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Date: June 6, 2003
Refer to: RRES-GPP-03-066

Mr. Mat Johansen
National Nuclear Security Administration
Department of Energy, MS A316
Los Alamos Site Operations
Los Alamos, NM 87545

SUBJECT: **CHARACTERIZATION WELL R-14 COMPLETION REPORTS**

Dear Mat:

Enclosed are two copies of the Characterization Well R-14 Completion Report. This report documents work completed under the Hydrological Work Plan.

If you have questions, please call me at (505) 665-4681.

Sincerely,

Charles Nylander, Program Manager
Groundwater Protection Program

CN/th

Enclosure: Characterization Well R-14 Completion Report (ER2003-0197/GPP-03-030)

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Remediation Program

RRES

LA-UR-03-1664
June 2003
ER2003-0197
GPP-03-030

Characterization Well R-14 Completion Report

Los Alamos
NATIONAL LABORATORY
Los Alamos NM 87545

Produced by the Groundwater Protection Program, Risk Reduction & Environmental Stewardship Division

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List of Acronyms and Abbreviations

AITH	array induction tool, version H
ASTM	American Society for Testing and Materials
bgs	below ground surface
CNTG	compensated neutron tool, model G
DH	down-hole
DOE	US Department of Energy
DQO	data quality objective
DR	dual rotary
DTH	down-the-hole
ECS	elemental capture spectroscopy
ER	Environmental Restoration (Project)
ESH	Environmental, Safety, and Health
FMI	formation microimager
FMU	Facility Management Unit
GIT	groundwater Investigations Team
GPS	global positioning system
hp	horsepower
ID	inner diameter

LANL	Los Alamos National Laboratory
NGS	natural gamma spectroscopy
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
OD	outer diameter
psi	pounds per square inch
PVC	polyvinyl chloride
RC	reverse circulation
RRES	Risk Reduction and Environmental Stewardship Division
SAP	sampling and analysis plan
SSHASP	site-specific health and safety plan
TA	technical area
TD	total depth
TKN	total Kjeldahl nitrogen
TLDM	triple detector litho-density
UDR	universal drill rig
UR-DTH	under-reaming down-the-hole (hammer)
VOC	volatile organic compound
WCSF	waste characterization strategy form
WGII	Washington Group International, Inc.

Metric to US Customary Unit Conversions

Multiply SI (Metric) Unit	by	To Obtain US Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

CHARACTERIZATION WELL R-14 COMPLETION REPORT

ABSTRACT

Characterization well R-14 was installed under the implementation of the "Hydrogeologic Workplan" (LANL 1998, 59599). The Nuclear Weapons Infrastructure, Facilities, and Construction Program funded this well, and the project was directed by the Environmental Restoration Project in accordance with the "Work Plan for Mortandad Canyon" (LANL 1997, 56835). Management of the drilling program was carried out by Washington Group International, Inc., under a subcontract to the Los Alamos National Laboratory (LANL or the Laboratory). The well is located in Ten Site Canyon, a tributary to Mortandad Canyon in the east-central portion of the Laboratory. It is downgradient of the active radioactive liquid waste treatment facility at Technical Area (TA)-50 and the former radioactive liquid waste and septic facilities at TA-35. This well is primarily designed to determine whether Laboratory releases and treatment plant effluents may be present in and around the Mortandad Canyon watershed and, if so, the extent to which contaminants affect groundwater quality.

In addition, hydrologic, geologic, geochemical, and geophysical information obtained during completion and subsequent sampling of this well will provide data to evaluate the hydrologic setting of Mortandad Canyon and contribute to implementing a Laboratory-wide groundwater monitoring network. Data from R-14 and similar wells support the Laboratory's Groundwater Protection Management Program Plan.

Core drilling was performed at R-14 to the depth of 306 ft. The R-14 borehole was then drilled to a total depth 1327 ft using air-rotary/fluid assisted and conventional mud-drilling methods. Samples of drill cuttings were collected at regular intervals for stratigraphic, petrographic, and geochemical analysis. Geologic strata encountered during drilling operations at R-14 included, in descending order, the Tshirege Member of the Bandelier Tuff; the Cerro Toledo interval of the Bandelier Tuff; the Otowi Member of the Bandelier Tuff, including the Guaje Pumice Bed; upper Puye Formation sediments; dactite lavas; and a sedimentary sequence making up a lower section of Puye Formation and underlying pumiceous sediments.

No perched water zones were encountered at R-14. The regional zone of groundwater saturation was encountered at a depth of 1182 ft in the Puye Formation. Groundwater samples were collected from the regional aquifer during well development to analyze selected organic and inorganic constituents, stable isotopes, and radionuclides.

Well installation was completed on July 02, 2002. Two screened intervals were placed within the regional aquifer. Straddle-packer injection tests were conducted on screen 2. A Westbay™ multiport system for groundwater sampling was installed in the well casing.

1.0 INTRODUCTION

This completion report summarizes the preparation, drilling, well construction and development, and related activities performed at the characterization well R-14 drilling site from May 16, 2002, to February 21, 2003. Well R-14 is located in Ten Site Canyon, a tributary to Mortandad Canyon in the east-central portion of the Los Alamos National Laboratory (LANL or the Laboratory) (Figure 1.0-1). This well is downgradient of the active radioactive liquid waste treatment facility at Technical Area (TA)-50 and of former radioactive liquid waste and septic facilities at TA-35.

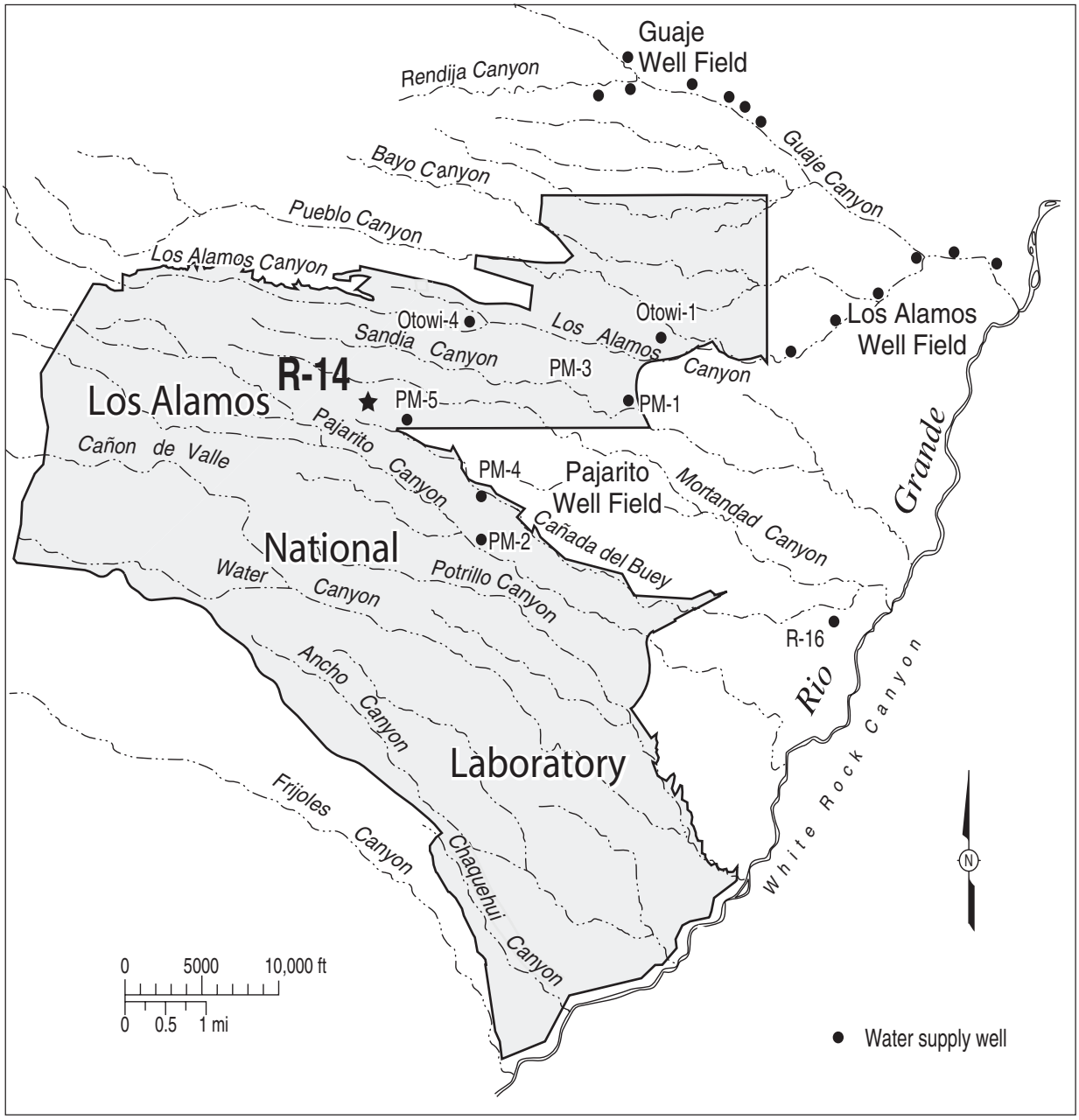


Figure 1.0-1. Map showing location of characterization well R-14

This well completion report focuses on operational activities associated with the drilling, sampling, and completion of well R-14. The information presented here was compiled from field reports and activity summaries generated by the Laboratory and the drilling subcontractor. Geophysical data and geodetic survey information are also included. Data from R-14 and similar wells support the Laboratory's Groundwater Protection Management Program Plan.

Results of these activities are discussed briefly and shown in tables and figures contained in this report. Detailed analysis and interpretation of geologic, geochemical, geophysical, and hydrologic data will be included in separate technical documents to be prepared by the Laboratory.

Well R-14 was funded by the Nuclear Weapons Infrastructure, Facilities, and Construction Program and installed by the Laboratory's Environmental Restoration (ER) Project, now called the Risk Reduction and Environmental Stewardship (RRES) Division. Washington Group International, Inc. (WGII), under contract to the Laboratory, was responsible for executing drilling activities.

The potential sources of groundwater contamination of most concern at R-14 are the present-day radioactive liquid waste treatment plant at TA-50 and the former radioactive liquid waste treatment plant at TA-35. R-14 primarily is designed to determine the potential impacts of TA-50 effluent discharges on groundwater quality in the regional zone of saturation just south of Mortandad Canyon. Liquid discharges from TA-50 enter Mortandad Canyon through the small Effluent Canyon tributary, and the Mortandad Canyon stream channel probably serves as a line source of recharge to deeper groundwater systems. Originally, the hydrogeologic work plan and the work plan for Mortandad Canyon called for siting well R-14 on the narrow mesa separating Mortandad Canyon and Ten Site Canyon (LANL 1998, 59599; LANL 1997, 56835). The well site was moved to the floor of Ten Site Canyon due to poor access to the original well location, and because the data quality objectives (DQOs) for this well were modified to include characterization of contaminants in the vadose zone beneath Ten Site Canyon that were the result of TA-35 releases (LANL 2002, 73440). The R-14 site in Ten Site Canyon also provides information about potential contaminants in the regional zone of saturation that could be drawn towards water supply well PM-5, located approximately one mile east-southeast. In addition, the geologic, water-quality, and water-level data from R-14 will be used to update the sitewide hydrologic and geologic conceptual models for the Laboratory.

2.0 PRELIMINARY ACTIVITIES

WGII received contractual authorization to begin administrative preparation tasks on November 14, 2001. One of these tasks included preparing a modification to existing site-specific health and safety plan (SSHASP) No. 273 to include well R-14. WGII also prepared the R-14 waste characterization strategy form (WCSF). The Laboratory prepared the "Sampling and Analysis Plan (SAP) for the Drilling and Testing of LANL Regional Aquifer Characterization Well R-14" (LANL 2002, 73440) to guide field personnel in the execution of R-14 field activities. The host facility, Facility Management Unit (FMU) 80, signed a Facility Tenant Agreement on April 10, 2002, to provide access and security control, safety and health, regulatory, and other work requirements for drilling and completion activities at well R-14.

A readiness review meeting was held on May 14, 2002, to discuss all administrative documents, permits, agreements, and plans pertaining to the R-14 project. The Groundwater Investigations Focus Area project leader signed the readiness review checklist for drill pad construction on May 14, 2002, authorizing the commencement of fieldwork. A second meeting was held May 29, 2002, at which time the readiness review checklist for R-14 drilling was signed.

K. R. Swerdfeger Construction, Inc., was subcontracted by WGII to conduct pre-drilling site preparation. Activities included clearing the site, trimming and removing trees, modifying the access road, grading the drill pad, and constructing a lined cuttings-containment area. Site preparation was conducted and completed from May 16 to 29, 2002.

Initially, the site was cleared of trees and stumps. A bulldozer then was used to cut back an outcrop of rock along the north side of the proposed drill pad to widen and level the site. Parts of the access road were graded and improved. The drill pad was constructed by building up and grading the selected area and compacting the fill. Base-course gravel was distributed and compacted to complete the drill pad. A cuttings-containment area was excavated along the north side of the drill pad and lined with a 6-mil polyethylene liner for storing drilling fluids and cuttings. An 80- by 25-ft secondary-fluids-containment area was constructed to accommodate two 20,000-gal. fluid-storage trailers and provide additional storage capacity for fluids pumped from the containment area. During construction of the secondary containment area, the ground surface was stripped of vegetation and graded and the perimeter was bermed. The area then was lined with 6-mil polyethylene sheeting that overlapped the berms. The cuttings-containment area was fenced and safety barriers were set in place. Office and supply trailers, generators, and safety lighting equipment were moved onto the site prior to Phase I drilling.

3.0 SUMMARY OF DRILLING ACTIVITIES

Dynatec Drilling Company, Inc. (Dynatec) completed drilling activities during May, June, and July 2002. Appendix A compares planned activities outlined in the scope of work with actual work performed. Well R-14 was drilled in two phases, described below in Sections 3.1 and 3.2.

Drilling activities included Phase I coring and Phase II borehole drilling. Phase I involved collecting continuous rock-core samples for geologic characterization and sample splits for chemical analysis. The borehole was cored to a depth of 306 ft below ground surface (bgs), thus achieving the planned coring depth of 300 ft. The objectives of Phase II drilling were to log and collect cuttings at regular intervals for the entire depth of the borehole, collect water samples if possible, and provide a borehole for geophysical measurements and installation of a characterization well. Both air-rotary fluid assist and conventional mud-rotary drilling methods were used to advance the R-14 borehole to a total depth (TD) of 1327 ft bgs.

Equipment and fabrication support for drilling activities were provided by the Field Support Facility. Figure 3.0-1 summarizes site activity information in a chronological graph of drilling and other on-site activities. Figure 3.0-2 summarizes well drilling and installation data and depicts groundwater and geologic conditions encountered.

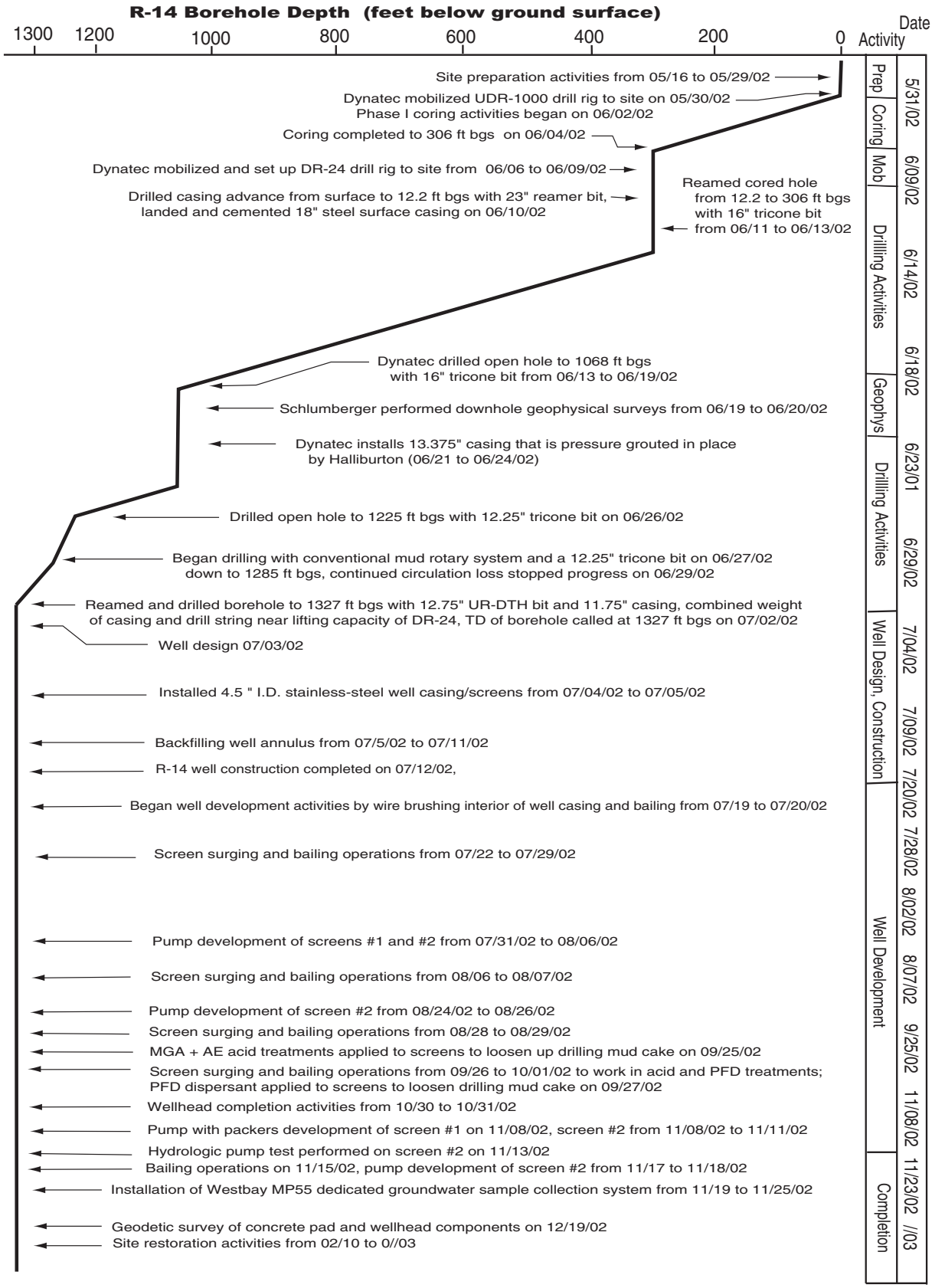


Figure 3.0-1. Operations chronology diagram

Location: In Ten Site Canyon, east of the former radioactive liquid waste and septic treatment facilities at TA-35 .

Survey coordinates (brass marker in NW corner of R-14 cement pad):
x: 1629855 E y: 1768953 N (NAD 83)
z: 7062.1 ft asl (NGVD 29)

Drilling: air rotary core w/ wireline retrieval, conventional mud drilling, casing advance.
R-14 Start date: 06/02/02.
R-14 End date: 07/02/02.

Borehole R-14 drilled to 1327 ft bgs (TD).

Data collection:
Hydrologic properties: Field hydraulic test: Constant Rate Injection Test on screen #2
Cores/cuttings submitted for geochemical and contaminant characterization: (24)
Groundwater samples submitted for geochem and contaminant characterization: (2)
Geologic properties: (11)
Mineralogy, petrography, and chemistry.

Borehole logs from R-14:
Lithologic: 0-1327 ft
Video (LANL tool): 0-923 ft. and 0-975 ft
Natural gamma (LANL tool): 0-1068 ft and 1046-1325 ft bgs
Schlumberger Logs: 0-12.2 ft (cased), 12.2-1068 ft (open hole): Litho density, Spectral Gamma, Elemental Capture, Thermal/Epithermal Neutron, Combinable Magnetic Resonance, and Natural Gamma.

Contaminants Detected in R-14 Water Samples: none

Well construction:
Drilling Completed: 07/02/02
Contract Geophysics: 06/19/02 - 06/20/02
Well Constructed : 07/04/02 - 07/11/02
Well Developed : 07/19/02 - 11/18/02
Westbay Installed : 11/19/02 - 11/25/02

Casing: 4.5-in I.D. stainless steel with external couplings.

Number of Screens: 2
4.5-in. I D pipe based, s.s. wire-wrapped with 0.010-in. slots.

Screen (perforated pipe interval):
Screen #1 - 1200.6-1233.2 ft. bgs.
Screen #2 - 1286.5-1293.1 ft. bgs.

Well development consisted of wire brushing, bailing, chemical treatments, surging, and pumping.

Groundwater occurrence was determined for R-14 by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. Static water levels were determined after the R-14 borehole was rested.

Groundwater samples collected from packed off screen intervals after well development.

Geologic contacts for R-14 were determined by examination of cuttings and interpretation of borehole video and geophysical logs. Contacts and stratigraphy may be refined by petrographic, geochemical, or mineralogic analysis of geologic samples.

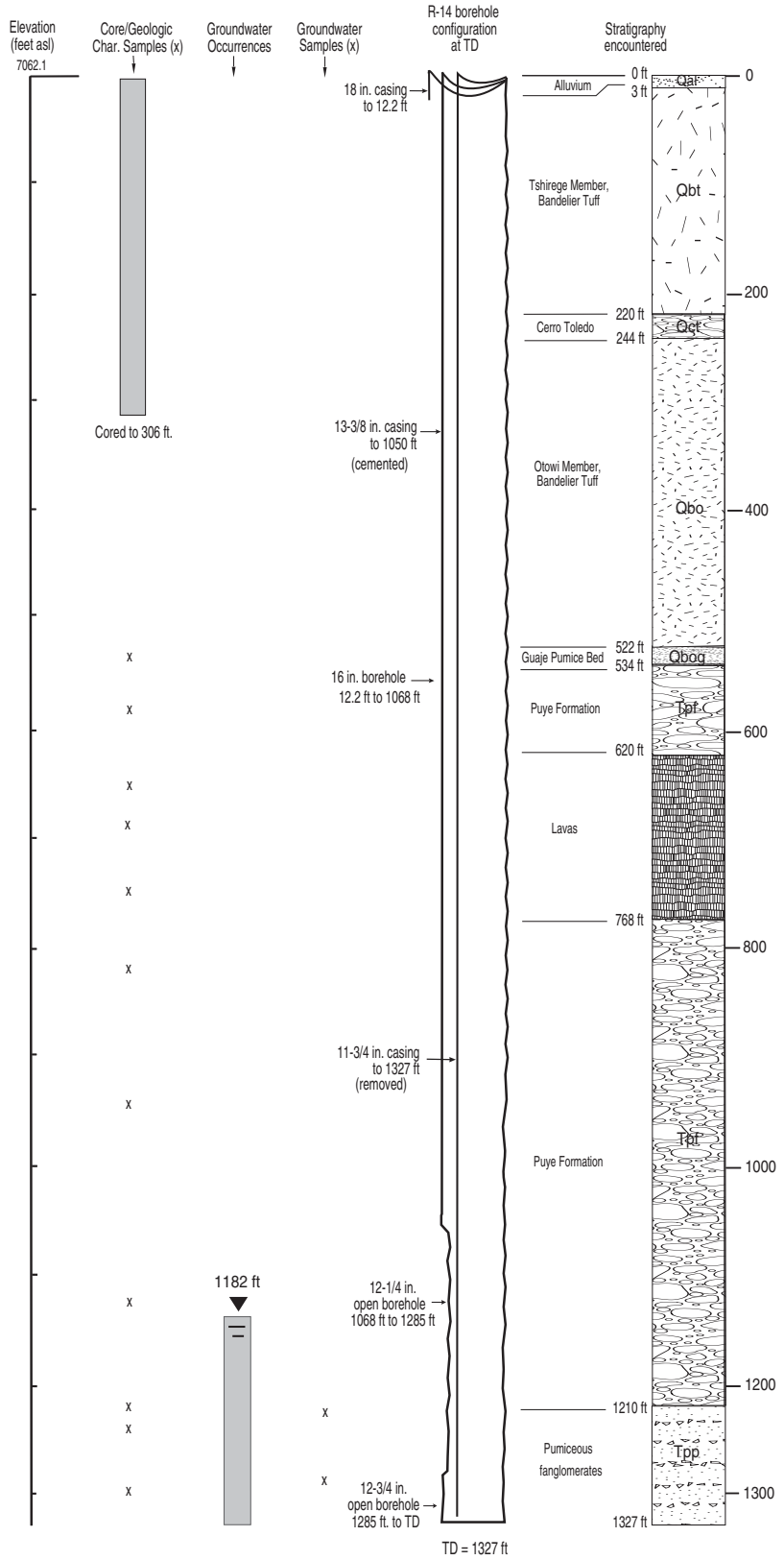


Figure 3.0-2. Well summary data sheet for characterization well R-14

3.1 Phase I Drilling

Phase I drilling activities were conducted from May 30 to June 5, 2002. Dynatec provided a Foremost™ universal drill rig (UDR) 1000 equipped with a wire-line core retrieval system. A 5-ft-long core barrel was used to collect 3-in.-diameter core samples. Dynatec mobilized the UDR-1000 rig and equipment to the site from May 30 to June 1, 2002, and core drilling was completed on June 4, 2002 (Figure 3.0-1). The borehole initially was advanced with a 4-in.-outside-diameter (OD) soft-rock core bit from the surface to 9 ft bgs. To prevent the collapse of alluvial sediments into the borehole during coring operations, a 10-ft section of 6-in.-OD steel surface casing was installed temporarily to a depth of about 9 ft bgs. Coring operations continued through Qbt 2 and 1 of the Tshirege Member of the Bandelier Tuff, the Cerro Toledo interval, and into the upper part of the Otowi Member of the Bandelier Tuff to a depth of 306 ft bgs. In the Cerro Toledo interval, core recovery problems occurred when rock fragments plugged the core bit. Soft, unconsolidated sediments in the Otowi tuff were also difficult to recover during coring. However, all sample split target intervals were retrieved and collected.

