. The concentration of a radionuclide in air or water that, under conditions of continuous exposure for one year by one exposure mode (i.e., ingestion of water, submersion in air, or inhalation), would result in either an effective dose equivalent of 0.1 rem (1 mSv) or a dose equivalent of 5 rem (50 mSv) to any tissue, including skin and lens of the eye. The standards for radionuclides in air and water are given in DOE Order 5400.5.

DOE U.S. Department of Energy. The federal agency that sponsors energy research and regulates nuclear materials used for weapons production.

dose A term denoting the quantity of radiation energy absorbed.

dose, absorbed The energy imparted to matter by ionizing radiation per unit mass of irradiated material. (The unit of absorbed dose is the rad.)

dose, effective The hypothetical whole-body dose that would give the same risk of cancer mortality and serious genetic disorder as a given exposure but that may be limited to a few organs. The effective dose equivalent is equal to the sum of individual organ doses, each weighted by degree of risk that the organ dose carries. For example, a 100 mrem dose to the lung, which has a weighting factor of 0.12, gives an effective dose that is equivalent to $100 \times 0.12 = 12$ mrem.

dose, equivalent A term used in radiation protection that expresses all types of radiation (alpha, beta, and so on) on a common scale for calculating the effective absorbed dose. It is the product of the absorbed dose in rads and certain modifying factors. (The unit of dose equivalent is the rem.)

dose, maximum boundary The greatest dose commitment, considering all potential routes of exposure from a facility's operation, to a hypothetical individual who is in an uncontrolled area where the highest dose rate occurs. It assumes that the hypothetical individual is present 100% of the time (full occupancy), and it does not take into account shielding (for example, by buildings).

dose, maximum individual The greatest dose commitment, considering all potential routes of exposure from a facility's operation, to an individual at or outside the Laboratory boundary where the highest dose

rate occurs. It takes into account shielding and occupancy factors that would apply to a real individual.

dose, population — The sum of the radiation doses to individuals of a population. It is expressed in units of person-rem. (For example, if 1,000 people each received a radiation dose of 1 rem, their population dose would be 1,000 person-rem.)

dose, whole body — A radiation dose commitment that involves exposure of the entire body (as opposed to an organ dose that involves exposure to a single organ or set of organs).

dosimeter — A portable detection device for measuring the total accumulated exposure to ionizing radiation.

EA — Environmental Assessment. A report that identifies potentially significant environmental impacts from any federally approved or funded project that may change the physical environment. If an EA shows significant impact, an Environmental Impact Statement is required.

effluent — A liquid or gaseous waste discharge to the environment.

EIS — Environmental Impact Statement. A detailed report, required by federal law, on the significant environmental impacts that a proposed major federal action would have on the environment. An EIS must be prepared by a government agency when a major federal action that will have significant environmental impacts is planned.

environmental surveillance — The collection and analysis of samples of air, water, soil, foodstuffs, biota, and other media to determine environmental quality of an industry or community. It is commonly performed at sites containing nuclear facilities.

EPA — Environmental Protection Agency. The federal agency responsible for enforcing environmental laws. Although State regulatory agencies may be authorized to administer some of this responsibility, EPA retains oversight authority to ensure protection of human health and the environment.

exposure — A measure of the ionization produced in air by x or gamma radiation. (The unit of exposure is the roentgen).

external radiation — Radiation originating from a source outside the body.

fission products — Atoms created by the splitting of larger atoms into smaller ones accompanied by release of energy.

friable asbestos — Asbestos that is brittle or readily crumbled.

gallery — An underground collection basin for spring discharges.

gamma radiation — Short-wavelength electromagnetic radiation of nuclear origin that has no mass or charge. Because of its short wavelength (high energy), gamma radiation can cause ionization. Other electromagnetic radiation (such as microwaves, visible light, and radiowaves) has longer wavelengths (lower energy) and cannot cause ionization.

gross alpha — The total amount of measured alpha activity without identification of specific radionuclides.

gross beta — The total amount of measured beta activity without identification of specific radionuclides.

groundwater — A subsurface body of water in the zone of saturation.

H^3 — Tritium. A radionuclide of hydrogen with a half-life of 12.3 years. The very low energy of its radioactivity decay makes it one of the least hazardous radionuclides.

half-life, radioactive — The time required for the activity of a radioactive substance to decrease to half its value by inherent radioactive decay. After two half-lives, one-fourth of the original activity remains ($1/2 \times 1/2$), after three half-lives, one-eighth ($1/2 \times 1/2 \times 1/2$), and so on.

hazardous waste — Wastes exhibiting any of the following characteristics: ignitability, corrosivity, reactivity, or EP-toxicity (yielding toxic constituents in a leaching test). In addition, EPA has listed as hazardous other wastes that do not necessarily exhibit these characteristics. Although the legal definition of hazardous waste is complex, the term more generally refers to any waste that EPA believes could pose a threat to human health and the environment if managed improperly. Resource Conservation and Recovery Act (RCRA) regulations set strict controls on the management of hazardous wastes.

hazardous waste constituent — The specific substance in a hazardous waste that makes it hazardous and therefore subject to regulation under Subtitle C of RCRA.

HSWA — Hazardous and Solid Waste Amendments of 1984 to RCRA. These amendments to RCRA greatly expanded the scope of hazardous waste regulation. In HSWA, Congress directed EPA to take measures to further reduce the risks to human health and the environment caused by hazardous wastes.

hydrology — The science dealing with the properties, distribution, and circulation of natural water systems.

internal radiation Radiation from a source within the body as a result of deposition of radionuclides in body tissues by processes such as ingestion, inhalation, or implantation. Potassium 40, a naturally occurring radionuclide, is a major source of internal radiation in living organisms.

ion An atom or compound that carries an electrical charge.

isotopes Forms of an element having the same number of protons in their nuclei but differing in the number of neutrons.

- long-lived isotope - A radionuclide that decays at such a slow rate that a quantity of it will exist for an extended period (half-life is greater than three years).
- short-lived isotope - A radionuclide that decays so rapidly that a given quantity is transformed almost completely into decay products within a short period (half-life is two days or less).

J Joule. The unit for work and energy equal to one newton along a distance of one meter.

LDR Land Disposal Restrictions (land ban). A regulatory program that identifies hazardous wastes that are restricted from land disposal. The regulations incorporate a phasing-in of restrictions in three stages.

MCL Maximum Contaminant Level. Maximum permissible level of a contaminant in water that is delivered to the free-flowing outlet of the ultimate user of a public water system (see Appendix A and Table A-4). The MCLs are specified by the EPA.

Mixed waste Waste which contains a hazardous waste component regulated under Subtitle C of the RCRA, and a radioactive component consisting of source, special nuclear, or byproduct material regulated under the federal Atomic Energy Act (AEA).

mrem Millirem (10^{-3} rem). See rem definition. The dose equivalent that is one-thousandth of a rem.

NEPA National Environmental Policy Act. This federal legislation, passed in 1969, requires federal agencies to evaluate the impacts of their proposed actions on the environment prior to decision making. One provision of NEPA requires the preparation of an EIS by federal agencies when major actions significantly affecting the quality of the human environment are proposed.

NESHAP National Emission Standards for Hazardous Air Pollutants. These standards are found in the Clean Air Act; they set limits for such pollutants as beryllium and radionuclides.

nonpoint source Any nonconfined area from which pollutants are discharged into a body of water (e.g., agricultural runoff, construction runoff, and parking lot drainage).

NPDES National Pollutant Discharge Elimination System. This federal regulation, under the Clean Water Act, requires permits for discharges into surface waterways.

nuclide A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons, number of neutrons, and energy content; or alternately, by the atomic number, mass number, and atomic mass. To be a distinct nuclide, the atom must be capable of existing for a measurable length of time.

part B permit The second narrative section submitted by treaters, storers, or disposers of hazardous wastes in the RCRA permitting process. It covers in detail the procedures followed at a facility to protect human health and the environment.

PCBs Polychlorinated biphenyls. A family of organic compounds used since 1926 in electric transformers as insulators and coolants, in lubricants, carbonless copy paper, adhesives, and caulking compounds. They are also produced in certain combustion processes. PCBs are extremely persistent in the environment because they do not break down into new and less harmful chemicals. PCBs are stored in the fatty tissues of humans and animals through the bioaccumulation process. EPA banned the use of PCBs, with limited exceptions, in 1976. In general, PCBs are not as toxic in acute short-term doses as some other chemicals, although acute and chronic exposure can cause liver damage. PCBs have also caused cancer in laboratory animals. When tested, most people show traces of PCBs in their blood and fatty tissues.

PDL Public Dose Limit. The new term for RPS, a standard for external and internal exposure to radioactivity as defined in DOE Order 5400.5 (see Appendix A and Table A-1).

perched water A groundwater body above an impermeable layer that is separated from an underlying main body of groundwater by an unsaturated zone.

person-rem The unit of population dose that expresses the sum of radiation exposures received by a population. For example,

two persons, each with a 0.5 rem exposure, receive 1 person-rem, and 500 people, each with an exposure of 0.002 rem, also receive 1 person-rem.

pH — A measure of the hydrogen ion concentration in an aqueous solution. Acidic solutions have a pH less than 7, basic solutions have a pH greater than 7, and neutral solutions have a pH of 7.

point source — Any confined and discrete conveyance from which pollutants are discharged into a body of water (e.g., pipe, ditch, well, or stack).

ppb — Part per billion. A unit measure of concentration equivalent to the weight/volume ratio expressed as μg/L or ng/mL.

ppm — Part per million. A unit measure of concentration equivalent to the weight/volume ratio expressed as mg/L.

QA — Quality assurance. Any action in environmental monitoring to assure the reliability of monitoring and measurement data. Aspects of quality assurance include procedures, interlaboratory comparison studies, evaluations, and documentation.

QC — Quality control. The routine application of procedures within environmental monitoring to obtain the required standards of performance in monitoring and measurement processes. QC procedures include calibration of instruments, control charts, and analysis of replicate and duplicate samples.

R — Roentgen. A unit of radiation exposure that expresses exposure in terms of the amount of ionization produced by x rays in a volume of air. One roentgen (R) is 2.58×10^{-4} coulombs per kilogram of air.

rad — A unit of absorbed dose from ionizing radiation. A dose of 1 rad equals the absorption of 100 ergs of radiation energy per gram of absorbing material.

radiation — The emission of particles or energy as a result of an atomic or nuclear process.

radionuclide — An unstable nuclide capable of spontaneous transformation into other nuclides by changing its nuclear configuration or energy level. This transformation is accompanied by the emission of photons or particles.

RCRA — Resource Conservation and Recovery Act of 1976. RCRA is an amendment to the first federal solid waste legislation, the

Solid Waste Disposal Act of 1965. In RCRA, Congress established initial directives and guidelines for EPA to regulate hazardous wastes.

reagent — Any substance used in a chemical reaction to detect or measure another substance or to convert one substance into another by means of the reaction that it causes.

release — Any discharge to the environment. Environment is broadly defined as any water, land, or ambient air.

rem — The unit of radiation dose equivalent that takes into account different kinds of ionizing radiation and permits them to be expressed on a common basis. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the necessary modifying factors.

RPS — Radiation Protection Standards. See PDL.

SARA — Superfund Amendments and Reauthorization Act of 1986. This act modifies and reauthorizes CERCLA. Title III of this act is also known as the Emergency Planning and Community Right-to-Know Act of 1986.

SWMU — Solid Waste Management Unit. Any discernible unit at which solid wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous waste. Such units include any area at or around a facility at which solid wastes have been routinely and systematically released. Potential release sites include, for example, waste tanks, septic tanks, firing sites, burn pits, sumps, landfills (material disposal areas), outfall areas, LANL canyons, and contaminated areas resulting from leaking product storage tanks (including petroleum).

TCLP — Toxicity Characteristic Leaching Procedure. An analytical method designed to determine the mobility of both organic and inorganic compounds present in liquid, solid, and multiphase wastes. It is used to determine applicability of the LDR to a waste.

TDS — Total Dissolved Solids. The portion of solid material in a waste stream that is dissolved and passed through a filter.

terrestrial radiation — Radiation emitted by naturally occurring radionuclides such as ^{40}K; the natural decay chains of ^{235}U, ^{238}U, or ^{232}Th; or cosmic-ray-induced radionuclides in the soil.

TLD — Thermoluminescent dosimeter. A material (the Laboratory uses lithium fluoride) that, after being exposed to radiation,

luminesces upon being heated. The amount of light the material emits is proportional to the amount of radiation (dose) to which it was exposed.

TRU — Transuranic waste. Waste contaminated with long-lived transuranic elements in concentrations within a specified range established by DOE, EPA, and NRC. These are elements shown above uranium on the chemistry periodic table, such as plutonium, americium, and neptunium.

TSCA — Toxic Substances Control Act. TSCA is intended to provide protection from substances manufactured, processed, distributed, or used in the United States. A mechanism is required by the Act for screening new substances before they enter the marketplace and for testing existing substances that are suspected of creating health hazards. Specific regulations may also be promulgated under this Act for controlling substances found to be detrimental to human health and to the environment.

TSP — Total suspended particulates. Refers to the concentration of particulates in suspension in the air irrespective of the nature, source, or size of the particulates.

tuff — Rock of compacted volcanic ash and dust.

uncontrolled area — An area beyond the boundaries of a controlled area (see controlled area in this glossary).

uranium, depleted — Uranium consisting primarily of ^{238}U and having less than 0.72 wt % ^{235}U. Except in rare cases, depleted uranium is manmade.

uranium, total — The amount of uranium in a sample, assuming that the uranium has the isotopic content of uranium in nature (99.27 wt % ^{238}U, 0.72 wt % ^{235}U, and 0.0057 wt % ^{234}U).

UST — Underground storage tank. A stationary device designed to contain petroleum products or hazardous materials. A tank is constructed primarily of nonearthen material and 10% or more of the volume of the tank system is below the surface of the ground.

vadose zone — The partially saturated or unsaturated region above the water table that does not yield water to wells.

VOC — Volatile organic compound. Liquid or solid organic compounds that have a tendency to spontaneously pass into the vapor state.

water table — The water level surface below the ground at which the unsaturated zone ends and the saturated zone begins. It is the level to which a well that is screened in the unconfined aquifer would fill with water.

water year — October through September.

watershed — The region draining into a river, river system, or body of water.

wetland — A lowland area, such as a marsh or swamp, that is inundated or saturated by surface water or groundwater sufficient to support hydrophytic vegetation typically adapted for life in saturated soils.

wind rose — A diagram that shows the frequency and intensity of wind from different directions at a particular place.

WLM — Working level month. A unit of exposure to ^{222}Rn and its decay products. Working level (WL) is any combination of the short-lived ^{222}Rn decay products in 1 L of air that will result in the emission of 1.3×10^5 MeV potential alpha energy. At equilibrium, 100 pCi/L of ^{222}Rn corresponds to 1 WL. Cumulative exposure is measured in working level months, which is 170 WL-h.

worldwide fallout — Radioactive debris from atmospheric weapons tests that has been deposited on the earth's surface after being airborne and cycling around the earth.

ACRONYMS AND ABBREVIATIONS

ADO	Associate Director for Operations
AEA	Atomic Energy Act of 1954
AEC	Atomic Energy Commission
AGL	above ground level
AIP	Agreement in Principle
AL	Albuquerque Operations Office (DOE)
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
AO	Administrative Order
AQCA	Air Quality Control Act (New Mexico)
AQCR	Air Quality Control Regulation (New Mexico)
ASL	above sea level
BIA	Bureau of Indian Affairs
BOD	biochemical oxygen demand
BRET	Biological Resource Evaluation Team (EM-8)
Btu	British thermal unit
CA	corrective activities
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAI	controlled-air incinerator
CEARP	Comprehensive Environmental Assessment and Response Program
CEI	Comprehensive Evaluation Inspection
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CGS	Canadian Geologic Survey
CHIEF	Clearinghouse Inventory of Emission Factors
CMI	corrective measures implementation
CMR	Chemistry-Metallurgical Research (LANL building)
CMS	corrective measures study
COC	chain-of-custody
COD	chemical oxygen demand

CSU	Colorado State University
CWA	Clean Water Act
CY	calendar year
D&D	decontamination and decommissioning
DAC	Derived Air Concentration Guide for Controlled Areas (DOE)
DCG	Derived Air Concentration Guide for Uncontrolled Areas (DOE)
DEC	DOE Environmental Checklist
DoD	Department of Defense
DOE	Department of Energy
DOE/AL	DOE/Albuquerque Operations Office
DOE/HQ	DOE Headquarters
DOE/HQ-EH	DOE Headquarters, Environment & Health
DOE/HQ-EM	DOE Headquarters, Environmental Management
DOE/LAAO	DOE/Los Alamos Area Office
DOT	Department of Transportation
DREF	dose rate effectiveness factor
EA	Environmental Assessment
EES	Earth and Environmental Sciences (LANL Division)
EES-1	Geology and Geochemistry Group
EES-3	Geophysics Group
EIS	Environmental Impact Statement
EM	Environmental Management (LANL Division)
EM-DO	Environmental Management Division Office
EM-7	Waste Management Group
EM-8	Environmental Protection Group
EM-9	Environmental Chemistry Group
EM-13	Environmental Restoration Group
EMSL-CI	Environmental Monitoring and Support Laboratory - Cincinnati
ENG	Facilities Engineering (LANL Division)
ENG-2	Facilities Engineering Planning Group
ENG-6	Engineering Maintenance Group
EO	Executive Order
EPA	Environmental Protection Agency
ER	Environmental Restoration Program

ERDA	Energy, Research, and Development Administration
ES	environmental survey
ES&H	Environment, Safety, and Health
FFCA	Federal Facilities Compliance Agreement
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FONSI	Finding of No Significant Impact
FS	feasibility study
FUSRAP	Formerly Utilized Sites Remedial Action Program
FY	fiscal year
GC	gas chromatography
GC/MS	gas chromatography/mass spectrometry
GET	General Employee Training
GIS/HEC	Geographic Information System and computer modeling
GSA	General Services Administration
HE	high-explosive
HEPA	high-efficiency particulate air (filter)
HQ	DOE Headquarters
HS	Health and Safety (LANL Division)
HS-DO	Health Safety Division Office
HS-3	Risk Management Support Group
HS-4	Health Physics Measurements Group
HS-5	Industrial Hygiene and Safety Group
HS-12	Health Physics Policy and Programs Group
HSWA	Hazardous and Solid Waste Amendments
HW	hazardous waste
HWA	Hazardous Waste Act (New Mexico)
HWMR	Hazardous Waste Management Regulations (New Mexico)
ICPMS	inductively coupled plasma mass spectrometry
ICRP	International Commission on Radiological Protection
IH	Industrial Hygiene
INC-7	Isotope Geochemistry Group (LANL)
JCI	Johnson Controls Inc.
JENV	JCI Environmental

LAAO	Los Alamos Area Office
LAMPF	Los Alamos Meson Physics Facility (a.k.a. Clinton P. Anderson Meson Physics Facility - LANL building)
LANL	Los Alamos National Laboratory (or the Laboratory)
LDR	land disposal restrictions
LERC	Laboratory Environmental Review Committee
LET	linear-energy-transfer
LLW	low-level waste
LOD	limit of detection
LOQ	limit of quantification
MAP	mixed activation product
MCL	maximum contaminant level
MDA	minimum detectable amount (activity)
MDL	minimum detection limit
MOU	Memorandum of Understanding
MS	mass spectrometry
NAAQS	National Ambient Air Quality Standard
NADP	National Atmospheric Deposition Program
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NENIX	Northern New Mexico Information Exchange
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NHPA	National Historic Preservation Act
NIOSH	National Institute of Occupational Safety and Health
NIST	National Institute of Standards and Technology
NMED	New Mexico Environment Department
NMEIB	New Mexico Environmental Improvement Board
NMEID	New Mexico Environmental Improvement Division (See NMED)
NMHWA	New Mexico Hazardous Waste Act
NMOCD	New Mexico Oil Conservation Division
NMWQCA	New Mexico Water Quality Control Act
NMWQCC	New Mexico Water Quality Control Commission
NMWQCCR	New Mexico Water Quality Control Commission Regulations

NOI	Notice of Intent
NOV	Notice of Violation
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NSPS	New Source Performance Standards
NWI	National Wetland Inventory
OHL	Occupational Health Laboratory (LANL building)
OSHA	Occupational Safety and Health Act
OU	operable unit
PA	performance assessment
PA-3	Community Relations Group (LANL)
PA/SI	preliminary assessment/site inspection
PAT	purge-and-trap gas chromatography/mass spectrometry
PCB	polychlorinated biphenyl
PCOC	Pest Control Oversight Committee (LANL Committee)
PDL	public dose limit
ppb	parts per billion
ppm	parts per million
PSD	Prevention of Significant Deterioration
QA	quality assurance
QAP	Quality Assurance Program
QAPP	Quality Assurance Program Plan
QC	quality control
R&D	research and development
RA	remedial action
RAPS	Regulated Air Pollutants System
RCG	Radioactivity Concentration Guide
RCRA	Resource Conservation and Recovery Act
RFA	RCRA facility assessment
RFI	RCRA facility investigation
RFP	Request for Proposal
RI	remedial investigation
RI/FS	remedial investigation/feasibility study

ROD	Record of Decision
RPS	Radiation Protection Standard
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SEN	Secretary of Energy Notice
SHPO	State Historic Preservation Officer (New Mexico)
SLD	Scientific Laboratory Division (New Mexico)
SOP	standard operating procedure
SPCC	Spill Prevention Control and Countermeasures
SRF	Size Reduction Facility
SRM	standard reference material
SRS	Savannah River Site
SUPERFUND	See CERCLA and SARA
SWSC	Sanitary Wastewater Systems Consolidation
SWDA	Solid Waste Disposal Act
SWMU	solid waste management unit
TA	Technical Area
TAP	toxic air pollutant
TCE	trichlorethylene
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
THM	trihalomethane
TLD	thermoluminescent dosimeter
TOC	total organic carbon
TOX	total organic halides (or halogens)
TRU	transuranic waste
TSCA	Toxic Substances Control Act
TSD	treatment, storage, and disposal
TSP	total suspended particulate matter
TSS	total suspended solids
TSTA	Tritium Systems Test Assembly
TU	tritium unit
UC	University of California
USC	United States Code

USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UST	underground storage tank
UV	ultraviolet
VOC	volatile organic compound
WL	working level
WLM	Working Level Month
WM	Waste Minimization
WM	Waste Management

Symbols for the Chemical Elements and Compounds

Actinium	Ac
Aluminum	Al
Americium	Am
Antimony	Sb
Argon	Ar
Arsenic	As
Astatine	At
Barium	Ba
Berkelium	Bk
Beryllium	Be
Bismuth	Bi
Boron	B
Bromine	Br
Cadmium	Cd
Calcium	Ca
Californium	Cf
Carbon	C
Cerium	Ce
Cesium	Cs
Chlorine	Cl
Chromium	Cr
Cobalt	Co
Copper	Cu
Curium	Cm
Dysprosium	Dy
Einsteinium	Es
Erbium	Er
Europium	Eu
Fermium	Fm
Fluorine	F
Francium	Fr
Gadolinium	Gd
Gallium	Ga
Germanium	Ge
Gold	Au
Hafnium	Hf
Helium	He
Holmium	Ho
Hydrogen	H
Hydrogen Oxide	H^2O
Indium	In
Iodine	I
Iridium	Ir
Iron	Fe
Krypton	Kr
Lanthanum	La
Lawrencium	Lr (Lw)
Lead	Pb
Lithium	Li
Lithium fluoride	Lif
Lutetium	Lu
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Mercury	Hg
Molybdenum	Mo
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Neon	Ne
Neptunium	Np
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Niobium	Nb
Nitrogen	N
Nitrogen dioxide	N0
Nobelium	No
Osmium	Os
Oxygen	O
Palladium	Pd
Phosphorus	P
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Plutonium	Pu
Polonium	Po
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Promethium	Pm
Protactinium	Pa
Radium	Ra
Radon	Rn
Rhenium	Re
Rhodium	RH
Rubidium	Rb
Ruthenium	Ru
Samarium	Sm
Scandium	Sc
Selenium	Se
Silicon	Si
Silver	Ag
Sodium	Na
Strontium	Sr
Sulfur	S
Tantalum	Ta
Technetium	Te
Tellurium	Te
Terbium	Tb
Thallium	Tl
Thorium	Th
Thulium	Tm
Tin	Sn
Titanium	Ti
Tritiated water	HT0
Tritium	H^3
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Aerial
Agenda
Agreement
AIP (Agreement in Principle
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EIS (Environmental Impact Statement)
Electrical
Emission
Engineering
Environmental
EOD (Explosive Ordnance Disposal)
EPA (Environmental Protection Agency)
Equipment
ERDA (Energy Research and Development Administration)
Erosion
ERPO (Environmental Restoration Program Office)
ES&H (Environment, Safety, and Health)
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MSA (Major System Acquisition)

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NFA (No Further Action)
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NMED (New Mexico Environment Department)
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Nonradioactive
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NRC (Nuclear Regulatory Commission)
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QP (Quality Procedure)
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Scope
Scrap
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Scrubber
Search
Security
Seep
Semivolatile
Septic
Sewer
Shaft
Sheet
Shell
Shot
Silver
Site
Sludge
Soil
Solid
Solvent
SOP (Standard Operating Procedure)
SOW (Statement of Scope of Work)
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Spill
Stack
Standard
Statistics
Status
Steamline
Steel
Storage
Strontium
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Tuballoy
Tuff

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Uranium
Urine
USGS (United States Geological Survey)
UST (Underground Storage Tank)
Utility

Validation
Variance
VE (Value Engineering)
Ventilation
Verification
Volatile
Volume

Warehouse
Waste
Water
WBS (Work Breakdown Structure)
Weapon
Well
Work
Working Group

Zinc

Spell et al. 1990, 0607

Journal of Volcanology and Geothermal Research, 43 (1990) 175–193
Elsevier Science Publishers B.V., Amsterdam

1

$^{40}Ar/^{39}Ar$ dating of the Bandelier Tuff and San Diego Canyon ignimbrites, Jemez Mountains, New Mexico: temporal constraints on magmatic evolution

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Abstract

Spell, T.L., Harrison, T.M. and Wolff, J.A., 1990. $^{40}Ar^{39}Ar$ dating of the Bandelier Tuff and San Diego Canyon ignimbrites, Jemez Mountains, New Mexico: temporal constraints on magmatic evolution. *J. Volcanol. Geotherm. Res.*, 43: 175–193.

The *Jemez Mountains volcanic field* (JMVF), located in north-central New Mexico, has been a site of basaltic to rhyolitic volcanism since the mid-Miocene with major caldera forming eruptions occurring in the Pleistocene. Eruption of the upper Bandelier Tuff (UBT) is associated with collapse of the Valles Caldera, whereas eruption of the lower Bandelier Tuff (LBT) resulted in formation of the Toledo Caldera. These events were previously dated by K-Ar at 1.12 ± 0.03 Ma and 1.45 ± 0.06 Ma, respectively. Pre-Bandelier explosive eruptions produced the San Diego Canyon (SDC) ignimbrites. SDC ignimbrite "B" has been dated at 2.84 ± 0.07 Ma, whereas SDC ignimbrite "A", which underlies "B", has been dated at 3.64 ± 1.64 Ma. Both of these dates are based on single K-Ar analyses.

$^{40}Ar/^{39}Ar$ dating of single sanidine crystals from these units indicates revision of the previously reported dates. Isochron analysis of 26 crystals from the UBT gives a common trapped $^{40}Ar/^{36}Ar$ component of 304.5, indicating the presence of excess ^{40}Ar in this unit, and defines an age of 1.14 ± 0.02 Ma. Isochron analysis of 26 crystals from the LBT indicates an atmospheric trapped component and an age of 1.51 ± 0.03 Ma. An age of 1.78 ± 0.04 Ma, based on the weighted mean of 5 individual analyses, is indicated for SDC ignimbrite "B", whereas 3 analyses from SDC ignimbrite "A" give a weighted mean age of 1.78 ± 0.07 Ma. Evidence for xenocrystic contamination in the SDC ignimbrites comes from analyses of a correlative air-fall pumice unit in the Puye Formation alluvial fan giving ages of 1.75 ± 0.08 and 3.50 ± 0.09 Ma. The presence of xenocrysts in bulk separates used for the original K-Ar analyses could account for the significantly older ages reported.

Geochemical data indicate that SDC ignimbrites are early eruptions from the magma chamber which evolved to produce the LBT, as compositions of SDC ignimbrite "B" are virtually identical to least evolved LBT samples. Differentiation during the 270-ka interval between eruption of SDC ignimbrite "B" and the LBT produced an array of high-silica rhyolite compositions which were erupted to form the LBT. Mixed pumices associated with eruption of the LBT indicated an influx of more mafic magma into the system which produced shifts in some incompatible trace-element ratios. Lavas and tephras of the Cerro Toledo Rhyolite record the geochemical evolution of the Bandelier magma system during the 370-ka interval between eruption of the LBT and the UBT.

The combined geochronologic and geochemical data place the establishment and evolution of the

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Tuff

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UST (Underground Storage Tank)
Utility

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Variance
VE (Value Engineering)
Ventilation
Verification
Volatile
Volume

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Waste
Water
WBS (Work Breakdown Structure)
Weapon
Well
Work
Working Group

Zinc

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 91, NO. B2, PAGES 1779–1798, FEBRUARY 10, 1986

Explosive Rhyolitic Volcanism in the Jemez Mountains: Vent Locations, Caldera Development and Relation to Regional Structure

STEPHEN SELF,[1] FRASER GOFF,[2] JAMIE N. GARDNER,[2] JOHN V. WRIGHT,[3] AND WILLIAM M. KITE[4]

Received by ER-RPF
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The Jemez volcanic field straddles the western margin of the Rio Grande rift where the rift is intersected by the Jemez lineament in north central New Mexico. The field has a record of volcanism extending back to before 13 Ma. Initial basaltic activity was related to active rifting, with minor rhyolitic eruptions occurring along N-S rift-bounding faults. Between 10 and 7 Ma, voluminous andesitic volcanism took place in the central Jemez Mountains area, overwhelming contemporaneous basaltic and rhyolitic magmatism. An apparent tectonic lull took place from 7 to 4 Ma, accompanied by lower eruption rates. During this interval, dacitic magmas were erupted to form the Tschicoma volcanic center, but mafic and rhyolitic volcanism virtually ceased. Since 4 Ma, accompanying resumption of rifting, a growing silicic magma system has been present under the central part of the Jemez Mountains, ultimately evolving to the magma body that produced the voluminous rhyolitic Bandelier tuffs. Explosive rhyolitic eruptions from this large magma body have occurred many times since 3 to 4 Ma. Early eruptions, 3.6–2.8 Ma, produced high-silica rhyolite ignimbrites restricted to the southwest part of the Jemez Mountains; formation of these units may have been accompanied by caldera collapse. These events were followed by the two caldera-forming Bandelier Tuff ignimbrite eruptions, 1.45 and 1.12 Ma. Post caldera explosive and effusive rhyolite eruptions have also tapped the magma body from vents generally located along ring fractures after both Bandelier events. Vent and caldera locations for the rhyolitic eruptions during 3–4 Ma have been inferred from grain size characteristics, dispersal patterns, and facies variations in the Plinian deposits and ignimbrites. Lithic breccia zones of the pre-Bandelier ignimbrites indicate possible caldera sources in the southwest part of the present Valles caldera. During the eruption of both Bandelier tuffs, initial plinian falls and early pyroclastic flows emanated from vents centrally located in the Jemez Mountains. In the lower Bandelier Tuff eruption a transition to ring fracture vents occurred before the emission of later pyroclastic flows, but there is no strong evidence to suggest such a transition occurred during the upper Bandelier eruption. Calderas associated with the lower and upper Bandelier tuffs (Toledo and Valles, respectively) are almost identical in location, as are the Plinian vent sites for these two large eruptions. The Toledo embayment, northeast of the Valles caldera, contains lava domes from up to 3.6 Ma and may be a caldera or crater associated with early explosive dacitic volcanism in the Tschicoma volcanic center. Post-1.4 Ma lava domes also fill this depression. The main volcanic features of the Jemez Mountains field, including the Valles caldera complex, eruption vents, and the apical graben of the post-Valles-Redondo resurgent block, appear to be aligned along the NE-SW trending Jemez fault zone. This zone, the local expression of a Precambrian basement feature (the Jemez lineament), has exerted strong control on the location and style of eruptions from the Bandelier rhyolitic magma system.

INTRODUCTION

The Jemez Mountains volcanic field of New Mexico is located at the intersection of the western margin of the north-south trending Rio Grande rift and the northeast trending Jemez lineament (Figure 1). The field contains one of three recently active silicic resurgent caldera systems in the continental United States, the Valles Caldera. This caldera was created by a series of catastrophic ignimbrite eruptions, the most recent of which formed the Tshirege Member of the Bandelier Tuff (here called the Upper Bandelier Tuff, UBT) at about 1.12 Ma [*Smith and Bailey*, 1966; *Doell et al.*, 1968; *Izett et al.*, 1981]. An earlier ignimbrite eruption formed the 1.45 Ma Otowi Member of the Bandelier Tuff (Lower Bandelier Tuff, LBT), accompanied by formation of the older Toledo caldera [*Smith et al.*, 1970]. These two rhyolitic, ignimbrite-forming eruptions are regarded as the culminating phase of volcanism within the Jemez Mountains volcanic field [*Smith*, 1979]. The Valles caldera and its associated rocks are best known from the pioneering work of R. L. Smith, R. A. Bailey, and C. S. Ross on ring-dike emplacement, formation of resurgent calderas, and eruption of compositionally zoned ignimbrite sheets [*Smith et al.*, 1961; *Smith and Bailey*, 1966, 1968]. For these reasons, many geologists consider it to be the "type" resurgent caldera. The volcanic history of the Jemez Mountains field is quite diverse and long-lived; it has produced voluminous mafic, intermediate, and silicic pyroclastic rocks, lava flows, and domes almost continuously since 13 Ma [*Bailey et al.*, 1969; *Smith et al.*, 1970; *Gardner*, 1982, 1983; *Gardner and Goff*, 1984; *Gardner et al.*, this issue].

The Valles caldera is also a major target for geothermal resource development due to its recent volcanic activity (most rhyolites as young as 0.1 Ma [*Doell et al.*, 1968]) and hot springs. A neutral chloride liquid-dominated geothermal system at temperatures of 260°-330°C [*Dondanville*, 1978] has been extensively drilled by Union Oil Company beneath the apical graben in the resurgent dome. Exploration by both private and public organizations continues today [*Laughlin*, 1981; *Goff and Grigsby*, 1982]. Because of the high conductive heat flow associated with the caldera, the first Hot Dry Rock geothermal system has been engineered in the Precambrian basement underlying the west flank of the Jemez Mountains [*Heiken and Goff*, 1983]. Recently, the Valles caldera has been considered to be a prime candidate as a site for the Continental Scientific Drilling Program (CSDP) [*Riecker*, 1983; *Goff et al.*, 1984*b*] which proposes to drill into an active magma-hydrothermal system to study the roots of the heat transfer zone between crystallizing magma and overlying convecting hot waters. The first CSDP shallow hole has been drilled in the southwesternmost zone of the Valles caldera, and it penetrated several of the ignimbrites discussed herein [*Goff et al.*, this issue].

In this paper we summarize recently acquired data on the

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ORIGINATOR NAME: Bruce J. MacFadden ORGANIZATION: —

SYMBOL: — DOCUMENT DATE: 6/30/77

SUBJECT/TITLE: American Journal of Science "Magnetic Polarity Stratigraphy of the Chamita Formation Stratotype (Mio-Pliocene) of North-Central New Mexico

RECORD TYPE (Circle relevant type for primary record; type of attachments should be selected on *Keywords List*):

Analytical Data	Excerpt	Map	Procedure	Summary
Article	FAX	Memo	Purchase Request	Table
Chain-of-Custody	Figure	Microform	Receipt Acknowledgment	Telephone Record
Chart	Form	Notebook	Report	TOC
Computer Output	Interview	Outline	Review	Transcription
Contract	Letter	Personal Notes	Sow	Video
Controlled Distribution	List	Photo	Study	Work Plan
Drawing	Logbook	Plan		Other

RECORD CATEGORY: P
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RECORD LOCATION: —
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E)_____ TO:_____ FROM:_____ SYMBOL:_____

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SUBJECT:_____

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DATED:_____

G)_____ TO:_____ FROM:_____ SYMBOL:_____

SUBJECT:_____

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DATED:_____

ENVIRONMENTAL RESTORATION
Records Processing Facility
ER Record Index Form

ER Records Detail Index Form for ER Record I.D. # 21569

DETAIL INDEX: Complete all fields; indicate if not applicable or appropriate; please write legibly.

TECH AREA(S)	ADS NO(S)	STRUCTURE NO(S)/MDA	SWMU/PRS NO(S)
LIST RELEVANT TECH AREA(S).	LIST RELEVANT ADS NO(S)	LIST RELEVANT STRUCTURE NO(S).	LIST RELEVANT SWMU NO(S)/PRS.
—	1129	—	—

DOCUMENT TO	ORIGINATOR NAMES
LIST RELEVANT RECIPIENTS.	LIST MULTIPLE ORIGINATORS.
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CORRECTION (Y/N) _____ CORRECTION #: _____

CORRECTION DESCRIPTION: _____

KEYWORDS: Circle relevant KEYWORDS from the list below for ER Record #: 21569

MISCELLANEOUS (List other indexing criteria as necessary; please write legibly):
OU 1129, Journal, Science, Magnetic, Polarity, Stratigraphy

Abandon
Aboveground Tank
Absorption
Abstract
Accelerator
Access
Accident
Acid
Active
Activities
Administrative
ADS (Activity Data Sheet)
Adsorption
AEC (Atomic Energy Commission)
Aerial
Agenda
Agreement
AIP (Agreement in Principle)
Air
Alpha
Americium
Analysis
Analytical
AOC (Area of Concern)
Approval
Aquifer
ARAR (Applicable, Relevant, or Appropriate Requirements)
Archaeology
Archive
Area
Arsenic
Asbestos
Asphalt
Assessment
Audit
.....
Backfill
Background
Bacteria
Barium
Baseline
BCP (Baseline Change Proposal)
Beds
Bermed Area
Beryllium
Beta
Biology
Blivit
Boiler
Boneyard
Bunker
Buried
Burn
.....
Cadmium
Caisson
Calibration
CAMU (Corrective Action Management Unit)
Canyon
Capacitor
Caustic
CEARP (Comprehensive Environmental Assessment and Response Program)
Cement
CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act)
Certification
Cesium
Chain of Custody
Chamber
Change Control
Change Order
Charge
Chart
Checklist
Chemical
Chromium
Cleanup
Clearance
Closure
Clothing
CMI/RA (Corrective Measures Implementation/Remedial Action)
CMS/FS (Corrective Measures Study/ Feasibility Study)
Cobalt
Comment
Committee
Community Relations
Company
Compliance
Compressed Gas
Computer Modeling
Computer Output
Concern
Concrete
Concurrence
Configuration
Construction
Container
Containment
Contaminant
Contract
Control
Controlled Distribution
Copper
Core
Corrective Action
Correspondence
Criteria
Cyanide
Cyanogen
.....
Data
Deadline
Debris
Decision Analysis
Decommission
Decontamination
Deficiency
Deliverable
Demolition
Description
Detection
Detonation
Development
Diesel
Discharge
Disposal
Documentation
DOE (Department of Energy)
Dose
DQO (Data Quality Objectives)
Draft
Drainage
Drainline
Drawing
Drilling
Drop Tower
Drum
Dry Well
Dump
.....
Ecology
Effluent
EIS (Environmental Impact Statement)
Electrical
Emission
Engineering
Environmental
EOD (Explosive Ordnance Disposal)
EPA (Environmental Protection Agency)
Equipment
ERDA (Energy Research and Development Administration)
Erosion
ERPO (Environmental Restoration Program Office)
ES&H (Environment, Safety, and Health)
Estimate
Evacuation
Evaluation
Evaporator
Evidence
Excavation
Exclusion
Exhaust
Experiment
Explosive
Exposure
Extension
Extraction
.....
Facility
Fallout
Farm
FAX
Fence
Field
Figure
Filter
FIMAD (Facility for Information Management, Analysis, and Display)
Finding
Fire
Firing Site
Fiscal
Fission
Five-Year Plan
Flow
Flow chart
Fluid
Form
Framework
Fuel
Fume
.....
Gamma
Gas
Generation
Generic
Geochemistry
Geology
Geophysics
Glass Beaker
Glove Box
Graph
Guidance
Gun
.....
Handling
Hazardous
Headquarters
Health
HE (High Explosive)
History
HMTA (Hazardous Material Transportation Act)
Hole
Home Owner
Hood
HSWA (Hazardous and Solid Waste Amendments)
Hydrology
Hygiene
.....
Impact
Implementation
Implosion
Impoundment
Inactive
Incident
Incinerator
Industrial
Infiltration
Injection Well
Injury
Inorganic
Inspection
Installation
Interim
Interim Action
Internal
Interview
Inventory
Investigation
IRM (Interim Remedial Measure)
Isotope
IWP (Installation Work Plan)
.....

Lab Job
Laboratory
Lagoon
Land
Landfill
Laundry
Leach
Lead
Leak
Legal
Letter
Limit
Lines
Liquid
List
Location
Log
Logbook

Magazine
Management
Manhole
Map
Material
MDA (Material Disposal Area)
Media
Meeting
Memo
Mercury
Metal
Microform
Minimization
Minutes
MIS (Management Information System)
Mixed Waste
MOA (Memo of Agreement)
Model
Modification
Money (Allocation, Appropriation, Budget, Cost, Funding, etc.)
Monitoring
Monthly Report
Mortar Impact Area
MOU (Memo of Understanding)
MSA (Major System Acquisition)

NEPA (National Environmental Policy Act)
NFA (No Further Action)
Nickel
Nitrate
NMED (New Mexico Environment Department)
NMEID (New Mexico Environmental Improvement Division)
NOD (Notice of Deficiency)
Nonexplosive
Nonradioactive
Notebook
Notification
NPDES (National Pollutant Discharge Elimination System)
NRC (Nuclear Regulatory Commission)
Nuclear

Observation
Off-gas
Oil
Open
Open Burning
Operation
Order
Organic
Organization
OSHA (Occupational Safety & Health Administration)
OSR (Operational Safety Requirements)
OU (Operable Unit)
Outfall
Outline

Pad
PA/RFA (Preliminary Assessment /RCRA Facility Assessment)
PCB (Polychlorinated Biphenyl)
Permit
Personal Notes
Personnel
Personnel Qualification
Photo
Pilot Study
Pipe
Pit
Plan
Plant
Plutonium
Point-of-Contact
Pollution
Polonium
Polaroid
Potential
Prevention
Priority
Procedure
Program
Programmatic
Project
Project Leader
Propellant
Property
Proposal
Protection
Protocol
PRS (Potential Release Site)
Public
Pump
Purchase Request

QA (Quality Assurance)
QP (Quality Procedure)
Quality
Quarterly Report

Radioactive
Radiochemistry
Radionuclide
Radium
Rationale
RCRA (Resource, Conservation, and Recovery Act)
Reactor
Receipt Acknowledgment
Recommendation
Reconnaissance
Records
Recovery
Recycle
Reduction
Reference
Regulation
Release
Remediation
Removal
Report
Request
Requirements
Research
Resin Bed
Resolution
Resource
Respirator
Response
Restoration
Restriction
Results
Review
Revision
RFI/RI (RCRA Facility Investigation/Remedial Investigation)
Risk
RPF (Records-Processing Facility)

Safety
Salamander
Salvage
Sample
Sampling Plan
Sanitary
Satellite
Schedule
Scope
Scrap
Scrap Detonation Site
Screening
Scrubber
Search
Security
Seep
Semivolatile
Septic
Sewer
Shaft
Sheet
Shell
Shot
Silver
Site
Sludge
Soil
Solid
Solvent
SOP (Standard Operating Procedure)
SOW (Statement of Scope of Work)
Specific
Spill
Stack
Standard
Statistics
Status
Steamline
Steel
Storage
Strontium
Structure
Study
Subcontractor
Subsurface
Summary
Sump
Support
Surface
Surveillance
Survey
Swipe
SWMU (Solid Waste Management Unit)
System

Table
Tank
Task
TCLP (Toxicity Characteristic Leaching Procedure)
TDD (Technical Document Description)
Technical
Technical Team
Technology
Telephone Record
Test Area
Testing
TLD (Thermoluminescent Dosimeter)
TOC (Table of Contents)
Townsite
Toxic
Tracking
Training
Transcription
Transfer
Transformer
Transmittal
Transport
Treatment
Trench
Trip Report
Tritium
TRU (Transuranic)
TSCA (Toxic Substances Control Act)
Tuballoy
Tuff

Underground
Update
Uranium
Urine
USGS (United States Geological Survey)
UST (Underground Storage Tank)
Utility

Validation
Variance
VE (Value Engineering)
Ventilation
Verification
Volatile
Volume

Warehouse
Waste
Water
WBS (Work Breakdown Structure)
Weapon
Well
Work
Working Group

Zinc

(31)

istry; edited by J. D. BURTON and P. S. LISS. P. xii, lon, 1976 (Academic Press, $17.50).—This book con- lly extended and revised" texts of lectures presented arine chemistry held in London in May, 1974. The rize . . . knowledge of the major aspects of estuarine Burton introduces the subject of estuarine chemistry. ter each is devoted to sedimentary processes (S. R. en), organic processes (P. C. Head), the behavior of mixing (Liss), heavy metals (A. J. de Groot, W. ma), and radioactive tracers (E. K. Duursma). The is a case study on the Firth of Clyde (D. W. Mackay land); this alone appears to expose a substantial but with no broader aim than to describe conditions system.

ocesses of geochemical interest occur in estuarine and e environment generally. In the short-term the chemi- iological turmoil of the mixing zone causes elements mical speciation and/or phase distribution from that e continental inputs. Over some longer, but poorly- nearshore environments may trap some fraction of the efore it can reach the deep sea: for example, estuarine diment in drowned river-valleys during interglacials. esses are related, except in research, which has largely n short-term phenomena.

ption noted above the chapters in this volume are iews of work published elsewhere. Since most of the ed on processes internal to estuaries, no sense of the material-balance question is conveyed. I find this to be . Otherwise the reviews are of mixed quality. The task literature has evidently not led the contributors to new problems in estuarine chemistry nor to startling solution of the old ones. This volume will therefore or its references to the original literature. Inevitably misstatements and incomplete representation of their l radionuclides, for instance, are only perfunctorily s, the scope of the book is sufficient that most readers references worth pursuing. American readers will ap- ous references to, and examples from, the European

LARRY BENNINGER

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SUMMER 1977

MAGNETIC POLARITY STRATIGRAPHY OF THE CHAMITA FORMATION STRATOTYPE (MIO-PLIOCENE) OF NORTH-CENTRAL NEW MEXICO

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Yale University, New Haven, Connecticut 06520

ABSTRACT. The Chamita Formation stratotype (uppermost Santa Fe Group) consists of 569 m of poorly indurated fluviatile clayey silts, silts, sands and gravels. Two informal units termed "lower tuffaceous zone" and "upper tuffaceous zone," which extend from 120 to 180 m and 320 to 360 m, respectively, are rich in air-fall and reworked volcaniclastic sediments. A minimum of 3 samples were collected from the fine-grained sediments for each of 135 sites spaced at a maximum stratigraphic interval of 7 m throughout the stratotype. Based on preliminary alternating field demagnetization studies, all specimens were routinely demagnetized in fields of at least 150 oersteds. Some specimens required further demagnetization in fields of up to 500 oersteds. Curie Point temperature determinations, which range from 555° to 580°C for 5 specimens, show that the remanence is probably carried by an iron-rich member of the titanomagnetite solid solution series as detrital remanent magnetization.

