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Radiological Survey of the Bayo Canyon, Los Alamos, New Mexico

June 1979

Final Report

Prepared for

U.S. Department of Energy
Assistant Secretary for Environment
Division of Environmental Control Technology

LOS ALAMOS NATIONAL LABORATORY
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PREFACE

This series of reports results from a program initiated in 1974 by the Atomic Energy Commission (AEC) for determination of the condition of sites formerly utilized by the Manhattan Engineer District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940's, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether or not the decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

This report contains data and information on the resurvey effort and the effect of residual contamination as a result of nuclear weapons development programs conducted in this area. The report documents the present radiological conditions within the realm of todays' sophisticated instrumentation and the impact on any future area development.

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RADIOLOGICAL SURVEY OF THE BAYO CANYON, LOS ALAMOS, NEW MEXICO

Summary

A portion of Bayo Canyon, located in Los Alamos County in north-centeral New Mexico, was used between 1944 and 1961 as a site for experiments employing conventional high explosives in conjunction with research on nuclear weapons development initially under auspices of the US Army Manhattan Engineer District and later the Atomic Energy Commission. The explosive test assemblies usually included components made from natural or depleted uranium and a radiation source for blast diagnostics. The sources contained several hundred to several thousand curies of ^{140}La (half-life 40.2 h) and a small proportion of ^{90}Sr (half-life 28.1 yr). The explosive detonation resulted in the dispersion of radioactive materials—uranium, ^{140}La and ^{90}Sr—in the form of aerosols and debris to the atmosphere and onto the ground around the firing points. Radiochemistry operations conducted at the site resulted in the generation of liquid and solid radioactive wastes, which were disposed into subsurface pits and leaching fields.

The site was decommissioned by 1963 with the removal or demolition of structures, cleanup of surface debris, and excavation of contaminated waste disposal facilities. Radiological surveys resulted in the conclusion that the site was sufficiently free of contamination to permit the land to be released from Federal government control. The land was transferred to Los Alamos County by Quit Claim Deed on July 1, 1967.

In 1976 the Energy Research and Development Administration (ERDA) identified the Bayo Canyon Site as one of the locations to be reevaluated as part of the Formerly Utilized Sites Remedial Action Program using modern instrumentation and analytical methods as a basis for determining whether any further corrective measures would be desirable. This resurvey was undertaken by the Los Alamos Scientific Laboratory (LASL) under contract to ERDA and subsequently to the Department of Energy.

The resurvey utilized information from a number of routine and special environmental surveillance studies conducted previously by LASL as well as extensive new instrumental measurements, soil sampling, and radiochemical analyses. Results showed that residual surface contamination due to ^{90}Sr averaged about 1.4 pCi/g or approximately 3 times the level attributable to worldwide fallout. Surface uranium averaged about 4.9 μg/g or about 1.5 times the amount naturally present in the volcanic-derived soils of the area. Subsurface contamination associated with the former waste disposal locations is largely confined within a total area of about 10 000 m^2 and down to depths of about 5 m. Of 378 subsurface samples, fewer than 12% exceeded 13 pCi/g of gross beta activity, which is comparable to the upper range of activities for uncontaminated local soils.

Health physics interpretation of the data indicates that the present population of Los Alamos living on mesas adjacent to Bayo Canyon is not receiving any incremental radiation doses due to the residual contamination. Potential future land uses of Bayo Canyon include development of a residential area.

Theoretical evaluation of such potential uses by means of exposure scenarios (including inhalation of contamination with dust by construction workers or residents) indicates that increments of radiation exposure due to residual contamination attributable to Bayo test operations would be small in comparison with either radiation protection guidelines or natural background.

The worst case evaluations for maximum individual exposures under these hypothetical conditions were calculated as 50 yr dose commitments, which represent the dose accumulated over 50 yr from exposure to radioactive material in the first year. Only several radionuclides are capable of irradiating an individual for years after exposure to that radionuclide. This occurs when these long-lived radioactive materials are inhaled or ingested and are incorporated into body tissues where they remain, such as incorporation of ^{90}Sr into bone. These dose commitments are compared to the current DOE Radiation Protection Standards for annual doses to individuals in the general public and to average annual doses of radiation received from natural radiation in the area. Comparing 50 yr dose commitments to annual exposure guidelines is considered conservative because the actual dose received in any one year from a radioisotope capable of irradiating the individual for years after exposure is considerably less than the 50 yr dose commitment.

The largest dose an average resident of Bayo Canyon would receive from present contamination levels would be 0.43 mrem/yr due to external penetrating radiation, which is 0.086% of DOE Guidelines and 0.24% of the dose received from natural radiation in Bayo Canyon. For maximum exposure it is assumed an individual consumes 50 kg/yr of vegetables and fruits produced from garden plots located in contaminated soil in Bayo Canyon. This individual could receive a 50 yr dose commitment of 45.6 mrem to the bone, which is 3.0% of the guidelines for annual exposure and 25% of annual exposure from natural radiation in the Canyon. Another exposure pathway is inhalation of contaminated dust due to construction activity in contaminated soil. The maximum postulated 50 yr dose commitment to a construction worker is 23 mrem to the bone from installation of underground structures or utilities. This would likely be a one-time exposure and would be only 1.5% of the DOE guidelines for annual exposure and 13% of the annual dose due to background radiation in the Canyon.

RADIOLOGICAL SURVEY OF THE BAYO CANYON, LOS ALAMOS, NEW MEXICO

I. INTRODUCTION

A. Purpose

Early in 1976 the Energy Research and Development Administration (ERDA) identified Bayo Canyon as one of several locations once used in, or affected by, operations of the U. S. Army Manhattan Engineer District (MED) or by early operations of the U. S. Atomic Energy Commission (AEC).[1] Bayo Canyon was subsequently resurveyed in 1976-77 for possible residual contamination.

Facilities in Bayo Canyon were constructed during 1943 and 1944 by MED. They were operated from 1944 until late 1946 by MED and subsequently by the AEC. Bayo Site was decommissioned under AEC auspices in 1963. At that time the site was surveyed by Los Alamos Scientific Laboratory (LASL), contractor to AEC for operation of the Bayo Canyon facility. Bayo Canyon was deemed sufficiently free of radiological contaminants to be deeded to Los Alamos County in 1967 without restriction on public access.[2,3] Radiation surveys made during operations and the decommissioning survey indicated that some remaining radioactivity in the soil gave radiation readings above natural background. The purpose of this resurvey was, therefore, to thoroughly document and assess radiological conditions within Bayo Canyon, using modern instrumentation and analytical methods as a basis for determining whether any corrective measures would be desirable.

B. Summary Site Description

1. Location. Bayo Canyon is adjacent to the townsite of Los Alamos in north central New Mexico about 100 km NNE of Albuquerque and 40 km NW of Santa Fe by air, as shown in Fig. 1. Bayo Canyon is one of many canyons cut into the Pajarito Plateau shown in Fig. 2.

2. Natural Charactersitics. Bayo Canyon is bounded on the south by Kwage Mesa and on the north by Otowi Mesa (see Fig. 3). The mean elevation for both mesas is about 2160 m. The floor of Bayo Canyon is about 2040 m at the location of the old site and the canyon slopes southeastward at a 3% grade. Bayo Canyon has a semiarid continental mountain climate characterized by normally fair weather. Thundershowers in late summer provide most of the 47 cm total annual precipitation. Winter snows provide the rest. Clay soils and frequent tuff outcrops on the mesa tops support a piñon-juniper bushland. Weathering has produced a rocky talus slope facing the south from Otowi Mesa, which supports a piñon-juniper bushland similar to that on the mesa tops. A sandy soil has developed on the talus slope facing north from Kwage Mesa and in the canyon floor, which supports a pine-fir overstory mixed with piñon and scrub oak, grading into grass and sagebrush on the canyon floor.

3. TA-10 Mission. The facility installed in Bayo Canyon was designated TA-10 site and often referred to as Bayo Site. Its layout is shown in Fig. 3. It was constructed to test assemblies containing conventional high explosives and including components fashioned from depleted uranium or natural uranium. The assemblies were loaded with a ^{140}La "source" of several hundred to several thousand curies for blast diagnostics. The lanthanum (half-life 40.1 hr)[4] was contaminated with a small proportion of ^{90}Sr (half-life 28.1 yr).[4] The ^{140}La was separated from its host material and prepared as a source in building TA-10-1. The assemblies were detonated at firing sites, which dispersed uranium and source activity to both air and ground. Liquid and solid

wastes generated at TA-10-1 were introduced into waste pits near TA-10-1, resulting in some subsurface contamination. The firing sites are shown at the west end of Fig. 3, and TA-10-1 is at the east end of Fig. 3.

Operating details are discussed further in Sec. II.A., Site History and Operation. Figures 4, 5, 6, and 7 give an impression of the Bayo Canyon facility prior to decommissioning in 1963.

4. Summary of Radiological Conditions. From 1949 through 1969 1.355 Ci of "natural uranium,"* 1.218 Ci of depleted uranium (see Appendix A), and between 30 and 40 Ci of ^{90}Sr were dispersed to the surface environment of Bayo Canyon and beyond by explosive testing (see Appendix E). An additional 85 to 120 Ci of ^{90}Sr were deposited in waste handling facilities near TA-10-1 and some fraction of that amount migrated into the subsurface environment, i.e., below 30 cm.

Most of the ^{90}Sr and uranium released to the surface environs was associated with debris—uranium and other metal fragments—from the test shots. Most of this debris was removed, as were buildings and utilities, during decommissioning in 1963, leaving a comparatively small amount of radioactivity at the surface of the site and in subsurface layers of soil. Bags of debris gathered during decommissioning read from 1 mrad/h to 12 mrad/h.[5]

Since decommissioning, only the 1977 resurvey has indicated traces of ^{90}Sr, and uranium debris in the top 30 cm—particularly across the 1.367×10^6 m^2 covered by the firing site and canyon floor grids. Vertical and horizontal distribution are uneven. With a few notable exceptions, this is in agreement with generally similar concentrations of ^{90}Sr in the small volumes of soil close to the alignments of former waste disposal systems and at appreciable depths below the surface. Table I provides a brief summary.

The 0-5 cm layer appears slightly more burdened with debris than other layers of the 0-30 cm surface, so it is taken as illustrative of them. Of 50 samples from the 0-5 cm layer that were analyzed for ^{90}Sr, 1 exceeded 9 pCi $^{90}Sr/g$ and 17 exceeded 1.0 pCi $^{90}Sr/g$. Random selection of 29 sample locations provided a representative sample distribution with a mean of 1.4 pCi $^{90}Sr/g$ which is about 3 times the level of local ^{90}Sr fallout. The maximum sample contained 132 pCi $^{90}Sr/g$. Of the corresponding 50 uranium results, 1 exceeded 10 $\mu g/g$ and 21 exceeded 4.00 $\mu g/g$. Random selection of 29 samples gave a representative mean of 4.9 $\mu g/g$, which is 44% greater than primordial uranium at 3.4 $\mu g/g$. Results from the 0-10 cm layer and the 0-30 cm layer tend toward lower mean values and less divergence from the mean.

Subsurface contamination is mostly low level and within 10 m of TA-10-1 and its acid waste system. The highest levels of activity were found in one test hole a few meters north of TA-10-42. Three hundred seventy-eight subsurface samples were screened for gross β activity and of these 68 were analyzed radiochemically for ^{90}Sr. Of the 68 analyzed radiochemically for ^{90}Sr, 12 exceeded 20 pCi $^{90}Sr/g$ and 8 exceeded 100 pCi/g. These results are higher than a representative value of the subsurface because the bases for sample selection were (1) sample location was suspected of contamination and (2) gross beta count was atypical. One sample containing 4400 pCi gross β/g came from a depth of 244 cm in a test hole drilled in 1974. The maximum sample contained 24 000 pCi gross β and came from between 430 cm and 490 cm below the surface in the same hole.

Airborne concentrations of ^{90}Sr and uranium in the Bayo Canyon vicinity are compared with that from other northern New Mexico locations in Table I. The results do not show a statistically significant difference in either ^{90}Sr or uranium concentrations. Finally, Table I provides a comparison of external penetrating radiation at Bayo Site and at adjacent locations and shows no statistically significant differences.

*See Glossary for a discussion.

5. Present and Projected Use. Present use of the canyon is exclusively recreational, with abundant evidence of picnicking, trail riding (horses and motorcycles), hiking, firearms practice, some wood cutting, and some piñon nut gathering. Projected uses include possible residential and light commercial development.

C. Summary Evaluation from Survey

1. Present Use

•Existing Population

Air sampling results shown in Section IV show that exposure of current residents (on mesas overlooking the west end of Bayo Canyon) to airborne ^{90}Sr and uranium is no different than that of other north central New Mexico residents exposed to fallout ^{90}Sr and primordial uranium in air.

•Recreational Use

Recreational users will not spend as much time in the canyon as either potential residents or potential construction workers. Moreover, interaction of recreational users with the soil layers is basically the same as that of potential residents, and at worst, the interaction is less severe than the worst case for construction workers. Consequently, 50 yr dose commitments for recreational users will be lower than for either potential residents or construction workers, discussed in the next paragraphs. A fifty year dose commitment represents that dose accumulated over fifty years from exposure to radioactive material during the first year. Only several radionuclides are capable of irradiating an individual for years after exposure to the nuclide in question. This occurs when these long-lived radioactive materials are inhaled or ingested and are incorporated into body tissues where they remain, e.g., incorporation of ^{90}Sr into bone.

2. Projected Use

•Construction Workers

Dose estimates for construction workers—in the event of canyon development—indicate that the critical organs are the lungs and bone. Moreover, the calculated 50 yr commitments, at most, would be about 1.5% of DOE annual radiation protection guidelines.

•Residents

Once background is accounted for, the total-integrated (internal plus external) 50 yr dose commitments to pertinent organs of the maximum individual resident hypothesized for a developed Bayo Canyon are, at most, 3% of DOE annual guidelines and, at most, 25% per cent of the dose imposed on the same organs in one year by the penetrating component of natural background.

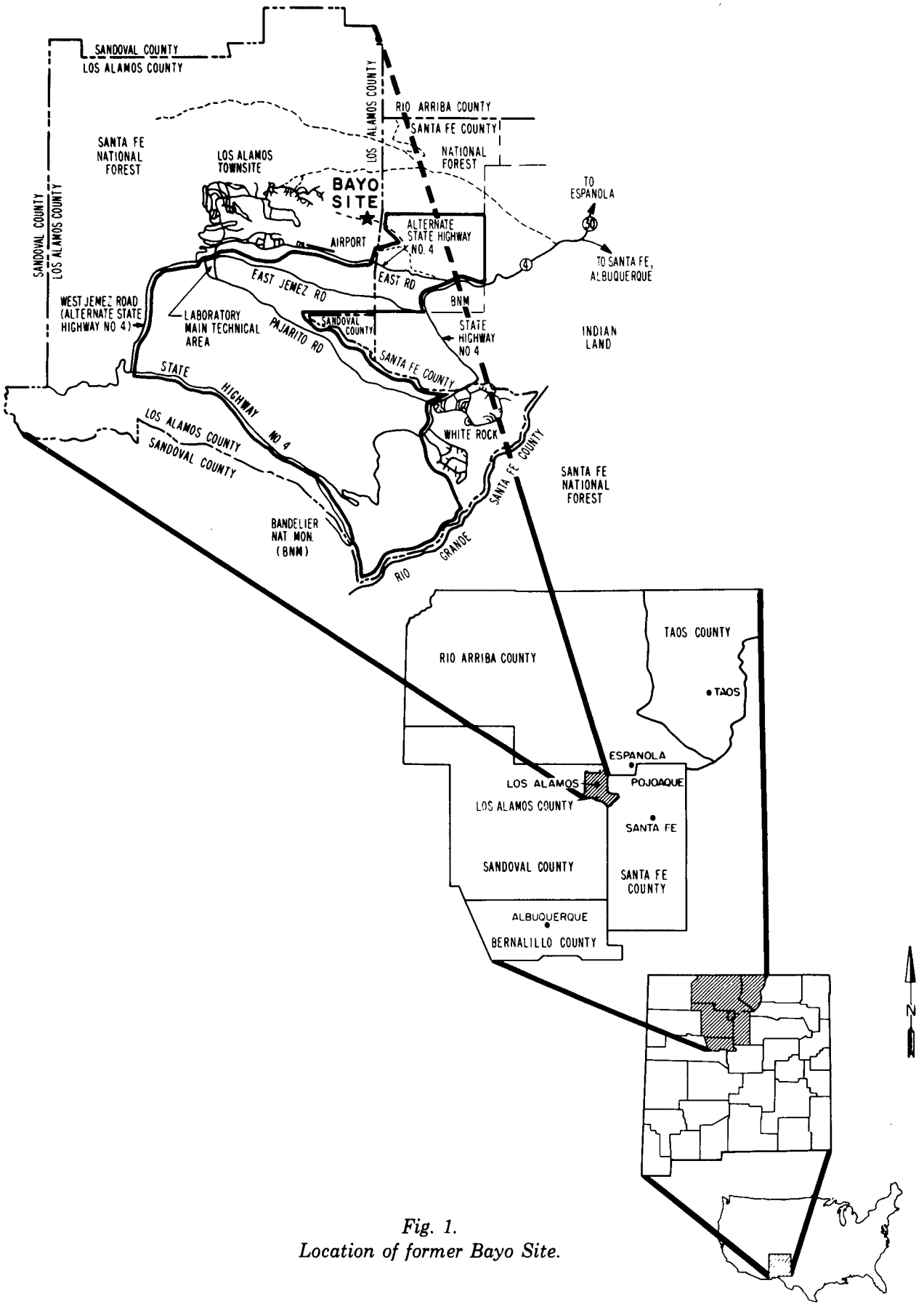

Fig. 1.
Location of former Bayo Site.

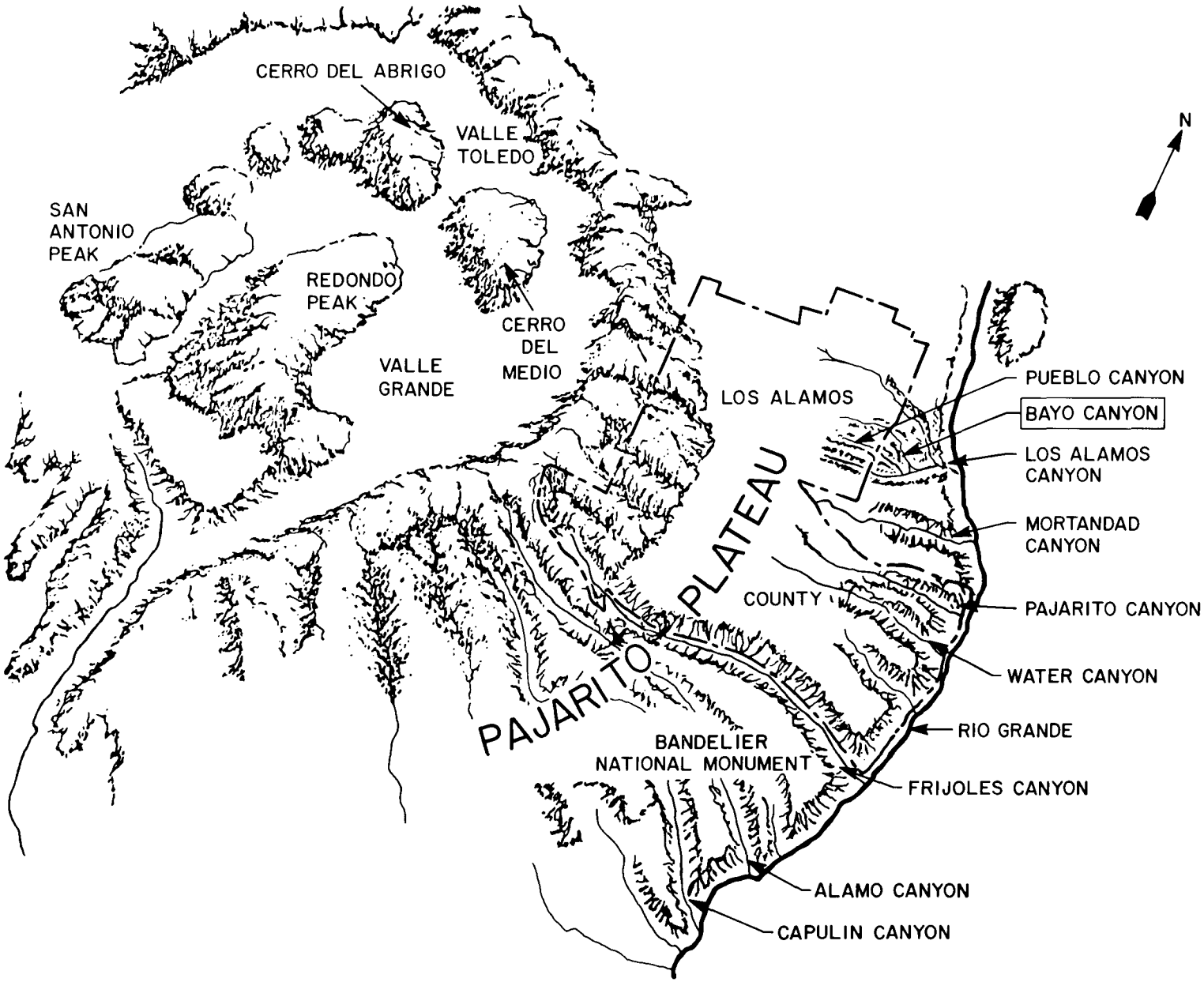

Fig. 2.
Physiographic setting of Bayo Canyon.

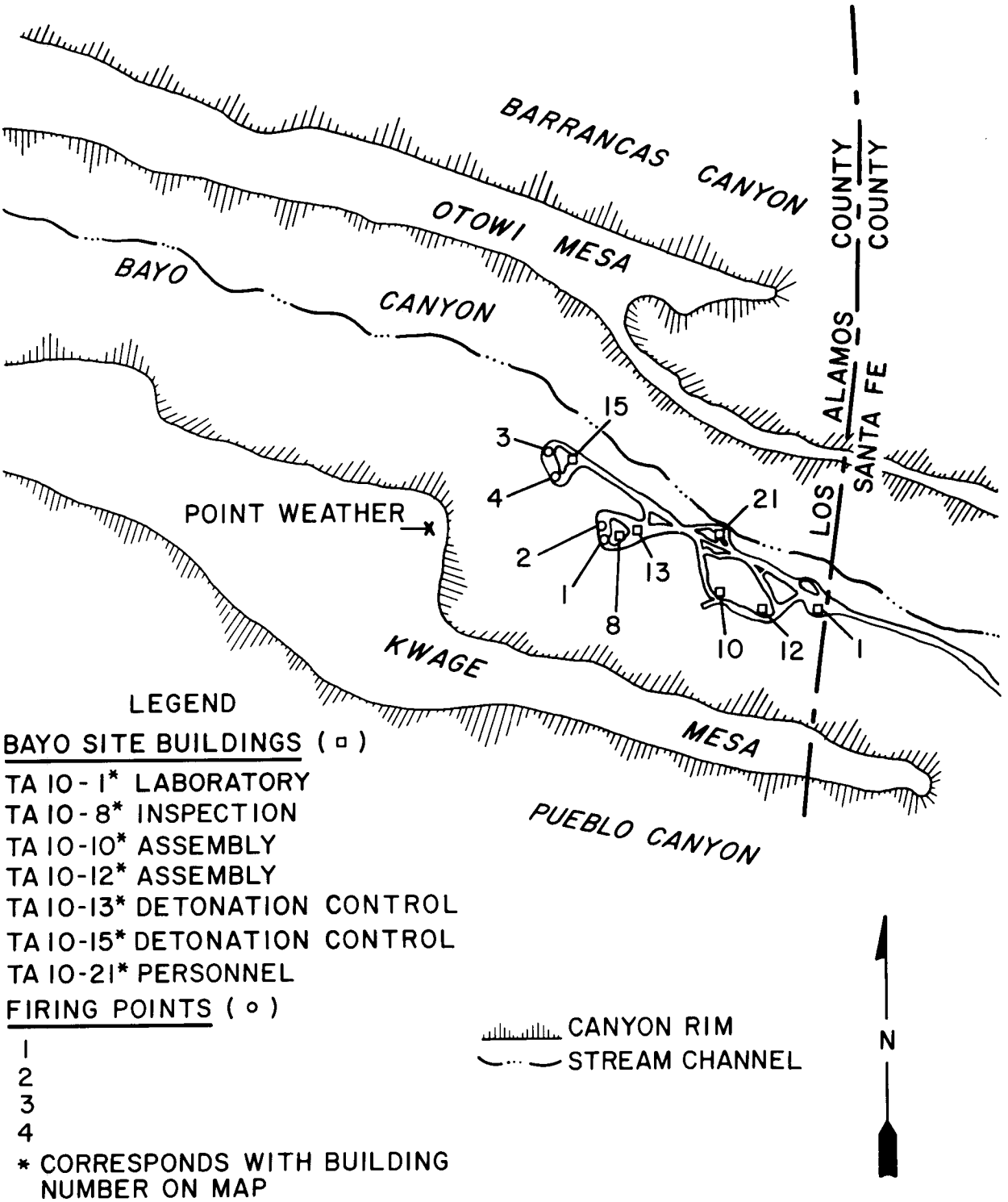

Fig. 3.
Layout of former Bayo Site.

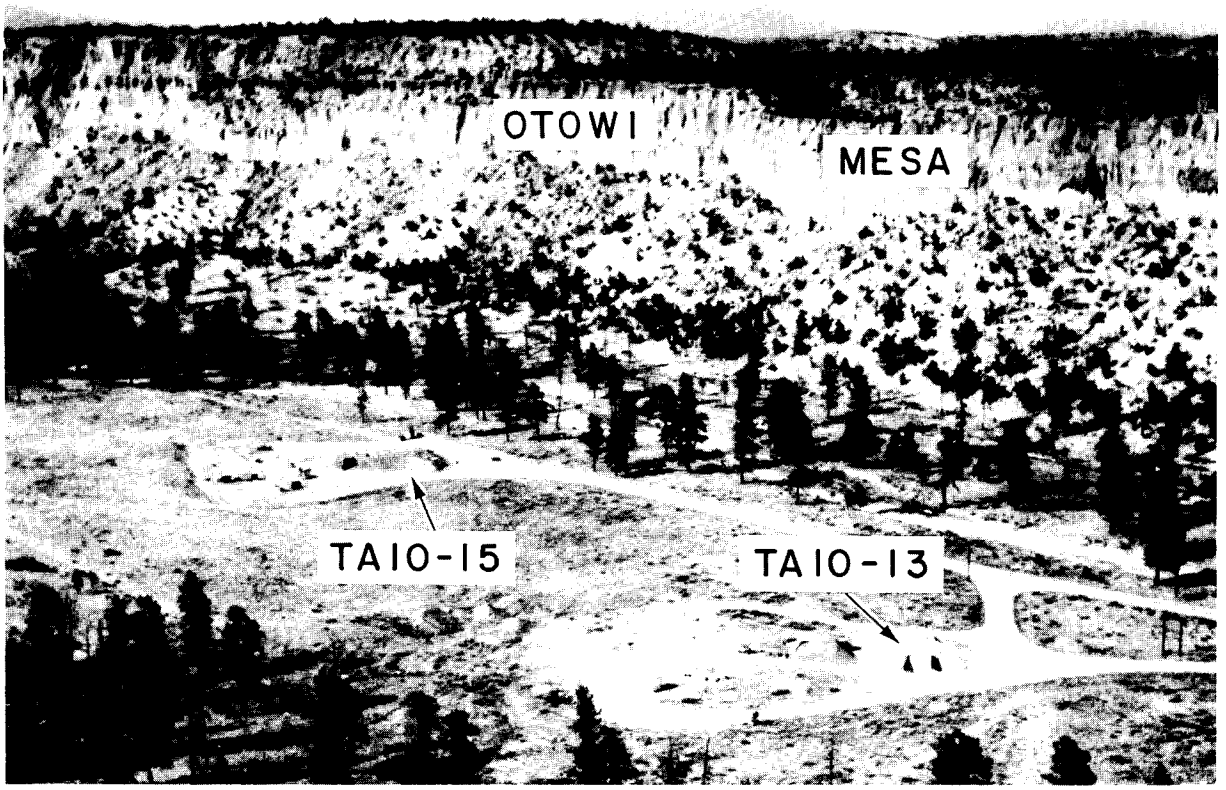

Fig. 4.
View to north from Kwage Mesa. Shows terrain in the vicinity of firing points. Control buildings TA10-13 and TA-15 are on the canyon floor in the foreground. Otowi Mesa and its south facing talus slope are in the background.

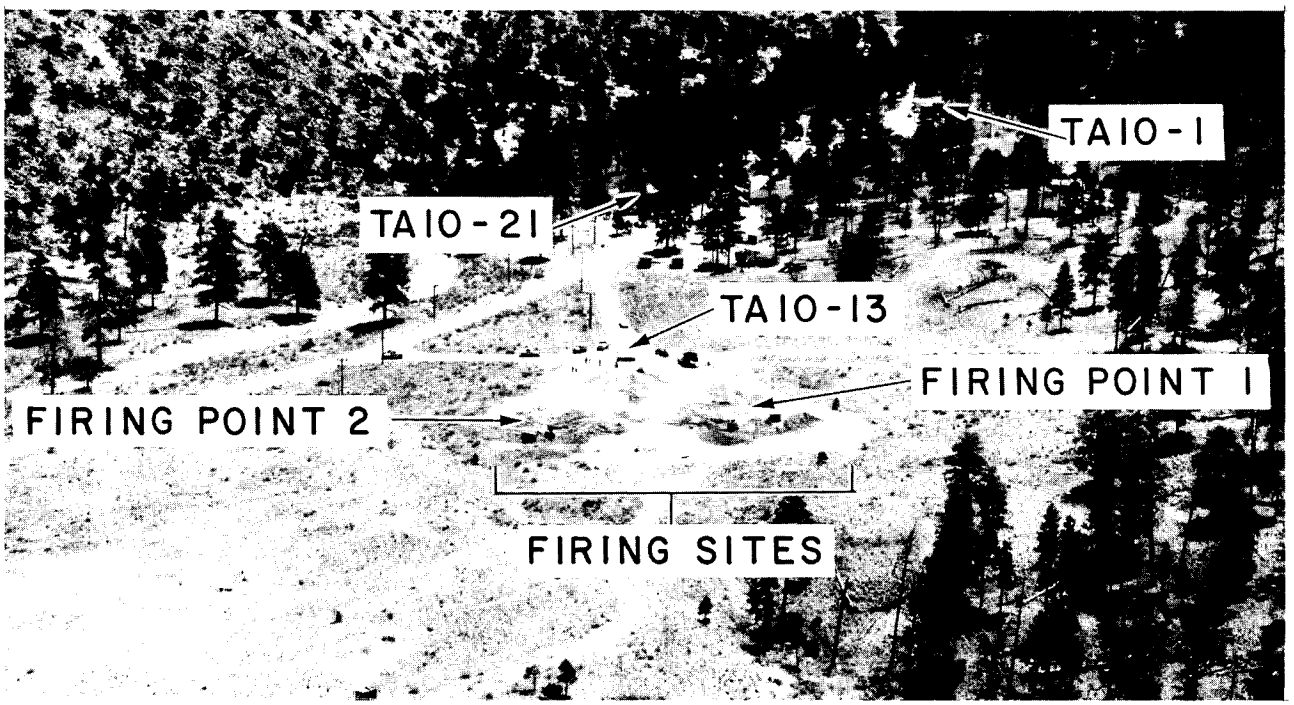

Fig. 5.
View looking east from Point Weather (Kwage Mesa).

Fig. 6.
Experimental detonation—disposal of structural and assembly fragments.

Fig. 7.
Experimental detonation—dispersal of aerosols.

TABLE I

RADIOLOGICAL CONDITIONS IN BAYO CANYON[a]

Soil Concentrations Attributable to Bayo Debris

Soil Depth cm	^{90}Sr (pCi/g)[c] Range[a]	^{90}Sr (pCi/g)[c] Mean[b] Bayo Debris	U (μg/g)[c] Range[a]	U (μg/g)[c] Mean[b] Bayo Debris
0 - 5	0.0-132	1.0	0.5-12.0	1.6
0 - 10	0.1-5.5	0.6	1.4-9.0	0.2
0 - 30	0.1-23.2	0.5	1.5-50	0.9
30 -122	0.1-67.2	10.3	---	---
Below 122[d]				

Air Concentrations

	^{90}Sr (fCi/m^3)[c] Range	^{90}Sr (fCi/m^3)[c] $\bar{X} \pm \sigma$	U (pg/m^3)[c] Range	U (pg/m^3)[c] $\bar{X} \pm \sigma$
Bayo Canyon	0.09-0.13	0.11 ± 0.03	2-134	52 ± 9
North Central New Mexico	0.14-0.17	0.15 ± 0.02	2-146	62 ± 12

External Penetrating Radiation

	Mesa Top 1	Mesa Top 2	Bayo Site Range	Bayo Site $\bar{X} (\pm \sigma)$
μR/h[c]	22.9	19.1	17.7-24.8	21.1 ± 2.2

[a]Range is from all 1977 radiochemical analyses.

[b]Mean Bayo debris is difference between mean of all generic radiochemical analyses (^{90}Sr at 0-5 cm for example) and what has been determined to be background.

[c]pCi/g, fCi/g, pg/g, μR/h, μg/g. See Glossary for definitions.

[d]Of 51 samples below 122 cm, which were analyzed for ^{90}Sr, 10 exceeded 20 pCi and 8 exceeded 100 pCi/g. Maximum ^{90}Sr activity detected was 4310 pCi/g, whereas the maximum radioactivity noted to date was 24 000 gross β pCi/g from the 1974 resurvey. The latter is believed to represent ~12 000 pCi ^{90}Sr/g in that sample.

II. SITE HISTORY AND OPERATION

A. Site Operation

Facilities for conducting experiments with high explosives were constructed in Bayo Canyon in 1943 for Project Y of the Manhattan Engineer District (MED). The facilities were utilized until 1961 for experiments relating to the development of nuclear weapons at the Los Alamos Scientific Laboratory operated by the Universty of California under contract to the AEC. In 1963 the Bayo Site, alternatively referred to as Technical Area 10 (TA-10), was decontaminated and demolished. The land was turned over to Los Alamos County in 1967.

The principal structures comprising TA-10 (see Figs. 3, 4, and 5) included a radiochemistry laboratory (TA-10-1), two assembly buildings (TA-10-10 and TA-10-12), an inspection building (TA-10-8), a personnel building (TA-10-21) and structures at two detonation control complexes, particularly the control buildings (TA10-13 and TA-10-15) and adjacent firing pads. Ancillary facilities included sanitary and radioactive liquid waste sewage lines, man holes, septic tanks and seepage pits, and solid radioactive waste disposal pits.