3.2 Phase II Drilling

Phase II drilling started on June 10, 2002, and was completed on July 2, 2002. Dynatec mobilized a Foremost™ dual-rotation (DR) 24 drill rig and equipment, including drill casing, 7-in. reverse circulation (RC) rods, and bit assembly components, to the site on June 6 through 9, 2002. The DR-24 rig was equipped with an air-rotary RC system. Open-hole and casing-advance techniques were employed during air-rotary drilling as determined by changing geologic and drilling conditions. Air-rotary drilling was assisted with a foam mixture that consisted of municipal water mixed with soda ash, QUICK-GEL®, LIQUI-TROL™, and QUICK-FOAM® (Appendix B, which can be found on a CD that is attached to the inside back cover of this report). After encountering the water table, Dynatec equipped the Foremost™ DR-24 drill rig with a conventional mud-rotary drilling system. The system included a mixing tank and pump assembly, a generator to power the mixing unit, a de-sander unit for removing solids from the discharged drilling fluids, and a large auxiliary pump. The fluid mixture used during conventional mud drilling typically consisted of municipal water mixed with QUICK-GEL® and LIQUI-TROL™. Table 3.2-1 summarizes the kinds and amounts of additives used in drilling R-14. Additives were used to improve borehole stability, minimize fluid loss, and facilitate cuttings removal from the borehole. During drilling operations, cuttings samples were collected for geologic characterization at 5-ft intervals from the RC system fluid-discharge hose.

Drilling began by reaming the cored borehole using a 23-in. quadcone reamer bit to advance and land an 18-in. steel surface casing to a depth of 12.2 ft bgs. The casing was cemented in place. From June 11 to June 13, 2002, the corehole was reamed with a 16-in. tricone bit from 12.2 ft bgs to 306 ft bgs. From June 13 to 19, 2002, the borehole was drilled open-hole from 306 ft bgs to 1068 ft bgs with a 16-in. tricone drill bit. Schlumberger, Inc., was mobilized to the site and collected borehole geophysics data on June 19 and 20, 2002. Additional geophysical data were collected using Laboratory geophysical tools.

On June 21, 2002, Dynatec began installing a 13.375-in. conductor casing to 1050 ft bgs, where it was landed on June 22, 2002. Halliburton, Inc., pressure-grouted the surface casing in place with cement, completing installation on June 24, 2002. Dynatec resumed drilling, reaming through approximately 47 ft of residual cement inside the surface casing back down to 1068 ft bgs. The borehole then was drilled open-hole with a 12.25-in. tricone bit into the top of the regional aquifer, stopping at 1225 ft bgs on June 26, 2002, to obtain a static water level, which was measured at 1180.9 ft bgs.

Table 3.2-1
Fluid Additives Used, Characterization Well R-14

Additive	Amount	Unit of Measure
Interval Drilled (0–848 ft)		
Water	22,200	gal.
Bentonite	7.300	lb
Liqui-Trol	4.25	lb
Quick-Foam	201	gal.
Soda ash	18	lb
Interval Drilled (848–1315 ft)		
Water	104,300	gal.
Bentonite	28,250	lb
Liqui-Trol	22	gal.
Quick-Foam	175	gal.
Pac-L	700	lb
N-Seal	1830	lb
Magma Fiber	2160	lb

On June 27, 2002, Dynatec switched to the conventional mud rotary system and continued open-hole drilling with the 12.25-in. bit from 1225 ft bgs to 1285 ft bgs. From June 29 to June 30, 2002, recurring problems with lost fluid circulation around 1285 ft bgs stalled progress. WGII and the Laboratory made the decision to install an 11.75-in. casing, to seal the zones where fluid loss was occurring. On July 2, 2002, Dynatec completed casing installation and reamed through 14 ft of slough back down to 1285 ft bgs. Air-rotary drilling resumed using casing-advance with a 12.75-in. under-reaming down-the-hole (UR-DTH) hammer bit and the 11.75-in. drill casing to 1327 ft bgs. At this time, Dynatec reported that the total combined weight of the drill string and drill casing was approaching the total lifting capacity of the DR-24 drill rig. Consequently, on July 2, 2002, the Laboratory called TD of the borehole at 1327 ft bgs and prepared for well installation.

4.0 SAMPLING AND ANALYSIS OF DRILL CUTTINGS AND GROUNDWATER

Continuous core collection was attempted throughout the entire interval from ground surface to 306 ft bgs according to the R-14 SAP (LANL 2002, 73440) during Phase-I coring operations. A total of 24 samples were analyzed for anions and contaminant profiles. Analytes included anions, moisture content, stable isotopes, radionuclides, and tritium. Results from these analyses are in the QA process and will be reported at a later date. Core segments were placed in sealed plastic sleeves and set in core boxes for curation. Anion/moisture samples were sealed in pre-weighed 8-ounce jars immediately after the core was retrieved. The remaining samples were placed in ziplock bags, then sealed in Protecore® bags. Samples collected for low-level radiation activity were screened and placed in ziplock bags.

Drill cuttings were collected according to the R-14 SAP during Phase II drilling operations. Material was collected from the reverse circulation outlet trough at 5-ft intervals as drilling conditions permitted. A portion of these cuttings was sieved (at >#10 and >#35 mesh) and placed in chip-tray bins along with an unsieved portion. These chip trays were then used to prepare the lithologic logs, which are presented in Appendix C. The remaining cuttings were placed in ziplock bags and set in core boxes for curation.

Eleven sample splits were submitted for mineralogy, petrography, and geochemical analysis prior to curation of material collected during drilling.

Groundwater samples were not collected from the open borehole during drilling because of the adverse impact of drilling mud and additives to the chemistry of groundwater. However, two samples were collected from screened interval at 1200.6–1233.2 and 1286.5–1293.1 ft bgs in the regional aquifer during development activities. The results are reported below.

Geochemistry of Sampled Waters

Groundwater samples were collected and analyzed for a select suite of constituents to investigate the presence of constituents from laboratory releases. Major potential contaminants of concern at R-14 include perchlorate, nitrate, and tritium.

Groundwater samples were collected using a packer/pump assembly that straddled each screen interval and analyzed for inorganic and radionuclide constituents. Filtered water was collected for metals, trace elements, major cations and major anion analysis. Nonfiltered water was collected for stable isotope, tritium, and radiochemical analyses. Filtered samples were passed through a 0.45-µm Gelman cartridge filter. Samples were acidified as needed with analytical-grade nitric acid to a pH of 2.0 or less for metal and major cation analyses. All groundwater samples collected in the field were stored at 4°C until they were analyzed.

Groundwater samples were analyzed by laboratories under contract to LANL under the University of California Los Alamos National Laboratory Statement of Work for Analytical Laboratories (LANL 2000, 71233) and at the Earth and Environmental Science (EES)-6 laboratory. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate + nitrite, oxalate, perchlorate, phosphate, and sulfate. Mercury was analyzed by cold vapor atomic absorption (CVAA). Inductively coupled (argon) plasma emission spectroscopy (ICPES) was used for aluminum, arsenic, barium, chromium, cobalt, copper, iron, manganese, nickel, selenium, silver, calcium, magnesium, potassium, silica, sodium, and zinc. Antimony, beryllium, cadmium, lead, thallium, vanadium, and uranium, were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS). Tritium activity in a groundwater sample was determined by electrolytic enrichment at the University of Miami. Americium-241 was analyzed according to HASL-300, cesium-137 by generic gamma spectroscopy, plutonium-238 and plutonium-239 by isotopic plutonium (HASL-300), strontium-90 by beta counting, and uranium-234, uranium-235, and uranium–238 by isotopic uranium (HASL-300). Delta deuterium and oxygen 18/16 ratios were determined at Geochron Laboratory. The precision limits (analytical error) for major ions and trace elements were generally less than ±10% using ICPES and ICPMS.

Results of screening analyses for regional groundwater samples collected from the Puye Formation in R-14 are provided in Table 4.1-1. Based on the analytical results for two samples, it appears that contamination from Laboratory discharges is not present in the regional aquifer at this well site.

5.0 BOREHOLE GEOPHYSICS

WGII (using Laboratory tools) and Schlumberger performed borehole-logging operations at well R-14. Table 5.0-1 lists the logging surveys performed.

Table 4.1-1
Hydrochemistry of Regional Aquifer Samples at R-14

Depth (ft)	**1200.6–1233.2**	**1286.5–1293.1**
Geologic Unit	**Puye Formation**	**Puye Formation**
Analytical Laboratory	**Contract and EES-6 Laboratories**	**Contract and EES-6 Laboratories**
Date Sampled	**11/08/02**	**11/11/02**
Inorganic (filtered)		
Alkalinity (lab; mg $CaCO_3$/L)	58.5	58
Conductivity (field; µS/cm)	132.2	129.9
pH (field)	6.90	6.67
Temperature (field; ^oC)	22.9	23.2
Turbidity (field; NTU)	0.69	0.36
Al (mg/L)	[0.030], U	[0.1], U
Sb (mg/L)	[0.002],U	[0.002],U
As (mg/L)	[0.005], U	[0.005], U
Ba (mg/L)	0.036	0.040
Be (mg/L)	[0.0002], U	[0.0002], U
B (mg/L)	0.018	0.008
Br (mg/L)	0.04	[0.01], U
Cd (mg/L)	[0.001], U	[0.001], U
Ca (mg/L)	9.9	9.9
Cl (mg/L)	1.92	1.81
ClO_4 (mg/L)	[0.002], U	[0.002], U
ClO_3 (mg/L)	[0.02], U	[0.02], U
Cr (mg/L)	[0.001], U	[0.002], U
Co (mg/L)	[0.002], U	[0.001], U
Cu (mg/L)	[0.005], U	[0.005], U
F (mg/L)	0.22	0.19
Fe (mg/L)	0.1	0.09
Pb (mg/L)	0.0001, J	0.0001, J
Mg (mg/L)	3.1	3.1
Mn (mg/L)	0.36	0.33
Mo (mg/L)	0.0018	0.0016
Hg (mg/L)	[0.00005], U	[0.00006], U
Ni (mg/L)	0.003, J	[0.002], U
NO_3 (mg/L; as N)	[0.002], U	0.05
NO_2 (mg/L; as N)	[0.002], U	[0.002], U
TKN (mg/L)	0.72	0.33
C_2O_4 (mg/L) (oxalate)	[0.02], U	[0.02], U
P (mg/L)	0.26	0.24
K (mg/L)	1.9	1.9

Table 4.1-1 (continued)

Depth (ft)	**1200.6–1233.2**	**1286.5–1293.1**
Geologic Unit	**Puye Formation**	**Puye Formation**
Analytical Laboratory	**Contract and EES-6 Laboratories**	**Contract and EES-6 Laboratories**
Date Sampled	**11/08/02**	**11/11/02**
Inorganic (filtered) (continued)		
Se (mg/L)	[0.005], U	[0.005], U
Ag (mg/L)	[0.005], U	[0.005], U
Na (mg/L)	13	12.9
SiO_2 (mg/L)	77.3	77.9
SO_4 (mg/L)	2.28	2.48
Tl (mg/L)	[0.0005], U	[0.0005], U
TOC (mg/L)	1.86	1.95
U (mg/L)	0.001	0.001
V (mg/L)	0.009	0.009
Zn (mg/L)	0.41	0.36
δD (permil)	-82	-83
$\delta^{18}O$ (permil)	-11.2	-10.9
Radionuclides (nonfiltered)		
Am^{241} (pCi/L) (nonfiltered)	[0.007], U	[0.0098], U
Cs^{137} (pCi/L) (nonfiltered)	[-1.05], U	[-0.003], U
Pu^{238} (pCi/L) (nonfiltered)	[0.008], U	[0.002], U
Pu^{239} (pCi/L) (nonfiltered)	[-0.031], U	[0.011], U
Sr^{90} (pCi/L) (nonfiltered)	[0.047], U	[-0.2], U
Tritium (pCi/L) (nonfiltered)	[0.26], U	[0.22], U
U^{234} (pCi/L) (nonfiltered)	0.64	0.66
U^{235} (pCi/L) (nonfiltered)	[0.025], U	0.033
U^{238} (pCi/L) (nonfiltered)	0.41	0.38

Note: U = not detected. Dash = not analyzed. TOC = total organic carbon. J = analyte is classified as “detected” but the reported concentration value is expected to be more uncertain than usual.

Table 5.0-1
Borehole and Well Logging Surveys, Characterization Well R-14

Surveyor	Date	Method	Cased Footage	Open-Hole Interval (ft bgs)	Remarks
Schlumberger	June 19 to 20, 2002	Logging Suite[a]	0–12.2	12.2–1068	Schlumberger borehole logging conducted in uncased R-14 borehole prior to installing 13.375-in. surface casing.
LANL/WGII	June 20, 2002	Video, natural gamma and induction tools	0–12.2	12.2–1068	LANL borehole logging conducted in uncased R-14 borehole prior to installing 13.375-in. surface casing.
LANL/WGII	July 3, 2002	Natural gamma	0–1327	NA[b]	Survey conducted to gather data for well design after reaching TD.
LANL/WGII	July 5, 2002	Video	0–1316	NA	Survey conducted to document and verify integrity of well construction.
LANL/WGII	November 14, 2002	Video	0–1316	NA	Survey conducted to document and verify well interior condition prior to Westbay™ installation.

[a] The Schlumberger suite of borehole logging surveys included combinable magnetic resonance, triple detector lithodensity, epithermal compensated neutron log, elemental capture spectroscopy, and spectral and natural gamma-ray spectroscopy.
[b] NA = Not applicable.

5.1 Geophysical Logging Using Laboratory Tools

Between June 20 and November 14, 2002, natural gamma, induction, and video camera logs were run in borehole R-14 by WGII using down-hole tools provided by the Laboratory. The gamma and induction logs were collected to provide lithologic and stratigraphic information that complement data gathered from core and cuttings. Video logs were performed as a quality assurance procedure during well construction and development. Two natural gamma logs were run by the Laboratory and WGII. Natural gamma logs have proven successful in discriminating between geologic units that contain varying concentrations of uranium, thorium, and potassium. The gamma tool also is used for verifying backfill placement. The first gamma log was performed inside the 18-in. surface casing from the surface to 12.2 ft bgs and in the open hole from 12.2 to 1068 ft bgs prior to installation of the 13.375-in. casing. An induction log was run in the borehole concurrently with the first Laboratory gamma log. The second natural gamma log was run inside the 18-in. surface casing from the surface to 12.2 ft bgs, in the 13.375-in. conductor casing from surface to 1050 ft bgs, and in the 11.75-in. drill casing from surface to borehole TD at 1327 ft bgs. Measurements of natural gamma activity were obtained every 0.1 ft as the logging tool was raised in the hole at a rate of about 15 ft/min.

Table 5.0-1 summarizes borehole and well logging surveys performed. The borehole video log (Appendix D) can be found on a CD that is attached to the inside back cover of this report.

5.2 Schlumberger Geophysical Logging

Schlumberger conducted borehole geophysical logging on June 19 through June 20, 2002, at R-14. A suite of logging surveys was run inside the 18-in. casing from surface to 12.2 ft bgs and open-hole from 12.2 to 1068 ft bgs.

The primary purpose of the Schlumberger logging work was to characterize conditions in the hydrogeologic units penetrated by the borehole, with an emphasis on determining moisture distribution and flow capacity, identifying perched and regional groundwater zones, and obtaining lithologic and stratigraphic data.

The Schlumberger suite of geophysical logging tools included the following:

- Combinable Magnetic Resonance (CMR™). Measures the nuclear magnetic resonance response to the formation, evaluates total and effective water-filled porosity of the shallow formation, and estimates pore size distribution and hydraulic conductivity.
- Triple Detector Litho-Density (TLD™). Measures formation bulk density related to porosity, photoelectric effects related to lithology, and borehole diameter using a single-arm caliper.
- Natural Gamma Spectroscopy (NGS™): Measures gross natural and spectral gamma-ray activity (including potassium, thorium, and uranium concentrations) in open- and cased-hole conditions to help characterize geology and lithology.
- Elemental Capture Spectroscopy (ECS™). Measures elemental weight concentrations of a variety of elements to characterize formation mineralogy, lithology, and water content.
- Compensated Neutron Tool, Model G (CNTG™). Measures volumetric water content beyond the casing to evaluate formation porosity and moisture content.

Additionally, a calibrated natural gamma tool was used and gross natural gamma-ray activity was recorded with every logging method (except NGS™) to correlate depth intervals between each survey.

The Schlumberger geophysical logs (compiled as a montage) and logging summary report for borehole R-14 are presented in Appendix E, which can be found on a CD that is attached to the inside back cover of this report.

6.0 LITHOLOGY AND HYDROGEOLOGY

A preliminary assessment of the hydrogeologic features encountered during drilling operations at R-14 is presented below. Included is a brief description of the geologic units identified during characterization of cuttings. Discussion of groundwater occurrences is based on drilling evidence and geophysical logging data.

6.1 Stratigraphy and Lithologic Logging

Lithologic descriptions are based on core samples and cuttings samples collected during drilling operations. Rock units and stratigraphic relationships were determined primarily from data collected by visual examination of drill cuttings samples and should be considered preliminary. The Laboratory may revise such interpretations after future detailed analysis of petrographic, geochemical, mineralogical, and geophysical logging data. A generalized stratigraphic column is shown in the well summary sheet for R-14 (Figure 3.0-2).

Fill (0 to 3.5 ft bgs)

Unconsolidated materials, including base-course gravel and reworked materials from the Bandelier Tuff used to construct the R-14 drill pad were noted in the interval from 0 to 3.5 ft bgs.

Tshirege Member of the Bandelier Tuff, Qbt 2 (3.5 to 80 ft bgs)

Qbt 2 of the Tshirege Member of the Bandelier Tuff, intersected from 3.5 to 80 ft bgs, is represented by rhyolite ash-flow tuff composed of pumice lapilli in a matrix of quartz and sanidine phenocrysts and abundant (up to 80% by volume) ash. Pumices, generally 1 to 2 cm long, are devitrified and typically flattened. Matrix ash is crystalline and devitrified. The unit exhibits a moderate degree of welding in the upper part and becomes less welded in its lower section.

Tshirege Member of the Bandelier Tuff, Qbt 1 (80 to 220 ft bgs)

Qbt 1v and Qbt 1g of the Tshirege Member of the Bandelier Tuff were recognized in R-14 between 80 and 220 ft bgs. They are discussed herein as a single, undivided rock unit. This rhyolite ash-flow tuff unit is composed of pumice lapilli (up to 4 cm long) and quartz and sanidine phenocrysts in a matrix of ash. The upper part of this interval is poorly welded to nonwelded and contains crystallized (devitrified) pumices and devitrified ash. In contrast, the lower part of the interval exhibits distinctive glassy, fibrous pumices and matrix ash with abundant glass shards, indicating its vitric nature relative to the upper section.

Cerro Toledo Interval (220 to 244 ft bgs)

The Cerro Toledo interval, typically made up of rhyolite tephra and volcaniclastic sediments in the investigation area, underlies the Tshirege Member in the interval from 220 to 244 ft bgs. Poor core recovery was experienced in this section. Examination of the limited sample material produced indicates the Cerro Toledo is made up locally of dacitic gravels and tuffaceous sand with minor pumice.

Otowi Member of the Bandelier Tuff (244 to 534 ft bgs), including the Guaje Pumice Bed (522 to 534 ft bgs)

The Otowi Member of the Bandelier Tuff, composed of rhyolite ash flow tuffs, was intersected in the 278-ft-thick interval from 244 to 522 ft bgs. Core and drill cuttings indicate that this unit is composed of fibrous glassy pumice, quartz and sanidine crystals, volcanic xenoliths, and vitric ash. Pumice lapilli in the upper part of the Otowi Member locally are yellowish brown in color. Chip samples typically contain 40% to 70% by volume dacite and andesite lithics that represent inclusions formerly enclosed in the tuff matrix. The lack of preserved indurated ash matrix in chip samples suggests this tuff interval is poorly welded to nonwelded.

Borehole R-14 intersected the Guaje Pumice Bed immediately below the Otowi Member of the Bandelier Tuff in the interval from 522 to 534 ft bgs. Drill cuttings indicate that the Guaje Pumice Bed consists of fibrous, vitric, rhyolitic pumice, quartz and sanidine crystals, and abundant dacite and andesite lithic fragments.

Upper Puye Formation (534 to 620 ft bgs)

The first of two fanglomerate sequences that represent the Pliocene Puye Formation at R-14 occurs in the interval from 534 to 620 ft bgs. Cuttings in this interval are finely ground by the effects of drilling. Chips appear to be composed exclusively of gray, aphanitic, aphyric to sparsely porphyritic dacite.

Unassigned Dacitic Lavas (620 to 768 ft bgs)

R-14 encountered a sequence of dacite flows in the interval from 620 to 768 ft bgs. Dacitic volcanics were not expected in this borehole. These volcanic rocks have not yet been classified, and it is not certain whether they should be grouped with dacites and andesites of the Tschicoma Formation or with the generally more mafic volcanics of the Cerros del Rio basalt. Therefore, dacites in this interval are not assigned to a rock unit and origin.

Dacites in the above interval are characterized as reddish brown, massive, aphyric, and aphanitic to sparely porphyritic with a finely crystalline groundmass. Fine-grained phenocrysts of pyroxene, plagioclase, and possibly quartz make up no more than 5% by volume.

Lower Puye Formation (768 to 1210 ft bgs) and Pumiceous Fanglomerates (1210 to 1327 ft bgs)

A sequence of fanglomerate deposits that forms a stratigraphically lower section of the Puye Formation was penetrated from 768 to 1210 ft bgs. Cuttings from the upper part of this interval (768 to 1068 ft bgs) contain abundant dacite and chips of gray clay. Sericite and/or clay alteration of dacite generally increases with depth. Cuttings from 1068 to 1210 ft bgs represent fine-to-coarse Puye sediments that contain a variety of volcanic clasts, predominantly porphyritic dacite with lesser latite, rhyolite, and minor pumice. The fanglomerates from 1210 ft bgs to the base of the sequence are pumice-bearing. Cuttings from this lowermost interval contain a significantly greater percentage of pumice than exhibited elsewhere in the sequence and also contain quartz and microcline from Precambrian sources. Stratigraphic assignment of the pumiceous sequence is uncertain.

6.2 Groundwater Occurrence and Characteristics

Well R-14 was expected to encounter both perched groundwater zones and regional aquifer saturation (Appendix A). Two potential zones of perched saturation were projected between 575 to 608 bgs (the anticipated depth of the Guaje Pumice Bed) and between 737 to 881 ft bgs (near the base of the expected Cerros del Rio basalt). Any perched water in small amounts could not be observed during fluid-assisted open-hole drilling operations because drilling with foam substantially reduced the ability to detect perched groundwater zones. The borehole video log confirmed that no perched horizons were present.

The regional water table was intersected in lower Puye fanglomerate sediments and measured at approximately 1182 ft bgs on June 26, 2002. Drilling beyond this depth switched to conventional mud-rotary techniques; thus it was not possible to make any observation of groundwater characteristics. No water samples were collected for chemical analysis during drilling operations.

7.0 WELL DESIGN AND CONSTRUCTION

7.1 Well Design

The well design for R-14 was completed jointly by the Laboratory and WGII, in consultation with the US Department of Energy (DOE), and the New Mexico Environment Department (NMED). Geophysical logs, video logs, borehole geologic samples, water-level data, field water-quality data, and drillers' observations were reviewed by the Groundwater Investigations Team to plan screen placement intervals for the well. The well design specified two screens to monitor the distribution and concentration of potential contaminants in the regional aquifer. The number and placement of screens were designed to meet the following criteria:

- to monitor near the top of the regional zone of saturation, and
- to monitor a deeper productive zone within the regional aquifer.

Productive intermediate perched groundwater zones were not encountered during drilling; therefore, no screens were placed above the regional aquifer. The planned and actual screen depths are given in Table 7.1-1.

Table 7.1-1
Summary of Well Screen Information, Characterization Well R-14

Screen	Planned Depth (ft)	Actual Depth (ft)	Geologic/Hydrologic Setting
1	1201.6–1234.6	1200.6–1233.2	Near top of regional zone of saturation in the Puye Formation
2	1286.8–1293.6	1286.5–1293.1	Deeper zone of the regional aquifer in pumiceous sediments

7.2 Well Construction

The well casing and pipe-based screens were manufactured using 4.5-in. inner diameter (ID)/5.0-in. OD, type 304, stainless steel fabricated to meet American Society for Testing and Materials (ASTM) 1994 A554 standards. The external couplings were also of type 304 stainless steel fabricated to meet ASTM standard A312, which exceed the tensile strength of the threaded casing ends. The pipe-based screens were fabricated by Weatherford Well Screens (Johnson Screens, Inc.) using 10-ft sections of blank well casing. A series of 0.5-in.-diameter holes were drilled in the pipe and then stainless steel wire wrap (0.010-in. spacing) and welded over the perforations. The final OD of the screens was 5.5 in.

The stainless steel well components were decontaminated at the well site using a high-pressure steam cleaner and scrub brushes. To centralize the well in the borehole, stainless steel centralizers were installed above and below each screen, and in several locations above the zone of regional saturation. All backfill materials were emplaced in the well annulus through a tremie pipe. An as-built drawing of the completed well is provided in Figure 7.2-1.

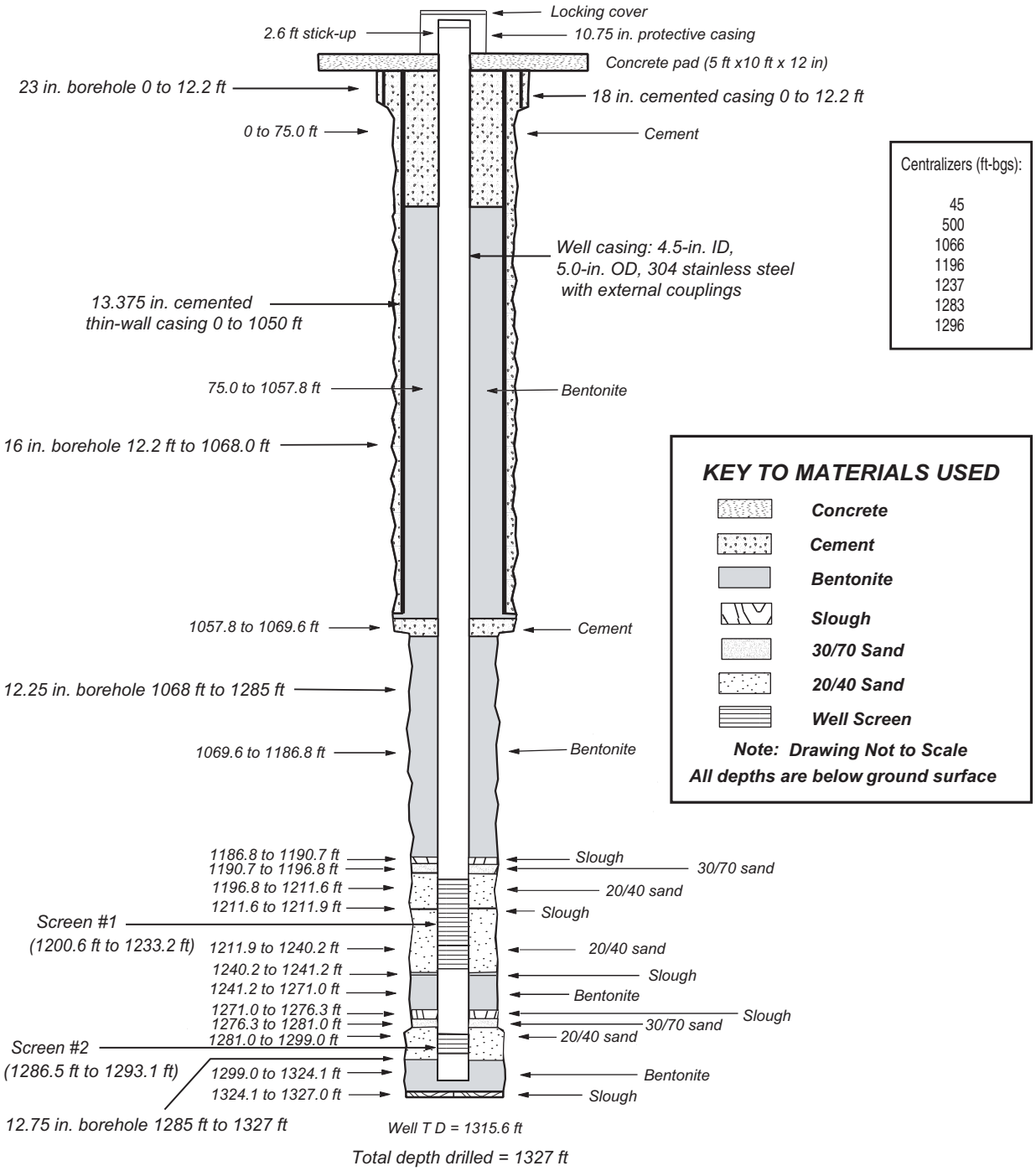
7.2.1 Well Installation

Well installation consisted of connecting stainless steel well screens and casing joints by means of threaded external couplers as specified in the well design. The base of the well was set at 1315.6 ft bgs. Dynatec installed the well casing from July 4 to 5, 2002 (Figure 3.0-1). Figure 7.2-1 illustrates the final well configuration and indicates the depths of the various well components from ground surface to TD.