Based principally on 111 statistically significant sites, the stratotype consists of 2 magnetic polarity zones designated as "N1-N6". Two previously published fission-track dates, one each from the lower and upper tuffaceous zones, and fossil mammals provide the independent control for the correlation of this magnetic polarity zonation to the worldwide magnetic polarity time scale. The mammalian assemblage from the stratotype consists of at least 19 taxa mostly concentrated at 325 m above the base. This fauna is similar to other late Hemphillian (late Miocene-early Pliocene) mammalian assemblages, for example, the Coffee Ranch Local Fauna from the Hemphillian stratotype.

Magnetic polarity zones N1 to N3, which extend from the base of the stratotype to 285 m, are predominantly of normal polarity; these zones represent medial to late epoch 5 time. Within epoch 5, the characteristic event A of reversed polarity, which extends from 110 to 165 m, is represented by zones R1-R2. Zones R3-R6, which extend from 285 m to the top of the stratotype, represent early to medial Gilbert time. Within the Gilbert, the characteristic event C of predominantly normal polarity, which extends from 375 to 470 m, is represented by zones N4-N5. The stratigraphic position of the fossil concentration at 325 m corresponds to early Gilbert time.

INTRODUCTION

The knowledge that the Earth's magnetic field has reversed in the geological past and that these reversals are frequently recorded in many types of rocks has provided geologists with a powerful tool for correlation. To a first-order approximation, the Earth's magnetic field can be modelled to that of a dipole magnet. When this dipole reverses, the change is a worldwide phenomenon that is recorded in rocks. Magnetic polarity stratigraphy is a subdiscipline of earth science that deals with the correlation of magnetic reversals. One of the most attractive facets of magnetic polarity stratigraphy is that remanence signatures are virtually independent of rock type, and, therefore, this method is less con-

strained by the problems of lithofacies and biofacies that have plagued the traditional stratigrapher.

Magnetic polarity stratigraphy is, however, dependent upon numerous subdisciplines for input of data. Once a "magnetic polarity zonation" is established in a given sequence, it is then necessary to draw upon some other information in order to place this zonation into a proper geochronological framework. In this report, this procedure is termed "magnetic polarity chronology." The independent data used for control have traditionally been derived from extrapolated rates of geological processes, such as those found in sea-floor spreading and sedimentation, radiometric age determinations, and biochronology of fossils.

Intensive research in magnetic polarity stratigraphy has been conducted for the last two decades. One of the primary goals of this research has been to establish a standard "magnetic polarity time scale" (MPTS). Concentrated efforts in construction of the MPTS were started by Cox, Doell, and Dalrymple (1963), who determined the polarity and radiometric ages of late Cenozoic volcanic rocks in the southwestern United States, and McDougall and Tarling (1963), who determined the polarity and radiometric ages of late Cenozoic basalts from Hawaii. These studies and many later ones led to the presentation of the MPTS for 0 to 4½ m.y. This standard time scale has undergone many additions and modifications, and it is still in a state of flux. The history of its development is complex and has been adequately reviewed elsewhere (for example, Dalrymple, 1972; Watkins, 1972). It is interesting to note that the MPTS for 0 to 4½ m.y. was developed in terrestrial sequences, but the application of this standard to ocean basins had a profound effect on the current revolution in earth science. Almost simultaneously with Cox, Doell, and Dalrymple (1963), Vine and Matthews (1963), in a classic paper, postulated that bilaterally symmetrical marine magnetic anomalies on either side of mid-oceanic ridges recorded reversals of the Earth's magnetic field and that this ocean floor record had resulted from axial spreading of crust. Vine and Matthews have since been credited with supplying the impetus that sparked the study of plate tectonics. Equipped with the knowledge of the late Cenozoic standard MPTS, Heirtzler and others (1968) extrapolated the marine magnetic anomaly data back in time to the late Cretaceous and produced the MPTS for approximately 0 to 80 m.y. This time scale has also been amended and modified (for example, Opdyke, Burkle, and Todd, 1974; Thever and Hammond, 1974a, 1974b; Tarling and Mitchell, 1976), and Larson and Pitman (1972) have extended it further back in time to late Jurassic. Thus, a standard time scale has been produced for approximately 0 to 160 m.y. (for a recent review, see Irving and Pullaiah, 1976).

Concomitant with the study of marine magnetic anomalies, there has been much work on the magnetic polarity stratigraphy of layer I oceanic sediments. The magnetic polarity stratigraphy of these marine

sediments is calibrated primarily by the biocl
The study of marine sediments has contribu
ments to the MPTS. The history of the develop
polarity stratigraphy has been reviewed by work
Watkins (1972), and Berggren and Van Couve

More recently there has been much interes
stratigraphy of terrestrial mammal-bearing/ s
world. North America potentially possesses m
ments and has been a logical place for this
biochronologic zonation sequence for main
American Land Mammal "Ages" has been
others (1911), Evernden and others (1964),
(1970), McKenna and others (1973), Tedford a
and Lundelius and others (1973). These reports
1911) incorporate relevant radiometric data,
preliminary control for the magnetic polarity
American sequences is available to a greater o
on the case in study.

Johnson, Opdyke, and Lindsay (1975) pres
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of southeastern Arizona that represents medial
time (early Blancan to late Irvingtonian age
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sequences in the western United States that
early Blancan time (medial Hemphillian to e
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of the Anza Borrego State Park of southern
medial Gilbert to medial Matuyama time (la
Irvingtonian age).

The purpose of this paper is to presen
stratigraphy and mammalian biochronology
ments of the Chamita Formation stratotyp
Mexico. MacFadden (1975) and MacFadden
already presented preliminary summaries and
sented a complete report of this research.

ABBREVIATIONS

The following abbreviations are used in the

MPTS — magnetic polarity time scale
a.f. — alternating field
NRM — natural remanent magnetization
oe — oersteds
L. F. — local fauna in the strict sense (see T
l. f. — an undescribed geographically restri
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seum of Natural History, New York

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the study of marine magnetic anomalies, there on the magnetic polarity stratigraphy of layer 2 magnetic polarity stratigraphy of these marine

sediments is calibrated primarily by the biochronology of microfossils. The study of marine sediments has contributed numerous embellishments to the MPTS. The history of the development of marine magnetic polarity stratigraphy has been reviewed by workers such as Opdyke (1972), Watkins (1972), and Berggren and Van Couvering (1974).

More recently there has been much interest in the magnetic polarity stratigraphy of terrestrial mammal-bearing sequences throughout the world. North America potentially possesses many mammal-bearing sediments and has been a logical place for this type of investigation. A biochronologic zonation sequence for mammals that define North American Land Mammal "Ages" has been presented by Wood and others (1941), Evernden and others (1964), Evernden and Evernden (1970), McKenna and others (1973), Tedford and others (1973, in press), and Lundelius and others (1973). These reports (except Wood and others, 1941) incorporate relevant radiometric data. Therefore, the necessary preliminary control for the magnetic polarity stratigraphy of the North American sequences is available to a greater or lesser degree depending on the case in study.

Johnson, Opdyke, and Lindsay (1975) present the magnetic polarity stratigraphy of the Plio-Pleistocene sequence from the San Pedro Valley of southeastern Arizona that represents medial Gilbert to early Brunhes time (early Blancan to late Irvingtonian age). Lindsay, Johnson, and Opdyke and others (1977) present the magnetic polarity stratigraphy sequences in the western United States that represent late epoch 5 to early Brunhes time (medial Hemphillian to early Rancholabrean age). Opdyke and others (1977) present the magnetic polarity stratigraphy Anza Borrego State Park of southern California that represents medial Gilbert to medial Matuyama time (late Hemphillian to early Irvingtonian age).

The purpose of this paper is to present the magnetic polarity stratigraphy and mammalian biochronology of the Mio-Pliocene sediments of the Chamita Formation stratotype of north-central New Mexico. MacFadden (1975) and MacFadden and Manley (1976) have already presented preliminary summaries and MacFadden (ms) has presented a complete report of this research.

ABBREVIATIONS

The following abbreviations are used in the text:

MPTS — magnetic polarity time scale
a.f. — alternating field
NRM — natural remanent magnetization
oe — oersteds
L.F. — local fauna in the strict sense (see Tedford, 1970)
L.L. — an undescribed geographically restricted assemblage
AMNH — Department of Vertebrate Paleontology, The American Museum of Natural History, New York

FAM — Frick: American Mammals, Department of Vertebrate Paleontology, The American Museum of Natural History, New York

UCMP — University of California Museum of Paleontology, Berkeley

GEOLOGICAL SETTING

The Chamita Formation stratotype is located at the apex of a triangle formed by the confluence of the Rio Grande and Rio Chama at an altitude of approx 1740 to 1920 m in the Espanola Valley of northcentral New Mexico (fig. 1). These outcrops are approx 17 km northwest of Santa Fe and 62 km southwest of Taos and are represented on the northwest half of the U. S. Geol. Survey 7.5' San Juan Pueblo Quadrangle (lat 36° 07'-36° 03' N; long 106° 03'-106° 05' E). The lower part of the stratotype is contained within "the NW ¼ of sect. 10 and the W ½ of sect. 3, T. 21 N., R. 8 E., in Rio Arriba County,

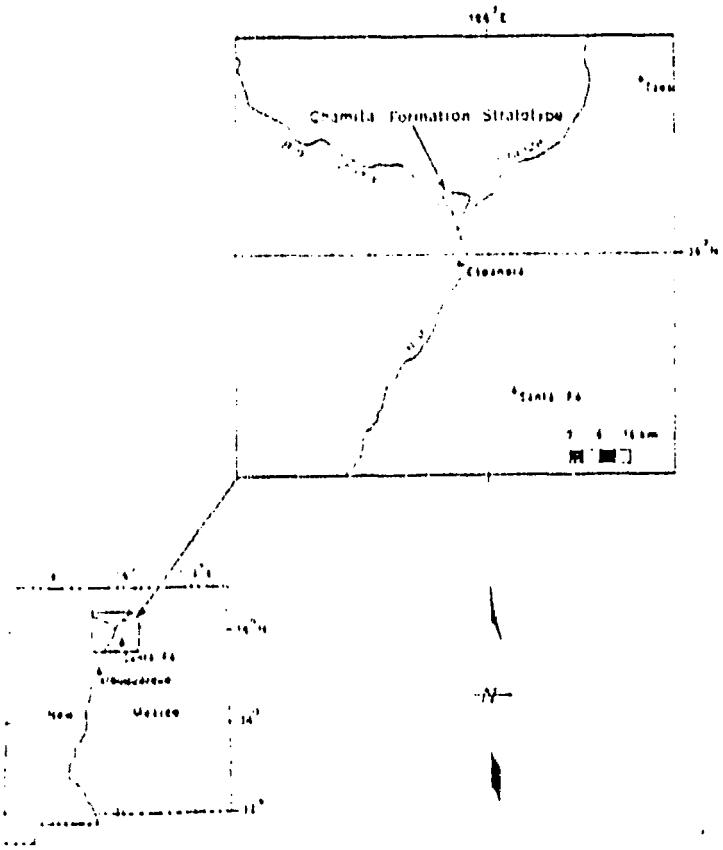


Fig. 1. Location of study area.

Formation stratotype (Mio-Pliocene) of north-

New Mexico (Galusha and Blick, 1971, p. 71
stratotype is approx 4 to 5 km north-northw
Galusha, personal commun., 1974; this report

The Santa Fe Group consists of the 'T
by the Chamita Formation (this latter unit
and Blick, 1971). Many geological aspects
ments, first called "Santa Fe marls" by Haye
ogists discussed elsewhere (for example,
Kelley, 1952, 1956; Baldwin, 1956; Speigal a
and Blick, 1971). In the broad sense, the Sa
catch-all designation for a complex of fluvia
and extrusive igneous rocks that were depos
depression" (Bryan, 1938, introduced this t
physiographic feature extends approximatel
Colo. to southern New Mexico and varies in
15 to 60 km (Kelley, 1956; Chapin, 1971;
Kelley, 1976; Cordell and Kottlowski, 1975).
is an approx north-south trending series of
nearly contiguous horst-grabin basins. The
type is found in one of these, the Espanola b

The Santa Fe Group is abundantly fossil
described fossil mammals collected from t
57Ma. During the present century, the Fri
under the direction of Fred Galusha and Jol
sands of specimens from this area over a p
and Blick (1971) present a complete history o
Fe fossil field. This same report discusses t
specimens, and Galusha (1974) presents a pr
fauna is very diverse but has not been adeq
reports of Santa Fe fossils have been prese
1926a), mastodonts (Frick, 1926b, 1933), horn
and oreodonts (Schultz and Falkenbach, 194
Some additional specimens were collected dur
beyond the scope of this paper to present a
of the fauna from the Chamita Formation.
considered for their biochronologic value.

The Chamita Formation has a maximum
stratotype and thins to a minimum of tens
related to the stratotype. The stratotype is
local sections correlated to one another by l
horizons (see MacFadden, ms, app B). Lo
mum of about 25°; however, most of the
relatively low dip (less than 15°, see pl. 1).
that trend approximately northwest-southea
the stratotype. The base of the stratotype is n
to sections where it lies on the Tesuque F

merican Mammals, Department of Vertebrate Pale-
. The American Museum of Natural History, New

ty of California Museum of Paleontology, Berkeley

GEOLOGICAL SETTING

formation stratotype is located at the apex of a the confluence of the Rio Grande and Rio Chama approx 1740 to 1920 m in the Espanola valley w Mexico (fig. 1). These outcrops are approx t Santa Fe and 62 km southwest of Taos and are northwest half of the U. S. Geol. Survey 7.5' San Juan (lat 36° 07'-36° 03' N; long 106° 03'-106° 07' E). he stratotype is contained within "the NW ¼ of sect. of sect. 3, T. 21 N., R. 8 E., in Rio Arriba County,

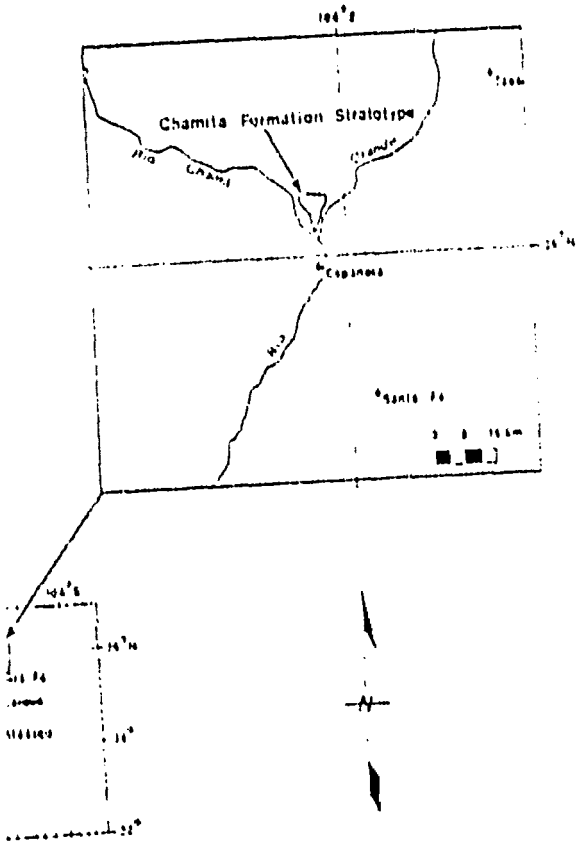


Fig. 1. Location of study area.

New Mexico (Galusha and Blick, 1971, p. 71)." The upper part of the stratotype is approx 4 to 5 km north-northwest of the lower stratotype (Galusha, personal commun., 1974; this report).

The Santa Fe Group consists of the Tesuque Formation overlain by the Chamita Formation (this latter unit was proposed by Galusha and Blick, 1971). Many geological aspects of these well-known sediments, first called "Santa Fe marls" by Hayden (1869), have been thoroughly discussed elsewhere (for example, Bryan, 1938; Denny, 1940; Kelley, 1952, 1956; Baldwin, 1956; Speigal and Baldwin, 1963; Galusha and Blick, 1971). In the broad sense, the Santa Fe Group has been a catch-all designation for a complex of fluviatile, aeolian, volcaniclastic, and extrusive igneous rocks that were deposited into the "Rio Grande depression" (Bryan, 1938, introduced this term). This major tectono-physiographic feature extends approximately 800 km from Leadville, Colo. to southern New Mexico and varies in width from approximately 15 to 60 km (Kelley, 1956; Chapin, 1971; Callender, Woodward, and Kelley, 1976; Cordell and Kottlowski, 1975). The Rio Grande depression is an approx north-south trending series of at least eight en echelon nearly contiguous horst-grabin basins. The Chamita Formation stratotype is found in one of these, the Espanola basin.

The Santa Fe Group is abundantly fossiliferous. In 1874, Cope first described fossil mammals collected from the Espanola basin (1874a, 1874b). During the present century, the Frick Laboratories, primarily under the direction of Ted Galusha and John C. Blick, collected thousands of specimens from this area over a period of decades. Galusha and Blick (1971) present a complete history of investigation of the Santa Fe fossil field. This same report discusses the biostratigraphy of some specimens, and Galusha (1971) presents a preliminary faunal list. The fauna is very diverse but has not been adequately studied. Taxonomic reports of Santa Fe fossils have been presented for carnivores (Frick, 1926a), mastodonts (Frick, 1926b, 1933), horned ruminants (Frick, 1937), and oreodonts (Schultz and Falkenbach, 1940, 1941, 1947, 1949, 1968). Some additional specimens were collected during the present study. It is beyond the scope of this paper to present a detailed taxonomic revision of the fauna from the Chamita Formation. The fossil mammals will be considered for their biochronologic value.

The Chamita Formation has a maximum thickness of 500 m in the stratotype and thins to a minimum of tens of meters in sections correlated to the stratotype. The stratotype is a composite of numerous local sections correlated to one another by laterally continuous marker horizons (see MacFadden, ms, app B). Locally, dips attain a maximum of about 25°; however, most of the Chamita Formation is of relatively low dip (less than 15°, see pl. 1). High-angle normal faults that trend approximately northwest-southeast are found throughout the stratotype. The base of the stratotype is not exposed, and correlation to sections where it lies on the Tesuque Formation is difficult. The

PLATE I

Geological setting of Chamita Formation stratotype. View from top of Black Mesa looking approximately southeast. The sparsely vegetated badlands in the foreground include the upper part of the stratotype. These sediments dip approximately to the south. The fossiliferous horizon that includes San Juan and Rak Camel Quarries is found in this part of the section. The flat vegetated area in the far-middle distance is the flood plain of the Rio Grande. Farther to the southeast, past the Rio Grande flood plain, are more sediments of the Santa Fe Group. In the far distance are the Sangre de Cristo Mountains, which form the eastern boundary of the Rio Grande depression in the Espanola basin.

Chamita Formation is overlain by Plio-Pleistoce
Conglomerate, olivine tholeiites of the Serville
ments of eroded high-level flood plain and pedi
of the Chamita Formation consist of poorly in
light brown clayey silts to medium sands. The
conglomerates. Volcanic sediments include a ba
west-southwest of the stratotype) and ashes that
volcaniclastic fragments. These fragments have
of 2 cm and imply a relative close source, that is
(Manley, personal commun., 1975). The ashes a
mary air-falls or secondarily reworked. In the Ch
type these ashes are concentrated in two zones th
referred to as the "lower and upper tuffaceous
Blick (1971), Galusha (1974), MacFadden (1975
and Manley (1976). The fluviatile sediments of
including those of the Chamita Formation, we
by alluvial fans in a semi-arid to humid climate
1940; Galusha and Blick, 1971).

PALEOMAGNETIC SAMPLING

A minimum of three separately-oriented s
from each of 135 sites in the Chamita Format
virtually every site, samples were separated by les
chosen so that the maximum stratigraphic sep
than 7 m. Samples were exclusively collected from
fine-sand fraction. Detailed stratigraphic section
large-scale (1:2400) plane table survey, indicate
magnetic sites, and fossil quarries (see MacFad
were also collected from Chamita Formation s
stratotype. Due to the poorly indurated nature of
samples had to be collected with great care. Larg
ples were extracted and carefully wrapped for shippi

In the laboratory, the poorly indurated sampl
larger than desired size on either a band saw or
saw. The specimens were then sanded into standar
few samples that were well indurated due to the
carbonate matrix were easily prepared on a dia
saw. By virtue of careful collection and preparatio
of the samples were found suitable for paleomagne

MAGNETIC MEASUREMENTS

Paleomagnetic specimens were measured on a
speed (7 hertz), fluxgate spinner magnetometer
DIGICO computer of the type described by Mol
demagnetization was performed on an apparatus
scribed by McElhinny (1966). Susceptibility meas
on a commercially available susceptibility bridge.

PLATE I

mita Formation stratotype. View from top of Black Mesa east. The sparsely vegetated badlands in the foreground e stratotype. These sediments dip approximately to the on that includes *San Juan and Rak Camel Quarries* tion. The flat vegetated area in the far-middle distance Grande. Farther to the southeast, past the Rio Grande nts of the Santa Fe Group. In the far distance are the which form the eastern boundary of the Rio Grande sin.

Chamita Formation is overlain by Plio-Pleistocene deposits of the Puyé Conglomerate, olivine tholeiites of the Servilleta Formation, and sediments of eroded high-level flood plain and pediment surfaces. Sediments of the Chamita Formation consist of poorly indurated tan, pink, and light brown clayey silts to medium sands. There are also interbedded conglomerates. Volcanic sediments include a basalt flow (approx 5 km west-southwest of the stratotype) and ashes that are rich in pumice and volcaniclastic fragments. These fragments have a maximum diameter of 2 cm and imply a relative close source, that is, the Jemez Mountains (Manley, personal commun., 1975). The ashes appear to be either primary air-falls or secondarily reworked. In the Chamita Formation stratotype these ashes are concentrated in two zones that have been informally referred to as the "lower and upper tuffaceous zones" by Galusha and Blick (1971), Galusha (1974), MacFadden (1975, ms) and MacFadden and Manley (1976). The fluviatile sediments of the Santa Fe Group, including those of the Chamita Formation, were probably deposited by alluvial fans in a semi-arid to humid climate (Bryan, 1938; Denny, 1940; Galusha and Blick, 1971).

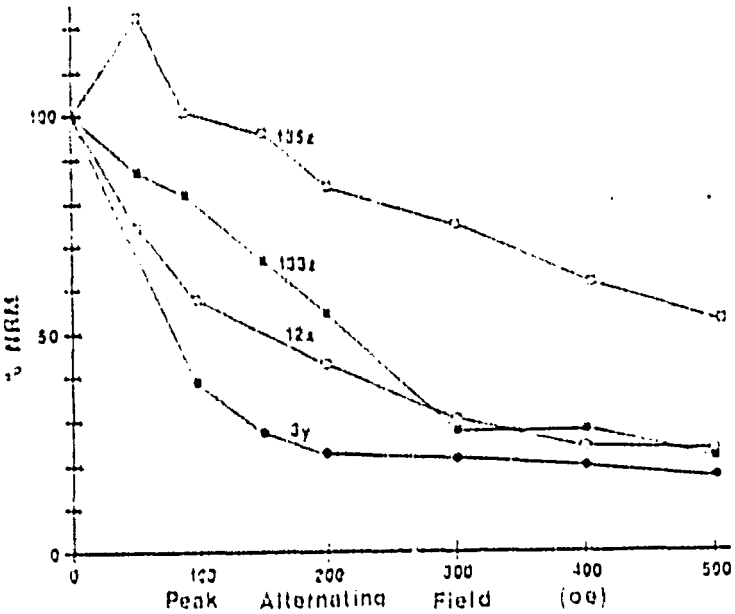
PALEOMAGNETIC SAMPLING

A minimum of three separately-oriented samples were collected from each of 135 sites in the Chamita Formation stratotype. Within virtually every site, samples were separated by less than 1 m. Sites were chosen so that the maximum stratigraphic separation was no more than 7 m. Samples were exclusively collected from the clayey-silt through fine-sand fraction. Detailed stratigraphic sections, coordinated with a large-scale (1:2400) plane table survey, indicate lithologic units, paleomagnetic sites, and fossil quarries (see MacFadden, ms). Some sites were also collected from Chamita Formation sediments outside the stratotype. Due to the poorly indurated nature of most of the sediments, samples had to be collected with great care. Large oriented hand samples were extracted and carefully wrapped for shipping.

In the laboratory, the poorly indurated samples were cut to slightly larger than desired size on either a band saw or a metal-cutting hand saw. The specimens were then sanded into standard 2.54 cm cubes. The few samples that were well indurated due to the presence of calcium carbonate matrix were easily prepared on a diamond-bladed circular saw. By virtue of careful collection and preparation, approx 98 percent of the samples were found suitable for paleomagnetic analysis.

MAGNETIC MEASUREMENTS

Paleomagnetic specimens were measured on a high sensitivity, slow speed (7 hertz), fluxgate spinner magnetometer integrated with a DIGICO computer of the type described by Molyneaux (1971). A. f. demagnetization was performed on an apparatus similar to that described by McElhinny (1966). Susceptibility measurements were made on a commercially available susceptibility bridge.



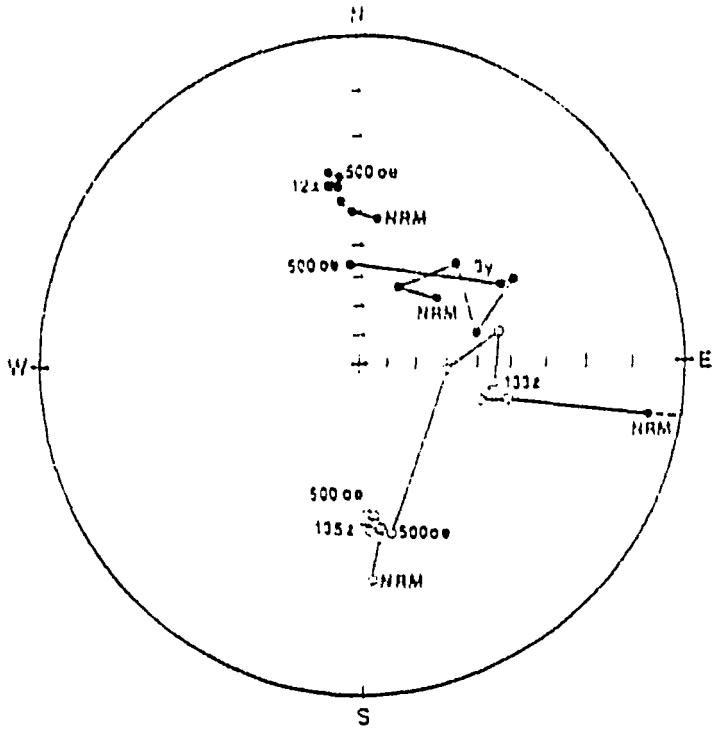


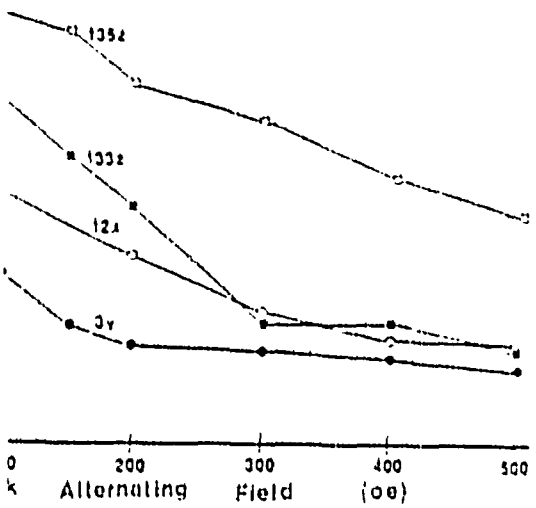
Fig. 2. Alternating field demagnetization curves for 4 specimens and equal-angle stereographic projections of same specimens showing change in directions of magnetization at successive alternating field demagnetizations. Filled circles represent positive inclinations, and open circles represent negative inclinations.

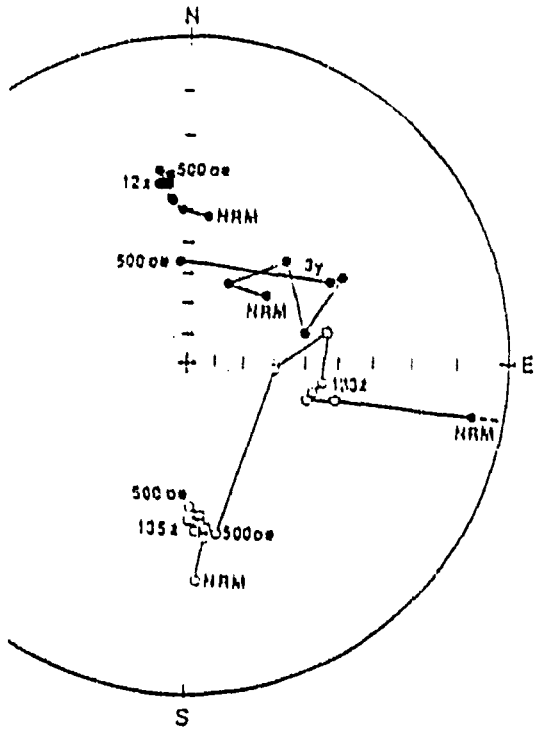
Preliminary demagnetization in successi of up to 500 oe was performed on selected-s the *Chamita Formation stratotype*. The m usually between 100 to 150 oe. The majority by 12x and 135z in figure 2, have weak seco are removed in low demagnetizing fields. Whe stereographic projection, these specimens rapi be the *primary direction of magnetization*. Ba it was decided that all specimens be demagn 150 oe. During this routine demagnetization, mens, such as 3y and 133z in figure 2, from behavior different from the majority of spe *within* sites was seen from these specimens afte of up to 500 oe. At 500 oe, some of these sp primary directions of magnetization and othe of these sites were later considered to be of i discussion below) or were rejected because the

NRM intensities for 101 specimen range to 3.90 × 10^{-4} emu/cc with a geometric mea (fig. 3). Intensities of magnetization for the demagnetization in peak alternating fields of 10^{-5} emu/cc to 6.00 × 10^{-4} emu/cc with a 10^{-5} emu/cc. The bimodal distribution of in at 150 oe (fig. 3, bottom) does not appear to tematic factors such as lithologic difference which was measured for 90 specimens, ranges to 7.38 × 10^{-5} emu/cc with a geometric mean o ratio of NRM/χ for most of these specime probably stable (see Irving, 1964, p. 92). Ba presented above, it appears that these sedimen possess a relatively stable magnetization.

Whenever possible, it is desirable to deter eral is the principal carrier of the remanen dominant magnetic mineral oftentimes provid acquisition of the remanence. In this context, tions were made for five specimens from repres throughout the stratotype. The method of sep modified Frantz isodynamic separator, is describ Jacobs (1972).

Thermomagnetic (J_s-T, where J_s is saturat is temperature) curves for each specimen (fig. 4) Curie Point balance determinations made on a Kent and Lowrie (1974). Curie Point temperat from these curves based on the graphic methe Wright, and Peck (1969).





1 demagnetization curves for 4 specimens and equal-angle
same specimens showing change in directions of mag-
ernating field demagnetizations. Filled circles represen
pen circles represent negative inclinations

Preliminary demagnetization in successive peak alternating fields of up to 500 oe was performed on selected specimens from throughout the Chamita Formation stratotype. The median destructive field is usually between 100 to 150 oe. The majority of specimens, represented by 12x and 135z in figure 2, have weak secondary magnetizations that are removed in low demagnetizing fields. When viewed from equal-angle stereographic projection, these specimens rapidly attain what appears to be the primary direction of magnetization. Based on preliminary results, it was decided that all specimens be demagnetized in fields of at least 150 oe. During this routine demagnetization, it was found that specimens, such as 3y and 133z in figure 2, from a few sites, demonstrated behavior different from the majority of specimens. Little consistency within sites was seen from these specimens after demagnetization in fields of up to 500 oe. At 500 oe, some of these specimens appear to attain primary directions of magnetization and others appear unstable. Many of these sites were later considered to be of indeterminate polarity (see discussion below) or were rejected because they are statistically random.

NRM intensities for 101 specimens range from 1.66×10^{-6} emu/cc to 3.90×10^{-4} emu/cc with a geometric mean of 2.69×10^{-5} emu/cc (fig. 3). Intensities of magnetization for the same 101 specimens after demagnetization in peak alternating fields of 150 oe range from 8.21×10^{-7} emu/cc to 6.00×10^{-4} emu/cc with a geometric mean of 1.03×10^{-5} emu/cc. The bimodal distribution of intensities of magnetization at 150 oe (fig. 3, bottom) does not appear to be related to possible systematic factors such as lithologic differences. The susceptibility (χ), which was measured for 99 specimens, ranges from 0.28×10^{-7} emu/cc to 7.58×10^{-7} emu/cc with a geometric mean of 8.01×10^{-8} emu/cc. The ratio of NRM/χ for most of these specimens implies that they are probably stable (see Irving, 1964, p. 92). Based on the measurements presented above, it appears that these sediments, with a few exceptions, possess a relatively stable magnetization.

Whenever possible, it is desirable to determine which magnetic mineral is the principal carrier of the remanence. Identification of the dominant magnetic mineral oftentimes provides a clue to the mode of acquisition of the remanence. In this context, magnetic mineral separations were made for five specimens from representative lithologies spaced throughout the stratotype. The method of separation, which employs a modified Franz isodynamic separator, is described by Lovlie, Lowrie, and Jacobs (1972).

Thermomagnetic (I_s-T, where I_s is saturation magnetization and T is temperature) curves for each specimen (fig. 4) were next obtained from Curie Point balance determinations made on an apparatus described by Kent and Lowrie (1974). Curie Point temperatures (θ_c) were interpreted from these curves based on the graphic method described by Gromme, Wright, and Peck (1969).

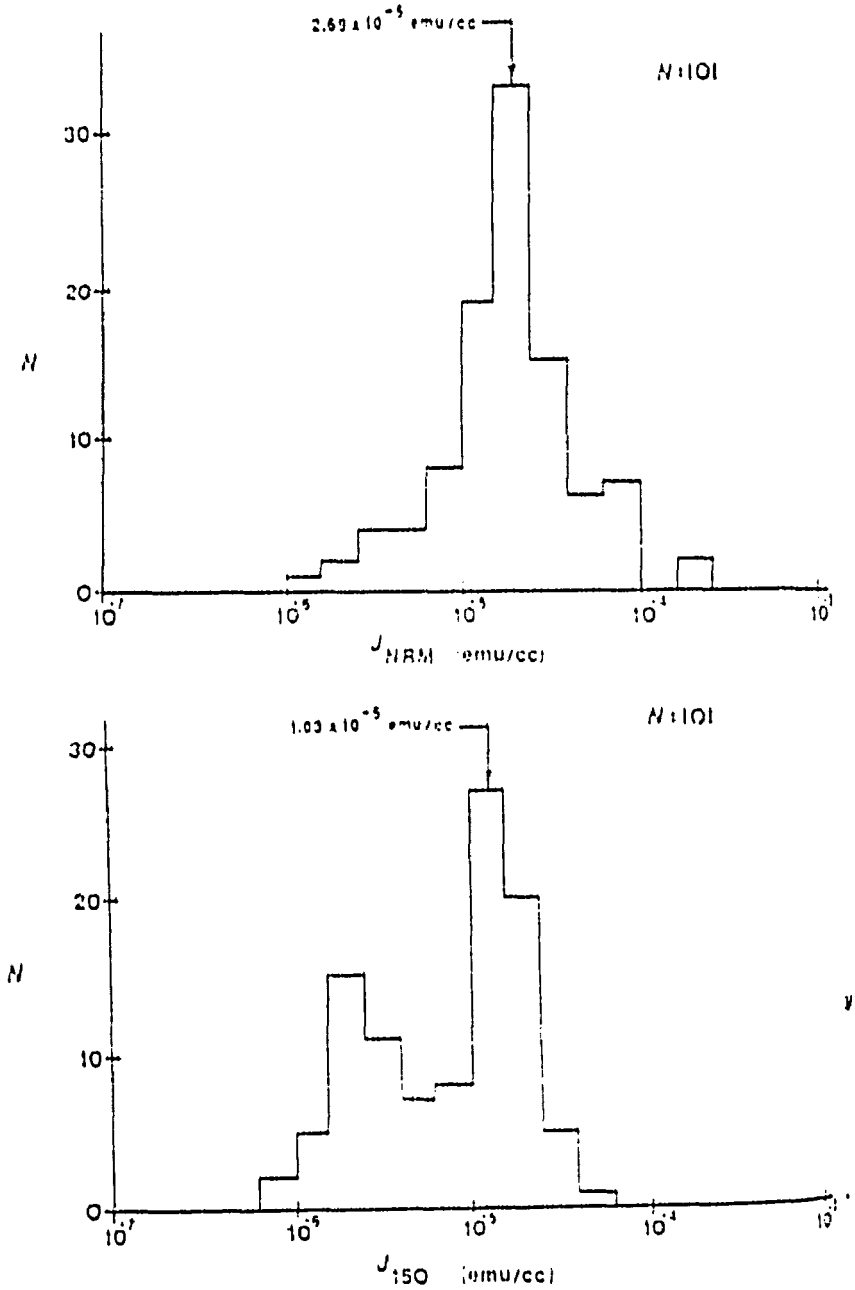


Fig. 3. NRM intensities of magnetization and intensities of magnetization after demagnetization in peak alternating fields of 150 oe. Geometric mean values for each are indicated by arrows.

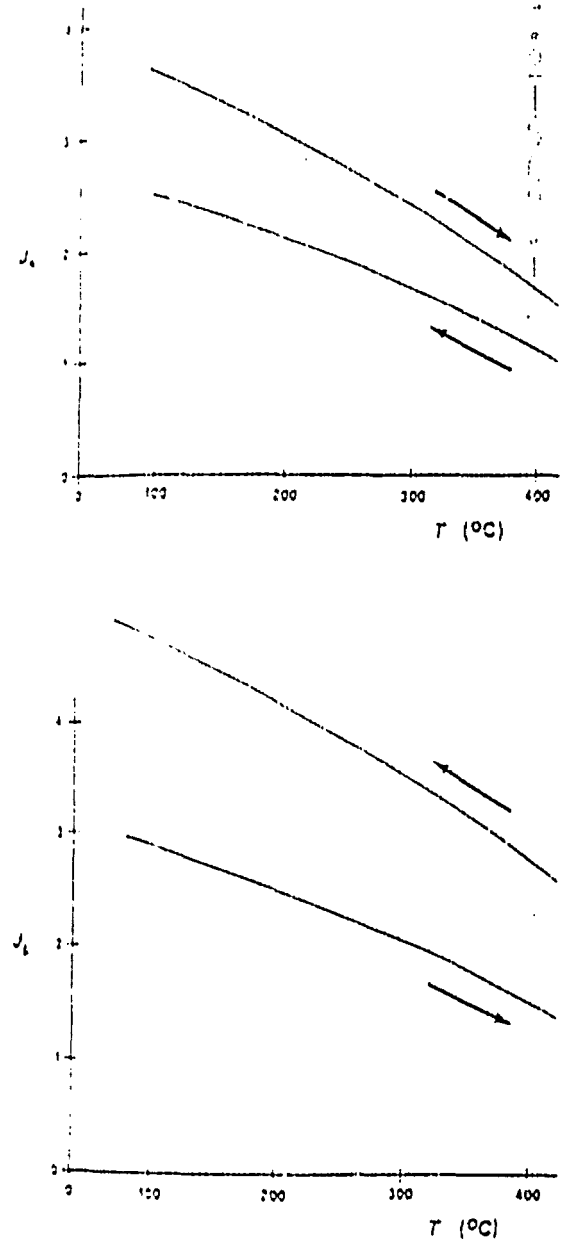
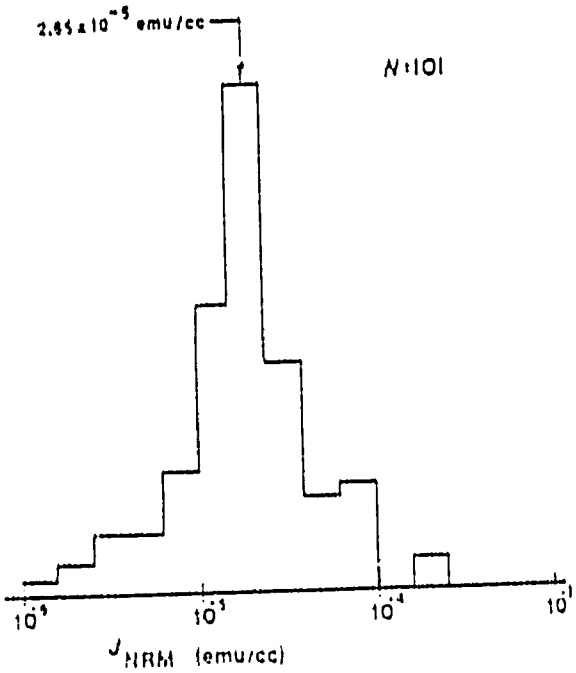
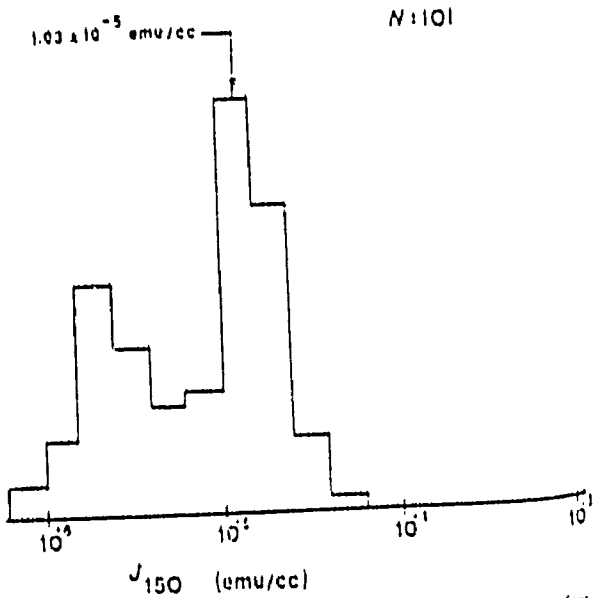
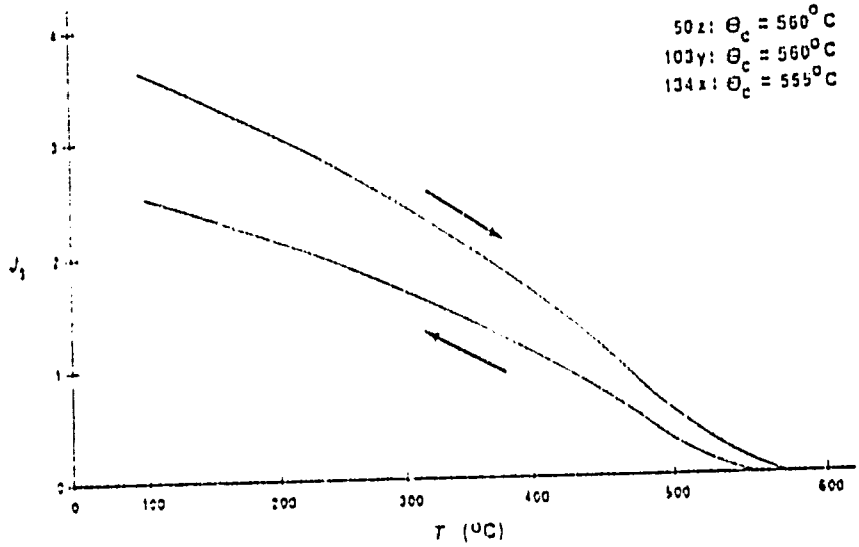


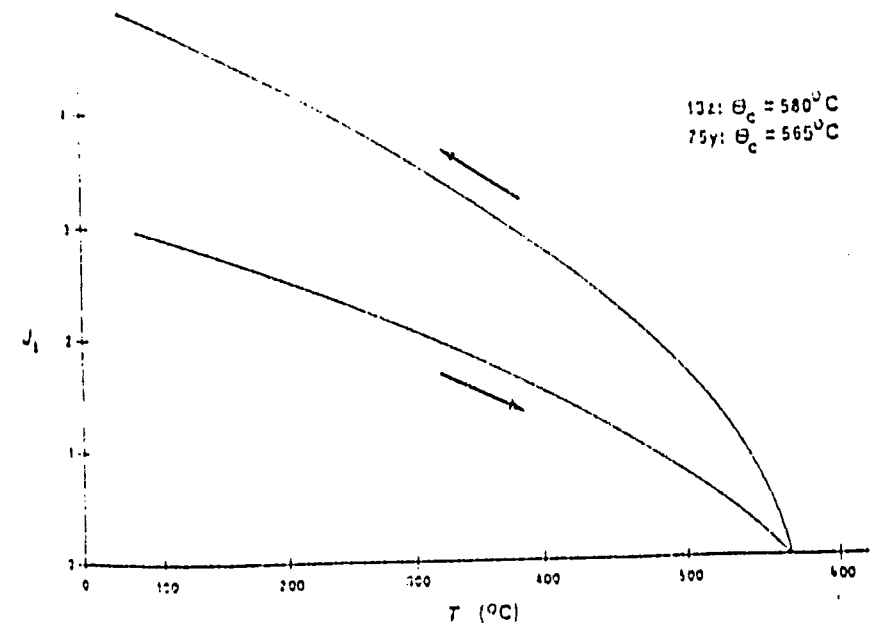
Fig. 4. Thermomagnetic (J_s-T) curves for magnetic specimens (12z, 50y, 75v, 103v, 131x). Specimens are divided by top and bottom curves, based on general behavior during heating. Saturation magnetization (J_s) is represented by temperatures (t_c) are indicated for each specimen.