Radioactivity was released to the environment in Bayo Canyon primarily by (1) the explosive shots, which contained radioactive materials, and by (2) the disposal of radioactive wastes from radiochemistry operations. Secondary sources included airborne exhausts from laboratory hoods, accidental spills, and redistribution during decommissioning operations.

The explosive test assemblies usually included components made from natural or depleted uranium and a radiation source for blast diagnostics. The sources contained several hundred to several thousand curies of ^{140}La (half-life 40.2 h) and a small proportion of ^{90}Sr (half-life 28.1 yr). The sources were prepared in the radiochemistry lab (TA-10-1) at Bayo Site by radiochemically separating the ^{140}La from a solution containing the radioactive parent ^{140}Ba (half-life 12.8 days), the stable daughter ^{140}Ce, and other impurities including ^{90}Sr. The separated ^{140}La and an unavoidable proportion of ^{90}Sr were precipitated onto a filter medium and encased in foil to form a source. (Separation, precipitation, and encapsulation were performed at TA-10-1 between 1944 and 1950. Subsequently, only the precipitation and encapsulation operations were performed there and the radiochemical separations were done at another laboratory still on DOE land). Other components of test devices were assembled in buildings TA-10-13 and TA-10-15; inspected in building TA-10-8, and placed on one of the shot pads. Once the source was inserted, the experiment was remotely detonated from one of the control buildings—TA-10-13 or TA-10-15.

The explosive detonation resulted in the dispersion of radioactive materials—uranium, ^{140}La, and ^{90}Sr—in the form of aerosols and solid debris (see Figs. 6 and 7). Depending on wind conditions, aerosols were dispersed to varying degrees both within Bayo Canyon and beyond the adjacent mesas. Standard procedures required a southwesterly wind at the time of detonation.[6] But routine post-shot surveys[7-8] out to about 5 miles did at times find ^{140}La contamination in the vicinity of State Road 4 and on Otowi and Kwage Mesas. On one occasion an aircraft was able to track airborne ^{140}La activity eastward across the Rio Grande Valley. Solid debris, including fragments of uranium and other metal components, was scattered around the firing points, largely within 90-125 m. Some large fragments were found 300-600 m away.[5] Some radioactivity was dispersed around the firing pads by water from post-shot cleanup. Radiation levels around the pads were frequently in the range of a few tenths to a few R/hr.

The disposal of liquid and solid radioactive wastes resulted in the deposition of radioactivity below the surface. Radioactive liquid wastes from the radiochemistry building (TA-10-1) were collected in so-called acid waste lines and flowed to holding tanks, pits, and a leaching field to the north. Liquids placed or flowing into the pits drained through an outlet pipe at the bottom into the earth. Liquid wastes from the storage tanks were periodically discharged directly into the stream channel. The basic components of the waste disposal system are depicted in Fig. 8.

Sanitary sewage lines, septic tanks, the TA-10-1 outfall line, and the TA-10-21 disposal pit, also shown in Fig. 8, may have received some contaminated liquid waste. Solid radioactive wastes were disposed into two of the the six pits located as shown on Fig. 8.

Other, smaller, quantities of radioactivity may have been released with the unfiltered exhausts from fume hoods used for the routine radiochemical processing carried out in Building TA-10-1. On one occasion, some plutonium was handled in a makeshift hood in Building TA-10-7. This resulted in the accidental dispersal of some alpha activity evidenced by contamination on the roof of the building. Some cleanup was undertaken and alpha activity remaining on the roof was stabilized by mastic.[10]

Bayo Site was decommissioned starting in 1960 with the demolition or burning of several buildings. In 1963 the rest of the buildings were demolished or burned, the sewer systems removed, the contaminated waste pits excavated, and surface debris picked up out to a radius of about 760 m from the detonation control buildings[5] (see Figs. 9-15). All debris was removed for disposal in the contaminated waste burial site at TA-54, which remains within the present Laboratory boundary. A summary of decommissioning is presented in Table II (Ref. 11). It is possible that some contamination was deposited on the surface soil as a result of the burning and excavation operations. However, once decommissioning was completed in 1963, no surface contamination could be detected in Bayo Canyon with portable instruments then in use.[5] (Such survey meters should have been able to detect from roughly 2 nCi at contact to roughly 20 nCi at 1 m of ^{90}Sr spread uniformly on a smooth, dry, surface of low atomic number. Any departure from such ideal conditions, as would be the case in field situations, would raise the detection limit appreciably.)[12]

During the decommissioning the highest levels of radioactivity were found associated with the acid sewer lines and waste disposal pits while low levels were found around the shot pads and some buildings. An attempt was made to remove all materials, including soil, that showed detectable contamination. Radiation levels encountered during excavation of waste pit TA-10-48 and the tank farm area ranged as high as 35 mrad/hr.[11] Some subsurface contamination was known to be left in the excavations of waste pit TA-10-48 (excavated to 7.9 m deep) and the tank farm (excavated to 6.01 m deep). The bottom of the TA-10-48 excavation read 1.5 mrad/h and samples from the first 1.22 m below the bottom (9.1 m below ground) ranged from 0 to 300 pCi ^{90}Sr per gram of soil. The bottom of the tank farm excavation also read 1.5 mrad/h. Both excavations were backfilled with uncontaminated dirt from other parts of the canyon.

Because of the wide dispersal of debris by the tests and continuing natural erosion processes, it was recognized at the time of decommissioning that there was a reasonable probability that some high-explosive and some potentially radioactive materials remained in the canyon. Thus, periodic surface surveys and searches were conducted in 1966, '67, '69, '71, '73, '75, and '76.[13-21] During such surveys a number of additional pieces of debris were located, with only a few of them being contaminated with ^{90}Sr or including normal or depleted uranium.

B. Previous Investigations

A number of investigations and studies have been conducted over the years, which contribute some data and understanding to the current comprehensive evaluation. They are described briefly in this section to provide historical context; significant data are incorporated in Chapter 4, Results, and additional relevant details are in appendixes.

In 1956, an investigation by the U. S. Geological Survey concluded that, because of the basically dry conditions in Bayo Canyon, there was little possibility that contaminants from the surface or from liquid waste disposal pit seepage would be able to move any significant distance as shallow groundwater (see Appendix A). In 1961, test holes were drilled to further investigate the possibility of movement of contaminants by subsurface water. There was no indication of any excess

moisture or perched water in the tuff or alluvium of Bayo Canyon. This confirmed the geohydrologic interpretation that insufficient water was introduced to the subsurface as a result of site operations or from runoff to permit any transport of contaminants downward toward the main aquifer. The main aquifer is about 240 m below the surface of the canyon and completely isolated from the surface by the great thickness of dry rock material.

In 1961-1962 an aerial gamma-radiation survey known as ARMS-II was conducted for the AEC in the vicinity of nuclear facilities and included portions of northern New Mexico out 30 to 50 km north and west of Bayo Canyon.[22] This survey showed that the radiation levels above the volcanic mass of the Pajarito Plateau generally tended to be higher than other formations in the area. Considerable variation was noted over relatively short distances. Bayo Canyon generally was included in the highest areas but was no higher than other large areas on the plateau and no unique observations were noted for Bayo Canyon itself.

In 1965 and in 1970 sediments were collected from two locations in the channel downstream from the Bayo Site. Radiochemical analyses showed no indication of contamination from the abandoned site.

In 1972, a special survey of a number of land parcels in the Los Alamos area included one tract of about 1.9 km^2 on the mesa just south of Bayo Canyon. *In situ* radiation measurements with sensitive portable instruments, and samples of soil and vegetation analyzed radiochemicaly were not statistically different from similar measurements made at reference locations in northern New Mexico[23] (analyses did not include ^{90}Sr).

Beginning in 1973 some preliminary resurvey work was undertaken in Bayo Canyon by the LASL Health Division at the request of the AEC to develop additional detail on radiological conditions. Four soil and sediment sampling plots were established along the stream bed centered at 2000 m intervals, one upstream from TA-10, one at the TA-10 site, and two downstream. The most important results were that all surface ^{90}Sr analyses were within the normal range attributable to worldwide fallout. Details of sampling and results are in Appendix A.

Subsurface samples were obtained as cuttings from three test holes augered with a truck-mounted drill rig during the 1973 work. One hole was drilled a few meters north of the location of the solid waste disposal pit (TA-10-48) (see Fig. 16). Radiochemical analyses of samples for ^{90}Sr were all less than the analytical detection limit indicating no subsurface migration. A second hole was drilled a few meters east of the location of the acid waste leaching field. Radiochemical analyses of samples for ^{90}Sr indicated some contamination to as much as about 20 pCi/g (~60 times average fallout levels) within 1.5 m of the surface. The third hole was drilled in between locations of two of the liquid waste disposal pits (TA-10-41 and -42). Radiochemical analyses detected ^{90}Sr contamination at levels up to 3.3 pCi/g (~10 times average fallout levels) within 1.5 m of the surface. Additional details of sampling and results are in Appendix A.

Because some subsurface contamination was indicated by the 1973 samples, an additional 11 auger holes were completed in 1974 (see Figs. 17 and 18). Auger samples were analyzed for gross-alpha and -beta activity. Sample results from a few meters north and west of pit TA-10-48 supported the 1973 finding that no migration had occurred to the north of the pit. Sample results from the north end of the acid leaching field and the sanitary outfall indicated no migration from the leaching field, but elevated (3-20 times background) beta activity occurred in the top 122 cm of soil around the sanitary outfall. Sample results north of the former TA-10-41 and TA-10-42 acid waste pits indicated migration through the tuff, but at an appreciable depth. A single sample had maximum activity of 24 000 pCi/g and occurred between 430 cm and 490 cm. Most samples were less than 10 pCi/g. These results are discussed further in Sections 4 and 5, whereas detailed information appears in Appendix A.

In October 1975 E.G.&G. (ARMS II) performed a second aerial survey at the request of LASL, which included some flights over Bayo Canyon from the west end of the canyon east across TA-10-1. The equipment used was greatly improved over that used in 1961-1962. As in 1962, however, the difficult terrain prevented exact mapping of aircraft position with radioactivity. These unpublished results showed no measurable quantity of ^{90}Y or depleted uranium in the Bayo Site vicinity. Natural uranium activity was only slightly higher than expected for most southwestern U.S. localities.

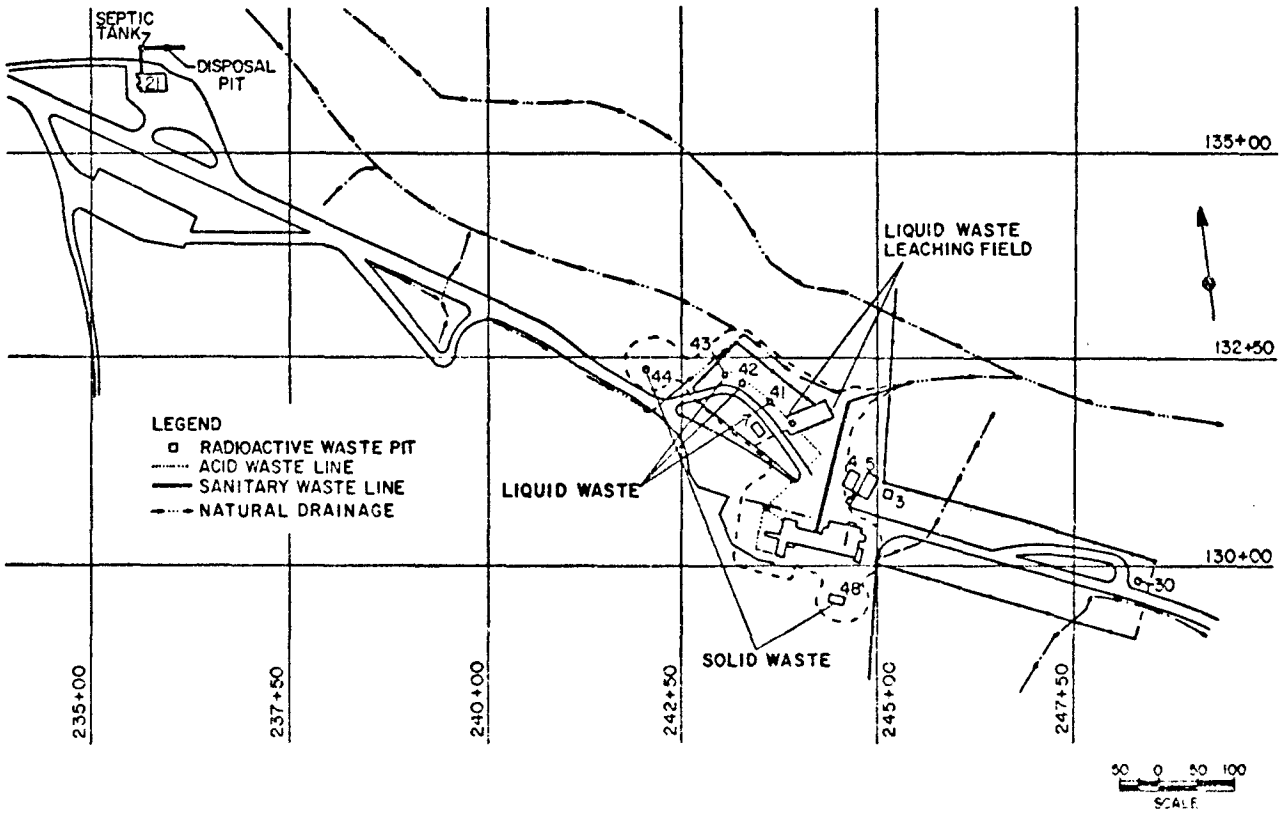

Fig. 8.
Waste handling facilities at Bayo Canyon.

Fig. 9.
Demolition of shot pad by building TA10-13.

Fig. 10.
Restoration of terrain after demolition of shot pad.

Fig. 11.
South elevation of TA10-1.

Fig. 12.
Demolition of TA10-1.

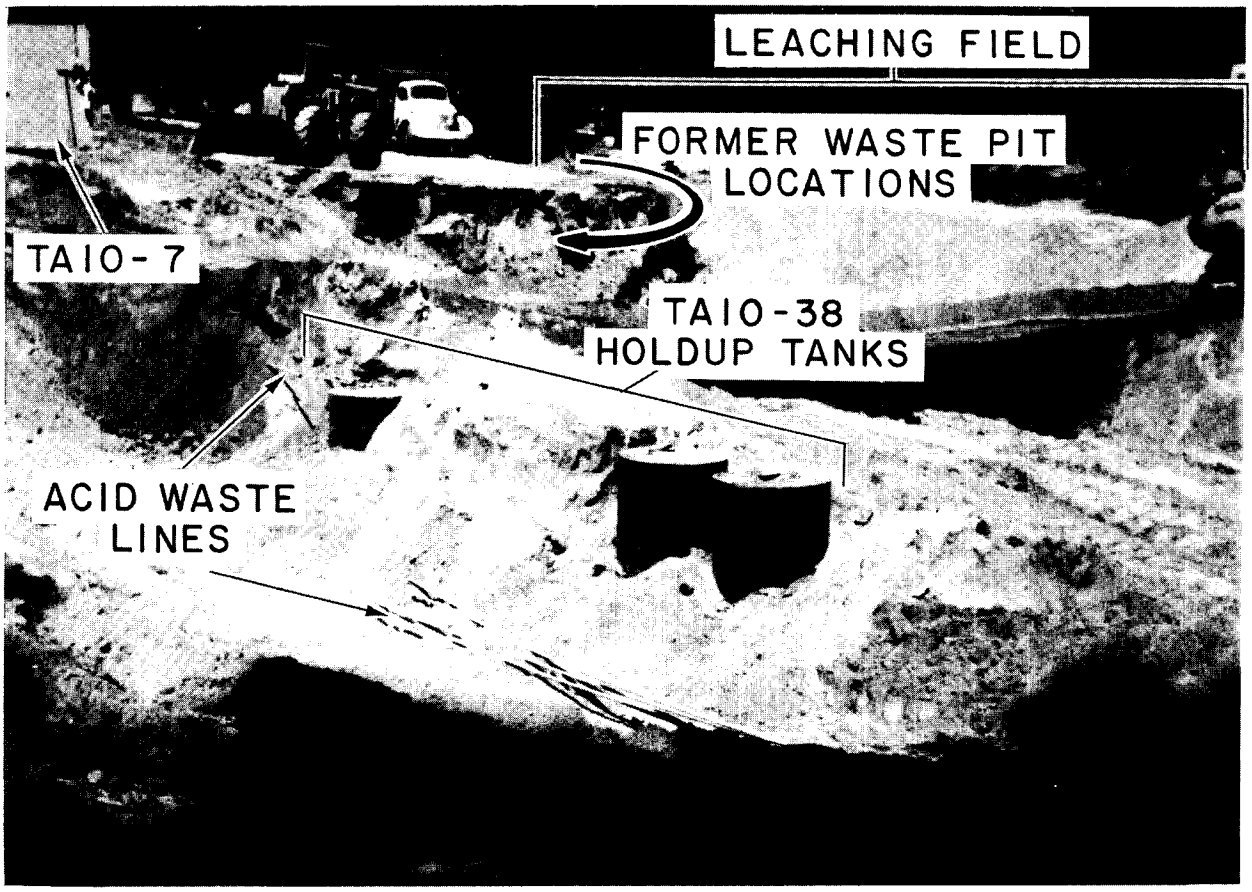

Fig. 13.
Demolition of waste handling facilities north of building TA10-1. Acid waste lines and hold up tanks are in the foreground below the tractor shed TA10-7. The leaching bed was about where the earth ramp appears and the tank farm was behind the earth ramp.

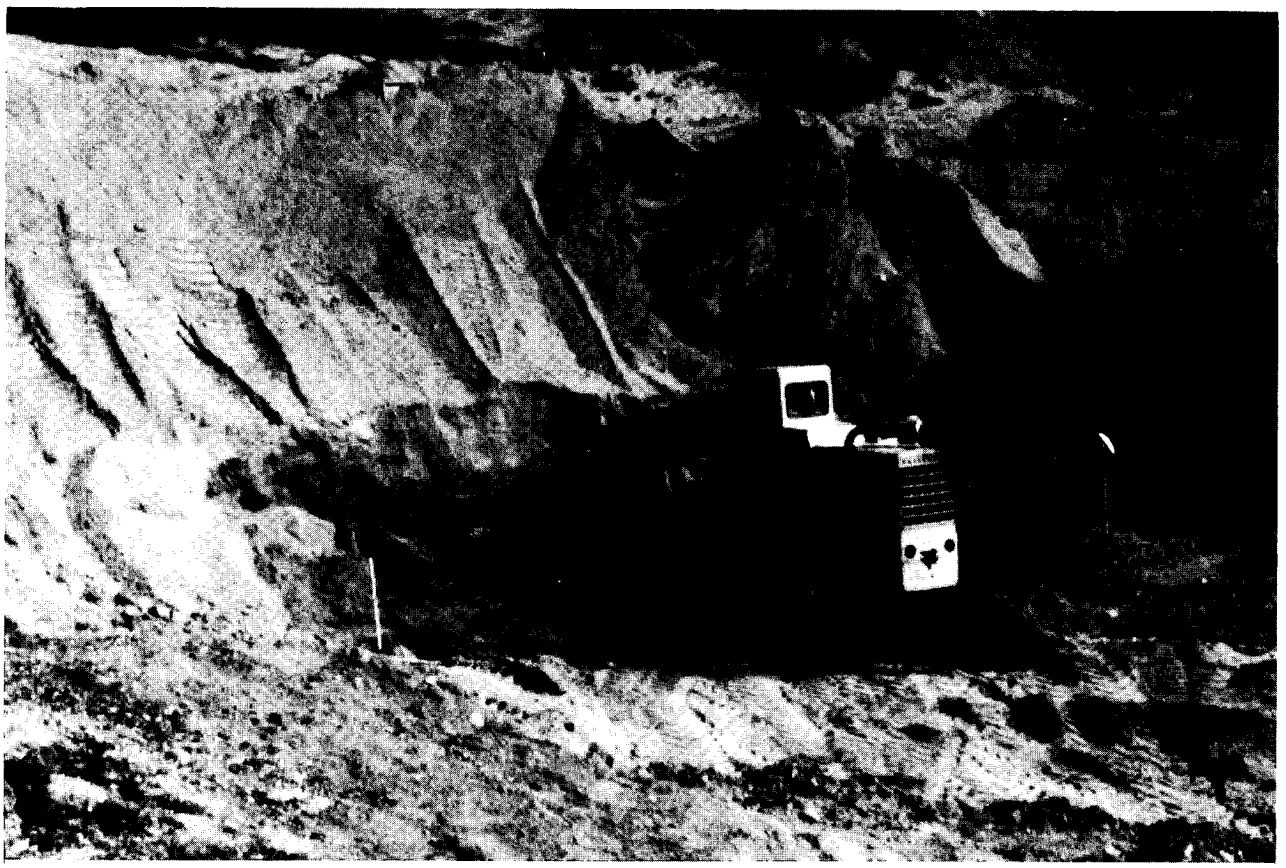

Fig. 14.
Tank farm excavation northwest from building TA10-7 in the vicinity of waste pits TA10-41 and TA10-42.

Fig. 15.
Restored terrain after decommissioning TA10-7 and waste handling facilities north of TA10-1.

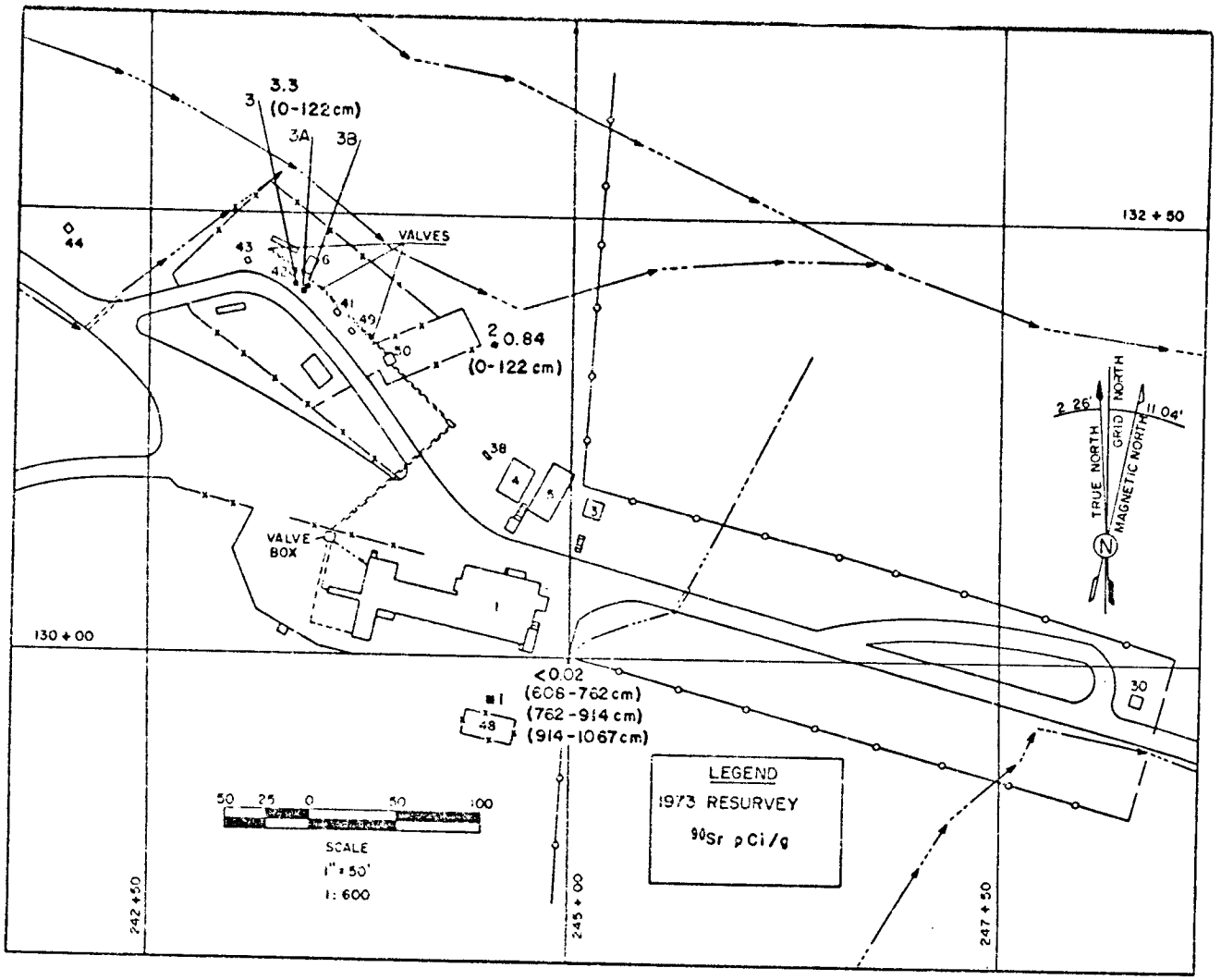

Fig. 16.
^{90}Sr in auger samples; 1973 resurvey effort.

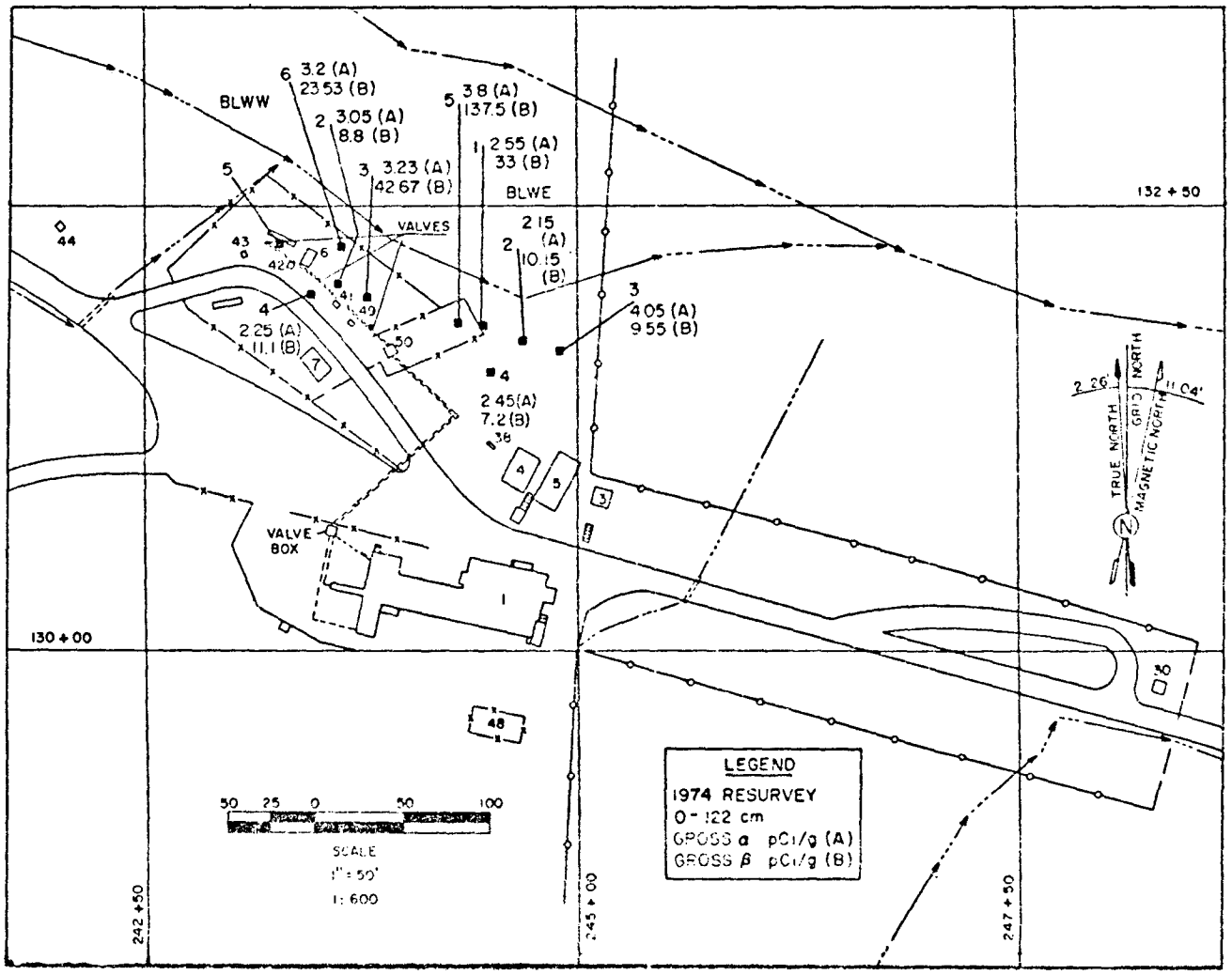

Fig. 17.
Gross α-β activity in auger samples; 0-122 cm depth; 1974 resurvey effort.

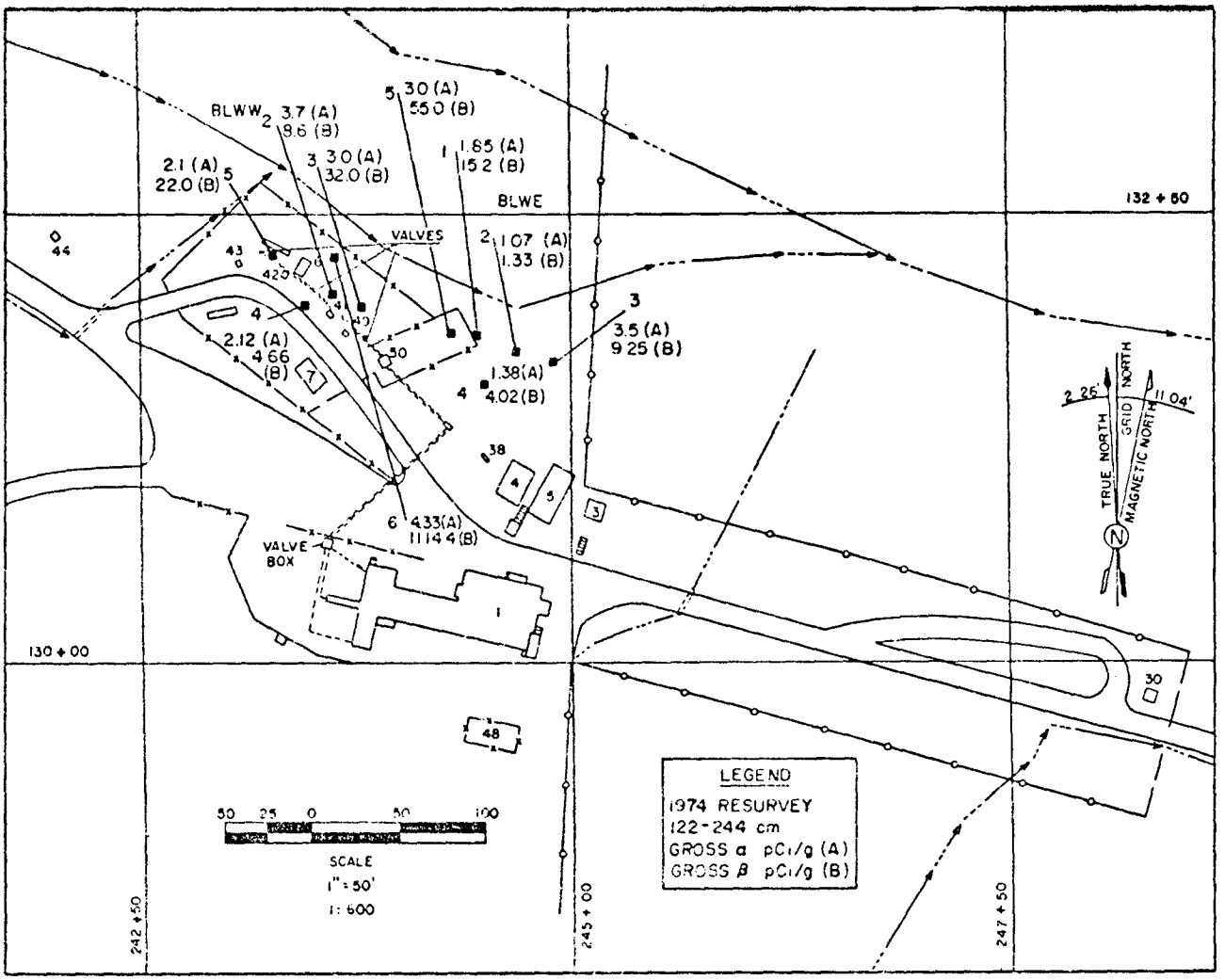

Fig. 18.
Gross α-β activity in auger samples; 122-124 cm depth; 1974 resurvey effort.

TABLE II

SIGNIFICANT STRUCTURES DECOMMISSIONED AT BAYO SITE

Structure Number	Structure Nomenclature	Date Removed	Potential Contamination	Disposition
TA-10-1	Radiochemistry Laboratory	1963	^{140}Ba,^{140}La,^{90}Sr, uranium	Burned, debris to Area G disposal pit; TA-54
TA-10-2	Source Storage	1963	^{140}Ba,^{140}La,^{90}Sr	Burned, debris to Area G disposal pit; TA-54
TA-10-3 TA-10-4 TA-10-5 TA-10-6	Storage	1960	^{140}Ba,^{140}La,^{90}Sr, uranium	Burned, debris to Area G disposal pit; TA-54
TA-10-7	Tractor Shed (plutonium, spill)	1963	^{140}Ba,^{140}La,^{90}Sr, uranium, ^{239}Pu	Burned, debris to Area G disposal pit; TA-54
TA-10-21	Personnel Building	1963	^{140}La, ^{90}Sr, uranium	No record of disposal
	Acid Waste System	1963	^{140}Ba,^{140}La,^{90}Sr	Removed to Area G pit; TA-54
	Sanitary Waste System	1963	^{140}Ba,^{140}LA,^{90}Sr	"
	Waste Pits	1963	^{140}Ba,^{140}La,^{90}Sr	"

III. METHODS AND APPROACH

The survey of the Bayo Canyon site was undertaken to provide a complete, up to date documentation of the existing radiological conditions as part of a nationwide effort to investigate facilities and lands formerly utilized by Manhattan Engineer District programs in World War II or subsequently by the AEC. The objective was to develop sufficient information to permit evaluation of the potential for exposure to radioactivity or radiation in excess of normal background under conditions of current or projected likely uses.

Land use in Bayo Canyon since July 1, 1967, when title was transferred to Los Alamos County by quit claim deed, has been an open area for recreation. Recreational uses have included hiking, picnicking, trail riding (motorcycle and horse), and firearms practice. Some firewood collecting, piñon nut picking, and Indian artifact hunting has taken place.