7.2.2 Annular Fill Placement

A steel tremie pipe was used to deliver annular materials at the depth intervals specified in the well design. The bottom of the borehole was measured with a tag line at 1324.1 ft bgs before fill material was introduced into the annulus. Dynatec installed the annular fill material from July 5 through July 11, 2002 (Figure 3.0-1). Filter packs across screened intervals consisted of silica sand materials mixed with municipal water and placed in the annulus as a fluid slurry. Bentonite materials were placed between screened intervals to seal the annular space and prevent interaction between water-bearing zones. Portland cement (mixed at a ratio of 5 gal. of water per bag of cement) was used to provide a foundation for the annular fill and for wellhead protection in the upper 75 ft of the borehole and behind the casing to 1050 ft. Approximately 13,631 gal. municipal water were used during annular fill material placement.

Table 7.2-1 lists the annular fill materials used. The final configuration of the annular materials is also illustrated in Figure 7.2-1.



Note: 1. Each screen interval lists the footage of the pipe perforations, not the top and bottom of screen joints.

2. The intervals of slough consist of sands and gravel of the Puye Formation.

3. Westbay multiport sampling system (MP-55) casing not shown.

4. Pipe-based screen: 4.5-in. ID, 5.563-in. OD,304 stainless steel with s.s. wire wrap; 0.010-in. slot.

5. Well sump interval: 1293.1 to 1315.6 ft

Figure 7.2-1. As built well configuration diagram, characterization well R-14

Table 7.2-1
Annular Fill Materials, Characterization Well R-14

Material	Use/Function	Amount	Unit*
20/40 sand (medium-grained)	To pack screened intervals	109.5	Bag
30/70 sand (fine grained)	To separate screen packs from bentonite or cement from bentonite	30	Bag
Benseal® bentonite (granular bentonite)	Produces slurry when mixed with water	2	Bag
Pelplug® bentonite pellets (0.25-in. by 0.375-in. refined elliptical pellets)	To provide borehole annular seal below water table	403	Bucket
Quick-Grout® bentonite grout (powdered bentonite)	To provide annular seal between casing strings	132	Bag
Portland® cement (mixed with municipal water at ratio of 5 gal. water for each bag of cement)	To provide annular support and surface seal on upper 100 ft of borehole	57	Bag

*Sand bag = 50 lb ea; bentonite bag/bucket = 50 lb ea; cement bag = 94 lb ea.

8.0 WELL DEVELOPMENT AND HYDROLOGIC TESTING

Dynatec conducted well development and hydrologic testing at R-14 from July 19 to November 18, 2002 (Figure 3.0-1). Development activities included preliminary bailing, wire-brushing, surging and bailing, and pumping. Baroid chemical additives were used to aid in wall-cake breakdown and to remove drilling mud wall cake (see Appendix B). Hydrologic injection tests were run after the well was developed.

8.1 Well Development

Well development at R-14 was accomplished by wire-brushing the well interior, bailing, surging, and pumping. After the well's interior was brushed, each screen was surged and bailed to flush particulate matter from the filter pack and formation. A submersible pump and packer system were then lowered to both screens and on/off cyclic pumping conducted to remove any remaining fines from the screened intervals. Criteria for R-14 well development were based on selected field water-quality parameters (turbidity, specific conductance, pH, and temperature) measured in groundwater samples. To monitor progress during each development procedure, groundwater samples were collected periodically, and time-series parameter measurements were recorded. One objective of well development was to remove suspended sediment from the water until turbidity (measured in nephelometric turbidity units [NTU]) decreased to a value of less than 5 NTU for three consecutive samples. Similarly, other measured parameters were required to stabilize before development procedures terminated. When these criteria were met, the well was declared developed.

Well development began on July 19, 2002, by bailing out the well sump to remove debris and sediment. The well casing and screens then were cleaned using a wire-brush system, and the sump was bailed again. Turbidity measurements ranged from 202 to 158 NTU, and 2025 gal. of water were bailed during this procedure (Table 8.1-1).

Surging techniques were employed across screens 1 and 2 using a wireline-controlled, weighted surge block for rapid upward strokes to retrieve fines and wall-cake materials from the screen filter pack and surrounding formation. The well screens were surged repeatedly, and then bailed and pumped. An estimated 7055 gal. of well water were purged from the well during the surge/bail procedure. Water turbidity measured 158 NTU at the beginning and 160 NTU at the end (Table 8.1-1).

Table 8.1-1
Development of R-14

Method	Water Produced (gal.)	Parameters[a]			
		pH	Temperature (°C)	Specific Conductance (µS/cm)[b]	Turbidity (NTU)
Preliminary bailing/wire brushing	2025	8.0–8.0	24.0–22.0	441–207	202–158
Surge/bail/pump	7055	7.9–7.7	22.1–20.1	223–150	158–4
Pump screen 1 w/packers	2110	7.7–7.6	19.1–22.6	158–139	6–1
Pump screen 2 w/packers	46,930	7.5–7.4	22.1–23.4	195–160	6–218
Surge/bail	870	7.5–7.7	23.3–23.1	247–342	>1000–>1000
Pump screen 2 w/out packers	9200	8.0–7.8	22.8–23.9	379–173	>1000–<1
Surge/bail	130	6.9–7.7	21.5–23.4	NM[c]	>1000–>1000
Chemical treatment (310 gal. in screen 1, 90 gal. in screen 2)	+400	—[d]	—	—	—
Surge/bail	290	3–4	NM	NM	NM
Chemical treatment; add 400 gal. PFD to well	+400	—	—	—	—
Surge/bail	1180	3.4–3.7	21.9–21.0	2249–1132	126–141
Pumping screen 2 w/packers	126,830	5.7–6.7	23.2–23.2	385–130	83–<1
Pumping screen 1w/packers	3500	7.0–6.9	22.2–22.9	134–132	<1–<1
TOTAL	205,010				

[a] Parameters presented as value at beginning followed by value at end of development method.
[b] Specific conductance reported in microsiemens per centimeter.
[c] NM = Not measured.
[d] Dash indicates no samples collected during chemical treatment.

Pump development of the R-14 well began on July 31, 2002. A 10-horsepower (hp) submersible pump was lowered to each screen with an inflatable packer system deployed with one packer above and one packer below the screened interval as appropriate to isolate the water-bearing zone. On/off cyclic pumping was conducted with nominal 30-min periods of nonpumping to allow the water level to recover in the well. Water samples were collected at frequent intervals to monitor parameters. Development pumping was first applied to screen 1. An estimated 2110 gal. of water were pumped from screen 1, and turbidity measurements were consistently near or below the acceptable well development criterion (5 NTU) throughout this pumping procedure (Table 8.1-1). An estimated 46,930 gal. of water were pumped from screen 2, with final turbidity reaching 218 NTU.

To accelerate development progress and dislodge particulates in the filter pack and formation, surge/bail procedures were attempted again at screens 1 and 2 on August 6 and 7, 2002. Development activities at R-14 were suspended for approximately two weeks. When pumping at screen 2 continued on August 24, 2002, the well produced a grayish-colored water. Surge-and-bail methods resumed August 28 through 29, 2002. Water bailed at this stage was extremely turbid and black in color. After Baroid representatives

were consulted, chemical treatments were applied to the well screens to enhance well development. On September 25, 2002, the first chemical treatment of the impacted well screens was carried out. A solution consisting of 30 lb AQUA-CLEAR™-MGA (modified granular acid) and 3 gal. AQUA-CLEAR™-AE (acid enhancer) per 100 gal. of municipal water was mixed on the site. A tremie pipe was used to inject 310 gal. of the solution into the screen 1 area and 90 gal. into the screen 2 area. Surge-and-bail procedures then were carried out at both screens from September 26 to October 1, 2002. During this procedure, an additional chemical treatment (a dispersant called PFD) was applied to the well on September 27, 2002. The solution consisted of 1.5 gal. PFD mixed with 400 gal. of municipal water. As water was withdrawn from the well, the pH was monitored with paper test strips. When the pH value returned to a range of 5.0 to 6.0, the well could be pumped.

From October 6 to October 10, 2002, pumping was resumed at screen 2. As pump development progressed, parameter values for specific conductance and pH stabilized, and turbidity readings declined to NTU values of less than one. Additional pumping from screens 1 and 2 was performed from November 8 to November 11, 2002, using inflatable packers above and below the screens to isolate the water-bearing intervals. Development pumping continued until an additional 136,690 gal. had been withdrawn (Table 8.1-1) and the ranges of monitoring measurements for all parameters were consistently acceptable.

8.2 Hydrologic Testing

On November 13, 2002, the Laboratory conducted three hydrologic tests across screen 2. Screen 1 straddles a geologic contact and was not tested because the unit to which results would apply was uncertain. Thus, testing focused on screen 2, which lies wholly within the pumiceous Puye. Three straddle-packer/injection tests were conducted: two short tests (1 min each with different injection rates) and one test of longer duration at a higher injection rate. After testing, approximately 4750 gal. of water were purged from the well. The short tests were analyzed by slug-test methods and the longer test was analyzed by pumping-test methods. The results of the injection tests will be presented in a separate report entitled “Hydrologic Tests at Characterization Well R-14” to be released later this year.

8.3 Installation of Westbay™ Monitoring System

A Westbay™ sampling system was installed inside the stainless steel well casing after development procedures were completed. Installation work was performed from November 18 to 25, 2002. The base of the multiport casing was set at 1311 ft bgs. The system is set in place using a series of packers inflated with de-ionized water and positioned to target each well screen with a set of valved ports. The R-14 system contains seven ports to inflate and test eight packers. Screen 1 is accessed by three measurement ports and screen 2 by two measurement ports. Both measurement zones also contain a pumping port.

Quarterly sampling of Westbay™-equipped wells will be conducted using a Laboratory-owned sampling trailer outfitted with the MOSDAX sampling system (controller, sampler probe, and sample bottle train) and a motorized winch-and boom-system. The Westbay™ summary MP casing log provides details of the installed system (Appendix F, which can be found on a CD that is attached to the inside back cover of this report).

9.0 WELLHEAD COMPLETION AND SITE RESTORATION

When operational tests were completed on the installed sampling system, the protective casing height was adjusted to accommodate a locking cap over the Westbay™ installation. Finish work commenced on the wellhead area, well components were surveyed, and the site underwent final cleanup and restoration.

9.1 Wellhead Completion

The surface completion for well R-14 involved construction of a reinforced (5000 psi) concrete pad, 5 ft wide by 10 ft long by 12 in. thick, around the well casing to ensure the long-term structural integrity of the well components (Figure 9.1-1). The concrete pad was poured on October 30, 2002. A brass survey pin was installed in the northwest corner of the concrete pad. A 10.75-in.-diameter steel casing with locking lid protects the well riser. Four 4-in.-diameter steel bollards were placed next to each side of the pad. The bollard on the west side can be removed to provide access to the well for sampling and maintenance. The pad was designed to be slightly elevated, with base coarse graded around the pad to allow drainage.

9.2 Geodetic Survey

Southwest Mountain Surveys, Inc. (NMPLS #6998) conducted a geodetic survey of well R-14 on December 19, 2002, using a global positioning satellite (GPS) system. The GPS system utilizes National Geodetic Vertical Datum (NGS) of 99/96 for vertical computations and the datum for the horizontal control network is North American Datum 1983 (NAD 83).

The survey located the brass cap monument in the northwest corner of the concrete pad and measured elevations to the top of the steel exterior protective casing, top of the Westbay™ cap, and top of the Westbay™ plate at R-14 (Table 9.2-1). The coordinates shown are in New Mexico State Plane coordinates, Central Zone (NAD 83) expressed in feet. To be consistent with current Laboratory standards, elevations are expressed in feet above mean sea level and referenced to the National Geodetic Vertical Datum of 1929 (NVGD29).

9.3 Site Restoration

Site restoration activities at R-14 were conducted from February 10 to March 13, 2003 (Figure 3.0-1). Waste management activities were performed before and during restoration. Waste materials were removed from the site, following the WCSF. Drilling-generated media, including drilling fluids, cuttings, and development water, were sampled for contaminant analysis. These data were reviewed by the Laboratory and NMED (Appendix G). The drill cuttings were used to help backfill the containment area and the drilling fluids and development water were applied downgradient of the site in accordance with the provisions of the Notification of Intent (NOI). The waste streams from spill clean up included petroleum-contaminated soils and absorbent materials used to clean up minor spills. After the Laboratory approved the waste profile forms, the waste streams were disposed of as New Mexico Special Waste. The drill site area was recontoured by K. R. Swerdfeger Construction, Inc., to conform to the surrounding topography. Before the area was recontoured, the cuttings-containment area was excavated and the plastic lining was removed. The containment basin and water-tank storage areas then were backfilled with dirt that had been bermed during pad construction and the area was regraded. Base-course gravel was also regraded and compacted across the site to form a smaller pad. In addition, a chipper was moved to the site to chip slash piles accumulated during tree removal procedures related to drill pad construction. The slash-pile chips were used to mulch reseeded areas of the site.

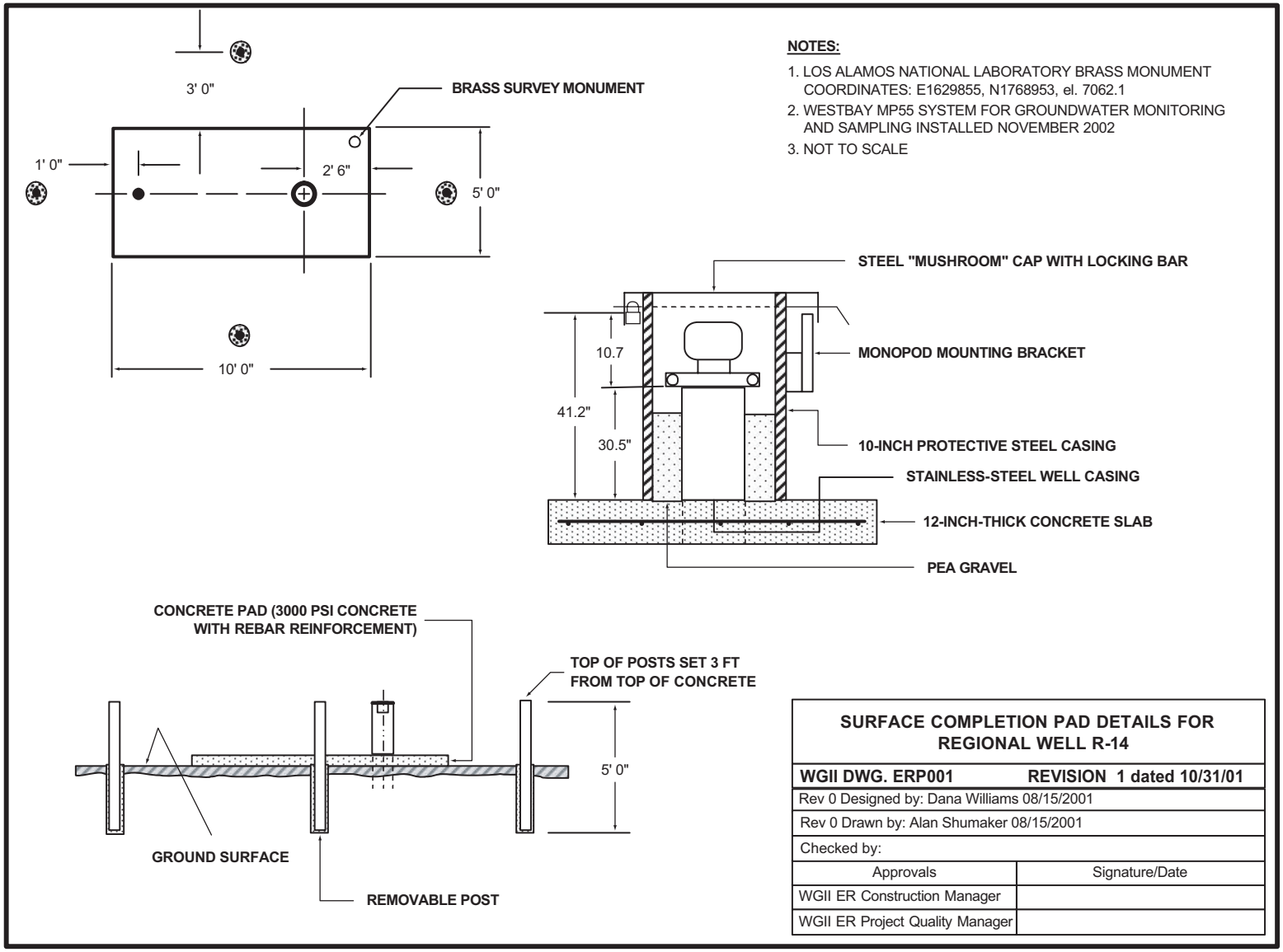


Figure 9.1-1. Surface completion configuration diagram

Table 9.2-1
Geodetic Data for Well R-14

Description	East	North	Elevation
Top of steel protective casing (north edge)	1629856.31	1768951.35	7065.60
Top of Westbay™ cap	1629856.58	1768951.62	7065.35
Top of Westbay™ plate	1629856.52	1768961.48	7064.83
Brass cap in R-14 pad	1629855.01	1768953.12	7062.08

The straw wattles and silt fences that are part of the R-14 site best management practice installations remain in place as needed. The site was re-seeded with a Laboratory-specified blend of native grasses mixed with mulch and fertilizer for regrowth of ground cover.

10.0 DEVIATIONS FROM THE R-14 SAP

Appendix A compares the actual characterization activities performed at R-14 with the planned activities described in the Hydrogeologic Workplan (LANL 1998, 59599) and the R-14 SAP (LANL 2002, 73440).

Significant deviations are discussed below:

- *Planned depth.* The SAP stated that the estimated drilling depth would be 1664 ft bgs; actual drill depth was 1327 ft bgs in the Lower Puye Formation and 145 ft in the regional aquifer. Due to limitations on lifting capacity of the drill rig, drilling was stopped at 1327 ft.
- *Surface casing.* The SAP stated that 18-in.-OD steel casing would be set to approximately 50 ft bgs and cemented in place. Because of the very shallow depth of bedrock, the 18-in. surface casing was cemented in place at a depth of 12.2 ft.
- *Conductor casing.* The SAP stated that 11.75-in. steel casing would be permanently installed from 0 to approximately 700 to 800 ft, or approximately 100 ft above the anticipated regional water level. Work performed involved setting 13.375-in. thin-wall steel casing to a depth of 1050 ft and cementing in place. The static water level measured during drilling was at 1181 ft bgs; casing was cemented approximately 131 ft above the regional water level.

11.0 ACKNOWLEDGMENTS

Dynatec Drilling Company provided the rotary drilling services.

Tetra-Tech EM Inc.; D. B. Stephens and Associates, Inc.; and S. M. Stoller provided support for well-site geology and sample collection.

Southwest Mountain Surveys provided the final geodetic survey of finished well components.

D. Thompson and C. Schultz of PMC Technologies (Exton, PA) and R. Lawrence, Paula Schuh, and E. Tow of Tetra-Tech EM Inc. (Albuquerque, New Mexico) contributed to the preparation of this report.

R. Bohn, D. Broxton, E. Louderbough, S. Pearson, W. Stone, and D. Vaniman of Los Alamos National Laboratory prepared and/or reviewed this report. R. Enz and T. Whitacre of DOE also reviewed this report.

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Appendix A

Activities Planned for R-14 Compared with Work Performed

Activity	Hydrogeologic Work Plan	Work Plan for Mortandad Canyon	R-14 Sampling and Analysis Plan	R-14 Actual Work
Planned Depth	100 to 500 ft below ground surface (bgs) into the regional aquifer	R-14 proposed depth of 1670 ft bgs	Estimated depth of 1664 ft bgs	Total drill depth 1327 ft bgs
Drilling Method	Methods may include, but are not limited to, hollow stem auger (HSA), air-rotary/Odex/ Stratex, air-rotary/ Barber rig, and mud-rotary drilling	Methods may include, but are not limited to HSA, air-rotary/Odex/Stratex, air-rotary/Barber rig, and mud-rotary drilling	Air rotary core, mud rotary flooded-reverse circulation, and fluid-assist air rotary with casing advance	Air rotary core with wireline retrieval, mud rotary flooded-reverse circulation, and fluid-assist air rotary with casing advance.
Amount of Core	10% of the borehole	Approximately 10%	Continuous core first 300 ft of borehole	Core from 0 to 306 ft bgs
Lithologic Log	Log to be prepared from core, cuttings, and drilling performance data.	Log to be prepared from core, cuttings, and drilling performance	Log to be prepared from core, cuttings, geophysical logs and drilling performance.	Log prepared from core, cuttings, geophysical logs, and drilling performance
Number of Water Samples Collected for Contaminant Analysis	A water sample may be collected from each saturated zone, five zones assumed. The number of sampling events after well completion is not specified.	For planning and conceptual design purposes, it has been assumed that four water-bearing zones will be encountered. Groundwater samples will be collected from each water-bearing zone.	No borehole groundwater screening samples will be collected during drilling.	No water samples obtained during drilling.
Water Sample Analysis	Initial sampling: Radiochemistry I, II, and III, tritium, general inorganics, stable isotopes, volatile organic compounds (VOCs), and metals. Saturated zones: radionuclides (tritium, ^{90}Sr, ^{137}Cs, ^{241}Am, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, beta, and gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements	Analytical suite for intermediate perched zone and regional aquifer groundwater Samples: major and minor ions, trace elements, organic compounds, dissolved organic carbon, total suspended solids, total dissolved solids, neutral species (SiO_2), hardness, cyanide, stable and radiogenic isotopes, and radionuclides.	Metals (dissolved), Anions (dissolved), 99Tc, gamma spec, ^{241}Am, ^{137}Cs, ^{238}Pu, ^{239,240}Pu, ^{234}U, ^{235}U, ^{238}U, ^{90}Sr, stable isotopes (^{18}O/^{16}O, D/H, ^{15}N/^{14}N), tritium, tritium (low level or direct counting), RVgross-alpha, beta, gamma, TUICPMS, TKN, CLO^{4-}	During well completion and development, groundwater samples (from screens 1 and 2) were analyzed for Metals (dissolved), Anions (dissolved), ^{241}Am, ^{137}Cs, ^{238}Pu, ^{239,240}Pu, ^{234}U, ^{235}U, ^{238}U, ^{90}Sr, stable isotopes (18O/16O, D/H, 15N/14N), tritium, tritium (low level or direct counting), U-total, perchlorate, alkalinity, and TKN.

Activity	Hydrogeologic Work Plan	Work Plan for Mortandad Canyon	R-14 Sampling and Analysis Plan	R-14 Actual Work
Water Sample Field Measurements	Alkalinity, pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, dissolved oxygen, turbidity	pH, specific conductance, temperature, turbidity	Parameters measured: pH, specific conductance, temperature, turbidity
Number of Core/ Cuttings Samples Collected for Contaminant Analysis	Twenty samples of core or cuttings to be analyzed for potential contaminant identification in each borehole.	Seventy-three samples of core or cuttings to be analyzed for potential contaminant identification in each borehole.	During coring, anion, stable isotope, radionuclide, and tritium profiles will be determined from the level of the canyon floor to the upper part of the Otowi Member (approximately 300 ft in depth). Up to five core or cuttings samples will be collected for geochemical and contaminant characterization within water-bearing zones encountered during drilling.	24 core/cuttings samples collected and submitted for analysis.
Core/Cuttings Sample Analytes	Uppermost core or cuttings sample to be analyzed for a full range of compounds: deeper samples will be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low and high detection levels), and metals. Four samples to be analyzed for VOCs.	Analytical suite for core and cuttings samples includes anions, trace elements, organic compounds, total organic carbon, cyanide, and radionuclides.	Analytical suite for core and cuttings samples includes anions, stable isotopes, tritium profiles, perchlorate, TKN, stable isotopes, ^{241}Am, ^{238}Pu, ^{239,240}Pu, ^{234}U, ^{235}U, ^{238}U, ^{90}Sr, gamma spectroscopy, gross alpha, beta, and gamma, radionuclides, and metals.	Core samples were analyzed for anions, stable isotopes (18O/16O, D/H, 15N/14N), ^{241}Am, ^{238,239,240}Pu, ^{234,235,238}U, ^{90}Sr, gamma spectroscopy, tritium and gross alpha, beta, and gamma.
Laboratory Hydraulic-Property Tests	Physical properties analyses will be conducted on 5 core samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	Physical properties analyses will be conducted on core samples and will typically include: moisture content, moisture potential, and saturated hydraulic conductivity.	Physical properties analyses will be conducted on core samples for moisture content.	No laboratory hydraulic property tests performed.