...ties of magnetization and intensities of magnetization after alternating fields of 150 oe. Geometric mean values for each





...Thermomagnetic (J_s-T) curves for magnetic mineral separations from 5 ...: 13z, 50z, 75y, 103y, 134x. Specimens are divided into two groups, represented by top and bottom curves, based on general behavior during heating and cooling. Saturation magnetization (J_s) is represented by arbitrary units. Curie point temperatures (θ_c) are indicated for each specimen.

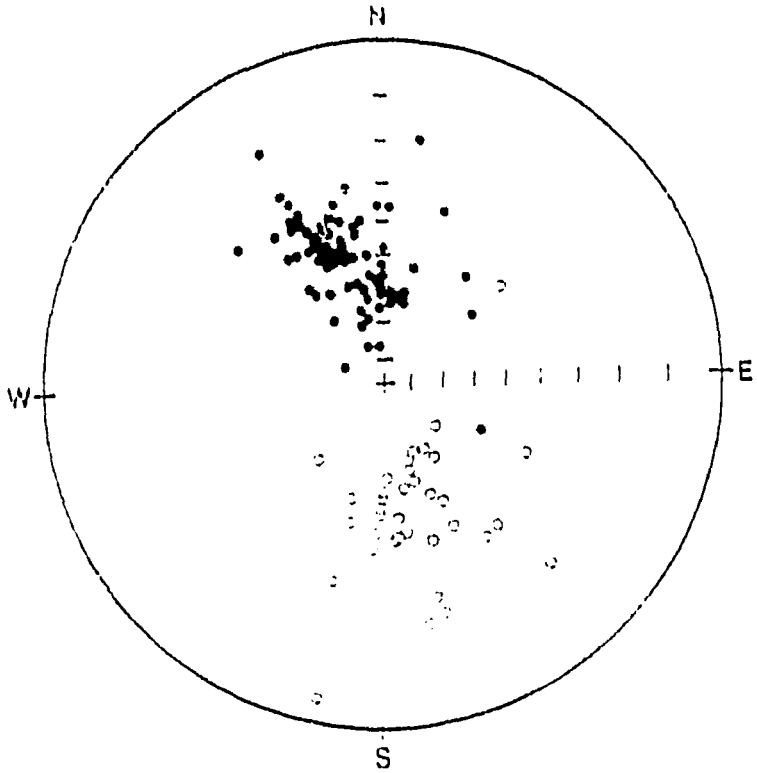


Fig. 5. Equal-angle stereographic projections of means for all 111 statistically significant sites. Filled circles represent positive inclinations, and open circles represent negative inclinations.

The behavior of the principal magnetic mineral, as evidenced in the thermomagnetic curves, can be classified into two groups: 1. Heating curve exhibits greater I_s than cooling curve (fig. 4, top). 2. Cooling curve exhibits greater I_s than heating curve (fig. 4, bottom). This latter type of curve is less common, and similar behavior is discussed for basalts (Gromme, Wright, and Peck, 1969) and marine volcanic ashes (Kent, ms.). This behavior results from the fact that the specimens were heated and cooled in air, as opposed to a vacuum. The greater I_s acquired during cooling is probably caused by oxidation of an unstable form of titanomagnetite (O'Reilly and Banerjee, 1967; Gromme, Wright, and Peck, 1969).

Stacey and Banerjee (1974) tabulate Curie Point temperatures for the titanomagnetite solid-solution series (Fe-Ti-O system). In this system, Curie Point temperatures are directly proportional to Fe content and attain a maximum of approximately 580°C for the magnetite end member. In the present study, θ_c ranges from 555° to 580°C. Therefore, based

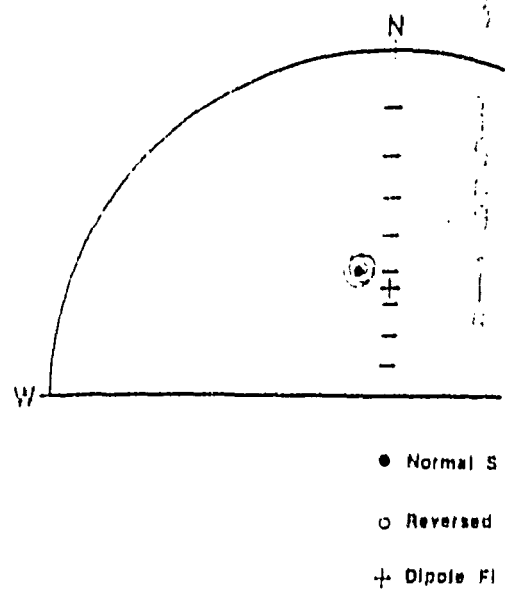
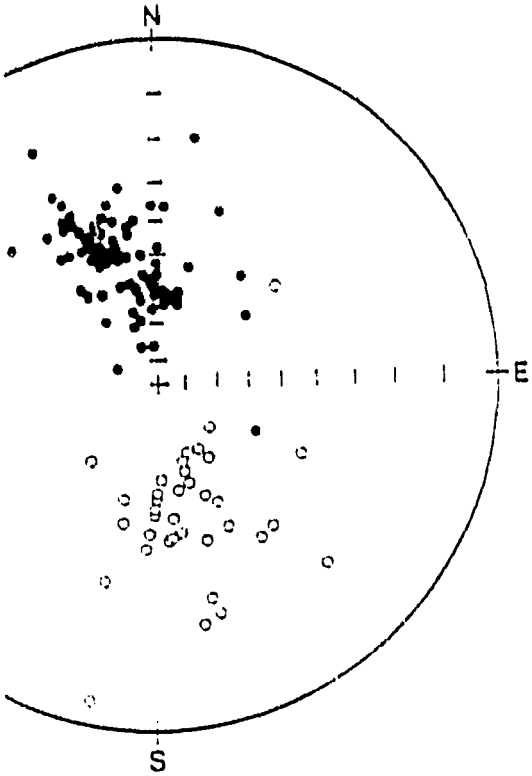


Fig. 6. Reversals test for consistency. Means of with 95 percent circles of confidence for each. Note div (see discussion in text).

on thermomagnetic analysis, the principle m iron-rich titanomagnetite, which, in a sedimen indicates that the primary remanence was acq magnetization (DRM) during the process of sed

The directional data after maximum a specimens and sites were statistically analyzed u by Fisher (1953). All sites were rejected in wh were random at the 95 percent probability leve the 135 sites collected from the Chamita Form tically significant. These sites are interpreted polarity, 35 of reversed polarity, 2 of intermedia terminate polarity (see discussion of these latter tions for all these sites are plotted on equal-angl in figure 5. The normal sites have declinations l assuming an axial geocentric dipole for at le versed sites have declinations less than the exp tion for this observation is not clear, but it co some small-scale tectonic rotation.

The normal sites have a mean direction clination 49.8° (k = 21.7, α_{95} = 3.6°), and the r direction of declination 166.9°, inclination −46 The mean of all normal and reversed (inverted) tion 345.8°, inclination 48.8° (k = 19.7, α_{95} = 3



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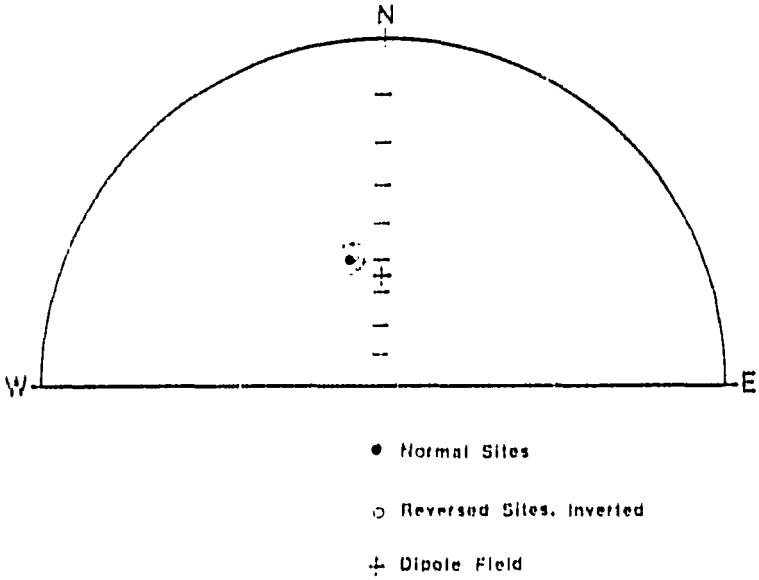

Fig. 6. Reversals test for consistency. Means of all normal and reversed sites with 95 percent circles of confidence for each. Note divergence from calculated dipole field (see discussion in text).

on thermomagnetic analysis, the principle magnetogenic mineral is an iron-rich titanomagnetite, which, in a sedimentary environment, usually indicates that the primary remanence was acquired by detrital remanent magnetization (DRM) during the process of sedimentation.

The directional data after maximum a. f. demagnetization of all specimens and sites were statistically analyzed using the method described by Fisher (1953). All sites were rejected in which the significance points were random at the 95 percent probability level. One-hundred eleven of the 135 sites collected from the Chamita Formation stratotype are statistically significant. These sites are interpreted as follows: 71 of normal polarity, 35 of reversed polarity, 2 of intermediate polarity, and 3 of indeterminate polarity (see discussion of these latter sites below). Mean directions for all these sites are plotted on equal-angle stereographic projection in figure 5. The normal sites have declinations less than the expected 360°, assuming an axial geocentric dipole for at least the Cenozoic. The reversed sites have declinations less than the expected 180°. The explanation for this observation is not clear, but it could possibly be a result of some small-scale tectonic rotation.

The normal sites have a mean direction of declination 345.4°, inclination 49.8° (k = 21.7, α_{95} = 3.6°), and the reversed sites have a mean direction of declination 166.9°, inclination −46.7° (k = 16.3, α_{95} = 6.1°). The mean of all normal and reversed (inverted) site directions is declination 355.8°, inclination 48.8° (k = 19.7, α_{95} = 3.1°), as shown in figure 6.

There is no difference between the normal and reversed sites as evidenced by the overlap of the α_{95} circles of confidence. This "reversals test" (McElhinny, 1973) provides strong evidence in support of the hypothesis that the directions obtained from paleomagnetic analysis reflect primary magnetizations acquired during reversals of the Earth's magnetic field. Inclinations for these normal and reversed sites are statistically different from that of the dipole field (55.5°) calculated for this latitude (tan I = 2 tan λ, where I = predicted inclination, λ = known latitude). The reason for this divergence is unclear. It is possibly correlated with the observed azimuthal offset of the site mean directions (fig. 5) and does not imply a falsification of the axial geocentric dipole hypothesis for which strong support has been presented elsewhere (see McElhinny, 1973, for a discussion of this problem).

MAGNETIC POLARITY ZONATION

Twelve magnetic polarity zones, given designations "N1-R6", are recognized in the Chamita Formation stratotype (fig. 7). The stratotype is a composite of numerous local sections correlated to one another in the type area, and, lithologically, it consists of five informal units: lower brown, lower tuffaceous zone, middle brown, upper tuffaceous zone, and upper brown (Galusha and Blick, 1971; Galusha, personal commun., 1971; this report). All stratigraphic measurements are approximate to within an accuracy of ± 5 m, which is due to average thicknesses taken from different local sections. All polarity boundaries are interpreted as lying midway between superposed sites of opposite polarities.

Zone N1, represented by 22 sites, extends from the base of the stratotype to 110 m. In between zones N1 and R1 is a site that is interpreted to be of intermediate polarity (declination 51.6°, inclination −42.9°). Zone R1, represented by 8 sites, extends from 110 to 115 m. Zone N2, represented by 1 site, extends a maximum of 10 m from 115 to 155 m. Zone R2, represented by 2 sites, extends a maximum of 10 m from 155 to 165 m. Zone N3, represented by 27 sites, extends from 165 to 285 m. Zone R3, represented by 1 site traced laterally for a few hundred meters, extends a maximum of 20 m from 285 to 300 m.

Zone I1 extends from 300 to 320 m. In this zone, a total of 8 sites were originally sampled of which only 3 are statistically significant and 5 are statistically random. Within the random sites, there is little consistency among specimens after demagnetization in peak alternating fields of up to 500 oe. Some sites have two specimens of one polarity and one specimen of the opposite polarity. Numerous specimens show directions with declinations near 0° but with negative inclinations. The three significant sites are characterized by a wide scatter of declinations and inclinations of normal magnetization (see fig. 7). The sites from zone I1 are believed to be shrouded by a relatively stable secondary "overprint" of normal magnetization that probably represents viscous remanent magnetization. It is concluded that the primary magnetization is not ade-

quately represented, and the polarity of this zo terminate.

Zone R4, represented by 12 sites, extends between zones R4 and N4 is 1 site that is interpre polarity. Zone N4, represented by 8 sites, extends R5, represented by 3 sites from one local sectio 150 m. Zone N5, represented by 6 sites, exten

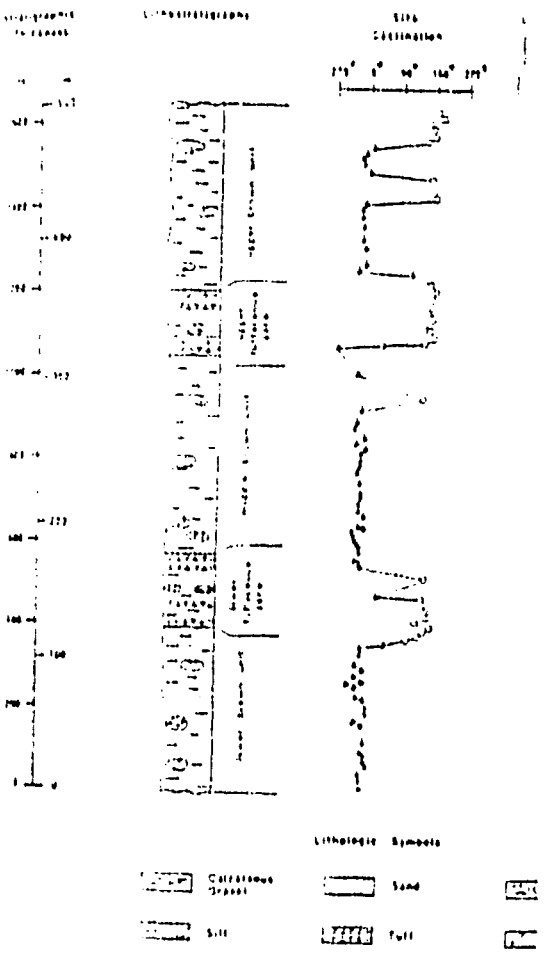

Fig. 7. Lithostratigraphy, site declination, site inclination of Chamita Formation stratotype. Lithostratigra names. For site declinations and inclinations, normal, indeterminate polarities are represented respectively by shaded circles. For magnetic polarity zones N1-R6, black, respectively normal, reversed, and indeterminate polarities.

:tween the normal and reversed sites as evidenced
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from paleomagnetic analysis reflect primary mag-
ing reversals of the Earth's magnetic field. Inclina-
and reversed sites are statistically different from
55.5°) calculated for this latitude (tan $I = 2 \tan \lambda$,
clination, λ = known latitude). The reason for
.ar. It is possibly correlated with the observed
site mean directions (fig. 5) and does not imply a
l geocentric dipole hypothesis for which strong
nted elsewhere (see McElhinny, 1973, for a dis-

.

AGNETIC POLARITY ZONATION

polarity zones, given designations "N1-R6", are
aita Formation stratotype (fig. 7). The stratotype
ous local sections correlated to one another in the
gically, it consists of five informal units: lower
zone, middle brown, upper tuffaceous zone, and
and Blick, 1971; Galusha, personal commun.
stratigraphic measurements are approximate to
5 m, which is due to average thicknesses taken
tions. All polarity boundaries are interpreted as
superposed sites of opposite polarities.

ed by 22 sites, extends from the base of the strato-
een zones N1 and R1 is a site that is interpreted
polarity (declination 51.6°, inclination −2.9°).
by 8 sites, extends from 110 to 145 m. Zone N2,
xtends a maximum of 10 m from 145 to 155 m.
y 2 sites, extends a maximum of 10 m from 155 to
esented by 27 sites, extends from 165 to 285 m.
y 1 site traced laterally for a few hundred meters,
20 m from 285 to 300 m.

rom 300 to 320 m. In this zone, a total of 5 sites
d of which only 3 are statistically significant and
om. Within the random sites, there is little con-
ns after demagnetization in peak alternating fields
sites have two specimens of one polarity and one
site polarity. Numerous specimens show direction
0° but with negative inclinations. The three signifi-
rized by a wide scatter of declinations and inclina-
etization (see fig. 7). The sites from zone I1 are
ed by a relatively stable secondary "overprint" of
that probably represents viscous remanent mag-
nded that the primary magnetization is not ade-

quately represented, and the polarity of this zone is considered "inde-terminate."

Zone R4, represented by 12 sites, extends from 320 to 375 m. In between zones R4 and N4 is 1 site that is interpreted to be of intermediate polarity. Zone N4, represented by 8 sites, extends from 375 to 430 m. Zone R5, represented by 3 sites from one local section, extends from 430 to 450 m. Zone N5, represented by 6 sites, extends from 450 to 470 m.

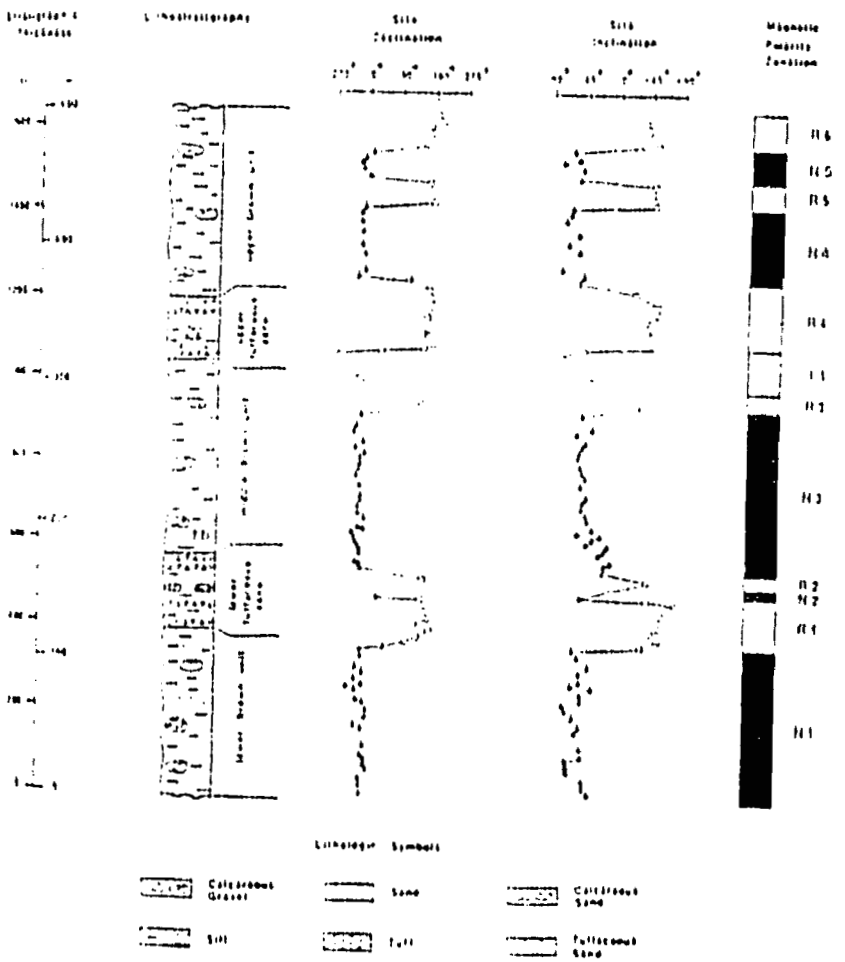

FIG. 7. Lithostratigraphy, site declination, site inclination, and magnetic polarity zonation of Chamita Formation stratotype. Lithostratigraphy includes informal unit names. Site declinations and inclinations, normal, reversed, intermediate, and indeterminate polarities are represented respectively by filled, open, half-filled, and shaded circles. For magnetic polarity zones N1-R6, black, white, and shaded represent respectively normal, reversed, and indeterminate polarities.

Zone R6, represented by 6 sites, extends from 470 m to the top of the stratotype.

Magnetic polarity stratigraphy consists of two interrelated phases that are termed "magnetic polarity zonation" and "magnetic polarity chronology" in this paper (also see Oriel and others, 1976; Watkins, 1976). Once a magnetic polarity zonation has been established for a given sequence, it is next desirable to correlate this zonation to the MPTS. This correlation has usually been achieved by one or more of the methods mentioned above. In the present study, radiometric age determinations and mammalian biochronology provide the principal input of data to determine the magnetic polarity chronology of the Chamita Formation stratotype.

MAMMALIAN BIOCHRONOLOGY

Fossil mammals are abundant in the Chamita Formation stratotype. These are preserved as weathered scraps of bone frequently found throughout the section and remains occasionally found *in situ*. The majority of well-preserved fossil mammals come from a horizon of green silty clay in which the San Juan and Rak Camel Quarries (collectively referred to below as "San Juan-Rak Camel Quarries horizon") are found. San Juan Quarry is located on the south side of an east-west trending ridge crest approximately 250 m south of Arroyo de los Borregos and 250 m west of New Mexico route 291 (lat 36° 6' N; long 106° 1' E; U.S. Geol. Survey San Juan Pueblo 7½' Quadrangle). The Rak Camel Quarries are found a few hundred meters north and northwest of San Juan Quarry on the north side of the same ridge crest and south of Arroyo de los Borregos. The Rak Camel Quarries consist of numerous localities within the same horizon as San Juan Quarry. All quarries are 5 m above the base of the upper tuffaceous zone. They are also 1 m above the top of magnetic polarity zone H.

At least 19 taxa of fossil mammals are found in the stratotype (table 1). As mentioned above, most of this fauna comes from one horizon. The remainder comes from scattered occurrences elsewhere in the section. Fossil occurrence data are indicated with varied limits in figure 8 based on available field records. In the present discussion, only taxa with adequate stratigraphic data are considered. Some specimens can be located precisely to a given stratigraphic horizon. These specimens are indicated with arrows pointing to the respective horizon (fig. 8). Other specimens can only be located within some stratigraphic interval as indicated by brackets (fig. 8). It is important to note that the brackets should not be mistaken for terlzones (observed local stratigraphic ranges of taxa).

Basically, three methods are used to determine a biochronology of an assemblage of fossil mammals (for a discussion, see Tedford, 1970): (1) first appearance of taxa, termed "datum planes" (see Berggren and Van Couvering, 1974; Johnson, Opdyke, and Lindsay, 1975; Lindsay, Johnson, and Opdyke, 1975; Opdyke and others, in press), (2) last appearance of taxa, also termed "datum planes," and (3) concurrent range zones, also termed "Optelian Zones." For the purposes of [illegible] ogy of the fauna from the Chamita Form[illegible] method will be used exclusively. The first two [illegible] because the fossil information content in th[illegible] make relevant statements concerning datum [illegible]

In the general overview, that is, with resp[illegible] fauna from the Chamita Formation stratotype [illegible] many of the definitive faunal elements listed [illegible] p. 12):

> "Hemphillian age — new provincia[illegible] *Hempaill member of the* Ogallala [Gron[illegible] *Hempaill local fauna from the* Coffee Ra[illegible] local fauna, Hemphill County, Panhand[illegible] Principal correlatives: Edson, Feldt Ran[illegible] Rattlesnake.
>
> Index fossils: *Agrotherium*, *Dipoides*, *L*[illegible]
>
> First appearance, ground sloths, *Lutra*[illegible]
>
> Last appearance: *Aphelops*, *Blastomery*[illegible] *Plaucenia*, *Pliohippus*, *Prosthenops*, *Teleoceras*.
>
> Characteristic fossils: *Hypolagus*, *Megat*[illegible] *patron*."

Numerous taxa listed in the Wood Co[illegible] Hemphillian are present in the fauna from th[illegible] type.[1] The absence of certain taxa can be att[illegible]

TABLE 1

Mammalian fauna from the Chamita

Class MAMMALIA*	
Order EDENTATA	
Family Megalonychidae	1
Pliomorphotherium galathea	
Order LAGOMORPHA	Orde[illegible]
Family Leporidae	1
Hypolagus vetus	
Order RODENTIA	Orde[illegible]
Family Mylagaulidae	1
Mylagaulus sp.	
Family Castoridae	
Dipoides? *williamsi*	Orde[illegible]
Rodentia, indeterminate	1
Order CARNIVORA	
Family Canidae	
Canis davisi	
Tephrocyon cf. *haydeni*	1
Family Procyonidae	
Bassariscus sp.	

* Higher categories follow classification of Simpson

[1] The Wood Committee lists "first appearance" a[illegible] Hemphillian faunal elements. In the present study, [illegible] are found in the Chamita Formation stratotype, are [illegible] (observed time ranges) and not their datum [illegible]

6 sites, extends from 470 m to the top of the

ratigraphy consists of two interrelated phases
tic polarity zonation" and "magnetic polarity
also see Oriel and others, 1976; Watkins, 1976).
zonation has been established for a given se-
e to correlate this zonation to the MPTS. This
een achieved by one or more of the methods
present study, radiometric age determinations
nology provide the principal input of data to
polarity chronology of the Chamita Formation

MMALIAN BIOCHRONOLOGY

abundant in the Chamita Formation stratotype
weathered scraps of bone frequently found
nd remains occasionally found *in situ*. The ma-
ossil mammals come from a horizon of green
an Juan and Rak Camel Quarries (collectively
Juan-Rak Camel Quarries horizon") are found
ted on the south side of an east-west trending
250 m south of Arroyo de los Borregos and
o route 291 (lat 36° 6′ N; long 106° 4′ E; U.S.
Solo 7 1/2′ Quadrangles). The Rak Camel Quarries
meters north and northwest of San Juan Quarry
same ridge crest and south of Arroyo de los
Quarries consist of numerous localities within
Juan Quarry. All quarries are 5 m above the
ous zone. They are also 1 m above the top of

ossil mammals are found in the stratotype (table
most of this fauna comes from one horizon. The
scattered occurrences elsewhere in the section
e indicated with varied limits in figure 8 based
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ods are used to determine a biochronology of an
mals (for a discussion, see Tedford, 1970): (1)
termed "datum planes" (see Berggren and Van
n, Opdyke, and Lindsay, 1975; Lindsay, Johnson,
yke and others, in press), (2) last appearance of
m planes," and (3) concurrent range zones, also

TABLE 1

Mammalian fauna from the Chamita Formation stratotype

Class MAMMALIA*

Order EDENTATA
- Family Megatoryctidae
  - *Phometanastes galushai*

Order LAGOMORPHA
- Family Leporidae
  - *Hypolagus vetus*

Order RODENTIA
- Family Mylagaulidae
  - *Mylagaulus* sp.
- Family Castoridae
  - *"Dipoides" wilsoni*
- Rodentia, indeterminate

Order CARNIVORA
- Family Canidae
  - *Canis dirus*
  - *Tomarctus* cf. *hordeni*
- Family Procyonidae
  - *Bassariscus* sp.
- Family Mustelidae
  - *Pteronura* sp.
  - *Photaxonica garberi*

Order PROBOSCIDEA
- Family Gomphotheriidae
  - *Longirostrine gomphotherid*

Order PERISSODACTYLA
- Family Equidae
  - *Astromerycs ansae*
  - *Dinohippus interpolatus*

Order ARTIODACTYLA
- Family Camelidae
  - *Megatylopus matthewi*
  - *Hemiauchenia vera*
  - *Hemiauchenia* sp.
- Family Antilocapridae
  - *Osbornoceros osborni*
  - *Hexameryx alexandrae*
  - *Pronocerus* sp.

* Higher categories follow classification of Simpson (1945).

termed "Oppelian Zones." For the purposes of establishing a biochronology of the fauna from the Chamita Formation stratotype, the latter method will be used exclusively. The first two methods are not applicable because the fossil information content in this fauna is not sufficient to make relevant statements concerning datum planes.

In the general overview, that is, with respect to higher categories, the fauna from the Chamita Formation stratotype is of Hemphillian age with many of the definitive faunal elements listed by Wood and others (1941, p. 12):

> "Hemphillian age — new provincial time term, based on the Hemphill member of the Ogallala (Group), which includes both the Hemphill local fauna from the Coffee Ranch Quarry and the Higgins local fauna, Hemphill County, Panhandle of Texas.
>
> Principal correlatives: Edson, Feldt Ranch, Wray, Thousand Creek, Rattlesnake.
>
> Index fossils: *Agriotherium*, *Dipoides*, *Hangoceros*, *Plesiogulo*.
>
> First appearance: ground sloths, *Latrania*, *Machairodus*, *Taxidea*.
>
> Last appearance: *Aphelops*, *Blastomeryx*, *Mylagaulus*, *Osteoborus*, *Phanchenia*, *Pliohippus*, *Prosthenops*, rhinoceroses, *Sphenophalos*, *Teleoceras*.
>
> Characteristic fossils: *Hypolagus*, *Megatylopus*, *Nannippus*, *Neohipparion*."

Numerous taxa listed in the Wood Committee's definition of the Hemphillian are present in the fauna from the Chamita Formation stratotype.[1] The absence of certain taxa can be attributed to a few factors: (1)

[1] The Wood Committee lists "first appearance" and "last appearance" for certain Hemphillian faunal elements. In the present study, some of these same taxa, which are found in the Chamita Formation stratotype, are discussed with respect to their ostensibly observed time ranges and not their datum planes.

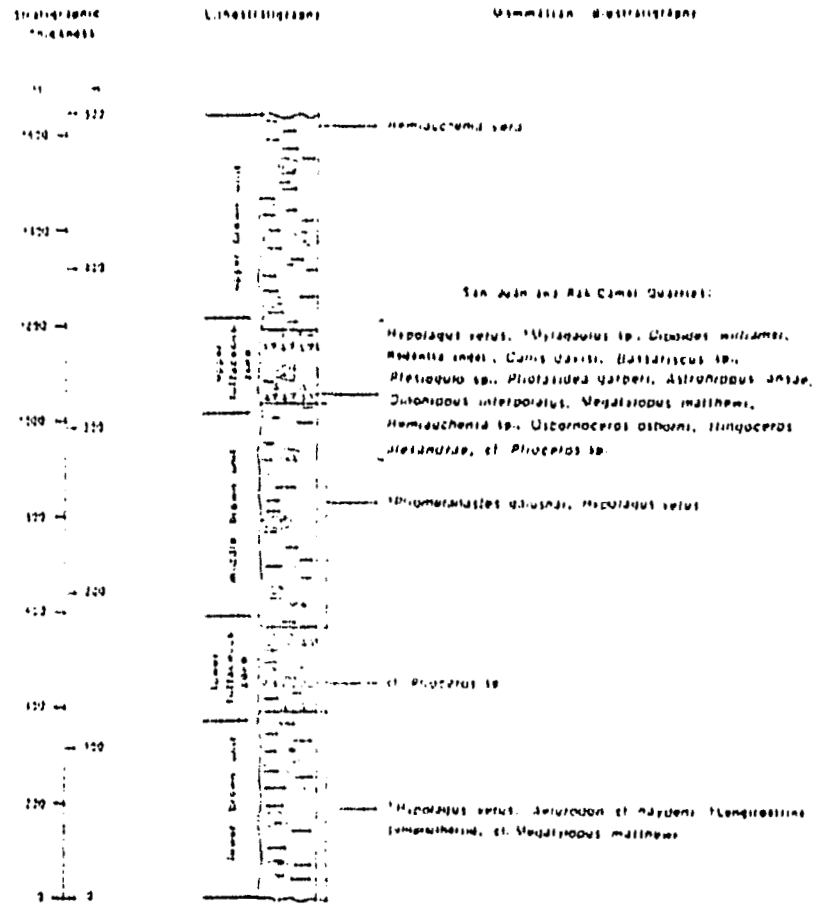


Fig. 8. Mammalian biostratigraphy of the Chamita Formation stratotype. See figure 7 for lithologic symbols.

This fauna represents a portion of time that is later than the last occurrence of some Hemphillian taxa, for example some horses. (2) Some faunal elements, particularly carnivores, when present in other Hemphillian assemblages, constitute a very small percentage of the individuals present (in contrast to ungulates). The absence of certain mammals in the stratotype is probably a result of sampling bias and not a biological phenomenon (for a discussion of sampling in mammalian assemblages, see Wolff, 1975). (3) Certain Hemphillian faunal elements had biogeographic ranges outside the stratotype and hence are not represented. (4) There has been a collecting bias against small-bodied forms, for example, insectivores, rodents, and lagomorphs. These factors should be tempered

with the realization that the fauna from t minimum of 19 taxa present, is not an actua paleocommunity. It is actually a taxonomical be attributed to an inadequate sample.

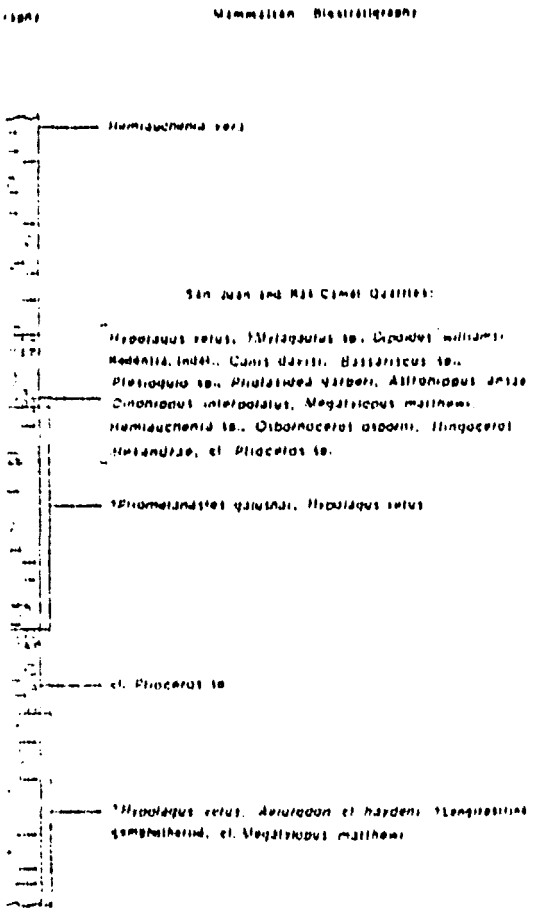
Approximately 4 m.y., from 8½ to 4 Hemphillian time (Tedford and others, in s set aside the radiometric data and discuss the fauna from the Chamita Formation strat already know, based on a comparison of highe is of Hemphillian age. We also know that prox 4 m.y. Given the frequency of geomag late Cenozoic, which is on the order of one p to correlate the magnetic polarity zonation of using its mammalian fauna at this power of r to examine more subtle aspects of this fauna, to compare taxa with other Hemphillian asse The following discussion presents an analysis of of the individual taxa of the fauna from the type.

?Pliometanastes galushai.—A single lowe sloth, FAM 77811, is described by Hirschfe authors list its occurrence from (1968, p. 282 between Round Mountain and San Juan c commun., 1971) locates this specimen in the of the stratotype. The genus *Pliometanastes* is ties that are all probably of early Hemphillian 1968; Tedford and others, in press). For reasc ing that *?P. galushai* is most properly placed i this sloth in the fauna from the stratotype re teilchron.[2] The concurrent range zonation figure 9.

Hypolagus vetus.—Numerous specimens from the lower brown unit (posteranials), in San Juan-Rak Camel Quarries horizon. These cement-filled anteroexternal fold and crenulate diagnostic for the genus. *H. vetus* from the lished measurements for material from the Tl Hemphillian of Nevada. This species also q ments ranging from late Clarendonian to Bl Plains to Oregon (Hesse, 1935; Dawson, 19 press).

[1] I am particularly grateful to Dr. Richard H. Te presently unpublished manuscript cited above. This mammalian biochronology that has been indispens present research.

[2] The species *?P. galushai* is of little biochronol to the Chamita Formation stratotype. In the present *Pliometanastes* is used for biochronologic analysis.



ratigraphy of the Chamita Formation stratotype. See

portion of time that is later than the last occur-
lian taxa, for example some horses. (2) Some
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esult of sampling bias and not a biological phe-
n of sampling in mammalian assemblages, see
Hemphillian faunal elements had biogeographic
ctype and hence are not represented. (4) There
as against small-bodied forms, for example, in-
lagomorphs. These factors should be tempered

with the realization that the fauna from the stratotype, with only a minimum of 19 taxa present, is not an actual sample of the mammalian paleocommunity. It is actually a taxonomically small assemblage that can be attributed to an inadequate sample.

Approximately 1 m.y., from 8½ to 4½ m.y., are represented by Hemphillian time (Tedford and others, in press).[2] For the moment, let us set aside the radiometric data and discuss the power of resolution of the fauna from the Chamita Formation stratotype in its own right. We already know, based on a comparison of higher categories, that this fauna is of Hemphillian age. We also know that the Hemphillian spans approx 4 m.y. Given the frequency of geomagnetic reversals during the late Cenozoic, which is on the order of one per 10^5 yrs, it is not possible to correlate the magnetic polarity zonation of the stratotype to the MPTS using its mammalian fauna at this power of resolution. We actually need to examine more subtle aspects of this fauna, that is, whenever possible, to compare taxa with other Hemphillian assemblages on the species level. The following discussion presents an analysis of the biochronologic utility of the individual taxa of the fauna from the Chamita Formation stratotype.

?Pliometanastes galushai.—A single lower jaw of this megalonychid sloth, FAM 77811, is described by Hirschfeld and Webb (1968). The authors list its occurrence from (1968, p. 283) "horizon stratigraphically between Round Mountain and San Juan Quarry." Galusha (personal commun., 1974) locates this specimen in the middle brown unit north of the stratotype. The genus *Pliometanastes* is found at many other localities that are all probably of early Hemphillian age (Hirschfeld and Webb, 1968; Tedford and others, in press). For reasons given below, and assuming that *?P. galushai* is most properly placed in this genus, the presence of this sloth in the fauna from the stratotype represents an extension of its teilchron.[3] The concurrent range zonation for this fauna is given in figure 9.

Hypolagus vetus.—Numerous specimens of this rabbit are known from the ?lower brown unit (postcranials), middle brown unit, and the San Juan-Rak Camel Quarries horizon. These specimens exhibit the deep, cement-filled anteroexternal fold and crenulated hypostriae on P_4 that are diagnostic for the genus. *H. vetus* from the stratotype agree with published measurements for material from the Thousand Creek Fauna, early Hemphillian of Nevada. This species also questionably occurs in sediments ranging from late Clarendonian to Blancan age from the Great Plains to Oregon (Hesse, 1935; Dawson, 1958; Tedford and others, in press).

[1] am particularly grateful to Dr. Richard H. Tedford for allowing access to the personally unpublished manuscript cited above. This report provides a synthesis of Hemphillian biochronology that has been indispensible during the course of the present research.

[2] species *?P. galushai* is of little biochronologic value, since it is restricted to the Chamita Formation stratotype. In the present discussion, the polytypic genus *Pliometanastes* is used for biochronologic analysis.

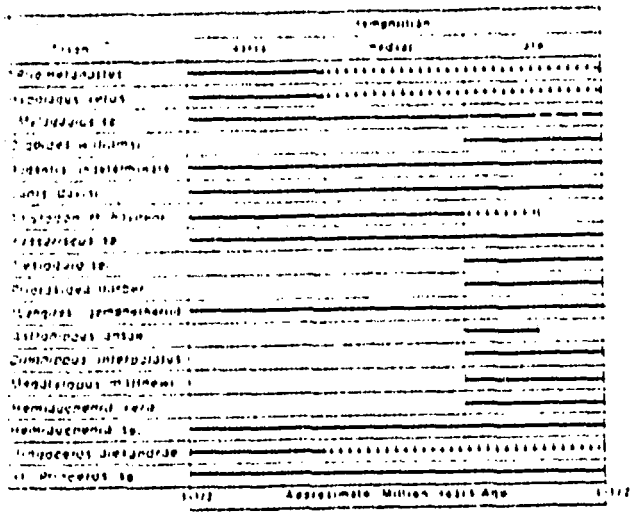


Fig. 9. Concurrent range zonation of the fauna from the Chamita Formation stratotype. Dashed lines indicate questionable range. Asterisked lines imply range extensions (see discussion in text).

M. [illegible].—A right lower jaw of this rodent, AMNH 100098, is from one of the Rak Camel Quarries. The taxonomy of mylagaulids is based primarily on the development of lakes in P_4 (Shotwell, 1958). In this specimen, the P_4 is missing unfortunately, and no reliable taxonomic assessment can be made. Mylagaulids are relatively rare in Hemphillian assemblages, but they have been reported from various localities: for example, Rome Fauna, early Hemphillian of Oregon (Shotwell, 1958); Feldt Ranch L.F., early Hemphillian of Nebraska (Hesse, 1935); McKay Reservoir L.F., late Hemphillian of Oregon (Shotwell, 1958); and Optima L.F., late Hemphillian of Oklahoma (Hesse, 1936). The mylagaulid from the Chamita Formation stratotype is questionably referred to *Mylagaulus*, *faute de mieux*, because all other Hemphillian mylagaulids are placed in this genus. This is admittedly circular reasoning, and little can be said about the biochronology of this taxon.

Dipodomys ordii.—Several specimens of this beaver are known from the San Juan-Rak Camel Quarries horizon. These agree in dental characters and size with the description given by Stirton (1936) and Shotwell (1955) from the White Cone L.F., late Hemphillian of Arizona (Stout, personal commun., 1976). The White Cone L.F. is bracketed by a maximum date of 6.7 m.y. (Scarborough, Damon and Shafiqullah, 1974) and a minimum date of 4.4 m.y. (Evernden and others, 1964). The magnetic polarity zonation of the Bidahochi Formation, in which this local fauna is found, is predominantly of normal polarity. This zonation probably correlates, at least in part, with epoch 5 of the MPTS (Opdyke, personal commun., 1976).