One option for disposition is a continuation of present recreational use. The second option is development of a residential area for as many as 400 homes—currently a tentative consideration by Los Alamos County and private developers.

The resurvey program was designed to provide a basis for estimating potential exposures under conditions of continued recreational use, during light construction, and as an occupied residential area. The sampling and measurement scheme attempted to account for previous use history as a testing area and was guided to some extent by data from previous investigations.

Four basic strata of sampling locations were laid out to assess surface and subsurface soil contamination:

1. Firing Sites—A polar coordinate scheme was constructed with nine concentric circles centered at a point between the two main firing pads and extending out 404 m with sampling points located at intervals of 61 m or less on each circle.

2. Canyon Floor—Rectangular grids were appended on either side of the circular pattern to provide more complete coverage of the general vicinity potentially influenced by the testing operations. Sampling points were located at 61 m intervals.

3. Structures—Sampling points were located around the perimeters of former building locations, along the alignments of industrial and sanitary liquid waste lines, and in the vicinity of former locations of waste pits, septic tanks, and the leaching field.

4. Stream Channel—Sampling points were located in natural drainage channels and the main stream channel to assess any redistribution or deposition of activity by runoff.

The basic patterns of the four strata are depicted in Figs. 19, 20, and 21 [detailed location and identification maps (Figs. 22, 23, and 24) are folded into the back cover of this report]. The patterns were utilized in different ways to take samples by various techniques, to identify subsets of randomly chosen or selected sample types or analyses, and to locate *in situ* measurements.

Initial field work consisted of general area surveys with sensitive portable instruments to determine any locations of particularly anomalous radiation levels at the surface that might require special investigation. The instruments utilized were a "micro-R" meter sensitive to a wide range of gamma radiation and a phoswich detector sensitive particularly to low energy x and gamma radiation. (Details of the instruments and detection limits are provided in Appendix B.) Either instrument would have responded to any major concentrations of uranium. The phoswich would have responded to any major concentrations of plutonium. Extra samples would have been taken at locations of anomalous (high) activity. Additional *in situ* penetrating radiation dose measurements were made at 78 points in the Firing Point and Canyon Floor Strata during sampling. Soil

samples were collected by five basic techniques to provide information on potential contamination at the surface (as would relate to resuspension), in shallow profiles (as would relate to light construction and gardening), and at depth (as would relate to deep foundation or utility construction). The techniques included:

- Surface samples—taken with 12.7 cm diam ring, 0-5 cm depth.

- Core samples—taken with 2.5 cm diam PVC pipe down to maximum depth of 30 cm.

- Profile samples—taken with ring or core but sectioned into intervals of 0-5, 5-10, 10-20, and 20-30 cm.

- Trench grab-samples—taken with scoop from walls or bottom of backhoe-dug trenches down to depths of about 1.2 m.

- Auger samples—taken from cuttings of augered holes (drilled by truck-mounted rig) at various intervals down to maximum depths of 12.8 m.

Detailed descriptions of the sampling techniques are included in Appendix C.

The soil samples were analyzed for gross and specific radioactivity content according to several selection schemes. All samples were analyzed instrumentally at LASL for gross-alpha and -beta activity by ZnS and plastic scintillator detectors, respectively. Subsets of the samples were determined by random choice (to provide unbiased estimates) or by special selection (such as for confirmation of contaminant or to provide a basis for correlation with gross activity analyses). These subsets were submitted for various radiochemical analyses. The largest number of radiochemical analyses were performed for ^{90}Sr, followed closely by total uranium, then ^{239}Pu, ^{238}Pu, and ^{137}Cs. Some radiochemical analyses were performed for ^{226}Ra and ^{232}Th to provide supplementary information. Most radiochemical analyses were performed by an independent commercial laboratory under contract to LASL. Some radiochemical analyses were performed by the Environmental Surveillance Group at LASL. Additional detail on the analytical methods and quality control is included in Appendix C.

Table III summarizes the soil sampling plan and analyses grouped by the four principal strata. Execution of the survey resulted in many additional samples and analyses to verify or clarify preliminary results. Results are summarized in Chapter 4, and detailed results are compiled in Appendix D.

Some limited sampling of vegetation and small rodents was undertaken.

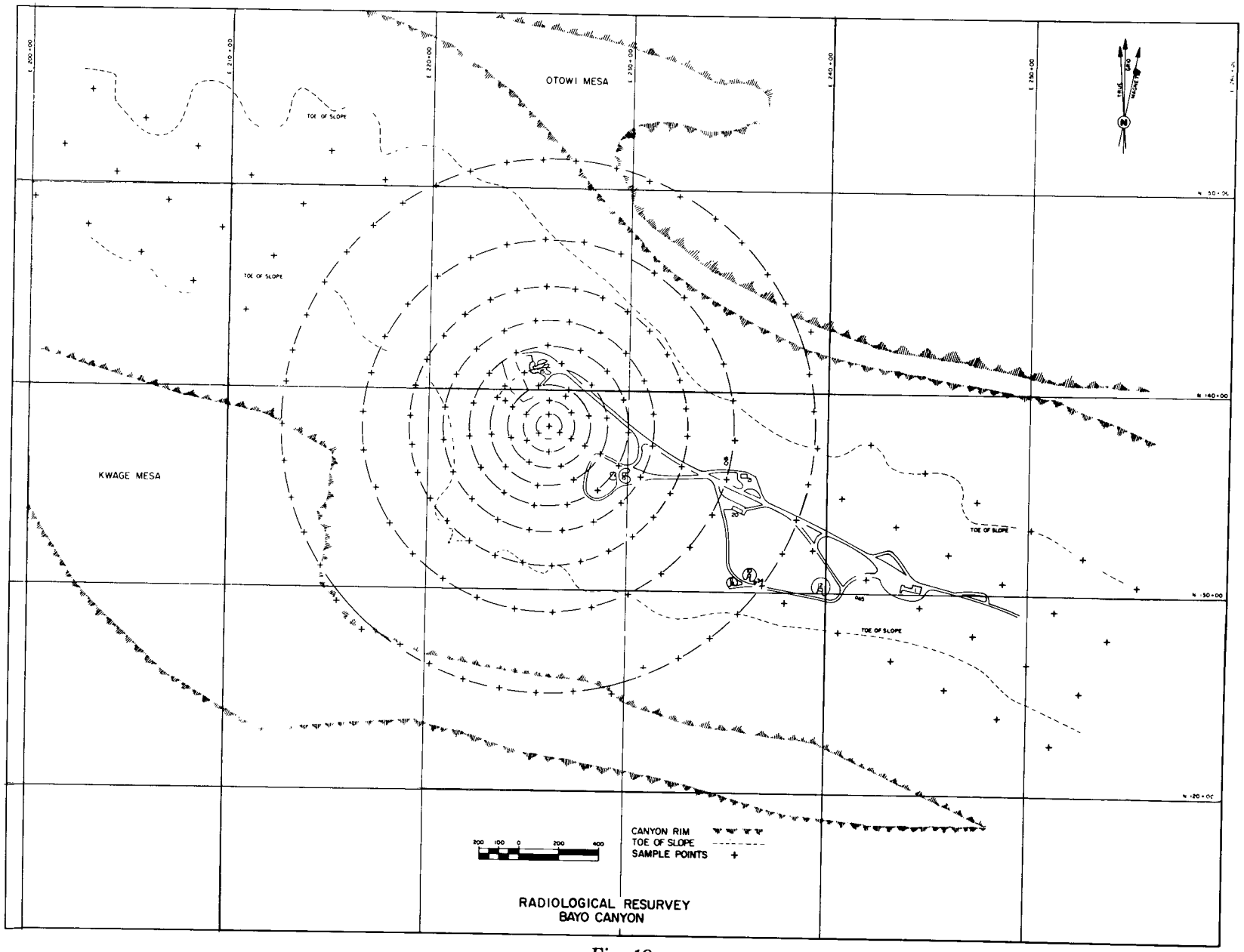

Fig. 19.
Firing site grid and canyon floor grid.

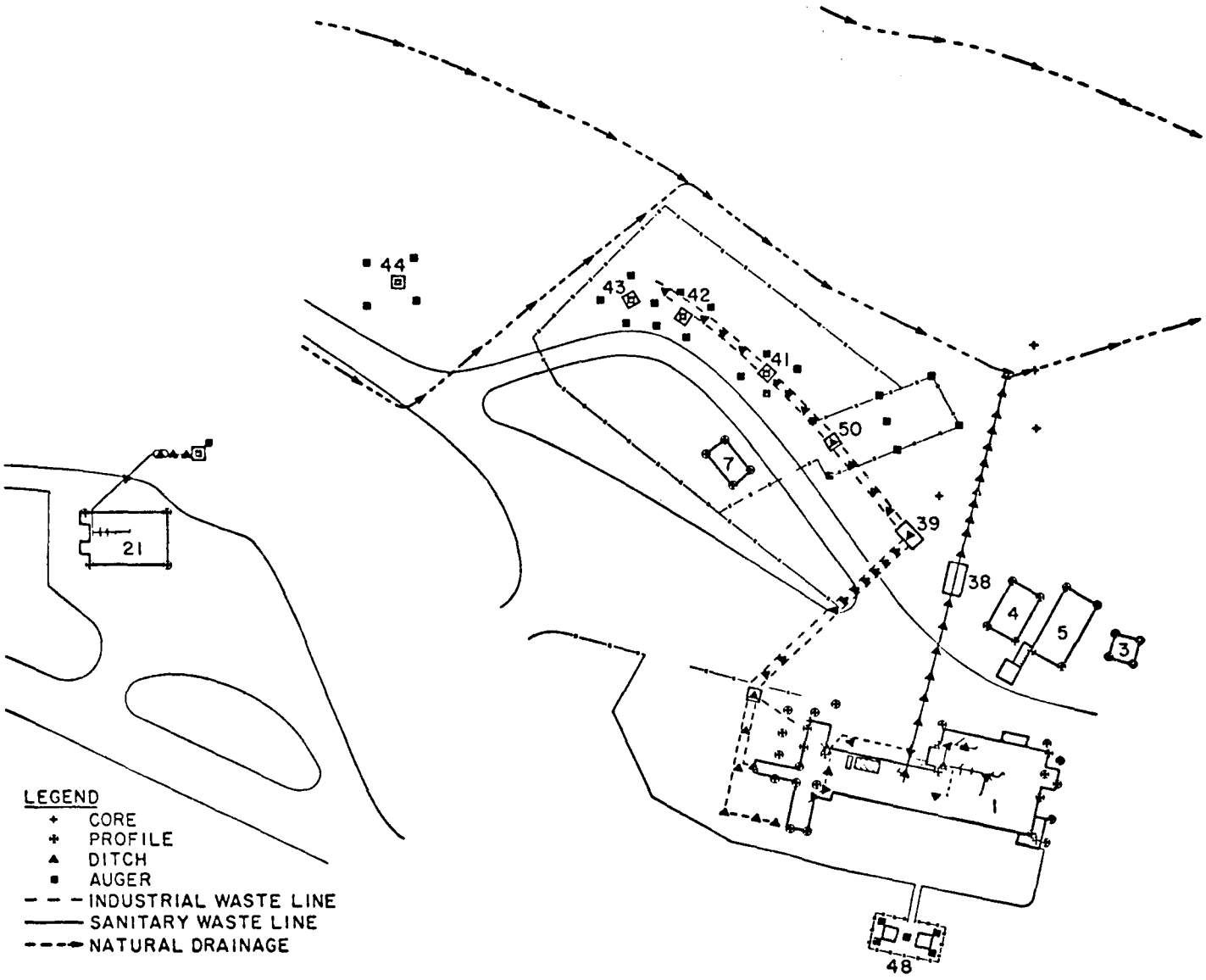

Fig. 20.
Structures grid.

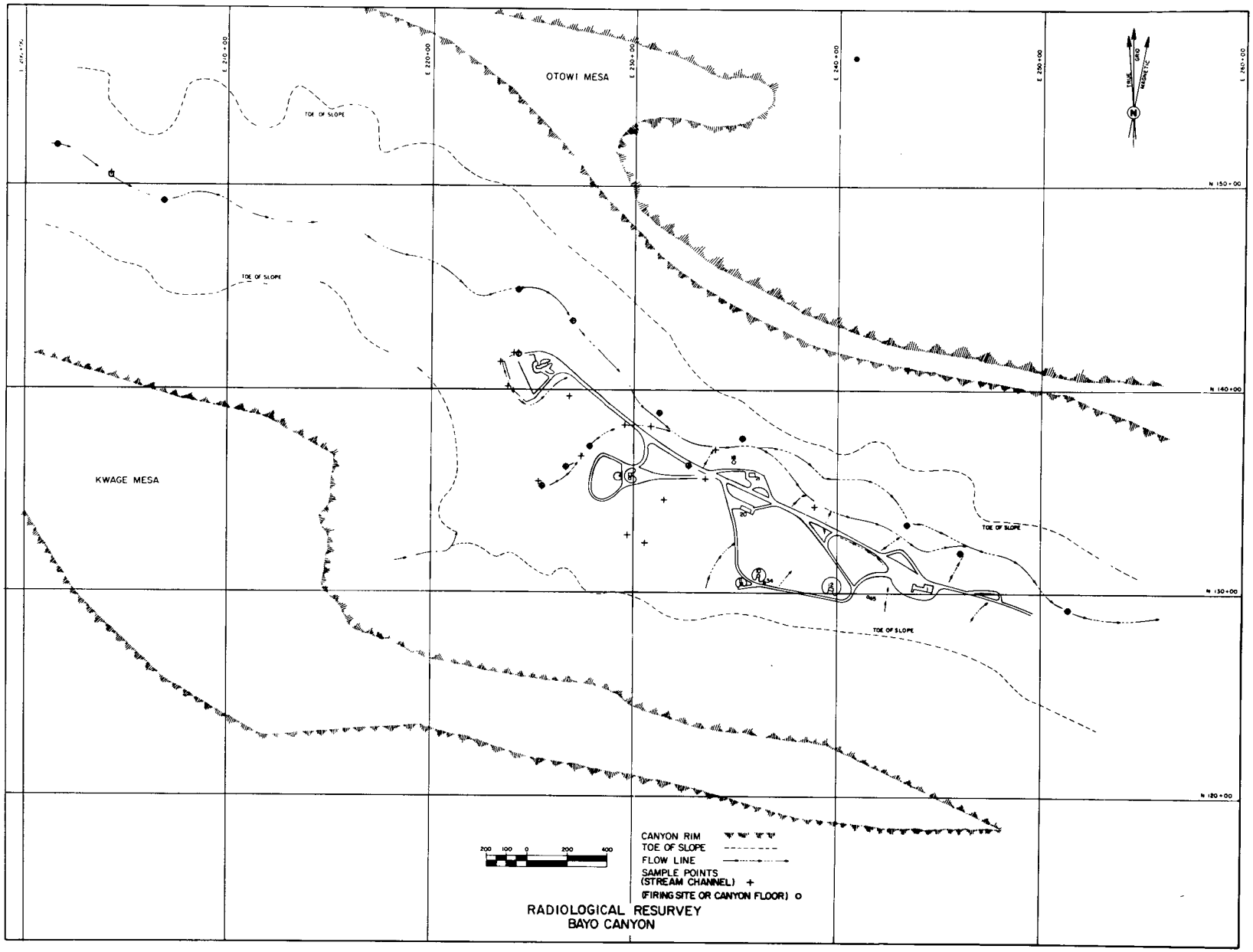

Fig. 21.
Stream channel sampling stations.

TABLE III

RESURVEY SAMPLING AND ANALYSIS SCHEME

Strata	Type	Number of Locations	Type	Number of Samples	Comment
Firing Site	Surface (0-5 cm)	168	Gross α,β	168	One sample at each point of grid
			Radiochemical	13	Random selection
				5	Discrete selection
	Core (0-30 cm)	168	Gross α,β	168	One sample at each point of grid
			Radiochemical	14	Random selection
				0	Discrete selection
	Profile (0-30 cm)	8	Gross α,β	4×8	Random selection
			Radiochemical	4×8	Random selection
Canyon Floor	Surface (0-5 cm)	41	Gross α,β	41	One sample at each point of grid
			Radiochemical	0	Random selection
				6	Discrete selection
	Core (0-30 cm)	41	Gross α,β	41	One sample at each point of grid
			Radiochemical	0	Random selection
				5	Discrete selection
	Profile (0-30 cm)	4	Gross α,β	4×4	Random selection
			Radiochemical	4×4	Random selection
Natural Drainage	Core (0-30 cm)	17	Gross α,β	17	One sample at each point on grid
			Radiochemical	0	Random selection
				6	Discrete selection
	Profile (0-30 cm)	10	Gross α,β	4×10	Sample each grid point
			Radiochemical	4×4	Random selection
				4×6	Discrete selection
Structures	Cores (0-30 cm)	18	Gross α,β	18	Perimeter of TA-10-1
			Radiochemical	18	Perimeter of TA-10-1
	Profiles (0-30 cm)	7	Gross α,β	4×7	Composites of building corners; 6 buildings
			Radiochemical	4×7	
	Trench grab (0-122 cm)	68	Gross α,β	68	3.048 m increments of sanitary and acid waste lines
			Radiochemical	8	Expected contamination
	Auger (>122 cm)	290	Gross α,β	290	Waste pits and leaching field
			Radiochemical	60	Expected contamination

IV. RESULTS

A. Radioactivity in Soil

A review of Section II.A, Site History and Operation, indicates three potential contaminants—^{90}Sr, uranium (depleted and natural), and fuel grade plutonium. *In-situ* instrument surveys with the micro R meter and the HPIC (described in Appendix B) indicated no anomalous increases in gamma activity on either the firing site grids or the canyon floor grids. Similar survey with the phoswich (also described in Appendix B) indicated no anomalous increases in 17 keV x-ray activity on the east side of the firing site grid nor on the east side of the canyon floor. A review of radiochemical data from 1973 and 1977 shows no plutonium concentrations as great as the EPA screening limit of 0.2 μCi/m^2.* Potentially significant contaminants are therefore ^{90}Sr and uranium.

Strontium-90 and total uranium would have been expected in Bayo Canyon even if Bayo Site had never operated because (1) atmospheric weapons testing by many nations has distributed ^{90}Sr to both atmosphere and soil on a worldwide scale, and (2) uranium is one of several natural radionuclides that are present in all terrestrial matter. Strontium from weapons testing is called "fallout ^{90}Sr" and naturally-occurring uranium is referred to as "primordial uranium" to distinguish them from Bayo operations debris. Site specific measurements of these nuclides were not made at Bayo Site prior to their operational introduction shortly after 1943. Consequently, estimates of fallout ^{90}Sr and primordial uranium were made on the basis of a literature review and observations from the current resurvey effort. See Appendix E for details. Estimates of soil concentrations in pertinent soil layers are provided in Table IV.

Results from some 1973 data for Bayo Site indicated that no elevated levels of ^{90}Sr were present in stream channel alluvium 2 km downstream from the firing sites. The 1973 data showed a rather uniform level of gross-beta activity in the 0-5 cm layer at 2 km upstream from the firing site and at the firing sites. However, gross-beta activity below 30 cm from augered samples taken in the vicinity of old waste pits averaged an order of magnitude higher than gross-beta activity in the 0-5 cm layer at either the firing sites or 2 km upstream. These results prompted some additional investigation of subsurface activity near the acid waste disposal system and the waste pits in 1974. The 1974 results are summarized by the statistics presented in Table V.

Most of the individual results are less than 10 pCi/g. This is presumed to be background beta activity from primordial radionuclides (and in the upper 30 cm from fallout as well). The large standard deviations reflect a small number of samples with a few significant deviations above the norm. Most of the deviate values are associated with auger samples from an auger hole located a few meters north of former waste pit 42. Locations are diagrammed in Appendix A. Gross beta maxima of 24 000 pCi/g and 4400 pCi/g occurred at 430 cm to 500 cm and at 244 cm, respectively.

Results from the 1977 resurvey are summarized through the statistics presented in Tables VI and VII. The statistics are arranged by strata described in Section 3, Methods. The surface layer, including stream channels, bounded by the outside perimeter of the firing site stratum and the canyon floor strata, was sampled randomly to provide an unbiased estimate of ^{90}Sr and uranium concentrations. Resulting statistics are presented, together with the wider range of sample results, which occurred when gross beta analysis of non-randomly selected samples were included in the data set. Additional statistics are provided from the non-random sampling of the natural drainage stratum and the structures stratum.

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*Only one of 106 samples was over 100 fCi/g; most were about 20 fCi/g— a distribution that would be expected at Los Alamos from worldwide fallout.[24]

The mean ^{90}Sr concentration in the 0-5 cm layer (1.4 pCi/g) representing an area of approximately 1.37×10^6 m^2 around the firing pads shows that the remaining contribution attributable to test operations (1.0 pCi/g) is two or three times the average local value for worldwide fallout (0.40 pCi/g). The highest value encountered was an isolated patch of activity at sampling location EB-3 a few meters south and east of former waste pit TA-10-48. This concentration (132 pCi/g) is about 330 times as great as the local value for worldwide fallout. However, another portion of the same sample, an adjacent core sample, and several supplementary samples taken within two meters showed only normal levels of activity.

Reliable estimates of local fallout concentrations in the 0-10 cm and the 0-30 cm layers are not available. The statistical uncertainty in analyses from the random sample profiles and from additional natural drainage profiles masks the expected decrease in concentration with depth. Corresponding data from the structures grids is less certain because the soils in the east grid where the structures were located were extensively mixed during decommissioning. Moreover, the selection of sampling sites was based on former structural locations—a selection that undoubtedly biased the results toward higher levels of activity.

Even considering the uncertainty in the data, it is evident that the results are consistent with some debris deposition superimposed on the background estimates given in Table IV.

B. Radioactivity in Air

Atmospheric concentrations of fallout ^{90}Sr and primordial uranium were estimated from regional and local samples, respectively, collected from the LASL air surveillance net. These background values were used as a basis for comparison of ^{90}Sr and U results from air samplers located adjacent to Bayo Canyon. One sampler is roughly 3 m above the canyon floor at the confluence of Pueblo and Bayo Canyons about 1.2 km east of Bayo Site. It would indicate any significant airborne activity resuspended from Bayo Canyon. The other two samplers are located roughly 6 m above the mesa top—one a few hundred meters north of the west end of Bayo Canyon, the other a few hundred meters southwest of the west end of Bayo Canyon. These samples would indicate any significant activity in the Los Alamos townsite due to airborne activity generated in Bayo Canyon.

Fallout ^{90}Sr samples were collected during the fourth quarter of 1976 from three regional stations located between 28 and 44 km east of Bayo Canyon. The fourth quarter 1976 results from both the canyon floor and the mesa top compare well with (1) the regional results, and (2) the results reported for other North American locations during the fourth quarter of 1975.* All three sets of results are presented in Table VIII for comparison. The concentration of ^{90}Sr activity in air around Bayo Canyon is statistically indistinguishable from the concentration expected regionally from fallout ^{90}Sr.

Primordial uranium in soil varies quite markedly in North Central New Mexico in relation to the varied geology of the region. Consequently, background samples were limited to perimeter samples of the routine LASL air surveillance net. Eighteen perimeter stations are located on the volcanic tuff of the Pajarito Plateau and would be expected to be more representative of local conditions than regional results taken in the Rio Grande Valley. Three of these perimeter stations are those used to monitor Bayo Canyon during the current resurvey. Samples were collected quarterly for uranium analysis and the results were averaged for the year. The results are presented in Table IX, which are taken from Table XI of Ref 24.

The concentration of uranium in air around Bayo Canyon is statistically indistinguishable from the concentration expected locally from primordial uranium.

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*The DOE Environmental Measurements Lab (HASL) discontinued ^{90}Sr analyses after 1975.

C. External Penetrating Radiation

Surveys of Bayo Site were taken with both an RS-111 ion chamber and by a survey van equipped with a GeLi detector. (The van and its crew were obtained under contract from the Lawrence Livermore Laboratory.) Exposure rates were taken at 1 m above the ground. Contributions to the gross exposure rate from Bayo debris were estimated from the net concentrations of ^{90}Y and total uranium in the 0-30 cm layer of soil. Strontium-90—a pure beta emitter—contributes no significant penetrating radiation. Its concentration in the 0-30 cm layer is 0.66 pCi/g. Yttrium-90, the decay product of strontium, is in secular equilibrium with ^{90}Sr and is therefore of equal concentration. Yttrium-90 does emit an energetic gamma ray, but the gamma ray abundance is low. The difference between estimated ^{90}Sr fallout (0.2 pCi/g) and total observed ^{90}Sr in the 0-30 cm layer (0.7 pCi/g) is the amount interpreted to be attributable to Bayo debris (0.5 pCi/g). The total uranium concentration at 0-30 cm is 4.3 μg/g, whereas primordial uranium is estimated to be 3.4 μg/g. The concentration of uranium attributable to Bayo debris is 0.9 μg/g. Measured exposure rates are compared against the calculated contribution from Bayo debris in Table X.

TABLE IV

FALLOUT ^{90}Sr AND PRIMORDIAL URANIUM IN BAYO CANYON SOIL[a]

Depth (cm)	^{90}Sr (pCi/g)	^{90}Sr Bases	Primordial U (μg/g)	Primordial U Bases
0 - 5	0.36	Refs 25,26,27 direct measurements	3.39	Refs 22,28 direct measurements
0 - 10	0.32	average of current data and interpolation from current data	3.39	average of current data and interpolation from current data
0 - 30	0.24	extrapolation from current data	3.39	Refs 22,28 direct measurements
0 - 122	<0.1	extrapolation from current data	5.50	extrapolation from current data and Ref 28
122 - 244	<0.1	extrapolation from current data	8.50	Ref 28
>244	<0.1	extrapolation from current data	8.50	Ref 29

[a]See Appendix F

TABLE V

GROSS-BETA ACTIVITY IN SUBSURFACE SOIL NEAR THE ACID WASTE DISPOSAL FACILITIES IN BAYO CANYON

Depth (cm)	Range (pCi/g)	$\bar{X} \pm \sigma$ (pCi/g)	Number of Samples
0 - 122	3 - 186	32 ± 42	20
122 - 244	1 - 4400	116 ± 332	37
>244	0.2 - 24 000	635 ± 1879	76

TABLE VI

^{90}Sr IN SOIL (pCi/g)

Strata: Firing Sites, Canyon Floor, and Natural Drainage

Depth (cm)	Random Samples			All Samples Analyzed	
	Range	$\bar{X} \pm \sigma$	No.	Range	No.
0 - 5	0.0 - 8.2	1.4 ± 1.9	29	0.0 - 132.0	43
0 - 10	0.1 - 5.5	0.9 ± 1.4	16	---	---
0 - 30	0.2 - 4.0	0.7 ± 0.9	30	0.1 - 23.2	37

Strata: Natural Drainage

	All Samples Analyzed		
0 - 5	0.0 - 8.2	2.2 ± 4.0	4
0 - 10	0.1 - 5.5	1.5 ± 2.6	4
0 - 30	0.2 - 4.0	1.3 ± 1.8	4

Strata: Structures

	All Samples Analyzed		
0 - 5	0.5 - 5.4	2.1 ± 1.7	7
0 - 10	0.3 - 4.7	2.2 ± 1.5	7
0 - 30	0.3 - 6.9	2.4 ± 1.5	30
0 - 122	0.1 - 67.2	10.3 ± 19.3	12

TABLE VII

URANIUM IN SOIL
(μg/g)

Strata: Firing Sites, Canyon Floor, and Natural Drainage

Depth (cm)	Random Samples			All Samples Analyzed	
	Range	$\bar{X} \pm \sigma$	No.	Range	No.
0 - 5	0.5 - 12.0	4.9 ± 2.5	29	0.5 - 12.0	43
0 - 10	1.8 - 9.0	3.6 ± 1.7	16	---	---
0 - 30	1.6 - 12.0	4.3 ± 2.1	30	1.5 - 12.0	63

Strata: Natural Drainage

	All Samples Analyzed		
0 - 5	2.1 - 7.6	4.2 ± 2.5	4
0 - 10	2.0 - 5.0	3.3 ± 1.4	4
0 - 30	1.6 - 3.6	2.6 ± 1.0	4

Strata: Structures

	All Samples Analyzed		
0 - 5	1.3 - 3.2	2.1 ± 0.6	7
0 - 10	1.4 - 2.9	2.0 ± 0.5	7
0 - 30	1.6 - 50	5.7 ± 8.7	30

TABLE VIII

COMPARISON OF ^{90}Sr IN SURFACE AIR
(fCi/m^3)

	Range	$\bar{X} \pm \sigma$	No.
Moosonee, Ontario	0.09-0.15	0.13±0.03	3[a]
Helena, Montana	0.17-0.18	0.18±0.01	3[a]
New York, New York	0.19-0.24	0.21±0.03	3[a]
Rocky Flats, Colorado	0.14-0.27	0.21±0.04	6[a]
Richmond, California	0.14-0.22	0.19±0.04	3[a]
Group Summary	0.09-0.27	0.18±0.07	18.
Española, New Mexico		0.17	1[b]
Pojoaque, New Mexico		0.14	1[b]
Santa Fe, New Mexico		0.14	1[b]
Group Summary		0.15±0.02	3
Bayo Canyon Floor		0.13	1[b]
Mesa Top (townsite)		0.09	1[b]
Group Summary		0.11 ±0.03	2

[a]EML-339 Department of Energy, Environmental Measurements Laboratory, 4th Quarter 1975.
[b]Los Alamos Scientific Laboratory Surveillance Net, 4th Quarter 1976.

TABLE IX

COMPARISON OF TOTAL URANIUM IN SURFACE AIR
(pg/m³)

Station Location	Range	$\bar{X} \pm \sigma$	No. of 12-14 Wk Samples
Perimeter Stations (0-4 km)			
Arkansas Avenue	27 - 105	66 ± 4	4
Golf Course	40 - 64	54 ± 3	4
Diamond Drive	50 - 179	111 ± 6	3
48th Street	39 - 63	53 ± 4	4
Fuller Lodge	64 - 109	80 ± 6	4
LA Airport	40 - 68	49 ± 4	4
Gulf Station	51 - 102	72 ± 4	3
Acorn Street	9 - 134	75 ± 4	4
Royal Crest	−7 - 35	23 ± 4	2
White Rock S.T.P.	47 - 77	56 ± 2	4
Pajarito Acres	32 - 56	45 ± 3	4
Bandelier	24 - 55	34 ± 4	4
Group Summary	7 - 179	59 ± 14	44
Bayo Canyon Stations			
Canyon Floor	37 - 61	45 ± 5	4
Mesa Top (townsite) 1	2 - 134	67 ± 6	3
Mesa Top (townsite) 2	4 - 77	43 ± 4	3
Group Summary	2 - 134	52 ± 9	10

TABLE X

EXTERNAL EXPOSURE
(μR/hr)

Measured Total Exposure Rates		
Background	**Ion Chamber**	**GeLi**
Mesa Top (1.61 km SW of Bayo Site)	22.9	23.9
Mesa Top (3.22 km W of Bayo Site)	19.1	20.4

	Ion Chamber			GeLi		
Bayo Site	**Range**	**$\bar{X} \pm \sigma$**	**No.**	**Range**	**$\bar{X} \pm \sigma$**	**No.**
Canyon Floor	17.7-24.3	20.6 ± 1.6	45	20.6-26.1	22.6 ± 2.5	4
Talus Slope	19.3-26.1	23.2 ± 1.6	21	---	---	---
Mesa Top	17.8-20.3	19.1 ± 0.9	12	---	---	---
Group Summary	17.7-26.1	21.0 ± 2.1	3			

	Calculated Exposure Rates[a] Attributable to Bayo Debris	
Debris Contribution	^{90}Sr-^{90}Y	4.1×10^{-3}
	Total Uranium	4.3×10^{-1}

[a]DOE 77-24, Table B-8.

V. EVALUATION

A. Potential For Exposure

The potential for exposure to residual radioactivity from Bayo Site operations depends in large degree on the uses of the land. Two principal uses must be considered:

1. Undeveloped County land open to recreational use (status quo), and

2. Development as a residential area for as many as 400 homes.

Both of these cases have been evaluated in terms of potential exposures to radioactivity and the resulting doses to individuals or to the general public.

The worst case evaluations for maximum individual exposures under these hypothetical conditions were calculated as 50 yr dose commitments, which represent the dose accumulated over 50 yr from exposure to radioactive material in the first year. Only several radionuclides are capable of irradiating an individual for years after exposure to that radionuclide. This occurs when these long-lived radioactive materials are inhaled or ingested and are incorporated into body tissues where they remain, such as incorporation of ^{90}Sr into bone. These dose commitments are compared to the current DOE Radiation Protection Standards for annual doses to individuals in the general public and to average annual doses of radiation received from natural radiation in the area. Comparing 50 yr dose commitments to annual exposure guidelines is considered conservative because the actual dose received in any one year from a radioisotope capable of irradiating the individual for years after exposure is considerably less than the 50 yr dose commitment.

1. Undeveloped Land. If Bayo Canyon remains in its current undeveloped state, the potentially exposed groups in the general public are (1) the occasional recreational users of the canyon and (2) the residents in Los Alamos townsite who live on mesas adjacent to Bayo Canyon (see Fig. A1, Appendix A).

The occasional recreational users who venture into Bayo Canyon for such activities as hiking, picnicking, and trail riding could be exposed to increments of external penetrating radiation or to increments of airborne contamination above natural background because of residual surface contamination from strontium and uranium. These users typically are present in the canyon for only a few hours at a time on an infrequent basis. Thus, potential exposures to such users would be considerably less than those that could be received by permanent residents should Bayo Canyon be developed. Los Alamos residents on the mesas above Bayo Site could be exposed to any increments of airborne contamination resuspended from Bayo Canyon floor. Since measurements of airborne radioactivity due to ^{90}Sr and U showed no elevation in the vicinity of Bayo Canyon, there is no increment of dose to present mesa residents attributable to residuals of Bayo operations.

2. Developed Land. If Bayo Canyon is developed for residential and light commerical use, the potentially exposed groups in the general public are (1) residents, (2) construction personnel, and (3) persons employed in the commerical establishments. These exposures are typically chronic exposures rather than occasional exposures common to recreational use. Residents and employees other than the construction workers will be present in the canyon eight or more hours a day for fifty weeks or more per year and possibly for many years. Construction workers will be present for perhaps eight years during development.