Activity	Hydrogeologic Work Plan	Work Plan for Mortandad Canyon	R-14 Sampling and Analysis Plan	R-14 Actual Work
Geology	Ten samples of core or cuttings will be collected for petrographic, X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses.	Selected samples of core or cuttings will be collected for petrographic, (XRF), (XRD) and K/Ar or 39Ar/40Ar isotopic dating analyses.	Analytical testing of samples may include mineralogy by XRD, petrography by modal analysis of thin sections, by electron microprobe, and/or by scanning electron microscope, and geochemistry by XRF	Eleven samples were characterized for mineralogy, petrography, and rock chemistry.
Geophysics	In general, open-hole geophysics includes caliper, electromagnetic Induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), fluid resistivity (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: Gamma-gamma density, natural gamma, and thermal neutron.	Geophysical logs will be run in the boreholes, and compact neutron moisture logs may be run in shallower portions of the boreholes. Natural gamma, neutron moisture, and density logs may be run in shallower portions of the boreholes. Natural gamma, neutron moisture, and density logs may be run if the drilling method and borehole stability permit. Other geophysical logs may be considered if, in the opinion of the technical team, they will satisfy a technical need. In general, open-hole geophysics includes caliper, electromagnetic induction, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: gamma-gamma density, natural gamma, and thermal neutron.	In general, open-hole geophysics includes caliper, electromagnetic Induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), fluid resistivity (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: Gamma-Gamma Density, Natural Gamma, and Thermal Neutron.	LANL tools: 0–12.2 ft bgs (cased), 12.2–1068 ft bgs (open hole): video, natural gamma, induction; 0–1327 ft bgs (cased): natural gamma; 0–1315 ft bgs (well): video Schlumberger geophysics: 0–12.2 ft bgs (cased), 12.2–1068 ft bgs (open hole): lithodensity, spectral gamma, natural gamma elemental capture, thermal-epithermal neutron, combinable magnetic resonance, and natural gamma

Activity	Hydrogeologic Work Plan	Work Plan for Mortandad Canyon	R-14 Sampling and Analysis Plan	R-14 Actual Work
Water-Level Measurements	Procedures and methods not specified in Hydrogeologic Workplan.	Procedures and methods not specified in Hydrogeologic Workplan.	Water levels will be determined for each saturated zone by water-level meter or by pressure transducer.	A water-level meter was used to determine groundwater levels.
Field Hydraulic-Property Tests	Tests to be conducted not specified in Hydrogeologic Workplan.	Tests to be conducted not specified in Hydrogeologic Workplan.	Slug tests will be performed following well development.	Falling head injection tests were conducted on screen #2.
Surface Casing	Approximately 20-in. outer diameter (OD), extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	Approximately 20-in. OD, extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	Install 18-in. or 20-in. OD steel casing to approximately 50 ft bgs and cement in place.	18-in. OD steel casing set at 12.2 ft bgs
Conductor Casing	Unless other technical methods are applied, a temporary steel casing, up to 14-in. OD, will be advanced to total depth of borehole.	Unless other technical methods are applied, a temporary steel casing, up to 14-in. OD, will be advanced to total depth of borehole.	Install 113/4-in. OD steel casing from 0 to ~700 to 800 ft bgs or approximately 100 ft above anticipated regional water level.	Install 13.375-in.-OD thin-wall steel casing from 0 to 1050 ft bgs.
Minimum Well Casing Size	6.625-in. OD	6.625-in. OD	5-in.-OD x 4.5-in.-ID	5-in.-OD x 4.5-in.-ID stainless steel casing w/ external couplings.
Well Screen	Machine-slotted (0.01-in.), stainless steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED.	Machine-slotted (0.01-in.), stainless steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED.	Well screen shall be constructed with multiple sections of 5-in. OD stainless steel pipe with wire wrap (0.01-in. slot opening).	Screened intervals constructed of 5.56-in.-OD (4.5-in.-ID) pipe with stainless steel, wire-wrapped, 0.010-in. slotted screen

Activity	Hydrogeologic Work Plan	Work Plan for Mortandad Canyon	R-14 Sampling and Analysis Plan	R-14 Actual Work
Filter Material	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen.	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen.	Filter pack shall extend at least 5 ft and no more than 10 ft above and below each well screen. No differentiation made between primary and secondary filter packs.	Primary filter pack consisted of 20/40 silica sand placed 6.1 ft below and 5.5 ft above screen #2. Secondary filter pack consisted of 30/70 silica sand placed in a layer 5.3 ft thick above screen. Primary filter pack consisted of 20/40 silica sand placed 7 ft below and 3.8 ft above screen 1. Secondary filter pack consisted of slough in a layer 1-ft-thick below and 30/70 silica placed in a layer 6.1-ft thick above primary filter pack.
Backfill Material (exclusive of filter materials)	Uncontaminated drill cuttings below sump and bentonite above sump.	Uncontaminated drill cuttings below sump and bentonite above sump.	Bentonite and cement in borehole or well annulus.	Slough in borehole and annulus below and around well sump from TD to 8.5 ft below bottom of well screen. Slough and bentonite seal above and below screen #1 filter pack. Slough and bentonite seal above and below screen #2 filter pack One cement plug from 1057.8 to 1069.6 ft and cement-bentonite grout from surface to 77 ft bgs.
Sump	Stainless steel casing with an end cap	Stainless steel casing with an end cap	Not specified	5-in.-OD stainless steel casing, 22.5 ft long, with an end cap.
Bottom Seal	Bentonite	Bentonite	Bentonite	Bentonite

Appendix B

Drill-Additive Product Specifications
(CD attached to inside back cover)

PAC™-L

Modified Natural Cellulosic Polymer

Description

PAC-L, modified natural cellulosic polymer, provides filtration control in most water-based drilling fluids without substantially increasing viscosity. PAC-L, when added to a QUIK-GEL® or BORE-GEL™ slurry, yields a drilling mud system suitable for drilling in sandy formation. PAC-L can be added to vegetable or mineral oil to provide an oil-based fluid suspension, which can be poured into drill string directly.

Applications/Functions

- Provide filtration control in fresh or brackish water-based drilling fluids
- Reduce fluid loss without significantly increasing fluid viscosity
- Encapsulate shale to prevent swelling and disintegration
- Promote borehole stability in water sensitive formations
- Minimize rod chatter, rotational torque and circulating pressure
- Improve hole cleaning and core recovery

Advantages

- Effective in fresh water, salt water and brackish water-based drilling fluids
- Effective in small quantities for filtration control
- Non-fermenting
- Compatible with other Baroid drilling fluid additives
- Resistant to harsh environments and contaminants

Typical Properties

Appearance	White, free-flowing powder
pH (1% aqueous solution)	7.75

Recommended Treatment

- Using a Venturi Mixer, or into vortex of a high-speed stirrer, add slowly and uniformly to the entire circulating system.

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Recommended Treatment

Approximate Amounts of PAC™-L Added to Water Based Fluids		
Desired Condition/Result		
Added to fresh or salt water	**lb/100 gal**	**kg/m^3**
Ÿ To stabilize water sensitive formation	3 – 7	4 – 8.5
Ÿ To reduce torque and lower circulating pressure	0.5 - 2	0.6 – 2.4
Added to QUIK-GEL® slurry (25 lb/100 gallons) or (30 kilograms per m^3)	**lb/100 gal**	**kg/m^3**
Ÿ To reduce filtration rate and improve borehole stability	0.5 - 2.0	0.6 – 2.4
Added to BORE-GEL™ slurry (35 lb/100 gallons) or (42 kilograms per m^3)	**lb/100 gal**	**kg/m^3**
Ÿ To reduce filtration rate and improve borehole stability	0.5 – 2.0	0.6 – 2.4

Note:
Very salty waters may require twice as much PAC-L as fresh water. Preferably, PAC-L should be mixed in fresh water before it is added to very salty water.

Packaging

PAC-L is packaged in 50-lb (22.7 kg) bags.

Availability

PAC-L can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products
A Product and Service Line of Halliburton Energy Services, Inc.
3000 N. Sam Houston Pkwy. E.
Houston, TX 77032

Customer Service	(800) 735-6075 Toll Free	(281) 871-4612
Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

N-SEAL™

Lost Circulation Material

Description

N-SEAL, acid soluble lost circulation material, is specially formulated extrusion spun mineral fiber. Due to its solubility in weak acids, N-SEAL is easily removed from production zones.

Applications/Functions

N-SEAL can be used in concentrations of up to 70 lb/100 gallons (86 kg/m^3) in slug treatments or as additive to entire system.

Advantages

- Acid soluble
- Easily-wetted
- Inorganic and non-fermenting

Typical Properties

Appearance	Gray white fiber
Specific gravity	2.6

Recommended Treatment

N-SEAL can be added directly through the hopper.

- For normal treatment to the active system, add 5-20 lb/100 gallons drilling fluid (6-24 kg/m^3)
- As a pill, add 20-70 lb/100 gallons of drilling fluid (24-86 kg/m^3)

N-SEAL is 95% acid soluble. To dissolve 1 lb of N-SEAL, treat with either

- 1-2 lb AQUA-CLEAR™ MGA (1-2 kg/kg)

  or
- 0.5-1 gal of 10% HCl/5% Acetic acid blend (1-2 liters/kg)

Packaging

N-SEAL is packaged in 30-lb (13.6 kg) multiwall paper bags.

Availability

N-SEAL can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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LIQUI-TROL™

Modified Cellulosic Polymer Suspension

Description

LIQUI-TROL is a free-flowing, liquid suspension of a modified natural cellulosic polymer, in an ultra-clean oil. LIQUI-TROL, when added to a QUIK-GEL® or BORE-GEL™ slurry, yields a drilling mud system suitable for drilling in water sensitive formations.

Applications/Functions

- Provide filtration control in fresh or brackish water-based drilling fluids
- Promote borehole stability in water sensitive formations
- Pour a slug of concentrate into drill string directly to sweep the hole
- Minimize rotational torque and circulating pressure
- Improve hole cleaning and core recovery
- Stiffen the foam to improve cuttings transport in air/gel-foam drilling
- Reduce air requirements, uphole velocity and borehole annulus pressure

Advantages

- Effective in fresh water, salt water and brackish water-based drilling fluids
- Effective in small quantities for filtration control
- Non-fermenting
- Compatible with other Baroid drilling fluid additives
- Resistant to harsh environments and contaminants

Typical Properties

Appearance	Off-white, free-flowing, viscous fluid
Specific gravity	0.98
pH (0.3% solution)	9.0
Flash point, PMCC °F (°C)	185, (85)
Pour point, °F (°C)	35, (1.7)
Freeze point, °F (°C)	-40, (-40)

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Recommended Treatment

- Using Venturi Mixer, or into vortex of a high-speed stirrer, add slowly and uniformly to entire circulating system.
- Used to slug down the rods to produce a high viscosity hole-cleaning sweep.

Approximate Amounts of LIQUI-TROL™ Added to Water-Based Fluids		
Desired Condition/Result		
Added to fresh or salt water	**qt/100 gal**	**liters/m^3**
• To stabilize water sensitive formation	4-6	10-15
• To reduce torque and lower circulating pressure	2-4	5-10
Added to QUIK-GEL® slurry (25 pounds per 100 gallons) (30 kilograms per m^3)	**qt/100 gal**	**liters/m^3**
• To enhance drilling mud fluid properties	1-2	2.5-5
• To improve drilling mud suspension and stabilization capabilities	2-4	5-10
Added to injection liquid in air/foam drilling	**qt/100 gal**	**liters/m^3**
• To improve foam performance and hole cleaning	1-4	2.5-10

Note:

Salt water may require twice as much LIQUI-TROL as fresh water. Preferably, LIQUI-TROL should be mixed in freshwater before it is added to salty water.

Packaging

LIQUI-TROL is packaged in 5-gal (19-liter) metal pails with an integrated, resealable pour spout.

Availability

LIQUI-TROL can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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HOLEPLUG®

Graded Sodium Bentonite

Description

HOLEPLUG is a naturally occurring Wyoming sodium bentonite clay that is a sized and graded chip material used to seal and plug earthen boreholes.

HOLEPLUG is available in two particle size grades:

- HOLEPLUG 3/4" (100% of particles pass through 3/4" screen; all particles retained on 3/8" screen)
- HOLEPLUG 3/8" (100% of particles pass through 3/8" screen; all particles retained on 1/4" screen)

Applications/Functions

- Highly recommended for use in grouting annulus in all types of wells, particularly environmental monitoring well applications
- Seal above gravel packs
- Plug decommissioned boreholes
- Stemming shotholes
- Seal around conductor pipe
- Seal lost circulation zones
- Shut off artesian flow

Advantages

- Prevents entry of surface water into boreholes
- High swelling potential
- In situ swelling to provide a superior seal with excellent casing stabilization
- Easier to apply than pellets
- Cost effective
- Simple to apply, mixing not required
- Prevents vertical movement of fluids in the hole between porous zones
- Forms a permanent, flexible downhole seal
- Allows hole re-entry
- Rehydratable
- ANSI/NSF Standard 60 certified

Typical Properties

Volume of 50-lb (22.7 kg) sack	
HOLEPLUG 3/4"	0.73 ft^3 or 0.027 yd^3 or 0.021 m^3
HOLEPLUG 3/8"	0.70 ft^3 or 0.026 yd^3 or 0.020 m^3
Permeability	1.5×10^{-9} cm/sec (in fresh water)
Appearance	Beige to tan chips

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Recommended Treatment

Plugging and Stemming Drill Holes

Due to shipping and handling, a small amount of fine bentonite particles may be present. For optimum results, HOLEPLUG® should be poured over a mesh or screen with ¼" (6.4 mm) openings to "sift out" the smaller particles. The screen should be large enough (approx.1 yd^2 or $1m^2$) to be folded into a "V" shape to allow sifting while the product is being poured into the hole. Also, HOLEPLUG should be poured slowly. Allow approximately two minutes to pour a 50-lb (22.7 kg) bag.

1. Position the screen with the lower end placed over the borehole
2. Slowly pour HOLEPLUG down the "V" so that fine particles fall through the screen before the larger particles fall into the borehole
3. Fill hole as required (above static water level or to ground level)
4. Observe all regulatory specifications

Stopping loss of circulation and stabilizing unconsolidated formations

1. Pull drill pipe out of hole
2. Pour HOLEPLUG into hole to fill above problem zone
3. Drill ahead slowly with reduced pump pressure

Plugging flowing wells

Pour HOLEPLUG into hole until water flow subsides or hole is filled to surface.

Treatment Considerations

§ Adequate annular space should be present to allow for the placement of HOLEPLUG into the area of concern without bridging. It is recommended that a minimum annular space of two inches on either side of the outside dimension of the casing be present. This will facilitate the placement of tremie lines and reduce the potential of the HOLEPLUG bridging during pouring operations. The use of this product should always correspond with applicable federal, state and local well construction guidelines.

Application Amounts

Amounts of HOLEPLUG® Required for Plugging Applications				
Hole Diameter (inches)	Hole Volume (ft^3/ft)	Pounds HOLEPLUG Needed to Fill One Foot	Feet Filled by One Bag HOLEPLUG	Bags HOLEPLUG Needed to Fill 100 ft
2	0.022	1.6	32.6	3.2
2.5	0.034	2.4	20.5	5.0
3	0.049	3.5	14.3	7.0
3.5	0.067	4.8	10.4	9.6
4	0.087	6.3	7.9	12.6
4.5	0.110	7.9	6.3	15.8
5	0.136	9.8	5.1	19.6
5.5	0.165	11.9	4.2	23.8
6	0.196	14.1	3.5	28.2
6.5	0.230	16.6	3.0	33.2
7	0.267	19.2	2.6	38.4
7.5	0.307	22.1	2.3	44.2
8	0.349	25.1	2.0	50.2
8.5	0.394	28.4	1.8	56.8
9	0.442	31.8	1.6	63.6
9.5	0.492	35.4	1.4	70.8
10	0.545	39.2	1.3	78.4
11	0.660	47.5	1.1	95.0
12	0.785	56.5	0.89	113.0
15	1.227	88.3	0.57	176.6
18	1.767	127.2	0.39	254.4
20	2.182	157.1	0.32	314.2
25	3.409	245.4	0.20	490.8
30	4.909	353.4	0.14	706.8

Application Amounts (metric equivalents)

Amounts of HOLEPLUG® Required for Plugging Applications				
Hole Diameter (mm)	Hole Volume (m^3/m)	Kilograms HOLEPLUG Needed to Fill One Meter	Meters Filled by One Bag HOLEPLUG	Bags HOLEPLUG Needed to Fill 10 meters
51	0.002	2.3	9.87	1.0
64	0.003	3.6	6.31	1.6
76	0.005	5.2	4.38	2.3
89	0.006	7.0	3.22	3.1
102	0.008	9.2	2.47	4.1
114	0.010	11.6	1.95	5.1
127	0.013	14.4	1.58	6.3
140	0.015	17.4	1.30	7.7
152	0.018	20.7	1.10	9.1
165	0.021	24.3	0.93	10.7
178	0.025	28.2	0.81	12.4
191	0.029	32.4	0.70	14.3
203	0.032	36.8	0.62	16.2
216	0.037	41.6	0.55	18.2
229	0.041	46.6	0.49	20.5
241	0.046	51.9	0.44	22.9
254	0.051	57.5	0.39	25.3
279	0.061	69.6	0.33	30.7
305	0.073	82.8	0.27	36.5
381	0.114	129.4	0.18	57.0
457	0.164	186.4	0.12	82.1
508	0.203	230.1	0.10	101.4
635	0.317	359.5	0.06	158.4
762	0.456	517.7	0.04	228.1

Packaging

HOLEPLUG graded bentonite is packaged in 50-lb (22.7 kg) multiwall paper bags.

Availability

HOLEPLUG can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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EZ-MUD®

Polymer Emulsion

Description

EZ-MUD, a liquid polymer emulsion containing partially hydrolyzed polyacrylamide/polyacrylate (PHPA) copolymer, is used primarily as a borehole stabilizer to prevent reactive shale and clay from swelling and sloughing. EZ-MUD is also added to low-solids drilling fluids to increase lubricity, fluid viscosity, and to improve carrying capacity of air/foam injection fluids.

Applications/Functions

- Stabilize reactive shale and clay formations
- Improve borehole stability
- Enhance slurry rheological properties
- Alleviate mud rings, bit balling and booting-off in clay formations
- Reduce drill pipe torque and pumping pressure
- Minimize rod chatter in diamond core drilling
- Create "stiff-foam" and maintain foam integrity
- Flocculate non-reactive solids in reserve pit at low concentrations

Advantages

- Mixes easily with minimum shear in fresh water
- Provides effective clay and shale stabilization with lower viscosity
- Imparts high degree of lubricity
- Non-fermenting
- Breaks down chemically with bleach (sodium hypochlorite)
- ANSI/NSF Standard 60 Certified

Typical Properties

Appearance	Thick, opaque white liquid
Density	8.5 lb/gal (1.02 g/cm^3)
pH (1 quart per 100 gallons water)	8.5
Flash point, PMCC °F, °C	>200 (>93.3)
Thermal stability, °F, °C	250 (121)

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Recommended Treatment

Approximate Amounts of EZ-MUD® Added to Drilling Fluid System			
Drilling Application/Desired Property	**Quarts/ 100 gal**	**Pints/bbl**	**Liters/m^3**
Added to fresh water (To formulate a clay-free drilling fluid)			
• To stabilize reactive clay and shale	0.5 - 2.0	0.5 - 1.75	1.25 - 5.0
• To retard rod vibration, reduce torque and pumping pressure	1.0 - 2.0	1.0 - 1.75	2.5 - 5.0
Added to QUIK-GEL® or BORE-GEL™ Drilling Fluids			
• To retard reactive shale and clay and enhance lubricity	0.5 - 1.0	0.5 - 1.0	1.25 - 2.5
Added to injection liquid in air/foam drilling applications			
• To improve foam performance and hole conditions	0.5 - 1.0	0.5 - 1.0	1.25 - 2.5

Notes:

- Make-up water used to mix EZ-MUD should meet the following quality:
  total chloride less than 1500 ppm (mg/L)
  total hardness less than 150 ppm as calcium
  total chlorine less than 50 ppm
  water pH between 8.5-9.5
- Reduce total hardness of make-up water by adding soda ash (sodium carbonate) at 0.5 to 1 pound per 100 gallons (0.6 - 1.2 kg/m^3) of make-up water.
- EZ-MUD can be chemically broken down with liquid bleach in regular household concentration (5% sodium hypochlorite). Use one gallon of liquid bleach per 100 gallons (10 liters/m^3) of fluid formulated with EZ-MUD. Do not use perfumed liquid bleach or solid calcium hypochlorite.

Packaging

EZ-MUD is packaged in 5-gal (19-liter) and 1-gal (3.8-liter) plastic containers.

Availability

EZ-MUD can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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BENSEAL®

Sealing and Plugging Agent

Description

BENSEAL is a granular (8-mesh), natural Wyoming sodium bentonite for use in sealing and grouting well casings and earthen structures. BENSEAL is not recommended for use as a drilling mud.

Applications/Functions

- Seal or grout plastic or steel casings in monitor and water well construction
- Seal or plug abandoned boreholes
- Seal leaking ponds, ditches and dams
- Soil stabilization
- Prepare BENSEAL/EZ-MUD® grouting system
- Aid in controlling loss of circulation

Advantages

- High swelling capacity
- Uniform particle size
- No heat of hydration
- Prevents commingling of aquifers and contamination from surface
- Forms a flexible seal to protect casing from corrosive contaminants
- Allows for hole re-entry
- ANSI/NSF Standard 60 certified

Typical Properties

Appearance	Bluish to gray granules
Dry screen analysis	85% of 8 mesh
Volume, ft^3/sack	0.7 (as packaged)
Specific gravity	2.6
Permeability	less than 1×10^{-8} cm/sec (in fresh water)

Recommended Treatment

As a casing drill and drive operation:

1. Dig a cone-shaped depression around casing. Depression should be 6 - 8 inches (152-203 mm) larger than the outside diameter of the casing and 2 - 3 feet (60-75 cm) deep.
2. Keep cone-shaped depression filled with dry BENSEAL while driving the casing.

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Recommended Treatment (continued)

Note:

When drilling and driving a 4" (102mm) pipe, expect to use 2.5 pounds of BENSEAL® per foot of hole or 3.7 kilograms of BENSEAL per meter of hole.

Sealing ponds or earthen structures:

Depending on the native soil, disc in or mix 3 to 5 pounds of BENSEAL per square foot (14-24 kg/m^2) uniformly over the area to be sealed so that a 6-inch (~152 mm) blanket of soil and BENSEAL is formed. Do not neglect the edges of the dam or the sides/walls of the pond. This sealing blanket should then be compacted in place and as a further protection to the sealing blanket, 2 to 4 inches (51-102 mm) of local soil or sand should cover the sealing blanket and be compacted.
If the leaking area can be identified and isolated, an attempt can be made to broadcast BENSEAL uniformly at 4 to 6 pounds of BENSEAL per square foot (20-30 kg/m^2) of surface area into the water over the area of concern.
Note*:* Bentonite is more effective as a sealing agent when confined. Therefore, every effort should be made to cover the BENSEAL after it is broadcast with a 2-3 inch (51-76 mm) layer of sand. This will reduce the potential for dispersion into the water and un-yielded bentonite particles interfering with the gill action of fish.

Lost returns (moderate):

1. Begin with the pit full of mud.
2. Raise the pump suction off bottom and place a shovel next to it and slightly under suction.
3. Pour dry BENSEAL slowly into the space between shovel and suction and pump it down the hole.

Packaging

BENSEAL is packaged in 50-lb (22.7 kg) multiwall paper bags, containing 0.7 ft^3 (0.02 m^3).

Availability

BENSEAL can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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AQUA-CLEAR™ PFD

Phosphate-Free Dispersant

Description

AQUA-CLEAR PFD is a concentrated liquid polymer dispersant that provides superior mud and sediment removal from the producing formation and gravel pack. This product is also a highly effective mud thinner. AQUA-CLEAR PFD contains no phosphates.

Applications/Functions

- Disperse mud, sediment and clay from the producing formation and gravel pack in the screened interval.
- Reduce viscosity and gel strength of drilling fluids

Advantages

- ANSI/NSF Standard 60 certified
- Reduces development time
- Increases well yield and capacity
- Safe to use on most plastics, rubber and metals
- Non-fermenting
- Reduces pumping costs

Typical Properties

Appearance	straw colored liquid
Specific gravity	1.2 to 1.4
pH (neat)	6.5 to 7.5

Recommended Treatment

As a Well Development Aid

- Determine volume of water in screen area and double the calculated volume to account for water in gravel pack and formation interface ***or*** determine the static volume of water and add 50% excess.
- Once the water volume is determined, calculate the required treatment volume of AQUA-CLEAR PFD by the following formula:

  AQUA-CLEAR PFD (gal or L) = 0.002 x Water Volume (gal or L)

This equates to one gallon of AQUA-CLEAR PFD for every 500 gallons of water (0.2% by volume) or 2.0 liters of AQUA-CLEAR PFD for every cubic meter of water.

- Mix thoroughly before introducing into well.
- The preferable application method utilizes a tremie line with the product applied into the screened area.
- If necessary, the AQUA-CLEAR PFD/water solution may be poured into the well.
- Mixture should be thoroughly blended in well, then agitated using a surge

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Recommended Treatment (continued)

and swab, jetting, or other developmental technique repeatedly every two hours for a period of up to 24 hours.

- Pump to waste until turbidity clears up and then connect well to distribution system.

As a Mud Thinner

- Start by adding one pint of AQUA-CLEAR™ PFD to 500 gallons of mud. Increase concentration until desired viscosity is achieved.

Well Capacity Chart (Gallons per Foot)					
Well Diameter (Inches)	**Well Capacity in Gallons/ft**	**Well Diameter (Inches)**	**Well Capacity in Gallons/ft**	**Well Diameter (Inches)**	**Well Capacity in Gallons/ft**
2	0.2	12	5.9	24	23.5
4	0.7	14	8.0	26	27.6
6	1.5	18	13.2	30	36.7
8	2.6	20	16.3	36	52.9
10	4.1	22	19.7	48	94.0

Well Capacity Chart (Liters per Meter)					
Well Diameter (millimeters)	**Well Capacity Liters/meter**	**Well Diameter (millimeters)**	**Well Capacity Liters/meter**	**Well Diameter (millimeters)**	**Well Capacity Liters/meter**
51	2.0	305	73.0	610	292.0
102	8.1	356	99.3	660	342.6
152	18.3	457	164.2	762	456.1
203	32.4	508	202.7	914	656.8
254	50.7	559	245.3	1219	1167.7

Note: The volumes in these tables show only the volume of water in a 1 foot or 1 meter section of a given size of screen. Excess volume must be included to account for water present in the formation interface and gravel pack.