[illegible] formation stratotype (Mio-Pliocene) of northe[illegible]

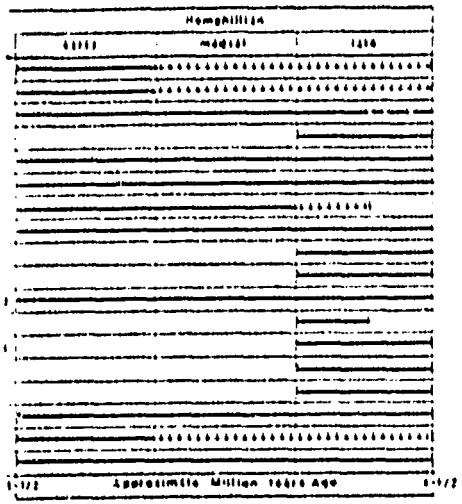
Rodentia, indeterminate.—Numerous ind[illegible] dents, which probably represent more than o[illegible] the San Juan-Rak Camel Quarries horizon.

Canis dirus.—There are several dentition[illegible] Juan-Rak Camel Quarries horizon. There ap[illegible] increase in size of this species correlated with [illegible] mens from the Chamita Formation stratotype a[illegible] pare with other samples from late-latest Hem[illegible] sample, the undescribed Wikieup L. F. from [illegible] commun., 1976).

Felinomon cf. *haydeni*.—A partial lower ja[illegible] F:AM 27359A, is known from near the bas[illegible] probably from the lower brown unit. The che[illegible] the base of the crown, and little of significance [illegible] dental morphology. However, the size of this sp[illegible] one of the largest and most robust in the AM[illegible] genus *Felurodon*, as presently recognized, shows [illegible] later, that is, Hemphillian, forms. Leidy (1858 [illegible] this genus in the species *F.* (subgenus *Epicyon*) [illegible] large size. F:AM 27359A apparently represents [illegible] *saevum* is known from some late Hemphillia[illegible] Higgins L. F. of Texas (Hesse, 1940), but it is n[illegible] latest Hemphillian localities (Tedford and oth[illegible]

Bassariscus sp.—Two lower jaws of this [illegible] known from the Chamita Formation stratotyp[illegible] consists of teeth mostly broken off from below [illegible] the Rak Camel Quarries. F:AM 49210, which [illegible] preserved, is from San Juan Quarry. The mol[illegible] are relatively robust and apparently represent [illegible] genus *Bassariscus* is known from the Hemingfo[illegible] the specific biochronology has not been adeq[illegible] forms are relatively small, and there is a gener[illegible] size. The *Bassariscus* from the stratotype is si[illegible] latest Hemphillian samples, for example, the [illegible] Wikieup L. F. of Arizona.

Pleiogulo sp.—A fragmentary palate of thi[illegible] is known from the San Juan-Rak Camel Quarri[illegible] of *Pleiogulo* represents dispersal into North [illegible] Hemphillian (Tedford and others, in press). I[illegible] lection, besides its occurrence in the Chamit[illegible] *Pleiogulo* is also found in the following late [illegible] Bone Valley Fauna of Florida, Edson L. F. of K[illegible] of Oklahoma, Collee Ranch L. F. of Texas, O[illegible] Arizona, and Wikieup L. F. of Arizona.



. zonation of the fauna from the Chamita Formation licate questionable range. Asterisked lines imply range ext).

. right lower jaw of this rodent, AMNH 100098, amel Quarries. The taxonomy of mylagaulids is velopment of lakes in P_1 (Shotwell, 1958). In this ing unfortunately, and no reliable taxonomic . Mylagaulids are relatively rare in Hemphillian have been reported from various localities: for early Hemphillian of Oregon (Shotwell, 1958); Hemphillian of Nebraska (Hesse, 1935); McKay phillian of Oregon (Shotwell, 1958); and Optima of Oklahoma (Hesse, 1936). The mylagaulid from stratotype is questionably referred to *Mylagaulus*, all other Hemphillian mylagaulids are placed in ittedly circular reasoning, and little can be said of this taxon.

ri.—Several specimens of this beaver are known Camel Quarries horizon. These agree in dental the description given by Stirton (1936) and Shoe ite Cone L.F., late Hemphillian of Arizona (Stout, o. The White Cone L.F. is bracketed by a maxi carborough, Damon and Shahqullah, 1974) and a n.v. (Evernden and others, 1964). The magnetic Bidahochi Formation, in which this local fauna ntly of normal polarity. This zonation probably ct, with epoch 5 of the MPTS (Opdyke, personal

Rodentia, indeterminate.—Numerous unprepared specimens of rodents, which probably represent more than one taxon, are known from the San Juan-Rak Camel Quarries horizon.

Canis davisi.—There are several dentitions of this dog from the San Juan-Rak Camel Quarries horizon. There appears to be a progressive increase in size of this species correlated with time. The *C. davisi* specimens from the Chamita Formation stratotype are relatively large and compare with other samples from late-latest Hemphillian local faunas, for example, the undescribed Wikieup L. F. from Arizona (Taylor, personal commun., 1976).

Aelurodon cf. *haydeni.*—A partial lower jaw of this dog-like mammal, F:AM 27359A, is known from near the base of the stratotype, most probably from the lower brown unit. The cheek teeth are broken off at the base of the crown, and little of significance can be said with respect to dental morphology. However, the size of this specimen is significant: it is one of the largest and most robust in the AMNH-F:AM collection. The genus *Aelurodon*, as presently recognized, shows a great increase in size in later, that is, Hemphillian, forms. Leidy (1858) included large forms of this genus in the species *A.* (subgenus *Epicyon*) *haydeni*. Because of its large size, F:AM 27359A apparently represents a late form. *Aelurodon* cf. *haydeni* is known from some late Hemphillian localities, for example, Higgins L. F. of Texas (Hesse, 1940), but it is not known from other late-latest Hemphillian localities (Tedford and others, in press).

Bassariscus sp.—Two lower jaws of this raccoon-like mammal are known from the Chamita Formation stratotype, AMNH 100099, which consists of teeth mostly broken off from below the crowns, is from one of the Rak Camel Quarries. F:AM 49210, which has some of the molars preserved, is from San Juan Quarry. The molars in the latter specimen are relatively robust and apparently represent an advanced form. The genus *Bassariscus* is known from the Hemingfordian to the Recent, and the specific biochronology has not been adequately presented. Earlier forms are relatively small, and there is a general trend toward increased size. The *Bassariscus* from the stratotype is similar to some other late-latest Hemphillian samples, for example, the F:AM specimens from the Wikieup L. F. of Arizona.

Plesiogulo sp.—A fragmentary palate of this carnivore, F:AM 49230, is known from the San Juan-Rak Camel Quarries horizon. The presence of *Plesiogulo* represents dispersal into North America during the late Hemphillian (Tedford and others, in press). In the AMNH-F:AM collection, besides its occurrence in the Chamita Formation stratotype, *Plesiogulo* is also found in the following late Hemphillian assemblages: Bone Valley Fauna of Florida, Edson L. F. of Kansas, Guymon Quarries, of Oklahoma, Coffee Ranch L. F. of Texas, Old Cabin Quarry L. F. of Arizona, and Wikieup L. F. of Arizona.

Pliotaxidea garberi.—One lower jaw with P_4-M_2 of this badger, F:AM 19232, is known from the San Juan-Rak Camel Quarries horizon. Wagner (1976) recently reviewed the specific taxonomy of the genus *Pliotaxidea* and recognized two species, *P. accadensis* and *P. garberi*. The dental characters that differentiate these two species are principally found in the cusps of M^2. The lower dental morphology is not diagnostic, and with only the lower jaw, relative size becomes important in specific identification. The lower dentition of the type of *P. accadensis*, UCMP 22290, appears to be significantly smaller than that of the type of *P. garberi*, UCMP 32122. The lower dentition of the badger from the Chamita Formation stratotype is very robust, even slightly more so than the type of *P. garberi*, and it apparently represents an advanced, that is, late Hemphillian, form.

[1]Longirostrine gomphotheriid.—Frick (1933, p. 645) illustrates an incomplete upper dentition, which includes both deciduous and permanent cheek teeth. Frick Laboratory field records for this specimen list the locality as: "San Juan, 1 mile up river from bridge in green layer." This occurrence is most probably from the lower brown unit in the southern part of the stratotype. This specimen is of little biochronologic significance due to its questionable taxonomy and stratigraphic position. Virtually its only value is to record the presence of a gomphotheriid in the fauna and to indicate a late Cenozoic teleichron.

Astromippus ansae.—Numerous specimens of this horse are known from the San Juan-Rak Camel Quarries horizon. This sample is similar in dental pattern and size to *A. ansae* from the Coffee Ranch L. F., late Hemphillian of Texas (Matthew and Stirton, 1930; Stirton, 1940). The teeth of *A. ansae* are much larger than *A. stockii*, a latest Hemphillian species described from the Yepomera Fauna of Chihauhua, Mexico (Lance, 1950). *A. ansae* has less anteriorly elongated protocones and less anteroposteriorly elongated metaconids and metastylids than does *A. stockii*. Based on the similarity to the *A. ansae* from the Coffee Ranch L.F., the *A. ansae* from the Chamita Formation stratotype indicates a late, but not latest, Hemphillian age.

Dinohippus interpolatus.—One lower jaw, F:AM 100091, and one lower molar of this horse are known from the San Juan-Rak Camel Quarries horizon. It compares both in dental characters and size with the sample from the Coffee Ranch L.F., late Hemphillian of Texas (Matthew and Stirton, 1930). Besides these occurrences, *D. interpolatus* is also known

[1] Fohen (1973, p. 229) records the presence of "*Teleoplhodon* (*Fatabeledes*) *grandensis*" from the "Chamita formation, which is of Hemphillian age, or metial Pliocene or even partially of the early part of the late Pliocene (Galusha and Blick, 1971: 7, 16)." It should be noted that the remains of this gomphotheri are actually from Battleship Mountain (Frick, 1933, p. 533). Presently, there is no way to corroborate the hypothesis that the Battleship Mountain localitis is Hemphillian age. It is just as plausible that this locality correlates to Round Mountain Quarry, which appears to have a late Clarendonian aspect to its assemblage.

from other late Hemphillian sites, for example, i California (Wagner, 1976).

Megatylopus matthewi.—Several specimens mostly from the San Juan-Rak Camel Quarries some large camelid posteranials from the lower ferred to this species. *M. matthewi* can be diagn with a complete posterointernal crescent and a (Webb, 1974). The type material of *M. matthew* Ranch L. F., late Hemphillian of Texas. The sa Formation stratotype is similar to that of the suggests a late Hemphillian age.

Hemiauchenia.—Several specimens of what of llama are present in the Chamita Formation s the generic characters of *Hemiauchenia* as diagno as the "llama buttresses" (anteroexternal and an reduced, simple, and triangular P_4. The larger sp sented by one lower jaw, F:AM 47940, and son from approx 10 m below the top of the stratotype in dental morphology and size to that of some localities, for example, Higgins and Coffee Ran species, *H.* sp., is known from several specimens Camel Quarries horizon. This species is signifi hypodigm of *H. vera*. In particular, the cheek transversely. The presence of *H.* sp. probably indi (Webb, 1974).

Antilocaprids.—There are at least two, and antelopes from the stratotype, namely, *Osbornoce alexandrae*, and cf. *Ploceros* sp. Frick (1937) base locaprids primarily on the morphology of horn c small-sized form with curved, pointed, and gracil is an intermediate-sized form with robust horn c tally. *Hingoceros* is a large-sized form with spir dental morphology of these antilocaprids is very of little value in the identification of particular ta available, it is necessary to separate these taxa base cations that follow are basically those of Frick (19

Osbornoceros osborni is represented by numer San Juan-Rak Camel Quarries horizon. This samp a discrete group of small-sized forms. The monoty it known only from the stratotype and referred s Formation. Little can be said with regard to the l cance of this taxon, since it is not recognized i diagnostic spiralled horn core fragment of *Hing* from the San Juan-Rak Camel Quarries horizon, a with the larger species, *I. alexandrae*. There are sized dentitions from this same horizon that are rel

–One lower jaw with P_4-M_2 of this badger, F:AM
San Juan-Rak Camel Quarries horizon. Wagner
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from other late Hemphillian sites, for example, the Turlock Lake L.F. of California (Wagner, 1976).

Megatylopus matthewi.—Several specimens of this camel are known mostly from the San Juan-Rak Camel Quarries horizon. There are also some large camelid posteranials from the lower brown unit that are referred to this species. *M. matthewi* can be diagnosed by the reduced P^3 with a complete posterointernal crescent and a reduced, but present, P_1 (Webb, 1974). The type material of *M. matthewi* comes from the Coffee Ranch L. F., late Hemphillian of Texas. The sample from the Chamita Formation stratotype is similar to that of the Coffee Ranch L. F. and suggests a late Hemphillian age.

Hemianchenia.—Several specimens of what appear to be two species of llama are present in the Chamita Formation stratotype. These exhibit the generic characters of *Hemianchenia* as diagnosed by Webb (1974) such as the "llama buttresses" (anteroexternal and anterointernal stylids) and reduced, simple, and triangular P_1. The larger species, *H. vera*, is represented by one lower jaw, F:AM 47940, and some referred metapodials from approx 10 m below the top of the stratotype. This sample is similar in dental morphology and size to that of some other late Hemphillian localities, for example, Higgins and Coffee Ranch L. F.'s. The smaller species, *H.* sp., is known from several specimens from the San Juan-Rak Camel Quarries horizon. This species is significantly smaller than the hypodigm of *H. vera*. In particular, the cheek teeth are very narrow transversely. The presence of *H.* sp. probably indicates a Hemphillian age (Webb, 1974).

Antilocapridae.—There are at least two, and possibly three, taxa of antelopes from the stratotype, namely, *Osbornoceros osborni*, *Hingoceros alexandrae*, and cf. *Phoceros* sp. Frick (1937) bases the taxonomy of antilocaprids primarily on the morphology of horn cores. *Osbornoceros* is a small-sized form with curved, pointed, and gracile horn cores. *Phoceros* is an intermediate-sized form with robust horn cores that bifurcate distally. *Hingoceros* is a large-sized form with spiralled horn cores. The dental morphology of these antilocaprids is very conservative, and it is of little value in the identification of particular taxa. Without horn cores available, it is necessary to separate these taxa based on size. The identifications that follow are basically those of Frick (1937).

Osbornoceros osborni is represented by numerous dentitions from the San Juan-Rak Camel Quarries horizon. This sample appears to represent a discrete group of small-sized forms. The monotypic genus *Osbornoceros* is known only from the stratotype and referred sections of the Chamita Formation. Little can be said with regard to the biochronological significance of this taxon, since it is not recognized in other assemblages. A diagnostic spiralled horn core fragment of *Hingoceros*, F:AM 52153, is from the San Juan-Rak Camel Quarries horizon, and it compares in size with the larger species, *H. alexandrae*. There are also numerous large-sized dentitions from this same horizon that are referable to *H. alexandrae*.

The type locality and only other published occurrence of this species is from the Thousand Creek Fauna, early Hemphillian of Nevada (Frick, 1937; Tedford and others, in press). There are numerous specimens of intermediate size that are questionably referred to *Pliocerus* sp. These appear to represent a discrete group, but they could also be statistical end-members of the range of variation of either *Osbornoceros* or *Hingoceros*. There is one specimen, AMNH 100090, that is from the lower tuffaceous zone, 130 m above the base of the stratotype. The remainder of this sample is from the San Juan-Rak Camel Quarries horizon. *Pliocerus*, which has a relatively long terlchron, is also known from Clarendonian-Hemphillian localities in Nebraska, Kansas, New Mexico, Nevada, and Oregon.

CONCLUSION: MAGNETIC POLARITY CHRONOLOGY

The magnetic polarity zonation for the Chamita Formation stratotype is presented above (text, fig. 7). As a conclusion to this report, it is now desirable to correlate this zonation to the MPTS. This correlation is achieved by input of data from the independent disciplines of mammalian biochronology and radiometric age determinations.

Based on the discussion of individual taxa and concurrent range zonation presented above (text, fig. 9), the biochronology of the mammalian fauna suggests a late, but not latest, Hemphillian age for the Chamita Formation stratotype. The individual taxa are of varied utility in this assertion. The majority of taxa, including the beaver "*Dipodes*" *williamsi*, the dog *Canis dirus* (see discussion above), the procyonid *Bassariscus* sp. (see discussion above), the mustelid *Plesiogale* sp., the badger *Pliotaxidea garbani*, the horses *Astrohippus ansae* and *Dinohippus interpolatus*, and the camels *Megatylopus matthewi* and *Hemiauchenia vera*, support the hypothesis of a late Hemphillian age. The long-ranging taxa, including the rodents ?*Mylagaulus* sp. and "indeterminate," the longirostrine gomphotheriid, the camel *Hemiauchenia* sp., and the antelope cf. *Pliocerus* sp., are of little biochronologic value. The sloth ?*Pliomerianastes*, the rabbit *Hypolagus vetus* (definite, not questionable occurrence, see Dawson, 1958), the dog *Aelurodon* cf. *haydeni*, and the antelope *Hingoceros alexandriae* are found elsewhere in early Hemphillian faunas (Frick, 1937; Dawson, 1958; Hirschfeld and Webb, 1968; Tedford and others, *in press*). It is asserted that the presence of these four taxa in the late Hemphillian fauna from the Chamita Formation stratotype represents extension of their terlchrons. The monotypic genus *Osbornoceros* is of little biochronoglic utility since it is unique to the Chamita Formation.

The fauna from the Chamita Formation stratotype is generally similar to the late Hemphillian assemblages of the southern Great Plains, including the Coffee Ranch L.F. of the Hemphillian stratotype, Panhandle of Texas, and the adjacent Optima L. F. from the Panhandle of Oklahoma (see Reed and Longnecker, 1932; Hesse, 1936, 1940; Wood and others, 1941; Evernden and others, 1964; Tedford and others, in press). A fission-track (glass) date of 5.3 ± 0.4 m.y. is known from the Hemphil-

lian stratotype (Boellstorff, 1976). MacFadden
two fission-track (zircon) dates from ashes
stratotype. The lower ash is 5 m below the top
at 170 m and also 5 m above the base of magn
ash is dated at 5.2 ± 1.0 m.y. The upper ash
upper tuffaceous zone at 365 m and also 15 m
polarity zone R4. This ash is dated at 5.6 ± 0.
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the assertion of approximate contemporaneity
and southern Great Plains faunas.

The late Hemphillian fauna from the Ch
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magnetic polarity zonation of the Chamita F
MPTS (fig. 10). Considering all the relevant
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time. Within epoch 5, the characteristic eve
which extends from 110 to 165 m, is represen
R3-R6, which extend from 285 m to the top
early to medial Gilbert time. Within the Gil
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by zones N4 and N5. Se. e workers represent
normal polarity, termed "C_1" and "C_2," punc
reversed polarity (Opdyke, 1972). This latter
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stratotype. The existence of this event in the
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section that apparently represents the same tim

Within event A of epoch 5 there is one zo
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Zone N2 is represented by one site each fro
zone is interpreted as a previously unrecogniz
based on average rates of sedimentation, has a
10^4 yrs. Detection of a short-period event is not
prior to approx 5 m.y. ago (Blakely, 1974).

Studies of terrestrial magnetic polarity s
as southwestern North America demonstrat
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The late Hemphillian fauna from the Chamita Formation stratotype and radiometric ages suggest an absolute time interval of roughly 6 to 4½ m.y. With this control in mind, it is now desirable to compare the magnetic polarity zonation of the Chamita Formation stratotype to the MPTS (fig. 10). Considering all the relevant data, numerous hypotheses could be constructed; the following is the most plausible: I assert that zones N1-N3, which extend from the base of the stratotype to 285 m and are of predominantly normal polarity, represent medial to late epoch 5 time. Within epoch 5, the characteristic event A of reversed polarity, which extends from 110 to 165 m, is represented by zones R1-R2. Zones R3-R6, which extend from 285 m to the top of the stratotype, represent early to medial Gilbert time. Within the Gilbert, event C of predominantly normal polarity, which extends from 375 to 470 m, is represented by zones N4 and N5. Some workers represent event C as two events of normal polarity, termed "C1" and "C2," punctuated by a short event of reversed polarity (Opdyke, 1972). This latter reversed event is probably represented by zone R5 that locally extends from 430 to 450 m in the stratotype. The existence of this event in the stratotype is not certain, because it is only recorded in one local section and not in another local section that apparently represents the same time interval.

Within event A of epoch 5 there is one zone of normal polarity, represented by N2, that has not previously been reported in the literature. Zone N2 is represented by one site each from two local sections. This zone is interpreted as a previously unrecognized short-period event that, based on average rates of sedimentation, has a duration on the order of 10^5 yrs. Detection of a short-period event is not surprising for the Cenozoic prior to approx 5 m.y. ago (Blakely, 1974).

Studies of terrestrial magnetic polarity stratigraphy in places such as southwestern North America demonstrate the feasibility of integrating different subdisciplines of earth science to formulate hypotheses. In this type of study there is positive feedback from paleomagnetism, paleontology, sedimentology, and geochronology. Extension of paleomagnetic studies to land has opened a new area of interest. Recognition of terrestrial sequences that correlate to the sea-floor anomaly and deep-sea sedimentary records corroborate the utility of the MPTS. The terrestrial record has been intensively investigated for the time interval of roughly

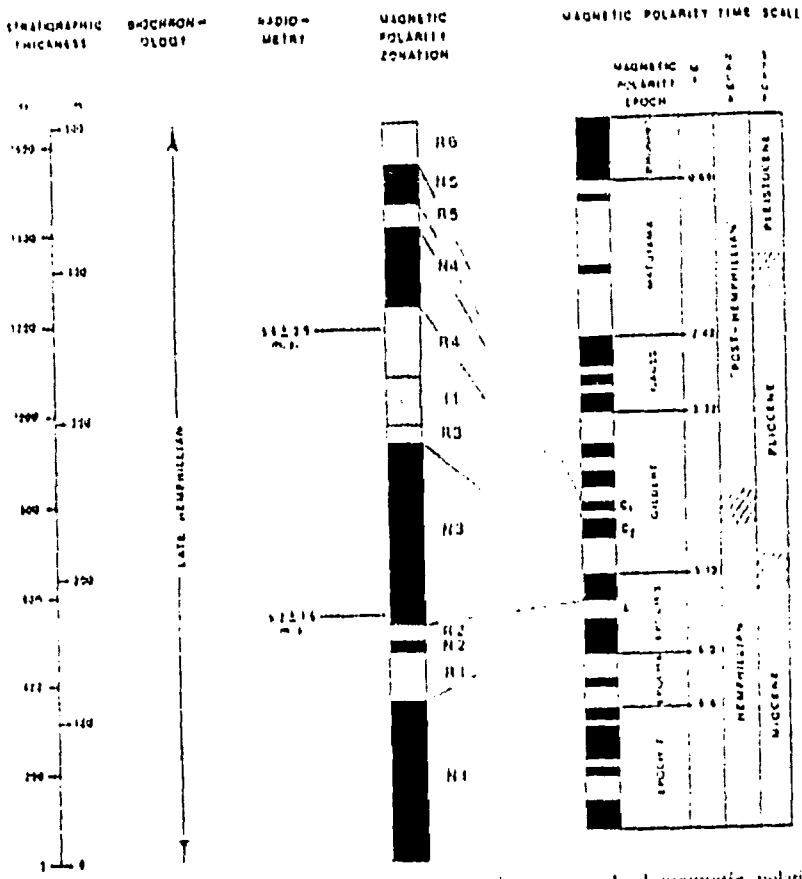

Fig. 10. Correlation of magnetic polarity zonation to standard magnetic polarity time scale using independent biochronologic and radiometric control. Radiometric age determinations are from MacFadden and Manley (1976). Boundaries of magnetic polarity epochs, in absolute m.y., are taken from Opdyke (1972) and Berggren and Van Couvering (1974). Boundaries between North American Land Mammal Ages and Cenozoic Stages are approximately indicated by zones of diagonal lines. See figure 1 for symbols.

0 to 5 m.y. ago. The next task is to extend the time scale back into the Cenozoic. This will be somewhat more difficult principally because of the proportional error margin associated with radiometric dates. Prior to roughly 5 m.y. ago, the error margin on most radiometric dates is too great to facilitate correlation of isolated magnetic polarity zones to the MPTS. In these cases terrestrial sequences that span several million years will be more attractive because of the possibility of pattern recognition, especially when dealing with time intervals with distinctive polarity signatures, for example, the long period of predominantly normal polarity that represents epoch 9 (= anomaly 5 on the ocean floor). Ultimately, in geographically separated areas characterized by faunal endemism, mag-

netic polarity stratigraphy will be used fo
Further ramifications of magnetic polarity's
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glance may appear unrelated, have initiate
science.

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partment of Geological Sciences at Columbia

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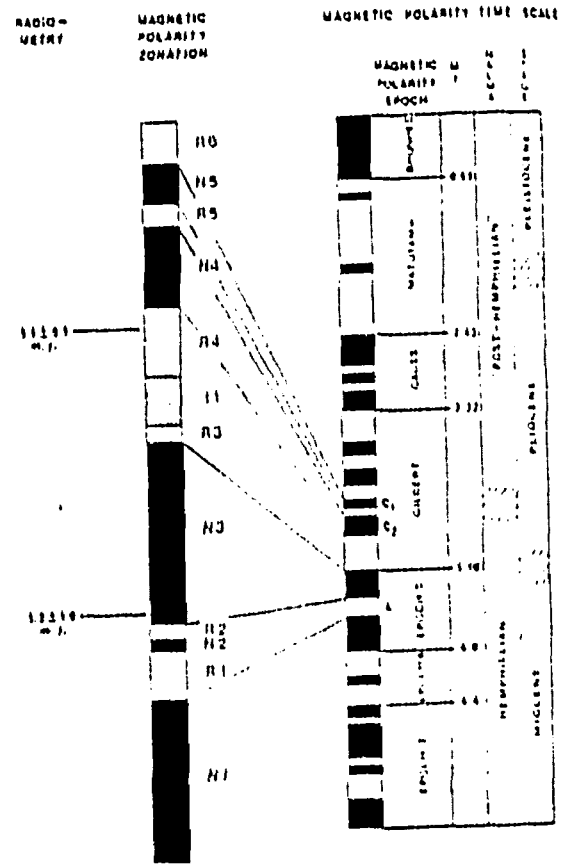

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Appendix

Sites outside stratotype

Five sites were sampled from sediments correlated by Galusha and Blick (1971) to the Chamita Formation stratotype. Based on paleomagnetic analysis, three of these proved to be statistically significant.

Galusha and Blick (1971) correlate sediments north of the type area to the stratotype. This correlation is made in a general way based on lithologic and faunal similarities. This correlation is indeed difficult because there are no distinct marker beds, for example, volcanic ashes, that can be traced laterally. North of the settlement of Lyden (U. S. Geol. Survey Lyden 7½' Quadrangle), in sediments underlying the Servilleta Formation of Black Mesa, Frick field parties collected numerous fossil mammals from "Lyden Quarry."[a] The assemblage from this horizon is generally similar to the fauna from the stratotype. Two paleomagnetic sites were analyzed from the approximate locality of Lyden Quarry; both are of reversed polarity. With preliminary data such as these, it is not worthwhile to make a definite statement with respect to the magnetic polarity chronology of this locality. As a first-order approximation based on the general similarity of the fossil mammals, one might very tentatively correlate the reversed sites at Lyden Quarry to early-medial Gilbert as represented in the stratotype. It must be realized that this hypothesis is quite vulnerable to falsification.

One site was collected from the Servilleta Formation that unconformably overlies Chamita Formation sediments several hundred meters northwest of the type area. This site is of reversed polarity. Ozima and others (1967) present radiometric dates for the Servilleta Formation near Taos that range from 4.5 to 3.6 m.y. Manley (1976) has obtained a K-Ar (whole rock) date of 2.78 ± 0.14 m.y. from the Servilleta Formation near the paleomagnetic locality sampled for the present study. This date demonstrates that the Servilleta Formation is younger to the south. The paleomagnetic site probably represents a reversed event during the Gauss Epoch, which is predominantly of normal polarity.

Two sites were sampled from Round Mountain Quarry. This quarry is located approximately 21 km southwest of the stratotype (a detailed locality description is given by Galusha and Blick, 1971). Only one site, which is located less than 5 m below the quarry horizon, proved to be statistically significant, and it is of normal polarity.

There has been considerable confusion with regard to the correlation of sediments outside the Chamita Formation stratotype. Galusha and Blick (1971) correlate the abbreviated section that includes Round Mountain Quarry to the stratotype. The mammalian assemblage from this locality is one of the most diverse from the entire Santa Fe Group, but it is largely undescribed. This assemblage appears to be considerably older than the fauna from the stratotype and is probably most similar to other late Clarendonian assemblages.

It is not possible to support a hypothesis concerning the single site of normal polarity at Round Mountain Quarry. It must be remembered that this locality and others, such as Battleship Mountain, appear to be significantly older than the stratotype. It is possible that the Round Mountain section is older than part of the upper Tesuque Formation.

[a] In F:AM field notes, there is occasional reference to a Lyden Quarry locality that is either "east of Taos road" or "east of Rio Grande." Any of these entries are actually geographically (and stratigraphically) closer to the *Osbornoceros* locality and should not be correlated definitely to Lyden Quarry.

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SUBJECT/TITLE: Sedimentation Pattern of a Rift-Filling Unit, Tesuque Formation (Miocene), Espanola Basin, Rio Grande Rift, New Mexico

RECORD TYPE (Circle relevant type for primary record; type of attachments should be selected on *Keywords List*):

Analytical Data	Excerpt	Map	Procedure	Summary
Article	FAX	Memo	Purchase Request	Table
Chain of Custody	Figure	Microform	Receipt Acknowledgment	Telephone Record
Chart	Form	Notebook	(Report)	TOC
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LIST RELEVANT TECH AREA(S)	LIST RELEVANT ADS NO(S)	LIST RELEVANT STRUCTURE NO(S).	LIST RELEVANT SWMU NO(S)/PRS
—	1129	—	—

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MISCELLANEOUS (List other indexing criteria as necessary; please write legibly):
OU 1129, Sedimentation, Miocene, Rift, excerpt, Rio Grande, Espanola

Abandon
Aboveground Tank
Absorption
Abstract
Accelerator
Access
Accident
Acid
Active
Activities
Administrative
ADS (Activity Data Sheet)
Adsorption
AEC (Atomic Energy Commission)
Aerial
Agenda
Agreement
AIP (Agreement in Principle)
Air
Alpha
Americium
Analysis
Analytical
AOC (Area of Concern)
Approval
Aquifer
ARAR (Applicable, Relevant, or Appropriate Requirements)
Archaeology
Archive
Area
Arsenic
Asbestos
Asphalt
Assessment
Audit

Backfill
Background
Bacteria
Barium
Baseline
BCP (Baseline Change Proposal)
Beds
Bermed Area
Beryllium
Beta
Biology
Bivit
Boiler
Boneyard
Bunker
Buried
Burn

Cadmium
Caisson
Calibration
CAMU (Corrective Action Management Unit)
Canyon
Capacitor
Caustic
CEARP (Comprehensive Environmental Assessment and Response Program)
Cement
CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act)
Certification
Cesium
Chain of Custody
Chamber
Change Control
Change Order
Charge
Chart
Checklist
Chemical
Chromium
Cleanup
Clearance
Closure
Clothing
CMI/RA (Corrective Measures Implementation/Remedial Action)
CMS/FS (Corrective Measures Study/ Feasibility Study)
Cobalt
Comment
Committee
Community Relations
Company
Compliance
Compressed Gas
Computer Modeling
Computer Output
Concern
Concrete
Concurrence
Configuration
Construction
Container
Containment
Contaminant
Contract
Control
Controlled Distribution
Copper
Core
Corrective Action
Correspondence
Criteria
Cyanide
Cyanogen

Data
Deadline
Debris
Decision Analysis
Decommission
Decontamination
Deficiency
Deliverable
Demolition
Description
Detection
Detonation
Development
Diesel
Discharge
Disposal
Documentation
DOE (Department of Energy)
Dose
DQO (Data Quality Objectives)
Draft
Drainage
Drainline
Drawing
Drilling
Drop Tower
Drum
Dry Well
Dump

Ecology
Effluent
EIS (Environmental Impact Statement)
Electrical
Emission
Engineering
Environmental
EOD (Explosive Ordnance Disposal)
EPA (Environmental Protection Agency)
Equipment
ERDA (Energy Research and Development Administration)
Erosion
ERPO (Environmental Restoration Program Office)
ES&H (Environment, Safety, and Health)
Estimate
Evacuation
Evaluation
Evaporator
Evidence
Excavation
Exclusion
Exhaust
Experiment
Explosive
Exposure
Extension
Extraction

Facility
Fallout
Farm
FAX
Fence
Field
Figure
Filter
FIMAD (Facility for Information Management, Analysis, and Display)
Finding
Fire
Firing Site
Fiscal
Fission
Five-Year Plan
Flow
Flow chart
Fluid
Form
Framework
Fuel
Fume

Gamma
Gas
Generation
Generic
Geochemistry
Geology
Geophysics
Glass Beaker
Glove Box
Graph
Guidance
Gun

Handling
Hazardous
Headquarters
Health
HE (High Explosive)
History
HMTA (Hazardous Material Transportation Act)
Hole
Home Owner
Hood
HSWA (Hazardous and Solid Waste Amendments)
Hydrology
Hygiene

Impact
Implementation
Implosion
Impoundment
Inactive
Incident
Incinerator
Industrial
Infiltration
Injection Well
Injury
Inorganic
Inspection
Installation
Interim
Interim Action
Internal
Interview
Inventory
Investigation
IRM (Interim Remedial Measure)
Isotope
IWP (Installation Work Plan)

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(2)

SEDIMENTATION PATTERN OF A RIFT-FILLING UNIT, TESUQUE FORMATION (MIOCENE), ESPAÑOLA BASIN, RIO GRANDE RIFT, NEW MEXICO

WILLIAM CAVAZZA

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SEDIMENTATION PATTERN OF A RIFT-FILLING UNIT, TESUQUE FORMATION (MIOCENE), ESPAÑOLA BASIN, RIO GRANDE RIFT, NEW MEXICO[1]

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ABSTRACT: The Miocene Tesuque Formation is a > 2,000m-thick sedimentary unit filling most of the Española basin, an asymmetrical basin which is part of the Rio Grande continental rift in north-central New Mexico (U.S.A.). It is composed of conglomerate, sandstone, mudrock, and limestone of nonmarine origin, with numerous interbedded ashfall-tuff layers. The sedimentation pattern of the Tesuque Formation was determined by the interaction of two distinct paleodrainage systems deriving from the eastern and northeastern margins of the Española basin during the rifting process. The two systems generated two lithosomes, which can be discriminated in outcrop by means of paleocurrent study, sandstone and conglomerate petrology, and sedimentary facies analysis. Their surficial expressions are called provinces A and B. Province A has westward paleocurrents and a mixed plutonic and medium-to-high-grade metamorphic provenance. Province B has SSW-directed paleocurrents and significant volcanic and sedimentary detrital inputs. Both provinces represent deposition in a dynamic alluvial-fluvial-lacustrine environment. Nevertheless, sedimentary facies of province A are representative of an ephemeral environmental regime, whereas those of province B seem to represent a more perennial regime.

The basin fill, as a whole, is organized in upward fining megasequences averaging about 200 m in thickness. The gradual passage from proximal to more distal environments of deposition is documented within several megasequences. The lower part of these megasequences is composed of braidplain deposits, whereas the upper (and finer) part is characterized by sandflat deposits, lacustrine carbonates and nodular calcretes.

Although the eastern margin of the Española basin (contributing the detritus of the Tesuque Formation) represents the relatively unfaulted side of a half graben, the documented upward fining megasequences are comparable to similar megasequences derived from tectonically active basin margins. This suggests that sedimentation style on a shallow ramp along the tectonically inactive side of a half graben can be determined by tectonism of the master fault system along the opposite (deeper) side of the basin.

INTRODUCTION

Early structural models envisioned continental rifts as rather simple structures characterized by two facing planar normal faults and a downfaulted keystone (e.g., Cloos 1930; Cogne et al. 1966; Illies 1981). This postulated structural symmetry was also reflected by proposed facies models, emphasizing valley symmetry and the existence of two opposing alluvial fan systems issuing from facing fault scarps.

Recent structural/geophysical studies have demonstrated that the fundamental structural element of continental rifts is the half graben rather than the symmetrical graben (Gibbs 1984; Rosendahl et al. 1986). Boundary faults are commonly listric, and they sole in low-angle, deep crustal detachments. Furthermore, continental rift systems commonly consist of several asymmetrical segments with opposing structural polarity (Bally 1982; Gibbs 1983, 1984; Bosworth 1985; Rosendahl et al. 1986).

The structural configuration of continental rifts results in complex sedimentation patterns. Extensive research on rift basin sedimentation in East Africa (Frostick and Reid 1980; Cohen et al. 1986; Reid and Frostick 1986; Tiercelin 1986; Williams et al. 1986; Williamson and Savage 1986) has demonstrated that half-graben shoulders are not the major sources of sediment, at least during early stages of rifting. In fact, they often become barriers to drainage, and the faulted margin may become sediment starved (Frostick and Reid 1987). Major sources of sediment to the rift basin are the axial drainage (if present) and the steeper streams which cross the half graben rollover (i.e., the ramp facing the boundary fault).

This paper documents the sedimentation pattern of an ancient continental rift basin, the Española basin of north-central New Mexico. In this asymmetrical basin, all of the rift deposits which are now observable in outcrop were derived from the ramp facing the major boundary fault and not from the rift shoulder. Nevertheless, vertical arrangement of the basin fill was determined by tectonism along the master fault.

REGIONAL SETTING

The Rio Grande rift is a late Cenozoic continental rift system traceable as a continuous single rift valley from central Colorado to central New Mexico over a distance of more than 1,000 km. According to Chapin (1979), rifting began between 32 and 27 Ma. The first phase of rifting was characterized by broad shallow basins. These early basins have been envisioned either as broad synclines (Baltz 1978) or as being bounded by low-angle normal faults (Baldridge et al. 1984). Subsequently, rifting has been characterized by right-echelon stepping of the linked basins forming the rift system (Kelley 1979, 1982). This structural pattern is most evident in the central portion of the Rio Grande rift in north-central New Mexico. In this region, from south to north, the Albuquerque-Belen, Española and San Luis basins step en echelon to the northeast and are separated by complex transverse structures. These three basins are half grabens with basin-fill sediments tilted oppositely in each successive basin.

The current morphology of the Rio Grande rift began

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Chemical Quality of Effluents and Their Influence on Water Quality in a Shallow Aquifer[1]

W. D. Purtymun, J. R. Buchholz, and T. E. Hakonson[2]

ABSTRACT

The chemical quality of liquid effluent released from an industrial waste treatment plant at the Los Alamos Scientific Laboratory controls the quality of water in a shallow aquifer in the alluvium of Mortandad Canyon. The dilution of the effluent with surface flow in the canyon reduces the concentrations of the chemicals as they move down gradient into the aquifer. Mass estimates of residual chemicals in solution in the aquifer average 1–6% of the total chemicals released to the canyon from 1963–1974. The average annual concentration of sodium, nitrate, chloride, and total dissolved solids in the aquifer through a 12-year period was directly correlated with annual average concentrations in the effluent. This relationship provides a means of predicting the impact of the chemical effluents on the quality of water in the aquifer.

Additional Index Words: dilution ratios, mass inventories, regression.

Industrial liquid wastes resulting from some of the scientific programs at the Los Alamos Scientific Laboratory (LASL) are collected and processed at a waste treatment plant at Technical Area (TA) 50 located adjacent to Mortandad Canyon. The plant, which became operational in June 1963, has been the sole source of treated effluents to Mortandad Canyon. Hydrologic studies which were initiated in 1960 have continued as a part of an overall evaluation of the impact of the effluents on the environment (1, 3, 4). The purpose of this study was to investigate annual changes in the chemical quality of water in the canyon resulting from the release of effluents through the period of 1963–1974. An annual mass inventory was made of chemical additions to the canyon and of the residual chemicals in storage in the aquifer; empirical data were used in developing a predictive model for estimating the concentrations of selected constituents in the aquifer.

METHODS AND MATERIALS

The stream in the upper reach of Mortandad Canyon is perennial due to the release of effluents from TA-50 and to additions of water from TA-48 which is located upstream from TA-50. The water from TA-48 (1.7×10^4 liters/day) results from a cooling pro-

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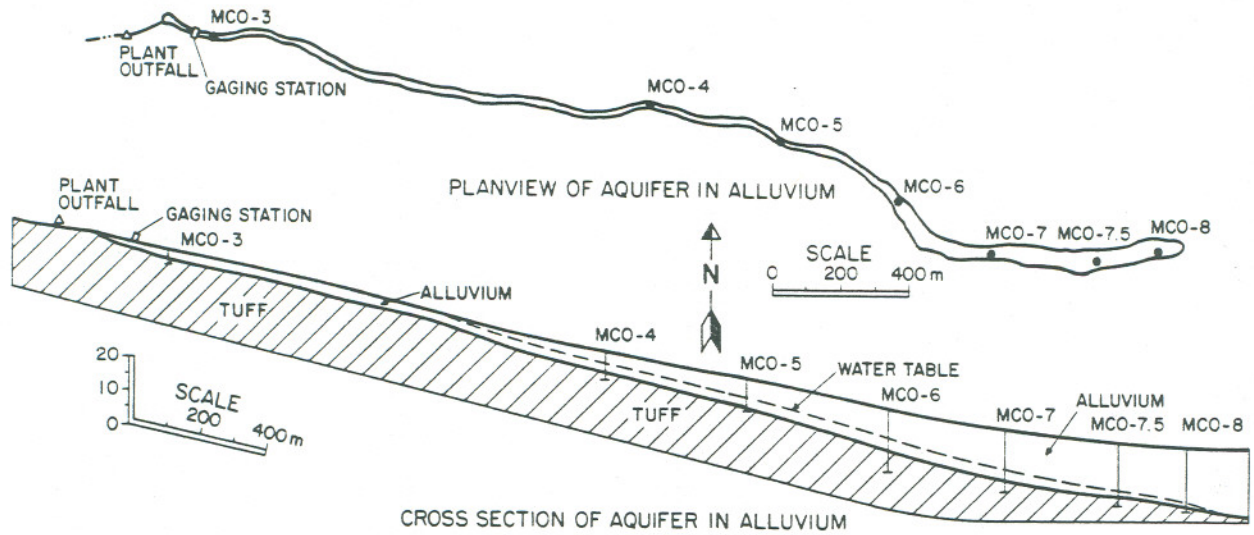

Fig. 1—Planview and cross section of aquifer in alluvium.

cess at this facility. Storm runoff adds to the surface flow in the canyon primarily during the spring and summer months. All of this water recharges a shallow aquifer that is perched in the alluvium on the underlying tuff (Fig. 1). Evapotranspiration and infiltration into the underlying tuff removes water from storage in the aquifer since the aquifer is not a part of the municipal or industrial water supply. The main aquifer which is the source of domestic and industrial water, lies at a depth of 293 m beneath the floor of the canyon. The two aquifers are separated by about 250 m of unsaturated strata.

The industrial liquid wastes collected at TA-50 contain varying amounts of chemical and radiochemical constituents. All of the influent wastes are subjected to a chemical-ion exchange treatment process. During treatment, various chemicals are added under controled conditions to enhance radionuclide decontamination factors. Some of the added chemicals remain in the effluent which is released when radioactivity is $< 10\%$ of the maximum permissible concentration (5). Records of volume of effluent released into the canyon are kept as part of the plant records.

The volume of surface water entering the canyon was determined from flow measurements obtained at a gaging station (Fig. 1). The station was equipped with a water-stage recorder on a 0.152-m (6-inch) modified Parshall flume (for low flow) overset with a 1.22-m (4-foot) wier (for large runoff events) and was rated using standard methods.

The volume of water in storage in the aquifer was determined from seven test holes across the canyon floor (Fig. 1). Water level measurements in the test holes were made in December to determine the volume of saturation at that time.

The chemical characteristics of TA-50 effluent were determined from composite samples of the wastes. Data from weekly composites were applied to release-volume and were averaged over the year. The chemical quality of water from the aquifer was determined 3–4 times annually and averaged for the year. Analytical methods used for various chemical constituents in the effluent and in the water from storage are outlined elsewhere (2).

RESULTS AND DISCUSSION

The volume of storm runoff and TA-48 water passing through the gaging station from 1962 through 1974 ranged from 25×10^3 m^3/year to 125×10^3 m^3/year for an average annual flow of about 58×10^3 m^3/year (Table 1). The volume of effluent released annually from TA-50 was less variable ranging from 40×10^3 m^3/year to 60×10^3 m^3/year. The dilution ratio (storm runoff and TA-48 water/TA-50 effluents) ranged from 0.6 to 1.7 from 1964–1974 and averaged about 1.0. The average annual volume of surface water (effluent and runoff) entering the canyon was about 105×10^3 m^3. There has been no surface flow out of the canyon during the period of study due to the rapid infiltration of surface water into the alluvium.