B. External Penetrating Dose

Most of Bayo Canyon, including the portion used or affected by experimental operations, has a higher natural background of external penetrating radiation than typical in the townsite areas of Los Alamos or White Rock, or on mesa tops. This is due in part to higher concentrations of naturally occurring radionuclides in the geologic formations surrounding the former operations site. It is also due in part to differences in the geometry of the canyon situation whereby radiation is received from the canyon walls as well as the floor. The available data, discussed in Sec. IV.C, indicate that average penetrating radiation in the canyon bottom is 21 ± 2 μR/h with somewhat higher values observed on the talus slopes. Table X summarizes the penetrating radiation data for the canyon and highlights the data from the area likely to have been affected by experimental operations. The level of external penetrating radiation at the operational area does not show a statistically significant, instrumentally measurable difference from other parts of the canyon. The canyon as a whole exhibits levels about 13% greater than observed in the townsite areas (see Tables X and D-XXXIII). Theoretical estimates can be made of penetrating radiation caused by strontium and uranium debris deposited on soil in the old operational areas. Table X shows that the increments of exposure rate attributable to the residual contaminants are less than the spatial and temporal variation in natural background. The dosimetric consequences of external exposure from the experimental debris remaining in Bayo Canyon are shown in Table XI.

The largest incremental contribution to penetrating dose attributable to the former Bayo Site is from residual uranium debris. The contribution is about 0.2% of the penetrating dose that would be received by residents in the area had Bayo Site never existed.

C. Dose From Internal Emitters

Bayo Canyon soil is a reservoir that could permit some radioactivity to make its way through various pathways to human tissues. The difference between the mean soil concentration of either ^{90}Sr or uranium and fallout strontium or primordial uranium, respectively, gives the expected mean concentrations of Bayo debris used in this evaluation. The values used are shown in Table XII. The values for debris in the surface layers 0-5 cm, 0-10 cm, and 0-30 cm are representative of the area within a 450 meter radius of the firing sites' center and of the canyon floor from 900 m upstream beyond the firing sites' center to 850 m downstream. The values for debris in the 0-122 cm layer, however, are only representative for an area 1×10^4 m^2 surrounding the laboratory building, its associated waste disposal facilities, and its contaminated storage buildings. The maximum gross beta value at or above 244 cm is 4400 pCi/g at 244 cm.

These values were used to make exposure evaluations in relation to potential human interaction with each soil layer. All ^{90}Sr values are presumed to be associated with ^{90}Y in secular equilibrium. The gross beta value at 244 cm is presumed to be a secular equilibrium mixture of ^{90}Sr and ^{90}Y. No likely exposure scenario was considered to be associated with the single maximum sample showing 24 000 pCi/g gross-β at a depth of 4.3 to 5 m.

Dose assessments were obtained by applying appropriate dose factors (see Table E-IV, Appendix E) to the uptake quantities indicated by critical pathway analysis. The dose factors used in the assessment yield the 50 yr dose commitment.

1. General Resuspension; 0-5 cm Layer of Soil. Residents of Bayo Canyon would be exposed to Bayo debris resuspended from the ground surface by air currents. Air activity concentration estimates based on a resuspension factor of 1×10^{-9} m^{-1} (Ref. 30) and a breathing rate of 8000 m^3/yr (Ref. 31) are presented in Table XIII for comparison with current air concentration standards. Fifty year dose commitments are shown in Table XIV.

2. Homegrown Produce; 0-10 cm Layer of Soil.
Estimates of internal dose from consumption of produce grown in Bayo Canyon gardens is based on a generous (25%) fraction of U. S. average dietary intake for homegrown produce (from page 349 of Ref. 31). The 25% fraction is based on an interview with an avid local vegetable gardner and on professional judgement. The assumption is in agreement with the maximum individual basis of this dose assessment. Dose estimates for the ingestion pathway indicate that the worst case 50 yr dose commitment (bone) is about 3.1% of the DOE Manual Chapter 0524 guidelines for annual dose.

3. Light Construction-Shallow Excavations; 0-30 cm Layer of Soil.
General exposure of construction crews to Bayo debris would be expected during construction, which could last several years. Exposure would come from aerosols generated by excavation work. Since surface deposited Bayo debris is most prevalent in the top 30 cm, it would be disturbed by essentially all excavation work. A higher breathing rate from relatively demanding physical work (43 ℓ/min) was applied to an annual exposure time of 1000 h (1/2 of 50 wk at 40 h per week) for this estimate.

The dust loading for construction activities was set at 10 mg/m^3, which is the threshold limit value for nuisance dusts in workroom air as set by the American Conference of Governmental Industrial Hygienists (ACGIH).[32] Dust loadings >10 mg/m^3 are possible, but it is doubtful that any long term exposure would occur at >10 mg/m^3 because "excessive concentrations of nuisance dusts may seriously reduce visibility, may cause unpleasant deposits in the eyes, ears, and nasal passages....".[32] A value for the corresponding radioactivity in air was calculated from concentrations of radioactivity in soil from the areas of concern. Calculations indicate that the dose to the lung would be the most significant and that the 50 yr dose commitment would be less than 0.03% of current DOE guidelines for the annual dose.

4. Light Construction-Foundations and Utilities; 0-122 cm Layer of Soil. This mode of exposure was assumed to involve construction personnel working in excavations 122 cm (~4 ft) deep. The concentration of uranium debris is negligible while concentrations of ^{90}Sr are assumed to average 17 pCi/g. The area potentially involved is restricted to that which could have been affected by subsurface deposition, i.e., within about 10 m of TA-10-1 and its waste handling facilities or within an area of about 10^4 m^2 (see Fig. 16). The limited area of interest places a corresponding limit on the amount of time spent installing utilities. The exposure scenario is described in Appendix E. Other assumptions are the same as those used for excavation in the 0-30 cm layer. Estimates indicate that dose to the bone would be the most significant. The 50 yr dose commitment would be about 0.1% of the current DOE guidelines for annual dose.

5. Light Construction-Sewer Line Installation; 122-244 cm Layer of Soil. This case was assumed to involve construction personnel working in ditches 244 cm (8 ft) deep. The land area of potential concern is the same as that described for the 30-122 cm layer of soil. In this case, the concentration of uranium debris is again negligible and the concentration of ^{90}Sr debris is assumed to be 1100 pCi/g. Moreover, the breathing zone is within 60 cm of the contaminated trench wall resulting in much less dilution of the aerosols generated in the trench. Aerosols would be generated by personnel brushing against the trench wall or bumping joints of sewer pipe against the wall. The duration of exposure is 60 h at a breathing rate of 43 ℓ/min. The 50 yr dose commitment to the bone is estimated to be about 1.4% of the current DOE guidelines for annual dose. Table XIV summarizes the dose estimates and compares them against current DOE guidelines and against natural sources of penetrating radiation in Bayo Canyon.

TABLE XI

EXTERNAL RADIATION
ANNUAL DOSE LIMITS VS ANNUAL EXPOSURE[a]
(mrem/yr)

Critical Organ	Background Dose Public Exposure		Dose Limit for Public[b] Above Background		Bayo Debris Dose Maximum Individual		
	Maximum[c] Individual	General[d] Public	Maximum Individual	General Public	Dose	% of Genl Pub Dose from Bkg	% of Genl Pub Dose Permitted
Whole Body	231	181±13.8	500	170	0.43	0.24	0.25
Gonads	231	181±13.8	---	170	0.43	0.24	0.25

[a]Exposure estimated for hypothetical population in continuous residence in Bayo Canyon.
[b]*Basic Radiation Protection Criteria*, National Council on Radiation Protection and Measurements.
[c]Based on the average of a group of rock samples taken from cliffs east of Bayo Site. K in K_2O was 2.9 wt% of rock, U was 8.4 μg/g of rock, and ^{232}Th was 28.3 μg/g of rock. Exposure rate including fallout and cosmic contribution was 26.4 μR/h.
[d]Based on 20.6±1.5 μR/h from 45 measurements on the canyon floor by HPIC.

TABLE XII

CONCENTRATIONS OF BAYO DEBRIS IN SOIL

Depth	^{90}Sr (pCi/g)			U (μg/g)		
	Mean	Fallout	Debris	Mean	Primordial	Debris
0 - 5 cm[a]	1.4	0.4	1.0	4.9	3.4	1.6
0 - 10 cm[a]	0.9	0.3	0.6	3.6	3.4	0.2
0 - 30 cm[a]	0.7	0.2	0.5	4.3	3.4	0.9
0 - 122 cm[b]	10.3	<0.1	10.3			

[a]General Bayo Site.
[b]Limited to approximately 90 m square area around disposal pits.

TABLE XIII

ESTIMATES OF AIRBORNE ACTIVITY DUE TO RESUSPENSION OF SURFACE AND BAYO DEBRIS AND RADIOACTIVITY CONCENTRATION
(μCi/ml)

Isotope	Annual Limits [a] Air Activity[b] Continuous Exposure[c]—Public		Annual Estimates Air[b] Activity Continuous Exposure[c] Bayo Resuspension
	Maximum Individual	General Population	
Soluble			
^{90}Sr	3×10^{-11}	1×10^{-11}	1×10^{-17}
^{90}Y	4×10^{-9}	1×10^{-9}	1×10^{-17}
U	3×10^{-12}	1×10^{-12}	8×10^{-16}
Insoluble			
^{90}Sr	2×10^{-10}	7×10^{-11}	1×10^{-17}
^{90}Y	3×10^{-9}	1×10^{-9}	1×10^{-17}
U	2×10^{-12}	7×10^{-13}	8×10^{-16}

[a]DOE Manual Chapter 0524.
[b]"Air activity" as used here means the average annual concentration in air.
[c]"Continuous Exposure" as used here means 8766 hours per year.

TABLE XIV

DOSE EVALUATION

Type of Dose	Contributing Soil Depth (cm)	50 yr Dose Commitment[a] (mrem) Whole Body	Bone	Lung	Kidney
Permanent Residents[b]					
General Resuspension	0-5	6.9×10^{-4}	1.1×10^{-2}	2.2×10^{-2}	1×10^{-3}
Garden Produce	0-10	1.14×10^{1}	4.56×10^{1}	na	2.1×10^{-3}
External Dose[c]	0-30	4.3×10^{-1}	4.3×10^{-1}	4.3×10^{-1}	4.3×10^{-1}
Integrated Dose[d]		1.18×10^{1}	4.6×10^{1}	4.3×10^{-1}	4.3×10^{-1}
Construction Workers[e]					
Excavation,landscaping	0-30	5.7×10^{-3}	9.5×10^{-2}	4.1×10^{-1}	2.0×10^{-2}
Foundations,utilities	0-122	1.2×10^{-1}	1.9×10^{0}	1.9×10^{-1}	0
Sewer installation	122-244	1.3×10^{0}	2.1×10^{1}	2.1×10^{0}	0
External Dose[f]	0-30	9.8×10^{-2}	9.8×10^{-2}	9.8×10^{-2}	9.8×10^{-2}
Integrated Dose[d] (worst case)		1.5×10^{0}	23.1×10^{0}	2.8×10^{0}	1.2×10^{-1}
0524 Guideline[g] (year of exposure)		5.0×10^{2}	1.5×10^{3}	1.5×10^{3}	1.5×10^{3}
% of Guideline (worst case)		2.4×10^{0}	3.1×10^{0}	1.9×10^{-1}	2.9×10^{-2}
% of Background[h] (worst case)		6.5×10^{0}	2.5×10^{1}	1.5×10^{0}	2.4×10^{-1}

[a]That dose accumulated over fifty years as a result of exposure to radioactive material during the first year of exposure.

[b]Hypothetical residents of Bayo Canyon assuming development occurs.

[c]Based on 8766 hours per year exposure (resident).

[d]Summation of internal plus external doses. For construction workers this includes total of excavation plus either foundation work or sewer work.

[e]Hypothetical construction workers in Bayo Canyon assuming development occurs.

[f]Based on 2000 hours per year exposure (construction workers).

[g]DOE Manual Chapter 0524, Appendix 0524, Part III, Radiation Protection Standards for the annual dose to the maximum individual from chronic exposure for the year of exposure.

[h]Penetrating components of background radiation based on 181 mrem/yr.

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APPENDIX A

GEOHYDROLOGY OF BAYO SITE, 1956-1974

by

William D. Purtymun

I. INTRODUCTION

Bayo Site was located in the upper-reach of Bayo Canyon. The Canyon heads on the Pajarito Plateau and is tributary to the lower reach of Los Alamos Canyon, which in turn drains into the Rio Grande (Fig. A-1). The canyon is cut into the Bandelier Tuff at Bayo Site (Figs. A-2 and A-3). The tuff is composed of three members, rhyolitic in composition, which, in ascending order, are the Guaje, Otowi, and Tshirege Members. The lower Guaje Member is a pumice fall consisting of lump pumice about 9 m thick. It is overlain by the Otowi Member, a massive ashfall and ashflow of nonwelded tuff. The member is about 42 m thick in the area. The upper Tshirege Member is composed of a series of ashfalls and ashflows of nonwelded to moderately welded tuff. The thickness in the area is about 60 m.

Bayo Site sits on the lower part of the Otowi Member that forms the floor of the canyon and slope of the canyon walls. The Tshirege Member forms the near-vertical to vertical wall of the canyon.

Further downstream Bayo Canyon cuts through the Puye Formation. The Puye Formation overlies the Tesuque Formation. The lower member of the Puye is composed of granite debris deposited as river channel material. It is a poorly consolidated sand, gravel, cobble, and boulder deposit that is about 15 m thick near the mouth of Bayo Canyon. In this area the gravels are excavated and used for construction purposes.

The upper member of the Puye Formation is made up of volcanic debris derived and deposited from volcanic terrain to the west. The member is a fanglomerate with lenses of ash and pumice. The fanglomerate is composed of latite, rhyolite, dacite, and quartzite boulders in a matrix of volcanic sand and gravels. The thickness of the unit in upper Bayo Canyon is estimated at about 200 m based on a test well (T-2) in the canyon to the south. The Puye Formation in the midreach of the canyon is interbedded with the basaltic rocks of Chino Mesa. One of these basalts outcrops in the canyon about 4000 m east of the site (Fig. A-3).

The Tesuque Formation is composed of arkosic siltstones, silty sandstones, and sandstones with occasional lenses of clay and pebbly conglomerate (Fig. A-2). The formation dips gently to the west near the mouth of Bayo Canyon.[A1] Its thickness exceeds 800 m in the area.

Soil has developed along the canyon floor and south wall of the canyon from weathering of the tuff. In general, it is a sandy soil that has poorly developed. The alluvium in the vicinity of the site is derived from weathering and erosion of the tuff. The alluvium is mainly sands and gravels with few cobbles or boulders. In the reach of the canyon below the site where the channel cuts into the Puye Formation, the cobble to boulder size materials increase, forming a large percent of the bed sediments.

The stream flow in the canyon is intermittent, with the largest percentage of runoff occurring during the summer from heavy thunderstorms. The runoff is generally of short duration over a period of several hours. There are no gaging stations in the canyon. No measurements have been made to determine the maximum discharge of this intermittent runoff. Theoretical maximum discharges at the Department of Energy (DOE) boundary were calculated for various flood-frequencies, by a method devised by Scott.[A2] The values were derived from nomographs using

climatic data appropriate to Los Alamos. The drainage area is 9.8 km^2 within the DOE Reservation and the channel has an average slope of 0.03. Maximum discharge for a 2-yr recurrence interval is 2.4 m^3/s; 5-yr interval is 6.1 m^3/s; 10-yr interval is 8.5 m^3/s; 25-yr interval is 17 m^3/s; and 50-yr interval is 19 m^3/s. Recurrence intervals can be interpreted as probabilities, e.g., a 2 yr recurrence interval signifies a 1 in 2 chance or probability of 0.5.

The intermittent runoff is the major transport media for radionuclide contaminants in the canyon area. The radionuclides are adsorbed or exchanged with ions in channel sediments or soil and are transported as suspended or bed sediments in the runoff.[A3,A4] A very minor amount of the radionuclides in the canyon area may be redissolved and transported in solution.[A5]

Three test holes were drilled in Bayo Site in 1961 to determine if water occurred in the alluvium or in the tuff at the Puye Formation contact. The test holes were dry with no indication of water in the alluvium of the channel or perched in the tuff above the fanglomerate of the Puye Formation.

There are no deep test holes penetrating into the top of the main aquifer at Bayo Site, thus, nothing is known of possible perched water in the Puye Formation and associated basaltic rocks of Chino Mesa. However, the data from the shallow holes and knowledge of the geology from deep test holes in adjacent canyons suggests there is no likely hydrologic connection with any surface water in Bayo Canyon and the main aquifer. The top of the main aquifer, an aquifer capable of municipal and industrial supply, lies about 240 m below land surface at Bayo Site in the sediments of the Tesuque Formation. The aquifer slopes gently to the east at about 7.6 m/km. The recharge to the aquifer is from the Valles Caldera to the east with little recharge contributed from canyons cut into the Pajarito Plateau.[A6]

II. ENVIRONMENTAL STUDIES

Tests at Bayo Site were conducted using high explosives and radioactive materials. The inventory of radionuclides expended at the site with the tests included 1.355 Ci of natural uranium and 1.218 Ci of ^{238}U.[A7] In addition, unknown amount of ^{140}La and ^{90}Sr (see Appendix E for estimates) was released to the environment with the tests. The ^{90}Sr was a contaminant of the ^{140}La that was used as a tracer with the explosives. Some environmental data in the canyon have been collected as part of the routine monitoring effort. Several special studies were also made in the area to determine geohydrologic conditions. The available information is summarized in the following section.

A. U.S. Geological Survey, 1956

The U.S. Geological Survey, in conjunction with LASL, made a reconnaissance of Bayo Site in May 1956. The following excerpt describes the findings.[A8]

> "Lanthanum and strontium are known to contaminate the ground and stream bed in the area. The half-life of lanthanum is short and will constitute no future danger to water supply, but the half-life of strontium is long enough to warrant further investigations of ground water and surface water movement.
>
> Surface contaminants could be transported by runoff and floodflow, although floodflow may also transport some of the contaminated solid material from the streambed in Bayo Canyon. These contaminants, however, may actually move downstream in either Bayo Canyon or Pueblo Canyon, due to a possible hydraulic connection between these two canyons somewhere near Hamilton Bend spring or Otowi Seep in Pueblo Canyon. In fact, wastes from Bayo Canyon site have been treated with nitric acid before disposition and water samples from Hamilton Bend spring are often high in nitrate.

There are several possible sources of radioactive contamination in Bayo Canyon, drain water from the shot pad, buried laboratory wastes, and laboratory wastes that were spilled on the ground. Of these sources, the last is of least importance, as these areas are small and isolated.

The shot pad is washed down with water after each shot, the wash water draining toward the streambed. The pad and the ground and drainage ditches near the pad show high radioactivity, although the radioactivity drops off rapidly with increased distance from the pad. The path of movement away from the pad has not been determined.

When the Bayo Canyon laboratories were in operation, most laboratory wastes were either buried in stainless steel tanks or poured into concrete disposal pits. The wastes that were poured into the concrete pits drained through an outlet pipe in the bottom of the pits and out into the ground downgradient from the pits. The wastes stored in the stainless steel tanks were periodically blown from the tanks, with high air pressure, and discharged directly into the streambed. In addition to standard disposal methods, laboratory wastes were occasionally dropped or spilled on the ground in patches near the laboratory buildings.

Several preliminary inspections of the area were made by the Health Division of the University of California and the Geological Survey in an effort to determine the movement of radioactive material in the canyon and through the soil profile.

On July 23, 1956, Messrs. Kennedy and Christenson of the University of California laboratory and Messrs. Conover, Waldron, and Abrahams of the Geological Survey inspected the Bayo Canyon site. Several concrete disposal pits were located but the location of the buried stainless steel tanks, believed to contain radioactive material, was not determined. A series of soil samples was taken in the soil profile near the old laboratory. The counts of the samples near the surface were about 15,000 c/m/ℓ (sic), but decreased to about 200 to 300 counts at about the 3 foot depth.

On July 24, 1956, Messrs. Kennedy and Hutchinson of the University Laboratory, and Messrs. Waldron and Abrahams attempted to locate the outlets from the concrete disposal pits and from the stainless steel pits but no water or moist areas were evident downgradient from the pits. About 1000 gallons of water were pumped into the discharge pipe of the stainless steel tanks at about 250 pounds of pressure, bypassing the tanks, but the outlet near the stream was not found. An electrical resistence type pipe finder was used by the utility division of the Zia Company to aid in locating the outlet pipe but the results were indefinite, although probable locations of the stainless steel tanks were determined."

Further studies (1961, 1973, and 1974) have indicated that the movement of contaminants into Pueblo Canyon by groundwater from Bayo Canyon is very unlikely as shown by the absence of surface water and water in alluvium. The nitrates in water at Hamilton Bend Spring are from the sanitary wastes that are released into Pueblo Canyon.

B. Radiation Survey Land Parcel B, 1972

A radiation survey was made of the mesa south of Bayo Site in 1972 (Fig. A-4). The survey was made to determine the extent to which the land had been used in LASL activities.[A9] The area of the survey, land parcel B, was about 1.9 km.^{2} Radiochemical analyses were made for a number of different radionuclides in soil and vegetation samples collected from the mesa (Table A-I). The

measurements of gross beta, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am and total uranium in soil and vegetation from the mesa, in general, were similar to those concentrations measured at locations undisturbed by nuclear energy installations.[A9] The tritium concentrations in some cases were above regional background data. The background data on soil and vegetation as shown on the tables were collected in northern New Mexico.

C. Soil and Sediments

Two sediment sampling stations were established in the canyon in 1965 (Fig. 4). They are located near the midreach of the canyon (B-1) and the other about Bayo Canyon above the junction with Los Alamos Canyon (B-2). The sediments are derived from the Bandelier Tuff and Puye Formation; particle-size distribution indicates that silt and clays made up less than 3% of the bed sediments (Table A-II).

Radiochemical analyses were made of sediments from the two stations in 1965 and 1970.[A10] The activity was low and within the range that would be expected from worldwide fallout. There was no indication of contamination from the abandoned site in Bayo Canyon (Table A-III).

A number of samples were collected and analyzed for gross-alpha, gross-beta, ^{238}Pu and ^{239}Pu in a study in Bayo Canyon in 1973. Samples of bed sediments and bank soil were collected at four stations (Fig. A-4). Station A is located 2000 m west of Bayo Site, B at Bayo Site, and C and D 2000 and 4600 m east of the site, respectively.

Five bed sediment samples were collected at 20 and 200 m east and west of a center station (Table A-IV). Gross alpha and plutonium concentrations were about background level in Areas A and B. The plutonium results of composite soil and sediments are higher than expected and are probably the result of contamination in collection or analyses. Gross-beta concentrations at Areas A and B ranged from 19 to 38 pCi/g, which is about twice background for the area. There were no gross alpha and beta analyses at Areas C or D.

Four samples of soil were collected 20 and 200 m north and south of the center at Areas A and B. Gross-alpha and plutonium were about background for the area, while gross-beta was about twice to three times normal background. Gross-beta concentrations ranged from 26 to 41 pCi/g (Table A-IV).

The high gross-beta activity appears to be surface contamination of ^{90}Sr, which dispersed from the lanthanum source with the explosives. The gross-beta activity in bed sediments collected in 1973 was much higher than collected east of Bayo Site in 1965 and 1970. This is probably because of placement of sample locations. The 1973 locations were in the site itself.

D. Test Holes

Test holes were drilled in the Bayo Site area in 1961 to determine if water was perched at the base of Bandelier Tuff at the Puye Formation contact (Fig. A-5). The silty sandstones and clays of the Puye could form a perching layer for infiltration of water through the alluvium and tuff. Three of the holes penetrated into the top of the fanglomerate (Table A-V). There was no indication of perched water or any excessive moisture in the tuff above the fanglomerate.[A11] The small volumes of water used during the life of the site (water was hauled to storage tanks) and normal precipitation and runoff in the drainage area precluded any transport mechanism for contaminants to the top of the conglomerate. The major contaminant, ^{90}Sr, in effluent is also readily adsorbed or exchanged with chemical ions found in the alluvium or tuff.[A12]

During 1963, the waste disposal pit was cleaned out and contaminated wastes, soil, alluvium, and tuff removed to a depth of 7.9 m. The wastes and contaminated materials were hauled to TA-54. The concrete and stainless steel tanks were also removed to TA-54.

In 1973 three test holes (M-series) were drilled to collect samples for analyses at select depth intervals in the area of the waste pit and outfall from the two tanks (Fig. 5). Test hole M-1 (TA-10-48, removed) penetrated the fill and tuff to a depth of 12.2 m at the solid waste pit. The log of the hole indicated fill to a depth of 7.9 m (Table V), although a later engineering survey indicated the hole was about 6 m north of the pit location. Plutonium and ^{90}Sr analyses of cutting at select depths indicated only background concentrations (Table A-VI). A second hole drilled in 1974 to a depth of 3.6 m in the pit contained only background gross-alpha and -beta activity. Background plutonium concentrations in the area related to "fallout" for ^{238}Pu ranged from 0.000 to 0.004 pCi/g and for ^{239}Pu ranged from 0.000 to 0.020 pCi/g in 1970. Strontium 90 ranged from 0.07 to 0.87 pCi/g.[A13,A14]

Hole M-2 was drilled near the outfall of the stainless steel tank (TA-10-38, removed) to a depth of 6.1 m. Analyses of cuttings from the surface to 0.5 m indicated only background concentrations of plutonium, while ^{90}Sr was high at the same depth interval (Table A-VI). A second ^{90}Sr analysis at depths from 3.1 to 4.6 m was low but was still above background, showing some contamination at depth.

The third hole, M-3, was drilled at or near the location of the concrete tank (TA-10-50, removed). Three attempts were made in the area as the hole encountered blocks of concrete. The drilling only reached a depth of 2.4 m (Table A-VI). Analyses of cuttings from the hole from the surface to 1.5 m contained only background concentrations of plutonium, while the same cuttings contained ^{90}Sr in excess of background (Table A-VI). The location of holes drilled in 1973 may have missed the exact location of the tanks; however, ^{90}Sr in the general area was above background indicating the presence of contaminants.

In 1974 12 test holes were drilled in the outfall area of the stainless steel and concrete tank. The holes were located around M-2 (stainless steel tank) and M-3 (concrete tank) as shown in Fig. A-5. The layout of the holes is shown in Fig. A-6.

The gross-alpha activity in the test holes around M-2 and M-3 was near background except for hole W-6 near test hole M-3 (Table A-VII). The samples from 2.3 to 3.1 m and from 4.6 to 7.6 m at test hole W-6 ranged from four to ten times background, indicating some infiltration and movement of contamination from the concrete tank.

Gross-beta activity in holes E-1, E-2, E-3, E-4, and E-5, near test hole M-2 (stainless steel tank) was above background from the surface to a depth of 2.3 m (Table A-VIII). Gross beta activity samples from Hole E-5 were above background to a depth of 10.7 m.

The gross-beta activity near test hole M-3 (concrete tank) at hole W-2 from surface to 1.5 m, at hole W-3 from the surface to 6.1 m, hole W-4 from 0.8 to 1.5 m, and hole W-5 from 1.5 to 2.3 m were significantly above background to indicate some movement of contaminants into those depth intervals. The gross-beta activity in all samples from hole W-6 was above background. The highest gross-beta activity occurred in samples from 2.3 to 10.7 m in the area of high gross alpha. The gross beta in this interval ranged from 1500 to 24 000 pCi/g indicating a large amount of contamination from the concrete tank.

III. SUMMARY

The main transport of contaminants in the hydrologic cycle is with storm runoff. The stream flow in the canyon is intermittent. The runoff volume is so low that there is no apparent water in the alluvium. The intermittent runoff is not a source of recharge to the main aquifer.

The bulk of the contaminants released to the environment in the canyon was natural U, ^{238}U and ^{90}Sr. The surface type of testing has dispersed the contaminants over a wide area.

The few soil samples taken in the canyon indicated high beta activity (as much as 10 times background), which is indicative of the ^{90}Sr. Sediment samples in the area of the site also contained above normal amount of beta activity. Sediment in the channel near the confluence of

Bayo Canyon with Los Alamos Canyon contained only background concentrations of gross-alpha, gross-beta, and plutonium. Plutonium was not used at the site. Analyses of soil, sediments, and cuttings from test holes contained only background plutonium concentrations.

Drill holes in the area of the solid waste pit only contained background concentrations of ^{90}Sr. Strontium 90 was detected in the areas of the stainless steel tank (removed) and concrete tank (removed) up to depths of 4.6 m. Gross beta activity was highest near the former location of the concrete tank to a depth of 10.6 m. The drill holes may not have been at the exact location of the tanks, but do indicate contamination at depths above normal background.

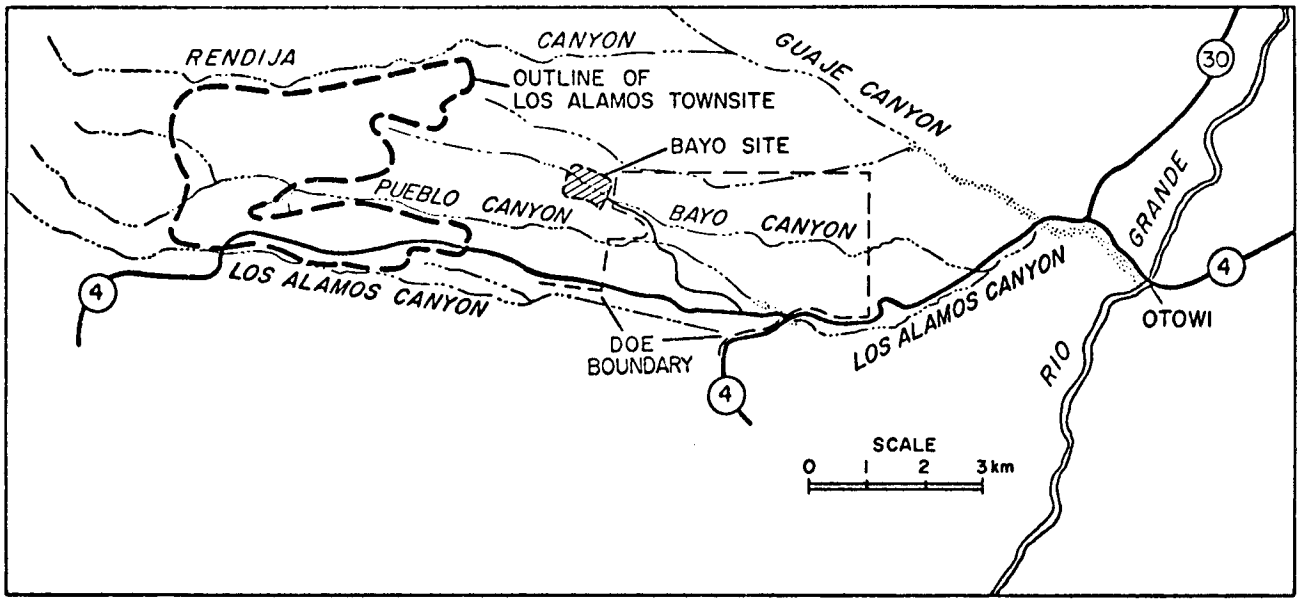

Fig. A-1.
Location of Bayo Site relative to Los Alamos townsite.

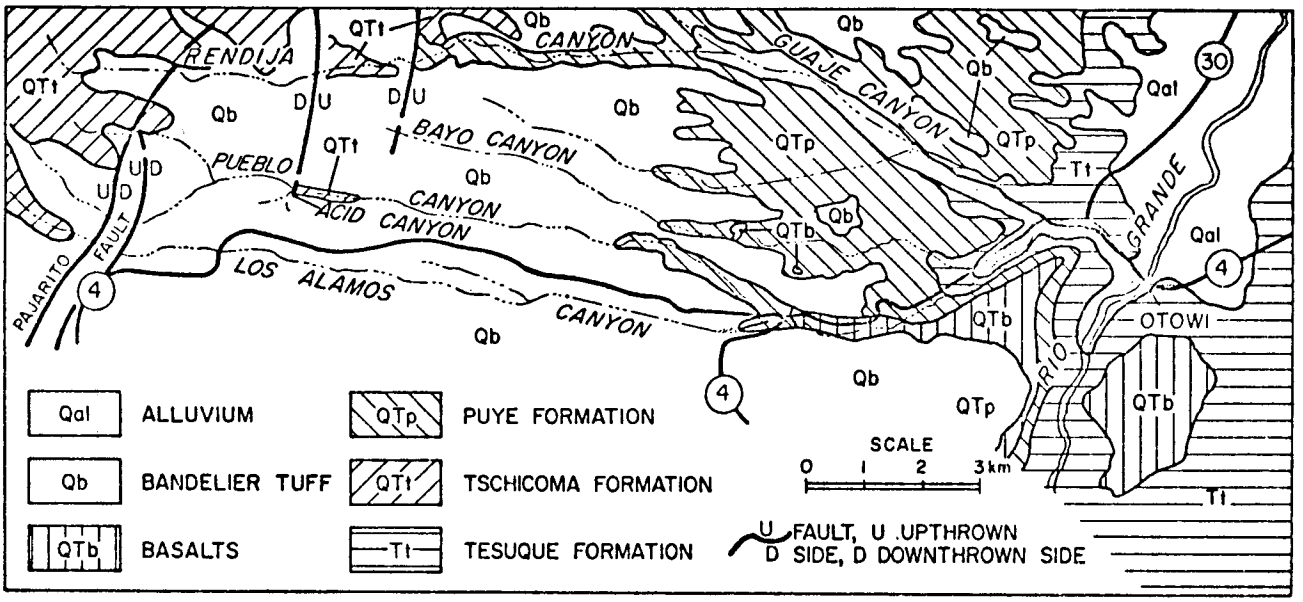

Fig. A-2.
Geologic map of the Pajarito Plateau adjacent to Bayo Site.