Packaging

AQUA-CLEAR PFD is packaged in a 5-gal (19-liters) plastic pail or 1-gal (3.8-liter) plastic container.

Availability

AQUA-CLEAR PFD can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you, contact the Customer Service Department in Houston or your area IDP Sales Representative.

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AQUA-CLEAR™ MGA

Modified Granular Acid

Description

AQUA-CLEAR MGA is a dry blend of granular acid and additives used in the removal of iron, manganese and carbonate scale. It retains strength longer than most liquid acids, which increases its cleaning capability.

Applications/Functions

- Disperse scale and incrustation
- Remove scale and incrustation from the water well screen, casing, gravel pack and pumping equipment
- Restore well production
- AQUA-CLEAR MGA can be used in combination with AQUA-CLEAR AE to remove more difficult scale and incrustation

Advantages

- ANSI/NSF Standard 60 certified
- Safe to use on all plastics, rubber and metals
- No harmful vapors
- Improves water quality (color, taste and appearance)
- Reduces equipment and piping failures due to scale build-up and corrosion
- Reduces pumping costs

Typical Properties

Appearance	Free-flowing, off-white granules
Specific gravity	2.00
pH (10% solution)	0.9
Solubility in water	Complete with slight to hazy turbidity

Recommended Treatment

- Record initial well water pH
- The preferred application method is to apply a solution of AQUA-CLEAR MGA into the screened interval through a tremie pipe.

Recommended Treatment (continued)

- Mix AQUA-CLEAR™ MGA with water at ½ - 1 pound per gallon of water or 0.06 - 0.12 kilograms per liter of water and apply directly into screened interval with a tremie pipe. When utilizing this method, calculate the volume of water in the screened area and double the calculated volume to account for the water in the gravel pack and formation interface.

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Note: The previous concentration of* AQUA-CLEAR™ MGA *is recommended for a complete reconditioning of an existing well.

- Calculation for volume in well:
- Gallons per foot = (diameter, inches)^2 x 0.042
- Liter per meter = (diameter, millimeters)^2 x 0.0008
- Displace solution into the well screen and formation, then surge, swab, agitate or jet well through screen and gravel pack for 20-30 minutes.
- Allow to stand in well for up to two hours and then repeat activity approximately every two hours for a period of 24 hours.
- Pump well to waste until well water pH is within 0.5 of original well pH.

  Note: Wastewater can be neutralized by adding soda ash or lime

- Chlorinate well and reconnect to water distribution system.

  Caution: Never mix chlorine and* AQUA-CLEAR MGA *in well.

- If necessary, AQUA-CLEAR MGA may be poured directly into well as per treatment table, but results will not be as good as if applied in a dissolved form via a tremie pipe. The undissolved form will require more mechanical agitation.

Note:

- ***In heavily encrusted wells, it is desirable to brush or scrape the casing and screen, then pump or airlift the debris to waste prior to treating with acid.***

The following charts recommend a concentration of* AQUA-CLEAR MGA *that is suitable for a typical maintenance treatment of an existing well.

AQUA-CLEAR MGA Application Amounts per 10 Feet of Standing Water					
Well Diameter (Inches)	**Pounds of Product**	**Well Diameter (Inches)**	**Pounds of Product**	**Well Diameter (Inches)**	**Pounds of Product**
2	0.35	12	12.73	24	50.94
4	1.41	14	17.33	26	59.78
5	2.21	16	22.64	28	69.33
6	3.18	18	28.65	30	79.60
8	5.66	20	35.37	36	114.61
10	8.84	22	42.80	48	203.75

Recommended Treatment (continued)

AQUA-CLEAR™ MGA Application Amounts per 10 Meters of Standing Water					
Well Diameter (millimeters)	**Kilograms of Product**	**Well Diameter (millimeters)**	**Kilograms of Product**	**Well Diameter (millimeters)**	**Kilograms of Product**
51	0.53	305	18.97	610	75.90
102	2.11	356	25.83	660	89.10
127	3.29	406	33.73	711	103.31
152	4.74	457	42.69	762	118.60
203	8.43	508	52.71	914	170.77
254	13.18	559	63.78	1219	303.60

Note: The concentrations of* AQUA-CLEAR MGA *shown in the previous tables do not take into account the 100% excess volume required to compensate for the water present in the formation interface and gravel pack. The previous tables only account for the product concentration required for the volume of water occupying a 10 foot or 10 meter section of a given size of screen.

For other diameters:

- Gallons per foot = (diameter, inches)^2 x 0.042
- Liter per meter = (diameter, millimeters)^2 x 0.0008
- Pounds of AQUA-CLEAR MGA = (gallons per foot x 8.34) x 0.026
- Kilograms of AQUA-CLEAR MGA = (liters per meter) x 0.026
- Double the calculated volume in order to take into account the water present in the gravel pack and formation interface.
- AQUA-CLEAR AE can be used with AQUA-CLEAR MGA for iron bacteria treatment. When used together, utilize one gallon of AQUA-CLEAR AE for every 10 pounds of AQUA-CLEAR MGA or 0.84 liters of AQUA-CLEAR AE for every kilogram of AQUA-CLEAR MGA.

Safety

- AQUA-CLEAR MGA is safe to handle when in dry form, but when mixed with water it should be handled in accordance with recognized standard practices for handling corrosive and acidic materials (refer to Material Safety Data Sheet).
- Avoid skin and eye contact – flush with water
- Do not ingest and avoid prolonged inhalation
- When disposing of waste fluid make sure to comply with all federal, state and local regulations as applicable.

Packaging

AQUA-CLEAR™ MGA is packaged in 5-gal (19-liter) pails containing 50 pounds (22.7 kg) and in 1-gallon (3.8-liter) plastic jars containing 10 pounds (4.5 kg).

Shipping

The following are required for commercial transport:

- Insurance policy must include an endorsement for transporting hazardous cargo.
- Vehicle driver must have a Hazmat endorsement on his/her Commercial Drivers License.
- Hazardous Materials Certificate of Registration issued by the U.S. Department of Transportation (renewable annually) is required.
- Consult the state in which operating for any additional requirements that may exist.
- No hazardous materials placard is required for shipments less than 1000 pounds.

Availability

AQUA-CLEAR MGA can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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AQUA-CLEAR™ AE

Acid Enhancer/Antifoulant

Description

AQUA-CLEAR AE is a liquid blend of acids and acid enhancers formulated to control bacterial slime contamination due to the presence of iron-related and sulphate-reducing bacteria.

Applications/Functions

- Remove the bio-mass matrix caused by bacterial fouling
- Reduce sulphur taste and odor in water
- Clean up well screens, pumps and distribution system
- Restore well productivity and reduce power and maintenance costs
- AQUA-CLEAR AE can be used in combination with AQUA-CLEAR MGA and other acids such as, hydrochloric (muriatic), phosphoric and sulfamic to enhance their effectiveness and to remove more difficult scale and incrustation

Advantages

- ANSI/NSF Standard 60 certified
- Safe to use on all plastics, rubber and metals
- Cost effective, efficient extended life treatment
- Improves water quality and renews well production rate
- Mitigates corrosion and equipment failure
- Reduces pumping costs

Typical Properties

Appearance	Light amber colored liquid
Specific gravity	1.08
pH of solution	1.1

Recommended Treatment

To treat bacteria fouling

- Record initial well water pH
- The preferred application method is to apply a solution of AQUA-CLEAR AE into the screened interval through a tremie pipe.

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Recommended Treatment (continued)

- Mix AQUA-CLEAR™ AE with water at 6 - 12 ounces per gallon of water or 47 - 94 ml per liter of water and apply directly into screened interval with a tremie pipe. When utilizing this method, calculate the volume of water in the screened area and double the calculated volume to account for the water in the gravel pack and formation interface.

Note: The above concentration of* AQUA-CLEAR AE *is recommended for a complete reconditioning of an existing well.

- Calculation for volume in well:
- Gallons per foot = (diameter, inches)^2 x 0.042
- Liter per meter = (diameter, millimeters)^2 x 0.0008
- Displace solution into the well screen and formation, then surge, swab, agitate or jet well through screen and gravel pack for 20-30 minutes.
- Allow to stand in well for up to two hours and then repeat activity approximately every two hours for a period of 24 hours.
- Pump well to waste until at least 23 well volumes have been removed and well water pH is within 0.5 of original well pH.

Note: Wastewater can be neutralized by adding soda ash or lime.

- Chlorinate well and reconnect to water distribution system.

Caution: Never mix chlorine and* AQUA-CLEAR AE *in well.

- If necessary, AQUA-CLEAR AE may be poured directly into well as per treatment table, but results will not be as good as if applied via a tremie pipe.

Notes:

- ***In heavily encrusted wells, it is desirable to brush or scrape the casing and screen, then pump or airlift the debris to waste prior to treating with acid.***
- ***The following charts recommend a concentration of* AQUA-CLEAR AE *that is suitable for a typical maintenance treatment of an existing well.***

AQUA-CLEAR AE Application Amounts per 10 Feet of Standing Water					
Well Diameter (Inches)	**Gallons of Product**	**Well Diameter (Inches)**	**Gallons of Product**	**Well Diameter (Inches)**	**Gallons of Product**
2	0.04	12	1.27	24	5.10
4	0.14	14	1.73	26	6.00
5	0.22	16	2.26	28	6.93
6	0.32	18	2.87	30	7.96
8	0.57	20	3.54	36	11.46
10	0.88	22	4.28	48	20.40

AQUA-CLEAR™ AE Application Amounts per 10 Meters of Standing Water					
Well Diameter (millimeters)	**Liters of Product**	**Well Diameter (millimeters)**	**Liters of Product**	**Well Diameter (millimeters)**	**Liters of Product**
51	0.49	305	17.60	610	70.35
102	1.95	356	23.94	660	82.57
127	3.05	406	31.27	711	95.76
152	4.40	457	39.57	762	109.93
203	7.82	508	48.86	914	158.29
254	12.21	559	59.12	1219	281.41

Recommended Treatment (continued)

Note: The concentrations of* AQUA-CLEAR AE *shown in the previous tables do not take into account the 100% excess volume required to compensate for the water present in the formation interface and gravel pack. The previous tables only account for the product concentration required for the volume of water occupying a 10 foot or 10 meter section of a given size of screen.

For other diameters:

- Gallons per foot = (diameter, inches)^2 x 0.042
- Liter per meter = (diameter, millimeters)^2 x 0.0008
- Gallons of AQUA-CLEAR AE = (gallons per foot x 8.34) x 0.0026
- Liters of AQUA-CLEAR AE = (liters per meter) x 0.0241
- Double the calculated volume in order to take into account the water present in the gravel pack and formation interface.

Treating Severe bio-fouling and scaling

- AQUA-CLEAR AE is used as an enhancer when mixed in the well with AQUA-CLEAR MGA
- One gallon of AQUA-CLEAR AE to every 10 pounds of AQUA-CLEAR MGA
- 3.8 liters of AQUA-CLEAR AE to every 4.5 kilograms of AQUA-CLEAR MGA

Safety

- Use recognized standard practices for handling corrosive and acidic materials (refer to Material Safety Data Sheet)
- Avoid skin and eye contact – flush with water
- Do not ingest and avoid prolonged inhalation
- When disposing of waste fluid make sure to comply with all federal, state and local regulations as applicable.

Packaging

AQUA-CLEAR™ AE is packaged in 1-gallon (3.8-liter) and 5-gallon (19-liter) plastic containers.

Shipping

- The following are required for commercial transport:
- Insurance policy must include an endorsement for transporting hazardous cargo.
- Vehicle driver must have a Hazmat endorsement on his/her Commercial Drivers License.
- Hazardous Materials Certificate of Registration issued by the U.S. Department of Transportation (renewable annually) is required.
- Consult the state in which operating for any additional requirements that may exist.
- No hazardous materials placard is required for shipments less than 1000 pounds.

Availability

AQUA-CLEAR AE can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you, contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products

A Product and Service Line of Halliburton Energy Services, Inc.

3000 N. Sam Houston Pkwy E.

Houston, TX 77032

Customer Service	(800) 735-6075 Toll Free	(281) 871-4612
Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

QUIK-FOAM®

High Performance Foaming Agent

Description

QUIK-FOAM, a proprietary blend of alcohol ethoxy sulfates (AES) which are biodegradable, is an effective foaming agent. QUIK-FOAM can be added to fresh, brine, or brackish water for air/foam, air/gel-foam, or mist drilling applications.

Applications/Functions

- Enhance the rate of cuttings removal
- Increase the ability of lifting large volumes of water
- Improve hole-cleaning capability of the airstream
- Reduce the sticking tendencies of wet clays, thereby eliminating mud rings and wall packing
- Reduce erosion of poorly consolidated formations
- Provide a technique for drilling in zones with lost circulation
- Increase borehole stability
- Reduce air-volume requirement
- Suppress dust during air drilling operation

Advantages

- ANSI/NSF Standard 60 Certified
- High quality, high expansion foam with a consistency similar to shaving foam
- High stability with excellent retention time
- Versatile and compatible with various types of make-up water
- Readily undergoes primary and ultimate (>99%) biodegradation
- Proven product for multi-discipline application

Typical Properties

Appearance	Light yellow, transparent liquid
Specific gravity	1.03
pH (0.5% solution)	7.1
Flash point, PMCC °F, °C	82, (28)
Pour point, °F, °C	0, (-18)

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Recommended Treatment

Approximate Amounts of QUIK-FOAM® Added to Injection Water			
Application	**Amount/100 gal**	**Amount/bbl**	**Liters/m^3**
Dry-air drilling (as a dust suppressant)	0.5 - 1 pints	0.2 - 0.5 pints	0.5 - 1.5
Mud-mist drilling in sticky clays	1 - 2 quarts	1 - 2 pints	2.5 - 5
Foam and gel-foam drilling	0.5 - 2 gallons	1.5 - 7 pints	5 - 20
As a slug to clean the annulus	1 pint*	0.5 pints*	0.5**

* in drill pipe, followed by 3 to 5 gallons of water; ** followed by 20 liters of water

Note:

Close product container immediately after use to avoid gelation of remaining QUIK-FOAM.

Product Make-ups for Air Drilling Injection Slurries				
Main Ingredient of Injection Slurry	**Water (gallons)**	**QUIK-GEL® viscosifier (pounds)**	**QUIK-TROL® polymer (pounds)**	**QUIK-FOAM foaming agent (% by volume)**
Foam Drilling System	100	…	…	0.02 - 3.0
Mixing/Injection Procedure Add QUIK-FOAM to injection water. Inject into the air stream at a rate necessary to maintain hole stability and penetration rate. Increase amount of QUIK-FOAM as required to compensate for downhole water dilution				
Firm-Foam Drilling System	100	…	0.5 - 1	0.1 - 2.0
Mixing/Injection Procedure Mix polymer with water before adding QUIK-FOAM. 1-2 pints of EZ MUD® may be used as a substitute for QUIK-TROL. Inject into the air stream at a rate necessary to maintain hole stability and penetration rate.				
Mud-Mist Drilling System	100	25	…	0.3 - 1.0
Mixing/Injection Procedure Mix viscosifier with water before adding QUIK-FOAM. Inject into the air stream at a rate necessary to maintain hole stability and penetration rate. Resulting viscosity is 32-40 sec/qt as measured by Marsh Funnel.				
Gel-Foam Drilling System	100	12 - 15	1	0.3 - 1.0
Mixing/Injection Procedure Mix viscosifier and polymer with water before adding QUIK-FOAM. Inject into the air stream at a rate necessary to maintain hole stability and penetration rate. Resulting viscosity is 32-40 sec/qt as measured by Marsh Funnel.				

Note:

In some states, it is illegal to discharge any foreign substance into the water shed due to potential contamination of ground water. After use, the foam mixture must be localized in an earthen pit or some type of containment and allowed to biodegrade naturally.

Packaging QUIK-FOAM® is packaged in 5-gal (19-liter) plastic containers or in 55-gal (208 liter) drums.

Availability QUIK-FOAM can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products,

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Appendix C

Lithology Log

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Construction Fill/reworked material	Construction fill. Upper 6 in. consists of base-course gravel; remaining interval made up of loose reworked materials derived from the Bandelier Tuff that contain organic debris.	0–3.5	7062.1–7058.6
Qbt 2, Tshirege Member of the Bandelier Tuff	Rhyolite tuff, light brownish-gray (5YR 6/1), crystal-rich, moderately welded. Composed of 4%–5% crystalline devitrified pumice fragments (up to 1.5 cm); 35% quartz and sanidine phenocrysts; 60% ash matrix, local yellowish Fe-oxide staining, core moist.	3.5–9.2	7058.6–7052.9
	Rhyolite tuff, light brownish-gray (5YR 6/1), crystal-rich, moderately to strongly welded. Composed of 10% flattened devitrified pumice lapilli (up to 2.0 cm); 25% quartz and sanidine phenocrysts (up to 2.0 mm); 60%–70% ash matrix, local yellowish brown oxide staining, moist.	9.2–14.2	7052.9–7047.9
	Rhyolite tuff, light brownish-gray (5YR 6/1), crystal-rich, pumice-poor, moderately welded. Composed of 1% white crystalline pumice; 25% quartz and sanidine phenocrysts (up to 2.0 mm); 70%–80% ash matrix, local yellowish brown oxide staining and oxidation of ferromagnesian minerals.	14.2–19.2	7047.9–7042.9
	Rhyolite tuff, light brownish-gray (5YR 6/1), crystal-rich, moderately to strongly welded. Composed of 15% pale gray crystalline pumice (up to 2 .0 cm) that are flattened; 30% quartz and sanidine phenocrysts (up to 3.0 mm); 50%–60% ash matrix with yellowish-brown oxide staining, particularly around pumices, and oxidation of ferromagnesian minerals.	19.2–24.2	7042.9–7037.9
	Rhyolite tuff, light brownish-gray (5YR 6/1), weakly to moderately welded. Composed of 10% pale gray crystalline hornblende-bearing pumice (up to 1.5 cm) that are flattened; 20% quartz and sanidine phenocrysts (up to 3.0 mm); 70% ash matrix. Core moist.	24.2–28.7	7037.9–7033.4
	Rhyolite tuff, light brownish-gray (5YR 6/1), crystal-rich, moderately to strongly welded. Composed of 12% gray crystalline devitrified and partly flattened pumice (up to 1.0 cm); 25% quartz and sanidine phenocrysts (up to 2.0 mm); 60%–70% ash matrix displays yellowish brown oxidation stains. Core moist.	28.7–34.3	7033.4–7027.8
	Rhyolite tuff, pale yellowish-brown (10YR 6/2), moderately welded. Composed of 5% light gray crystalline devitrified and flattened pumice (up to 1.5 cm); 20% quartz and sanidine phenocrysts (up to 2.0 mm); 70%–80% ash matrix with abundant brown oxidation stains. Core moist.	34.3–40.8	7027.8–7021.3
	Rhyolite tuff, light brownish-gray (5YR 6/1), crystal-rich, moderately welded, locally fissile. Composed of 5% gray crystalline slightly flattened pumice (up to 1.0 cm); 25% quartz and sanidine phenocrysts (up to 4.0 mm); 70% ash matrix displays brown oxidation stains. Core moist.	40.8–43.8	7021.3–7018.3
	Rhyolite tuff, light brownish-gray (5YR 6/1), moderately to strongly welded. Composed of 5% gray devitrified and flattened pumice lapilli (up to 2.0 cm); 18% quartz and sanidine phenocrysts (up to 6.0 mm); 70%–75% devitrified ash matrix with abundant yellowish-brown oxidation stains. Core moist.	43.8–48.8	7018.3–7013.3