The volume of water in the aquifer in December was relatively constant from year to year (Table 1). Seasonal variations were observed with lowest volumes occurring during the winter and early spring and maximums occurring after spring snowmelt and storm runoff during the summer. The volume of water in storage at the end of each calendar year ranged from 19×10^3 m^3 to 30×10^3 m^3 during 1961–1974. Annual losses of water (i.e., added volume–storage volume) ranged from 65×10^3 m^3 to 146×10^3 m^3/year through a 13-year observation period and averaged 105×10^3 m^3 or about the same volume that entered the canyon each year. Water losses from the aquifer were attributed to infiltration and/or evapotranspiration. The losses attributed to evapotranspiration were estimated at about 15% based upon work described

Table 1—The estimated balance of water in the Mortandad Canyon watershed

Year	Effluent TA-50	Storm runoff and TA-48 water	Dilution ratio	Storage in aquifer†	Annual surface and ground water loss in canyon
	$\times 10^3$ m^3			$\times 10^3$ m^3	
1961	--	--	--	20	--
1962	--	70	--	20	70
1963	27‡	125	--	22	150
1964	51	59	1.2	24	108
1965	49	75	1.5	25	123
1966	53	35	0.7	20	93
1967	60	79	1.3	30	129
1968	60	52	0.9	24	118
1969	54	93	1.7	25	146
1970	53	50	0.9	20	108
1971	46	29	0.6	29	66
1972	57	26	0.5	23	89
1973	54	37	0.7	19	95
1974	40	25	0.6	19	65

† Storage as of December 31.
‡ Six months (July to December).

Table 2—Chemical quality of industrial effluent from TA-50; storm runoff and waste water from TA-48.

Effluent TA-50	Chemical constituents										Specific conductance at 25C	pH
	Calcium	Magnesium	Sodium	Carbonate	Bicarbonate	Chloride	Fluoride	Nitrate	Dissolved solids	Total hardness		
year	mg/liter										μmhos/cm	
1963†	52	1.4	188	302	376	28	1.7	63	830	135	1,730	11.6
1964	36	0.9	219	280	386	41	2.5	97	960	94	1,950	11.6
1965	40	0.8	196	278	367	30	2.2	131	860	109	2,070	10.9
1966	52	3.2	151	213	292	17	1.4	50	660	145	1,280	11.4
1967	110	3.1	120	226	306	21	2.3	55	570	289	1,520	11.2
1968	100	2.7	153	265	353	28	3.2	63	620	259	1,630	11.2
1969	91	2.3	286	300	428	34	2.7	131	940	235	1,990	11.2
1970	56	4.8	406	354	472	38	2.1	551	1,500	155	2,340	11.2
1971	42	3.9	433	218	641	169	2.7	372	1,590	120	2,450	9.2
1972	30	3.6	571	91	506	108	1.2	766	1,670	91	2,570	8.8
1973	33	5	310	52	331	60	1.5	310	1,150	105	1,530	9.0
1974	43	4	443	256	561	53	2.6	290	1,540	123	2,640	7.9
Storm runoff	29 (26)‡	3 (46)	22 (26)	0	102 (31)	9 (46)	0.3 (75)	0.5 (41)	174 (21)	103 (17)	192 (35)	8.7
Waste water TA-48	11 (28)	4.3 (77)	58 (49)	0	140 (34)	7.6 (45)	0.9 (33)	1.0 (53)	280 (47)	47 (43)	202 (44)	7.5

† Six months (July to December).

‡ Parenthetic values equal the coefficient of variation [(standard deviation/mean) × 100]; storm runoff means based on a sample size of 12, waste water (TA-48) on a sample size of 9.

elsewhere with infiltration accounting for the remainder (4).

The alluvium in Mortandad Canyon is derived from erosion and weathering of a rhyolite tuff. This alluvium is quite permeable; studies using tritium and chloride as tracers indicate water velocity in the aquifer ranges from 2 to 20 m/day with the higher velocity occurring in the upper reaches of the canyon. Total travel time from the effluent outfall to the eastern extent of the aquifer (about 3 km) is about 1 year (4).

The water from the cooling process at TA-48 originates from a supply which contains ambient levels of the various chemicals. Chemicals are not added during use of this water, thus, chemical quality has not changed significantly through the years (Table 2). Analysis of storm runoff indicates little chemical changes over a 12-year observation period as evidenced by the generally small coefficients of variation (Table 2).

Liquid effluents from TA-50 are the major source of chemicals entering Mortandad Canyon (Table 2). Most of the measured chemical concentrations generally averaged 2 to 20 times higher in TA-50 effluent than in the other two sources (TA-48 and runoff). One exception was magnesium, which averaged higher in storm runoff water. Many of the chemicals in the effluent from TA-50 have increased since 1963 although not in a consistent pattern. Parameters exhibiting increases include magnesium, sodium, bicarbonate, chloride, nitrate, dissolved solids, and conductivity. Relatively stable or decreasing values were observed for calcium, carbonate, fluoride, total hardness, and pH.

The release of industrial effluents into the canyon has changed the quality of the water in the aquifer (Table 3). The pH of the water has changed from 6 to 8 due to the alkaline nature of the liquid effluents. Most of the remaining chemical parameters have increased since 1962, although not consistently with time. The levels of fluoride and bicarbonate have approximately doubled, while for values for calcium, magnesium, sodium, chloride, nitrate, dissolved solids, and specific conductance have increased by factors of 3 to 7. Carbonates remained nondetectable in aquifer water through the entire observation period due to their conversion to HCO_3^- and CO_2 under the conditions in the aquifer.

Annual average concentrations of sodium, chloride, nitrate, and total dissolved solids in the effluent were compared with corresponding concentrations in solution in the aquifer to determine the relationship between

Table 3—Chemical quality of water in aquifer

Year	Chemical constituents										Specific conductance at 25C	pH
	Calcium	Magnesium	Sodium	Carbonate	Bicarbonate	Chloride	Fluoride	Nitrate	Dissolved solids	Total hardness		
	mg/liter										μmhos/cm	
1962	11	4	32	0	91	7	0.6	3.0	320	45	360	6.8
1963	14	5	53	0	90	9	0.5	16	310	67	360	7.2
1964	19	7	100	0	123	21	0.7	68	500	76	510	7.5
1965	16	5	99	0	143	13	0.7	40	400	59	440	7.6
1966	18	4	97	0	172	25	0.4	28	400	62	470	7.7
1967	21	7	140	0	147	16	0.7	15	340	82	400	7.7
1968	17	6	110	0	138	12	0.7	8	300	68	360	7.9
1969	23	5	140	0	129	11	0.5	25	370	81	410	8.2
1970	26	7	132	0	143	15	0.5	137	530	84	560	7.6
1971	44	11	228	0	176	54	0.9	366	990	153	1,130	7.7
1972	40	11	215	0	223	54	0.7	248	910	144	1,000	7.5
1973	33	7	164	0	221	34	1.0	204	786	112	910	7.7
1974	27	6	188	0	254	32	1.0	207	785	93	970	7.7

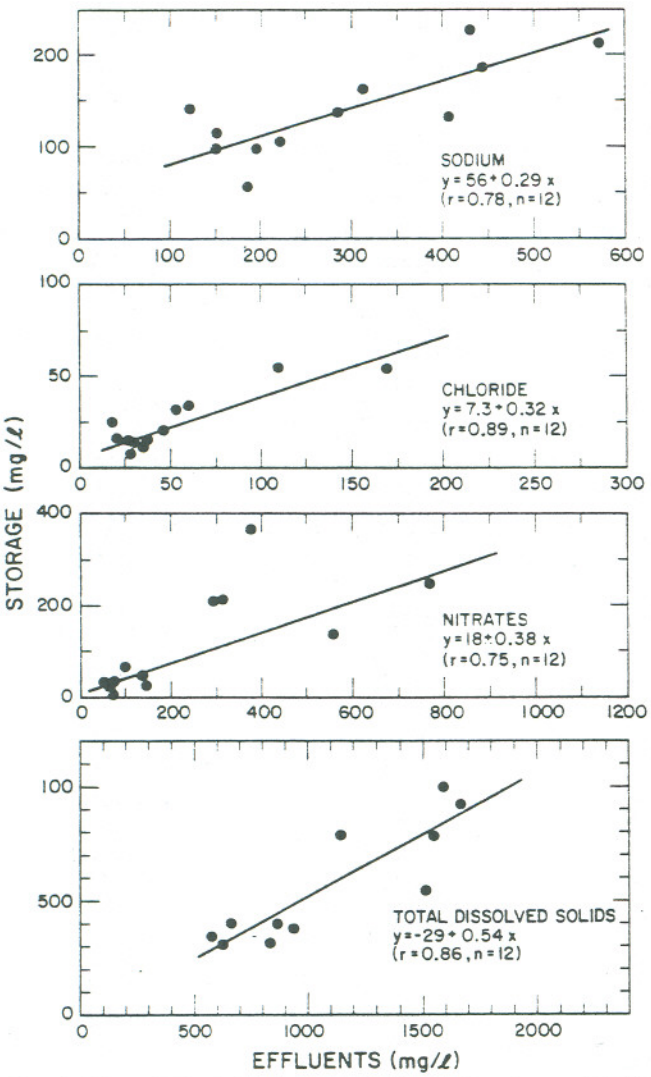

Fig. 2—The relationship of concentrations of sodium, chloride, nitrate, and total dissolved solids in treated effluent to corresponding concentrations in solution in the aquifer.

chemical release and levels appearing in the aquifer (Fig. 2). The linear least squares regressions were all highly significant ($P < 0.01$) with multiple correlation coefficients (r^2) ranging from 0.61 to 0.80.

The slopes of the four regression lines indicate that concentrations of the chemicals in solution in the aquifer averaged from 30–50% of those measured in the effluent when prerelease concentrations (i.e., intercept values) were taken into consideration. Recall that the chemical effluents from TA-50 are diluted with about equal volumes of storm runoff and TA-48 water. Thus, the reduction in chemical concentrations in the aquifer could be the result of dilution alone. The intercepts of the regression lines for sodium, chloride, and nitrate were not significantly different from pre-effluent release levels of chemicals in the aquifer indicating a rapid "turn-over" of

Table 4—Mass inventory of chemicals released and in storage

Constituents	Effluents, TA-50 1963–1974	In storage 1962	In storage 1974
	kg × 10^3		
Calcium	35	0.2	0.5
Magnesium	1.8	0.08	0.1
Sodium	170	0.6	3.6
Carbonate	84	0	0
Bicarbonate	150	1.8	4.8
Chloride	31	0.1	0.6
Fluoride	1.3	0.01	0.02
Nitrate	150	0.06	3.9
Total dissolved solids	640	6.4	15

the water in storage. This is supported by results of the tracer studies indicating water transit times of about 1 year (4).

The mass of chemicals added to Mortandad Canyon was estimated from the concentration and volume data in Tables 1 and 2. Corresponding estimates for aquifer water were made from data in Tables 1 and 3. About 625,000 kg of the eight chemicals listed in Table 4 were released into Mortandad Canyon from 1963–1974. Nearly 90% of this mass consisted of nitrates, bicarbonates, carbonates, and sodium with calcium, magnesium, chloride, and fluoride comprising the remainder.

Mass inventories of most of the chemicals in solution in the aquifer during 1974 were higher by factors of 2 to 65 over pre-effluent release inventories (Table 4) and averaged 1–6% of the total chemical releases. The largest increases over prerelease inventories were noted for sodium and nitrate, reflecting relatively larger concentrations of these chemicals in TA-50 effluent.

Chemical concentrations in solution in the aquifer have increased over prerelease levels, however, there has not been a steady accumulation of these materials in the water with time. The rapid loss of water and its associated chemicals from the aquifer prevents chemical accumulation and indicates that cessation of effluent release to the canyon would rapidly improve the quality of water in the aquifer.

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LANL PROCEDURE ADOPTION COVER PAGE

APPROVALS

Controlled Copy 7

Mark D. Shepard for JOHN DEJOIA 6/18/03
WGII Program Manager / Date

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Author: Rick Haaker

ENVIRONMENTAL RESTORATION PROJECT

A Department of Energy Environmental Cleanup Program

Washington Group International Environmental Restoration Project Standard Operating Procedure

for:

Use of Gamma Scintillation Detectors for Soil Screening

Los Alamos
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Revision (Date)	*Prepared By*	*Description of Changes*	*Affected Pages*
Rev 0, 07/18/01	Rick Haaker	New Procedure	All
Rev 1, 06/23/03	Andrew Crowder	Change to non-site specific use	All

Use of Gamma Scintillation Detectors for Soil Screening

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Procedure for use of gamma scintillation detectors to estimate radionuclide concentrations in soil samples

NOTE: ER Project personnel may produce paper copies of this procedure printed from the controlled-document electronic file located at http://erinternal.lanl.gov/documents/Procedures/qps.htm. However, it is their responsibility to ensure that they are trained to and utilizing the current version of this procedure. The author may be contacted if text is unclear.

1.0 PURPOSE

This procedure describes the use of gamma scintillation detectors and the single channel analysis method to estimate and record concentrations of radionuclides in soil samples. The intended audience for this procedure includes health physicists, radiological engineers and instrument technologists.

2.0 SCOPE

2.1 This SOP is a mandatory document and shall be implemented by all ER Project participants when they perform soil gamma screening for americium-241 and cesium-137 for the ER Project.

2.2 Subcontractors who perform work under the ER Project's quality program shall follow this SOP for soil gamma screening for americium-241 and cesium-137 or use their own procedure, as long as the substitute meets the requirements prescribed by the ER Project Quality Management Plan and is approved by the ER Project's Quality Program Project Leader (QPPL) before starting the designated activities.

3.0 TRAINING

3.1 All users of this SOP are trained by reading the procedure in addition to hands on training, and the training is documented in accordance with QAP-2.1.

3.2 The **Field Team Leader** (FTL) shall monitor the proper implementation of this procedure and ensures that relevant team members have completed all applicable training assignments in accordance with QAP-2.1.

4.0 DEFINITIONS

NOTE: A glossary of definitions can be located on the ER Project internal homepage *http://erinternal.lanl.gov.*

4.1 Threshold Setting – The pulse height threshold in millivolts. In order to be counted, a photon must produce a voltage spike in the detector circuit that is greater than the threshold setting but less than the threshold setting plus window setting.

4.2 Window In - A configuration on a single channel analyzer that causes the scaler to only count photons that deposit a specific range of energy within the detector.

4.3 Window Setting - The width in millivolts of the window that determines how broad of an energy range of pulses can be counted by the scaler.

5.0 BACKGROUND AND PRECAUTIONS

Note: This SOP is to be used in conjunction with an approved SSHASP. Also, consult the SSHASP for information on and use of all PPE.

Note: This SOP is to be used only on characterized sites such as TA21-011(k) where the radiological contaminants are known and thus the potential interferences are understood. The response factors (GeoFac) provided in Tables A.1 and A.3 are appropriate for Los Alamos soils in the geometry specified. The GeoFac values that are provided should overestimate soil concentrations by about 30 per cent in most instances. The GeoFac values may need to be re-determined if any changes are made to the sample, detector, counting geometry, media to be screened or the isotopes of interest.

6.0 RESPONSIBLE PERSONNEL

The following personnel are responsible for activities identified in this procedure:

- Author
- Field Team Leader
- Quality Program Project Leader

7.0 EQUIPMENT

7.1 Suggested equipment and supplies needed to implement this procedure are:

- Ludlum 2221 Single Channel Analzyer, or equivalent;
- Gamma Scintillation Detector;
- Rubbermaid 14 oz low-form container (round shape);
- Saran wrap (or similar plastic cling wrapping material);
- Calibrated radiation source(s); and

- Calibrated scale.

7.2 The recommended detectors and energy ranges for cesium-137 and americium-241 are:

Isotope	Recommended Detector	Energy Range of Interest
Americium-241 photopeak	Eberline PG-2 or equivalent	45 to 75 KeV
Cesium-137 photopeak plus continuim	Ludlum 44-10 or equivalent	200 to 800 KeV

8.0 PROCEDURE

Note: Deviations from SOPs are made in accordance with QAP-5.1, Procedure Development and documented in accordance with QAP-5.4, Control of Field Notebooks.

Note: The following procedure contains a response factor that is a function of density, composition and geometry. The basis for the response factor must be documented in a memo to the project file.

8.1 The detector and sample geometry indicated in Figure 1 is mandatory. The low-form containers may be re-used without decontamination provided that they are lined with a thin layer of Saran Wrap (or equivalent) that is replaced each time a new sample is counted.

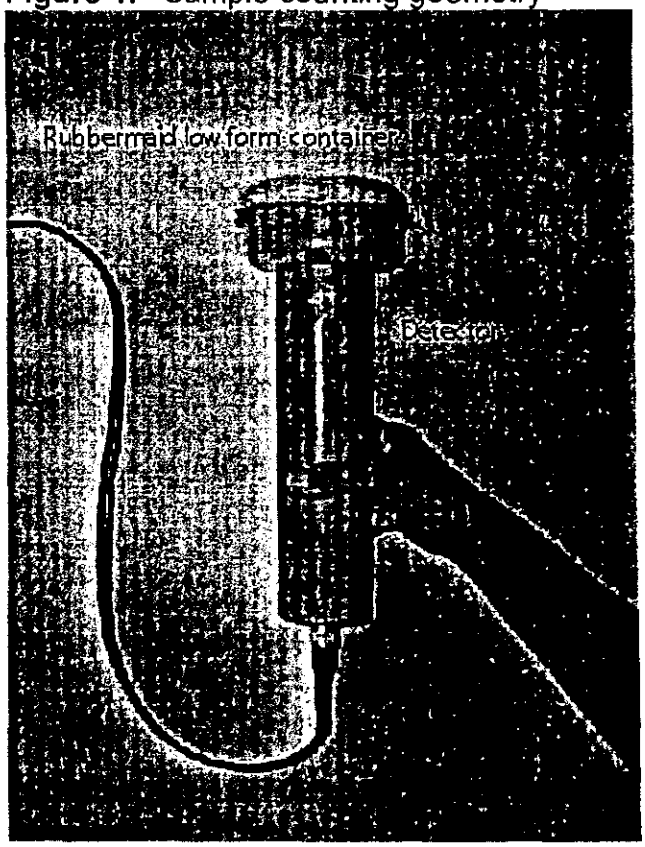
8.2 Preliminary Detector Setup. The following steps are involved in setting up the voltage, window and threshold. Setup for the americum-241 photopeak involves only a one-point calibration. Setup of the cesium-137 region of interest is slightly more complicated since it is based on a two point energy calibration.

8.2.1 Am-241 photopeak: Set up the ratemeter/scaler and PG-2 detector with the window "In" and the unit turned on. Adjust the high voltage reading to a low value (~400 volts) then adjust the threshold to 55 millivolts and the window to 10 millivolts. Place the Am-241 source directly beneath the detector. Roughly set the voltage by eye to give the maximum count rate. As you turn up the voltage, the count rate will gradually increase to a maximum value and then drop off again. Now, precisely set the voltage by performing a series of integrated counts at HV intervals of about 3 volts. Once the voltage giving the maximum count rate is obtained, set the instrument to that voltage. If a more intense Am-241 source is needed, any commercially manufactured

Am-241 source may be used to set the operating voltage. Once the voltage has been set adjust the threshold to 45.0 millivolts and the window to 30.0 millivolts to give a photon energy region of interest of 45 to 75 KeV.

8.2.2 Cesium –137 photopeak: Set up the ratemeter/scaler and Ludlum 44-10 detector with the window "In" and the unit turned on.

Figure 1. Sample counting geometry



Adjust the high voltage reading to a low value (~400 volts) then adjust the threshold to 63.1 millivolts and the window to 6 millivolts. Place the Cs-137 source directly beneath the detector. Roughly set the voltage by eye to give the maximum count rate. As you turn up the voltage, the count rate will gradually increase to a maximum value and then drop off again. Now, precisely set the voltage by performing a series of integrated counts at HV intervals of about 3 volts about the rough maximum voltage. Once the voltage giving the maximum count rate is obtained, set the instrument to that voltage.

8.2.3 Cesium-137 region of interest: Step 8.2.2 has been completed on the ratemeter/scaler and Ludlum 44-10.

8.2.3.1 Replace the cesium-137 source with an americium-241 source and then set the window to 2 millivolts. Gradually turn down the threshold and observe the count rate. The count rate should reach increase to a maximum at a threshold of around 5 mV. If a more intense Am-241 source is needed, any commercially manufactured Am-241 source may be used to determine the threshold setting. Record the threshold and window values for the maximum count rate in the field logbook.

8.2.3.2 Now solve the linear equation for KeV gamma energy versus millivolts: (1) step 8.2.2 produced results 661 KeV and 66.1 mV, and (2) step 8.2.3.1 produced results "60 KeV" and "THRESHOLD + 1 mV".

8.2.3.3 Calculate the mV setting that correspond to 200KeV and set the threshold to that value.

8.2.3.4 Calculate the mV setting that corresponds to 800 KeV. Set the window so that the window and threshold mV values sum to this mV value.

8.3 Response Factor. If media other than soil or crushed tuff will be counted, estimate a preliminary response factor for each type of detector used, if possible. The response factors may be modeled using MCNP or other appropriate software. The basis of the response factor shall be described in a memo to the project file. Once analytical data is obtained from a fixed laboratory, the response factor may be adjusted. The equations given in the Attachment assume that the response factor has the following units:

$$(\text{Counts / Photon Emitted})_{\text{volume source}} / (\text{Counts / Photon Emitted})_{\text{disk source}}.$$

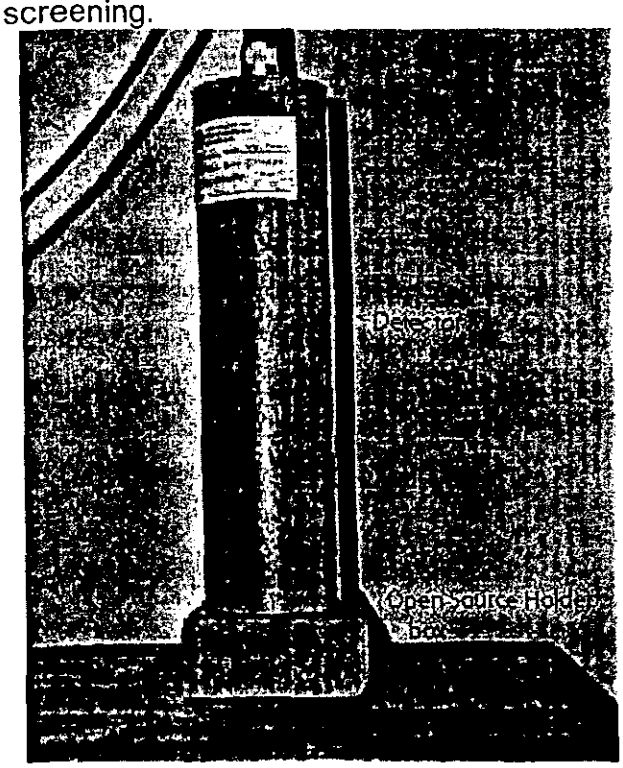
8.4 Daily Operability checks. Perform the following checks before the first use of the day:

8.4.1 <u>In the WGI office,</u> verify operability of the ratemeter/scaler detector. Check battery reading. Verify current calibration date and settings for High Voltage, Window and Threshold. Record the readings in your field logbook.

8.4.2 <u>In the WGI office,</u> perform a response check. Count the cailbrated source and background for 120 seconds. Use a calibrated source in the configuration shown in Figure 2 for the PG-2 (Am-241 source). Use a calibrated source and the configuration shown in Figure 3 for Cs-137. For the Ludlum-44-10, both the 16.8 cm distance between the Cs-137 source and the detector and the orientation are mandatory. Record the readings.

8.4.3 At the fixed counting location, set up the instrument on-site in the configuration shown in Figure 1.

Figure 2: Am-241 Source Check Configuration. The detector shown is a Ludlum 44-10. Normally an Eberline PG-2 would be used for Am-241 soil screening.



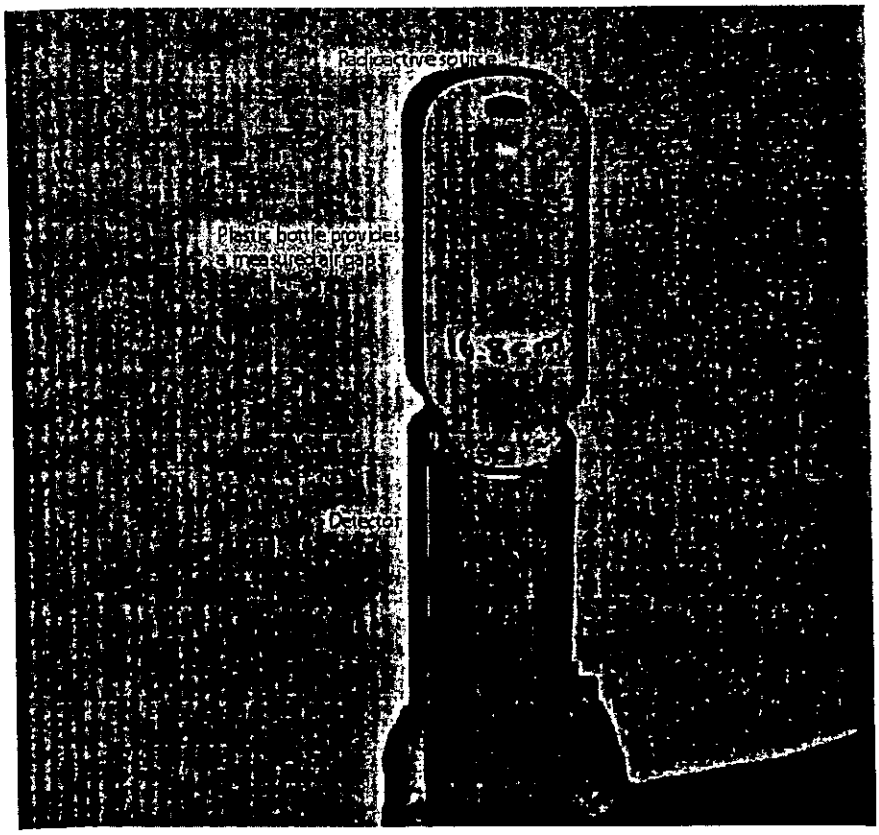
8.4.4 Measure the number of counts in the count interval on a "reference" soil sample collected from an area in the vicinity of the site that is free of radiological contamination. Record the count result (counts) and count duration (seconds or minutes).

8.4.5 Weigh the calibration masses alone and in combination to obtain a scale response for the 400, 700, and 1200 gm masses. The balance performance is acceptable for site gamma screening if all of the measured weights of the calibration masses are within 5 g of the expected values.

8.4.6 Determine the tare weight on an empty Rubbermaid container with lid.

8.4.7 Record all information in a logbook.

Figure 3. Cs-137 source check configuration



8.5 Counting samples. Once the equipment has been response checked for the day, you may proceed to counting the samples.

8.5.1 Determine the gross weight of the sample, including the container cover.

8.5.2 Measure the number of counts in the count interval on the soil sample and note the duration of the count (seconds or minutes).

8.5.3 Enter all data in a field notebook.

8.5.4 Review the data and results.

8.5.5 If a lower detection limit is desired, count the background "reference" (step 8.4.4) and samples (step 8.5.2) for a longer time period. 60-second counts on the reference and samples are expected to give a minimum detectable activity of roughly 10 pCi/g.

8.6 Calculations. The sample problem given in the Attachment provides all equations used in the estimation of concentrations and MDAs.

8.7 Daily Software Checks. Run the test problem to verify that the software calculates the same result for the test problems once rounding error is taken into account.

8.8 Data Management. Record all data in a field logbook or on forms. Suitable forms can be printed out for almost all data from the Microsoft Access database for the counting data.

9.0 REFERENCES

The following documents have been cited/used within this procedure:

- WGII Contractor's Quality Management Plan for the ERPDP
- WGII QAP2.1, Indoctrination and Training
- WGII QAP 4.1, Site Document Control
- WGII QAP 4.2, Site Records Management
- WGII QAP 5.1, Procedure Development
- WGII QAP 5.4, Control of Field Notebooks

10.0 RECORDS

The **FTL** is responsible for submitting the following records (processed in accordance with QAP-4.2, Site Records Management) to the Records Processing Facility.

- Field Notebook
- Sample Collection Logs
- Chain of Custody Forms
- Microsoft Access counting database file

11.0 ATTACHMENTS

11.1 Attachment A: Calculations and Test Problem

Calculations and Test Problem

The pertinent equations used for both Cs-137 and Am-241 estimates are:

Net Weight (NetWt):

NetWt = GrossWt – TareWt

Efficiency (cpm/pCi) (Eff):

Eff = [(SourceCt / SourceS) - (BkgdCt / BkgdS)] * 60 * 2.22 / SA

Net CPM (NetCPM):

NetCPM = [(SampleCt / SampleS) - (SoilBkgdCt / SoilBkgdS)] * 60

Estimated Activity (pCi/g) (EstAct):

EstAct = NetCPM / (Eff * GeoFac * NetWt)

Estimated Minimum Detectable Count Rate (MDCPM):

MDCPM = (3 + 3.29 * ([SoilBkgdct / SoilBkgdS] * SampleS *

(1 + [SampleS / SoilBkgdS])) $^{0.5}$) * 60 / SampleS

Estimated Minimum Detectable Activity (pCi/g) (EstMDA):

EstMDA = MDCPM / (Eff * GeoFac * NetWt)

Am-241 test problem

Table A.1 Test Input Data for Am-241 Test Problem.

Description	Name	Value
Sample Count Result	SampleCt	20000
Gross Weight of the sample with lid	GrossWt	600
Calibrated Source Count Result	SourceCt	3000
Background Count Result	BkgdCt	500
Reference Soil Count Result	SoilBkgdCt	550
Source Count Duration, Seconds	SourceS	60
Sample count Duration, Seconds	SampleS	120
Background count duration, seconds	BkgdS	180
Reference Soil Count, Seconds	SoilBkgdS	240

Source Activity, dpm	SA	15400
Container Tare Weight with Lid	TareWt	30
Response factor	GeoFac	*

The Am-241 test calculations shall produce the results provided in Table A.2 once round-off is taken into account. If this result cannot be reproduced, contact the author of this procedure.

Table A.2. Am-241 Test Problem Results.

Description	**Name**	**Value**
Net Weight	NetWt	570
Efficiency	Eff	0.4084415584
Net CPM	NetCPM	9862.5
Estimated Activity (pCi/g)	EstAct	270.3879
Estimated Minimum Detectable Count Rate	MDCPM	34.91010794
Estimateed Minimum Detectable Activity (pCi/g)	EstMDA	0.9570870

Cs-137 test problem *

Table A.3. Test Problem Data for the Cs-137 Test Problem

Description	**Name**	**Value**
Sample Count Result	SampleCt	70000
Gross Weight of the sample with lid	GrossWt	600
Calibrated Source Count Result	SourceCt	100998
Background Count Result	BkgdCt	18234
Reference Soil Count Result	SoilBkgdCt	37000
Source Count Duration, Seconds	SourceS	360

* For Am-241 only, GeoFac = 0.093756 + 4.2955 E-5 (Tare Wt – Gross Wt)

Sample count Duration, Seconds	SampleS	380
Background count duration, seconds	BkgdS	320
Reference Soil Count, Seconds	SoilBkgdS	300
Source Activity, dpm	SA	5994000
Container Tare Weight with Lid	TareWt	30
Response factor	GeoFac	7.6038

The Cs-137 test calculations shall produce the results provided in Table A.4 once round-off is taken into account. If not, contact the author of this procedure.

Table A.4. Cs-137 Test Problem Results.

Description	**Name**	**Value**
Net Weight	NetWt	570
Efficiency, cpm/pCi	Eff	0.004961944
Net CPM	NetCPM	3652.631579
Estimated Activity (pCi/g)	EstAct	28.08187
Estimated Minimum Detectable Count Rate	MDCPM	169.7863368
Estimateed Minimum Detectable Activity (pCi/g)	EstMDA	1.305338

Attachment 4

Response to Specific Comment #3

- screening of samples using fixed geometry field screening measurements in accordance with WGII SOP-10.15 Rev. 1 (WGII 2002, 76842)
- collection of confirmation samples submitted for off-site contract laboratory analysis
- post-remediation and post-restoration gross gamma mapping surveys of the site.

Some deviations from the approved VCM Plan occurred. Table 2.4-2 outlines the VCM Plan/ROC specification, the actual field work performed, and the rationale for the required deviation.

Table 2.4-2
Summary of VCM Plan Specifications, Fieldwork, and Rationale for Deviations

VCM Plan/ROC Specification(s)		Actual Fieldwork Performed		Rationale for Deviation
Number of Samples	Analytes Measured	Number of Samples	Analytes Measured	
10 confirmation samples from two depth intervals (0–12 in and 24–36 in. beneath an elevation equal to the bottom of the drainline) at 5 locations along outfall drainline.	cesium-137 by gamma spec., americium-241 by alpha spec., isotopic plutonium, and strontium-90.	27 confirmation samples from 15 locations. 6 of the 15 sample locations within drainline trench; 9 of the 15 sample locations east and west of trench 12 of the 15 locations were sampled at multiple depths: 0–12 in. and 24–36 in. beneath an elevation equal to bottom of drainline.	cesium-137 by gamma spec., americium-241 by alpha spec., isotopic plutonium, and strontium-90.	Additional confirmation samples were collected to determine horizontal and vertical extent of contamination and to verify that cleanup levels were met.
The final site-wide gross gamma walkover survey will be completed after site restoration and revegetation.		The final site-wide gross gamma walkover survey was completed after all remediated areas had been covered with clean fill, but before revegetation.		Performing the survey before revegetation allowed for better site access, and had any high levels of contaminants been found, they would have been easier to remediate.
Field work was planned to be complete by July 31, 2003.		Final demobilization from the site not completed until October 1, 2003.		Delay due to the winter weather conditions which slowed progress, increased volume of soil removed, the resulting increase in area to be restored, and the increased area to be revegetated.

During the VCM, it was decided that a small area within Reach DP-2 with a cesium-137 concentration exceeding the target cleanup level of 150 pCi/g would be remediated. Reach DP-2 is contiguous with SWMU 21-011(k). The area selected for remediation comprised a portion of a c3 geomorphic unit previously mapped and characterized by the Canyons Investigation Team, and had a cesium-137 value of 441 pCi/g (LANL 1999, 63915). The area was located on the south channel bank approximately 250 ft downstream of SWMU 21-011(k). Excavation of this area was guided by the same approach used at SWMU 21-011(k). A total volume of 12 yd^3 of sediment was removed. Confirmation samples were collected and the results are shown in Appendix K. A full assessment of the entire Los Alamos/Pueblo

Canyon watershed, including the DP Canyon reaches, will be presented in the Los Alamos/Pueblo Canyon Investigation Report currently in preparation, and scheduled for submittal to the NMED in 2004.

2.4.3 Site Restoration Activities

Site restoration activities began on May 20, 2003. Photographs documenting site restoration activities are provided in Appendix I (Photos I-29 to I-46). The objectives of the site restoration were to fill all remediated areas with clean fill, recontour the site, install BMPs, and revegetate the site. The DP Canyon slope area is made up of tuff bedrock and is too steep for heavy equipment to cut in benches for the placement of fill. Therefore, the remediation design was modified to reflect the operational problems faced in the field.

The first phase in restoration involved placement of logs and tree stumps, stockpiled during the site preparation activities, into the bottom of the deepest excavations. Clean fill was placed on top of these logs and stumps and was compacted. To facilitate the delivery of clean fill, a loop road was constructed through the site to allow large 18-wheel trucks with end-dump trailers to easily access the north end of the site. A total of 900 yd^3 of clean fill was delivered to the site from two sources. Approximately one-third of the fill originated from excavations within the Quemazon housing development on the Pajarito Plateau, a location distant from historical Laboratory operations; the other two-thirds originated from a mixed fill stockpile owned by the site work contractor (SG Western Construction Inc.) in San Juan, New Mexico.

Upon arrival on site, all fill was screened for radionuclide contamination using a combination of gross gamma direct surveys and field screening (Table 2.4-1). All surveying and field screening results for the fill material were below the local background concentrations of radionuclide activities used for the remediation process. Therefore, all fill was deemed acceptable for use in the restoration.

In addition, all fill brought to the site was classified using the American Society for Testing and Materials (ASTM) Visual-Manual Procedure for the classification of soils. Fill used in the restoration ranged in classification from SM (silty sand with gravel) to SC (clayey sand with gravel). Moisture content of the fill material ranged from dry to slightly moist. Therefore, all fill used conformed to the specifications outlined in ASTM D2488, and was deemed acceptable for use in the restoration of SWMU 21-011(k). Once the larger remediated areas were filled and compacted, the remaining fill was used to recontour the site.

Following recontouring, stormwater run-on and runoff controls were implemented across the site in accordance with the stormwater pollution prevention plan (LANL 2002, 73189). These activities included reinforcement of the berm along the northern perimeter of the site near the DP Canyon channel, backfilling of the excavated western drainage channel, and placement and construction of numerous BMPs to control runoff and soil erosion. In addition, a diversion ditch was excavated along the southern perimeter of the site, north of DP Road, to prevent stormwater from running onto the slope and divert it away from the site.

In June 2003, the final walk-over gross gamma survey was performed to document the post-VCM count rates across the site (Figure 2.4-7). This survey indicated contaminant concentrations are below cleanup criteria specified in the VCM plan and no additional areas of elevated concentrations above cleanup criteria had been found during restoration activities. Nearly 15,000 gross gamma counts were recorded during this survey with an average of 23,285 cpm. This count rate roughly corresponds to a contaminant concentration of 40 pCi/g for cesium-137 based on known correlations between real-time gross gamma screening and fixed laboratory analysis reported in Appendix F of the SWMU 21-011(k) VCM Plan.

Attachment 5

Response to Specific Comment #4

Appendix D

Analytical Suites and Results

APPENDIX D ANALYTICAL SUITES AND RESULTS

D-1.0 TARGET ANALYTES AND DETECTION LIMITS

Tables D-1.0-1 through D-1.0-5 include the minimum required detection limits or quantitation limits, as prescribed in the Environmental Restoration (ER) Project (now the Risk Reduction and Environmental Stewardship Division–Remediation Services [RRES-RS] Project) analytical services statement of work (SOW) for contract laboratories (LANL 1995, 49738; LANL 2000, 71233) and the "Quality Assurance Project Plan Requirements for Sampling and Analysis" (LANL 1996, 54609). In most cases, the reporting limits for the analytes were significantly lower than the detection or quantitation limits in these tables. Summary tables presented in Sections 2.3, 2.4, 3.3, and 3.4 include sample-specific detection or quantitation limits for each analyte.

Table D-1.0-1
Target Analytes and Estimated Detection Limits for Inorganic Chemical Analyses

Analyte	EPA[a] Sample Preparation Method	Analytical Technique	EDL[b] (mg/kg)
Aluminum	3050A	ICPES[c]	40
Antimony	3050A	ICPES	12
Arsenic	7060/3050A	ICPES/GFAA[d]	2
Barium	3050A	ICPES	40
Beryllium	3050A	ICPES	1
Cadmium	3050A	ICPES	1
Calcium	3050A	ICPES	1000
Chromium	3050A	ICPES	0.5
Cobalt	3050A	ICPES	10
Copper	3050A	ICPES	5
Iron	3050A	ICPES	20
Lead	7421/3050A	ICPES/ICPMS[e]	0.6
Magnesium	3050A	ICPES	1000
Manganese	3050A	ICPES	3
Mercury	7471	CVAA[f]	0.1
Nickel	3050A	ICPES	8
Perchlorate	314.0	ICPES	0.1
Potassium	3050A	ICPES	1000
Selenium	7740/3050A	ICPES/GFAA	1
Silver	3050A	ICPES	2
Sodium	3050A	ICPES	1000
Thallium	7841/3050A	ICPES/GFAA/ICPMS	2
Vanadium	3050A	ICPES	10
Zinc	3050A	ICPES	4

[a] EPA = US Environmental Protection Agency.
[b] EDL = Estimated detection limit.
[c] ICPES = Inductively coupled plasma emission spectroscopy by EPA SW-846 Method 6010.
[d] GFAA = Graphite furnace atomic absorption.
[e] ICPMS = Inductively coupled plasma mass spectrometry by EPA SW-846 Method 6020.
[f] CVAA = Cold vapor atomic absorption spectroscopy.

Table D-1.0-2
Target Analytes and Estimated Quantitation Limits for Volatile Organic Compound Analyses

Target Analyte	Soil/Solids EQL* (µg/kg)	Target Analyte	Soil/Solids EQL* (µg/kg)
Acetone	20	1,3-Dichloropropane	5
Benzene	5	2,2-Dichloropropane	5
Bromobenzene	5	1,1-Dichloropropene	5
Bromochloromethane	5	cis-1,3-Dichloropropene	5
Bromodichloromethane	5	trans-1,3-Dichloropropene	5
Bromoform	5	Ethylbenzene	5
Bromomethane	10	Hexachlorobutadiene	10
2-Butanone	20	2-Hexanone	20
n-Butylbenzene	5	Iodomethane	5
sec-Butylbenzene	5	Isopropylbenzene	5
tert-Butylbenzene	5	4-Isopropyltoluene	5
Carbon disulfide	5	4-Methyl-2-pentanone	20
Carbon tetrachloride	5	Methylene chloride	5
Chlorobenzene	5	Naphthalene	10
Chlorodibromomethane	5	1-Propylbenzene	5
Chloroethane	10	Styrene	5
Chloroform	5	1,1,1,2-Tetrachloroethane	5
Chloromethane	10	1,1,2,2-Tetrachloroethane	5
2-Chlorotoluene	5	Tetrachloroethene	5
4-Chlorotoluene	5	Toluene	5
1,2-Dimbromo-3-chloropropane	10	1,1,2-Trichloro-1,2,2-trifluoroethane	5
1,2-Dibromoethane	5	1,2,3-Trichlorobenzene	5
Dibromomethane	5	1,2,4-Trichlorobenzene	10
1,2-Dichlorobenzene	5	1,1,1-Trichloroethane	5
1,3-Dichlorobenzene	5	1,1,2-Trichloroethane	5
1,4-Dichlorobenzene	5	Trichloroethene	5
Dichlorodifluoromethane	10	Trichlorofluoromethane	5
1,1-Dichloroethane	5	1,2,3-Trichloropropane	5
1,2-Dichloroethane	5	1,2,4-Trimethylbenzene	5
1,1-Dichloroethene	5	1,3,5-Trimethylbenzene	5
cis-1,2-Dichloroethene	5	Vinyl chloride	10
trans-1,2-Dichloroethene	5	Xylene (total)	5
1,2-Dichloropropane	5		

Note: All analyses were completed by EPA contract laboratory program Method OLM2.0 or the equivalent EPA Method 8260. These methods are based on purge and trap sample extraction/concentration followed by gas chromatography/mass spectrometry.

*EQL = Estimated quantitation limit.

Table D-1.0-3
Target Analytes and Estimated Quantitation Limits for Pesticide Analyses

Analyte	Soil/Solids EQL (µg/kg)
Aldrin	1.7
BHC [alpha-]	1.7
BHC [beta-]	1.7
BHC [delta-]	1.7
BHC [gamma-]	1.7
Chlordane [alpha-]	1.7
Chlordane [gamma-]	1.7
DDD [4,4'-]	3.3
DDE [4,4'-]	3.3
DDT [4,4'-]	3.3
Dieldrin	3.3
Endosulfan I	1.7
Endosulfan II	3.3
Endosulfan sulfate	3.3*
Endrin	3.3
Endrin aldehyde	3.3
Endrin ketone	3.3*
Heptachlor	1.7
Heptachlor epoxide	1.7
Methoxychlor [4,4'-]	1.7
Toxaphene (technical grade)	170

Note: All analyses were completed by EPA contract laboratory program Method OLM2.0 or the equivalent EPA Method 8260. These methods are based on purge and trap sample extraction/concentration followed by gas chromatography/mass spectrometry.

*Not in table in SW-846.

Table D-1.0-4
Target Analytes and Estimated Quantitation Limits for PCB Analyses

Analyte	Soil/Solids EQL* (µg/kg)
Aroclor-1016	33
Aroclor-1221	67
Aroclor-1232	33
Aroclor-1242	33
Aroclor-1248	33
Aroclor-1254	33
Aroclor-1260	33

Note. All analyses were completed by EPA contract laboratory program Method OLM1.8 or the equivalent EPA Method 8081. These methods are based on solvent extraction, concentration, and gas chromatography/electron capture detection and quantitation.

* EQLs for the samples are based on no gel permeation chromatography (GPC) cleanup being performed. The laboratories' GPC equipment determines the sample-specific EQL based on the volume of extract the GPC equipment uses. However, the laboratories are requested, if possible, to report sample-specific EQLs of no more than twice the value listed in the table.

Table D-1.0-5
Target Analytes and Estimated Quantitation Limits for Radionuclide Analyses

Analyte	Soil/Solids EQL[a] (pCi/g, except as noted)
Americium-241	0.05
Cesium-134	NA[b]
Cesium-137	0.10
Cobalt-60	0.50
Europium-152	NA
Plutonium-238	0.05
Plutonium-239	0.05
Ruthenium-106	NA
Sodium-22	NA
Strontium-90	0.5
Thorium-228	0.1
Thorium-230	0.1
Thorium-232	0.1
Tritium	250 pCi/L
Uranium-234	0.1
Uranium-235	0.1
Uranium-238	0.1

Note: All analyses were completed by EPA contract laboratory program Method OLM1.8 or the equivalent EPA Method 8081. These methods are based on solvent extraction, concentration, and gas chromatography/electron capture detection and quantitation.