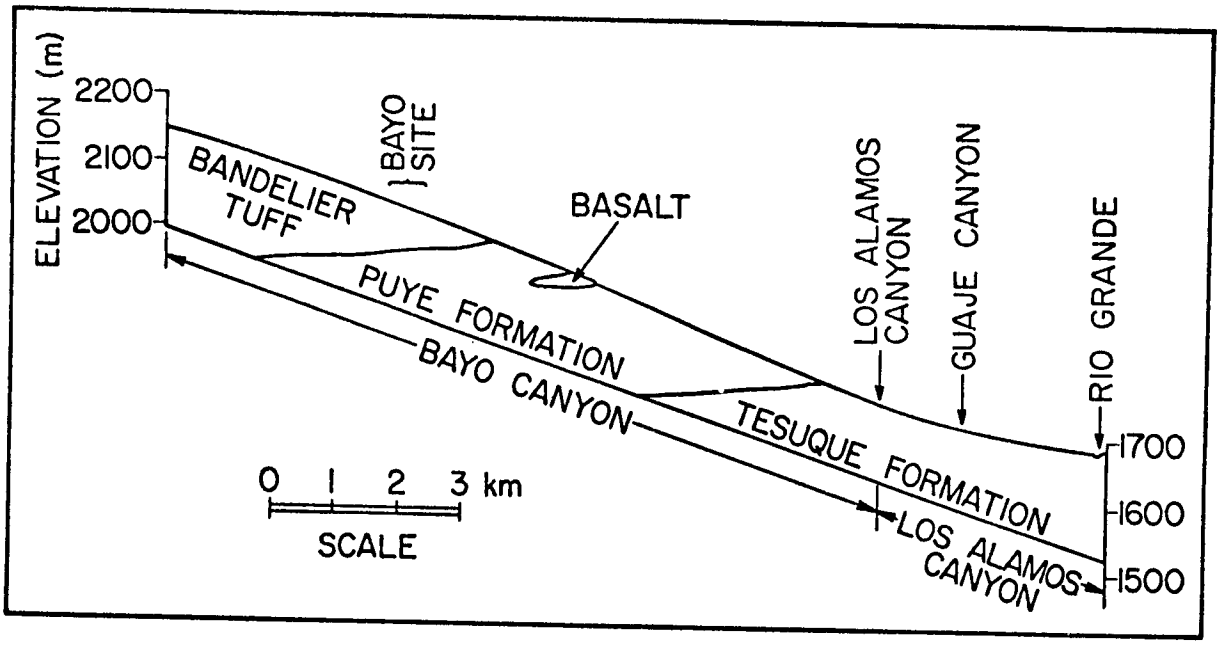

Fig. A-3.
Geology underlying alluvium in Bayo and lower Los Alamos Canyons.

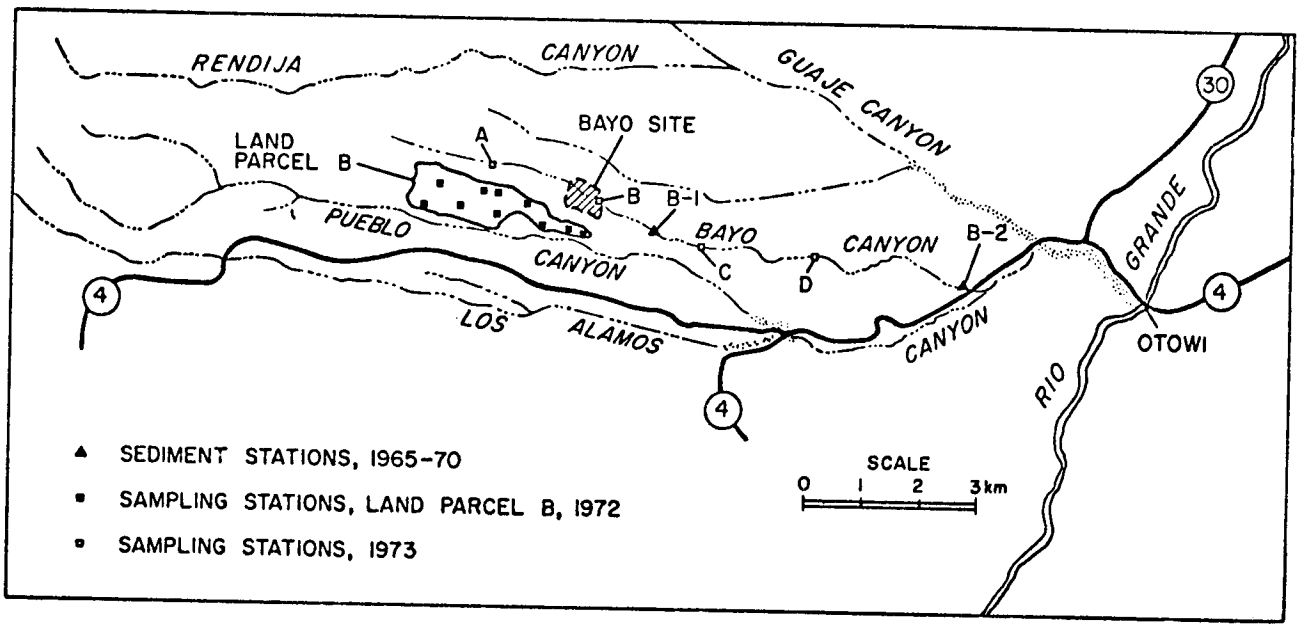

Fig. A-4.
Location of sampling station and Land Parcel B in and adjacent to Bayo Canyon.

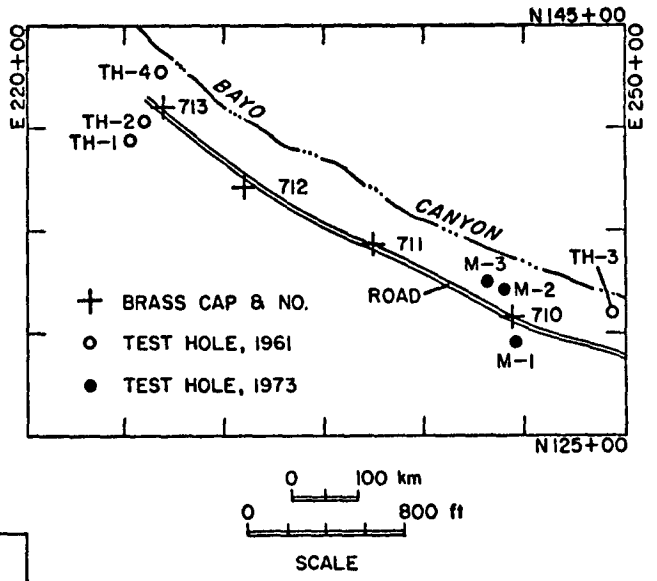

Fig. A-5.
Test holes drilled at Bayo Site, 1961 and 1973.

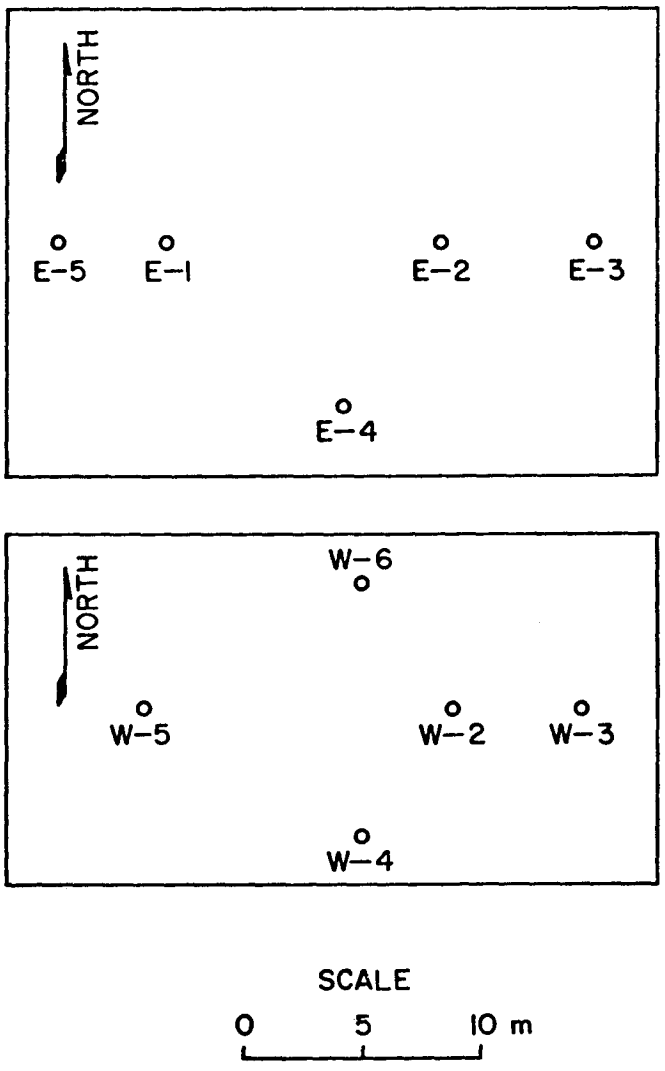

Fig. A-6.
Layout of test holes drilled near test hole M-2 (E-series) and test hole M-3 (W-series).

TABLE A-I

RADIOCHEMICAL ANALYSES OF SOIL AND VEGETATION FROM LAND PARCEL B, 1972

(analyses in pCi/g, except as noted)

Material	Analysis	Range	Average
Vegetation (Bkg)	^{3}H[a]	<1.0	<1.0
Vegetation	^{3}H[a]	<1.0 - 5.8	<2.8
Soil (Bkg)	Gross Beta	16.2 - 31.7	23.8
Soil	Gross Beta	20.0 - 26.3	22.8
Vegetation (Bkg)	Gross Beta	4.2 - 5.1	4.6
Vegetation	Gross Beta	4.4 - 6.0	5.3
Soil (Bkg)	^{137}Cs	1.2 - 5.7	3.6
Soil	^{137}Cs	1.9 - 4.0	2.9
Vegetation (Bkg)	^{137}Cs	0.5 - 2.4	1.6
Vegetation	^{137}Cs	0.5 - 6.1	2.2
Soil (Bkg)	^{238}Pu	0.01 - 0.50	0.13
Soil	^{238}Pu	<0.01 - 0.20	<0.11
Vegetation (Bkg)	^{238}Pu	0.002 - 0.005	0.004
Vegetation	^{238}Pu	0.005 - 0.007	0.006
Soil (Bkg)	^{239}Pu	0.02 - 0.11	0.05
Soil	^{239}Pu	0.01 - 0.08	0.05
Vegetation (Bkg)	^{239}Pu	<0.001 - 0.003	0.002
Vegetation	^{239}Pu	0.005 - 0.006	0.005
Soil (Bkg)	^{241}Am	0.03 - 0.09	0.06
Soil	^{241}Am	0.01 - 0.14	0.10
Vegetation (Bkg)	^{241}Am	0.003 - 0.012	0.007
Vegetation	^{241}Am	0.006 - 0.012	0.009
Soil (Bkg)	Total U[b]	0.16 - 1.24	0.58
Soil	Total U[b]	0.71 - 1.13	0.92
Vegetation (Bkg)	Total U[b]	<0.02 - 0.05	<0.03
Vegetation	Total U[b]	0.10 - 0.12	0.11

[a] Ci/mℓ

[b] μg/g

TABLE A-II

PARTICLE-SIZE DISTRIBUTION OF SEDIMENTS IN BAYO CANYON

Grade	Distribution (percent by weight) Station B-1	Station B-2
Granules	2.0	2.0
Sand		
Very Coarse	40.5	24.5
Coarse	40.0	46.5
Medium	10.5	16.0
Fine	3.5	6.5
Very Fine	1.5	1.5
Silt and Clay	2.0	2.5

TABLE A-III

RADIOCHEMICAL ANALYSES OF SEDIMENTS IN BAYO CANYON 1965 AND 1970

Determination	Station B-1 11/24/65 (c/m/g)	Station B-1 2/5/70 (pCi/g)
Gross alpha	1	<1
Gross beta	<1	<1
Gross gamma	<1	<1
^{238}Pu	---	<0.001
^{239}Pu	---	0.004

Determination	Station B-2 11/24/65 (c/m/g)	Station B-2 2/5/70 (pCi/g)
Gross alpha	3	<1
Gross beta	21	<1
Gross gamma	<1	<1
^{238}Pu	---	<0.001
^{239}Pu	---	0.004

TABLE A-IV

RADIOCHEMICAL ANALYSES OF SEDIMENTS AND SOIL IN BAYO CANYON, 1973
(analyses in pCi/g)

Bed Sediments	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu
Area A				
W200 m	1.9	26	0.009	0.003
W 20 m	1.5	27	0.008	0.006
Center	1.0	19	0.009	0.003
E 20 m	0.8	27	0.005	0.005
E200 m	2.1	38	0.001	0.000
Area B				
W200	0.7	23	0.004	0.002
W 20 m	1.5	31	0.004	0.003
Center	1.6	24	0.002	0.014
E 20 m	1.1	21	0.002	0.008
E200 m	2.6	32	0.003	0.024
Area C				
W200 m	---	---	0.005	0.001
W 20 m	---	---	0.004	0.004
Center	---	---	0.002	0.001
E 20 m	---	---	0.009	0.004
Soil				
Area A				
S200 m	2.8	37	0.002	0.017
S 20 m	3.7	41	0.009	0.028
N 20 m	1.8	30	0.007	0.022
N200 m	2.7	31	0.007	0.022
Area B				
S200 m	2.5	35	0.013	0.019
S 20 m	2.2	35	0.017	0.000
N 20 m	1.6	31	0.009	0.005
N200 m	0.8	26	0.003	0.000

TABLE A-V

LOG OF TEST HOLES DRILLED IN BAYO SITE
1961 AND 1963

Hole No.	Log (m)		
	Alluvium	Tuff	Conglomerate
TH-1 (1961)	---	0 - 25.7	25.7 - 27.1
TH-2 (1961)	0 - 1.5	1.5 - 7.6	---
TH-3 (1961)	0 - 3.6	3.6 - 19.8	19.8 - 21.3
TH-4 (1961)	0 - 3.1	3.1 - 23.3	23.0 - 24.1
M-1 (1973)	0 - 7.9[a]	7.9 - 12.2	---
M-2 (1973)	0 - 4.6[a]	4.6 - 6.1	---
M-3 (1973)	0 - 2.4[a]	---	---

[a]Fill or reworked tuff

Remarks: All holes were dry

TABLE A-VI

GROSS ALPHA, GROSS BETA, AND PLUTONIUM ANALYSES FROM HOLES M-1, M-2, AND M-3
1973

Hole No.	Depth (m)		pCi/g				
	From	To	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{90}Sr
M-1	0	1.5	86	163	---	---	---
	1.5	3.1	67	171	---	---	---
	3.1	4.6	60	197	---	---	---
	4.6	6.1	67	187	---	---	---
	6.1	7.6	42	190	---	---	<0.05
	7.6	9.1	59	204	0.013	0.013	<0.05
	9.1	10.7	66	231	---	---	<0.5
M-2	0.	1.5	43	417	---	---	---
	1.5	3.1	49	234	0.008	0.210	42.0
	3.1	4.6	67	144	---	---	1.9
	4.6	6.1	72	135	---	---	---
M-3	0	1.5	63 [a]	301 [a]	---	---	---
	1.5	3.1	57 [b]	317 [b]	0.006	0.014	7.4

[a]Average 3 analyses

[b]Average 2 analyses

TABLE A-VII

GROSS ALPHA ACTIVITY IN CUTTINGS FROM HOLES NEAR TEST HOLES M-2 AND M-3, 1974
(analyses in pCi/g)

Depth (m)		Near Test Hole M-2					Near Test Hole M-3				
From	To	E-1	E-1	E-3	E-4	E-5	W-2	W-3	W-4	W-5	W-6
0.	0.6	2.5	3.1	4.1	2.8	3.4	1.8	3.4	1.7	---	3.1
0.6	1.2	2.6	---	4.0	2.1	4.2	4.2	3.3	2.8	---	---
1.2	1.8	1.9	1.2	5.0	1.0	---	3.8	3.7	2.4	2.1	3.3
1.8	2.4	1.8	1.6	3.3	1.0	2.7	---	2.3	1.9	---	3.9
2.4	3.0	2.6	---	---	1.6	---	---	2.9	1.0	---	6.9
3.0	3.7	2.2	1.5	3.0	1.3	2.8	---	---	1.4	---	2.5
3.7	4.3	3.0	1.4	5.2	1.8	2.4	---	3.1	---	---	12.0
4.3	4.9	2.4	1.3	43.0	3.0	3.7	---	3.6	2.1	---	59
4.9	5.5	2.7	1.6	3.6	4.9	1.9	---	---	---	---	---
5.5	6.1	---	---	---	1.6	2.1	---	---	---	---	---
6.1	7.6	3.8	2.1	3.8	3.8	3.7	---	2.1	4.4	---	0.5
7.6	9.1	---	2.7	---	---	3.7	---	4.9	4.4	---	5.7
9.1	10.6	---	---	---	---	---	---	4.8	4.6	---	---

TABLE A-VIII

GROSS BETA ACTIVITY IN CUTTINGS FROM HOLES NEAR TEST HOLES M-2 AND M-3, 1974
(analyses in pCi/g)

Depth (m)		Near Test Hole M-2					Near Test Hole M-3				
From	To	E-1	E-2	E-3	E-4	E-5	W-2	W-3	W-4	W-5	W-6
0.	0.6	35	10.3	9.2	11.2	186	6.7	47	5.9	---	34
0.6	1.2	31	---	9.9	3.2	89	10.9	36	16	---	18
1.2	1.8	10.7	1.1	15	1.1	---	7.8	30	2.1	22	21
1.8	2.4	3.9	1.5	8.1	3.4	39	---	30	1.6	---	4400
2.4	3.0	4.4	---	---	4.7	---	---	12	1.0	---	20
3.0	3.7	3.1	3.7	3.9	1.4	16	---	---	2.3	---	21
3.7	4.3	5.6	1.8	10.3	1.0	28	---	9.9	---	---	2300.0
4.3	4.9	4.1	3.4	5.2	7.5	---	---	12	5.4	---	24 000.0
4.9	5.5	4.7	1.7	6.5	3.5	20	---	---	---	---	---
5.5	6.1	---	---	---	2.4	21	---	---	---	---	---
6.1	7.6	42.	5.5	6.1	2.9	16.0	---	4.6	4.1	---	6400.0
7.6	9.1	---	9.0	---	---	18	---	6.5	3.2	---	---
9.1	10.6	---	---	---	---	---	---	5.6	3.6	---	1510

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APPENDIX B

INSTRUMENTATION AND RADIOCHEMICAL ANALYSES

In Situ Radiation Measurements

In situ radiation measurements of x and gamma radiation were made by three different instrument systems: a micro-R meter, a high-pressure ionization chamber (HPIC), and the field phoswich (**phos**phor sand**wich**).

The micro-R meter is a Ludlum Model 12S count-rate meter in which a NaI(T1) scintillation crystal is used as the detector. This detector has the advantage of being sensitive enough to read μR/h directly. A disadvantage is that its response is quite dependent upon photon energy (Fig. B-1). The instrument was calibrated with a known flux of ^{226}Ra (and daughters) gamma rays. Measurements with this instrument in Bayo Canyon in 1977 agreed with previous measurements (1973; see Appendix A and Ref. B1) with the same model. Experience at LASL indicates that the Ludlum 12S readings would be reduced slightly if normalized to agree with thermoluminescent dosimeters (TLD), or with the high pressure ion chambers (HPIC). See Appendix A and Ref. B1.

A Reuter-Stokes Model RSS-111 spherical, high-pressure ionization chamber filled to 14 atm with pure argon was also used. Its factory calibrated response was checked at various TLD measurement locations. In contrast to the micro-R meter, it has a flat energy response over a wide range of energies (Fig. B-1) and is thus well suited to make environmental gross-gamma measurements.

The modification of the field portable phoswich used in this survey is described in Ref B2. The unit was equipped with a timer-scaler to allow timed, integrated response, thereby attaining a lower detection limit that would be less dependent on subjective interpretations of the rate meter.

For work in Bayo Canyon, the phoswich was adjusted to the x-ray energy band from 5 keV to 25 keV in order to enhance the detection of the 17 keV photon from plutonium while minimizing interference from ^{137}Cs at 30 keV.

The phoswich was taken to the field and tuned to this energy band with the aid of a portable multichannel analyzer, an ^{241}Am source, and a ^{137}Cs source. The detection limit for this tuning and for a 100 second count in the laboratory at 95% confidence was 2 nCi/g for soil spiked with ^{239}Pu.

Sample Analyses

•Gross Alpha and Gross Beta

All soil samples were analyzed for gross-beta and gross-alpha activity by exposing an appropriate scintillator (alpha or beta) to the gross particle emission of a petri dish full of the dried soil sample. This procedure effectively screened all samples for concentrations of alpha or beta emitting contaminants that would exceed that attributable to naturally occuring radionuclides or weapons testing fallout by a substantial margin. The method was originated by R. D. Evans during the 1940s, and adapted to good effect as a screening device for alpha contamination by LASL during the TA-1 cleanup.[B3]

The alpha probe was calibrated with a petri dish of dried soil homogenized with enough ^{239}Pu to yield 2000 pCi ^{239}Pu per gram of soil. Repetitive counts of empty petri dishes gave an instrument background of 3.03 ± 1.07 c/m which was equivalent to 20 ± 10 α pCi/g of soil at the 67% confidence interval. The alpha detection limit (instrument background + σ) at 67% confidence was

therefore 30 pCi/g. Gross alpha activity from seven uncontaminated local soils ranged from 20 pCi/g to 40 pCi/g.* Samples exceeding the higher value were suspected of being contaminated. Gross alpha results with instrument background subtracted are provided in most tables of Appendix D. These results should be interpreted to the nearest 10 pCi/g.

The beta probe was calbrated with a petri dish full of dried soil homogenized with enough ^{90}Sr-^{90}Y to yield 1950 pCi ^{90}Sr-^{90}Y per gram of soil. Repetitive counts of empty petri dishes gave an instrument background of 38.11 ± 2.53 counts/min, which was equivalent to 8 ± 1 β pCi per gram of soil at the 67% confidence level. The beta detection limit (instrument background + σ) at 67% confidence was, therefore, 9 pCi/g. Gross beta activity from eight uncontaminated local soils ranged from 2 pCi/g to 6 pCi/g.* Samples exceeding 6 pCi/g were suspected of being contaminated. Gross beta results with instrument background subtracted are provided in most tables of Appendix D. These results should be interpreted to the nearest pCi/g. Both detectors are shown in Fig. B-2 with their sample holders (which minimize light scatter) and their scaler units.

• Radiochemical Analyses

Soil samples were oven dried, homogenized, and submitted to the subcontractor for analysis. Soil samples were submitted in weighed 10 g aliquots and biota in 100 g aliquots. The subcontractor dissolved the samples in an acid bath and chemically separated the species of interest. The samples were deposited on planchets and ashed to minimize self absorption. Alpha emitters were analyzed by alpha spectrometry; beta emitters by low background proportional counters. Table B-I lists the subcontractors analytical capability specifications.

Ten per cent of the samples sent to the subcontractor were either spikes** or blanks*** submitted to evaluate the quality of analytical results reported. The quality control samples were prepared from silt from the bottom of a deep water well known to be free from any man-made radionuclides, particularly ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$. Table B-II presents analyses of blank control samples submitted to the subcontractor. The accuracy of the analyses can be summarized by the ratio of the amount of activity reported for a spike sample to the amount actually added. Table B-III summarizes the quantity of each nuclide spiked into each control sample as well as the reported analytical result and the quality control ratio. Reported analytical results are not background corrected. Table B-IV summarizes the means, the standard deviations, and the ranges of blanks and quality control ratios.

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*Instrument background subtracted.

**A spike is a quantity of standard sample matrix to which a known quantity of test material has been added.

***A blank is a quantity of standard sample matrix that has not been treated with test materials.

It must be noted that most spikes were of low concentration in an attempt to simulate low level environmental contamination with the attendant difficulty in attaining complete homogeneity. This contributed to spread in analytical results, especially in the case of naturally occurring radionuclides because they have a variable distribution in soils, including our control soil.

Seventeen uranium values reported for blank samples are presented in Table B-II. Fourteen of these were normally distributed about a mean of 1.23 μg uranium per gram of soil. The remaining blanks were 11.0, 5.7, and 2.5 μg/g. Since these concentrations were well above the analytical detection limit (see Table B-I), they can be resolved to the nearest 1.0 μg/g and readily distinguished from background. These three results are then considered outliers and deleted from data reduction. The value 1.23 μg/g is considered representative of natural uranium in the silt control soil, and it is subtracted from each of the spike results. Nineteen uranium values were reported for spike samples in Table B-III. Eighteen of these produced quality control ratios which averaged 0.89 as shown in Table B-IV. The 19th result (0.38 μg/g) was less than two standard deviations different from either the detection limit or the sensitivity of analysis. The uncertainty in these numbers produces meaningless results in the calculation of a QC ratio so the value was deleted from the data set.

Blanks analyzed for ^{137}Cs, ^{90}Sr, and ^{239,240}Pu were generally at the detection limit of the analytical procedure. Moreover, the source of control soil precludes all but the remote prospect that fallout radioactivity will contaminate control soil so no background corrections were made for these nuclides. The mean quality control ratio for 26 ^{90}Sr spikes was 0.93, and that for 11 ^{137}Cs spikes was 0.81. The mean quality control ratio for five ^{239,240}Pu spikes was 1.16. Four additional spikes were deleted from the data set. Three of these were 0.0065 pCi/g (less than the detection limit of 0.01 $\pm$ 0.01 pCi/g) which produced a meaningless quality control ratio. The fourth additional spike (0.032 pCi/g) was analyzed in a sequence of test samples that contained sufficient activity ($\sim$100 pCi/g max) to be analyzed in a segregated laboratory. The analytical result of 0.14 pCi/g is believed to contain cross contamination from the adjacent samples, and was deleted.

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TABLE B-I

RADIOCHEMICAL SPECIFICATIONS[a]

Isotope	Sample Type	Detection Limit[b]	Sensitivity[c]
^{90}Sr	Soil	0.1 pCi/g±100%	1.0 pCi/g±30%
	Biota	0.01 pCi/g±100%	0.1 pCi/g± 30%
U[d]	Soil	0.5 μg/g±100%	2 μg/g±20%
	Biota	0.05 μg/g±100%	0.2 μg/g±20%
^{239}Pu[e]	Soil	0.01 pCi/g±100%	0.1 pCi/g±15%
	Biota	0.001 pCi/g±100%	0.01 pCi/g±15%
^{137}Cs	Soil	0.1 pCi/g±100%	1.0 pCi/g±30%
	Biota	0.01 pCi/g±100%	0.1 pCi/g±30%

[a]Error is counting error at 2σ or 95% confidence and includes error of tracer yield.

[b]Blanks will agree within the detection limit error listed.

[c]Spikes will agree within the sensitivity error listed.

[d]Uranium result includes all isotopes of uranium present in the sample whether primordial, normal, depleted, or enriched uranium is present.

[e]^{238}Pu error corresponds to that obtained when ^{239}Pu specifications are met.

TABLE B-II

RESULTS OF INDIVIDUAL RADIOCHEMICAL ANALYSES OF BLANK (UNSPIKED) QUALITY CONTROL SOIL SAMPLES

Uranium (μg/g)	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	^{239,240}Pu (pCi/g)
1.9 ± 0.0038	0.0 ± 0.32	0.0 ± 0.019	0.026 ± 0.007
11.0 ± 11.0	0.32 ± 0.11	0.0 ± 0.17	0.0 ± 0.005
5.7 ± 0.0342	0.0 ± 0.82		0.0 ± 0.005
1.7 ± 0.0034	0.0 ± 0.77		
4.2 ± 0.0168	0.0 ± 0.23		
1.7 ± 0.0034	0.0 ± 0.23		
2.5 ± 0.0075	0.13 ± 0.04		
1.2 ± 0.0024	0.12 ± 0.05		
1.0 ± 0.0020	0.17 ± 0.03		
0.8 ± 0.0016	0.0 ± 0.05		
1.0 ± 0.0020			
1.0 ± 0.0020			
1.1 ± 0.0022			
0.9 ± 0.0027			
1.0 ± 0.0030			
0.5 ± 0.0005			
0.9 ± 0.0027			

TABLE B-III

RESULTS OF INDIVIDUAL RADIOCHEMICAL ANALYSIS OF SPIKED QUALITY CONTROL SOIL SAMPLES

Uranium			^{90}Sr		
Analysis (μg/g)	Spike (μg/g)	QC Ratio	Analysis (pCi/g)	Spike (pCi/g)	QC Ratio
48.8 ± 2.51	37.8	1.29	514 ± 51.40	520	0.99
34.8 ± 1.39	37.8	0.92	50.9 ± 0.51	49	1.04
61. ± 0.05	3.78	1.61	45.5 ± 0.23	52	0.88
309 ± 46.35	454	0.68	0.50 ± 0.00	0.52	0.96
34.8 ± 0.69	37.8	0.92	10.4 ± 0.21	10.6	0.98
3.7 ± 0.03	3.8	0.97	96.2 ± 1.92	106	0.91
0.07 ± 0.00	0.38	0.18	0.14 ± 0.01	0.11	1.27
2.3 ± 0.01	2.3	1.00	1.07 ± 0.04	1.06	1.01
2.8 ± 0.02	3.8	0.74	0.16 ± 0.07	0.21	0.76
7.0 ± 0.01	7.6	0.92	1.30 ± 0.09	2.1	0.62
40.8 ± 1.63	37.8	1.08	21.03 ± 21.20	21.2	0.99
2.2 ± 0.01	3.8	0.58	39.5 ± 0.79	212	0.19
3.0 ± 0.02	3.8	0.79	19.63 ± 0.39	21.2	0.93
17.8 ± 0.18	15.1	1.18	41.35 ± 0.83	53	0.78
10.3 ± 0.06	15.1	0.68	1.23 ± 0.09	1.06	1.16
20.8 ± 0.21	37.8	0.55	29.37 ± 0.58	31.8	0.92
10.8 ± 0.11	15.1	0.72	46.1 ± 0.92	53	0.87
1.7 ± 0.01	3.8	0.45	43.9 ± 1.32	53	0.83
7.2 ± 0.06	7.6	0.95	9.72 ± 0.49	10.6	0.92
			2.07 ± 0.10	2.1	0.99
			46.2 ± 2.31	53	0.87
			27.0 ± 1.35	21.2	1.27
			2.16 ± 0.11	2.1	1.03
			10.3 ± 0.52	10.6	0.97
			1.03 ± 0.06	1.06	0.97
			0.142 ± 0.06	0.11	1.29

$^{239,240}Pu$			^{137}Cs		
Analysis (pCi/g)	Spike (pCi/g)	QC Ratio	Analysis (pCi/g)	Spike (pCi/g)	QC Ratio
0.0 ± 0.005	0.0065	0.00	17.5 ± 0.18	21.6	0.81
0.0 ± 0.005	0.0065	0.00	41.0 ± 0.41	43.2	0.95
0.03 ± 0.017	0.0065	4.62	1.76 ± 0.09	2.2	0.80
0.012 ± 0.007	0.013	0.92	38.8 ± 0.39	43.2	0.90
0.14 ± 0.027	0.032	4.38	8.67 ± 0.43	10.8	0.80
0.039 ± 0.011	0.032	1.22	16.6 ± 0.83	21.6	0.77
0.078 ± 0.013	0.064	1.22	16.1 ± 0.81	21.6	0.75
0.048 ± 0.016	0.032	1.50	40.9 ± 2.05	43.2	0.95
0.012 ± 0.004	0.013	0.92	16.6 ± 0.83	21.6	0.77
			8.5 ± 0.43	10.8	0.79
			1.38 ± 0.12	2.2	0.63

TABLE B-IV

INTERPRETATION OF QUALITY CONTROL RESULTS

Analyte	Blanks		No. of Samples	Quality Control Ratio		No. of Samples
	Range	$\bar{x} \pm \sigma$		Range	$\bar{x} \pm \sigma$	
Total Uranium (μg/g)	0.5-2.5	1.23 ± 0.53	14	0.45-1.61	0.89 ± 0.28	18
^{90}Sr (pCi/g)	0.0-0.17	0.05 ± 0.07	9	0.19-1.29	0.93 ± 0.22	25
^{137}Cs (pCi/g)	0.0-0.0	0.0	2	0.63-0.95	0.81 ± 0.09	11
^{239,240}Pu (pCi/g)	0.0-0.026	0.007 ± 0.013	4	0.92-1.50	1.16 ± 0.24	5

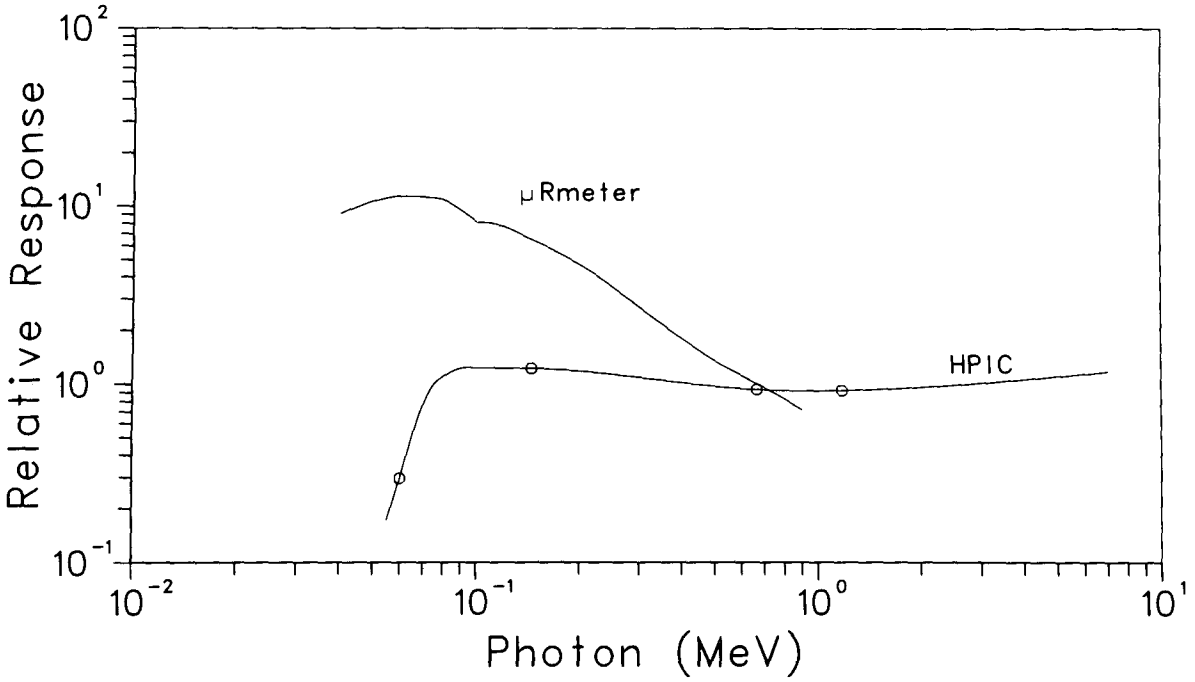

Fig. B-1.

Response of an RSS-111 monitor as a function of incident gamma-ray energy and compared to the response of the μR meter. Continuous line on the HPIC curve represents theoretical response. Circled points on the HPIC curve represent actual values measured with ^{241}Am, ^{141}Ce, and NBS-traceable sources ^{137}Cs and ^{60}Co.