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbt 2, Tshirege Member of the Bandelier Tuff	No core recovery in this interval.	48.8–54.3	7013.3–7007.8
	Rhyolite tuff, light brownish-gray (5YR 6/1), weakly welded. Composed of 18% gray to yellowish brown crystalline (devitrified) pumice lapilli (up to 5.0 cm) that are mostly flattened; 18% quartz and sanidine phenocrysts (up to 4.0 mm); 50%–60% microcrystalline devitrified ash matrix. Core dry.	54.3–56.0	7007.8–7006.1
	Rhyolite tuff, light brownish-gray (5YR 6/1), weakly welded to nonwelded partings that are 0.5 to 1.0 cm thick. Composed of 5% gray crystalline (devitrified) pumice lapilli (1.0 to 5.0 cm); 12% quartz and sanidine phenocrysts (up to 2.0 mm); 80%–85% devitrified ash matrix with many yellow-brown oxidation stains. Core dry.	56–61	7006.1–7001.1
	Rhyolite tuff, light brownish-gray (5YR 6/1), weakly welded, fissile. Composed of 12% brownish-gray devitrified pumice lapilli (up to 1.5 cm); 8% quartz and sanidine phenocrysts (up to 2.0 mm), some dacitic xenolithic fragments (up to 4.0 cm); 70%–80% ash matrix with numerous brown oxidation stains.	61–66	7001.1–6996.1
	Rhyolite tuff, light brownish gray (5YR 6/1), weakly welded, fissile. Composed of 20% gray to brownish gray devitrified (crystalline) pumice lapilli (up to 2.0 cm) that are flattened; 10% quartz and sanidine phenocrysts (up to 2.0 mm); 70% ash matrix with numerous brown oxidation stains.	66–71	6996.1–6991.1
	Rhyolite tuff, light brownish-gray (5YR 6/1), weakly welded to nonwelded. Composed of 8% gray to brownish-gray devitrified (crystalline) pumice lapilli (up to 0.5 cm) that are partly flattened; 18% quartz and sanidine phenocrysts (up to 2.0 mm); 70%–75% ash matrix with yellowish-brown oxidation stains. Core dry.	71–75.6	6991.1–6986.5
	Rhyolite tuff, light brownish-gray (5YR 6/1), weakly welded to nonwelded, fissile with partings up to 1.0 cm. Composed of 12% grayish-white devitrified (crystalline) pumice lapilli (up to 1.0 cm) that are partly flattened; 10% quartz and sanidine phenocrysts (up to 1.0 mm); 75%–80% ash matrix with brown oxidation stains. Core dry. Qbt 2/Qbt 1v contact estimated at 80.0 ft bgs.	75.6–81	6986.5–6981.1
Qbt 1, (undivided), Tshirege Member of the Bandelier Tuff	Rhyolite tuff, light brownish-gray (5YR 6/1), pumice-rich, weakly welded, local partings. Composed of 25% gray to brownish-gray crystalline pumice lapilli (up to 3.0 cm) that are flattened; 8% quartz and sanidine phenocrysts (up to 2.0 mm); 60%–65% ash matrix with brown oxidation stains. Core dry.	81–86	6981.1–6976.1
	Rhyolite tuff, light brownish-gray (5YR 6/1), pumice-rich, weakly welded to nonwelded, locally fissile. Composed of 35% gray microcrystalline (devitrified) pumice lapilli (up to 1.0 cm) that are partly flattened; 5% quartz and sanidine phenocrysts (up to 1.0 mm); 60% ash matrix with brown oxidation stains. Core dry.	86–91	6976.1–6971.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbt 1, (undivided), Tshirege Member of the Bandelier Tuff	Rhyolite tuff, pinkish-gray (5YR 8/1), pumice-rich, weakly welded to nonwelded. Composed of 30% gray microcrystalline (devitrified) pumice lapilli (up to 1.5 cm) that are partly flattened; 3% quartz and sanidine phenocrysts (up to 2.0 mm); 65%–70% ash matrix with brown oxidation stains. Core dry.	91–96	6971.1–6966.1
	Rhyolite tuff, pinkish gray (5YR 8/1), pumice-rich, weakly welded to nonwelded. Composed of 35% gray to grayish brown microcrystalline (devitrified) pumice lapilli (up to 2.0 cm) that are partly flattened; 8% quartz and sanidine phenocrysts (up to 1.0 mm); 55%–60% ash matrix with local brown oxidation stains. Core moist.	96–101	6966.1–6961.1
	Rhyolite tuff, pinkish gray (5YR 8/1), pumice-rich, nonwelded. Composed of 30% gray to brown microcrystalline (devitrified) pumice lapilli (up to 1.5 cm) that are flattened; 10% quartz and sanidine phenocrysts (up to 3.0 mm); 60% ash matrix with minor brown oxidation staining. Core dry.	101–106	6961.1–6956.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), pumice-rich, nonwelded. Composed of 30% brown fibrous crystalline (devitrified) pumice lapilli (up to 1.8 cm); 12% quartz and sanidine phenocrysts (up to 2.0 mm); 60%–65% ash matrix with minor brown oxidation staining. Core moist.	106–111	6956.1–6951.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), pumice- and crystal-rich, nonwelded. Composed of 30% brown fibrous crystalline (devitrified) pumice lapilli (up to 2.5 cm); 30% sanidine and pinkish quartz phenocrysts (up to 2.0 mm); 35%–40% ash matrix with minor brown oxidation staining; minor dacitic xenoliths (up to 8.0 mm). Core moist.	111–116	6951.1–6946.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), pumice- and crystal-rich, nonwelded. Composed of 25% brown fibrous crystalline pumice lapilli (up to 1.5 cm); 20% sanidine and pinkish quartz phenocrysts (up to 3.0 mm); 5% oxidized basalt and/or latite xenoliths (up to 2.5 cm); 50% ash matrix. Core moist.	116–119	6946.1–6943.1
	Rhyolite tuff, pale orange (10YR 8/2), nonwelded. Composed of 5% light brownish-gray fibrous microcrystalline pumice lapilli (up to 1.5 cm); 18%–20% sanidine and quartz phenocrysts (up to 2.0 mm); 2%–5% dacitic xenoliths (up to 3.0 cm); 70%–75% altered ash matrix is waxy and clay-rich. Core moist.	119–123.4	6943.1–6938.7
	No core recovery in this interval.	123.4–126	6938.7–6936.1
	Rhyolite tuff, grayish-orange (10YR 7/4), pumice-rich, vitric, nonwelded. Composed of 60% orange fibrous glassy pumice lapilli (up to 1.5 cm); 10% sanidine and quartz phenocrysts (up to 2.0 mm); rare dacitic xenoliths; 30% biotite-bearing vitric ash matrix. Core moist.	126–131	6936.1–6931.1
	Rhyolite tuff, light brown (5YR 6/4), pumice-rich, vitric, nonwelded. Composed of 45% fibrous glassy pumice lapilli (up to 2.5 cm); 20% sanidine and quartz phenocrysts (up to 2.0 mm); 2% dacitic xenoliths (up to 3.0 mm); 35%–40% vitric ash matrix with abundant glass shards. Core dry.	131–136	6931.1–6926.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbt 1, (undivided), Tshirege Member of the Bandelier Tuff	Rhyolite tuff, pale yellowish-brown (10YR 6/2), pumice-rich, vitric, nonwelded. Composed of 30% fibrous glassy pumice lapilli (up to 1.8 cm); 15% sanidine and quartz phenocrysts (up to 3.0 mm); 10% gray to reddish-brown dacitic xenoliths; 45%–50% vitric ash matrix with abundant glass shards. Core dry.	136–140.4	6926.1–6921.7
	Rhyolite tuff, grayish-orange pink (5YR 7/2), pumice-rich, vitric, nonwelded. Composed of 30% fibrous glassy pumice lapilli (up to 2.0 cm); 15% sanidine and quartz phenocrysts (up to 3.0 mm); 3% gray to reddish-brown volcanic xenoliths; 50%–55% vitric ash matrix. Core dry.	140.4–143.5	6921.7–6918.6
	Rhyolite tuff, grayish-orange pink (5YR 7/2), pumice-rich, vitric, nonwelded. Composed of 30% fibrous glassy pumice lapilli (up to 0.8 cm); 15% sanidine and quartz phenocrysts (up to 3.0 mm); rare gray volcanic xenoliths (up to 3.0 mm); 50%–55% vitric ash matrix. Core dry.	143.5–148.5	6918.6–6913.6
	Rhyolite tuff, grayish-orange pink (5YR 7/2), vitric, nonwelded. Composed of 10% fibrous glassy pumice lapilli (up to 3.5 cm); 18% sanidine and quartz phenocrysts (up to 2.0 mm); 2% gray to reddish-brown dacitic xenoliths (up to 1.0 mm); 65%–70% vitric ash matrix with abundant glass shards. Core dry.	148.5–153.4	6913.6–6908.7
	Rhyolite tuff, grayish-orange pink (5YR 7/2), vitric, nonwelded. Composed of 5% fibrous glassy pumice lapilli (up to 1.0 cm); 15% sanidine and quartz phenocrysts (up to 2.0 mm); 2% gray to reddish-brown quartz-latite xenoliths (up to 1.0 mm); 75%–80% vitric ash matrix with abundant glass shards. Core dry.	153.4–158.8	6908.7–6903.3
	Rhyolite tuff, grayish orange pink (5YR 7/2), vitric, nonwelded. Composed of 15% fibrous glassy pumice lapilli (up to 3.5 cm); 15% sanidine and quartz phenocrysts (up to 2.0 mm); 1%–2% gray to reddish-brown dacitic xenoliths (up to 1.0 mm); 65%–70% vitric ash matrix with abundant glass shards. Core dry.	158.8–162.5	6903.3–6899.6
	Rhyolite tuff, grayish-orange pink (5YR 7/2), pumice-rich, vitric, nonwelded. Composed of 25% fibrous glassy pumice lapilli (up to 3.5 cm); 15% sanidine and quartz phenocrysts (up to 2.0 mm); 1% gray to reddish-brown dacitic xenoliths (up to 1.0 mm); 65%–70% vitric ash matrix with abundant glass shards. Core dry.	162.5–164.2	6899.6–6897.9
	Rhyolite tuff, grayish orange pink (5YR 7/2), pumice-rich, vitric, nonwelded. Composed of 30% fibrous glassy pumice lapilli (up to 2.0 cm); 15% sanidine and quartz phenocrysts (up to 2.0 mm); rare volcanic xenoliths (up to 1.0 mm); 55% vitric ash matrix with abundant glass shards. Core dry.	164.2–168.3	6897.9–6893.8
	No core recovery in this interval.	168.3–176	6893.8–6886.1
	Rhyolite tuff, grayish-orange pink (5YR 7/2), pumice-rich, vitric, nonwelded. Composed of 25% fibrous glassy pumice lapilli (up to 2.0 cm); 10% sanidine and quartz phenocrysts (up to 2.0 mm); rare volcanic xenoliths (up to 1.0 mm); 60%–65% vitric ash matrix with abundant glass shards. Core dry.	176–178	6886.1–6884.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbt 1, (undivided), Tshirege Member of the Bandelier Tuff	No core recovery in this interval.	178–181	6884.1–6881.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), vitric, nonwelded. Composed of 20% glassy pumice lapilli (up to 3.5 cm); 12% sanidine and quartz phenocrysts (up to 4.0 mm); 1% dark gray dacitic xenoliths (up to 4.0 mm); 65%–70% vitric ash matrix with abundant glass shards. Core dry.	181–182.8	6881.1–6879.3
	Rhyolite tuff, grayish-orange pink (5YR 7/2), pumice-rich, vitric, nonwelded. Composed of 25% fibrous glassy pumice lapilli (up to 3.0 cm); 15% sanidine and quartz phenocrysts (up to 4.0 mm); 1% gray dacitic xenoliths (up to 5.0 mm); 60%–65% vitric ash matrix with abundant glass shards. Core moist.	182.8–188.3	6879.3–6873.8
	No core recovery in this interval.	188.3–191	6873.8–6871.1
	Rhyolite tuff, very pale orange (10YR 8/2), pumice-rich, vitric, nonwelded. Composed of 25%–35% fibrous glassy pumice lapilli (up to 3.0 cm); 10%–15% sanidine and quartz phenocrysts (up to 2.0 mm); 1% volcanic xenoliths (up to 4.0 mm); 50%–60% vitric ash matrix.	191–194.1	6871.1–6868
Qbt 1	No core recovery in this interval.	194.1–201	6868–6861.1
	Rhyolite tuff, very pale orange (10YR 8/2), pumice-rich, vitric, nonwelded. Composed of 35% fibrous glassy pumice lapilli (up to 1.5 cm); 15% sanidine and quartz phenocrysts (up to 2.0 mm); 1% volcanic xenoliths (up to 1.0 mm); 45%–50% vitric ash matrix. Core dry.	201–203	6861.1–6859.1
	No core recovery in this interval.	203–206	6859.1–6856.1
	Rhyolite tuff, very pale orange (10YR 8/2), vitric, nonwelded. Composed of 5% fibrous glassy pumice lapilli (up to 1.5 cm); 15% sanidine and quartz phenocrysts (up to 3.0 mm); 1% gray to reddish-brown volcanic xenoliths (up to 4.0 mm); 75%–80% vitric ash matrix. Core dry.	206–207.8	6856.1–6854.3
	No core recovery in this interval.	207.8–211	6854.3–6851.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), vitric, nonwelded, friable. Composed of 18% white glassy pumice lapilli (up to 2.5 cm); 18% sanidine and quartz phenocrysts (up to 4.0 mm); 1%–2% gray to reddish-brown volcanic xenoliths (up to 5.0 mm); 55%–60% vitric ash matrix with abundant glassy shards. Core dry.	211–213.8	6851.1–6848.3
	No core recovery in this interval.	213.8–216	6848.3–6846.1
	Volcaniclastic sediments, pale yellowish-brown (10YR 6/2), tuffaceous, unconsolidated, pumice-rich. Composed of 60% white glassy pumice fragments (up to 1.0 cm); 30% sanidine and quartz grains; 3% lithic fragments; 7%–10% ash and silt. Core moist.	216–218.3	6846.1–6843.8
Qct Cerro Toledo Interval	No core recovery in this interval. Qbt 1g/Qct contact estimated at 220.0 ft bgs.	218.3–221	6843.8–6841.1
	Volcaniclastic sediments, silty sand (SM), with light brown gravel (5YR 6/4), tuffaceous, unconsolidated, pebble-size clasts up to 1.5 cm. Composed of volcanic lithologies with minor pumice fragments. Core dry.	221–223.2	6841.1–6838.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qct Cerro Toledo Interval	No core recovery in this interval.	223.2–226	6838.9–6836.1
	Volcaniclastic sediments, sand (SW) with gravel, grayish-orange (10YR 7/4), 10% subrounded gravel clasts up to 3.0 cm, unconsolidated. Composed of volcanic lithologies (dominantly dacite). Core moist.	226–229	6836.1–6833.1
	No core recovery in this interval.	229–232	6833.1–6830.1
	Very poor core recovery in this interval. Volcaniclastic gravels, dacite-rich.	232–232.4	6830.1–6829.7
	No core recovery in this interval. Qct/Qbo contact estimated at 244.0 ft bgs.	232.4–244	6829.7–6818.1
Qbo Otowi Member of the Bandelier Tuff	Rhyolite tuff, very pale orange (10YR 8/2), vitric, nonwelded. Composed of 20% orange to yellowish-brown glassy fibrous pumice lapilli (up to 3.0 cm); 5% quartz and sanidine phenocrysts (up to 2.0 mm); 2% reddish-brown volcanic xenoliths (up to 5 mm); 70%–75% vitric ash matrix with abundant glassy shards and streaks of orange Fe-oxide staining. Core dry.	244–248.8	6818.1–6813.3
	No core recovery in this interval.	248.8–251	6813.3–6811.1
	Rhyolite tuff, moderate orange pink (5YR 8/4), vitric, nonwelded. Composed of 10%–20% glassy fibrous pumice lapilli; 10%–20% quartz and sanidine phenocrysts; 3%–5% gray to reddish-brown volcanic xenoliths (up to 5.0 mm); 55–65% vitric ash matrix with glassy shards. Core dry.	251–252.1	6811.1–6810
	No core recovery in this interval.	252.1–263.8	6810–6798.3
	Rhyolite tuff, very pale orange (10YR 8/2), vitric, nonwelded. Composed of 15%–20% glassy fibrous pumice lapilli; 20% quartz and sanidine phenocrysts; 1%–2% volcanic xenoliths; 60%–65% vitric ash matrix. Core dry.	263.8–272.9	6798.3–6789.2
	Rhyolite tuff, grayish-orange pink (5YR 7/2), vitric, nonwelded. Composed of 10%–15% glassy fibrous pumice lapilli; 20%–25% quartz, sanidine, and ferromagnesian phenocrysts; 1%–2% volcanic xenoliths; 50%–60% vitric ash matrix. Core dry.	272.9–278.3	6789.2–6783.8
	Rhyolite tuff, very pale orange (10YR 8/2), vitric, nonwelded. Composed of 10%–15% glassy fibrous pumice lapilli; 20% quartz and sanidine phenocrysts (up to 2.0 mm); 3% ferromagnesian phenocrysts; 1%–2% volcanic xenoliths; 55%–65% vitric ash matrix. Core slightly moist.	278.3–287.2	6783.8–6774.9
	Rhyolite tuff, very pale orange (10YR 8/2), vitric, nonwelded. Composed of 20% glassy fibrous pumice lapilli; 20% quartz and sanidine phenocrysts (up to 2.0 mm); 2% ferromagnesian phenocrysts; 2% volcanic xenoliths; 50%–60% vitric ash matrix. Core slightly moist.	287.2–299.6	6774.9–6762.5
	No core recovery in this interval. Rotary drill cuttings collected and described in the interval 306 to the total borehole depth at 1325 ft bgs.	299.6–306	6762.5–6756.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbo Otowi Member of the Bandelier Tuff	Rhyolite tuff, light brownish-gray (5YR 6/1), lithic-rich, poorly welded. WR/+10F: (i.e., unsieved sample and plus No. 10 sieved sample fraction) 20% glassy, fibrous and sugar-textured pumice fragments (up to 1 cm); 10% quartz and sanidine crystals (up to 3.0 mm); 70% gray to reddish-brown dacitic and andesitic lithic fragments (up to 0.7 cm).	306–311	6756.1–6751.1
	Rhyolite tuff, medium light gray (N6), lithic-rich, poorly welded to nonwelded. WR/+10F: 15% pale orange glassy, fibrous pumice fragments (up to 0.8 cm); 10% quartz and sanidine crystals; 70%–75% gray to reddish-brown dacitic and andesitic lithic fragments (up to 0.7 cm) with minor siltstone and obsidian.	311–318	6751.1–6744.1
	Rhyolite tuff, very light gray (N8), lithic-rich, poorly welded to nonwelded. WR/+10F: 5% pale orange glassy, fibrous pumice fragments (up to 0.7 cm); 20% quartz and sanidine crystals (up to 2.0 mm); 70%–75% gray to reddish-brown dacitic and andesitic lithic fragments (up to 0.7 cm); 5% volcanic ash.	318–323	6744.1–6739.1
	Rhyolite tuff, medium light gray (N6), lithic-rich, poorly welded to nonwelded. WR/+10F: 20% white to pale orange glassy, fibrous pumice fragments (up to 0.7 cm); 20% quartz and sanidine crystals (up to 4.0 mm); 57% gray to pink dacitic lithic fragments (up to 0.7 cm); 3% volcanic ash.	323–328	6739.1–6734.1
	Rhyolite tuff, very light gray (N8), crystal-rich, poorly welded to nonwelded. WR/+10F: 5%–10% white to pale orange glassy, fibrous pumice fragments (up to 0.8 cm); 60%–70% quartz and sanidine crystals (up to 3.0 mm); 20% dacitic and andesitic lithic fragments; 10% volcanic ash.	328–333	6734.1–6729.1
	Rhyolite tuff, light gray (N7), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 5% white to pale orange glassy, fibrous pumice fragments (up to 0.5 cm); 50% quartz and sanidine crystals (up to 4.0 mm); 40% dacitic lithic fragments; 5%–10% volcanic ash.	333–353	6729.1–6709.1
	Rhyolite tuff, very light gray (N8), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 2% white to pale orange glassy, fibrous pumice fragments; 60% quartz and sanidine crystals; 35%–40% dacitic and minor obsidian lithic fragments; 1%–3% volcanic ash.	353–358	6709.1–6704.1
	Rhyolite tuff, light gray (N7), lithic-rich, poorly welded to nonwelded. WR/+10F: 3%–8% white to pale orange glassy, fibrous pumice fragments; 15% quartz and sanidine crystals; 75% dacitic and andesite lithic fragments, minor obsidian; 2%–3% volcanic ash.	358–378	6704.1–6684.1
	Rhyolite tuff, very light gray (N8), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 2%–3% white to light gray glassy, fibrous pumice fragments; 50% quartz and sanidine crystals; 45% dacitic and andesite lithic fragments, minor obsidian; 2%–3% volcanic ash.	378–383	6684.1–6679.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbo Otowi Member of the Bandelier Tuff	Rhyolite tuff, light brownish-gray (5YR 6/1), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 3% white to pale orange glassy, fibrous to sugar-textured pumice fragments; 45% quartz and sanidine crystals; 47% dacitic, rhyolite, and obsidian lithic fragments; 5% volcanic ash.	383–393	6679.1–6669.1
	Rhyolite tuff, light gray (N7), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 1%–2% white to pale orange glassy, fibrous pumice fragments; 25% quartz and sanidine crystals; 65% dacitic, rhyodacite, and rhyolite lithic fragments; 10% volcanic ash.	393–398	6669.1–6664.1
	Rhyolite tuff, light gray (N7), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 5% white to pale orange glassy, fibrous to sugar-textured pumice fragments; 40% quartz and sanidine crystals (up to 3 mm); 45% dacitic, rhyodacite, and rhyolite lithic fragments, minor obsidian; 10% volcanic ash.	398–408	6664.1–6654.1
	Rhyolite tuff, light gray (N7), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 3%–5% white to pale orange glassy, fibrous to sugar-textured pumice fragments; 40% quartz and sanidine crystals (up to 3 mm); 40% dacitic with minor andesitic, rhyodacite, and obsidian lithic fragments; 15%–20% volcanic ash.	408–413	6654.1–6649.1
	Rhyolite tuff, light gray (N7), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 2% white to pale orange glassy, fibrous pumice fragments; 50% quartz and sanidine crystals (up to 3 mm); 35%–40% dacitic with minor andesitic, rhyodacite, and obsidian lithic fragments; 10% volcanic ash.	413–418	6649.1–6644.1
	Rhyolite tuff, light gray (N7), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 2%–3% white to pale orange glassy, fibrous to sugar-textured pumice fragments (up to 0.6 cm); 35% quartz and sanidine crystals (up to 3.0 mm); 50%–55% dacitic lithic fragments with minor andesite, rhyodacite, and obsidian (up to 4.0 mm); 7% volcanic ash.	418–438	6644.1–6624.1
	Rhyolite tuff, light gray (N7), lithic-rich, poorly welded to nonwelded. WR/+10F: 1%–2% white to pale orange glassy, fibrous to sugar-textured pumice fragments (up to 0.3 cm); 25% quartz and sanidine crystals (up to 3.0 mm); 65%–70% dacitic lithic fragments with minor andesite and rhyodacite; 1%–3% volcanic ash.	438–443	6624.1–6619.1
	Rhyolite tuff, medium light gray (N6), pumice- and lithic-rich, poorly welded to nonwelded. WR/+10F: 60% white glassy, fibrous pumice fragments (up to 0.7 cm); 5% quartz and sanidine crystals (up to 3.0 mm); 35% dacite and minor rhyolite lithic fragments; 1%–3% volcanic ash.	443–448	6619.1–6614.1
	Rhyolite tuff, very light gray (N8), crystal-rich, poorly welded to nonwelded. WR/+10F: 1% white glassy, fibrous pumice fragments; 75% quartz and sanidine crystals (up to 4 mm); 15% dacite and andesite lithic fragments; 10% volcanic ash. Some larger crystals and lithic fragments in +10F sample are rounded.	448–453	6614.1–6609.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbo Otowi Member of the Bandelier Tuff	Rhyolite tuff, very light gray (N8), crystal-rich, poorly welded to nonwelded. WR/+10F: 5% white glassy, fibrous pumice fragments; 75% quartz and sanidine crystals (up to 4.0 mm); 35% lithic fragments (dacite, andesite, and minor obsidian up to 3.0 mm); 15% volcanic ash.	453–463	6609.1–6599.1
	Rhyolite tuff, very light gray (N8), crystal- and lithic-rich, poorly welded to nonwelded. WR/+10F: 8% white glassy, fibrous pumice fragments (up to 0.5 cm); 45% quartz and sanidine crystals (up to 2.0 mm); 30% lithic fragments (dacite, andesite, and minor obsidian up to 5.0 mm); 17% volcanic ash.	463–478	6599.1–6584.1
	Rhyolite tuff, light gray (N7), crystal-rich, poorly welded to nonwelded. WR/+10F: 8% white glassy, fibrous pumice fragments (up to 0.4 cm); 45% quartz and sanidine crystals (up to 3.0 mm); 25% lithic fragments (dacite and latite up to 5.0 mm); 15% volcanic ash.	478–488	6584.1–6574.1
	Rhyolite tuff, light gray (N7), pumice- and lithic-rich, poorly welded to nonwelded. +10F: 50% white glassy pumice fragments (up to 0.3 cm); 3%–5% quartz and sanidine crystals; 45%–50% dacitic lithic fragments. +35F (i.e., plus No. 35 sieved sample fraction): contains more than 50% quartz and sanidine crystals.	488–498	6574.1–6564.1
	Rhyolite tuff, light gray (N7), crystal- and lithic-rich, poorly welded to nonwelded. WR: 5% white pumice fragments; 60% quartz and sanidine crystals; 35% dacitic lithic fragments.	498–503	6564.1–6559.1
	Rhyolite tuff, light gray (N7), pumice- and lithic-rich, poorly welded to nonwelded. WR/+10F: 40%–50% white glassy, fibrous pumice fragments; 5%–10% quartz and sanidine crystals; 40%–50% volcanic lithic fragments (up to 3 mm).	503–508	6559.1–6554.1
	Rhyolite tuff, light gray (N7), crystal-rich, poorly welded to nonwelded. WR/+10F: 5% white glassy, fibrous pumice fragments (up to 0.3 cm); 70% quartz and sanidine crystals (up to 2 mm); 20% volcanic lithic fragments (dacite and andesite); 5% fine volcanic ash.	508–513	6554.1–6549.1
	Rhyolite tuff, light gray (N7), crystal-rich, poorly welded to nonwelded. WR/+10F: 5% white glassy fibrous pumice fragments (up to 0.4 cm); 20% quartz and sanidine crystals (up to 2 mm); 20% volcanic lithic fragments (dacite and andesite); 5% fine volcanic ash. Qbo/Qbog contact estimated at 522 ft bgs.	513–523	6549.1–6539.1
Qbog, Guaje Pumice Bed	Tephra, medium light gray (N6), crystal- and lithic-rich, nonwelded. WR/+10F: 20% white fibrous to glassy pumice fragments (up to 0.5 cm); 30% quartz and sanidine crystals (up to 3 mm); 50% gray to reddish brown, volcanic lithic fragments (dacite, latite).	523–533	6539.1–6529.1
	Transitional Qbog/Tpf interval-medium light gray (N6), 40% tephra, nonwelded; 60% Tschicoma dacite. WR/+10F: 15% white fibrous to glassy pumice fragments (up to 0.3 cm); 15% quartz and sanidine crystals (up to 3 mm); 10% volcanic ash; 50% dark gray. fine grained dacite lithic fragments. Note: basal Qbog contact with underlying Puye volcanic sediments estimated at 534 ft bgs.	533–538	6529.1–6524.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation, (upper section)	Volcanic sediments, dark gray (N3). +10F: fragments of dacite volcanic rock, aphanitic, aphyric, massive; some remnant tephra present, probably from drilling contamination.	538–543	6524.1–6519.1
	Volcanic sediments, medium dark gray (N4) to dark gray (N3), sparsely porphyritic with aphanitic groundmass, massive. +10F: rare phenocrysts of pyroxene and quartz; minor tephra present, probably from drilling contamination.	543–548	6519.1–6514.1
	Volcanic sediments, medium dark gray (N5), sparsely porphyritic with aphanitic groundmass, massive. +10F: dark gray to reddish-brown dacite fragments, rare phenocrysts of pyroxene and plagioclase; rare tephra present.	548–558	6514.1–6504.1
	Volcanic sediments, medium dark gray (N5), sparsely porphyritic with aphanitic groundmass, massive. +10F: similar lithology to interval 548–558 ft; however, only a small volume of +10F sample recovered.	558–563	6504.1–6499.1
	Volcanic sediments, medium dark gray (N5), sparsely porphyritic with aphanitic groundmass, massive. +10F: dark gray to reddish brown dacite fragments, angular chips, rare phenocrysts of yellowish-green pyroxene and plagioclase; rare tephra present.	563–593	6499.1–6469.1
	Volcanic sediments, pale red (10YR 6/2) to grayish-red (10R 4/2), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: angular chips, rare phenocrysts of yellowish-green pyroxene, plagioclase, and probably quartz; reddish coloration suggests oxidized zone, possible brecciation. Note: basal Tpf contact with underlying section of dacite volcanics estimated at 620 ft bgs.	593–628	6469.1–6434.1
Td, Dacite (unassigned)	Dacite, medium light gray (N6), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: angular chips, light gray to reddish-brown dacite, euhedral phenocrysts of pyroxene, plagioclase, and probably quartz; partly reddish coloration suggests oxidized breccia zone.	628–638	6434.1–6424.1
	Dacite, medium light gray (N6), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: 98% chips light gray to reddish-brown dacite, euhedral phenocrysts of pyroxene, plagioclase, and probably quartz; 1%–2% yellowish-brown sandstone fragments.	638–643	6424.1–6419.1
	Dacite, medium light gray (N6), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: chips light gray to reddish-brown dacite, minor phenocrysts of translucent yellowish-brown pyroxene, plagioclase, hornblende, and probably quartz.	643–663	6419.1–6399.1
	Dacite, medium light gray (N6), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: chips light gray to reddish-brown dacite, minor phenocrysts of translucent yellowish-brown euhedral pyroxene, subhedral plagioclase, and euhedral biotite.	663–718	6399.1–6344.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Td, Dacite (unassigned)	Dacite, light gray (N5), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: chips light gray to reddish-brown dacite, minor phenocrysts of translucent yellowish-brown euhedral pyroxene, subhedral plagioclase, and numerous small mafic minerals. Note: Td/Tpf contact estimated at 768 ft bgs.	718–778	6344.1–6284.1
Tpf, Puye Formation (lower section)	Dacitic sediments, medium light gray (N6), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: chips light gray to reddish-brown dacite, minor phenocrysts of translucent yellowish-brown euhedral pyroxene, subhedral plagioclase, and small mafic minerals; unidentified sugar-textured crystals, possibly zeolites, in-filling some vugs.	778–838	6284.1–6224.1
	Dacitic sediments, medium gray (N5), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: chips (flat, platy) of dark gray to reddish-brown dacite, minor phenocrysts of translucent yellowish-brown euhedral pyroxene, subhedral plagioclase, and anhedral quartz; chips of gray clay.	838–848	6224.1–6214.1
	Dacitic sediments, medium dark gray (N4), sparsely porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: chips (flat, platy flakes) of dark gray to reddish brown dacite, minor phenocrysts of translucent yellowish and black opaque euhedral pyroxene, subhedral plagioclase, and anhedral quartz; abundant chips of gray clay denote an apparent zone of clay alteration from 848 to 878 ft bgs.	848–863	6214.1–6199.1
	Clayey sand with dacites, light brownish-gray (5YR 6/1). +10F: lenticular chips of dacite, sparsely porphyritic with aphanitic groundmass, euhedral pyroxene, subhedral plagioclase; abundant platy chips of clay.	863–868	6199.1–6194.1
	Dacitic sediments and silt, light brownish-gray (5YR 6/1), slightly porphyritic with aphanitic groundmass, massive. +10F: dacite phenocrysts (3%–5% volume) include pyroxene, biotite, hornblende, plagioclase, and quartz; groundmass weakly sericitized.	868–878	6194.1–6184.1
	Dacitic sediments, medium light gray (N6), slightly porphyritic with aphanitic to finely crystalline groundmass, massive. +10F: flat, platy chips of gray and reddish-brown dacitic sediments: 3%-5% phenocrysts include pyroxene, biotite, hornblende, plagioclase, and quartz; groundmass weakly altered.	878–888	6184.1–6174.1
	Dacitic sediments, medium gray (N5), aphyric, aphanitic to finely crystalline, massive. +10F: flat, platy dacite chips, siliceous groundmass; with alteration. WR sample is clay rich. Note: only 1%–2% of sample was retained on No. 10 sieve.	888–898	6174.1–6164.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation (lower section)	Dacitic sediments, medium gray (N5), aphyric, aphanitic to finely crystalline, massive. +10F: 50% flat, platy dacite chips; 50% white clay (?) shards that appear to be rinds of altered dacitic sediments. Lower 5 ft of the interval contains minor fine-grained sandstone and limonitic clay. WR sample clay rich. Note: only 5% of sample was retained on the No. 10 sieve.	898–908	6164.1–6154.1
	Dacitic sediments, medium gray (N5) and light brownish-gray (5YR 6/1), aphyric, aphanitic to finely crystalline, massive. +10F: 80% flat, platy dacite chips; 20% white, platy clay shards WR sample clay rich.	908–918	6154.1–6144.1
	Dacitic sediments, medium gray (N5) and light brownish-gray (5YR 6/1), aphyric, aphanitic to finely crystalline, massive. +35F: 80% flat, platy dacite chips; 20% white, platy clay shards WR sample clay rich. Note: none of the sample retained on No. 10 sieve.	918–928	6144.1–6134.1
	Dacitic sediments, medium gray (N5), aphyric, aphanitic to finely crystalline, massive. +35F: 100% flat, platy dacite chips; unidentified dark green iridescent mineral present as coatings. Note: none of the sample retained on No. 10 sieve.	928–938	6134.1–6124.1
	Dacitic sediments, medium gray (N5), finely crystalline aphyric to weakly porphyritic with aphanitic groundmass, massive. +35F: 100% flat, platy dacite chips. Note: none of the sample retained on No. 10 sieve.	938–943	6124.1–6119.1
	Dacitic sediments, medium gray (N5) to light brownish-gray (5YR 6/1), finely crystalline aphyric to weakly porphyritic with aphanitic groundmass, massive. +10F: 95%–97% flat, platy dacite chips, minor fine-grained phenocrysts of plagioclase and biotite; 3%–5% white platy flakes of clay or strongly altered dacitic sediments. WR sample clay rich.	943–958	6119.1–6104.1
	Dacitic sediments, medium gray (N5), finely crystalline aphyric to sparsely porphyritic with aphanitic groundmass, massive. +10F: 100% platy dacite chips, fine-grained phenocrysts of plagioclase and biotite; partly altered and bleached.	958–963	6104.1–6099.1
	Dacitic sediments, light gray (N6), finely crystalline aphyric to weakly porphyritic with aphanitic groundmass, massive. +35F: 100% platy dacite chips as in the interval 958–963 ft; partly altered and bleached. None of the sample retained on the No. 10 sieve.	963–973	6099.1–6089.1
	Dacitic sediments, light brownish-gray (5YR 6/1), aphyric, aphanitic, massive. +10F: 100% platy dacite chips, approximately half display strong alteration. WR sample clay rich.	973–983	6089.1–6079.1
	Dacitic sediments, medium gray (N5), aphyric, aphanitic, massive. +10F: 100% platy dacite chips commonly exhibiting sericite alteration and bleaching; minor clay content.	983–988	6079.1–6074.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation (lower section)	Dacitic sediments, grayish-orange pink (5YR 7/2), finely crystalline aphyric to sparsely porphyritic with aphanitic groundmass, massive. +10F: platy dacite chips; clay present as rinds and flakes (less than 5% of sample retained on No. 10 sieve).	988–998	6074.1–6064.1
	Dacitic sediments, light brownish-gray (5YR 6/12), finely crystalline to aphanitic, massive. +10F: none of the sample retained. +35F:100% platy dacite chips. WR sample clay rich.	998–1008	6064.1–6054.1
	Dacitic sediments, grayish-orange pink (5YR 7/2), aphyric, aphanitic, massive. +10F: none of the sample retained. +35F: only 5% of sample retained on No. 35 sieve, platy dacite chips; clay present as rinds and flakes.	1008–1023	6054.1–6039.1
	Dacitic sediments, light brownish-gray (5YR 6/12), finely crystalline to aphanitic, massive. +10F: none of the sample retained. +35F:100% dacite chips exhibit moderate to strong alteration. WR sample clay rich.	1023–1038	6039.1–6024.1
	Dacitic sediments, medium light gray (N5), finely crystalline to aphanitic, massive. +10F: 100% dacite chips with moderate alteration and bleaching. WR sample clay rich.	1038–1043	6024.1–6019.1
	Dacitic sediments, medium light gray (N5), finely crystalline to aphanitic, massive. +10F: none of the sample retained. +35F: 100% dacite chips exhibit moderate sericitic alteration and bleaching. WR sample clay rich.	1043–1068	6019.1–5994.1
	No cuttings sample collected.	1068–1070	5994.1–5992.1
	Volcaniclastic sediments, gravel (GW) with sand, light gray (N6), pebbles (up to 1.5 cm) mostly subrounded. +10F: clasts composed of 70%–80% aphanitic to porphyritic dacites; 10%–15% black vitrophyre (obsidian); 3%–7% distinctive white siliceous clay.	1070–1080	5992.1–5982.1
	Volcaniclastic sediments, sand (SW) with gravel, light gray (N7), pebbles (up to 2.0 cm) angular to subrounded. +10F: clasts composed dominantly of dacite with some rhyolite.	1080–1085	5982.1–5977.1
	Volcaniclastic sediments, silty sand (SM) with gravel, medium light gray (N6), pebbles (up to 1.0 cm) angular to subrounded. +10F: clasts composed dominantly of dacite with some rhyolite, latite, and pumice.	1085–1100	5977.1–5962.1
	Volcaniclastic sediments, silty sand (SM), light brownish-gray (5YR 6/1) to pale yellow-orange (10YR 6/2), sand grains angular to subrounded. +10F: clasts composed dominantly of dacite with some rhyolite, latite, and minor pumice.	1100–1120	5962.1–5942.1
	Volcaniclastic sediments, silty sand (SM), light brownish-gray (5YR 6/1) to grayish-orange pink (5YR 7/2), sand grains angular to subrounded. +10F: clasts composed dominantly of dacite with some rhyolite, latite, and minor pumice.	1120–1140	5942.1–5922.1
	Volcaniclastic sediments, sand (SW) with silt, light brownish-gray (5YR 6/1), clasts angular to subrounded. +10F: clasts composed dominantly of dacite with some rhyolite, pumice, and minor latite.	1140–1145	5922.1–5917.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation (lower section)	Volcaniclastic sediments, silty sand (SM), grayish-orange pink (5YR 7/2), sand grains angular to subrounded. +10F: clasts composed dominantly of dacite with some rhyolite, latite, and pumice.	1145–1165	5917.1–5897.1
	Volcaniclastic sediments, sand (SW) with silt, light brownish-gray (5YR 6/1), clasts angular to rounded. +10F: clasts composed dominantly of dacite with some latite and pumice.	1165–1170	5897.1–5892.1
	Volcaniclastic sediments, silty sand (SM), light brownish-gray (5YR 6/1), clasts angular to subrounded. +10F: clasts composed dominantly of dacite with some pumice and latite.	1170–1185	5892.1–5877.1
	Volcaniclastic sediments, silty sand (SM), grayish-orange pink (5YR 7/2), sand grains angular to subrounded. +10F: clasts composed dominantly of dacite with some rhyolite and pumice.	1185–1200	5877.1–5862.1
	Volcaniclastic sediments, sand (SW) with gravel, light brownish-gray (5YR 6/1), pebble clasts (up to 0.7 cm) angular to rounded. +10F: clasts composed dominantly of dacite. +35F: contains some quartz grains.	1200–1205	5862.1–5857.1
	Volcaniclastic sediments, silty sand (SM), pale yellowish-brown (10YR 6/2), grains angular to subangular. +10F: clasts composed dominantly of dacite with some quartz, minor pumice.	1205–1210	5857.1–5852.1
	Clastic sediments, silty sand (SM), very pale orange (10YR 8/2), sand grains angular to rounded. +10F: clasts composed dominantly of dacite with some quartz, latite, and pumice. +35F: contains greater percentage of quartz. Note: the interval from 1210 to 1325 ft bgs contains increased appearance of quartz and pumice.	1210–1225	5852.1–5837.1
	Clastic sediments, sand (SW) with clay, light brownish-gray (5YR 6/1), grains angular to rounded. +10F: clasts composed dominantly of dacite and pumice with some latite and quartz. +35F: contains greater percentages of quartz.	1225–1230	5837.1–5832.1
	Clastic sediments, clayey sand (SC), pinkish-gray (5YR 8/1), sand grains angular to rounded. +10F: clasts composed dominantly of dacite with some quartz, rhyolite, and pumice. +35F: contains greater percentages of quartz.	1230–1245	5832.1–5817.1
	Clastic sediments, clayey sand (SC), pinkish gray (5YR 8/1), sand grains angular to subrounded. +10F: clasts composed dominantly of dacite and pumice with some latite and quartz. +35F: contains greater percentages of quartz.	1245–1255	5817.1–5807.1
	Clastic sediments, sand (SW) with clay, pinkish-gray (5YR 8/1), sand grains angular to subrounded. +10F: clasts composed dominantly of dacite and pumice with minor rhyolite, latite, and quartz. +35F: contains greater percentages of quartz.	1255–1265	5807.1–5797.1
	No cuttings recovered; lost circulation.	1265–1290	5797.1–5772.1
	Clastic sediments, sand (SW) with silt, pinkish-gray (5YR 8/1), sand grains angular to rounded. +10F: clasts composed dominantly of quartz, microcline, and pumice with minor dacite.	1290–1295	5772.1–5767.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation (lower section)	Clastic sediments, sand (SW) with silt, pinkish-gray (5YR 8/1), sand grains angular to rounded. +10F: clasts composed dominantly of pumice, quartz, and dacite with minor microcline.	1295–1300	5767.1–5762.1
	Clastic sediments, sand (SW) with silt, pinkish-gray (5YR 8/1), sand grains angular to rounded. +10F: clasts composed dominantly of pumice, with some quartz, minor dacite and microcline.	1300–1305	5762.1–5757.1
	Clastic sediments, silty sand (SM), very pale orange (10YR 8/2), sand grains angular to rounded. +10F: clasts composed dominantly of quartz and microcline with some pumice, dacite, and rhyolite.	1305–1320	5757.1–5742.1
	Clastic sediments, silty sand (SM), grayish-orange pink (5YR 7/2), sand grains angular to rounded. +10F: clasts composed dominantly of quartz, pumice, and dacite with minor microcline and basalt.	1320–1325	5742.1–5737.1
	R-14 BOREHOLE TOTAL DEPTH (TD). = 1327 FT BGS		