[a] EQLs for the samples are based on no gel permeation chromatography (GPC) cleanup being performed. The laboratories' GPC equipment determines the sample-specific EQL based on the volume of extract the GPC equipment uses. However, the laboratories are requested, if possible, to report sample-specific EQLs of no more than twice the value listed in the table.

[b] EQL not applicable.

Efforts were made to ensure that detection limits for inorganic chemicals were below Los Alamos National Laboratory (the Laboratory) background values (BVs) (LANL 1998, 59730). Instances in which the detection limits were greater than BVs are noted and discussed in Section 2.4.3 of this report.

D-2.0 ANALYTE SUITES AND DATA SUMMARY

Table D-2.0-1 presents the analytical results for samples collected in 1993, 2001, and 2003 for media remaining at Solid Waste Management Unit (SWMU) 21-011(k) following the voluntary corrective measure (VCM). The confirmation results from the 1996 interim action are not included in Table D-2.0-1 because these sample locations were removed as part of the VCM and are no longer present. The report qualifier "U" indicates that the analyte was analyzed for but not detected and that the reported value is the sample-specific estimated quantitation limit or detection limit. The report qualifier "J" indicates that the reported value should be regarded as estimated. The report qualifier "J+" indicates that the reported value should be regarded as estimated and biased high. The report qualifier "UJ" indicates that the analyte was analyzed for but not detected and that the reported value is an estimate of the sample-specific quantitation limit or detection limit. The report qualifier "R" indicates that the reported value should be regarded as rejected.

Table D-2.0-1
Analytical Results for SWMU 21-011(k)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-01591	AAA4009	0.0–0.5	ALLH	Americium-241	8.963000298	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Cesium-137	42.63999939	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Plutonium-238	0.859000027	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Plutonium-239	12.77299976	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Strontium-90	8.600000381	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Thorium-228	1.379999995	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Thorium-230	1.419999957	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Thorium-232	1.450000048	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Tritium	0.113315508	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Uranium-234	1.399999976	pCi/g	None
21-01591	AAA4009	0.0–0.5	ALLH	Uranium-235	0.07	pCi/g	U
21-01591	AAA4009	0.0–0.5	ALLH	Uranium-238	1.25999999	pCi/g	None
21-11204	MD21-01-0030	2.0–3.0	ALLH	Cesium-134	0.064	pCi/g	R
21-11205	MD21-01-0034	4.0–5.0	ALLH	Acetone	0.050000001	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aldrin	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aluminum	5000	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Americium-241	6.900000095	pCi/g	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Antimony	0.289999992	mg/kg	UJ
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aroclor-1016	0.040000003	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aroclor-1221	0.081	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aroclor-1232	0.040000003	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aroclor-1242	0.040000003	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aroclor-1248	0.040000003	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aroclor-1254	0.040000003	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Aroclor-1260	0.040000003	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Arsenic	2.099999905	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Barium	43	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Benzene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Beryllium	0.980000019	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	BHC[alpha-]	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	BHC[beta-]	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	BHC[delta-]	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	BHC[gamma-]	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Bromobenzene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Bromochloromethane	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Bromodichloromethane	0.006	mg/kg	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-11205	MD21-01-0034	4.0–5.0	ALLH	Bromoform	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Bromomethane	0.012	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Butanone[2-]	0.024	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Butylbenzene[n-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Butylbenzene[sec-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Butylbenzene[tert-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Cadmium	0.109999999	mg/kg	J
21-11205	MD21-01-0034	4.0–5.0	ALLH	Calcium	760	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Carbon disulfide	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Carbon tetrachloride	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Cesium-134	0.028000001	pCi/g	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Cesium-137	3.779999971	pCi/g	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chlordane[alpha-]	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chlordane[gamma-]	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chlorobenzene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chlorodibromomethane	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chloroethane	0.012	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chloroform	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chloromethane	0.012	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chlorotoluene[2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chlorotoluene[4-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Chromium	6.5	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Cobalt	1.399999976	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Cobalt-60	0.007	pCi/g	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Copper	3.5	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	DDD[4,4'-]	0.004	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	DDE[4,4'-]	0.004	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	DDT[4,4'-]	0.004	mg/kg	UJ
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dibromo-3-Chloropropane[1,2-]	0.012	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dibromoethane[1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dibromomethane	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichlorobenzene[1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichlorobenzene[1,3-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichlorobenzene[1,4-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichlorodifluoromethane	0.012	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloroethane[1,1-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloroethane[1,2-]	0.006	mg/kg	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloroethene[1,1-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloroethene[cis-1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloroethene[trans-1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloropropane[1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloropropane[1,3-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloropropane[2,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloropropene[1,1-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloropropene[cis-1,3-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dichloropropene[trans-1,3-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Dieldrin	0.004	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Endosulfan I	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Endosulfan II	0.004	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Endosulfan sulfate	0.004	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Endrin	0.004	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Endrin aldehyde	0.004	mg/kg	UJ
21-11205	MD21-01-0034	4.0–5.0	ALLH	Endrin ketone	0.004	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Ethylbenzene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Europium-152	-0.2	pCi/g	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Heptachlor	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Heptachlor epoxide	0.002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Hexachlorobutadiene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Hexanone[2-]	0.024	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Iodomethane	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Iron	6500	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Isopropylbenzene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Isopropyltoluene[4-]	0.026000001	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Lead	7.099999905	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Magnesium	710	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Manganese	260	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Mercury	0.0031	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Methoxychlor[4,4'-]	0.020000001	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Methyl-2-pentanone[4-]	0.024	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Methylene chloride	0.072000004	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Naphthalene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Nickel	6.199999809	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Perchlorate	0.028700002	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Plutonium-238	0.209999993	pCi/g	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Plutonium-239	1.00999999	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-11205	MD21-01-0034	4.0–5.0	ALLH	Potassium	1300	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Propylbenzene[1-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Ruthenium-106	0.090000004	pCi/g	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Selenium	0.300000012	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Silver	0.057999998	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Sodium	550	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Sodium-22	-0.02	pCi/g	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Strontium-90	1.019999981	pCi/g	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Styrene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Tetrachloroethane[1,1,1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Tetrachloroethane[1,1,2,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Tetrachloroethene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Thallium	0.340000004	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Toluene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Toxaphene (technical grade)	0.200000003	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trichloro-1,2,2-trifluoroethane[1,1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trichlorobenzene[1,2,3-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trichlorobenzene[1,2,4-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trichloroethane[1,1,1-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trichloroethane[1,1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trichloroethene	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trichlorofluoromethane	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trichloropropane[1,2,3-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trimethylbenzene[1,2,4-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Trimethylbenzene[1,3,5-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Uranium-235	0.389999986	pCi/g	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Vanadium	7.400000095	mg/kg	None
21-11205	MD21-01-0034	4.0–5.0	ALLH	Vinyl chloride	0.012	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Xylene (total)	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Xylene[1,2-]	0.006	mg/kg	U
21-11205	MD21-01-0034	4.0–5.0	ALLH	Zinc	30	mg/kg	None
21-03-21380	MD21-03-49651	8-9	QBT3	Americium-241	0.135	PCI/G	None
21-03-21380	MD21-03-49652	9-10	QBT3	Americium-241	0.107	PCI/G	None
21-03-21380	MD21-03-49651	8-9	QBT3	Cesium-134	0.064	PCI/G	U
21-03-21380	MD21-03-49652	9-10	QBT3	Cesium-134	0.052	PCI/G	U
21-03-21380	MD21-03-49651	8-9	QBT3	Cesium-137	2.272	PCI/G	
21-03-21380	MD21-03-49652	9-10	QBT3	Cesium-137	1.522	PCI/G	