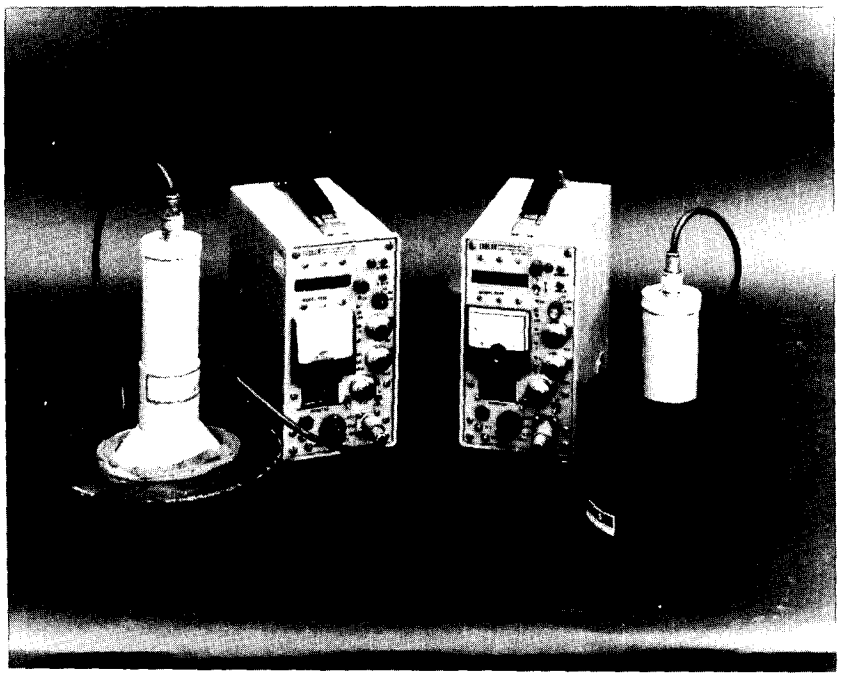

Fig. B-2.

Gross alpha and beta probes with scalers. Left to right: alpha probe, scaler, scaler, beta probe.

APPENDIX C

SAMPLE COLLECTION AND PREPARATION METHODOLOGY

Soil samples from the circular and rectangular grids were taken within 2 m of the survey point. Once the location was chosen, a 9 cm diam by 10 cm deep ring was driven 5 cm into the ground and the soil around the ring was removed with a trowel. The trowel was slid under the sample, which was then placed in a plastic bag. Next, a 2.5 cm diam by 60 cm deep PVC tube was driven 30 cm into the ground. When the tube was extracted from the soil, the core sample remained in the tube until it was shaken into a plastic bag. Profile samples divided the 0-30 cm soil column into 0-5, 5-10, 10-20, and 20-30 cm intervals. The 0-5 cm and 5-10 cm intervals were taken by the ring method. The 10-20 cm and 20-30 cm intervals were taken by the core method where cores were driven by 10 cm increments. The sample in each profile interval was put in a separate plastic bag.

Bed sediment samples from the natural drainage system were taken at the survey point, 2 m upstream and 2 m downstream. Only the 30 cm core technique and a few profiles were taken in bed sediments. The three samples were identified separately for analysis.

Subsurface samples from former foundation locations and industrial or sanitary waste alignments were taken by trenching across the location of interest to a depth of 122 cm with a backhoe. A grab sample was obtained at the 122 cm level with a stainless steel scoop and placed in a plastic bag.

Subsurface migration under waste pits, leaching fields, and outfalls were sampled from greater than 122 cm to as deep as 2000 cm by a truck mounted auger drill. The drill was stopped at 152 cm intervals and a suitable grab sample of the cuttings was obtained with the stainless steel scoop.

Samples were immediately placed in 30 cm by 30 cm plastic bags for transfer to the laboratory and the bags were marked as they were obtained with sample point identity (by stratum, grid point, depth, sample technique, and date). Each sampling device was cleaned before taking the next sample.

Once the samples were in the laboratory, 75-100 g of soil was transferred into a sterile plastic petri dish and leveled to the rim with a wooden tongue depressor. In order to minimize cross-contamination, the transfer was done within the plastic bag and in a fume hood. Tongue depressors and surgeon's gloves used in transfers were discarded after each transfer. After transfer, the soil samples were dried under an infrared light for about 4 min. Samples prepared in this way were analyzed for gross-alpha and gross-beta activity according to the method described in Appendix B.

An additional 10 g portion of soil from samples chosen for radiochemistry was homogenized with stainless steel mortar and pestle, placed in a plastic vial, dried 15 min in an oven at 75°C, sealed, marked, packed, and shipped to the subcontracted analytical laboratory. Radiochemical methods are also described in Appendix B.

APPENDIX D

SURVEY DATA

The data in this appendix consist of the 1977 survey results organized into 32 tables of which the first 30 deal with radioactivity in soil. Tables XXXI and XXXII deal with radioactivity in grasses. Corresponding data for rodents were omitted as unreliable because of insufficient biomass.

Gross alpha and gross beta results for soils (soils and bedrock) were obtained by scintillation counting described in Appendix B, Instrumentation. Available radiochemical analyses of some samples are presented with scintillator counter results to allow comparisons. Tables of results are arranged according to depth in the soil, and depth in turn is related to the sampling method as described in Section III, Methods. Tables D-I and D-II include ring samples and the 0-5 cm depth of profile samples. Tables D-III through D-V span the profile intervals from 5 cm to 30 cm. Tables D-VI through D-X relate to the 0-30 cm depth of soil. Samples from the latter were taken by core sampling. Table D-XI and D-XII are from the samples scooped from trenches dug by backhoe. The latter samples were used to evaluate the interval from 60 to 120 cm. Tables D-XIII through D-XXX were taken in 150 cm increments to as deep as 2000 cm by auger drill to evaluate depth intervals below 120 cm. Tables D-XXXIII and D-XXXIV contain data on penetrating radiation measurements. An index of tables precedes the actual data tables.

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Table D-III. Gross-Alpha and -Beta Activity vs Selected Radiochemical Analyses in the 5-10 cm Layer.

Table D-IV. Gross-Alpha and -Beta Activity vs Selected Radiochemical Analyses in the 10-20 cm Layer.

Table D-V. Gross-Alpha and -Beta Activity vs Selected Radiochemical Analyses in the 20-30 cm Layer.

Table D-VI. Gross-Alpha and -Beta Activity in 0-30 cm Layer.

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Table D-XIII. Gross-Alpha and -Beta Activity in the 0-150 cm Layer.

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Table D-XVI. Gross-Alpha and -Beta Actvity vs ^{90}Sr Activity in the 150-300 cm Layer.

Table D-XVII. Gross-Alpha and -Beta Activity in 300-460 cm Layer.

Table D-XVIII. Gross-Alpha and -Beta Activity vs ^{90}Sr and Uranium in 300-460 cm Layer.

Table D-XIX. Gross-Alpha and -Beta Activity in 460-600 cm Layer.

Table D-XX. Gross-Alpha and -Beta Activity vs Selected Radiochemical Analyses in 460-600 cm Layer.
Table D-XXI. Gross-Alpha and -Beta Activity in 600-760 cm Layer.
Table D-XXII. Gross-Alpha and -Beta Activity vs Selected Radiochemical Analyses in 600-760 cm Layer.
Table D-XXIII. Gross-Alpha and -Beta Activity in 760-920 cm Layer.
Table D-XXIV. Gross-Alpha and -Beta Activity vs ^{90}Sr and Uranium in the 760-920 cm Layer.
Table D-XXV. Gross-Alpha and -Beta Activity in 920-1070 cm Layer.
Table D-XXVI. Gross-Alpha and -Beta Activity vs ^{90}Sr in 920-1020 cm Layer.
Table D-XXVII. Gross-Alpha and -Beta Activity in 1070-1220 cm Layer.
Table D-XXVIII. Gross-Alpha and -Beta Activity in 1220-1370 cm Layer.
Table D-XXIX. Gross-Alpha and -Beta Activity in 1370-1530 cm Layer.
Table D-XXX. Gross-Alpha and -Beta Activity in 1530-2000 cm Layer.
Table D-XXXI. Background Radioactivity in Grasses.
Table D-XXXII. Radioactivity in Bayo Site Grasses.
Table D-XXXIII. External Penetrating Radiation in the Townsite.
Table D-XXXIV. External Penetrating Radiation at the Former Bayo Site.

TABLE D-I

GROSS-ALPHA AND -BETA ACTIVITY IN 0-5 CM LAYER
(pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α	Location	Gross β	Gross α
CTR	1	25	C5-15	2	35	C7-24	3	8
CTR-5	0	32	C6-1	3	13	C7-25	3	19
CTR-5b	0	32	C6-2	2	32	C7-26	2	17
C1-1	3	44	C6-3	2	25	C7-27	2	10
C1-2	2	48	C6-4	4	14	C7-28	3	10
C1-3	4	27	C6-5	3	12	C7-29	2	14
C2-1	3	80	C6-6	0	23	C7-30	3	35
C2-2	3	27	C6-7	2	13	C8-1	6	8
C2-3	2	50	C6-8	2	0	C8-2	5	10
C2-4	4	36	C6-9	2	27	C8-3	6	11
C2-5	4	44	C6-10	1	19	C8-4	6	19
C2-6	3	29	C6-11	5	5	C8-5	5	25
C3-1	3	12	C6-12	2	19	C8-6	6	8
C3-2	2	36	C6-13	2	30	C8-7	4	27
C3-3	4	23	C6-14	2	14	C8-8	5	35
C3-4	2	41	C6-15	2	30	C8-9	3	37
C3-5	6	44	C6-16	2	36	C8-10	3	7
C3-6	2	31	C6-17	3	11	C8-11	5	10
C3-7	4	30	C6-18	3	22	C8-12	7	30
C3-8	2	16	C6-19	1	24	C8-13	5	21
C4-1	4	47	C6-20	2	30	C8-14	6	1
C4-2	1	5	C7-1	2	20	C8-15	5	25
C4-3	6	30	C7-2	2	45	C8-16	5	10
C4-4	3	20	C7-3	1	29	C8-17	6	10
C4-5	3	20	C7-4	3	22	C8-18	4	9
C4-6	8	25	C7-5	3	8	C8-19	4	29
C4-7	3	12	C7-6	3	16	C8-20	4	4
C4-8	3	23	C7-7	1	17	C8-21	3	25
C4-9	3	18	C7-8	2	2	C8-22	2	20
C4-10	3	30	C7-9	2	16	C8-23	3	5
C5-1	1	26	C7-10	2	7	C8-24	3	0
C5-2	6	14	C7-11	1	29	C8-25	3	16
C5-3	3	36	C7-12	4	2	C8-26	1	0
C5-4	4	20	C7-13	4	13	C8-27	4	16
C5-5	3	74	C7-14	3	10	C8-28	1	7
C5-6	4	27	C7-15	3	13	C8-29	2	0
C5-7	3	23	C7-16	2	25	C8-30	3	32
C5-8	4	16	C7-17	3	11	C9-1	4	12
C5-9	4	41	C7-18	3	13	C9-2	3	18
C5-10	3	29	C7-19	2	27	C9-3	5	26
C5-11	4	29	C7-20	2	25	C9-4	4	15
C5-12	3	29	C7-21	1	18	C9-5	4	18
C5-13	3	26	C7-22	4	22	C9-6	5	22
C5-14	4	45	C7-23	3	23	C9-7	1	60

TABLE D-I (cont)

Location	Gross β	Gross α
C9-8	4	57
C9-9	7	32
C9-10	4	53
C9-11	5	38
C9-12	5	36
C9-13	4	24
C9-14	7	18
C9-15	3	44
C9-16	4	23
C9-17	4	34
C9-18	3	33
C9-19	3	54
C9-20	2	38
C9-21	1	14
C9-22	5	24
C9-23	5	10
C9-24	3	18
C9-25	3	10
C9-26	4	5
C9-27	4	16
C9-28	4	32
C9-29	5	10
C9-30	5	2
C9-31	5	22
C9-32	4	2
C9-33	4	17
C9-34	3	27
C9-35	3	14
C9-36	5	16
C9-37	8	10
C9-38	6	13
C9-39	4	20
C9-40	5	12
C9-41	5	7
C9-42	7	15
C9-43	4	10
C9-44	3	9
C9-45	5	15
WA-1	5	44
WA-2	2	14
WA-3	1	12
WA-4	1	16
WA-5	5	14
WB-1	3	23
WB-2	1	10
WB-3	3	8
WB-4	2	11
WB-5	2	24
WC-1	4	8
WC-2	3	17
WC-3	7	11
WC-4	1	7
WC-5	3	6
WD-5	2	8
WD-6	7	6
EA-1	1	4
EA-2	1	24
EA-3	1	20
EA-4	5	24
EA-5	3	10
EA-6	2	30
EB-1	3	14
EB-2	2	23
EB-3	36	2
EB-4	3	8
EB-5	2	6
EB-6	2	18
EC-1	6	22
EC-2	2	7
EC-3	2	17
EC-4	1	8
EC-5	0	22
EC-6	4	17
ED-1	1	6
ED-2	6	14
ED-3	1	22
ED-4	3	10
ED-5	1	11
ED-6	2	18
C2-1P	4	38
C3-5P	7	32
C6-17P	6	22
C7-18P	5	5
C8-2P	5	10
C8-14P	5	1
C9-3P	5	26
C9-45P	3	23
WB-5P	5	39
WC-3P	5	2
EB-2P	6	24
EC-1P	6	22
SC-2BP	4	17
SC-4CP	2	14
SC-6CP	1	0
SC-7CP	3	4
TA10-1#1	2	18
TA10-1#2	2	14
TA10-3	4	19
TA10-4	3	19
TA10-5	3	4
TA10-7	2	7
TA10-21	3	26

TABLE D-II

GROSS-ALPHA AND -BETA ACTIVITY VS SELECTED RADIOCHEMICAL ANALYSES IN THE 0-5 CM LAYER
(pCi/g except as noted)

Location	Gross β	^{90}Sr	^{137}Cs	Gross α	U-T[a]	^{238}Pu	^{239}Pu
CTR	1	0.75	0.12	25	4.2	0.0	0.014
CTR-5	0	0.78	0.21	32	4.1	0.0	0.014
CTR-5b	0	0.46	0.0	32	4.4	0.0	0.027
C1-3	4	3.45	---	27	9.5	---	---
C2-1	3	(3.40)[b]	---	80	(0.54)[b]	---	0.058
C2-4	4	4.13	---	36	7.8	---	---
C5-2	6	3.27	0.15	14	4.3	0.0	0.0
C5-5	3	0.60	---	74	4.0	---	---
C5-11	4	1.95	---	29	8.9	---	---
C6-11	5	0.41	---	5	4.6	---	---
C7-9	2	0.61	---	16	4.7	---	---
C7-21	1	0.23	---	18	7.0	---	---
C8-1	6	0.89	1.49	8	3.6	0.027	0.03
C8-16	5	0.79	---	10	4.5	0.14	8.76
C8-17	6	2.5	2.13	10	3.7	0.0	0.079
C9-8	4	0.45	0.579	58	3.5	0.0	0.032
C9-10	4	0.49	0.688	53	3.3	0.0	0.066
C9-14	7	0.69	---	18	4.5	---	---
C9-19	3	1.00	1.85	54	3.2	0.0	0.166
C9-33	4	3.7	---	17	5.9	---	---
WA-1	5	0.87	---	44	3.6	---	---
WA-5	5	0.48	---	14	3.4	---	---
WD-6	7	0.97	---	6	5.6	---	---
EA-4	5	0.30	0.33	24	3.7	0.0	0.022
EB-3	36	132.0	1.14	2	2.4	0.009	0.076
EC-6	4	0.221	0.16	17	2.6	0.0	0.0
ED-2	6	0.29	0.20	14	4.6	0.0	0.03
C2-1P	4	3.4	---	38	0.54	---	---
C3-5P	7	3.8	---	32	12.0	---	---
C6-17P	6	0.218	---	22	2.9	---	---
C7-18P	5	0.62	---	5	4.1	---	---
C8-2P	5	0.55	0.20	10	2.5	0.0	0.0
C8-14P	5	0.207	---	2	3.0	---	---
C9-3P	5	0.63	0.73	26	3.9	0.0	0.013
C9-45P	3	0.34	0.30	23	6.8	0.0	0.20
WB-5P	11	0.191	---	39	3.9	---	---
WC-3P	5	0.73	---	2	4.8	---	---
EB-2P	6	0.09	0.50	24	3.4	0.0	0.020
EC-1P	6	0.98	1.51	22	2.9	0.0	0.052
SC-2BP	4	8.20	---	17	7.6	---	---
SC-4CP	2	0.0	---	14	4.7	---	---
SC-6CP	1	0.078	0.0	0	2.1	0.003	0.0
SC-7CP	3	0.36	0.49	4	2.5	0.0	0.013
TA10-1#1	2	5.40	0.25	18	3.2	0.004	0.098
TA10-1#2	2	2.81	0.38	14	2.3	0.015	0.030
TA10-3	4	1.54	0.47	19	1.7	0.0	0.029
TA10-4	3	1.92	0.18	19	1.3	0.0	0.019
TA10-5	3	1.87	0.38	4	1.5	0.006	0.02
TA10-7	2	0.69	0.18	7	2.1	0.005	0.008
TA10-21	3	0.47	0.31	26	2.4	0.001	0.0113

[a]Total uranium in μg/g.

[b]See C2-1P

TABLE D-III

GROSS-ALPHA AND -BETA ACTIVITY VS SELECTED RADIOCHEMICAL ANALYSES IN THE 5-10 CM LAYER
(pCi/g except as noted)

Location	Gross β	^{90}Sr	^{137}Cs	Gross α	U-T[a]	^{238}Pu	^{239}Pu
C2-1P	4	0.31	---	22	3.0	---	---
C3-5P	6	1.73	---	21	5.9	---	---
C6-17P	6	0.08	---	2	2.7	---	---
C7-18P	4	0.43	---	25	4.1	---	---
C8-2P	4	0.40	0.0	34	2.2	0.0	0.0
C8-14P	4	0.55	---	18	3.1	---	---
C9-3P	5	0.82	0.48	36	3.6	0.0	0.018
C9-45P	4	0.30	0.19	26	1.6	0.0047	0.018
WB-5P	4	0.289	---	22	3.1	---	---
WC-3P	6	0.173	---	2	4.4	---	---
EB-2P	5	1.03	0.0	23	3.4	0.0	0.0
EC-1P	4	0.10	0.0	15	2.1	0.0	0.0
SC-2BP	6	2.77	---	41	2.3	---	---
SC-4CP	3	0.28	---	18	3.1	---	---
SC-6CP	3	0.26	0.0	8	1.9	0.0017	0.004
SC-7CP	3	0.20	0.0	5	2.1	0.0	0.0076
TA10-1#1	4	3.99	0.11	30	2.6	0.014	0.007
TA10-1#2	4	3.85	0.071	17	1.4	0.0	0.054
TA10-3	2	2.64	0.17	14	2.5	0.034	0.076
TA10-4	3	1.41	0.12	4	1.4	0.0	0.0
TA10-5	3	2.93	0.24	23	1.4	0.004	0.030
TA10-7	3	0.48	0.09	29	2.0	0.0	0.0101
TA10-21	3	0.15	0.042	37	2.0	0.0	0.007

[a]Total uranium in μg/g.

TABLE D-IV

GROSS-ALPHA AND -BETA ACTIVITY VS SELECTED RADIOCHEMICAL ANALYSES IN THE 10-20 CM LAYER
(pCi/g except as noted)

Location	Gross β	^{90}Sr	^{137}Cs	Gross α	U-T[a]	^{238}Pu	^{239}Pu
C2-1P	4	0.211	---	37	3.4	---	---
C3-5P	3	0.025	---	23	3.1	---	---
C6-17P	5	0.07	---	8	2.8	---	---
C7-18P	4	0.07	---	26	3.2	---	---
C8-2P	5	0.177	0.0	30	2.2	0.0	0.015
C8-14P	7	0.34	---	16	3.1	---	---
C9-3P	4	0.52	0.0	2	3.7	0.0	0.013
C9-45P	3	0.38	0.14	5	2.9	0.0077	0.013
WB-5P	6	0.193	---	10	3.4	---	---
WC-3P	5	0.172	---	10	4.8	---	---
EB-2P	5	0.212	0.0	9	3.1	0.0	0.013
EC-1P	4	0.110	0.0	14	2.4	0.0	0.021
SC-2BP	4	2.62	---	37	3.0	---	---
SC-4CP	2	0.61	---	26	3.1	---	---
SC-6CP	1	0.23	0.08	2	1.2	0.0	0.011
SC-7CP	3	0.32	0.47	7	1.6	0.0039	0.0087
TA10-1#1	4	3.30	0.0	23	2.2	0.0	0.011
TA10-1#2	3	3.56	0.071	23	1.9	0.0076	0.019
TA10-3	3	5.17	0.22	18	2.3	0.0	0.122
TA10-4	1	0.70	0.0	8	1.9	0.0	0.0
TA10-5	3	2.91	0.02	20	1.4	0.005	0.036
TA10-7	3	0.23	0.035	23	2.9	0.014	0.011
TA10-21	4	0.18	0.0	22	2.0	0.0	0.0

[a]Total uranium in μg/g.

TABLE D-V

GROSS-ALPHA AND -BETA ACTIVITY VS SELECTED RADIOCHEMICAL ANALYSES IN THE 20-30 CM LAYER
(pCi/g except as noted)

Location	Gross β	^{90}Sr	^{137}Cs	Gross β	U-T[b]	^{238}Pu	^{239}Pu
C2-1P	5	0.05	---	1	2.9	---	---
C3-5P	4	0.189	---	24	2.9	---	---
C6-17P	3	0.243	---	6	2.8	---	---
C7-18P	4	0.0	---	8	3.9	---	---
C8-2P	5	0.222	0.0	22	2.6	0.0	0.011
C8-14P	4	0.19	---	5	3.5	---	---
C9-3P	2	0.215	0.0	2	3.3	0.0	0.0
C9-45P	3	0.17	0.10	13	3.1	0.0088	0.019
WB-5P	4	0.141	---	15	3.1	---	---
WC-3P	6	0.06	---	2	4.4	---	---
EB-2P	4	0.254	0.0	20	3.2	0.0	0.016
EC-1P	4	0.114	0.0	12	2.4	0.0	0.0
SC-2BP	5	3.81	---	38	2.8	---	---
SC-4CP	4	1.00	---	11	3.2	---	---
SC-6CP	1	0.29	0.12	6	1.5	0.0	0.003
SC-7CP	3	0.27	0.50	5	1.8	0.0	0.020
TA10-1#1	2	2.23	0.034	10	1.6	0.0	0.012
TA10-1#2	4	4.16	0.057	25	1.1	0.010	0.019
TA10-3	2	0.57	0.07	32	1.9	0.004	0.031
TA10-4	3	0.54	0.051	10	2.5	0.0	0.002
TA10-5	4	1.04	0.0	10	3.3	0.0	0.005
TA10-7	3	0.16	0.042	17	2.5	0.0022	0.0045
TA10-21	2	0.27	0.058	13	3.6	0.0	0.005

[a]Total uranium in μg/g.

TABLE D-VI
GROSS-ALPHA AND -BETA ACTIVITY IN 0-30 CM LAYER
(pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α	Location	Gross β	Gross α
CTR	2	35	C6-5	1	22	C8-2	6	25
C1-1	2	52	C6-6	5	26	C8-3	6	20
C1-2	3	51	C6-7*			C8-4	3	15
C1-3	2	32	C6-8	1	19	C8-5	5	10
C2-1	1	29	C6-9	2	44	C8-6	6	26
C2-2	2	62	C6-10	3	22	C8-7	5	8
C2-3	2	29	C6-11	3	17	C8-8	4	46
C2-4	2	39	C6-12	3	23	C8-9	4	42
C2-5	3	23	C6-13	2	32	C8-10	5	26
C2-6	1	39	C6-14	3	37	C8-11	5	17
C3-1	1	20	C6-15	2	19	C8-12*		
C3-2	3	25	C6-16	2	22	C8-13	5	4
C3-3	2	24	C6-17	1	29	C8-14	4	15
C3-4	1	47	C6-18	1	23	C8-15	5	11
C3-5	3	25	C6-19	2	29	C8-16	4	20
C3-6	4	16	C6-20	2	26	C8-17	4	35
C3-7	4	30	C7-1	2	41	C8-18	6	25
C3-8	4	32	C7-2	5	14	C8-19	5	19
C4-1	3	51	C7-3	5	27	C8-20	5	11
C4-2	2	12	C7-4	4	27	C8-21	4	20
C4-3	3	38	C7-5	1	17	C8-22	3	5
C4-4	4	25	C7-6*			C8-23	3	5
C4-5	3	26	C7-7	2	29	C8-24	3	2
C4-6	2	45	C7-8	2	19	C8-25	3	14
C4-7	2	47	C7-9*			C8-26	3	1
C4-8	2	30	C7-10	2	22	C8-27	4	11
C4-9	2	35	C7-11	1	18	C8-28	2	4
C4-10	4	48	C7-12	3	13	C8-29	2	22
C5-1	2	30	C7-13	2	13	C8-30	2	32
C5-2	2	27	C7-14	5	0	C9-1	7	15
C5-3	4	26	C7-15	2	17	C9-2	2	15
C5-4	1	29	C7-16	6	9	C9-3	4	21
C5-5	4	38	C7-17	3	30	C9-4	4	24
C5-6	3	23	C7-18	2	41	C9-5	4	45
C5-7	3	26	C7-19	3	12	C9-6	3	12
C5-8	3	12	C7-20	4	23	C9-7*		
C5-9	4	19	C7-21	4	23	C9-8	4	53
C5-10	7	42	C7-22	2	22	C9-9	3	45
C5-11	4	32	C7-23	2	7	C9-10	3	73
C5-12	3	12	C7-24	3	11	C9-11	5	50
C5-13	3	23	C7-25	2	10	C9-12*		
C5-14	3	24	C7-26	4	20	C9-13	4	16
C5-15	0	35	C7-27	2	14	C9-14	3	23
C6-1	2	36	C7-28	1	0	C9-15	4	21
C6-2	6	10	C7-29	2	30	C9-16	3	54
C6-3	3	24	C7-30	2	23	C9-17	3	36
C6-4	1	16	C8-1	2	36	C9-18*		

*Not sampled; bedrock < 30 cm.

TABLE D-VI (cont)

Location	Gross β	Gross α	Location	Gross β	Gross α	Location	Gross β	Gross α
C9-19*			EB-6	6	22	SC-6C1	2	11
C9-20*			EC-1	1	6	SC-6C2	3	50
C9-21	4	22	EC-2	1	0	SC-6C3	1	4
C9-22	4	14	EC-3	1	13	SC-7C1	2	17
C9-23	9	8	EC-4	5	1	SC-7C2	2	2
C9-24	6	21	EC-5	3	10	SC-7C3	1	12
C9-25	4	24	EC-6	2	16	SC-8C1	2	48
C9-26	5	4	ED-1	2	20	SC-8C2	2	50
C9-27	4	10	ED-2	2	0	SC-8C3	3	37
C9-28	5	10	ED-3	2	17	SC-1D1	2	27
C9-29	5	9	ED-4	2	10	SC-1D2	3	25
C9-30*			ED-5	2	12	SC-1D3	2	36
C9-31*			ED-6	5	26	SC-2D1	2	25
C9-32	4	10	C2-1P	4	24	SC-2D2	4	30
C9-33*			C3-5P	5	37	SC-2D3	2	47
C9-34	3	19	C6-17P	5	10	SC-3D1	2	33
C9-35	2	30	C7-18P	5	16	SC-3D2	2	23
C9-36	4	15	C8-2P	5	24	SC-3D3	2	27
C9-37	5	24	C8-14P	5	10	SC-4D1	3	18
C9-38	6	10	C9-3P	4	17	SC-4D2	2	27
C9-39	5	36	C9-45P	3	17	SC-4D3	1	16
C9-40*			WB-5P	5	22	SC-2BP	5	33
C9-41	6	28	WC-3P	6	4	SC-4CP	3	17
C9-42	5	23	EB-2P	5	19	SC-6CP	2	4
C9-43	6	6	EC-1P	5	16	SC-7CP	3	5
C9-44	4	7	SC-1A1	4	17	10-1N	4	33
C9-45	5	12	SC-1A2	4	17	10-1E	4	29
WA-1	2	38	SC-1A3	6	23	10-2E	3	22
WA-2	1	23	SC-2A1	7	41	10-3E	2	35
WA-3	1	18	SC-2A2	3	30	10-4E	2	24
WA-4	1	12	SC-2A3	2	42	10-5E	3	37
WA-5	3	25	SC-1B1	5	35	10-6E	2	12
WB-1	3	13	SC-1B2	4	19	10-7E	4	16
WB-2	1	12	SC-1B3	6	18	10-8E	0	30
WB-3	5	10	SC-2B1	4	37	10-1W	2	30
WB-4	1	19	SC-2B2	4	37	10-2W	1	33
WB-5	2	22	SC-2B3	3	39	10-3W	2	18
WC-1	5	13	SC-3B1	12	14	10-4W	3	25
WC-2	2	12	SC-3B2	5	25	10-5W	4	27
WC-3	2	14	SC-3B3	7	35	10-6W	3	12
WC-4	3	0	SC-1C1	2	12	10-7W	2	33
WC-5	1	10	SC-1C2	1	19	1001	1	17
WD-5	2	20	SC-1C3	2	17	1002	4	1
WD-6	2	6	SC-2C1	2	42	1003	3	19
EA-1	2	47	SC-2C2	2	8	1004	3	33
EA-2	2	7	SC-2C3	3	18	1005	3	25
EA-3	1	29	SC-3C1	2	19	1006	2	19
EA-4	3	22	SC-3C2	3	31	1008	5	27
EA-5	4	24	SC-3C3	1	33	TA10-1#1P	3	20
EA-6	2	41	SC-4C1	1	22	TA10-1#2P	3	20
EB-1	4	24	SC-4C2	2	14	TA10-3P	3	21
EB-2	2	32	SC-4C3	1	17	TA10-4P	3	10
EB-3	4	10	SC-5C1	1	35	TA10-5P	3	14
EB-4	3	22	SC-5C2	2	36	TA10-7P	3	19
EB-5	1	23	SC-5C3	2	31	TA10-21P	3	24

*Not sampled; bedrock <30 cm.

TABLE D-VII

GROSS-ALPHA AND -BETA ACTIVITY VS SELECTED RADIOCHEMICAL ANALYSES IN THE 0-30 CM LAYER (pCi/g except as noted)

Location	Gross β	^{90}Sr	^{137}Cs	Gross α	U-T[a]	^{238}Pu	^{239}Pu
CTR	2	0.34	0.0	35	3.6	0.0	0.027
C3-3	2	0.41	---	24	7.0	---	---
C3-7	4	4.05	---	30	12.0	---	---
C4-2	2	0.36	---	12	6.9	---	---
C5-9	4	0.61	---	18	4.6	---	---
C6-2	6	1.23	0.0	10	4.9	0.0	0.0
C6-6	5	0.49	---	26	3.8	---	---
C6-15	2	0.23	---	19	4.9	---	---
C7-2	5	0.54	0.19	14	4.4	0.0	0.0
C7-16	6	0.79	---	9	5.5	---	
C8-9	4	0.27	---	42	3.4	---	---
C8-21	4	0.23	---	20	7.8	---	---
C9-1	7	0.43	0.0	15	3.3	0.0	0.12
C9-24	6	0.45	---	21	4.5	---	---
WB-3	5	0.237	---	10	2.9	---	---
WC-1	5	0.223	---	13	3.8	---	---
EB-6	6	0.267	0.26	22	3.3	0.0	0.026
EC-4	5	0.60	0.0	1	1.6	0.0	0.08
ED-6	5	0.144	0.26	26	4.1	0.0	0.026
C2-1P	4	0.70	---	24	2.69	---	---
C3-5P	5	0.99	---	37	4.98	---	---
C6-17P	5	0.15	---	10	2.80	---	---
C7-18P	5	0.20	---	16	3.70	---	---
C8-2P	5	0.29	0.05	24	2.38	0.0	0.01
C8-14P	5	0.30	---	10	3.18	---	---
C9-3P	4	0.49	0.30	17	3.63	0.0	0.01
C9-45P	3	0.29	0.18	17	3.40	0.01	0.02
WB-5P	5	0.19	---	22	3.3	---	---
WC-3P	6	0.23	---	4	4.60	---	---
EB-2P	5	0.34	0.13	19	3.2	0.0	0.01
EC-1P	5	0.26	0.38	16	2.4	0.0	0.0
SC-3B1	12	4.27	---	14	7.2	---	---
SC-3B2	5	8.77	---	25	5.9	---	---
SC-3B3	7	23.2	---	35	19.0	---	---
SC-8C1	2	0.17	0.19	48	1.5	0.0	0.007
SC-8C2	2	0.59	0.50	50	2.5	0.004	0.022
SC-8C3	3	0.28	0.14	37	1.6	0.0	0.024
SC-2BP	5	3.97	---	33	3.97	---	---
SC-4CP	3	0.58	---	17	3.53	---	---
SC-6CP	2	0.23	0.05	4	1.68	0.0	0.0
SC-7CP	3	0.29	0.37	5	2.00	0.0	0.01
10-1N	4	0.95	---	33	4.2	---	---
10-1E	4	3.5	---	29	6.6	---	---
10-2E	3	1.86	---	22	3.6	---	---
10-3E	2	2.18	---	35	3.8	---	---

TABLE D-VII (cont)

Location	Gross β	^{90}Sr	^{137}Cs	Gross α	U-T[a]	^{238}Pu	^{239}Pu
10-4E	2	1.64	---	24	3.4	---	---
10-5E	3	4.23	---	37	3.0	---	---
10-6E	2	3.95	---	12	3.1	---	---
10-7E	4	3.64	---	16	5.4	---	---
10-8E	0	2.18	---	30	11.1	---	---
10-1W	2	1.55	---	30	3.4	---	---
10-2W	1	2.59	---	33	50.0	---	---
10-3W	2	2.86	---	18	10.0	---	---
10-4W	3	1.55	---	25	3.3	---	---
10-5W	4	4.09	---	27	3.4	---	---
10-6W	3	3.00	---	12	3.1	---	---
10-7W	2	0.62	---	33	3.5	---	---
1001	1	2.36	---	17	1.7	---	---
1002	4	1.14	---	1	8.4	---	---
1003	3	0.41	---	19	7.4	---	---
1004	3	2.91	---	33	6.5	---	---
1005	3	3.86	---	25	3.3	---	---
1006	2	2.00	---	19	5.7	---	---
1008	5	6.91	---	27	3.3	---	---
TA10-1#1P	3	3.73	0.10	20	2.40	0.0	0.03
TA10-1#2P	3	3.60	0.14	20	1.68	0.01	0.03
TA10-3P	3	2.48	0.23	21	2.10	0.01	0.06
TA10-4P	3	1.17	0.09	10	1.78	0.0	0.01
TA10-5P	3	2.19	0.16	14	1.90	0.0	0.02
TA10-7P	3	0.39	0.09	19	2.38	0.01	0.01
TA10-21P	3	0.27	0.10	24	2.50	0.0	0.01

[a]Total uranium in $\mu g/g$.