Notes:

1. American Society for Testing Materials (ASTM) standards (D 2488-90: Standard Practice and Identification of Soils [Visual-Manual Procedure]) were used to describe the texture of drill chip samples for sedimentary rocks such as alluvium and the Puye Formation. ASTM method D 2488-90 incorporates the Unified Soil Classification System (USCS) as a standard for field examination and description of soils. The following standard USCS symbols were used in the R-14 lithologic log:

SW = well graded sand	SM = silty sand	CH = clay, high plasticity
GW = well graded gravel	GM = silty gravel	SC = clayey /sand
GP = poorly graded gravel	GC = clayey gravel	

2. Cuttings at R-14 were collected from ground surface to 1327 ft bgs at nominal 5-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR) sample; (2) +10F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) +35F sieved fraction (No. 35 sieve equivalent to 0.50 mm).
3. The term *percent,* as used in the above descriptions, refers to percent by volume for a given sample component.
4. Color designations such as hue, value, and chroma (e.g., 5YR 5/2) are from the Geological Society of America's Rock Color Chart.

Appendix D

LANL Borehole Video Log
(CD attached to inside back cover)

TO VIEW THE VIDEO THAT ACCOMPANIES THIS DOCUMENT, PLEASE CALL THE HAZARDOUS WASTE BUREAU AT 505-476-6000 TO MAKE AN APPOINTMENT

Appendix E

Schlumberger Geophysical Report/Montage
(CD attached to inside back cover)

Baker Hughes gas

GEOFRAME PROCESSED INTERPRETATION

Integrated Log Well Montage

Processed Wireline Geophysics Data

* A Mark of Schlumberger

Using the following logs: CMR* nuclear magnetic resonance
NGT* and ECS* geochemical spectroscopy
AIT*, CNTG*, TLD*

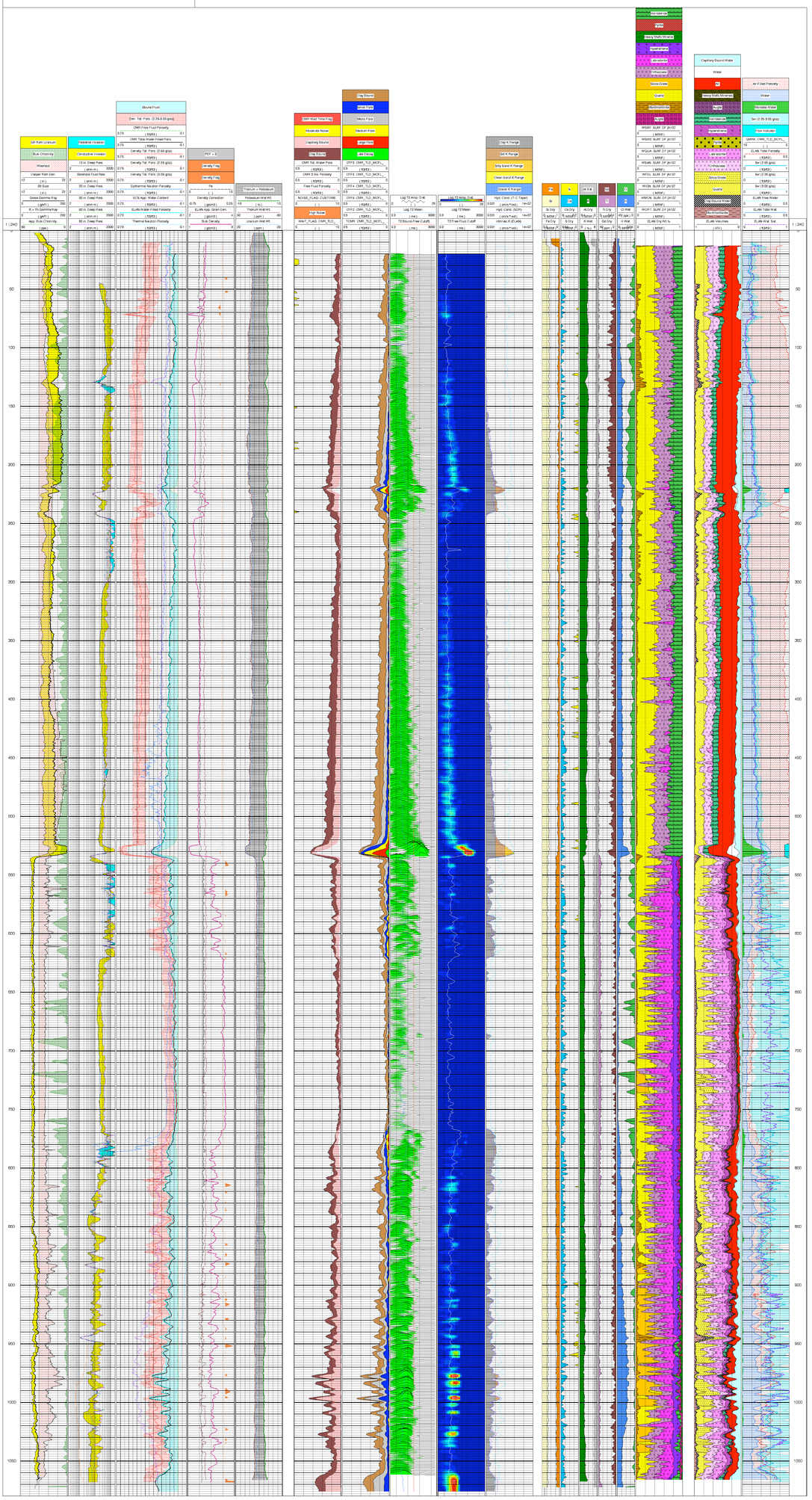
COMPANY:	Washington Group
WELL:	R-14
FIELD:	Los Alamos Characterization and Monitoring Well Network
COUNTY:	Los Alamos
STATE:	New Mexico
COUNTRY:	U.S.
Date Logged:	19-Jun-2002 Date Processed: 15-Jan-2003
Well Location:	
Elevations:	KB: 7094.00 ft DF: 7094.00 ft GL: 7080.00 ft
API Number:	None Available Job Number:

FOLD HERE The well name, location, borehole reference data were furnished by the customer

All interpretations, opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretations, and we shall not be liable or responsible for any loss or damage arising in connection with the use of such information. Our interpretations represent our best judgment based on the information available to us at the time of such interpretation. Data integrities are also subject to Clause 4 of our General Terms and Conditions as set out in our Current Price Schedule.

Field Recording:	Location:	Farmington	Software Version:	1009-006	Engineer: Meg Sadowski
Office Recording:	ICS Center	SKS Sacramento	Baseline:	GF 3-6-1	Log Analyst: Neil Clayton
Mud and Borehole Measurements:					
Rm @ Measured temperature:	@		BHT:		Bitsize: 15.0 in
Rmf @ Measured temperature:	@		Type Fluid in Hole:		Air/Foam
Rmc @ Measured temperature:	@		Mud Density:		

Remarks:
AIT tool run used as primary depth reference.
Neutron porosity logs extremely affected by drilling foam, especially below 770 ft. depth.
No porosity or water saturation constraints in ELAN analyses



Geophysical Logging Report

Schlumberger Water Services
February 2003

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1.0 ABSTRACT

This report describes the borehole geophysical logging measurements acquired in characterization well R-14 by Schlumberger, logged in June 2002 just prior to well completion. It also presents the final processed results from these measurements and discusses the interpretation of these results. The logs were acquired in open hole drilled with a 16 in diameter bit size. The primary purpose of the geophysical logging was to characterize the geologic/hydrogeologic section intersected by the well with emphasis on determining moisture content, perched groundwater zones, capacity for flow, and the stratigraphy/mineralogy of geologic units. A secondary purpose of the geophysical logging was to evaluate the borehole conditions such as borehole diameter versus depth and degree of drilling fluid invasion. These objectives were accomplished by measuring, nearly continuously, along the length of the well: (1) total and effective water-filled porosity and pore size distribution, from which an estimate of hydraulic conductivity is made, (2) bulk density (sensitive to total water- plus air-filled porosity) and photoelectric effect (sensitive to lithology), (3) bulk electrical resistivity at multiple depths of investigation, (4) bulk concentrations of a number of elements, (5) spectral natural gamma ray, including potassium, thorium, and uranium concentrations, and (6) borehole diameter.

Preliminary results of these measurements were generated in the logging truck at the time the geophysical services were performed and are documented in field logs provided on-site. However, the measurements presented in the field results are not corrected for borehole casing and fluid conditions and are provided as separate, individual logs. The field results were reprocessed by Schlumberger to (1) correct/improve the measurements, as best as possible, for borehole/formation environmental conditions, (2) perform an integrated analysis of the log measurements so that they are all coherent, and (3) combine the logs in a single presentation, enabling integrated interpretation. The reprocessed log results provide better quantitative property estimates that are consistent for all applicable measurements, as well as estimates of properties that otherwise could not be reliably estimated from the single measurements alone (e.g. total porosity inclusive of all water and air present, water saturation, mineralogy).

Most of the geophysical log measurements from Well R-14 provide very good quality results that are consistent with each other through much of the borehole. The quality of some of the water content measurements was degraded due to the presence of varying wetness drilling foam in the borehole, but a least one water content measurement was of good quality throughout. Borehole washouts, especially in the lower portion of the hole, adversely affected some of the measurements, but the tools mostly compensated for the non-ideal borehole conditions. Through the integrated analysis and interpretation of all the logs, the individual shortcomings of the specific measurements are reduced. Thus, the integrated log analysis results (e.g. the optimized water-filled porosity log) are the most robust single representation of the geophysical log results—providing a wealth of valuable high resolution information on the geologic and hydrogeologic environment of the R-14 locale.

Important results from the processed geophysical logs in R-14 include the following.

1. The inferred water saturation remains below 75% through most of the logged section with no significant fully saturated intervals. These results, interpreted independent of other data sources, suggest that the regional aquifer groundwater level lies somewhere below the bottom of the log interval (1063 ft) and that there are no significant perched water zones within the logged section.

2. Water-filled porosity is less than 20% through most of the logged section, ranging from a low of 3% to a high of 31%. The highest water-filled porosities (greater than 20%) occur in the zones 524–534 ft, 975–1000 ft, 1024–1030 ft, and 1062–1066 ft, which also have high total (air plus water) porosity.

3. Effective water-filled porosity (moveable water) is less than 3% through most of the logged section (averaging less than 1%), ranging from a low of 0% to a high of 26%. Correspondingly, the inferred hydraulic conductivity is generally very low. The highest effective water-filled porosities (greater than 2%) occur in the zones 212–240 ft, 520–534 ft, 584–588 ft, 597–602 ft, 607–620 ft, and 771–783 ft; the top two intervals are likely within the Bandelier Tuff sequence (the second likely corresponding to the Guaje Pumice Bed) and, from the integrated log analysis, appear to be directly underlain by clays, which possibly act as inhibitors to downward flow. As would be expected, inferred hydraulic conductivity is highest in these zones, although it is also high (relative to other intervals) in the zones 975–1000 ft and 1062–1066 ft, which have high total water-filled porosity.

4. The integrated log analysis shows a dense, low total porosity (less than 10%), and mafic-mineral rich zone from 623–767 ft that likely corresponds to a massive basalt and is surrounded by zones with similar mineral content, but higher porosity, that are likely composed of fractured basalt. Towards the bottom of the log interval the amount of heavy mafic minerals decreases, replaced by small amounts of hornblende, but otherwise the inferred mineral composition remains relatively constant.

5. A volcanic tuff sequence (likely the Bandelier Tuff) in the upper half of the logged interval (10–534 ft) is clearly distinguished by the logs and is characterized by

    - very high porosity (70%) and high water content (30%) in the bottom 10 ft (524–534 ft), which likely corresponds to the Guaje Pumice Bed;

    - lower, but still high, porosity (35–55%) and sequences of steadily decreasing water content in the upward direction (ranging from 3–20%) throughout the remainder of the tuff sequence up to the top of the log interval (10 ft);

    - a distinct drop in the gross gamma log, resulting from decreases in potassium and thorium, across the zone 216–246 ft, for which the integrated log analysis shows decreased total porosity and increased amounts of clay, with higher water content (15–20%) directly above the clays.

6. The borehole was largely washed out throughout the log interval, the diameter ranging from 17–22 in compared to a 16 in bit size. However, the washouts were no worse than most other Los Alamos wells and the borehole rugosity was less. These conditions, combined with the fact that the well did not have to be drilled casing-advance prior to the logging and, thus, was almost completely open hole, resulted in very good quality geophysical logs.

2.0 INTRODUCTION

Geophysical logging services were performed in characterization well R-14 by Schlumberger in June 2002, prior to initial well completion. The purpose of these services was to acquire in situ measurements that help characterize the borehole, near-borehole, and abutting geologic formation environment. The primary objective of the geophysical logging was to provide in situ evaluation of formation properties (hydrogeology and geology) intersected by the well. This information was (and is) used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to design the well completion, better understand subsurface site conditions, and assist in overall decision-making.

The primary geophysical logging services performed by Schlumberger in well R-14 were the

- Combinable Magnetic Resonance (CMR*) tool to measure the nuclear magnetic resonance response of the formation, which is used to evaluate total and effective water-filled porosity of the shallow formation and to estimate pore size distribution and in situ hydraulic conductivity;
- Compensated Neutron Tool, model G (CNTG*) to measure volumetric water content of the formation, which is used to evaluate moist/porous zones;
- Triple detector Litho-Density (TLD*) tool to measure formation bulk density , which is used to estimate total porosity;
- Array Induction Tool, version H, (AITH*) to measure formation electrical resistivity at five depths of investigation, which is used to evaluate drilling fluid invasion into the formation, presence of moist zones far from the borehole wall, and presence of clay-rich zones;
- Natural Gamma Spectroscopy (NGS) tool to measure gross natural gamma and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations, which is used to evaluate geology/lithology, particularly the amount of clay and potassium-bearing minerals;
- Elemental Capture Spectroscopy (ECS*) tool to measure elemental weight percent concentrations of a number of elements – used to characterize mineralogy and lithology of the formation.

In addition, calibrated gross gamma ray (GR) was recorded with every service except the NGS, for the purpose of depth matching the logging runs to each other. Table 2.1 summarizes the geophysical logging runs performed in R-14.

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* Mark of Schlumberger

Table 2.1
Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in borehole R-14

Date of Logging	Borehole Status	Run #	Tool 1	Tool 2	Tool 3	Depth Interval (ft)
19-June-2002	Open hole below 10 ft Bit size of 16 in. Surface casing above 10 ft Casing OD of 18 in.	1	CNTG	TLD	GR	10–1063 ft
Same	Same	2	AITH	GR		47–1060 ft
Same	Same	3	CMR	GR		20–1076 ft
Same	Same	4	ECS	GR		10–1072 ft
Same	Same	5	NGS	GR		2–1067 ft

2.1 Technology Description

Geophysical logging represents mature, yet constantly evolving, technologies employed as the principal methods of borehole analysis in subsurface characterization. Geophysical logs have a long history of use in the groundwater industry for aquifer delineation and basic characterization. More recently, advanced logging technologies, developed for the petroleum industry, are being applied for characterizing a wide range of groundwater-related physical properties.

Wireline geophysical logging systems consist of three components (Figure 2.1):

1. downhole instrument (or sonde) introduced into a borehole that measures one or more physical properties of the formation (a logging “tool” is usually defined as the sonde plus required accompanying electronic cartridges;
2. cable that connects the sonde to the surface, conducting power downhole and transmitting data uphole; and
3. logging truck that controls sonde location, provides power and houses a computer that controls sonde operation, as well as processes and displays data in real time. The resulting data are shown on a continuous strip chart commonly called a log.