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-03-21380	MD21-03-49651	8-9	QBT3	Cobalt-60	0.002	PCI/G	U
21-03-21380	MD21-03-49652	9-10	QBT3	Cobalt-60	-0.015	PCI/G	U
21-03-21380	MD21-03-49651	8-9	QBT3	Europium-152	0.186	PCI/G	
21-03-21380	MD21-03-49652	9-10	QBT3	Europium-152	0.276	PCI/G	
21-03-21380	MD21-03-49651	8-9	QBT3	Plutonium-238	0.036	PCI/G	
21-03-21380	MD21-03-49652	9-10	QBT3	Plutonium-238	0.028	PCI/G	U
21-03-21380	MD21-03-49651	8-9	QBT3	Plutonium-239	0.201	PCI/G	
21-03-21380	MD21-03-49652	9-10	QBT3	Plutonium-239	0.154	PCI/G	
21-03-21380	MD21-03-49651	8-9	QBT3	Ruthenium-106	-0.011	PCI/G	U
21-03-21380	MD21-03-49652	9-10	QBT3	Ruthenium-106	0.041	PCI/G	U
21-03-21380	MD21-03-49651	8-9	QBT3	Sodium-22	-0.014	PCI/G	U
21-03-21380	MD21-03-49652	9-10	QBT3	Sodium-22	0.008	PCI/G	U
21-03-21380	MD21-03-49651	8-9	QBT3	Strontium-90	1.827	PCI/G	
21-03-21380	MD21-03-49652	9-10	QBT3	Strontium-90	0.751	PCI/G	
21-03-21380	MD21-03-49651	8-9	QBT3	Uranium-235	0.059	PCI/G	
21-03-21380	MD21-03-49652	9-10	QBT3	Uranium-235	0.211	PCI/G	
21-03-21382	MD21-03-49655	8.0–9.0	Qbt 3	Uranium-235	0.370999992	pCi/g	None
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Americium-241	0.36500001	pCi/g	None
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Cesium-134	0.061999999	pCi/g	U
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Cesium-137	1.69599998	pCi/g	None
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Cobalt-60	-0.005	pCi/g	U
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Europium-152	0.136999995	pCi/g	None
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Plutonium-238	0.055	pCi/g	None
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Plutonium-239	0.300999999	pCi/g	None
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Ruthenium-106	-0.04	pCi/g	U
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Sodium-22	-0.013	pCi/g	U
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Strontium-90	1.569000006	pCi/g	None
21-03-21382	MD21-03-49656	9.0–10.0	Qbt 3	Uranium-235	0.203999996	pCi/g	None
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Americium-241	0.112000003	pCi/g	None
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Cesium-134	-0.198	pCi/g	U
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Cesium-137	1.699000001	pCi/g	None
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Cobalt-60	0.014	pCi/g	U
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Europium-152	0.108999997	pCi/g	None
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Plutonium-238	0.02	pCi/g	U
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Plutonium-239	0.237000003	pCi/g	None
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Ruthenium-106	0.052999999	pCi/g	U
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Sodium-22	0	pCi/g	U
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Strontium-90	2.548000097	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-03-21386	MD21-03-49663	8.0–9.0	Qbt 3	Uranium-235	0.184	pCi/g	None
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Americium-241	0.079000004	pCi/g	None
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Cesium-134	0.067000002	pCi/g	U
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Cesium-137	1.646999955	pCi/g	None
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Cobalt-60	-0.002	pCi/g	U
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Europium-152	0.282000005	pCi/g	None
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Plutonium-238	0.018999999	pCi/g	U
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Plutonium-239	0.081	pCi/g	None
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Ruthenium-106	-0.033	pCi/g	U
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Sodium-22	0	pCi/g	U
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Strontium-90	2.140000105	pCi/g	None
21-03-21386	MD21-03-49664	9.0–10.0	Qbt 3	Uranium-235	0.232999995	pCi/g	None
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Americium-241	0.037	pCi/g	None
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Cesium-134	0.081	pCi/g	U
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Cesium-137	1.873000026	pCi/g	None
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Cobalt-60	-0.009	pCi/g	U
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Europium-152	0.129999995	pCi/g	None
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Plutonium-238	0	pCi/g	U
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Plutonium-239	0.063000001	pCi/g	None
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Ruthenium-106	0.007	pCi/g	U
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Sodium-22	-0.003	pCi/g	U
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Strontium-90	1.95599997	pCi/g	None
21-03-21387	MD21-03-49665	8.0–9.0	Qbt 3	Uranium-235	0.129999995	pCi/g	U
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Americium-241	0.046	pCi/g	None
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Cesium-134	-0.007	pCi/g	U
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Cesium-137	1.338999987	pCi/g	None
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Cobalt-60	0.009	pCi/g	U
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Europium-152	0.172999993	pCi/g	None
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Plutonium-238	0.035	pCi/g	None
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Plutonium-239	0.138999999	pCi/g	None
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Ruthenium-106	0.059999999	pCi/g	U
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Sodium-22	-0.009	pCi/g	U
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Strontium-90	0.915000021	pCi/g	None
21-03-21387	MD21-03-49666	9.0–10.0	Qbt 3	Uranium-235	0.143000007	pCi/g	U
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Americium-241	1.47300005	pCi/g	None
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Cesium-134	0.059999999	pCi/g	U
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Cesium-137	64.60299683	pCi/g	None
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Cobalt-60	0.006	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Europium-152	0.270000011	pCi/g	None
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Plutonium-238	0.186000004	pCi/g	None
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Plutonium-239	7.511000156	pCi/g	None
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Ruthenium-106	-0.191	pCi/g	U
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Sodium-22	0	pCi/g	U
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Strontium-90	23.11100006	pCi/g	None
21-03-21388	MD21-03-49667	8.0–9.0	Qbt 3	Uranium-235	0.203999996	pCi/g	None
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Americium-241	0.072999999	pCi/g	None
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Cesium-134	0.055	pCi/g	U
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Cesium-137	1.078999996	pCi/g	None
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Cobalt-60	0.015	pCi/g	U
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Europium-152	0.224999994	pCi/g	None
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Plutonium-238	0.008	pCi/g	U
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Plutonium-239	0.194000006	pCi/g	None
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Ruthenium-106	0.009	pCi/g	U
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Sodium-22	0	pCi/g	U
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Strontium-90	4.683000088	pCi/g	None
21-03-21388	MD21-03-49668	9.0–10.0	Qbt 3	Uranium-235	0.166999996	pCi/g	None
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Americium-241	0.368000001	pCi/g	None
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Cesium-134	0.075999998	pCi/g	None
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Cesium-137	6.793000221	pCi/g	None
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Cobalt-60	0.001	pCi/g	U
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Europium-152	0.234999999	pCi/g	None
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Plutonium-238	0.145999998	pCi/g	None
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Plutonium-239	0.964999974	pCi/g	None
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Ruthenium-106	-0.119	pCi/g	U
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Sodium-22	0.009	pCi/g	U
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Strontium-90	6.243000031	pCi/g	None
21-03-21389	MD21-03-49669	8.0–9.0	Qbt 3	Uranium-235	0.188999996	pCi/g	None
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Americium-241	0.648000002	pCi/g	None
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Cesium-134	0.059	pCi/g	U
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Cesium-137	7.367000103	pCi/g	None
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Cobalt-60	-0.001	pCi/g	U
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Europium-152	0.201000005	pCi/g	None
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Plutonium-238	0.137999997	pCi/g	None
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Plutonium-239	1.366000056	pCi/g	None
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Ruthenium-106	-0.05	pCi/g	U
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Sodium-22	0.003	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Strontium-90	4.90899992	pCi/g	None
21-03-21389	MD21-03-49670	9.0–10.0	Qbt 3	Uranium-235	0.214000002	pCi/g	None
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Americium-241	0.101999998	pCi/g	None
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Cesium-134	-0.02	pCi/g	U
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Cesium-137	1.549000025	pCi/g	None
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Cobalt-60	-0.001	pCi/g	U
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Europium-152	0.118000001	pCi/g	U
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Plutonium-238	0.027000001	pCi/g	U
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Plutonium-239	0.372000009	pCi/g	None
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Ruthenium-106	0.179000005	pCi/g	U
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Sodium-22	0.008	pCi/g	U
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Strontium-90	0.112999998	pCi/g	U
21-03-21390	MD21-03-49671	8.0–9.0	Qbt 3	Uranium-235	0.156000003	pCi/g	U
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Americium-241	0.097999997	pCi/g	None
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Cesium-134	0.083999999	pCi/g	U
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Cesium-137	0.31099999	pCi/g	None
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Cobalt-60	-0.002	pCi/g	U
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Europium-152	0.189999998	pCi/g	None
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Plutonium-238	0.011	pCi/g	U
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Plutonium-239	0.273000002	pCi/g	None
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Ruthenium-106	-0.023	pCi/g	U
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Sodium-22	0.001	pCi/g	U
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Strontium-90	-0.095	pCi/g	U
21-03-21390	MD21-03-49672	9.0–10.0	Qbt 3	Uranium-235	0.207000002	pCi/g	None
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Americium-241	0.913999975	pCi/g	None
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Cesium-134	0.071000002	pCi/g	U
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Cesium-137	12.6420002	pCi/g	None
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Cobalt-60	-0.008	pCi/g	U
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Europium-152	0.136000007	pCi/g	None
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Plutonium-238	0.345999986	pCi/g	None
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Plutonium-239	1.440999985	pCi/g	None
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Ruthenium-106	-0.037	pCi/g	U
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Sodium-22	-0.018	pCi/g	U
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Strontium-90	3.325000048	pCi/g	None
21-03-21391	MD21-03-49673	8.0–9.0	Qbt 3	Uranium-235	0.186000004	pCi/g	U
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Americium-241	0.328000009	pCi/g	None
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Cesium-134	0.072999999	pCi/g	U
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Cesium-137	2.869999886	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Cobalt-60	0.002	pCi/g	U
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Europium-152	0.206	pCi/g	None
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Plutonium-238	0.029999999	pCi/g	None
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Plutonium-239	1.758999944	pCi/g	None
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Ruthenium-106	0.086999997	pCi/g	U
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Sodium-22	0.002	pCi/g	U
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Strontium-90	0.405999988	pCi/g	U
21-03-21392	MD21-03-49675	5.0–6.0	Qbt 3	Uranium-235	0.195999995	pCi/g	U
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Americium-241	0.437000006	pCi/g	None
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Cesium-134	-0.289	pCi/g	U
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Cesium-137	5.971000195	pCi/g	None
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Cobalt-60	-0.011	pCi/g	U
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Europium-152	0.209999993	pCi/g	None
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Plutonium-238	0.115000002	pCi/g	None
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Plutonium-239	2.667999983	pCi/g	None
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Ruthenium-106	0.107000001	pCi/g	U
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Sodium-22	0.017000001	pCi/g	U
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Strontium-90	1.213000059	pCi/g	None
21-03-21392	MD21-03-49676	6.0–7.0	Qbt 3	Uranium-235	0.216999993	pCi/g	None
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Americium-241	0.81099999	pCi/g	None
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Cesium-134	0.092	pCi/g	U
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Cesium-137	66.34100342	pCi/g	None
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Cobalt-60	-0.005	pCi/g	U
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Europium-152	0.155000001	pCi/g	U
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Plutonium-238	0.114	pCi/g	None
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Plutonium-239	3.594000101	pCi/g	None
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Ruthenium-106	-0.029	pCi/g	U
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Sodium-22	0.011	pCi/g	U
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Strontium-90	12.95199966	pCi/g	None
21-03-21393	MD21-03-49677	5.0–6.0	Qbt 3	Uranium-235	0.202000007	pCi/g	None
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Americium-241	0.094999999	pCi/g	None
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Cesium-134	0.107000001	pCi/g	U
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Cesium-137	1.138000011	pCi/g	None
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Cobalt-60	0.004	pCi/g	U
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Europium-152	0.193000004	pCi/g	None
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Plutonium-238	0.016000001	pCi/g	U
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Plutonium-239	0.256999999	pCi/g	None
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Ruthenium-106	-0.074	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Sodium-22	-0.005	pCi/g	U
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Strontium-90	0.25	pCi/g	U
21-03-21393	MD21-03-49678	6.0–7.0	Qbt 3	Uranium-235	0.217999995	pCi/g	None
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Americium-241	0.196999997	pCi/g	None
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Cesium-134	0.083999999	pCi/g	U
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Cesium-137	9.289999962	pCi/g	None
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Cobalt-60	-0.008	pCi/g	U
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Europium-152	0.192000002	pCi/g	None
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Plutonium-238	0.030999999	pCi/g	U
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Plutonium-239	0.640999973	pCi/g	None
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Ruthenium-106	-0.013	pCi/g	U
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Sodium-22	-0.007	pCi/g	U
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Strontium-90	5.850999832	pCi/g	None
21-03-21394	MD21-03-49679	5.0–6.0	Qbt 3	Uranium-235	0.200000003	pCi/g	U
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Americium-241	0.625999987	pCi/g	None
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Cesium-134	0.066	pCi/g	U
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Cesium-137	14.34899998	pCi/g	None
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Cobalt-60	0.005	pCi/g	U
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Europium-152	0.266000003	pCi/g	None
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Plutonium-238	0.148000002	pCi/g	None
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Plutonium-239	6.340000153	pCi/g	None
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Ruthenium-106	0.119000003	pCi/g	U
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Sodium-22	-0.013	pCi/g	U
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Strontium-90	4.322000027	pCi/g	None
21-03-21394	MD21-03-49680	6.0–7.0	Qbt 3	Uranium-235	0.138999999	pCi/g	None
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Americium-241	0.35800001	pCi/g	None
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Cesium-134	0.083999999	pCi/g	U
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Cesium-137	3.04399991	pCi/g	None
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Cobalt-60	-0.002	pCi/g	U
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Europium-152	0.172999993	pCi/g	None
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Plutonium-238	0.130999997	pCi/g	None
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Plutonium-239	3.743999958	pCi/g	None
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Ruthenium-106	0.191	pCi/g	U
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Sodium-22	-0.004	pCi/g	U
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Strontium-90	1.065000057	pCi/g	None
21-03-21395	MD21-03-49681	5.0–6.0	Qbt 3	Uranium-235	0.202000007	pCi/g	None
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Americium-241	1.22300005	pCi/g	None
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Cesium-134	-0.018	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Cesium-137	11.72900009	pCi/g	None
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Cobalt-60	0.002	pCi/g	U
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Europium-152	0.170000002	pCi/g	None
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Plutonium-238	0.246999994	pCi/g	None
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Plutonium-239	12.26099968	pCi/g	None
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Ruthenium-106	-0.025	pCi/g	U
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Sodium-22	-0.001	pCi/g	U
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Strontium-90	5.474999905	pCi/g	None
21-03-21396	MD21-03-49683	3.0–4.0	Qbt 3	Uranium-235	0.075999998	pCi/g	U
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Americium-241	1.047000051	pCi/g	None
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Cesium-134	0.075000003	pCi/g	U
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Cesium-137	4.519999981	pCi/g	None
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Cobalt-60	0.003	pCi/g	U
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Europium-152	0.284000009	pCi/g	None
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Plutonium-238	0.155000001	pCi/g	None
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Plutonium-239	8.215999603	pCi/g	None
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Ruthenium-106	-0.047	pCi/g	U
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Sodium-22	0.002	pCi/g	U
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Strontium-90	2.184000015	pCi/g	None
21-03-21398	MD21-03-49687	1.0–2.0	Qbt 3	Uranium-235	0.157000005	pCi/g	None
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Americium-241	0.122000001	pCi/g	None
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Cesium-134	0.089000002	pCi/g	U
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Cesium-137	3.003999949	pCi/g	None
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Cobalt-60	-0.012	pCi/g	U
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Europium-152	0.155000001	pCi/g	None
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Plutonium-238	0.026000001	pCi/g	U
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Plutonium-239	1.059000015	pCi/g	None
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Ruthenium-106	-0.145	pCi/g	U
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Sodium-22	0.02	pCi/g	U
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Strontium-90	0.768000007	pCi/g	None
21-03-21395	MD21-03-49699	5.0–6.0	Qbt 3	Uranium-235	0.214000002	pCi/g	None
21-22198	MD21-03-51509	0.0–0.5	ALLH	Americium-241	3.484999895	pCi/g	None
21-22198	MD21-03-51509	0.0–0.5	ALLH	Cesium-134	-0.169	pCi/g	U
21-22198	MD21-03-51509	0.0–0.5	ALLH	Cesium-137	39.79000092	pCi/g	None
21-22198	MD21-03-51509	0.0–0.5	ALLH	Cobalt-60	-0.001	pCi/g	U
21-22198	MD21-03-51509	0.0–0.5	ALLH	Europium-152	0.241999999	pCi/g	None
21-22198	MD21-03-51509	0.0–0.5	ALLH	Plutonium-238	0.38499999	pCi/g	None
21-22198	MD21-03-51509	0.0–0.5	ALLH	Plutonium-239	4.097000122	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22198	MD21-03-51509	0.0–0.5	ALLH	Ruthenium-106	-0.17399999	pCi/g	U
21-22198	MD21-03-51509	0.0–0.5	ALLH	Sodium-22	0.005	pCi/g	U
21-22198	MD21-03-51509	0.0–0.5	ALLH	Strontium-90	6.987999916	pCi/g	None
21-22198	MD21-03-51509	0.0–0.5	ALLH	Uranium-235	0.268999994	pCi/g	None
21-22199	MD21-03-51510	0.0–0.5	ALLH	Americium-241	0.967999995	pCi/g	None
21-22199	MD21-03-51510	0.0–0.5	ALLH	Cesium-134	0.068999998	pCi/g	U
21-22199	MD21-03-51510	0.0–0.5	ALLH	Cesium-137	15.85400009	pCi/g	None
21-22199	MD21-03-51510	0.0–0.5	ALLH	Cobalt-60	0.009	pCi/g	U
21-22199	MD21-03-51510	0.0–0.5	ALLH	Europium-152	0.48300001	pCi/g	None
21-22199	MD21-03-51510	0.0–0.5	ALLH	Plutonium-238	0.149000004	pCi/g	None
21-22199	MD21-03-51510	0.0–0.5	ALLH	Plutonium-239	1.269000053	pCi/g	None
21-22199	MD21-03-51510	0.0–0.5	ALLH	Ruthenium-106	0.018999999	pCi/g	U
21-22199	MD21-03-51510	0.0–0.5	ALLH	Sodium-22	-0.018	pCi/g	U
21-22199	MD21-03-51510	0.0–0.5	ALLH	Strontium-90	3.453999996	pCi/g	None
21-22199	MD21-03-51510	0.0–0.5	ALLH	Uranium-235	0.284999996	pCi/g	None
21-22200	MD21-03-51511	0.0–0.5	ALLH	Americium-241	0.423999995	pCi/g	None
21-22200	MD21-03-51511	0.0–0.5	ALLH	Cesium-134	0.07	pCi/g	U
21-22200	MD21-03-51511	0.0–0.5	ALLH	Cesium-137	0.626999974	pCi/g	None
21-22200	MD21-03-51511	0.0–0.5	ALLH	Cobalt-60	-0.001	pCi/g	U
21-22200	MD21-03-51511	0.0–0.5	ALLH	Europium-152	0.446999997	pCi/g	None
21-22200	MD21-03-51511	0.0–0.5	ALLH	Plutonium-238	0.090000004	pCi/g	None
21-22200	MD21-03-51511	0.0–0.5	ALLH	Plutonium-239	1.047000051	pCi/g	None
21-22200	MD21-03-51511	0.0–0.5	ALLH	Ruthenium-106	0.109999999	pCi/g	U
21-22200	MD21-03-51511	0.0–0.5	ALLH	Sodium-22	0.012	pCi/g	U
21-22200	MD21-03-51511	0.0–0.5	ALLH	Strontium-90	0.280000001	pCi/g	U
21-22200	MD21-03-51511	0.0–0.5	ALLH	Uranium-235	0.254000008	pCi/g	None
21-22201	MD21-03-51512	0.0–0.5	ALLH	Americium-241	4.915999889	pCi/g	None
21-22201	MD21-03-51512	0.0–0.5	ALLH	Cesium-134	0.098999999	pCi/g	U
21-22201	MD21-03-51512	0.0–0.5	ALLH	Cesium-137	46.18700027	pCi/g	None
21-22201	MD21-03-51512	0.0–0.5	ALLH	Cobalt-60	0.011	pCi/g	U
21-22201	MD21-03-51512	0.0–0.5	ALLH	Europium-152	0.298999995	pCi/g	U
21-22201	MD21-03-51512	0.0–0.5	ALLH	Plutonium-238	0.319999993	pCi/g	None
21-22201	MD21-03-51512	0.0–0.5	ALLH	Plutonium-239	1.896999955	pCi/g	None
21-22201	MD21-03-51512	0.0–0.5	ALLH	Ruthenium-106	0.128000006	pCi/g	U
21-22201	MD21-03-51512	0.0–0.5	ALLH	Sodium-22	0.002	pCi/g	U
21-22201	MD21-03-51512	0.0–0.5	ALLH	Strontium-90	0.237000003	pCi/g	U
21-22201	MD21-03-51512	0.0–0.5	ALLH	Uranium-235	0.286000013	pCi/g	None
21-22202	MD21-03-51513	0.0–0.5	ALLH	Americium-241	25.16600037	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22202	MD21-03-51513	0.0–0.5	ALLH	Cesium-134	0.079000004	pCi/g	U
21-22202	MD21-03-51513	0.0–0.5	ALLH	Cesium-137	11.19499969	pCi/g	None
21-22202	MD21-03-51513	0.0–0.5	ALLH	Cobalt-60	0	pCi/g	U
21-22202	MD21-03-51513	0.0–0.5	ALLH	Europium-152	0.337000012	pCi/g	None
21-22202	MD21-03-51513	0.0–0.5	ALLH	Plutonium-238	1.187000036	pCi/g	None
21-22202	MD21-03-51513	0.0–0.5	ALLH	Plutonium-239	4.732999802	pCi/g	None
21-22202	MD21-03-51513	0.0–0.5	ALLH	Ruthenium-106	-0.115	pCi/g	U
21-22202	MD21-03-51513	0.0–0.5	ALLH	Sodium-22	0.011	pCi/g	U
21-22202	MD21-03-51513	0.0–0.5	ALLH	Strontium-90	3.835999966	pCi/g	None
21-22202	MD21-03-51513	0.0–0.5	ALLH	Uranium-235	0.277999997	pCi/g	None
21-22203	MD21-03-51514	0.0–0.5	ALLH	Americium-241	0.310000002	pCi/g	None
21-22203	MD21-03-51514	0.0–0.5	ALLH	Cesium-134	0.059999999	pCi/g	U
21-22203	MD21-03-51514	0.0–0.5	ALLH	Cesium-137	1.419999957	pCi/g	None
21-22203	MD21-03-51514	0.0–0.5	ALLH	Cobalt-60	-0.002	pCi/g	U
21-22203	MD21-03-51514	0.0–0.5	ALLH	Europium-152	0.246000007	pCi/g	None
21-22203	MD21-03-51514	0.0–0.5	ALLH	Plutonium-238	0.056000002	pCi/g	None
21-22203	MD21-03-51514	0.0–0.5	ALLH	Plutonium-239	0.649999976	pCi/g	None
21-22203	MD21-03-51514	0.0–0.5	ALLH	Ruthenium-106	-0.019	pCi/g	U
21-22203	MD21-03-51514	0.0–0.5	ALLH	Sodium-22	-0.008	pCi/g	U
21-22203	MD21-03-51514	0.0–0.5	ALLH	Strontium-90	0.27700001	pCi/g	U
21-22203	MD21-03-51514	0.0–0.5	ALLH	Uranium-235	0.284999996	pCi/g	None
21-22204	MD21-03-51515	0.0–0.5	ALLH	Americium-241	0.143999994	pCi/g	None
21-22204	MD21-03-51515	0.0–0.5	ALLH	Cesium-134	0.078000002	pCi/g	U
21-22204	MD21-03-51515	0.0–0.5	ALLH	Cesium-137	0.083999999	pCi/g	None
21-22204	MD21-03-51515	0.0–0.5	ALLH	Cobalt-60	0.015	pCi/g	U
21-22204	MD21-03-51515	0.0–0.5	ALLH	Europium-152	0.296999991	pCi/g	U
21-22204	MD21-03-51515	0.0–0.5	ALLH	Plutonium-238	0.033	pCi/g	None
21-22204	MD21-03-51515	0.0–0.5	ALLH	Plutonium-239	8.517000198	pCi/g	None
21-22204	MD21-03-51515	0.0–0.5	ALLH	Ruthenium-106	0.07	pCi/g	U
21-22204	MD21-03-51515	0.0–0.5	ALLH	Sodium-22	0.013	pCi/g	U
21-22204	MD21-03-51515	0.0–0.5	ALLH	Strontium-90	0.395000011	pCi/g	U
21-22204	MD21-03-51515	0.0–0.5	ALLH	Uranium-235	0.156000003	pCi/g	U
21-22205	MD21-03-51516	0.0–0.5	ALLH	Americium-241	0.145999998	pCi/g	None
21-22205	MD21-03-51516	0.0–0.5	ALLH	Cesium-134	0.066	pCi/g	U
21-22205	MD21-03-51516	0.0–0.5	ALLH	Cesium-137	0.911000013	pCi/g	None
21-22205	MD21-03-51516	0.0–0.5	ALLH	Cobalt-60	-0.015	pCi/g	U
21-22205	MD21-03-51516	0.0–0.5	ALLH	Europium-152	0.256999999	pCi/g	U
21-22205	MD21-03-51516	0.0–0.5	ALLH	Plutonium-238	0.014	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22205	MD21-03-51516	0.0–0.5	ALLH	Plutonium-239	1.626999974	pCi/g	None
21-22205	MD21-03-51516	0.0–0.5	ALLH	Ruthenium-106	-0.116	pCi/g	U
21-22205	MD21-03-51516	0.0–0.5	ALLH	Sodium-22	0.008	pCi/g	U
21-22205	MD21-03-51516	0.0–0.5	ALLH	Strontium-90	0.675000012	pCi/g	None
21-22205	MD21-03-51516	0.0–0.5	ALLH	Uranium-235	0.237000003	pCi/g	U
21-22206	MD21-03-51517	0.0–0.5	ALLH	Americium-241	0.129999995	pCi/g	None
21-22206	MD21-03-51517	0.0–0.5	ALLH	Cesium-134	0.071999997	pCi/g	U
21-22206	MD21-03-51517	0.0–0.5	ALLH	Cesium-137	0.497999996	pCi/g	None
21-22206	MD21-03-51517	0.0–0.5	ALLH	Cobalt-60	-0.002	pCi/g	U
21-22206	MD21-03-51517	0.0–0.5	ALLH	Europium-152	0.317000002	pCi/g	U
21-22206	MD21-03-51517	0.0–0.5	ALLH	Plutonium-238	0.022	pCi/g	None
21-22206	MD21-03-51517	0.0–0.5	ALLH	Plutonium-239	0.963	pCi/g	None
21-22206	MD21-03-51517	0.0–0.5	ALLH	Ruthenium-106	-0.002	pCi/g	U
21-22206	MD21-03-51517	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22206	MD21-03-51517	0.0–0.5	ALLH	Strontium-90	0.209000006	pCi/g	U
21-22206	MD21-03-51517	0.0–0.5	ALLH	Uranium-235	0.268000007	pCi/g	None
21-22207	MD21-03-51518	0.0–0.5	ALLH	Americium-241	0.823000014	pCi/g	None
21-22207	MD21-03-51518	0.0–0.5	ALLH	Cesium-134	0.043000001	pCi/g	U
21-22207	MD21-03-51518	0.0–0.5	ALLH	Cesium-137	15.95699978	pCi/g	None
21-22207	MD21-03-51518	0.0–0.5	ALLH	Cobalt-60	-0.009	pCi/g	U
21-22207	MD21-03-51518	0.0–0.5	ALLH	Europium-152	0.256999999	pCi/g	U
21-22207	MD21-03-51518	0.0–0.5	ALLH	Plutonium-238	0.202999994	pCi/g	None
21-22207	MD21-03-51518	0.0–0.5	ALLH	Plutonium-239	1.625	pCi/g	None
21-22207	MD21-03-51518	0.0–0.5	ALLH	Ruthenium-106	0.252999991	pCi/g	U
21-22207	MD21-03-51518	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22207	MD21-03-51518	0.0–0.5	ALLH	Strontium-90	3.59800005	pCi/g	None
21-22207	MD21-03-51518	0.0–0.5	ALLH	Uranium-235	0.148000002	pCi/g	U
21-22208	MD21-03-51519	0.0–0.5	ALLH	Americium-241	1.055999994	pCi/g	None
21-22208	MD21-03-51519	0.0–0.5	ALLH	Cesium-134	0.086000003	pCi/g	U
21-22208	MD21-03-51519	0.0–0.5	ALLH	Cesium-137	3.750999928	pCi/g	None
21-22208	MD21-03-51519	0.0–0.5	ALLH	Cobalt-60	0.004	pCi/g	U
21-22208	MD21-03-51519	0.0–0.5	ALLH	Europium-152	0.404000014	pCi/g	None
21-22208	MD21-03-51519	0.0–0.5	ALLH	Plutonium-238	0.104999997	pCi/g	None
21-22208	MD21-03-51519	0.0–0.5	ALLH	Plutonium-239	0.481000006	pCi/g	None
21-22208	MD21-03-51519	0.0–0.5	ALLH	Ruthenium-106	0.083999999	pCi/g	U
21-22208	MD21-03-51519	0.0–0.5	ALLH	Sodium-22	-0.001	pCi/g	U
21-22208	MD21-03-51519	0.0–0.5	ALLH	Strontium-90	1.277999997	pCi/g	None
21-22208	MD21-03-51519	0.0–0.5	ALLH	Uranium-235	0.298999995	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22209	MD21-03-51520	0.0–0.5	ALLH	Americium-241	0.35800001	pCi/g	None
21-22209	MD21-03-51520	0.0–0.5	ALLH	Cesium-134	0.056000002	pCi/g	U
21-22209	MD21-03-51520	0.0–0.5	ALLH	Cesium-137	18.23500061	pCi/g	None
21-22209	MD21-03-51520	0.0–0.5	ALLH	Cobalt-60	0.011	pCi/g	U
21-22209	MD21-03-51520	0.0–0.5	ALLH	Europium-152	0.259000003	pCi/g	U
21-22209	MD21-03-51520	0.0–0.5	ALLH	Plutonium-238	0.131999999	pCi/g	None
21-22209	MD21-03-51520	0.0–0.5	ALLH	Plutonium-239	0.782000005	pCi/g	None
21-22209	MD21-03-51520	0.0–0.5	ALLH	Ruthenium-106	-0.164	pCi/g	U
21-22209	MD21-03-51520	0.0–0.5	ALLH	Sodium-22	-0.009	pCi/g	U
21-22209	MD21-03-51520	0.0–0.5	ALLH	Strontium-90	3.257999897	pCi/g	None
21-22209	MD21-03-51520	0.0–0.5	ALLH	Uranium-235	0.081	pCi/g	U
21-22210	MD21-03-51521	0.0–0.5	ALLH	Americium-241	1.238000035	pCi/g	None
21-22210	MD21-03-51521	0.0–0.5	ALLH	Cesium-134	0.068000004	pCi/g	U
21-22210	MD21-03-51521	0.0–0.5	ALLH	Cesium-137	61.40999985	pCi/g	None
21-22210	MD21-03-51521	0.0–0.5	ALLH	Cobalt-60	0.01	pCi/g	U
21-22210	MD21-03-51521	0.0–0.5	ALLH	Europium-152	0.298000008	pCi/g	U
21-22210	MD21-03-51521	0.0–0.5	ALLH	Plutonium-238	0.510999978	pCi/g	None
21-22210	MD21-03-51521	0.0–0.5	ALLH	Plutonium-239	20.40399933	pCi/g	None
21-22210	MD21-03-51521	0.0–0.5	ALLH	Ruthenium-106	-0.053	pCi/g	U
21-22210	MD21-03-51521	0.0–0.5	ALLH	Sodium-22	-0.01	pCi/g	U
21-22210	MD21-03-51521	0.0–0.5	ALLH	Strontium-90	9.498000145	pCi/g	None
21-22210	MD21-03-51521	0.0–0.5	ALLH	Uranium-235	0.270999998	pCi/g	None
21-22211	MD21-03-51522	0.0–0.5	ALLH	Americium-241	1.036000013	pCi/g	None
21-22211	MD21-03-51522	0.0–0.5	ALLH	Cesium-134	0.07	pCi/g	U
21-22211	MD21-03-51522	0.0–0.5	ALLH	Cesium-137	26.94499969	pCi/g	None
21-22211	MD21-03-51522	0.0–0.5	ALLH	Cobalt-60	-0.005	pCi/g	U
21-22211	MD21-03-51522	0.0–0.5	ALLH	Europium-152	0.256999999	pCi/g	U
21-22211	MD21-03-51522	0.0–0.5	ALLH	Plutonium-238	0.199000001	pCi/g	None
21-22211	MD21-03-51522	0.0–0.5	ALLH	Plutonium-239	1.416000009	pCi/g	None
21-22211	MD21-03-51522	0.0–0.5	ALLH	Ruthenium-106	0.197999999	pCi/g	U
21-22211	MD21-03-51522	0.0–0.5	ALLH	Sodium-22	0.002	pCi/g	U
21-22211	MD21-03-51522	0.0–0.5	ALLH	Strontium-90	5.552999973	pCi/g	None
21-22211	MD21-03-51522	0.0–0.5	ALLH	Uranium-235	0.254000008	pCi/g	None
21-22212	MD21-03-51523	0.0–0.5	ALLH	Americium-241	0.991999984	pCi/g	None
21-22212	MD21-03-51523	0.0–0.5	ALLH	Cesium-134	0.075999998	pCi/g	U
21-22212	MD21-03-51523	0.0–0.5	ALLH	Cesium-137	54.8409996	pCi/g	None
21-22212	MD21-03-51523	0.0–0.5	ALLH	Cobalt-60	0.005	pCi/g	U
21-22212	MD21-03-51523	0.0–0.5	ALLH	Europium-152	0.381999999	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22212	MD21-03-51523	0.0–0.5	ALLH	Plutonium-238	0.254999995	pCi/g	None
21-22212	MD21-03-51523	0.0–0.5	ALLH	Plutonium-239	1.572000027	pCi/g	None
21-22212	MD21-03-51523	0.0–0.5	ALLH	Ruthenium-106	0.142000005	pCi/g	U
21-22212	MD21-03-51523	0.0–0.5	ALLH	Sodium-22	-0.001	pCi/g	U
21-22212	MD21-03-51523	0.0–0.5	ALLH	Strontium-90	8.475000381	pCi/g	None
21-22212	MD21-03-51523	0.0–0.5	ALLH	Uranium-235	0.239999995	pCi/g	None
21-22213	MD21-03-51524	0.0–0.5	ALLH	Americium-241	1.123999953	pCi/g	None
21-22213	MD21-03-51524	0.0–0.5	ALLH	Cesium-134	0.057	pCi/g	U
21-22213	MD21-03-51524	0.0–0.5	ALLH	Cesium-137	22.07099915	pCi/g	None
21-22213	MD21-03-51524	0.0–0.5	ALLH	Cobalt-60	0	pCi/g	U
21-22213	MD21-03-51524	0.0–0.5	ALLH	Europium-152	0.331	pCi/g	U
21-22213	MD21-03-51524	0.0–0.5	ALLH	Plutonium-238	0.280999988	pCi/g	None
21-22213	MD21-03-51524	0.0–0.5	ALLH	Plutonium-239	1.49000001	pCi/g	None
21-22213	MD21-03-51524	0.0–0.5	ALLH	Ruthenium-106	0.116999999	pCi/g	U
21-22213	MD21-03-51524	0.0–0.5	ALLH	Sodium-22	0.001	pCi/g	U
21-22213	MD21-03-51524	0.0–0.5	ALLH	Strontium-90	4.991000175	pCi/g	None
21-22213	MD21-03-51524	0.0–0.5	ALLH	Uranium-235	0.263999999	pCi/g	None
21-22214	MD21-03-51525	0.0–0.5	ALLH	Americium-241	1.090999961	pCi/g	None
21-22214	MD21-03-51525	0.0–0.5	ALLH	Cesium-134	0.057999998	pCi/g	U
21-22214	MD21-03-51525	0.0–0.5	ALLH	Cesium-137	35.59199905	pCi/g	None
21-22214	MD21-03-51525	0.0–0.5	ALLH	Cobalt-60	-0.002	pCi/g	U
21-22214	MD21-03-51525	0.0–0.5	ALLH	Europium-152	0.254999995	pCi/g	None
21-22214	MD21-03-51525	0.0–0.5	ALLH	Plutonium-238	0.206	pCi/g	None
21-22214	MD21-03-51525	0.0–0.5	ALLH	Plutonium-239	1.40199995	pCi/g	None
21-22214	MD21-03-51525	0.0–0.5	ALLH	Ruthenium-106	-0.057	pCi/g	U
21-22214	MD21-03-51525	0.0–0.5	ALLH	Sodium-22	-0.015	pCi/g	U
21-22214	MD21-03-51525	0.0–0.5	ALLH	Strontium-90	6.518000126	pCi/g	None
21-22214	MD21-03-51525	0.0–0.5	ALLH	Uranium-235	0.209000006	pCi/g	None
21-22215	MD21-03-51526	0.0–0.5	ALLH	Americium-241	13.67099953	pCi/g	None
21-22215	MD21-03-51526	0.0–0.5	ALLH	Cesium-134	0.116999999	pCi/g	U
21-22215	MD21-03-51526	0.0–0.5	ALLH	Cesium-137	43.8730011	pCi/g	None
21-22215	MD21-03-51526	0.0–0.5	ALLH	Cobalt-60	-0.017	pCi/g	U
21-22215	MD21-03-51526	0.0–0.5	ALLH	Europium-152	0.138999999	pCi/g	None
21-22215	MD21-03-51526	0.0–0.5	ALLH	Plutonium-238	2.907000065	pCi/g	None
21-22215	MD21-03-51526	0.0–0.5	ALLH	Plutonium-239	13.32199955	pCi/g	None
21-22215	MD21-03-51526	0.0–0.5	ALLH	Ruthenium-106	-0.086	pCi/g	U
21-22215	MD21-03-51526	0.0–0.5	ALLH	Sodium-22	-0.002	pCi/g	U
21-22215	MD21-03-51526	0.0–0.5	ALLH	Strontium-90	13.60200024	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22215	MD21-03-51526	0.0–0.5	ALLH	Uranium-235	0.42899999	pCi/g	U
21-22216	MD21-03-51527	0.0–0.5	ALLH	Americium-241	5.382999897	pCi/g	None
21-22216	MD21-03-51527	0.0–0.5	ALLH	Cesium-134	0.093999997	pCi/g	U
21-22216	MD21-03-51527	0.0–0.5	ALLH	Cesium-137	4.59800005	pCi/g	None
21-22216	MD21-03-51527	0.0–0.5	ALLH	Cobalt-60	-0.001	pCi/g	U
21-22216	MD21-03-51527	0.0–0.5	ALLH	Europium-152	0.144999996	pCi/g	None
21-22216	MD21-03-51527	0.0–0.5	ALLH	Plutonium-238	0.961000025	pCi/g	None
21-22216	MD21-03-51527	0.0–0.5	ALLH	Plutonium-239	3.229000092	pCi/g	None
21-22216	MD21-03-51527	0.0–0.5	ALLH	Ruthenium-106	0.027000001	pCi/g	U
21-22216	MD21-03-51527	0.0–0.5	ALLH	Sodium-22	0.011	pCi/g	U
21-22216	MD21-03-51527	0.0–0.5	ALLH	Strontium-90	2.243999958	pCi/g	None
21-22216	MD21-03-51527	0.0–0.5	ALLH	Uranium-235	0.243000001	pCi/g	None
21-22217	MD21-03-51528	0.0–0.5	ALLH	Americium-241	41.63100052	pCi/g	None
21-22217	MD21-03-51528	0.0–0.5	ALLH	Cesium-134	0.097999997	pCi/g	U
21-22217	MD21-03-51528	0.0–0.5	ALLH	Cesium-137	31.61400032	pCi/g	None
21-22217	MD21-03-51528	0.0–0.5	ALLH	Cobalt-60	-0.009	pCi/g	U
21-22217	MD21-03-51528	0.0–0.5	ALLH	Europium-152	0.169	pCi/g	None
21-22217	MD21-03-51528	0.0–0.5	ALLH	Plutonium-238	4.754000187	pCi/g	None
21-22217	MD21-03-51528	0.0–0.5	ALLH	Plutonium-239	29.00600052	pCi/g	None
21-22217	MD21-03-51528	0.0–0.5	ALLH	Ruthenium-106	0.236000001	pCi/g	U
21-22217	MD21-03-51528	0.0–0.5	ALLH	Sodium-22	-0.005	pCi/g	U
21-22217	MD21-03-51528	0.0–0.5	ALLH	Strontium-90	18.75399971	pCi/g	None
21-22217	MD21-03-51528	0.0–0.5	ALLH	Uranium-235	0.409999996	pCi/g	U
21-22218	MD21-03-51529	0.0–0.5	ALLH	Americium-241	1.121000051	pCi/g	None
21-22218	MD21-03-51529	0.0–0.5	ALLH	Cesium-134	0.075999998	pCi/g	U
21-22218	MD21-03-51529	0.0–0.5	ALLH	Cesium-137	7.734000206	pCi/g	None
21-22218	MD21-03-51529	0.0–0.5	ALLH	Cobalt-60	-0.002	pCi/g	U
21-22218	MD21-03-51529	0.0–0.5	ALLH	Europium-152	0.395999998	pCi/g	None
21-22218	MD21-03-51529	0.0–0.5	ALLH	Plutonium-238	0.059999999	pCi/g	None
21-22218	MD21-03-51529	0.0–0.5	ALLH	Plutonium-239	1.422999978	pCi/g	None
21-22218	MD21-03-51529	0.0–0.5	ALLH	Ruthenium-106	0.104000002	pCi/g	U
21-22218	MD21-03-51529	0.0–0.5	ALLH	Sodium-22	0.005	pCi/g	U
21-22218	MD21-03-51529	0.0–0.5	ALLH	Strontium-90	8.43999958	pCi/g	None
21-22218	MD21-03-51529	0.0–0.5	ALLH	Uranium-235	0.263999999	pCi/g	None
21-22219	MD21-03-51530	0.0–0.5	ALLH	Americium-241	3.470999956	pCi/g	None
21-22219	MD21-03-51530	0.0–0.5	ALLH	Cesium-134	0.075000003	pCi/g	U
21-22219	MD21-03-51530	0.0–0.5	ALLH	Cesium-137	92.14800262	pCi/g	None
21-22219	MD21-03-51530	0.0–0.5	ALLH	Cobalt-60	-0.02	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22219	MD21-03-51530	0.0–0.5	ALLH	Europium-152	0.264999986	pCi/g	None
21-22219	MD21-03-51530	0.0–0.5	ALLH	Plutonium-238	0.312000006	pCi/g	None
21-22219	MD21-03-51530	0.0–0.5	ALLH	Plutonium-239	6.214000225	pCi/g	None
21-22219	MD21-03-51530	0.0–0.5	ALLH	Ruthenium-106	-0.04	pCi/g	U
21-22219	MD21-03-51530	0.0–0.5	ALLH	Sodium-22	-0.009	pCi/g	U
21-22219	MD21-03-51530	0.0–0.5	ALLH	Strontium-90	31.96899986	pCi/g	None
21-22219	MD21-03-51530	0.0–0.5	ALLH	Uranium-235	0.354000002	pCi/g	None
21-22220	MD21-03-51531	0.0–0.5	ALLH	Americium-241	3.25	pCi/g	None
21-22220	MD21-03-51531	0.0–0.5	ALLH	Cesium-134	-0.15800001	pCi/g	U
21-22220	MD21-03-51531	0.0–0.5	ALLH	Cesium-137	100.3199997	pCi/g	None
21-22220	MD21-03-51531	0.0–0.5	ALLH	Cobalt-60	-0.004	pCi/g	U
21-22220	MD21-03-51531	0.0–0.5	ALLH	Europium-152	0.300000012	pCi/g	None
21-22220	MD21-03-51531	0.0–0.5	ALLH	Plutonium-238	1.531000018	pCi/g	None
21-22220	MD21-03-51531	0.0–0.5	ALLH	Plutonium-239	6.223999977	pCi/g	None
21-22220	MD21-03-51531	0.0–0.5	ALLH	Ruthenium-106	-0.046	pCi/g	U
21-22220	MD21-03-51531	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22220	MD21-03-51531	0.0–0.5	ALLH	Strontium-90	16.26399994	pCi/g	None
21-22220	MD21-03-51531	0.0–0.5	ALLH	Uranium-235	0.294999987	pCi/g	None
21-22221	MD21-03-51532	0.0–0.5	ALLH	Americium-241	9.548000336	pCi/g	None
21-22221	MD21-03-51532	0.0–0.5	ALLH	Cesium-134	-0.21600001	pCi/g	U
21-22221	MD21-03-51532	0.0–0.5	ALLH	Cesium-137	134.1999969	pCi/g	None
21-22221	MD21-03-51532	0.0–0.5	ALLH	Cobalt-60	0.01	pCi/g	U
21-22221	MD21-03-51532	0.0–0.5	ALLH	Europium-152	0.312999994	pCi/g	None
21-22221	MD21-03-51532	0.0–0.5	ALLH	Plutonium-238	2.493000031	pCi/g	None
21-22221	MD21-03-51532	0.0–0.5	ALLH	Plutonium-239	11.30300045	pCi/g	None
21-22221	MD21-03-51532	0.0–0.5	ALLH	Ruthenium-106	-0.26199999	pCi/g	U
21-22221	MD21-03-51532	0.0–0.5	ALLH	Sodium-22	-0.007	pCi/g	U
21-22221	MD21-03-51532	0.0–0.5	ALLH	Strontium-90	21.8409996	pCi/g	None
21-22221	MD21-03-51532	0.0–0.5	ALLH	Uranium-235	0.280000001	pCi/g	None
21-22222	MD21-03-51533	0.0–0.5	ALLH	Americium-241	9.569999695	pCi/g	None
21-22222	MD21-03-51533	0.0–0.5	ALLH	Cesium-134	0.068000004	pCi/g	U
21-22222	MD21-03-51533	0.0–0.5	ALLH	Cesium-137	118.8899994	pCi/g	None
21-22222	MD21-03-51533	0.0–0.5	ALLH	Cobalt-60	0.005	pCi/g	U
21-22222	MD21-03-51533	0.0–0.5	ALLH	Europium-152	0.36500001	pCi/g	None
21-22222	MD21-03-51533	0.0–0.5	ALLH	Plutonium-238	2.130000114	pCi/g	None
21-22222	MD21-03-51533	0.0–0.5	ALLH	Plutonium-239	14.02200031	pCi/g	None
21-22222	MD21-03-51533	0.0–0.5	ALLH	Ruthenium-106	-0.043	pCi/g	U
21-22222	MD21-03-51533	0.0–0.5	ALLH	Sodium-22	0.017999999	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22222	MD21-03-51533	0.0–0.5	ALLH	Strontium-90	26.84399986	pCi/g	None
21-22222	MD21-03-51533	0.0–0.5	ALLH	Uranium-235	0.086999997	pCi/g	U
21-22223	MD21-03-51534	0.0–0.5	ALLH	Americium-241	5.089000225	pCi/g	None
21-22223	MD21-03-51534	0.0–0.5	ALLH	Cesium-134	0.046999998	pCi/g	U
21-22223	MD21-03-51534	0.0–0.5	ALLH	Cesium-137	67.68099976	pCi/g	None
21-22223	MD21-03-51534	0.0–0.5	ALLH	Cobalt-60	-0.006	pCi/g	U
21-22223	MD21-03-51534	0.0–0.5	ALLH	Europium-152	0.229000002	pCi/g	None
21-22223	MD21-03-51534	0.0–0.5	ALLH	Plutonium-238	1.062999964	pCi/g	None
21-22223	MD21-03-51534	0.0–0.5	ALLH	Plutonium-239	5.697999954	pCi/g	None
21-22223	MD21-03-51534	0.0–0.5	ALLH	Ruthenium-106	0.066	pCi/g	U
21-22223	MD21-03-51534	0.0–0.5	ALLH	Sodium-22	-0.019	pCi/g	U
21-22223	MD21-03-51534	0.0–0.5	ALLH	Strontium-90	8.295000076	pCi/g	None
21-22223	MD21-03-51534	0.0–0.5	ALLH	Uranium-235	0.268999994	pCi/g	None
21-22224	MD21-03-51535	0.0–0.5	ALLH	Americium-241	4.506000042	pCi/g	None
21-22224	MD21-03-51535	0.0–0.5	ALLH	Cesium-134	0.059	pCi/g	U
21-22224	MD21-03-51535	0.0–0.5	ALLH	Cesium-137	94.1230011	pCi/g	None
21-22224	MD21-03-51535	0.0–0.5	ALLH	Cobalt-60	-0.01	pCi/g	U
21-22224	MD21-03-51535	0.0–0.5	ALLH	Europium-152	0.245000005	pCi/g	U
21-22224	MD21-03-51535	0.0–0.5	ALLH	Plutonium-238	1.932000041	pCi/g	None
21-22224	MD21-03-51535	0.0–0.5	ALLH	Plutonium-239	6.818999767	pCi/g	None
21-22224	MD21-03-51535	0.0–0.5	ALLH	Ruthenium-106	0.158999994	pCi/g	U
21-22224	MD21-03-51535	0.0–0.5	ALLH	Sodium-22	0.004	pCi/g	U
21-22224	MD21-03-51535	0.0–0.5	ALLH	Strontium-90	16.92900085	pCi/g	None
21-22224	MD21-03-51535	0.0–0.5	ALLH	Uranium-235	0.264999986	pCi/g	None
21-22225	MD21-03-51536	0.0–0.5	ALLH	Americium-241	10.63599968	pCi/g	None
21-22225	MD21-03-51536	0.0–0.5	ALLH	Cesium-134	0.145999998	pCi/g	U
21-22225	MD21-03-51536	0.0–0.5	ALLH	Cesium-137	99.52899933	pCi/g	None
21-22225	MD21-03-51536	0.0–0.5	ALLH	Cobalt-60	-0.005	pCi/g	U
21-22225	MD21-03-51536	0.0–0.5	ALLH	Europium-152	0.188999996	pCi/g	U
21-22225	MD21-03-51536	0.0–0.5	ALLH	Plutonium-238	1.55400002	pCi/g	None
21-22225	MD21-03-51536	0.0–0.5	ALLH	Plutonium-239	10.11600018	pCi/g	None
21-22225	MD21-03-51536	0.0–0.5	ALLH	Ruthenium-106	0.195999995	pCi/g	U
21-22225	MD21-03-51536	0.0–0.5	ALLH	Sodium-22	0.022	pCi/g	U
21-22225	MD21-03-51536	0.0–0.5	ALLH	Strontium-90	22.6590004	pCi/g	None
21-22225	MD21-03-51536	0.0–0.5	ALLH	Uranium-235	0.270999998	pCi/g	None
21-22226	MD21-03-51537	0.0–0.5	ALLH	Americium-241	6.869999886	pCi/g	None
21-22226	MD21-03-51537	0.0–0.5	ALLH	Cesium-134	0.050999999	pCi/g	U
21-22226	MD21-03-51537	0.0–0.5	ALLH	Cesium-137	86.03600311	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22226	MD21-03-51537	0.0–0.5	ALLH	Cobalt-60	-0.007	pCi/g	U
21-22226	MD21-03-51537	0.0–0.5	ALLH	Europium-152	0.407999992	pCi/g	None
21-22226	MD21-03-51537	0.0–0.5	ALLH	Plutonium-238	1.5	pCi/g	None
21-22226	MD21-03-51537	0.0–0.5	ALLH	Plutonium-239	9.170000076	pCi/g	None
21-22226	MD21-03-51537	0.0–0.5	ALLH	Ruthenium-106	-0.067	pCi/g	U
21-22226	MD21-03-51537	0.0–0.5	ALLH	Sodium-22	-0.001	pCi/g	U
21-22226	MD21-03-51537	0.0–0.5	ALLH	Strontium-90	16.84600067	pCi/g	None
21-22226	MD21-03-51537	0.0–0.5	ALLH	Uranium-235	0.263999999	pCi/g	None
21-22227	MD21-03-51538	0.0–0.5	ALLH	Americium-241	2.016000032	pCi/g	None
21-22227	MD21-03-51538	0.0–0.5	ALLH	Cesium-134	0.063000001	pCi/g	U
21-22227	MD21-03-51538	0.0–0.5	ALLH	Cesium-137	32.06200027	pCi/g	None
21-22227	MD21-03-51538	0.0–0.5	ALLH	Cobalt-60	-0.002	pCi/g	U
21-22227	MD21-03-51538	0.0–0.5	ALLH	Europium-152	0.34799999	pCi/g	None
21-22227	MD21-03-51538	0.0–0.5	ALLH	Plutonium-238	0.597000003	pCi/g	None
21-22227	MD21-03-51538	0.0–0.5	ALLH	Plutonium-239	3.946000099	pCi/g	None
21-22227	MD21-03-51538	0.0–0.5	ALLH	Ruthenium-106	0.048	pCi/g	U
21-22227	MD21-03-51538	0.0–0.5	ALLH	Sodium-22	-0.008	pCi/g	U
21-22227	MD21-03-51538	0.0–0.5	ALLH	Strontium-90	6.210000038	pCi/g	None
21-22227	MD21-03-51538	0.0–0.5	ALLH	Uranium-235	0.103	pCi/g	U
21-22228	MD21-03-51539	0.0–0.5	ALLH	Americium-241	1.830000043	pCi/g	None
21-22228	MD21-03-51539	0.0–0.5	ALLH	Cesium-134	-0.26699999	pCi/g	U
21-22228	MD21-03-51539	0.0–0.5	ALLH	Cesium-137	15.64799976	pCi/g	None
21-22228	MD21-03-51539	0.0–0.5	ALLH	Cobalt-60	-0.006	pCi/g	U
21-22228	MD21-03-51539	0.0–0.5	ALLH	Europium-152	0.310000002	pCi/g	None
21-22228	MD21-03-51539	0.0–0.5	ALLH	Plutonium-238	0.321999997	pCi/g	None
21-22228	MD21-03-51539	0.0–0.5	ALLH	Plutonium-239	2.45600009	pCi/g	None
21-22228	MD21-03-51539	0.0–0.5	ALLH	Ruthenium-106	-0.054	pCi/g	U
21-22228	MD21-03-51539	0.0–0.5	ALLH	Sodium-22	0.014	pCi/g	U
21-22228	MD21-03-51539	0.0–0.5	ALLH	Strontium-90	4.321000099	pCi/g	None
21-22228	MD21-03-51539	0.0–0.5	ALLH	Uranium-235	0.280999988	pCi/g	None
21-22229	MD21-03-51540	0.0–0.5	ALLH	Americium-241	2.430000067	pCi/g	None
21-22229	MD21-03-51540	0.0–0.5	ALLH	Cesium-134	0.057999998	pCi/g	U
21-22229	MD21-03-51540	0.0–0.5	ALLH	Cesium-137	15.28600025	pCi/g	None
21-22229	MD21-03-51540	0.0–0.5	ALLH	Cobalt-60	0.007	pCi/g	U
21-22229	MD21-03-51540	0.0–0.5	ALLH	Europium-152	0.532999992	pCi/g	None
21-22229	MD21-03-51540	0.0–0.5	ALLH	Plutonium-238	0.184	pCi/g	None
21-22229	MD21-03-51540	0.0–0.5	ALLH	Plutonium-239	1.710999966	pCi/g	None
21-22229	MD21-03-51540	0.0–0.5	ALLH	Ruthenium-106	-0.113	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22229	MD21-03-51540	0.0–0.5	ALLH	Sodium-22	0.005	pCi/g	U
21-22229	MD21-03-51540	0.0–0.5	ALLH	Strontium-90	3.118999958	pCi/g	None
21-22229	MD21-03-51540	0.0–0.5	ALLH	Uranium-235	0.245000005	pCi/g	None
21-22230	MD21-03-51541	0.0–0.5	ALLH	Americium-241	3.562000036	pCi/g	None
21-22230	MD21-03-51541	0.0–0.5	ALLH	Cesium-134	0.078000002	pCi/g	U
21-22230	MD21-03-51541	0.0–0.5	ALLH	Cesium-137	55.49599838	pCi/g	None
21-22230	MD21-03-51541	0.0–0.5	ALLH	Cobalt-60	-0.011	pCi/g	U
21-22230	MD21-03-51541	0.0–0.5	ALLH	Europium-152	0.629000008	pCi/g	None
21-22230	MD21-03-51541	0.0–0.5	ALLH	Plutonium-238	0.223000005	pCi/g	None
21-22230	MD21-03-51541	0.0–0.5	ALLH	Plutonium-239	8.166999817	pCi/g	None
21-22230	MD21-03-51541	0.0–0.5	ALLH	Ruthenium-106	-0.206	pCi/g	U
21-22230	MD21-03-51541	0.0–0.5	ALLH	Sodium-22	0.007	pCi/g	U
21-22230	MD21-03-51541	0.0–0.5	ALLH	Strontium-90	20.7310009	pCi/g	None
21-22230	MD21-03-51541	0.0–0.5	ALLH	Uranium-235	0.416000009	pCi/g	U
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Americium-241	5.080999851	pCi/g	None
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Cesium-134	0.104000002	pCi/g	U
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Cesium-137	36.57500076	pCi/g	None
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Cobalt-60	-0.008	pCi/g	U
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Europium-152	0.405999988	pCi/g	None
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Plutonium-238	0.377999991	pCi/g	None
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Plutonium-239	7.989999771	pCi/g	None
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Ruthenium-106	0.135000005	pCi/g	U
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Sodium-22	0	pCi/g	U
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Strontium-90	8.751999855	pCi/g	None
21-22231	MD21-03-51542	0.0–0.5	Qbt 3	Uranium-235	0.30399999	pCi/g	None
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Americium-241	1.26699996	pCi/g	None
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Cesium-134	-0.067	pCi/g	U
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Cesium-137	24.98900032	pCi/g	None
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Cobalt-60	-0.005	pCi/g	U
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Europium-152	0.228	pCi/g	None
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Plutonium-238	0.050000001	pCi/g	None
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Plutonium-239	1.79400003	pCi/g	None
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Ruthenium-106	-0.002	pCi/g	U
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Sodium-22	0	pCi/g	U
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Strontium-90	9.114999771	pCi/g	None
21-22232	MD21-03-51543	0.0–0.5	Qbt 3	Uranium-235	0.275999993	pCi/g	None
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Americium-241	0.231999993	pCi/g	None
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Cesium-134	-0.021	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Cesium-137	45.29199982	pCi/g	None
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Cobalt-60	-0.004	pCi/g	U
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Europium-152	0.270999998	pCi/g	None
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Plutonium-238	0.028999999	pCi/g	U
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Plutonium-239	0.666999996	pCi/g	None
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Ruthenium-106	-0.149	pCi/g	U
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Sodium-22	0.018999999	pCi/g	U
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Strontium-90	25.54000092	pCi/g	None
21-22233	MD21-03-51544	0.0–0.5	Qbt 3	Uranium-235	0.223000005	pCi/g	None
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Americium-241	0.294999987	pCi/g	None
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Cesium-134	0.068999998	pCi/g	U
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Cesium-137	76.93599701	pCi/g	None
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Cobalt-60	-0.01	pCi/g	U
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Europium-152	0.312000006	pCi/g	None
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Plutonium-238	0.030999999	pCi/g	None
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Plutonium-239	1.162999988	pCi/g	None
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Ruthenium-106	-0.066	pCi/g	U
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Sodium-22	0.012	pCi/g	U
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Strontium-90	41.11999893	pCi/g	None
21-22234	MD21-03-51545	0.0–0.5	Qbt 3	Uranium-235	0.246000007	pCi/g	None
21-22235	MD21-03-51546	0.0–0.5	ALLH	Americium-241	0.467000008	pCi/g	None
21-22235	MD21-03-51546	0.0–0.5	ALLH	Cesium-134	0.082999997	pCi/g	None
21-22235	MD21-03-51546	0.0–0.5	ALLH	Cesium-137	99.15399933	pCi/g	None
21-22235	MD21-03-51546	0.0–0.5	ALLH	Cobalt-60	-0.005	pCi/g	U
21-22235	MD21-03-51546	0.0–0.5	ALLH	Europium-152	0.386999995	pCi/g	None
21-22235	MD21-03-51546	0.0–0.5	ALLH	Plutonium-238	0.046	pCi/g	None
21-22235	MD21-03-51546	0.0–0.5	ALLH	Plutonium-239	1.458999991	pCi/g	None
21-22235	MD21-03-51546	0.0–0.5	ALLH	Ruthenium-106	-0.061	pCi/g	U
21-22235	MD21-03-51546	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22235	MD21-03-51546	0.0–0.5	ALLH	Strontium-90	48.20899963	pCi/g	None
21-22235	MD21-03-51546	0.0–0.5	ALLH	Uranium-235	0.330000013	pCi/g	None
21-22236	MD21-03-51547	0.0–0.5	ALLH	Americium-241	2.217000008	pCi/g	None
21-22236	MD21-03-51547	0.0–0.5	ALLH	Cesium-134	0.075999998	pCi/g	U
21-22236	MD21-03-51547	0.0–0.5	ALLH	Cesium-137	79.60199738	pCi/g	None
21-22236	MD21-03-51547	0.0–0.5	ALLH	Cobalt-60	-0.001	pCi/g	U
21-22236	MD21-03-51547	0.0–0.5	ALLH	Europium-152	0.81400001	pCi/g	None
21-22236	MD21-03-51547	0.0–0.5	ALLH	Plutonium-238	0.123999998	pCi/g	None
21-22236	MD21-03-51547	0.0–0.5	ALLH	Plutonium-239	3.913000107	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22236	MD21-03-51547	0.0–0.5	ALLH	Ruthenium-106	0.120999999	pCi/g	U
21-22236	MD21-03-51547	0.0–0.5	ALLH	Sodium-22	0.014	pCi/g	U
21-22236	MD21-03-51547	0.0–0.5	ALLH	Strontium-90	24.10700035	pCi/g	None
21-22236	MD21-03-51547	0.0–0.5	ALLH	Uranium-235	0.314999998	pCi/g	None
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Americium-241	1.59800005	pCi/g	None
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Cesium-134	0.144999996	pCi/g	U
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Cesium-137	84.68299866	pCi/g	None
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Cobalt-60	-0.007	pCi/g	U
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Europium-152	0.467000008	pCi/g	None
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Plutonium-238	0.104999997	pCi/g	None
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Plutonium-239	1.911000013	pCi/g	None
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Ruthenium-106	0.016000001	pCi/g	U
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Sodium-22	0.002	pCi/g	U
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Strontium-90	29.75499916	pCi/g	None
21-22237	MD21-03-51548	0.0–0.5	Qbt 3	Uranium-235	0.294	pCi/g	None
21-22238	MD21-03-51549	0.0–0.5	ALLH	Americium-241	9.654999733	pCi/g	None
21-22238	MD21-03-51549	0.0–0.5	ALLH	Cesium-134	0.108000003	pCi/g	U
21-22238	MD21-03-51549	0.0–0.5	ALLH	Cesium-137	16.06900024	pCi/g	None
21-22238	MD21-03-51549	0.0–0.5	ALLH	Cobalt-60	-0.01	pCi/g	U
21-22238	MD21-03-51549	0.0–0.5	ALLH	Europium-152	0.379000008	pCi/g	None
21-22238	MD21-03-51549	0.0–0.5	ALLH	Plutonium-238	0.363999993	pCi/g	None
21-22238	MD21-03-51549	0.0–0.5	ALLH	Plutonium-239	11.89099979	pCi/g	None
21-22238	MD21-03-51549	0.0–0.5	ALLH	Ruthenium-106	-0.029	pCi/g	U
21-22238	MD21-03-51549	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22238	MD21-03-51549	0.0–0.5	ALLH	Strontium-90	3.046999931	pCi/g	None
21-22238	MD21-03-51549	0.0–0.5	ALLH	Uranium-235	0.303000003	pCi/g	U
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Americium-241	7.909999847	pCi/g	None
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Cesium-134	-0.32100001	pCi/g	U
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Cesium-137	24.91500092	pCi/g	None
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Cobalt-60	-0.026	pCi/g	U
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Europium-152	0.188999996	pCi/g	U
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Plutonium-238	1.335000038	pCi/g	None
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Plutonium-239	5.644999981	pCi/g	None
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Ruthenium-106	-0.168	pCi/g	U
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Sodium-22	0.003	pCi/g	U
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Strontium-90	12.01200008	pCi/g	None
21-22239	MD21-03-51550	0.0–0.5	Qbt 3	Uranium-235	0.449000001	pCi/g	None
21-22240	MD21-03-51551	0.0–0.5	ALLH	Americium-241	1.485999942	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22240	MD21-03-51551	0.0–0.5	ALLH	Cesium-134	0.104000002	pCi/g	U
21-22240	MD21-03-51551	0.0–0.5	ALLH	Cesium-137	2.855999947	pCi/g	None
21-22240	MD21-03-51551	0.0–0.5	ALLH	Cobalt-60	-0.005	pCi/g	U
21-22240	MD21-03-51551	0.0–0.5	ALLH	Europium-152	0.233999997	pCi/g	None
21-22240	MD21-03-51551	0.0–0.5	ALLH	Plutonium-238	0.150999993	pCi/g	None
21-22240	MD21-03-51551	0.0–0.5	ALLH	Plutonium-239	2.789000034	pCi/g	None
21-22240	MD21-03-51551	0.0–0.5	ALLH	Ruthenium-106	0.024	pCi/g	U
21-22240	MD21-03-51551	0.0–0.5	ALLH	Sodium-22	0.008	pCi/g	U
21-22240	MD21-03-51551	0.0–0.5	ALLH	Strontium-90	1.085000038	pCi/g	None
21-22240	MD21-03-51551	0.0–0.5	ALLH	Uranium-235	0.248999998	pCi/g	U
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Americium-241	28.90099907	pCi/g	None
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Cesium-134	0.086999997	pCi/g	U
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Cesium-137	78.8239975	pCi/g	None
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Cobalt-60	0.001	pCi/g	U
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Europium-152	0.214000002	pCi/g	None
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Plutonium-238	2.960000038	pCi/g	None
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Plutonium-239	11.83899975	pCi/g	None
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Ruthenium-106	0.141000003	pCi/g	U
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Sodium-22	0	pCi/g	U
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Strontium-90	29.35300064	pCi/g	None
21-22241	MD21-03-51552	0.0–0.5	Qbt 3	Uranium-235	0.444000006	pCi/g	None
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Americium-241	7.771999836	pCi/g	None
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Cesium-134	-0.099	pCi/g	U
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Cesium-137	62.94800186	pCi/g	None
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Cobalt-60	-0.008	pCi/g	U
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Europium-152	0.244000003	pCi/g	U
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Plutonium-238	0.312000006	pCi/g	None
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Plutonium-239	10.05200005	pCi/g	None
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Ruthenium-106	0.241999999	pCi/g	U
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Sodium-22	0.028000001	pCi/g	U
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Strontium-90	16.94799995	pCi/g	None
21-22242	MD21-03-51553	0.0–0.5	Qbt 3	Uranium-235	0.173999995	pCi/g	U
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Americium-241	1.338999987	pCi/g	None
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Cesium-134	-0.20200001	pCi/g	U
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Cesium-137	26.86899948	pCi/g	None
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Cobalt-60	0.003	pCi/g	U
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Europium-152	0.486000001	pCi/g	None
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Plutonium-238	0.078000002	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Plutonium-239	1.66900003	pCi/g	None
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Ruthenium-106	-0.028	pCi/g	U
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Sodium-22	-0.01	pCi/g	U
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Strontium-90	9.711000443	pCi/g	None
21-22243	MD21-03-51554	0.0–0.5	Qbt 3	Uranium-235	0.32100001	pCi/g	None
21-22244	MD21-03-51555	0.0–0.5	ALLH	Americium-241	2.227999926	pCi/g	None
21-22244	MD21-03-51555	0.0–0.5	ALLH	Cesium-134	0.172000006	pCi/g	U
21-22244	MD21-03-51555	0.0–0.5	ALLH	Cesium-137	12.41899967	pCi/g	None
21-22244	MD21-03-51555	0.0–0.5	ALLH	Cobalt-60	0.012	pCi/g	U
21-22244	MD21-03-51555	0.0–0.5	ALLH	Europium-152	0.386999995	pCi/g	U
21-22244	MD21-03-51555	0.0–0.5	ALLH	Plutonium-238	0.166999996	pCi/g	None
21-22244	MD21-03-51555	0.0–0.5	ALLH	Plutonium-239	2.227999926	pCi/g	None
21-22244	MD21-03-51555	0.0–0.5	ALLH	Ruthenium-106	-0.126	pCi/g	U
21-22244	MD21-03-51555	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22244	MD21-03-51555	0.0–0.5	ALLH	Strontium-90	5.518000126	pCi/g	None
21-22244	MD21-03-51555	0.0–0.5	ALLH	Uranium-235	0.388999999	pCi/g	U
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Americium-241	99.8239975	pCi/g	None
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Cesium-134	-0.359	pCi/g	U
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Cesium-137	75.47699738	pCi/g	None
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Cobalt-60	0.017999999	pCi/g	U
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Europium-152	0.123999998	pCi/g	U
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Plutonium-238	7.337999821	pCi/g	None
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Plutonium-239	27.60199928	pCi/g	None
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Ruthenium-106	0.414000005	pCi/g	U
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Sodium-22	-0.005	pCi/g	U
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Strontium-90	41.67300034	pCi/g	None
21-22245	MD21-03-51556	0.0–0.5	Qbt 3	Uranium-235	0.537	pCi/g	U
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Americium-241	2.740999937	pCi/g	None
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Cesium-134	-0.19599999	pCi/g	U
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Cesium-137	17.30200005	pCi/g	None
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Cobalt-60	0.032000002	pCi/g	U
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Europium-152	0.307000011	pCi/g	U
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Plutonium-238	0.405999988	pCi/g	None
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Plutonium-239	1.809000015	pCi/g	None
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Ruthenium-106	-0.05	pCi/g	U
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Sodium-22	-0.007	pCi/g	U
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Strontium-90	6.129000187	pCi/g	None
21-22246	MD21-03-51557	0.0–0.5	Qbt 3	Uranium-235	0.316000015	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Americium-241	5.040999889	pCi/g	None
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Cesium-134	0.07	pCi/g	U
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Cesium-137	69.28500366	pCi/g	None
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Cobalt-60	-0.005	pCi/g	U
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Europium-152	0.247999996	pCi/g	None
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Plutonium-238	0.270999998	pCi/g	None
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Plutonium-239	6.644000053	pCi/g	None
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Ruthenium-106	-0.185	pCi/g	U
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Sodium-22	0	pCi/g	U
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Strontium-90	20.00699997	pCi/g	None
21-22247	MD21-03-51558	0.0–0.5	Qbt 3	Uranium-235	0.307000011	pCi/g	None
21-22248	MD21-03-51559	0.0–0.5	ALLH	Americium-241	1.756999969	pCi/g	None
21-22248	MD21-03-51559	0.0–0.5	ALLH	Cesium-134	0.068999998	pCi/g	U
21-22248	MD21-03-51559	0.0–0.5	ALLH	Cesium-137	16.94000053	pCi/g	None
21-22248	MD21-03-51559	0.0–0.5	ALLH	Cobalt-60	-0.023	pCi/g	U
21-22248	MD21-03-51559	0.0–0.5	ALLH	Europium-152	0.294	pCi/g	None
21-22248	MD21-03-51559	0.0–0.5	ALLH	Plutonium-238	0.166999996	pCi/g	None
21-22248	MD21-03-51559	0.0–0.5	ALLH	Plutonium-239	2.062999964	pCi/g	None
21-22248	MD21-03-51559	0.0–0.5	ALLH	Ruthenium-106	-0.015	pCi/g	U
21-22248	MD21-03-51559	0.0–0.5	ALLH	Sodium-22	0.025	pCi/g	U
21-22248	MD21-03-51559	0.0–0.5	ALLH	Strontium-90	13.74199963	pCi/g	None
21-22248	MD21-03-51559	0.0–0.5	ALLH	Uranium-235	0.363999993	pCi/g	None
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Americium-241	15.55099964	pCi/g	None
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Cesium-134	-0.032	pCi/g	U
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Cesium-137	52.07899857	pCi/g	None
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Cobalt-60	0	pCi/g	U
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Europium-152	0.067000002	pCi/g	U
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Plutonium-238	2.39199996	pCi/g	None
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Plutonium-239	16.81500053	pCi/g	None
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Ruthenium-106	-0.021	pCi/g	U
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Sodium-22	0.013	pCi/g	U
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Strontium-90	18.52899933	pCi/g	None
21-22249	MD21-03-51560	0.0–0.5	Qbt 3	Uranium-235	0.38499999	pCi/g	None
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Americium-241	2.86500001	pCi/g	None
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Cesium-134	0.158999994	pCi/g	U
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Cesium-137	20.16200066	pCi/g	None
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Cobalt-60	-0.008	pCi/g	U
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Europium-152	0.405000001	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Plutonium-238	0.307000011	pCi/g	None
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Plutonium-239	1.644000053	pCi/g	None
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Ruthenium-106	0.054000001	pCi/g	U
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Sodium-22	0.013	pCi/g	U
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Strontium-90	6.585000038	pCi/g	None
21-22250	MD21-03-51561	0.0–0.5	Qbt 3	Uranium-235	0.337000012	pCi/g	None
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Americium-241	3.306999922	pCi/g	None
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Cesium-134	0.093999997	pCi/g	U
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Cesium-137	20.1760006	pCi/g	None
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Cobalt-60	-0.016	pCi/g	U
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Europium-152	0.541999996	pCi/g	None
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Plutonium-238	0.136999995	pCi/g	None
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Plutonium-239	3.53399992	pCi/g	None
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Ruthenium-106	0.120999999	pCi/g	U
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Sodium-22	-0.007	pCi/g	U
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Strontium-90	8.647000313	pCi/g	None
21-22251	MD21-03-51562	0.0–0.5	Qbt 3	Uranium-235	0.27700001	pCi/g	None
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Americium-241	0.56099999	pCi/g	None
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Cesium-134	0.092	pCi/g	U
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Cesium-137	53.70500183	pCi/g	None
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Cobalt-60	0.017000001	pCi/g	U
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Europium-152	0.35800001	pCi/g	None
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Plutonium-238	0.039999999	pCi/g	None
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Plutonium-239	1.182000041	pCi/g	None
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Ruthenium-106	0.238999993	pCi/g	U
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Sodium-22	0.002	pCi/g	U
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Strontium-90	27.34600067	pCi/g	None
21-22252	MD21-03-51563	0.0–0.5	Qbt 3	Uranium-235	0.356999993	pCi/g	None
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Americium-241	37.42900085	pCi/g	None
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Cesium-134	0.100000001	pCi/g	U
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Cesium-137	158.4600067	pCi/g	None
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Cobalt-60	-0.009	pCi/g	U
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Europium-152	0.246999994	pCi/g	None
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Plutonium-238	3.119999886	pCi/g	None
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Plutonium-239	35.70700073	pCi/g	None
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Ruthenium-106	-0.24699999	pCi/g	U
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Sodium-22	0.016000001	pCi/g	U
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Strontium-90	43.70600128	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22253	MD21-03-51564	0.0–0.5	Qbt 3	Uranium-235	0.460999995	pCi/g	None
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Americium-241	9.265999794	pCi/g	None
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Cesium-134	0.109999999	pCi/g	U
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Cesium-137	168.0899963	pCi/g	None
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Cobalt-60	-0.008	pCi/g	U
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Europium-152	0.150999993	pCi/g	U
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Plutonium-238	2.263000011	pCi/g	None
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Plutonium-239	11.8380003	pCi/g	None
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Ruthenium-106	-0.33399999	pCi/g	U
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Sodium-22	-0.022	pCi/g	U
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Strontium-90	35.24399948	pCi/g	None
21-22254	MD21-03-51565	0.0–0.5	Qbt 3	Uranium-235	0.560000002	pCi/g	None
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Americium-241	0.108999997	pCi/g	None
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Cesium-134	0.114	pCi/g	U
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Cesium-137	0.324999988	pCi/g	None
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Cobalt-60	-0.02	pCi/g	U
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Europium-152	0.216999993	pCi/g	None
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Plutonium-238	0.009	pCi/g	U
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Plutonium-239	0.163000003	pCi/g	None
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Ruthenium-106	0.268999994	pCi/g	U
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Sodium-22	-0.01	pCi/g	U
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Strontium-90	-0.008	pCi/g	U
21-22255	MD21-03-51566	0.0–0.5	Qbt 3	Uranium-235	0.152999997	pCi/g	U
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Americium-241	0.307999998	pCi/g	None
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Cesium-134	-0.27200001	pCi/g	U
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Cesium-137	12.01399994	pCi/g	None
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Cobalt-60	-0.01	pCi/g	U
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Europium-152	0.231999993	pCi/g	None
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Plutonium-238	0.136999995	pCi/g	None
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Plutonium-239	3.53399992	pCi/g	None
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Ruthenium-106	0.093999997	pCi/g	U
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Sodium-22	0	pCi/g	U
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Strontium-90	1.968999982	pCi/g	None
21-22256	MD21-03-51567	0.0–0.5	Qbt 3	Uranium-235	0.266000003	pCi/g	None
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Americium-241	1.223999977	pCi/g	None
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Cesium-134	0.085000001	pCi/g	U
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Cesium-137	10.88199997	pCi/g	None
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Cobalt-60	-0.005	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Europium-152	0.354000002	pCi/g	None
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Plutonium-238	0.039999999	pCi/g	None
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Plutonium-239	1.182000041	pCi/g	None
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Ruthenium-106	-0.126	pCi/g	U
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Sodium-22	0.003	pCi/g	U
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Strontium-90	1.33099997	pCi/g	None
21-22257	MD21-03-51568	0.0–0.5	Qbt 3	Uranium-235	0.342000008	pCi/g	None
21-22201	MD21-03-51569	0.0–0.5	ALLH	Americium-241	4.528999805	pCi/g	None
21-22201	MD21-03-51569	0.0–0.5	ALLH	Cesium-134	0.096000001	pCi/g	U
21-22201	MD21-03-51569	0.0–0.5	ALLH	Cesium-137	40.07699966	pCi/g	None
21-22201	MD21-03-51569	0.0–0.5	ALLH	Cobalt-60	-0.009	pCi/g	U
21-22201	MD21-03-51569	0.0–0.5	ALLH	Europium-152	0.261000007	pCi/g	None
21-22201	MD21-03-51569	0.0–0.5	ALLH	Plutonium-238	0.414000005	pCi/g	None
21-22201	MD21-03-51569	0.0–0.5	ALLH	Plutonium-239	2.413000107	pCi/g	None
21-22201	MD21-03-51569	0.0–0.5	ALLH	Ruthenium-106	0.179000005	pCi/g	U
21-22201	MD21-03-51569	0.0–0.5	ALLH	Sodium-22	-0.007	pCi/g	U
21-22201	MD21-03-51569	0.0–0.5	ALLH	Strontium-90	8.616000175	pCi/g	None
21-22201	MD21-03-51569	0.0–0.5	ALLH	Uranium-235	0.39199999	pCi/g	U
21-22200	MD21-03-51570	0.0–0.5	ALLH	Americium-241	0.238000005	pCi/g	None
21-22200	MD21-03-51570	0.0–0.5	ALLH	Cesium-134	0.041000001	pCi/g	U
21-22200	MD21-03-51570	0.0–0.5	ALLH	Cesium-137	0.595000029	pCi/g	None
21-22200	MD21-03-51570	0.0–0.5	ALLH	Cobalt-60	0.037999999	pCi/g	None
21-22200	MD21-03-51570	0.0–0.5	ALLH	Europium-152	0.241999999	pCi/g	None
21-22200	MD21-03-51570	0.0–0.5	ALLH	Plutonium-238	0.052999999	pCi/g	None
21-22200	MD21-03-51570	0.0–0.5	ALLH	Plutonium-239	1.40199995	pCi/g	None
21-22200	MD21-03-51570	0.0–0.5	ALLH	Ruthenium-106	-0.052	pCi/g	U
21-22200	MD21-03-51570	0.0–0.5	ALLH	Sodium-22	0.026000001	pCi/g	U
21-22200	MD21-03-51570	0.0–0.5	ALLH	Strontium-90	0.275999993	pCi/g	U
21-22200	MD21-03-51570	0.0–0.5	ALLH	Uranium-235	0.316000015	pCi/g	None
21-22199	MD21-03-51571	0.0–0.5	ALLH	Americium-241	1.059999943	pCi/g	None
21-22199	MD21-03-51571	0.0–0.5	ALLH	Cesium-134	0.078000002	pCi/g	U
21-22199	MD21-03-51571	0.0–0.5	ALLH	Cesium-137	14.83399963	pCi/g	None
21-22199	MD21-03-51571	0.0–0.5	ALLH	Cobalt-60	-0.007	pCi/g	U
21-22199	MD21-03-51571	0.0–0.5	ALLH	Europium-152	0.268000007	pCi/g	None
21-22199	MD21-03-51571	0.0–0.5	ALLH	Plutonium-238	0.164000005	pCi/g	None
21-22199	MD21-03-51571	0.0–0.5	ALLH	Plutonium-239	1.414000034	pCi/g	None
21-22199	MD21-03-51571	0.0–0.5	ALLH	Ruthenium-106	0.104000002	pCi/g	U
21-22199	MD21-03-51571	0.0–0.5	ALLH	Sodium-22	-0.002	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22199	MD21-03-51571	0.0–0.5	ALLH	Strontium-90	2.482000113	pCi/g	None
21-22199	MD21-03-51571	0.0–0.5	ALLH	Uranium-235	0.289000005	pCi/g	None
21-22198	MD21-03-51572	0.0–0.5	ALLH	Americium-241	2.720000029	pCi/g	None
21-22198	MD21-03-51572	0.0–0.5	ALLH	Cesium-134	-0.064	pCi/g	U
21-22198	MD21-03-51572	0.0–0.5	ALLH	Cesium-137	38.96300125	pCi/g	None
21-22198	MD21-03-51572	0.0–0.5	ALLH	Cobalt-60	-0.018	pCi/g	U
21-22198	MD21-03-51572	0.0–0.5	ALLH	Europium-152	0.209999993	pCi/g	None
21-22198	MD21-03-51572	0.0–0.5	ALLH	Plutonium-238	0.321999997	pCi/g	None
21-22198	MD21-03-51572	0.0–0.5	ALLH	Plutonium-239	3.375	pCi/g	None
21-22198	MD21-03-51572	0.0–0.5	ALLH	Ruthenium-106	-0.131	pCi/g	U
21-22198	MD21-03-51572	0.0–0.5	ALLH	Sodium-22	0.001	pCi/g	U
21-22198	MD21-03-51572	0.0–0.5	ALLH	Strontium-90	4.448999882	pCi/g	None
21-22198	MD21-03-51572	0.0–0.5	ALLH	Uranium-235	0.312000006	pCi/g	U
21-22235	MD21-03-51573	0.0–0.5	ALLH	Americium-241	0.43900001	pCi/g	None
21-22235	MD21-03-51573	0.0–0.5	ALLH	Cesium-134	-0.168	pCi/g	U
21-22235	MD21-03-51573	0.0–0.5	ALLH	Cesium-137	89.11699677	pCi/g	None
21-22235	MD21-03-51573	0.0–0.5	ALLH	Cobalt-60	-0.002	pCi/g	U
21-22235	MD21-03-51573	0.0–0.5	ALLH	Europium-152	0.370999992	pCi/g	None
21-22235	MD21-03-51573	0.0–0.5	ALLH	Plutonium-238	0.079999998	pCi/g	None
21-22235	MD21-03-51573	0.0–0.5	ALLH	Plutonium-239	1.842000008	pCi/g	None
21-22235	MD21-03-51573	0.0–0.5	ALLH	Ruthenium-106	-0.27500001	pCi/g	U
21-22235	MD21-03-51573	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22235	MD21-03-51573	0.0–0.5	ALLH	Strontium-90	44.04700089	pCi/g	None
21-22235	MD21-03-51573	0.0–0.5	ALLH	Uranium-235	0.282999992	pCi/g	None
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Americium-241	0.314999998	pCi/g	J-
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Cesium-134	0.115999997	pCi/g	U
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Cesium-137	3.838999987	pCi/g	None
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Cobalt-60	0.012	pCi/g	U
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Europium-152	0.266000003	pCi/g	None
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Plutonium-238	0.043000001	pCi/g	None
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Plutonium-239	0.229000002	pCi/g	None
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Ruthenium-106	-0.131	pCi/g	U
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Sodium-22	-0.018	pCi/g	U
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Strontium-90	1.886999965	pCi/g	None
21-22258	MD21-03-51574	0.0–0.5	Qbt 3	Uranium-235	0.307999998	pCi/g	U
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Americium-241	3.25999999	pCi/g	J-
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Cesium-134	0.505999982	pCi/g	None
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Cesium-137	29.69599915	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Cobalt-60	-0.002	pCi/g	U
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Europium-152	0.187000006	pCi/g	U
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Plutonium-238	0.104000002	pCi/g	None
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Plutonium-239	0.727999985	pCi/g	None
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Ruthenium-106	0.048	pCi/g	U
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Sodium-22	0.02	pCi/g	U
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Strontium-90	5.306000233	pCi/g	None
21-22259	MD21-03-51575	0.0–0.5	Qbt 3	Uranium-235	0.345999986	pCi/g	U
21-22260	MD21-03-51576	0.0–0.5	ALLH	Americium-241	3.461999893	pCi/g	J-
21-22260	MD21-03-51576	0.0–0.5	ALLH	Cesium-134	0.077	pCi/g	U
21-22260	MD21-03-51576	0.0–0.5	ALLH	Cesium-137	25.79999924	pCi/g	None
21-22260	MD21-03-51576	0.0–0.5	ALLH	Cobalt-60	-0.003	pCi/g	U
21-22260	MD21-03-51576	0.0–0.5	ALLH	Europium-152	0.547999978	pCi/g	None
21-22260	MD21-03-51576	0.0–0.5	ALLH	Plutonium-238	0.167999998	pCi/g	None
21-22260	MD21-03-51576	0.0–0.5	ALLH	Plutonium-239	3.969000101	pCi/g	None
21-22260	MD21-03-51576	0.0–0.5	ALLH	Ruthenium-106	0.199000001	pCi/g	U
21-22260	MD21-03-51576	0.0–0.5	ALLH	Sodium-22	0.006	pCi/g	U
21-22260	MD21-03-51576	0.0–0.5	ALLH	Strontium-90	3.822000027	pCi/g	None
21-22260	MD21-03-51576	0.0–0.5	ALLH	Uranium-235	0.361999989	pCi/g	None
21-22261	MD21-03-51577	0.0–0.5	ALLH	Americium-241	0.508000016	pCi/g	J-
21-22261	MD21-03-51577	0.0–0.5	ALLH	Cesium-134	0.082000002	pCi/g	U
21-22261	MD21-03-51577	0.0–0.5	ALLH	Cesium-137	13.1420002	pCi/g	None
21-22261	MD21-03-51577	0.0–0.5	ALLH	Cobalt-60	0.008	pCi/g	U
21-22261	MD21-03-51577	0.0–0.5	ALLH	Europium-152	0.317999989	pCi/g	None
21-22261	MD21-03-51577	0.0–0.5	ALLH	Plutonium-238	0.086000003	pCi/g	None
21-22261	MD21-03-51577	0.0–0.5	ALLH	Plutonium-239	0.853999972	pCi/g	None
21-22261	MD21-03-51577	0.0–0.5	ALLH	Ruthenium-106	0.090999998	pCi/g	U
21-22261	MD21-03-51577	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22261	MD21-03-51577	0.0–0.5	ALLH	Strontium-90	2.102999926	pCi/g	None
21-22261	MD21-03-51577	0.0–0.5	ALLH	Uranium-235	0.202000007	pCi/g	None
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Americium-241	9.821000099	pCi/g	None
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Cesium-134	0.081	pCi/g	U
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Cesium-137	69.03199768	pCi/g	None
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Cobalt-60	0.005	pCi/g	U
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Europium-152	0.323000014	pCi/g	None
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Plutonium-238	0.51700002	pCi/g	None
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Plutonium-239	9.138999939	pCi/g	None
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Ruthenium-106	-0.145	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Sodium-22	0.006	pCi/g	U
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Strontium-90	24.42700005	pCi/g	None
21-22262	MD21-03-51578	0.0–0.5	Qbt 3	Uranium-235	0.264999986	pCi/g	None
21-22263	MD21-03-51579	0.0–0.5	ALLH	Americium-241	0.944000006	pCi/g	None
21-22263	MD21-03-51579	0.0–0.5	ALLH	Cesium-134	0.270000011	pCi/g	U
21-22263	MD21-03-51579	0.0–0.5	ALLH	Cesium-137	43.30599976	pCi/g	None
21-22263	MD21-03-51579	0.0–0.5	ALLH	Cobalt-60	-0.008	pCi/g	U
21-22263	MD21-03-51579	0.0–0.5	ALLH	Europium-152	0.287999988	pCi/g	None
21-22263	MD21-03-51579	0.0–0.5	ALLH	Plutonium-238	0.178000003	pCi/g	None
21-22263	MD21-03-51579	0.0–0.5	ALLH	Plutonium-239	4.171000004	pCi/g	None
21-22263	MD21-03-51579	0.0–0.5	ALLH	Ruthenium-106	-0.329	pCi/g	U
21-22263	MD21-03-51579	0.0–0.5	ALLH	Sodium-22	0.014	pCi/g	U
21-22263	MD21-03-51579	0.0–0.5	ALLH	Strontium-90	12.84899998	pCi/g	None
21-22263	MD21-03-51579	0.0–0.5	ALLH	Uranium-235	0.393000007	pCi/g	None
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Americium-241	44.92900085	pCi/g	None
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Cesium-134	-0.025	pCi/g	U
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Cesium-137	157.3399963	pCi/g	None
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Cobalt-60	0.011	pCi/g	U
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Europium-152	0.108000003	pCi/g	U
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Plutonium-238	2.924000025	pCi/g	None
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Plutonium-239	18.52300072	pCi/g	None
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Ruthenium-106	0.303000003	pCi/g	U
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Sodium-22	-0.019	pCi/g	U
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Strontium-90	35.31499863	pCi/g	None
21-22264	MD21-03-51580	0.0–0.5	Qbt 3	Uranium-235	0.453999996	pCi/g	None
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Americium-241	20.68000031	pCi/g	None
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Cesium-134	0.077	pCi/g	U
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Cesium-137	36.20199966	pCi/g	None
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Cobalt-60	-0.015	pCi/g	U
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Europium-152	0.223000005	pCi/g	U
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Plutonium-238	0.670000017	pCi/g	None
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Plutonium-239	9.295999527	pCi/g	None
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Ruthenium-106	0.007	pCi/g	U
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Sodium-22	-0.004	pCi/g	U
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Strontium-90	11.44400024	pCi/g	None
21-22265	MD21-03-51581	0.0–0.5	Qbt 3	Uranium-235	0.180999994	pCi/g	U
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Americium-241	56.32899857	pCi/g	None
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Cesium-134	0.068000004	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Cesium-137	68.16699982	pCi/g	None
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Cobalt-60	-0.001	pCi/g	U
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Europium-152	0.122000001	pCi/g	None
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Plutonium-238	5.749000072	pCi/g	None
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Plutonium-239	59.36899948	pCi/g	None
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Ruthenium-106	-0.17200001	pCi/g	U
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Sodium-22	0.007	pCi/g	U
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Strontium-90	26.29500008	pCi/g	None
21-22266	MD21-03-51582	0.0–0.5	Qbt 3	Uranium-235	0.338	pCi/g	None
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Americium-241	1.774000049	pCi/g	None
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Cesium-134	0.057	pCi/g	U
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Cesium-137	63.89899826	pCi/g	None
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Cobalt-60	-0.019	pCi/g	U
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Europium-152	0.342000008	pCi/g	None
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Plutonium-238	0.246000007	pCi/g	None
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Plutonium-239	3.509000063	pCi/g	None
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Ruthenium-106	0	pCi/g	U
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Sodium-22	-0.025	pCi/g	U
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Strontium-90	25.24900055	pCi/g	None
21-22267	MD21-03-51583	0.0–0.5	Qbt 3	Uranium-235	0.162	pCi/g	U
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Americium-241	5.493999958	pCi/g	None
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Cesium-134	0.082000002	pCi/g	U
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Cesium-137	34.65399933	pCi/g	None
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Cobalt-60	0.001	pCi/g	U
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Europium-152	0.291999996	pCi/g	None
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Plutonium-238	0.349000007	pCi/g	None
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Plutonium-239	14.69400024	pCi/g	None
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Ruthenium-106	0.136999995	pCi/g	U
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Sodium-22	-0.001	pCi/g	U
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Strontium-90	6.112999916	pCi/g	None
21-22268	MD21-03-51584	0.0–0.5	Qbt 3	Uranium-235	0.252999991	pCi/g	None
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Americium-241	23.24799919	pCi/g	None
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Cesium-134	0.075000003	pCi/g	U
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Cesium-137	37.04499817	pCi/g	None
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Cobalt-60	0.009	pCi/g	U
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Europium-152	0.101999998	pCi/g	None
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Plutonium-238	2.721999884	pCi/g	None
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Plutonium-239	25.44300079	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Ruthenium-106	0.025	pCi/g	U
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Sodium-22	0.003	pCi/g	U
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Strontium-90	20.8010006	pCi/g	None
21-22269	MD21-03-51585	0.0–0.5	Qbt 3	Uranium-235	0.257999986	pCi/g	None
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Americium-241	33.1570015	pCi/g	None
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Cesium-134	0.409000009	pCi/g	U
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Cesium-137	76.03900146	pCi/g	None
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Cobalt-60	0.007	pCi/g	U
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Europium-152	0.133000001	pCi/g	U
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Plutonium-238	4.758999825	pCi/g	None
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Plutonium-239	37.68299866	pCi/g	None
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Ruthenium-106	0.218999997	pCi/g	U
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Sodium-22	-0.006	pCi/g	U
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Strontium-90	26.95599937	pCi/g	None
21-22270	MD21-03-51586	0.0–0.5	Qbt 3	Uranium-235	0.312000006	pCi/g	None
21-22271	MD21-03-51587	0.0–0.5	ALLH	Americium-241	3.065000057	pCi/g	None
21-22271	MD21-03-51587	0.0–0.5	ALLH	Cesium-134	-0.146	pCi/g	U
21-22271	MD21-03-51587	0.0–0.5	ALLH	Cesium-137	7.428999901	pCi/g	None
21-22271	MD21-03-51587	0.0–0.5	ALLH	Cobalt-60	-0.001	pCi/g	U
21-22271	MD21-03-51587	0.0–0.5	ALLH	Europium-152	0.521000028	pCi/g	None
21-22271	MD21-03-51587	0.0–0.5	ALLH	Plutonium-238	0.263999999	pCi/g	None
21-22271	MD21-03-51587	0.0–0.5	ALLH	Plutonium-239	8.824999809	pCi/g	None
21-22271	MD21-03-51587	0.0–0.5	ALLH	Ruthenium-106	0.056000002	pCi/g	U
21-22271	MD21-03-51587	0.0–0.5	ALLH	Sodium-22	-0.006	pCi/g	U
21-22271	MD21-03-51587	0.0–0.5	ALLH	Strontium-90	1.172999978	pCi/g	None
21-22271	MD21-03-51587	0.0–0.5	ALLH	Uranium-235	0.270000011	pCi/g	None
21-22272	MD21-03-51588	0.0–0.5	ALLH	Americium-241	8.99600029	pCi/g	None
21-22272	MD21-03-51588	0.0–0.5	ALLH	Cesium-134	0.064999998	pCi/g	U
21-22272	MD21-03-51588	0.0–0.5	ALLH	Cesium-137	93.16899872	pCi/g	None
21-22272	MD21-03-51588	0.0–0.5	ALLH	Cobalt-60	0.016000001	pCi/g	U
21-22272	MD21-03-51588	0.0–0.5	ALLH	Europium-152	0.237000003	pCi/g	U
21-22272	MD21-03-51588	0.0–0.5	ALLH	Plutonium-238	0.864000022	pCi/g	None
21-22272	MD21-03-51588	0.0–0.5	ALLH	Plutonium-239	23.50900078	pCi/g	None
21-22272	MD21-03-51588	0.0–0.5	ALLH	Ruthenium-106	0.012	pCi/g	U
21-22272	MD21-03-51588	0.0–0.5	ALLH	Sodium-22	0.015	pCi/g	U
21-22272	MD21-03-51588	0.0–0.5	ALLH	Strontium-90	21.39100075	pCi/g	None
21-22272	MD21-03-51588	0.0–0.5	ALLH	Uranium-235	0.282999992	pCi/g	None
21-22273	MD21-03-51589	0.0–0.5	ALLH	Americium-241	2.242000103	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22273	MD21-03-51589	0.0–0.5	ALLH	Cesium-134	0.083999999	pCi/g	U
21-22273	MD21-03-51589	0.0–0.5	ALLH	Cesium-137	38.04199982	pCi/g	None
21-22273	MD21-03-51589	0.0–0.5	ALLH	Cobalt-60	0.006	pCi/g	U
21-22273	MD21-03-51589	0.0–0.5	ALLH	Europium-152	0.245000005	pCi/g	None
21-22273	MD21-03-51589	0.0–0.5	ALLH	Plutonium-238	0.345999986	pCi/g	None
21-22273	MD21-03-51589	0.0–0.5	ALLH	Plutonium-239	4.822999954	pCi/g	None
21-22273	MD21-03-51589	0.0–0.5	ALLH	Ruthenium-106	-0.116	pCi/g	U
21-22273	MD21-03-51589	0.0–0.5	ALLH	Sodium-22	0.016000001	pCi/g	U
21-22273	MD21-03-51589	0.0–0.5	ALLH	Strontium-90	7.668000221	pCi/g	None
21-22273	MD21-03-51589	0.0–0.5	ALLH	Uranium-235	0.246999994	pCi/g	None
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Americium-241	4.337999821	pCi/g	None
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Cesium-134	0.143000007	pCi/g	U
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Cesium-137	180.2100067	pCi/g	None
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Cobalt-60	-0.008	pCi/g	U
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Europium-152	0.30399999	pCi/g	None
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Plutonium-238	0.39199999	pCi/g	None
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Plutonium-239	15.32299995	pCi/g	None
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Ruthenium-106	0.008	pCi/g	U
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Sodium-22	0.003	pCi/g	U
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Strontium-90	36.9129982	pCi/g	None
21-22274	MD21-03-51590	0.0–0.5	Qbt 3	Uranium-235	0.268999994	pCi/g	None
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Americium-241	0.048999999	pCi/g	None
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Cesium-134	0.075000003	pCi/g	U
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Cesium-137	83.21800232	pCi/g	None
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Cobalt-60	-0.009	pCi/g	U
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Europium-152	0.354000002	pCi/g	None
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Plutonium-238	0.026000001	pCi/g	None
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Plutonium-239	0.996999979	pCi/g	None
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Ruthenium-106	0.048999999	pCi/g	U
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Sodium-22	-0.002	pCi/g	U
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Strontium-90	18.30200005	pCi/g	None
21-22275	MD21-03-51591	0.0–0.5	Qbt 3	Uranium-235	0.282999992	pCi/g	None
21-22276	MD21-03-51592	0.0–0.5	ALLH	Americium-241	1.404999971	pCi/g	None
21-22276	MD21-03-51592	0.0–0.5	ALLH	Cesium-134	0.050000001	pCi/g	U
21-22276	MD21-03-51592	0.0–0.5	ALLH	Cesium-137	91.21499634	pCi/g	None
21-22276	MD21-03-51592	0.0–0.5	ALLH	Cobalt-60	-0.012	pCi/g	U
21-22276	MD21-03-51592	0.0–0.5	ALLH	Europium-152	0.349000007	pCi/g	None
21-22276	MD21-03-51592	0.0–0.5	ALLH	Plutonium-238	0.545000017	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22276	MD21-03-51592	0.0–0.5	ALLH	Plutonium-239	5.250999928	pCi/g	None
21-22276	MD21-03-51592	0.0–0.5	ALLH	Ruthenium-106	0.022	pCi/g	U
21-22276	MD21-03-51592	0.0–0.5	ALLH	Sodium-22	-0.007	pCi/g	U
21-22276	MD21-03-51592	0.0–0.5	ALLH	Strontium-90	8.706000328	pCi/g	None
21-22276	MD21-03-51592	0.0–0.5	ALLH	Uranium-235	0.264999986	pCi/g	None
21-22277	MD21-03-51593	0.0–0.5	ALLH	Americium-241	1.582000017	pCi/g	None
21-22277	MD21-03-51593	0.0–0.5	ALLH	Cesium-134	0.083999999	pCi/g	U
21-22277	MD21-03-51593	0.0–0.5	ALLH	Cesium-137	51.33599854	pCi/g	None
21-22277	MD21-03-51593	0.0–0.5	ALLH	Cobalt-60	0.001	pCi/g	U
21-22277	MD21-03-51593	0.0–0.5	ALLH	Europium-152	0.254999995	pCi/g	None
21-22277	MD21-03-51593	0.0–0.5	ALLH	Plutonium-238	0.568000019	pCi/g	None
21-22277	MD21-03-51593	0.0–0.5	ALLH	Plutonium-239	4.235000134	pCi/g	None
21-22277	MD21-03-51593	0.0–0.5	ALLH	Ruthenium-106	-0.167	pCi/g	U
21-22277	MD21-03-51593	0.0–0.5	ALLH	Sodium-22	0.009	pCi/g	U
21-22277	MD21-03-51593	0.0–0.5	ALLH	Strontium-90	7.269999981	pCi/g	None
21-22277	MD21-03-51593	0.0–0.5	ALLH	Uranium-235	0.206	pCi/g	None
21-22278	MD21-03-51594	0.0–0.5	ALLH	Americium-241	0.685000002	pCi/g	None
21-22278	MD21-03-51594	0.0–0.5	ALLH	Cesium-134	0.109999999	pCi/g	U
21-22278	MD21-03-51594	0.0–0.5	ALLH	Cesium-137	30.66200066	pCi/g	None
21-22278	MD21-03-51594	0.0–0.5	ALLH	Cobalt-60	0.013	pCi/g	U
21-22278	MD21-03-51594	0.0–0.5	ALLH	Europium-152	0.229000002	pCi/g	None
21-22278	MD21-03-51594	0.0–0.5	ALLH	Plutonium-238	0.203999996	pCi/g	None
21-22278	MD21-03-51594	0.0–0.5	ALLH	Plutonium-239	1.799000025	pCi/g	None
21-22278	MD21-03-51594	0.0–0.5	ALLH	Ruthenium-106	0.111000001	pCi/g	U
21-22278	MD21-03-51594	0.0–0.5	ALLH	Sodium-22	0.001	pCi/g	U
21-22278	MD21-03-51594	0.0–0.5	ALLH	Strontium-90	4.703999996	pCi/g	None
21-22278	MD21-03-51594	0.0–0.5	ALLH	Uranium-235	0.287	pCi/g	None
21-22279	MD21-03-51595	0.0–0.5	ALLH	Americium-241	1	pCi/g	None
21-22279	MD21-03-51595	0.0–0.5	ALLH	Cesium-134	0.068999998	pCi/g	U
21-22279	MD21-03-51595	0.0–0.5	ALLH	Cesium-137	66.17700195	pCi/g	None
21-22279	MD21-03-51595	0.0–0.5	ALLH	Cobalt-60	-0.004	pCi/g	U
21-22279	MD21-03-51595	0.0–0.5	ALLH	Europium-152	0.374000013	pCi/g	None
21-22279	MD21-03-51595	0.0–0.5	ALLH	Plutonium-238	0.388000011	pCi/g	None
21-22279	MD21-03-51595	0.0–0.5	ALLH	Plutonium-239	3.24000001	pCi/g	None
21-22279	MD21-03-51595	0.0–0.5	ALLH	Ruthenium-106	0.210999995	pCi/g	U
21-22279	MD21-03-51595	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22279	MD21-03-51595	0.0–0.5	ALLH	Strontium-90	8.527000427	pCi/g	None
21-22279	MD21-03-51595	0.0–0.5	ALLH	Uranium-235	0.199000001	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22280	MD21-03-51596	0.0–0.5	ALLH	Americium-241	0.578000009	pCi/g	None
21-22280	MD21-03-51596	0.0–0.5	ALLH	Cesium-134	-0.009	pCi/g	U
21-22280	MD21-03-51596	0.0–0.5	ALLH	Cesium-137	21.66900063	pCi/g	None
21-22280	MD21-03-51596	0.0–0.5	ALLH	Cobalt-60	0.006	pCi/g	U
21-22280	MD21-03-51596	0.0–0.5	ALLH	Europium-152	0.191	pCi/g	None
21-22280	MD21-03-51596	0.0–0.5	ALLH	Plutonium-238	0.216999993	pCi/g	None
21-22280	MD21-03-51596	0.0–0.5	ALLH	Plutonium-239	2.051000118	pCi/g	None
21-22280	MD21-03-51596	0.0–0.5	ALLH	Ruthenium-106	-0.088	pCi/g	U
21-22280	MD21-03-51596	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22280	MD21-03-51596	0.0–0.5	ALLH	Strontium-90	3.351999998	pCi/g	None
21-22280	MD21-03-51596	0.0–0.5	ALLH	Uranium-235	0.266000003	pCi/g	None
21-22281	MD21-03-51597	0.0–0.5	ALLH	Americium-241	2.052999973	pCi/g	None
21-22281	MD21-03-51597	0.0–0.5	ALLH	Cesium-134	0.083999999	pCi/g	U
21-22281	MD21-03-51597	0.0–0.5	ALLH	Cesium-137	62.68600082	pCi/g	None
21-22281	MD21-03-51597	0.0–0.5	ALLH	Cobalt-60	-0.008	pCi/g	U
21-22281	MD21-03-51597	0.0–0.5	ALLH	Europium-152	0.279000014	pCi/g	None
21-22281	MD21-03-51597	0.0–0.5	ALLH	Plutonium-238	0.522000015	pCi/g	None
21-22281	MD21-03-51597	0.0–0.5	ALLH	Plutonium-239	7.052999973	pCi/g	None
21-22281	MD21-03-51597	0.0–0.5	ALLH	Ruthenium-106	-0.15000001	pCi/g	U
21-22281	MD21-03-51597	0.0–0.5	ALLH	Sodium-22	0.002	pCi/g	U
21-22281	MD21-03-51597	0.0–0.5	ALLH	Strontium-90	11.39400005	pCi/g	None
21-22281	MD21-03-51597	0.0–0.5	ALLH	Uranium-235	0.286000013	pCi/g	None
21-22282	MD21-03-51598	0.0–0.5	ALLH	Americium-241	1.430999994	pCi/g	None
21-22282	MD21-03-51598	0.0–0.5	ALLH	Cesium-134	0.054000001	pCi/g	U
21-22282	MD21-03-51598	0.0–0.5	ALLH	Cesium-137	25.63699913	pCi/g	None
21-22282	MD21-03-51598	0.0–0.5	ALLH	Cobalt-60	-0.004	pCi/g	U
21-22282	MD21-03-51598	0.0–0.5	ALLH	Europium-152	0.349000007	pCi/g	None
21-22282	MD21-03-51598	0.0–0.5	ALLH	Plutonium-238	0.361999989	pCi/g	None
21-22282	MD21-03-51598	0.0–0.5	ALLH	Plutonium-239	2.726999998	pCi/g	None
21-22282	MD21-03-51598	0.0–0.5	ALLH	Ruthenium-106	-0.106	pCi/g	U
21-22282	MD21-03-51598	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22282	MD21-03-51598	0.0–0.5	ALLH	Strontium-90	3.622999907	pCi/g	None
21-22282	MD21-03-51598	0.0–0.5	ALLH	Uranium-235	0.261999995	pCi/g	None
21-22283	MD21-03-51599	0.0–0.5	ALLH	Americium-241	0.181999996	pCi/g	None
21-22283	MD21-03-51599	0.0–0.5	ALLH	Cesium-134	0.052000001	pCi/g	U
21-22283	MD21-03-51599	0.0–0.5	ALLH	Cesium-137	1.786000013	pCi/g	None
21-22283	MD21-03-51599	0.0–0.5	ALLH	Cobalt-60	-0.024	pCi/g	U
21-22283	MD21-03-51599	0.0–0.5	ALLH	Europium-152	0.203999996	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22283	MD21-03-51599	0.0–0.5	ALLH	Plutonium-238	0.014	pCi/g	U
21-22283	MD21-03-51599	0.0–0.5	ALLH	Plutonium-239	0.165000007	pCi/g	None
21-22283	MD21-03-51599	0.0–0.5	ALLH	Ruthenium-106	0.107000001	pCi/g	U
21-22283	MD21-03-51599	0.0–0.5	ALLH	Sodium-22	-0.011	pCi/g	U
21-22283	MD21-03-51599	0.0–0.5	ALLH	Strontium-90	0.261000007	pCi/g	U
21-22283	MD21-03-51599	0.0–0.5	ALLH	Uranium-235	0.25	pCi/g	None
21-22284	MD21-03-51600	0.0–0.5	ALLH	Americium-241	1.644999981	pCi/g	None
21-22284	MD21-03-51600	0.0–0.5	ALLH	Cesium-134	0.071000002	pCi/g	U
21-22284	MD21-03-51600	0.0–0.5	ALLH	Cesium-137	113.9499969	pCi/g	None
21-22284	MD21-03-51600	0.0–0.5	ALLH	Cobalt-60	0.001	pCi/g	U
21-22284	MD21-03-51600	0.0–0.5	ALLH	Europium-152	0.273000002	pCi/g	None
21-22284	MD21-03-51600	0.0–0.5	ALLH	Plutonium-238	0.828000009	pCi/g	None
21-22284	MD21-03-51600	0.0–0.5	ALLH	Plutonium-239	6.991000175	pCi/g	None
21-22284	MD21-03-51600	0.0–0.5	ALLH	Ruthenium-106	-0.271	pCi/g	U
21-22284	MD21-03-51600	0.0–0.5	ALLH	Sodium-22	0.012	pCi/g	U
21-22284	MD21-03-51600	0.0–0.5	ALLH	Strontium-90	10.99199963	pCi/g	None
21-22284	MD21-03-51600	0.0–0.5	ALLH	Uranium-235	0.294999987	pCi/g	None
21-22285	MD21-03-51601	0.0–0.5	ALLH	Americium-241	1.236999989	pCi/g	None
21-22285	MD21-03-51601	0.0–0.5	ALLH	Cesium-134	-0.198	pCi/g	U
21-22285	MD21-03-51601	0.0–0.5	ALLH	Cesium-137	44.58800125	pCi/g	None
21-22285	MD21-03-51601	0.0–0.5	ALLH	Cobalt-60	0.005	pCi/g	U
21-22285	MD21-03-51601	0.0–0.5	ALLH	Europium-152	0.153999999	pCi/g	U
21-22285	MD21-03-51601	0.0–0.5	ALLH	Plutonium-238	0.305999994	pCi/g	None
21-22285	MD21-03-51601	0.0–0.5	ALLH	Plutonium-239	2.947999954	pCi/g	None
21-22285	MD21-03-51601	0.0–0.5	ALLH	Ruthenium-106	0.300000012	pCi/g	U
21-22285	MD21-03-51601	0.0–0.5	ALLH	Sodium-22	0	pCi/g	U
21-22285	MD21-03-51601	0.0–0.5	ALLH	Strontium-90	7.388999939	pCi/g	None
21-22285	MD21-03-51601	0.0–0.5	ALLH	Uranium-235	0.035999998	pCi/g	U
21-22286	MD21-03-51602	0.0–0.5	ALLH	Americium-241	1.921000004	pCi/g	None
21-22286	MD21-03-51602	0.0–0.5	ALLH	Cesium-134	0.068999998	pCi/g	U
21-22286	MD21-03-51602	0.0–0.5	ALLH	Cesium-137	76.2460022	pCi/g	None
21-22286	MD21-03-51602	0.0–0.5	ALLH	Cobalt-60	-0.005	pCi/g	U
21-22286	MD21-03-51602	0.0–0.5	ALLH	Europium-152	0.31099999	pCi/g	None
21-22286	MD21-03-51602	0.0–0.5	ALLH	Plutonium-238	0.460000008	pCi/g	None
21-22286	MD21-03-51602	0.0–0.5	ALLH	Plutonium-239	5.022999763	pCi/g	None
21-22286	MD21-03-51602	0.0–0.5	ALLH	Ruthenium-106	-0.245	pCi/g	U
21-22286	MD21-03-51602	0.0–0.5	ALLH	Sodium-22	0.003	pCi/g	U
21-22286	MD21-03-51602	0.0–0.5	ALLH	Strontium-90	8.397999763	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22286	MD21-03-51602	0.0–0.5	ALLH	Uranium-235	0.303000003	pCi/g	None
21-22287	MD21-03-51603	0.0–0.5	ALLH	Americium-241	1.644000053	pCi/g	None
21-22287	MD21-03-51603	0.0–0.5	ALLH	Cesium-134	0.100000001	pCi/g	U
21-22287	MD21-03-51603	0.0–0.5	ALLH	Cesium-137	69.22299957	pCi/g	None
21-22287	MD21-03-51603	0.0–0.5	ALLH	Cobalt-60	0	pCi/g	U
21-22287	MD21-03-51603	0.0–0.5	ALLH	Europium-152	0.26699999	pCi/g	None
21-22287	MD21-03-51603	0.0–0.5	ALLH	Plutonium-238	0.194999993	pCi/g	None
21-22287	MD21-03-51603	0.0–0.5	ALLH	Plutonium-239	2.875999928	pCi/g	None
21-22287	MD21-03-51603	0.0–0.5	ALLH	Ruthenium-106	0.165000007	pCi/g	U
21-22287	MD21-03-51603	0.0–0.5	ALLH	Sodium-22	0.006	pCi/g	U
21-22287	MD21-03-51603	0.0–0.5	ALLH	Strontium-90	15.78600025	pCi/g	None
21-22287	MD21-03-51603	0.0–0.5	ALLH	Uranium-235	0.231000006	pCi/g	None
21-22288	MD21-03-51604	0.0–0.5	ALLH	Americium-241	4.282000065	pCi/g	None
21-22288	MD21-03-51604	0.0–0.5	ALLH	Cesium-134	0.090000004	pCi/g	U
21-22288	MD21-03-51604	0.0–0.5	ALLH	Cesium-137	70.14800262	pCi/g	None
21-22288	MD21-03-51604	0.0–0.5	ALLH	Cobalt-60	0	pCi/g	U
21-22288	MD21-03-51604	0.0–0.5	ALLH	Europium-152	0.247999996	pCi/g	U
21-22288	MD21-03-51604	0.0–0.5	ALLH	Plutonium-238	0.644999981	pCi/g	None
21-22288	MD21-03-51604	0.0–0.5	ALLH	Plutonium-239	4.348999977	pCi/g	None
21-22288	MD21-03-51604	0.0–0.5	ALLH	Ruthenium-106	0.216999993	pCi/g	U
21-22288	MD21-03-51604	0.0–0.5	ALLH	Sodium-22	-0.009	pCi/g	U
21-22288	MD21-03-51604	0.0–0.5	ALLH	Strontium-90	18.97999954	pCi/g	None
21-22288	MD21-03-51604	0.0–0.5	ALLH	Uranium-235	0.340999991	pCi/g	None
21-22289	MD21-03-51605	0.0–0.5	ALLH	Americium-241	24.12899971	pCi/g	None
21-22289	MD21-03-51605	0.0–0.5	ALLH	Cesium-134	0.189999998	pCi/g	U
21-22289	MD21-03-51605	0.0–0.5	ALLH	Cesium-137	114.4400024	pCi/g	None
21-22289	MD21-03-51605	0.0–0.5	ALLH	Cobalt-60	-0.016	pCi/g	U
21-22289	MD21-03-51605	0.0–0.5	ALLH	Europium-152	0.085000001	pCi/g	U
21-22289	MD21-03-51605	0.0–0.5	ALLH	Plutonium-238	2.085999966	pCi/g	None
21-22289	MD21-03-51605	0.0–0.5	ALLH	Plutonium-239	8.642000198	pCi/g	None
21-22289	MD21-03-51605	0.0–0.5	ALLH	Ruthenium-106	0.143999994	pCi/g	U
21-22289	MD21-03-51605	0.0–0.5	ALLH	Sodium-22	-0.015	pCi/g	U
21-22289	MD21-03-51605	0.0–0.5	ALLH	Strontium-90	25.95400047	pCi/g	None
21-22289	MD21-03-51605	0.0–0.5	ALLH	Uranium-235	0.414000005	pCi/g	None
21-22290	MD21-03-51606	0.0–0.5	ALLH	Americium-241	6.607999802	pCi/g	None
21-22290	MD21-03-51606	0.0–0.5	ALLH	Cesium-134	0.017000001	pCi/g	U
21-22290	MD21-03-51606	0.0–0.5	ALLH	Cesium-137	78.39099884	pCi/g	None
21-22290	MD21-03-51606	0.0–0.5	ALLH	Cobalt-60	-0.002	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22290	MD21-03-51606	0.0–0.5	ALLH	Europium-152	0.170000002	pCi/g	U
21-22290	MD21-03-51606	0.0–0.5	ALLH	Plutonium-238	0.555999994	pCi/g	None
21-22290	MD21-03-51606	0.0–0.5	ALLH	Plutonium-239	15.63500023	pCi/g	None
21-22290	MD21-03-51606	0.0–0.5	ALLH	Ruthenium-106	-0.19	pCi/g	U
21-22290	MD21-03-51606	0.0–0.5	ALLH	Sodium-22	0.021	pCi/g	U
21-22290	MD21-03-51606	0.0–0.5	ALLH	Strontium-90	30.43199921	pCi/g	None
21-22290	MD21-03-51606	0.0–0.5	ALLH	Uranium-235	0.335000008	pCi/g	None
21-22291	MD21-03-51607	0.0–0.5	ALLH	Americium-241	2.084000111	pCi/g	None
21-22291	MD21-03-51607	0.0–0.5	ALLH	Cesium-134	0.07	pCi/g	U
21-22291	MD21-03-51607	0.0–0.5	ALLH	Cesium-137	88.19499969	pCi/g	None
21-22291	MD21-03-51607	0.0–0.5	ALLH	Cobalt-60	0.014	pCi/g	U
21-22291	MD21-03-51607	0.0–0.5	ALLH	Europium-152	0.289000005	pCi/g	None
21-22291	MD21-03-51607	0.0–0.5	ALLH	Plutonium-238	0.195999995	pCi/g	None
21-22291	MD21-03-51607	0.0–0.5	ALLH	Plutonium-239	8.241999626	pCi/g	None
21-22291	MD21-03-51607	0.0–0.5	ALLH	Ruthenium-106	0.104999997	pCi/g	U
21-22291	MD21-03-51607	0.0–0.5	ALLH	Sodium-22	-0.007	pCi/g	U
21-22291	MD21-03-51607	0.0–0.5	ALLH	Strontium-90	17.77599907	pCi/g	None
21-22291	MD21-03-51607	0.0–0.5	ALLH	Uranium-235	0.30399999	pCi/g	None
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Americium-241	40.86600113	pCi/g	None
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Cesium-134	0.123999998	pCi/g	U
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Cesium-137	105.3799973	pCi/g	None
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Cobalt-60	0.003	pCi/g	U
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Europium-152	0.028000001	pCi/g	U
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Plutonium-238	4.931000233	pCi/g	None
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Plutonium-239	20.64299965	pCi/g	None
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Ruthenium-106	-0.124	pCi/g	U
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Sodium-22	-0.027	pCi/g	U
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Strontium-90	38.01300049	pCi/g	None
21-22292	MD21-03-51608	0.0–0.5	Qbt 3	Uranium-235	0.259000003	pCi/g	U
21-22261	MD21-03-51634	0.0–0.5	ALLH	Americium-241	0.296000004	pCi/g	J-
21-22261	MD21-03-51634	0.0–0.5	ALLH	Cesium-134	0.075999998	pCi/g	U
21-22261	MD21-03-51634	0.0–0.5	ALLH	Cesium-137	12.52000046	pCi/g	None
21-22261	MD21-03-51634	0.0–0.5	ALLH	Cobalt-60	0.011	pCi/g	U
21-22261	MD21-03-51634	0.0–0.5	ALLH	Europium-152	0.244000003	pCi/g	None
21-22261	MD21-03-51634	0.0–0.5	ALLH	Plutonium-238	0.017000001	pCi/g	U
21-22261	MD21-03-51634	0.0–0.5	ALLH	Plutonium-239	0.782999992	pCi/g	None
21-22261	MD21-03-51634	0.0–0.5	ALLH	Ruthenium-106	-0.022	pCi/g	U
21-22261	MD21-03-51634	0.0–0.5	ALLH	Sodium-22	0.003	pCi/g	U