TABLE D-VIII

GROSS-ALPHA AND -BETA ACTIVITY VS PENETRATING DOSE FROM THE 0-30 CM LAYER (pCi/g vs μR/h)

Location	Gross β	Gross α	Pen. Dose[a]	Location	Gross β	Gross α	Pen. Dose[a]
CTR	2	35	20.00	C8-4	3	15	22.00
C1-1	2	52	20.00	C8-13	5	4	21.70
C2-1	1	29	20.80	C8-14	4	15	26.12
C2-4	2	39	21.00	C8-15	5	11	22.77
C3-1	1	20	21.18	C8-16	4	20	21.70
C4-5	3	26	20.00	C8-17	4	35	20.85
C4-8	2	30	20.00	C8-18	6	25	21.00
C5-1	2	30	21.00	C8-19	5	19	22.23
C5-5	4	38	20.00	C8-20	5	11	22.61
C5-10	7	42	18.00	C8-22	3	5	22.75
C6-1	2	36	18.00	C8-23	3	5	24.83
C6-2	6	10	21.00	C8-24	3	2	24.70
C6-3	3	24	21.00	C8-25	3	14	22.75
C6-4	1	16	21.00	C8-26	3	1	23.03
C6-7	---	---	23.00	C8-27	4	11	23.73
C6-10	3	22	23.00	C8-28	2	4	21.66
C6-13	2	32	20.00	C9-1	7	15	21.18
C6-16	2	22	20.00	C9-2	2	15	18.96
C6-19	2	29	18.00	C9-3	4	21	23.73
C7-1	2	41	20.50	C9-4	4	24	22.00
C7-3	5	27	19.43	C9-7	---	---	19.52
C7-4	4	27	21.00	C9-8	4	53	18.70
C7-5	1	17	22.00	C9-9	3	45	19.55
C7-7	2	29	22.00	C9-10	3	73	19.08
C7-10	2	22	23.00	C9-11	5	50	18.97
C7-15	2	17	22.00	C9-12	---	---	18.48
C7-16	6	9	24.26	C9-16	3	54	20.19
C7-17	3	30	21.34	C9-17	3	36	18.20
C7-18	2	41	20.50	C9-18	---	---	19.36
C7-19	3	12	20.54	C9-19	---	---	19.21
C7-20	4	23	20.04	C9-20	---	---	19.08
C7-21	4	23	20.92	C9-22	4	14	23.72
C7-22	2	22	21.84	C9-23	9	8	21.00
C7-23	2	7	22.30	C9-24	6	21	21.22
C7-24	3	11	24.14	C9-25	4	24	21.03
C7-25	2	10	22.60	C9-26	5	4	17.66
C7-26	4	20	23.12	C9-27	4	10	21.60
C7-27	2	14	20.29	C9-28	5	10	23.38
C7-28	1	0	18.83	C9-29	5	9	24.35
C8-1	2	36	20.00	C9-30	---	---	24.35
C8-2	6	25	19.18	C9-33	---	---	22.00
C8-3	6	20	19.67	C9-40	---	---	20.00

[a]Total penetrating photon dose from all sources in μR/h.

TABLE D-IX

NATURALLY OCCURRING URANIUM AND THORIUM IN SURFACE SOIL
(μg/g)

Location	U-T[a]	^{232}Th
C8-17	3.70	16.8
C9-8	3.50	20.1
C9-10	3.30	16.6
C9-19	3.20	15.7
EB-3	2.40	11.9
SC-8C1	1.60	12.3
SC-8C2	2.50	11.5
SC-8C3	1.50	9.2

[a]Total uranium

TABLE D-X

IN SITU MEASUREMENT[a] OF NATURALLY OCCURRING RADIONUCLIDES VS PENETRATING DOSE ESTIMATES[b]

Location	^{40}K (pCi/g)	U-T (μg/g)	^{232}Th (μg/g)	μR/hr
No. Mesa (GLO Landmark)	35.5	6.09	19.5	23.89
No. Mesa (Stables)	29.5	3.98	15.1	20.44
WB-3	32.7	5.09	16.4	21.54
Bayo Floor (Pit under Bayo Point)	33.9	5.33	16.9	22.16
C9-27	37.3	8.09	22.7	26.14
EB-3	35.0	3.91	13.8	20.55
Otowi Mesa (Survey Landmark)	32.8	0.51	16.1	18.95

[a]GeLi γ spectral analyses.

[b]Estimate includes 0.45 μR/h for fallout and ~7 μR for cosmic influence.

TABLE D-XI

GROSS-ALPHA AND -BETA ACTIVITY IN 60-120 CM LAYER

(pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α	Location	Gross β	Gross α
BDH-1	4	47	BDH-26	4	49	BDH-46	3	49
BDH-2	2	26	BDH-27	8	42	BDH-47	2	39
BDH-3	1	24	BDH-28	7	36	BDH-48	2	62
BDH-4	4	20	BDH-29	2	37	BDH-49&50	4	26
BDH-5	2	18	BDH-30	13	41	BDH-51	3	35
BDH-6	4	44	BDH-31	3	29	BDH-52	4	56
BDH-7	4	27	BDH-32	3	39	BDH-53	2	20
BDH-8&9	3	47	BDH-33	2	41	BDH-54	9	44
BDH-10	5	23	BDH-34	4	22	BDH-55	2	23
BDH-11	2	49	BDH-33&34	2	32	BDH-56	2	36
BDH-12	2	48	BDH-35	3	36	BDH-57	3	51
BDH-13	2	47	BDH-36	4	25	BDH-58	2	8
BDH-14	2	39	BDH-35&36	4	38	BDH-59	12	6
BDH-15	1	25	BDH-38	2	27	BDH-60	48	0
BDH-16	2	43	BDH-39	2	29	BDH-61	4	27
BDH-17	2	33	BDH-40	3	49	BDH-62	2	23
BDH-18	2	37	BDH-39&40	3	12	BDH-63	2	18
BDH-19	4	26	BDH-41	3	36	BDH-64	3	32
BDH-20&21	5	42	BDH-42	3	22	BDH-65	4	44
BDH-22	2	27	BDH-41&42	2	24	BDH-66	2	14
BDH-23	1	30	BDH-43	3	30	BDH-67	3	17
BDH-24	2	12	BDH-44	1	37	BDH-69	3	4
BDH-24&25	3	20	BDH-45	3	26			

TABLE D-XII

GROSS-ALPHA AND -BETA ACTIVITY VS SELECTED RADIOCHEMICAL ANALYSES IN THE 60-120 CM LAYER

(pCi/g except as noted)

Location	Gross β	^{90}Sr	^{137}Cs	Gross α	U-T[a]	^{238}Pu	^{239}Pu
BDH-1	4	5.08	---	47	---	---	---
BDH-8&9	3	0.11	---	47	---	---	---
BDH-20&21	5	5.81	---	42	---	---	---
BDH-24&25	3	9.46	---	20	---	---	---
BDH-30	13	26.2	---	41	---	---	---
BDH-49&50	4	0.37	---	26	---	---	---
BDH-60	48	67.2	0.0	0	1.00	0.0	0.0
BDH-69	3	0.06	---	4	---	---	---

[a]Total uranium in μg/g.

TABLE D-XIII

GROSS-ALPHA AND -BETA ACTIVITY IN THE 0-150 CM LAYER (pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-1	2	29	41SW-1	3	32
48B-1	2	17	41C-1	6	20
48AA-1	2	46	42N-1	6	8
48BB-1	2	33	42S-1	4	22
48C-1	0	36	42E-1	8	8
50AL-1	8	30	42W-1	5	22
50BL-1	1	14	42C-1	6	8
50CL-1	4	10	43N-1	3	8
50DL-1	2	32	43S-1	4	46
50EL-1	3	27	43E-1	7	22
50FL-1	2	23	43W-1	5	15
50GL-1	10	33	43C-1	5	24
2168A-1	1	22	44N-1	3	6
2168B-1	2	17	44S-1	4	8
41NW-1	4	20	44E-1	4	29
41SE-1	4	15	44W-1	3	20
41NE-1	3	11	44C-1	2	20

TABLE D-XIV

GROSS-ALPHA AND -BETA ACTIVITY VS ^{90}Sr ACTIVITY IN THE 0-150 CM LAYER (pCi/g)

Location	Gross β	^{90}Sr	Gross α
41SE-1	4	2.46	15
42S-1	4	0.21	22
43N-1	3	1.13	8
43S-1	4	0.31	46

TABLE D-XV

GROSS-ALPHA AND -BETA ACTIVITY IN 150-300 CM LAYER (pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-2	3	42	41SW-2	3	39
48B-2	2	51	41C-2	35	32
48AA-2	4	17	42N-2	3	17
48BB-2	5	39	42S-2	5	22
48C-2	4	20	42E-2	4	22
50AL-2	4	5	42W-2	8	29
50BL-2	1	16	42C-2	17	6
50CL-2	3	14	43N-2	3	5
50DL-2	3	12	43S-2	4	25
50EL-2	3	33	43E-2	5	10
50FL-2	2	22	43W-2	2	17
50GL-2	2	10	43C-2	5	51
2168A-2	2	24	44N-2	2	11
2168B-2	2	24	44S-2	4	20
41NW-2	4	13	44E-2	3	20
41SE-2	3	0	44W-2	2	24
41NE-2	3	0	44C-2	2	22

TABLE D-XVI

GROSS-ALPHA AND -BETA ACTIVITY VS ^{90}Sr ACTIVITY IN THE 150-300 CM LAYER (pCi/g)

Location	Gross β	^{90}Sr	Gross α
41NW-2	4	0.23	13
41SE-2	3	1.04	0
41NE-2	3	1.90	0
42N-2	3	2.90	17
43N-2	3	0.04	5
43S-2	4	0.15	25
44E-2	3	0.10	20

TABLE D-XVII

GROSS-ALPHA AND -BETA ACTIVITY IN 300-460 CM LAYER (pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-3	3	23	41SW-3	4	6
48B-3	15	12	41C-3	501	32
48AA-3	7	41	42N-3	3	11
48BB-3	91	22	42S-3	4	13
48C-3	3	38	42E-3	3	22
50AL-3	2	10	42W-3	169	25
50BL-3	2	13	42C-3	4	27
50CL-3	1	12	43N-3	2	22
50DL-3	2	16	43S-3	3	24
50EL-3	1	17	43E-3	905	24
50FL-3	3	13	43W-3	4	15
50GL-3	2	36	43C-3	69	18
2168A-3	2	24	44N-3	4	29
2168B-3	1	26	44S-3	2	17
41NW-3	4	13	44E-3	3	1
41SE-3	3	1	44W-3	4	18
41NE-3	4	3	44C-3	3	43

TABLE D-XVIII

GROSS-ALPHA AND -BETA ACTIVITY VS ^{90}Sr AND URANIUM IN 300-460 CM LAYER (pCi/g except as noted)

Location	Gross β	^{90}Sr	Gross α	U-T[a]
48B-3	15	---	12	2.80
48BB-3	91	---	22	5.60
41C-3	501	1140.00	32	---
43E-3	905	1290.0	24	---

[a]Total uranium in μg/g.

TABLE D-XIX

GROSS-ALPHA AND -BETA ACTIVITY IN 460-600 CM LAYER (pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-4	5	24	41SW-4	3	11
48B-4	5	25	41C-4	539	20
48AA-4	4	17	42N-4	48	30
48BB-4	291	24	42S-4	4	22
48C-4	2	27	42E-4	3	22
50AL-4	---	--	42W-4	206	24
50BL-4	3	29	42C-4	185	17
50CL-4	3	54	43N-4	3	13
50DL-4	2	35	43S-4	3	29
50EL-4	0	29	43E-4	2214	27
50FL-4	3	18	43W-4	4	27
50GL-4	2	18	43C-4	33	30
2168A-4	0	22	44N-4	4	8
2168B-4	2	25	44S-4	5	15
41NW-4	4	6	44E-4	3	13
41SE-4	10	32	44W-4	4	25
41NE-4	4	11	44C-4	3	49

TABLE XX

GROSS-ALPHA AND -BETA ACTIVITY VS SELECTED RADIOCHEMICAL ANALYSES IN 460-600 CM LAYER (pCi/g except as noted)

Location	Gross β	^{90}Sr	^{137}Cs	Gross α	U-T[a]	^{238}Pu	^{239}Pu
48BB-4	291	810.0	0.025	24	1.9	0.0	0.9
41NW-4	4	0.30	---	6	---	---	---
41NE-4	4	2.60	---	11	---	---	---
41SW-4	3	0.10	---	11	---	---	---
41C-4	539	1060.0	---	20	---	---	---
43N-4	3	0.20	---	13	---	---	---
43S-4	3	0.00	---	29	---	---	---
43E-4	2214	4310.0	---	27	---	---	---
43W-4	4	0.00	---	27	---	---	---

[a]Total uranium in μg/g.

TABLE D-XXI

GROSS-ALPHA AND -BETA ACTIVITY IN 600-760 CM LAYER
(pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-5	2	32	41SW-5	4	18
48B-5	3	25	41C-5	355	18
48AA-5	3	6	42N-5	109	25
48BB-5	46	17	42S-5	3	32
48C-5	3	22	42E-5	4	10
50AL-5	---	---	42W-5	839	29
50BL-5	2	61	42C-5	47	22
50CL-5	1	31	43N-5	3	13
50DL-5	1	44	43S-5	4	24
50EL-5	2	25	43E-5	389	8
50FL-5	2	41	43W-5	3	36
50GL-5	1	45	43C-5	12	22
2168A-5	3	26	44N-5	3	8
2168B-5	4	29	44S-5	4	15
41NW-5	4	24	44E-5	2	20
41SE-5	5	20	44W-5	1	20
41NE-5	105	46	44C-5	3	41

TABLE D-XXII

GROSS-ALPHA AND -BETA ACTIVITY VS SELECTED RADIOCHEMICAL ANALYSES IN 600-760 CM LAYER
pCi/g except as noted)

Location	Gross β	^{90}Sr	^{137}Cs	Gross α	U-T[a]	^{238}Pu	^{239}Pu
48BB-5	46	169.00	0.0	17	4.1	0.0	0.011
2168A-5	3	1.59	---	26	---	---	---
2168B-5	4	0.15	---	29	---	---	---
41NE-5	105	90.00	---	46	---	---	---
41SW-5	4	0.50	---	18	---	---	---
42N-5	109	176.0	---	25	---	---	---
43N-5	3	0.09	---	13	---	---	---
43S-5	4	0.09	---	24	---	---	---
43W-5	3	0.22	---	36	---	---	---

[a]Total uranium in μg/g.

TABLE D-XXIII

GROSS-ALPHA AND -BETA ACTIVITY IN 760-920 CM LAYER (pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-6	3	31	41C-6	208	55
48B-6	3	25	42N-6	49	30
48AA-6	2	36	42S-6	4	32
48BB-6	23	25	42E-6	5	29
48C-6	2	29	42W-6	227	18
50AL-6	2	42	42C-6	52	32
50BL-6	2	74	43N-6	4	15
50CL-6	3	51	43S-6	4	32
50DL-6	2	58	43E-6	224	43
50EL-6	3	49	43W-6	4	39
50FL-6	4	14	43C-6	20	20
50GL-6	4	60	44N-6	4	18
41NW-6	4	51	44S-6	5	25
41SE-6	4	32	44E-6	4	13
41NE-6	22	41	44W-6	2	20
41SW-6	3	17	44C-6	3	36

TABLE D-XXIV

GROSS-ALPHA AND -BETA ACTIVITY VS ^{90}Sr AND URANIUM IN THE 760-920 CM LAYER (pCi/g except as noted)

Location	Gross β	^{90}Sr	Gross α	U-T[a]
48BB-6	23	---	25	5.00
41NW-6	4	0.32	51	---
41SW-6	3	0.61	17	---
43N-6	4	0.20	15	---
43S-6	4	0.0	32	---
43W-6	4	0.10	39	---

[a]Total uranium in μg/g.

TABLE D-XXV

GROSS-ALPHA AND -BETA ACTIVITY IN 920-1070 CM LAYER (pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-7	5	22	41C-7	140	24
48B-7	5	18	42N-7	4	43
48AA-7	5	14	42S-7	4	36
48BB-7	20	13	42E-7	5	15
48C-7	3	10	42W-7	108	36
50AL-7	4	58	42C-7	39	8
50BL-7	5	38	43N-7	4	20
50CL-7	4	61	43S-7	3	18
50DL-7	4	77	43E-7	318	18
50EL-7	6	57	43W-7	6	15
50FL-7	4	38	43C-7	30	15
50GL-7	4	41	44N-7	3	8
41NW-7	5	55	44S-7	3	29
41SE-7	5	56	44E-7	4	29
41NE-7	14	39	44W-7	3	39
41SW-7	4	55	44C-7	3	48

TABLE D-XXVI

GROSS-ALPHA AND -BETA ACTIVITY VS ^{90}Sr IN 920-1070 CM LAYER (pCi/g)

Location	Gross β	^{90}Sr	Gross α
48A-7	5	0.50	22
48B-7	5	0.77	18
48AA-7	5	0.71	14
48BB-7	20	37.2	13
48C-7	3	0.16	10
50AL-7	4	0.31	58
50BL-7	5	0.07	38
50CL-7	4	0.12	61
50DL-7	4	0.16	77
50EL-7	6	0.18	57
50FL-7	4	0.22	38
50GL-7	4	0.12	41
41SW-7	4	0.0	55
41C-7	140	335.0	24
43N-7	4	0.0	20

TABLE D-XXVII

GROSS-ALPHA AND -BETA ACTIVITY IN 1070-1220 CM LAYER
(pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-8	3	16	42N-8	8	110
48B-8	3	12	42S-8	6	44
48AA-8	4	6	42E-8	7	17
48BB-8	5	10	42W-8	138	22
50AL-8	4	52	42C-8	20	27
50BL-8	4	54	43N-8	5	55
50CL-8	3	83	43S-8	5	36
50DL-8	3	62	43E-8	148	25
50EL-8	4	33	43W-8	6	25
50FL-8	3	107	43C-8	11	13
50GL-8	4	38	44N-8	5	24
41NW-8	6	55	44S-8	5	37
41SE-8	6	56	44E-8	3	49
41NE-8	19	34	44W-8	4	56
41SW-8	4	74	44C-8	6	46
41C-8	85	63			

TABLE D-XXVIII

GROSS-ALPHA AND -BETA ACTIVITY IN 1220-1370 CM LAYER
(pCi/g)

Location	Gross β	Gross α	Location	Gross β	Gross α
48A-9	3	22	50CL-9	4	25
48B-9	3	22	50DL-9	4	39
48AA-9	2	4	50EL-9	5	49
48BB-9	8	14	50FL-9	3	64
50AL-9	4	43	50GL-9	5	54
50BL-9	3	42			

TABLE D-XXIX

GROSS-ALPHA AND -BETA ACTIVITY IN 1370-1530 CM LAYER (pCi/g)

Location	Gross β	Gross α
48A-10	4	16
48B-10	3	14
48AA-10	3	10
48BB-10	8	4
50AL-10	2	42
50BL-10	2	51
50CL-10	4	56
50DL-10	4	39
50EL-10	5	35
50FL-10	6	77
50GL-70	4	43

TABLE D-XXX

GROSS-ALPHA AND -BETA ACTIVITY IN 1530-2000 CM LAYER (pCi/g)

Location	Gross β	Gross α
50AL-11	4	37
50AL-12	4	37
50AL-13	1	36

TABLE D-XXXI

BACKGROUND RADIOACTIVITY IN GRASSES
(pCi/g except as noted)

Location	^{90}Sr	^{137}Cs	U-T[a]	^{238}Pu	^{239}Pu
2NE	0.205	0.181	0.07	0.00075	0.00227
4NW	0.205	0.210	0.10	0.0	0.00280
4SW	0.236	0.221	0.09	0.0	0.00489
8SE	0.208	0.150	0.06	0.00107	0.00208
G.G.	0.263	0.307	0.06	0.00039	0.00071
7NW	2.81	0.192	0.06	0.00042	0.0035
8NE	0.179	0.217	0.08	0.00137	0.0036
7SE	0.505	0.285	0.07	0.0	0.00453
8SW	0.789	0.256	0.06	0.0065	0.0041

[a] Total uranium in $\mu g/g$.

TABLE D-XXXII

RADIOACTIVITY IN BAYO SITE GRASSES
(pCi/g except as noted)

Location	^{90}Sr	^{137}Cs	U-T[a]	^{238}Pu	^{239}Pu
EG	0.491	0.061	0.05	0.00069	0.00128
EA-2	0.791	0.109	0.05	0.0	0.00209
EC-2&3	0.852	0.046	0.14	0.0	0.00222
EC-4&5	0.505	0.178	0.05	0.0	0.00241
WB-2	0.408	0.105	0.06	0.00028	0.00207
WB-3	0.572	0.032	0.04	0.0	0.00127
C2-5	0.594	0.062	0.05	0.0	0.00195
C6-10	0.185	0.081	0.07	0.0	0.00152
C6-20	0.0365	0.037	0.06	0.0	0.00131
C7-28	0.246	0.067	0.03	0.00015	0.00557
C7-30	0.446	0.071	0.06	0.00020	0.00178
C8-1	0.375	0.111	0.0001	0.00039	0.00239
C8-20	0.326	0.045	0.06	0.00016	0.00124
C9-2	0.341	0.168	0.10	0.0	0.00287
C9-25	0.198	0.109	0.07	0.00078	0.00261

[a]Total uranium in $\mu g/g$.

TABLE D-XXXIII

EXTERNAL PENETRATING RADIATION IN THE TOWNSITE

TLD Station	Results $\mu R/h$[a]
1. Barranca School	17.3
2. Cumbres School	17.6
3. Golf Course	18.5
4. Arkansas Avenue	18.8
5. Diamond Drive	18.8
6. 48th Street	19.0
7. Fuller Lodge	21.2
8. Acorn Street	17.9
10. Los Alamos Airport	19.7
28. Pajarito Acres	15.9
29. White Rock Sewer Treatment Plant	17.4
	$\bar{x} \pm \sigma = 18.4 \pm 1.4$

[a]4th Quarter 1976 measurements by high-pressure ion chamber.

TABLE D-XXXIV

EXTERNAL PENETRATING RADIATION[a] AT THE FORMER BAYO SITE

Canyon Floor

Location	μR/hr	Location	μR/hr	Location	μR/hr	Location	μR/hr	Location	μR/hr
C2-1	20.8	C7-21	20.9	C7-30	19.0	C9-1	21.2	EB-3	18.1
C3-1	21.2	C7-22	21.8	C8-2	19.2	C9-2	19.0	EB-4	20.5
C7-2	19.1	C7-23	22.3	C8-3	19.7	C9-25	21.0	EB-5	19.4
C7-3	19.4	C7-24	24.1	C8-16	21.7	C9-26	17.7	EB-6	20.2
C7-13	20.0	C7-25	22.6	C8-17	20.9	C9-27	21.6	EC-2	18.7
C7-16	24.3	C7-26	23.1	C8-18	21.0	C9-28	23.4	EC-3	18.4
C7-17	21.3	C7-27	20.3	C8-19	22.2	C9-44	20.2	EC-4	19.0
C7-18	20.5	C7-28	18.8	C8-20	22.6	C9-45	19.7	EC-5	19.2
C7-19	20.5	C7-29	19.3	C8-30	20.7	EB-2	21.0	EC-6	19.9
C7-20	20.1								

Talus Slopes

Location	μR/hr	Location	μR/hr
C7-15	22.0	C9-3	23.7
C8-13	21.7	C9-22	23.7
C8-14	26.1	C9-23	21.0
C8-15	22.8	C9-24	21.2
C8-22	22.7	C9-29	19.3
C8-23	24.8	C9-30	24.4
C8-24	24.7	C9-31	23.5
C8-25	22.7	C9-37	24.6
C8-26	23.0	C9-41	24.2
C8-27	23.7	C9-42	23.3
C8-28	21.7	C9-43	23.8

Mesa Tops

Location	μR/hr	Location	μR/hr
C9-7	19.2	C9-16	20.2
C9-8	19.0	C9-17	18.2
C9-9	17.8	C9-18	19.4
C9-10	19.2	C9-19	19.2
C9-11	19.1	C9-20	18.0
C9-12	18.5	C9-40	20.3
C9-13	20.2		

[a]Measurements by High Pressure Ion Chamber.

APPENDIX E

INTERPRETATION OF DATA

The data presented here are intended to clarify the bases and methods of evaluation behind many of the numbers appearing in the text, particularly Section IV, Results, and Section V, Evaluation.

Statistics of Sampling Scheme and Results

The accuracy of radiochemical analyses was expressed by the mean of quality control ratios for each nuclide as presented in Table B-IV, Appendix B. Estimates of uranium and ^{90}Sr concentrations in soil were based on surface soil samples for each of the three layers of surface soil (0-5 cm, 0-10 cm, and 0-30 cm). Uranium and ^{90}Sr estimates for these layers appear to underestimate the true population mean, but the difference in each case is well within the uncertainty of the estimate. The precision of sampling results is expressed as the percent error in the estimate of the population mean.

Since (1) the random selection of surface soil samples from the sampling grid resulted in a known sample size, N, for each of the three layers of surface soil (0-5 cm, 0-10 cm, and 0-30 cm), and (2) the sample standard deviation, S, can be used as an estimate of the population standard deviation, σ, in the expression $\bar{X} \pm t_c \sigma/\sqrt{N}$ for each soil layer, it is possible to specify the per cent error in the estimate of each population mean, $\bar{X}$, based on the corresponding sample mean, $\bar{X}$, and an acceptable confidence interval.[E1,E2] In each case the per cent error in the estimate was acceptable as shown in Table E-I. Samples obtained in the structures strata were selected to show whether significant contamination existed in suspect locations. The numbers of samples selected for this purpose were very large relative to the number of radiochemical analyses that could be performed. Consequently, no random sampling strategy was employed and the sample means, including the layers from 0-122 cm and deeper than 122 cm, are likely to be biased to reflect higher levels of activity than the true population mean. Dose estimates based on the biased averages used result in more restrictive radiological assessment than would be the case with an unbiased estimate.

The frequency distributions shown in Fig. E-1 indicate a two population distribution in the 0-5 cm layer. The lower concentration population of each distribution, respectively, is probably representative of local fallout ^{90}Sr (0.49 pCi/g) and primordial uranium (3.88 μg/g). The statistics of these apparently different populations were obtained by fitting the data to a cumulative distribution of a mix of two gaussians.[E3] Other estimates are given in Table E-II. Since the more radiologically restrictive interpretation with regard to Bayo debris occurs with a smaller background, and since the mean of the lower concentration population, background, may be raised somewhat by overlapping contributions from Bayo debris, we have adopted 0.40 pCi/g as representative of ^{90}Sr background and 3.40 μg/g as representative of primordial uranium.

No reported data have been found regarding fallout ^{90}Sr and primordial uranium in the 0-10 cm layer of local soils. Values for each sample in the 0-10 cm layer are the average of the 0-5 cm profile and its corresponding 5-10 cm profile. For ^{90}Sr the ratio of the 0-5 cm layer mean (known) to the 0-10 cm layer mean (known) was set equal to the ratio of the 0-5 cm estimate (known) and the 0-10 cm estimate (unknown). The result was 0.30 pCi/g. For uranium a uniform vertical distribution was assumed so the concentration was 3.40 μg/g as in the 0-5 cm layer.

The frequency distributions shown in Fig. E-2 indicate that fallout ^{90}Sr might be 0.33 pCi/g, whereas primordial uranium cannot be resolved. In the absence of supporting data, 0.20 pCi/g was chosen as representative of fallout Sr in the 0-30 cm layer. The frequency distribution of uranium in Fig. E-2 cannot be resolved into two populations. The value 3.40 μg/g, based on the assumption of uniform distribution, was retained for the 0-30 cm layer of soil.

Inventory of Bayo Debris

A. Estimate Based on the Historical Record (1944-1961)

1. Uranium (see Appendix A, Geohydrology of Bayo Canyon by W. D. Purtymun)

natural (normal) uranium = 2000 kg
depleted uranium = 3380 kg
total expended in tests = 5380 kg

2. ^{90}Sr

- 254 experiments[E8,E9]
- First shot 9/22/44
- First ^{140}La shot 20-25 Ci 10/?/44
- First tuballoy + ^{140}La shot 600 Ci 4/18/45
- First 27 shots 9/22/44-6/16/45
- Total of source strengths from the first 27 shots = 7837 Ci.

} Bayo Operating Records

Evidently each shot did not contain a ^{140}La source as, for example, the first shot. The minimum average source strength, 301 Ci, follows from the assumption that 26 of the first 27 shots did contain ^{140}La. If, on the other hand, the first tuballoy + ^{140}La shot at 600 Ci was a representative average, then 14 of the first 27 shots contained a ^{140}La source.

- ^{140}La sources from 6/16/45-9/?/50 were less than 10 000 Ci (probably same as prior to 6/16/45)
- Bayo Site shut down 9/?/50-3/?/52 to prepare for larger ^{140}La source operation
- estimated ^{90}Sr content:
  - T. N. White estimate dated 2/2/50[E10]
  upper limit = 100 mCi ^{90}Sr/source
  average = 10 mCi ^{90}Sr/source
  experiment rate = 10 sources/year

  (If the average ^{140}La strength per source was 300 Ci, then the activity per cent of ^{90}Sr would be 0.003%.)

  - other estimates of ^{90}Sr content:

wt% in Source	wt% Remaining in ^{140}La "Soup" Isotope Solubility
10 or less	99%+
0.01	99%+
0.0001	99%+

•High Estimate of Bayo Debris Inventory

Assumptions: −13 shots during 9/22/44-6/16/45 at 300 Ci ea
−65 shots during 6/16/45-9/?/50 at 300 Ci ea
−130 shots during 3/?/51-?/?/62 at 10 000 Ci ea
−the ratio of source-strength used to the shipment strength received for the first tuballoy ^{140}La shot is typical.
−100 times as much ^{90}Sr remains with the extractant as that which goes into the source.

Source preparation in TA-10-1 was terminated during the last half of 1950 so it is presumed that no significant discharges were made to the waste pits after that time. Discharges to the waste pits would have been:

$$78 \text{ shots} \times 300 \text{ Ci/source} \times \frac{1000 \text{ Ci/shipment (Tu)}}{600 \text{ Ci/source (Tu)}}$$

$$\times 0.3\% \frac{^{90}\text{Sr}}{^{140}\text{La "Soup"}}$$

$$= 117 \text{ Ci } ^{90}\text{Sr}$$

Discharges to the atmosphere would have been:

78 shots × 300 Ci/source = 23 400 Ci ^{140}La "Soup"
130 shots × 10 000 Ci/source = 1 300 000 Ci ^{140}La "Soup"
Total = 1 323 400 Ci ^{140}La "Soup"
or 39.6 Ci ^{90}Sr

•Low Estimate of Bayo Inventory Debris

Assumptions are the same for the low estimate except for a lower number of ^{140}La source shots; i.e., 8 during 9/22/44-6/16/45, 50 during 6/16/45-9/?/50, and 100 during 3/?/52-?/?/62. The quantity in the waste pits would have been 87 Ci ^{90}Sr and the quantity released to the atmosphere would have been 30.6 Ci ^{90}Sr.

During decommissioning, all waste handling systems and their contents and all surface debris were removed from the canyon. In addition, surface and subsurface rocks and soils showing positive radioactivity in excess of background were excavated and disposed of. This effort most certainly must have removed all but a small fraction of the radioactivity deposited by Bayo operations.

B. Estimates of Bayo Inventory Based on Current Measurements

The surface area of the firing site grid and both canyon floor grids totals 1.367×10^6 m^2. Assuming the density of local soils is typically 1.4 g/cc, the mass of soil in the 0-5 cm layer is 9.56×10^{10} g. This soil mass would contain 0.1 Ci of ^{90}Sr if contaminated to 0.1 pCi/g by Bayo debris compared to a content of 0.03 Ci of ^{90}Sr from fallout. In the same way estimates of the current inventory of Bayo debris and background have been made for pertinent layers of soil. These results appear in Table E-III.

According to these estimates ^{90}Sr deposited as Bayo debris represents a 10 fold increase over that due to fallout background, but it is only 1% of the low estimate of ^{90}Sr released to the environs. Uranium deposited as Bayo debris is 25% of primordial uranium, and 10% of that released to the environs. Evidently the 1963 decommissioning efforts were quite effective in removing ^{90}Sr and uranium from the site.

Dose Estimates

Dose estimates are based on human interaction with pertinent layers of soil. Dose estimates for significant pathways are based on 50 yr dose commitments due to 1 yr exposure of an adult whose habits maximize exposure. The term 50 yr dose commitment as used here means the dose accumulated through 50 yr after one year's chronic exposure. Dose factors used in this evaluation are presented in Table E-IV (Refs. E-11, E-12, E-13).

A. 0-5 cm soil layer

Inhalation of resuspended debris is the significant pathway for this layer and the maximum individual is the full time resident adult. A resuspension factor of $1 \times 10^{-8}\ m^{-1}$ (Ref. E14) was used to calculate airborne concentrations of ^{90}Sr and total uranium. The uranium value was adjusted to natural and depleted uranium components from information given in Appendix A and further divided into isotopes through Refs. E15 and E16. Isotopic concentrations were converted to units of activity to agree with the ^{90}Sr concentration units (Refs. E17 and E18). The quantity of material inhaled was estimated by applying a breathing rate of 8000 m^3/yr (Ref. E19) to the airborne concentration and none of the inhaled material was presumed to be exhaled. Dose factors (Refs. E11, E12) were applied to the inhaled quantities of radionuclides to obtain doses to critical organs. The dose to the bone was calculated as shown in Table E-V. Doses to other critical organs were calculated in the same way for Table XIV.

B. 0-10 cm layer

Ingestion of garden produce is the significant pathway for this layer of soil. The mass concentration of uranium was converted to activity concentration as described for the 0-5 cm layer. Estimates for the quantity of debris ingested with garden produce were based on an assumed total produce intake of 550 g/day[E19] and consideration of the following:

- Los Alamos has a limited growing seasson (May—October).
- Bayo Canyon lots would be of limited size to accommodate gardens.
- Cultural preference is to buy food rather than raise it.