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22261	MD21-03-51634	0.0–0.5	ALLH	Strontium-90	3.39199996	pCi/g	None
21-22261	MD21-03-51634	0.0–0.5	ALLH	Uranium-235	0.164000005	pCi/g	U
21-22281	MD21-03-51635	0.0–0.5	ALLH	Americium-241	1.338999987	pCi/g	None
21-22281	MD21-03-51635	0.0–0.5	ALLH	Cesium-134	-0.17200001	pCi/g	U
21-22281	MD21-03-51635	0.0–0.5	ALLH	Cesium-137	57.37200165	pCi/g	None
21-22281	MD21-03-51635	0.0–0.5	ALLH	Cobalt-60	0.003	pCi/g	U
21-22281	MD21-03-51635	0.0–0.5	ALLH	Europium-152	0.263000011	pCi/g	None
21-22281	MD21-03-51635	0.0–0.5	ALLH	Plutonium-238	0.751999974	pCi/g	None
21-22281	MD21-03-51635	0.0–0.5	ALLH	Plutonium-239	5.190999985	pCi/g	None
21-22281	MD21-03-51635	0.0–0.5	ALLH	Ruthenium-106	-0.086	pCi/g	U
21-22281	MD21-03-51635	0.0–0.5	ALLH	Sodium-22	-0.007	pCi/g	U
21-22281	MD21-03-51635	0.0–0.5	ALLH	Strontium-90	13.76900005	pCi/g	None
21-22281	MD21-03-51635	0.0–0.5	ALLH	Uranium-235	0.238000005	pCi/g	None
21-22283	MD21-03-51636	0.0–0.5	ALLH	Americium-241	0.041999999	pCi/g	U
21-22283	MD21-03-51636	0.0–0.5	ALLH	Cesium-134	0.096000001	pCi/g	U
21-22283	MD21-03-51636	0.0–0.5	ALLH	Cesium-137	1.930999994	pCi/g	None
21-22283	MD21-03-51636	0.0–0.5	ALLH	Cobalt-60	0	pCi/g	U
21-22283	MD21-03-51636	0.0–0.5	ALLH	Europium-152	0.340000004	pCi/g	None
21-22283	MD21-03-51636	0.0–0.5	ALLH	Plutonium-238	0.035999998	pCi/g	None
21-22283	MD21-03-51636	0.0–0.5	ALLH	Plutonium-239	0.107000001	pCi/g	None
21-22283	MD21-03-51636	0.0–0.5	ALLH	Ruthenium-106	0	pCi/g	U
21-22283	MD21-03-51636	0.0–0.5	ALLH	Sodium-22	-0.017	pCi/g	U
21-22283	MD21-03-51636	0.0–0.5	ALLH	Strontium-90	0.688000023	pCi/g	None
21-22283	MD21-03-51636	0.0–0.5	ALLH	Uranium-235	0.261000007	pCi/g	None
21-22285	MD21-03-51637	0.0–0.5	ALLH	Americium-241	1.149000049	pCi/g	None
21-22285	MD21-03-51637	0.0–0.5	ALLH	Cesium-134	0.085000001	pCi/g	U
21-22285	MD21-03-51637	0.0–0.5	ALLH	Cesium-137	38.59000015	pCi/g	None
21-22285	MD21-03-51637	0.0–0.5	ALLH	Cobalt-60	-0.009	pCi/g	U
21-22285	MD21-03-51637	0.0–0.5	ALLH	Europium-152	0.233999997	pCi/g	None
21-22285	MD21-03-51637	0.0–0.5	ALLH	Plutonium-238	0.43900001	pCi/g	None
21-22285	MD21-03-51637	0.0–0.5	ALLH	Plutonium-239	9.131999969	pCi/g	None
21-22285	MD21-03-51637	0.0–0.5	ALLH	Ruthenium-106	0.150000006	pCi/g	U
21-22285	MD21-03-51637	0.0–0.5	ALLH	Sodium-22	0.002	pCi/g	U
21-22285	MD21-03-51637	0.0–0.5	ALLH	Strontium-90	5.697999954	pCi/g	None
21-22285	MD21-03-51637	0.0–0.5	ALLH	Uranium-235	0.234999999	pCi/g	None
21-22287	MD21-03-51638	0.0–0.5	ALLH	Americium-241	1.838000059	pCi/g	None
21-22287	MD21-03-51638	0.0–0.5	ALLH	Cesium-134	0.090999998	pCi/g	U
21-22287	MD21-03-51638	0.0–0.5	ALLH	Cesium-137	64.72299957	pCi/g	None

Table D-2.0-1 (continued)

Location ID	Sample ID*	Depth (ft)	Media Code	Analyte	Result	Unit	Report Qualifier
21-22287	MD21-03-51638	0.0–0.5	ALLH	Cobalt-60	-0.006	pCi/g	U
21-22287	MD21-03-51638	0.0–0.5	ALLH	Europium-152	0.237000003	pCi/g	U
21-22287	MD21-03-51638	0.0–0.5	ALLH	Plutonium-238	0.213	pCi/g	None
21-22287	MD21-03-51638	0.0–0.5	ALLH	Plutonium-239	3.733999968	pCi/g	None
21-22287	MD21-03-51638	0.0–0.5	ALLH	Ruthenium-106	0.005	pCi/g	U
21-22287	MD21-03-51638	0.0–0.5	ALLH	Sodium-22	0.01	pCi/g	U
21-22287	MD21-03-51638	0.0–0.5	ALLH	Strontium-90	21.03100014	pCi/g	None
21-22287	MD21-03-51638	0.0–0.5	ALLH	Uranium-235	0.033	pCi/g	U

* The sample identification (ID) includes the year the sample was collected, e.g., the “01” in MD21-01-0030 indicates that the sample was collected in 2001, with the exception of the 1993 samples, which are designated with “AAA.”

D-3.0 REFERENCES

The following list includes all references cited in this appendix. Parenthetical information following each reference provides the author, publication date, and the ER record identification (ER ID) number. This information also is included in the citations in the text. ER ID numbers are assigned by the Laboratory’s RRES-RS Records Processing Facility (RPF) are used to locate copies of the actual documents at the RPF and, where applicable, with the ER Project reference library titled “Reference Set for Material Disposal Areas, Technical Area 21”.

Copies of the reference library are maintained at the NMED Hazardous Waste Bureau; the DOE Los Alamos Area Office; United States EPA, Region VI; and RRES-RS. This library is a living collection of documents that was developed to ensure that the administrative authority has all the necessary material to review the decisions and actions proposed in this document. However, documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), July 1995. "Statement of Work–Analytical Support," Revision 2, RFP No. 9-XS1-Q4257, Los Alamos, New Mexico. (LANL 1995, 49738)

LANL (Los Alamos National Laboratory), March 1996. "Quality Assurance Project Plan Requirements for Sampling and Analysis," Los Alamos National Laboratory report LA-UR-96-441, Los Alamos, New Mexico. (LANL 1996, 54609)