We estimate that the maximum individual would not consume over 25% of the annual dietary intake of 200 kg of produce from garden plots in Bayo Canyon. The transfer factors from soil to produce used in this evaluation, in units of μCi/kg veg per μCi/kg soil were 2.0×10^{-1} for ^{90}Sr, 2.5×10^{-3} for ^{90}Y, and 2.5×10^{-3} for U (Ref. E11). As in the case of the 0-5 cm layer, 0-10 cm soil concentrations were reduced to units of radioactivity per isotope. Doses to the bone were calculated as shown in Table E-VI. Doses for other critical organs were calculated in the same way for Table XIV.

C. 0-30 cm soil layer

Inhalation of aerosols generated by mechanical disturbance of the soil during excavation for light construction is the significant pathway for this layer of soil. This case was evaluated by assuming the dust loading of air inhaled by a construction worker to be 10 mg/m^3. This value is the threshold limit value for nuisance dusts as set by the American Conference of Governmental Industrial Hygienists (ACGIH).[E20] Dust loadings >10 mg/m^3 are possible but it is doubtful that any long term exposure would occur at >10 mg/m^3 because "excessive concentrations of nuisance dust may seriously reduce visibility, may cause unpleasant deposits in the eyes, ears, and nasal passages...or cause injury to the skin or mucous membranes..."[E20] A value for the corresponding radioactivity in air was calculated from concentrations of radioactivity in soil from the areas of concern. Then, a breathing rate of 43 ℓ/min was adopted from page 347 of Ref E19. The dirt from which the aerosols were generated was assumed contaminated to 0.5 pCi/g ^{90}Sr and 0.9 $\mu g/g$ uranium. The receptor in this case is a construction worker employed during the construction season from April through October. Since some time would be devoted to tasks other than excavation, an exposure time of 1000 h was considered reasonable. Aside from these different assumptions, doses were calculated in the same manner as for the 0-5 cm layer.

D. 0-122 cm soil layer

Inhalation of aerosols generated by mechanical disturbance of the soil during trenching operations for foundations and utility lines is the significant pathway for this layer of soil. The degree of contamination appropriate to this scenario (17 pCi/g ^{90}Sr and 0 $\mu g/g$ uranium) is restricted to the area within 10 m of TA-10-1 and its waste handling systems, which should be sufficient for six small tract homes. Estimates of exposure time for the maximum individual were 360 h for the six houses. Other assumptions were the same as for the 0-30 m layer, and doses were calculated in the same manner.

E. 122-244 cm soil layer

Inhalation of aerosols generated by mechanical disturbance of soil during the installation of sewer lines or manholes is the significant pathway for this layer of soil. The average contamination assumed for this scenario is 1100 pCi/g ^{90}Sr and no uranium. Since the area containing this degree of contamination is even more limited than the preceding case, an exposure time of 60 h for a construction worker was considered reasonable with a breathing rate of 43 ℓ/min. Other assumptions are the same as for the 0-122 cm layer and doses were calculated in the same manner.

F. Deeper than 244 cm

Although higher levels of activity (20 000 pCi/g gross β) occur at greater depths, there is no plausible reason for human activity at such depth because proposed zoning is residential and light commercial. Moreover, the existing sewer main from Barrancas Mesa through Bayo Canyon to the Bayo Treatment Plant is already less than 244 cm deep. The 20 000 pCi/g occurs at about 430 cm. Mechanisms that could conceivably release these materials to the environment (erosion or volcanism) are unlikely to occur during the next ten half lives of the ^{90}Sr (280 yr) at which time the activity concentration would be about 20 dpm/g. Consequently, no dose estimates have been made for this layer.

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TABLE E-I

SPECIFICATION OF PRECISION (% CONFIDENCE) AND ACCURACY (% ERROR) IN POPULATION MEAN ESTIMATES

Soil Layer	N	% Confidence	% Error
0-5 cm	29	90	21.5
0-10 cm	15	90	30
0-20 cm	30	90	21

TABLE E-II

ESTIMATES OF BACKGROUND ^{90}Sr AND URANIUM

^{90}Sr	
Ref E3	0.32 pCi/g (local soil)
Ref E4	0.55 pCi/g (local soil)
	0.37 pCi/g (local sediment)
Ref E5	0.34 pCi/g (south central to central New Mexico)
Uranium	
Ref E6	8 μg/g Bayo Canyon rock
Ref E7	8 μg/g Bayo Canyon rock
Present Resurvey	3.91 μg/g East canyon floor grid soil and rock[a]
	8.09 μg/g West canyon floor grid soil and rock[a]
	5.09 μg/g West canyon floor grid soil and rock[a]
	3.42 μg/g Four soil samples. Three from firing site station; one from east canyon floor grid[b]

[a]These results were from *in situ* measurements by a GeLi detector. Consequently, they are representative of the 0-30 cm layer—both soil and rocks. Generally primordial uranium is presumed to have a uniform vertical distribution which would mean that these measurements are valid for the 0-5 cm layer.

[b]0-5 cm soil samples.

TABLE E-III

COMPARISON OF INVENTORY ESTIMATES

Layer cm	Inventory Estimate from 1977 Field Survey Data				Estimated Pre-Cleanup Inventory Based on Records Search			
	Debris		Background		High Estimate		Low Estimate	
	^{90}Sr[a]	Total[b] Uranium	^{90}Sr[a]	Total[b] Uranium	^{90}Sr[a]	Total[b] Uranium	^{90}Sr[a]	Total[b] Uranium
0 - 5[c]	0.1	153	0.03	354	39.6	5380	30.6	5380
0 - 10[c]	0.1	38	0.06	651				
0 - 30[c]	0.3	517	0.12	1950	---	---	---	---
30 - 122[d]	0.2	---	---	---	---	---	---	---
122 - 244[d]	0.0	---	---	---	117	---	87.	---
>244 [d]	0.9	---	---	---				
0 - >244	1.4	517	0.12	1950	156.6	5380	117.6	5380

[a]Ci

[b]kg

[c]Samples from firing sites, canyon floor, and stream channel strata.

[d]Samples from structures stratum.

TABLE E-IV

DOSE FACTORS

Mode	Isotope	Solubility	Dose Commitment Factor (mrem/50 yr per pCi ingested or inhaled in first year) Whole Body	Bone	Lung	Kidney
Inhalation	$^{90}Sr + D^{a}$	(S)	7.62×10^{2}	1.24×10^{4}	---	0
		(I)	---	---	1.20×10^{3}	---
	^{90}Y	(S)	7.01×10^{-3}	2.61×10^{-1}	---	0
		(I)	---	---	2.12×10^{1}	---
	$^{238}U+D$	(S)	5.67×10^{2}	9.58×10^{3}	---	2.18×10^{3}
		(I)	---	---	4.58×10^{4}	---
	^{236}U	(S)	6.20×10^{2}	1.00×10^{4}	---	2.39×10^{3}
		(I)	---	---	5.00×10^{4}	---
	$^{235}U+D$	(S)	6.07×10^{2}	1.00×10^{4}	---	2.34×10^{3}
		(I)	---	---	4.90×10^{4}	---
	^{234}U	(S)	6.46×10^{2}	1.04×10^{4}	---	2.49×10^{3}
		(I)	---	---	5.22×10^{4}	---
Ingestion	$^{90}Sr+D$	(S)	1.86×10^{3}	7.58×10^{3}	---	0
		(I)	---	---	0	---
	^{90}Y	(S)	2.58×10^{-4}	9.62×10^{-3}	0	0
	$^{238}U+D$	(S)	4.54×10^{1}	7.67×10^{2}	0	1.75×10^{2}
	^{236}U	(S)	4.69×10^{1}	8.10×10^{2}	0	1.91×10^{2}
	$^{235}U+D$	(S)	4.86×10^{1}	8.01×10^{2}	0	1.87×10^{2}
	^{234}U	(S)	5.17×10^{1}	8.36×10^{2}	0	1.99×10^{2}

[a] +D means all contributions to dose from daughter products are included.

Note: Ref E11 provides factors for the inhalation pathway to all critical organs except kidneys and for every radionuclide except ^{90}Y.

Ref E12 provides factors for the inhalation pathway to the whole body, bone, and lung for ^{90}Y.

Ref E13 provides factors for the ingestion pathway for all critical organs and for either pathway to the kidney.

TABLE E-V

DOSE TO BONE FROM INHALATION

Nuclide	Intake (μCi per year)	×	Dose Factor (mrem/μCi per year)	=	50 Year Dose Commitment (mrem)
$^{90}Sr + D^a$	5.6×10^{-7}		1.2×10^{4}		6.7×10^{-3}
$^{238}U + D^a$	3.0×10^{-7}		9.6×10^{3}		2.9×10^{-3}
^{236}U	1.3×10^{-9}		1.0×10^{4}		1.3×10^{-5}
$^{235}U + D^a$	7.5×10^{-9}		1.0×10^{4}		7.5×10^{-5}
^{234}U	1.3×10^{-7}		1.0×10^{4}		1.3×10^{-3}
Total Dose					1.1×10^{-2}

[a]+D means all contributions to dose from daughter products are included.

TABLE E-VI

DOSE TO BONE FROM INGESTION

Nuclide	Intake (μCi per year)	×	Dose Factor (mrem/μCi per year)	=	50 Year Dose Commitment (mrem)
$^{90}Sr + D^a$	6.0×10^{-3}		7.6×10^{3}		45.6
$^{238}U + D^a$	8.3×10^{-6}		7.7×10^{2}		negligible
^{236}U	3.6×10^{-8}		8.0×10^{2}		negligible
$^{235}U + D^a$	2.1×10^{-8}		8.0×10^{2}		negligible
^{234}U	3.6×10^{-6}		8.4×10^{2}		negligible
Total Dose					45.6

[a]+D means all contributions to dose from daughter products are considered.

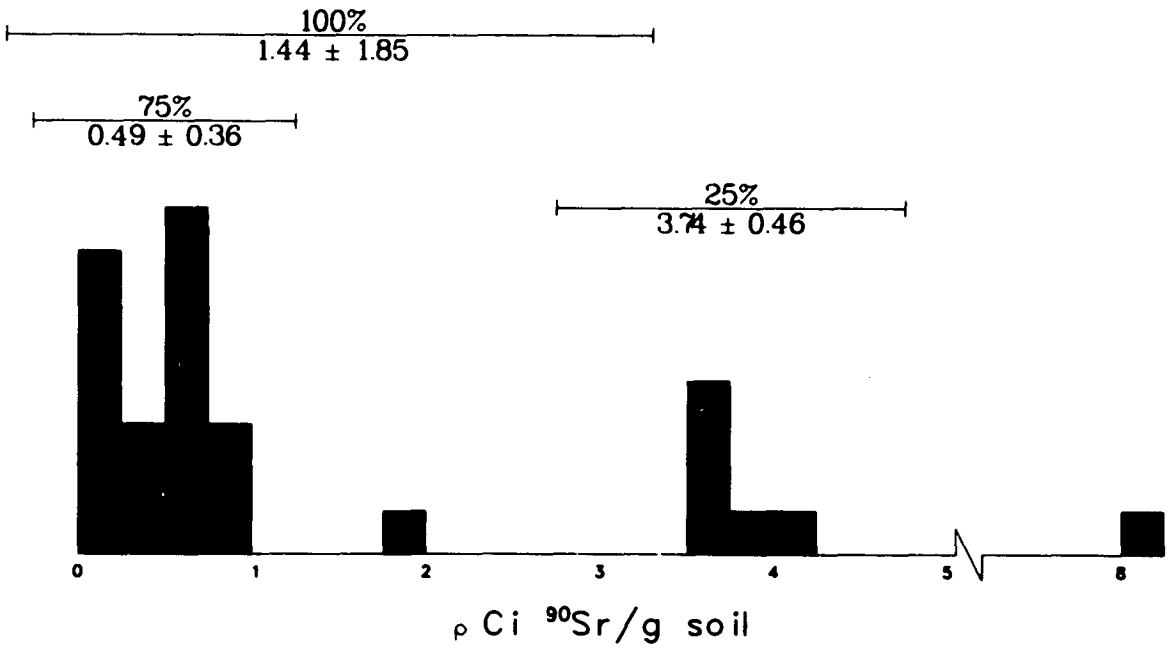

Fig. E-1.
Frequency Distribution—^{90}Sr in 0-5 cm.

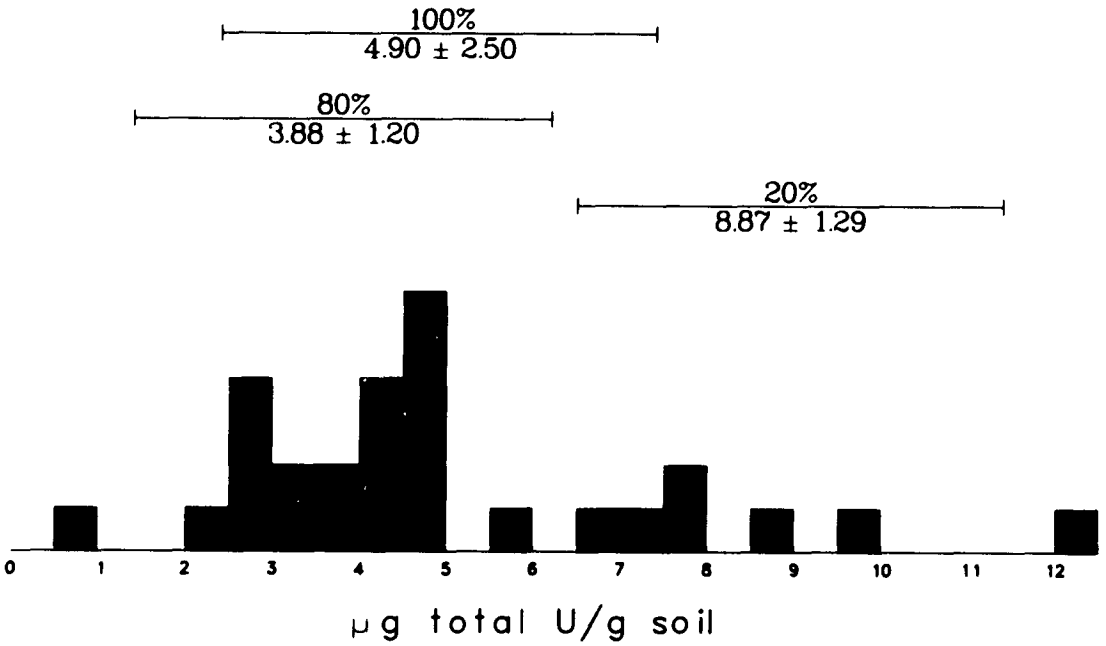

Fig. E-2.
Frequency Distribution—Total U in 0-5 cm.

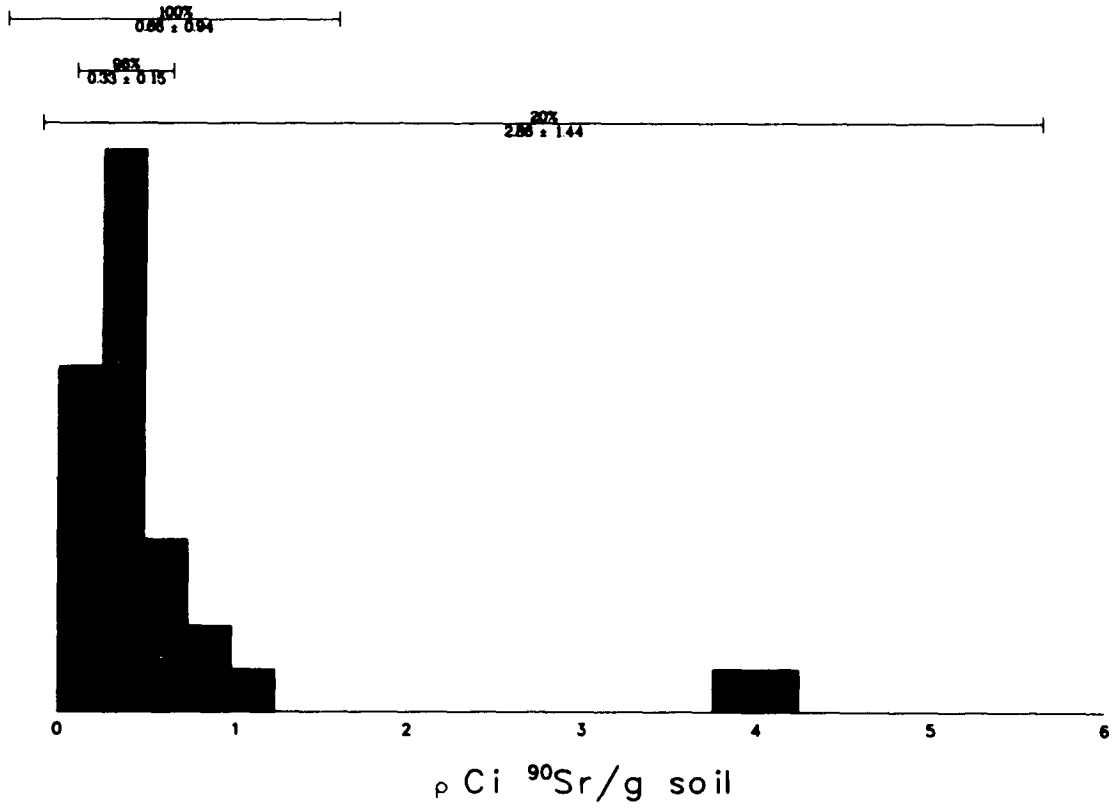

Fig. E-3.
Frequency Distribution—^{90}Sr in 0-30 cm.

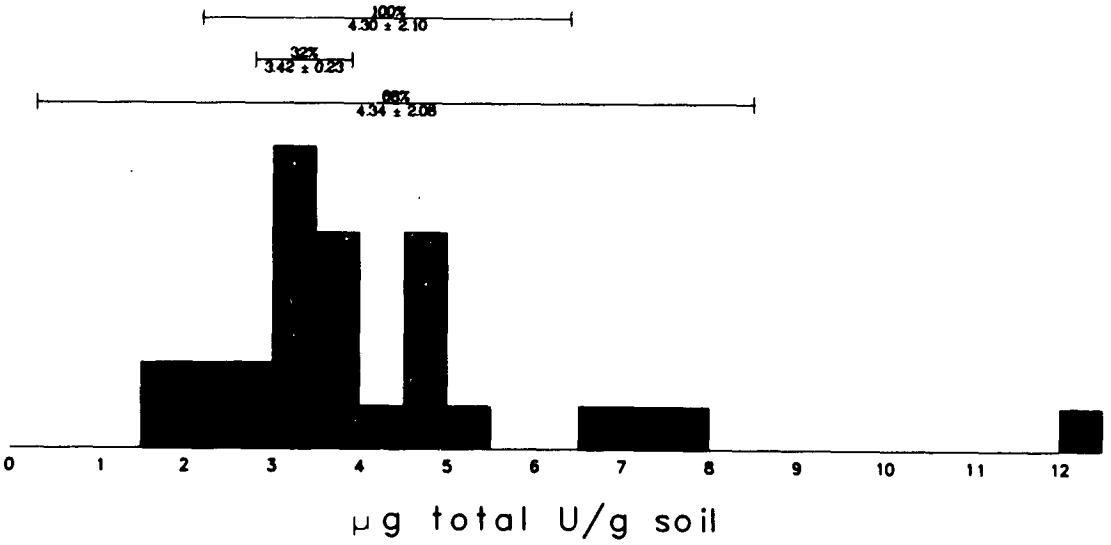

Fig. E-4.
Frequency Distribution—Total U in 0-30 cm.

GLOSSARY

Acid sewer	A sewer system designed to receive wastes from laboratory-related activity, including liquids contaminated with hazardous chemicals and radioactivity, for transmission to industrial waste treatment facilities or other discharg points. Often referred to as industrial waste line.
Alpha particle	A charged particle emitted from the nucleus of certain radioactive atoms. It has a charge and mass equal in magnitude to those of a helium nucleus, i.e., two protons and two neutrons.
Beta particle	A charged particle emitted from the nucleus of certain radioactive atoms. It has a charge and mass equal to those of the electron.
Curie	The special unit of radioactivity. One curie equals 3.70×10^{10} nuclear transformations per second (abbreviated Ci).
Gamma ray	Short-wavelength electromagnetic ionizing radiation of nuclear origin (has no mass or charge).
Gram	The basic unit of mass in the metric system (abbreviated g). It is 0.03937 times as big as an ounce.
Gross alpha	The total amount of measured alpha activity including natural alpha activity levels.
Gross beta	The total amount of measured beta activity including natural beta activity levels.
Maximum Permissible Concentration	The concentration of radioactivity in the environment that is determined to result in whole-body or oran doses equal to the Radiation Protection Standards for external and internal exposure (abbreviated MPC).
Meter	The basic unit of length in the metric system (abbreviated m). It is 3.048 times as big as one foot.

Metric Units

Measurements in the metric system are usually modified in factors of 10^{-3} by adding Roman prefixes as below:

Factor	Prefix	Symbol	Example
10^{-2}	centi	c	1 cm = 1×10^{-2} m = 0.01 m
10^{-3}	milli	m	1 mrem = 1×10^{-3} rem = 0.001 rem
10^{-6}	micro	μ	1 μg = 1×10^{-6} g = 0.000001 g
10^{-9}	nano	n	1 nCi = 1×10^{-9} Ci = etc
10^{-12}	pico	p	1 pCi = 1×10^{-12} Ci = etc
10^{-15}	femto	f	1 fCi = 1×10^{-15} Ci = etc

Rad

The unit of absorbed radiation dose. It applies to the fraction of energy deposited by ionizing radiation in a unit volume of material exposed. 1 Rad = 1×10^{-2} Joules per kilogram.

Rem

The unit of dose equivalence used for radiation protection applications. It is the product of the absorbed radiation dose (D), the quality factor Q (which accounts for differences in biological effect between various types of ionizing radiation), and N the product of any other modifying factors (such as dose distribution in organs), rem = DQN.

Roentgen

The unit of radiation exposure (abbreviated R). It applies only to the amount of charge produced by x or gamma radiaton in air. 1R = 2.58×10^{-4} coulombs per kilogram.

Sanitary sewer

A sewer system designed to receive wastes from normal human activities, exclusive of laboratory-generated wastes, for example, wastes from rest rooms, lavatories, showers, and food-halding activities, for transmission to septic tanks, treatment facilities, or other discharge points.

Tuff

A compacted, extrusive, igneous rock comprising volcanic ash and dust.

Uranium

Primordial uranium

Uranium which was incorporated into earth's lithosphere at the time of creation. This uranium is universally distributed in the lithosphere in varying concentrations, but it is normally in equilibrium with its decay products. It contains 99.27% of ^{238}U and 0.72% of ^{235}U. It is usually called natural uranium.

Normal uranium

Uranium which has been refined from primordial uranium by removing its decay products. It contains 99.27% of ^{238}U and 0.72% of ^{235}U. It is frequently called natural uranium.

Natural uranium	See primordial uranium and normal uranium.
Enriched uranium	Uranium which has been enriched to more than 0.72% ^{235}U.
Depleted uranium	Uranium which has been depeleted to less than 0.72% ^{235}U.

ACRONYMS AND ABBREVIATIONS

AEC	Atomic Energy Commission
ALO	Albuquerque Operations Office
c	counts
cpm	counts per minute
dis	disintegrations
ERDA	Energy Research and Development Administration
HPIC	high-pressure ionization chamber
LAAO	Los Alamos Area Office
LASL	Los Alamos Scientific Laboratory
NCRP	National Council on Radiation Protection
RCG	Radioactivity Concentration Guide
rem	roentgen equivalent man
TLD	thermoluminescent dosimeter
ZnS	zinc sulfide

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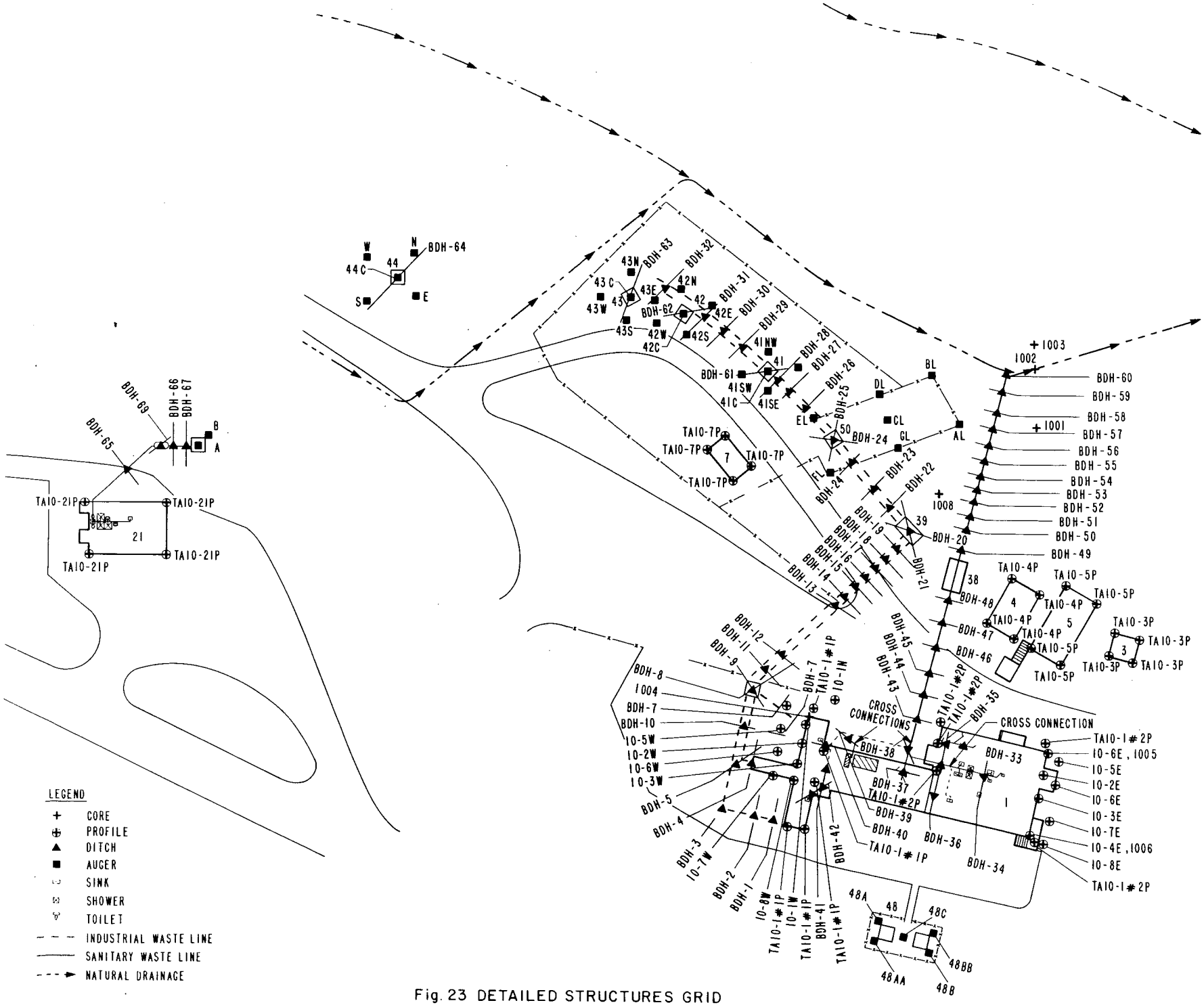

Fig. 23 DETAILED STRUCTURES GRID

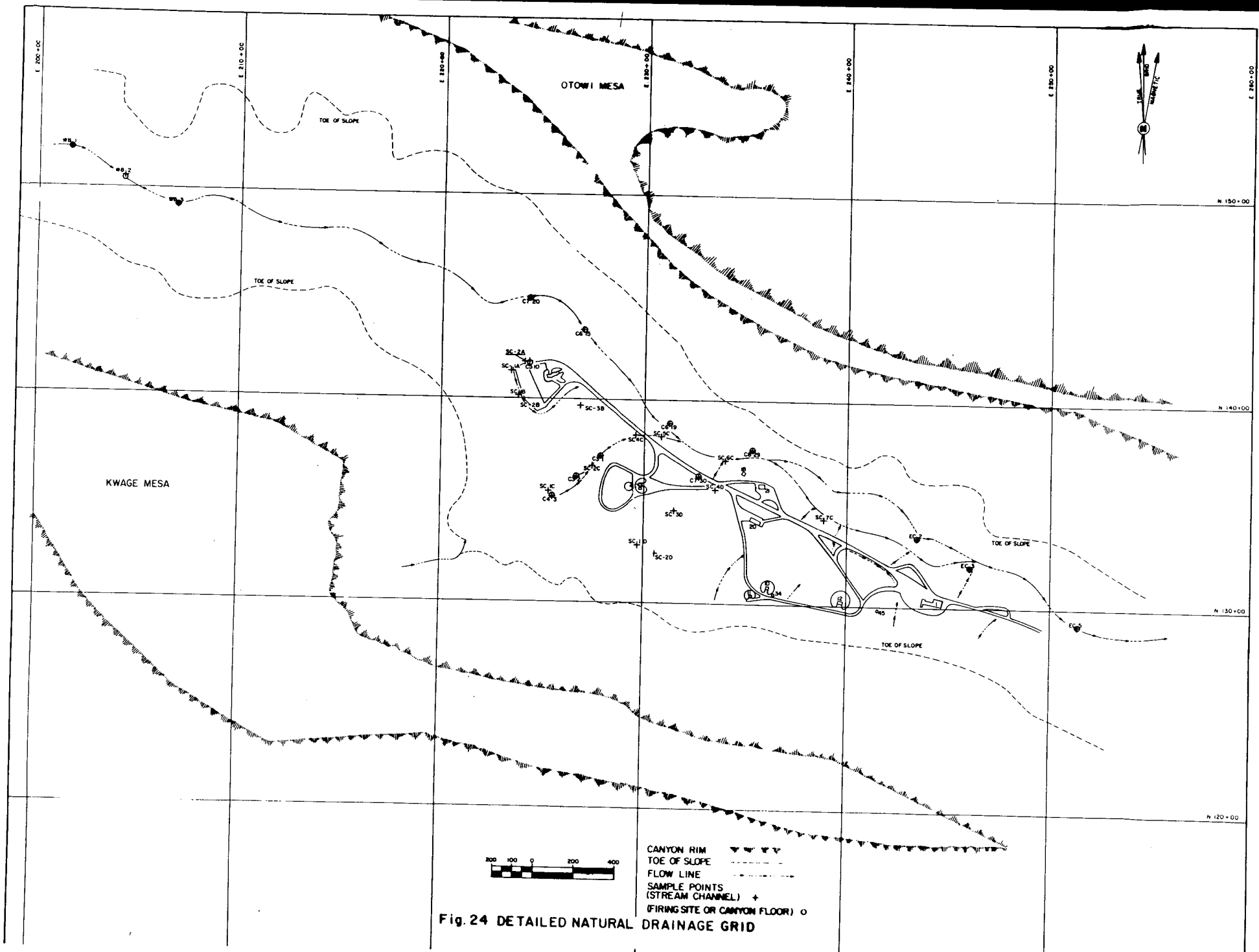

Fig. 24 DETAILED NATURAL DRAINAGE GRID

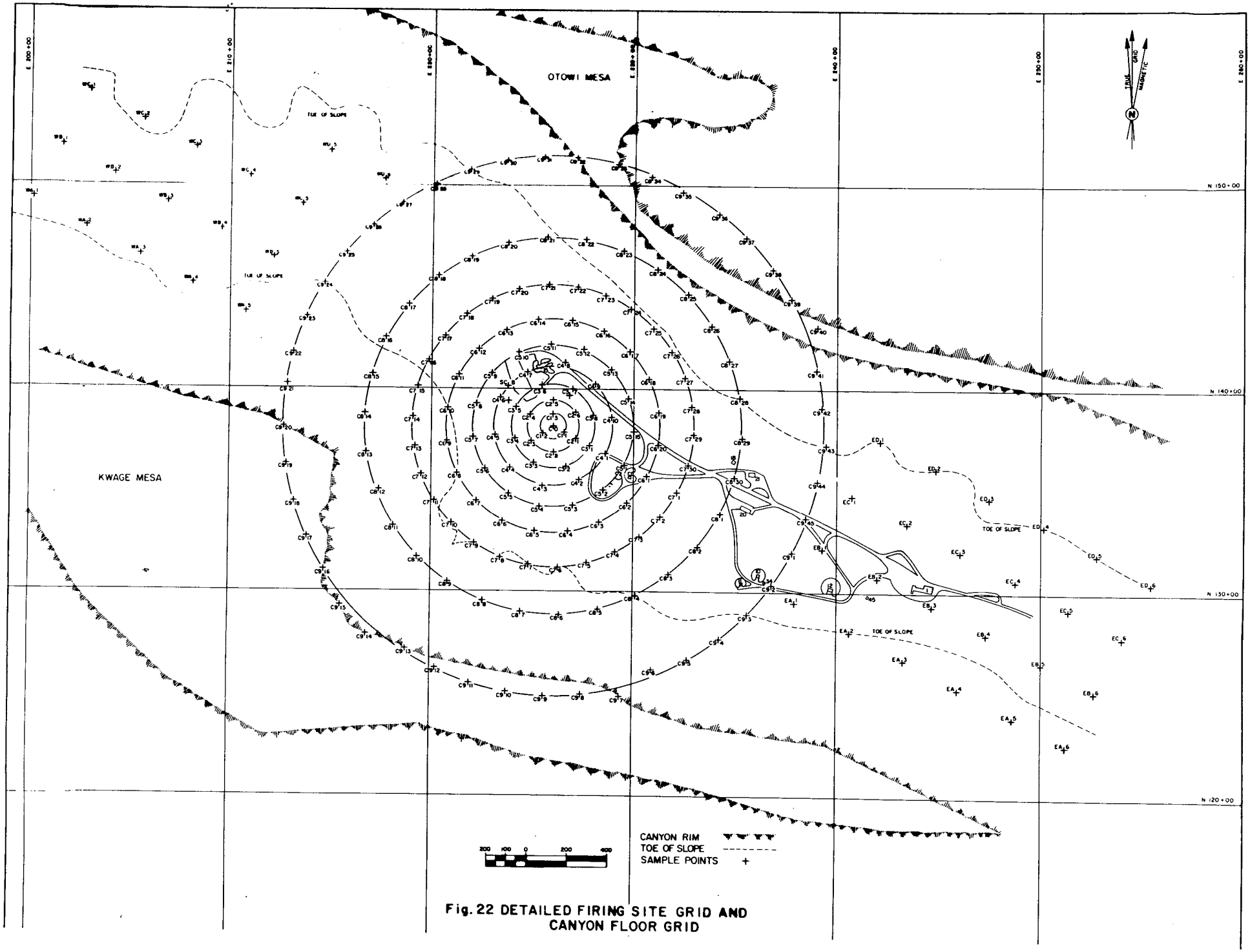

Fig. 22 DETAILED FIRING SITE GRID AND CANYON FLOOR GRID