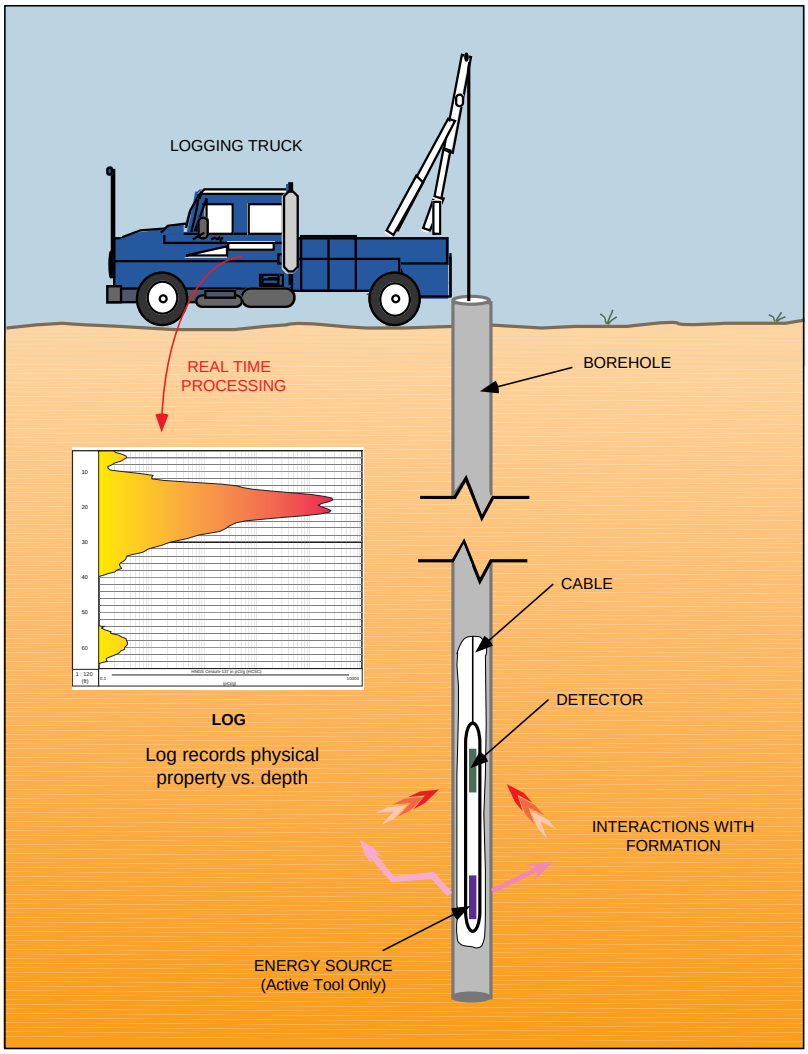


Figure 2.1: Schematic diagram of a wireline logging system in operation.

Geophysical logging systems are designed to give an accurate and precise in situ measurement of formation properties. Formation parameters commonly measured include porosity, moisture content, bulk geochemistry, hydraulic conductivity, orientation of bedding and fractures, identification and quantification of specific radionuclides and other elements, and many others. Similarly, logging systems provide accurate and precise measurements of completed well parameters, such as casing geometry, casing thickness, cement bond, and annular fill composition. Logging systems can also be used for downhole sampling and testing.

The integration of multiple logging technologies plus other data types (e.g., geologist's log, core analyses, surface geophysics, hydrologic test analyses) can lead to a fairly comprehensive picture of the subsurface. The precision of the measurements, in concert with the potential to measure the same volume repeatedly (i.e., re-enter the same borehole), enhances the use of logging systems for monitoring.

2.1.1 Compensated Neutron Tool, Model G (CNTG)

The CNTG tool measures the hydrogen index (HI), which is usually closely related to hydrogen concentration and water volume and can be employed in either open or cased, water or air filled boreholes. The HI measurement is made by emitting high-energy neutrons from a 16-Ci Americium-Beryllium neutron source, which collide with atoms in the volume surrounding the tool and are slowed to epithermal and thermal energy levels. The number of slowed neutrons returning to a set of detectors is then measured. The CNTG contains two He-3 thermal detectors, spaced 37.8 cm (15 in.) and 62 cm (24.7 in.) above the neutron source, as well as two He-3 epithermal neutron detectors spaced 11.6 in. and 20.5 in. below the source. This model of the CNT makes an HI measurement from epithermal neutrons in addition to one from thermal neutrons. The detectors count the neutrons that have been reduced to thermal/epithermal energy level. Measured count rates from the detectors are used to compute a ratio that varies primarily with the hydrogen concentration, or HI, of the media, and is related to formation water-filled porosity. Environmental effects are reduced using the ratio of the two count rates from the two detectors, which are affected in a similar manner by the environment. Residual environmental effects can be corrected with offsite processing. While the HI measurement is calibrated to provide a volumetric water content estimate, it is affected by lithology; it measures all hydrogen in clays, including that in hydroxyl molecules, as well as other oddball neutron absorbers, typically resulting in an elevated porosity in clays.

The CNTG provides two different porosity measurements, thermal and epithermal. The advantage of the epithermal measurement is that it provides a measurement in air-filled boreholes (not possible with the thermal measurement) and is relatively insensitive to thermal neutron absorbers (such as chlorine in salt water and the rare earth elements in shale). However, because of less efficient detection and of the relatively brief time spent by the neutrons in the epithermal energy band, epithermal count rates are lower than thermal count rates, under identical conditions in water-filled boreholes, by a factor of ten.

The measurements are calibrated in open and cased boreholes, albeit the measurement will be affected by the annular fill between the casing and the formation. The median depth of investigation is approximately 7 in. and vertical resolution approximately 18 in., although the thermal measurement can be resolution-enhanced to 8 in.

Basic measurement specifications for the CNTG are shown below.

Range of Measurement (water content):	0 to 60 %
Repeatability (Precision) (1 standard deviation or σ):	0– 20% = <1% porosity 20 to 30% = ± 2% porosity above 45% = ± 5% porosity

2.1.2 Combinable Magnetic Resonance (CMR)

The CMR makes pulse-echo nuclear magnetic resonance (NMR) measurements that are sensitive to the hydrogen nuclei (protons) contained in the pore space of the formation. These measurements contain information relating to both pore water volume and pore size. The pore size information can be used to partition the formation porosity into bound and free fluid volumes. This information can, in turn, be used to estimate formation hydraulic conductivity and water producibility. The pore size information also can be used to extrapolate relative grain size. The pore size information is unique to NMR logging devices.

The CMR log uses a compact magnet and antenna sensor package mounted in a pad-like skid that is pressed against the borehole wall. The tool has a vertical resolution of 6 in. (15 cm) and a median depth

of investigation of 1.5 in. (4 cm). Since the CMR makes a shallow measurement that requires good borehole wall-to-pad contact, disruption of contact between the skid and the wall because of borehole washout or hole rugosity affects data quality, resulting in erroneously high/low total and free water content in water/air-filled hole. The measurement also can be significantly affected by a sizeable presence of iron-bearing minerals, such as magnetite.

Basic measurement specifications for the CMR and a schematic diagram of the tool and sensor section are shown below and in Figure 2.2, respectively. The measurement specifications assume good logging conditions, good contact between the CMR pad and the borehole wall, and the absence of large amounts of magnetic material in the borehole environment.

Repeatability (σ):	Total water-filled porosity	1%
	Effective water-filled porosity:	0.5%
Total margin of error:	2%	

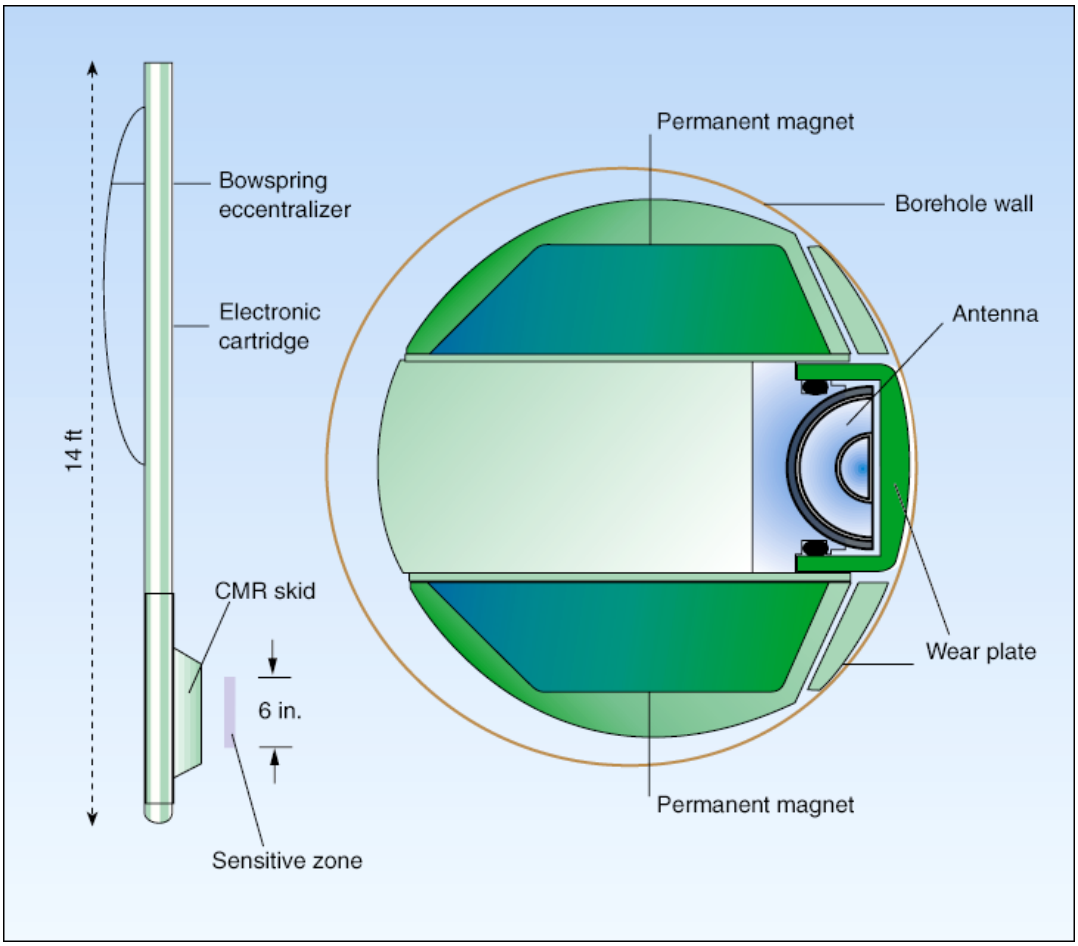


Figure 2.2. Schematic diagram of CMR tool with an enlarged cross-section of the sensor section

2.1.3 Triple Detector Litho-Density Tool (TLD)

The TLD tool is a triple-detector gamma-gamma (gamma ray source and gamma ray detectors) system for measuring compensated bulk density and formation photoelectric factor (P_e). Formation bulk density is

a function of porosity, rock matrix density, and pore fluid density, and P_e is a measure of the average atomic number of the formation that corresponds to formation chemistry and lithology. The tool uses a focused gamma source (1.5-curie ^{137}Cs) to emit a large flux of gamma rays into the formation and measures the resulting gamma intensity in dual near and far detectors. From these spectral measurements, a robust, environmentally corrected calculation of bulk density is made. True matrix porosity can be calculated based on bulk density, an estimation of matrix grain density (aided by the P_e measurement) and fluid densities. This porosity is unaffected by bound hydrogen in clays, as is porosity from neutron devices. The detectors, like the source, are highly focused because of their small size and heavy shielding and thus produce a high-resolution measurement.

The TLD also employs a third backscatter detector that improves the environmental correction for borehole washouts and rugosity, improves the dynamic range of the P_e, and has higher count rates and, thus, better measurement statistics, in hard rocks.

The TLD tool has a vertical resolution as high as 1.2 in. (3 cm) and a depth of investigation of 4 in. (10 cm). The tool is sensitive to changes in bulk density down to 0.01 g/cm3 and can be run in open hole and certain types of cased hole completions, and in both saturated and unsaturated formations.

The TLD uses a pad-like skid that is pressed against the borehole wall. Because the tool has a relatively shallow depth of investigation, it can be severely affected by borehole washouts and rugosity.

A schematic diagram of a TLD-type sensor system is shown in Figure 2.3.

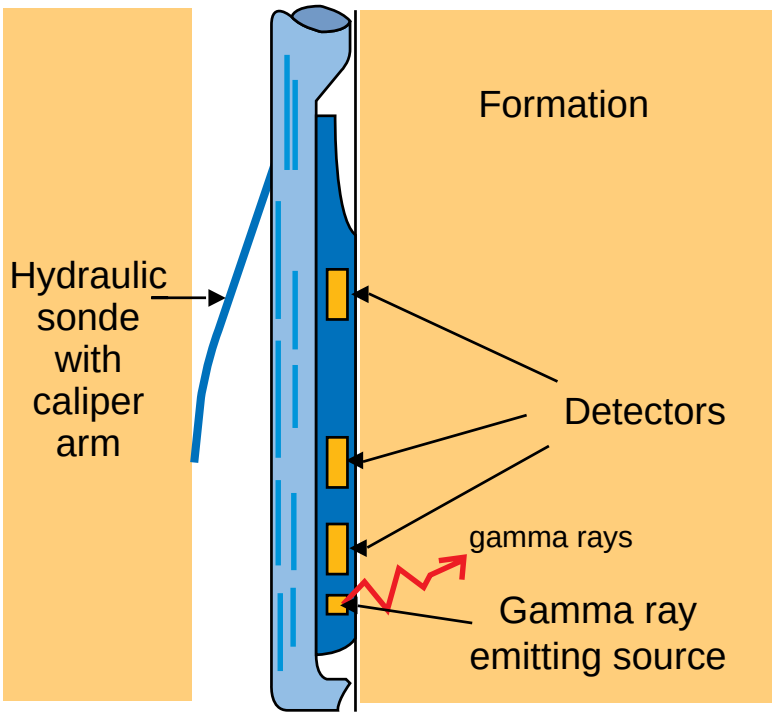


Figure 2.3. Schematic diagram of TLD-type density logging system.

2.1.4 Natural Gamma Ray Spectroscopy (NGS) Tool

The NGS tool is a passive gamma ray measuring sonde that can be used in either open or cased boreholes. The tool measures the natural gamma activity energy spectrum with two sodium-iodide crystal

detectors and uses a spectral weighted-least squares processing algorithm to resolve the three most common components of naturally occurring radiation—potassium, thorium, and uranium. The tool is designed for continuous logging and provides a depth/time averaged continuous log of the three elemental components in relative wt%. In addition, the standard gamma ray and gamma ray minus uranium are computed. The spectral gamma measurements are useful for evaluating clay content and clay type, especially when integrated with other types of log measurements.

Basic specifications for the NGS and a schematic diagram of the measurement sensor are shown below and in Figure 2.4, respectively.

Range of measurement:	GR	0 to >750 API units;
	K	0 to ~50%;
	Th	0 to ~10,000 ppm;
	U	0 to ~10,000 ppm
Statistical precision (σ):	Th–1.5 ppm; U–0.9 ppm; K–0.25%	
Min./Max. hole size:	4.5 in. / 24 in.	
Depth of Investigation:	9.5 in (24 cm)	

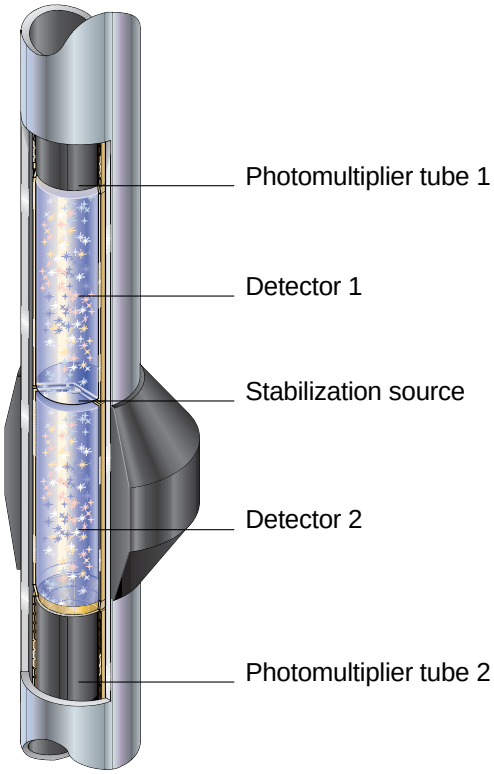


Figure 2.4. Schematic diagram of NGS sensor

2.1.5 Elemental Capture Spectrometer (ECS)

The ECS geophysical logging tool provides accurate measurements of the relative weight % concentrations of specific elements in the formation (such as Si, Ca, Fe, S, Ti, and Gd). The measurements have sensitivities as low as 1% dry weight concentration or less (dependent on which element and the logging speed).

The ECS actively emits a large flux of neutrons into the region surrounding the probe using a 16-Ci Americium-Beryllium chemical neutron source. The neutrons collide and interact with atomic nuclei, prompting the release of gamma rays having characteristic energies, depending on the specific element and type of interaction. These induced gamma rays are measured by the tool's scintillation gamma ray detector, resulting in a total gamma energy spectrum measurement when the sum of gamma rays generated from all neutron-element interactions is considered. A weighted least squares algorithm is used to decompose the gamma ray contributions from specific elements based on a known detector

spectral response, or standard, for each important constituent. The relative spectral contribution of the elements, or relative elemental yields, are converted to relative elemental dry weight % based on measurement characteristics of the tool type and an assumed mineralogical assemblage (oxide closure model).

The ECS employs a large shielded BGO spectral gamma ray detector that has very good measurement statistics. Because of the large detector, the ECS has a 5 in (127 mm) diameter.

The ECS works in either open or cased hole, and is relatively insensitive to borehole conditions, since the measurement is a dry matrix measurement (fluid contributions to the measurement are removed in the standard processing) and the radius of investigation is about 1 ft (30 cm). Thus, the ECS provides robust direct concentration measurements of important mineral-forming elements and provides robust mineralogical/lithologic control, very useful for developing a continuous mineralogy model along the borehole section when integrated with other wireline logs and core analysis results.

The statistical precision of the ECS measurement, for the standard suite of elements it measures, is shown in Table 2.2.

Table 2.2
ECS elemental weight % statistical precision at 100 ft/hr (30 m/hr) logging speed and 1.5 ft (0.46 m) depth average

Element	Weight % Precision (1 σ)
Si	0.63
Fe	0.07
S	0.27
Ca	0.57
Ti	0.03
Gd (ppm)	0.65
H	0.12

2.1.6 Array Induction Tool, Version H (AITH)

The AITH is a focused electrical induction probe that measures electrical conductivity/resistivity at multiple depths of investigation and vertical resolutions. The measurement is made by emitting an electromagnetic field that induces a current in the formation, subsequently creating a secondary electromagnetic field that is measured by the tool. The tool measures R- and X-signals from eight arrays, six of which operate at two frequencies simultaneously. The surface acquisition unit processes these raw measurements into five resistivity logs in real-time, each with matched vertical resolution and with median depths of investigation ranging from 10 to 90 in (25–230 cm). These depths of investigation change minimally over the entire range of formation conductivities. Each set of five logs is available in vertical resolution widths of 4, 2, and 1 ft (120, 60 and 30.5 cm).

From these measurements the AITH provides quantitative estimates of the following.

- True bulk formation resistivity–Formation resistivity is a function of water content, water salinity, and clay content.
- Drilling fluid invasion–In instances where the borehole fluid and formation fluid possess contrasting conductivity values, the depth of invasion of filtrate can be mapped and the zones with higher permeability can be identified.

The results are also useful for stratigraphic correlation. Vertical resolutions down to 1 ft (30.5 cm) show laminations and other formation structures with minimal environmental effects.

Since a current is not directly emitted into the formation, the measurement does not require water in the borehole and is accurate in the sub-saturated zone above the water table.

The AITH is largely insensitive to borehole environmental conditions since it has a deep depth of investigation.

Basic measurement specifications for the AITH are shown below and a schematic diagram of the basic tool setup in Figure 2.5.

Range of measurement:	0.2–2000 Ohm.m
Total measurement error:	2% of measurement
Min/Max. hole size:	4.75 in./20 in.
Vertical Resolution:	1 ft (30.5 cm), 2 ft (61 cm), 4 ft (122 cm)
Depth of Investigation:	10, 20, 30, 60 and 90 in. (median response) (25, 51, 76, 153, and 229 cm)

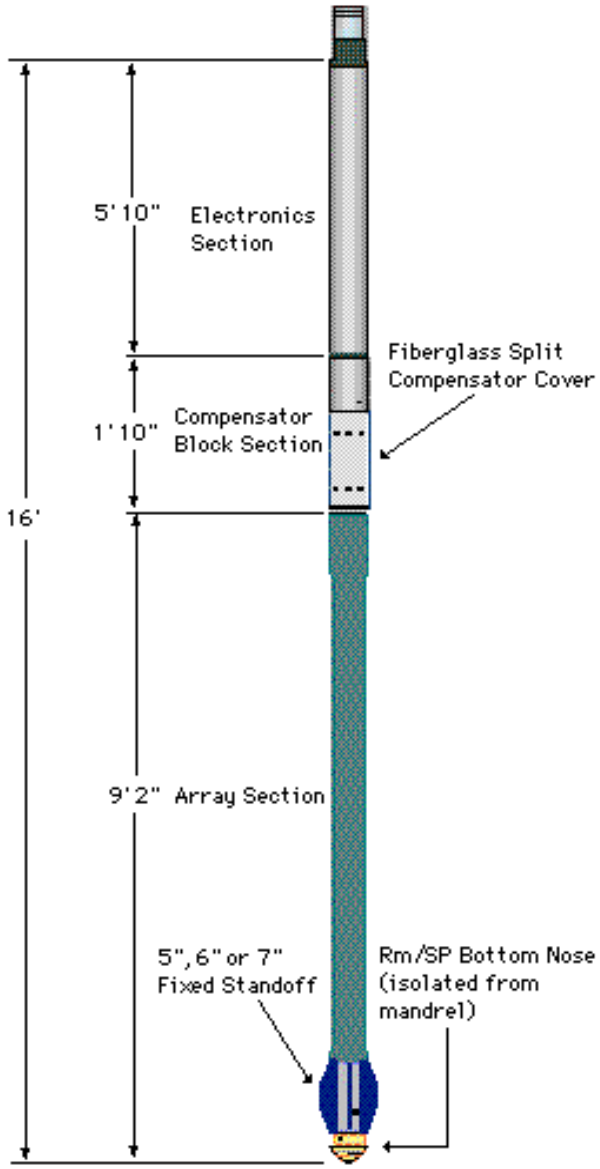


Figure 2.5. Schematic diagram of AIT tool, showing component lengths and standard logging setup.

3.0 METHODOLOGY

This section describes the methods employed by Schlumberger for performed geophysical logging services in Well R-14, including the following stages/tasks:

- Measurement acquisition at the well site
- Quality assessment of logs
- Reprocessing of field data

3.1 Acquisition procedure

Once the well drilling project team notified Schlumberger that each well was ready for geophysical well logging, the Schlumberger district in Farmington, NM, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Upon arriving at the LANL site, the crew completed site entry paperwork and received site-specific safety training.

After arriving at the well site, the crew proceeded to rig up the wireline logging system, including

1. parking and stabilizing the logging truck in a position relative to the borehole that is best for performing the surveys;
2. performing any required environmental protection procedures (e.g., covering the ground with plastic liner, where the tools will be assembled, and around the well) as specified in the work order;
3. setting up a lower and an upper sheave wheel (the latter attached to, and hanging above, the borehole from the drilling rig/mast truck);
4. threading the wireline cable through the sheaves; and
5. attaching the appropriate sonde(s) for the first run to the end of the cable.

Next, pre-logging checks and any required calibrations were performed on the logging sondes and the tool string was lowered into the borehole. If any of the tools required active radioactive sources (in this case a neutron and gamma source for the CNTG/ECS and TLD, respectively) just prior to lowering the tool string, the sources were taken out of their carrying shields and placed in the appropriate tool source-holding locations using special source handling tools. The tool string was lowered to the bottom of the borehole and brought up at the appropriate logging speed as measurements were made. At least two logging runs (one main and one repeat) were made with each tool string.

Upon reaching the surface any radioactive sources were removed from the tools and returned to their appropriate storage shields, thus eliminating any radiation hazards. The tool string was cleaned as it was pulled out of the hole.

The second tool string was attached to the cable for another suite of logging runs.

After completion of the surveys, any post-logging measurement checks were performed. Before departure, the engineer printed the field logs (including calibration summaries) for on site distribution and sent the data via satellite to the Schlumberger data archiving center in Sedalia, CO. The Schlumberger data processing center was alerted that the data were ready for initial post-acquisition processing.

3.2 Log Quality Control and Assessment

Schlumberger has a thorough set of procedures and protocols for ensuring that the geophysical logging measurements are of very high quality. This includes careful calibration of tools when they are first built, regular recalibrations and tool measurement/maintenance checks, and real-time monitoring of log quality as measurements are made. Indeed, one of the primary responsibilities of the logging engineer is to ensure, before and during acquisition, that the log measurements meet prescribed quality criteria.

CNTG

The calibration and verification methodology for the CNTG consists of an initial base calibration and verification, monthly shop verification, and a wellsite before and after verification. The initial base calibration constitutes the development of a measurement to moisture content algorithm for a certain set of environmental conditions. The calibration is based on Monte Carlo computer modeling and measurements in the Schlumberger EECF calibration models in Houston, TX. This initial base calibration only has to be performed once for a certain set of conditions.

Schlumberger also performs what is called a “master calibration,” which is actually a verification of water-filled borehole conditions where the CNTG measurements are checked in a water tank with known saturated porosity. In addition, detector and neutron generator electronics are checked, and detector plateau voltages are set.

Detector electronics verifications are also performed before and after every logging run of the CNTG, constituting the well site before and after verifications.

NGS

The Schlumberger calibration and verification methodology for the NGS, similar to the CNTG, consists of an initial base calibration and verification, routine shop verification, and a wellsite before and after verification. The initial base calibration constitutes the development of measurement to gross gamma activity and spectral gamma activity algorithms, accounting for environmental conditions that influence the measurements. The initial base calibration only has to be performed once for a certain set of conditions.

The NGS gross gamma measurement in API units is made by taking a linear combination of U, Th, and K gamma activity yields to determine total count rates and then converting total count rates to API units. The coefficients of the linear combination and the API conversion are determined from the NGS response in the API test pits at the University of Houston (the API calibration standard) and calibration facilities at the Schlumberger Environmental Effects Calibration Facility (EECF) in Houston, which are tied to the API test pits.

In order to calibrate the spectral gamma activity measurements the response function of the NGS to each radioactive isotope of interest must be determined. The response function is the spectrum that would be observed by the tool for a given detector resolution and gain if just the one element were present and evenly distributed in the formation in a certain concentration. Such a spectrum is called a spectral standard. For natural gamma ray logging Th, U and K standards are used. Test formations with known concentrations of radionuclides at the API test pits and EECF are used to determine the NGS spectral standards.

The routine shop verification, referred to as a “master calibration” by Schlumberger, consists of measuring the NGS response to a thorium blanket with known Th activity and a background check. During the background check the detector response to an internal 22Na stabilization source is measured. In addition, detector electronics checks are performed. The primary task of the shop verification is to set the electronic gain ratios properly so that the Th and 22Na gamma peaks occur at the correct energy levels.

NGS response to the stabilization source and detector electronics verifications are also performed before and after every logging run of the NGS, constituting the wellsite before and after verifications.

ECS

The Schlumberger calibration and verification methodology for the ECS, similar to the NGS, consists of an initial base calibration and verification, routine shop verification, and a well site before and after verification. The initial base calibration constitutes the development of gamma ray energy elemental spectral standards for each of the elements the tool measures, accounting for environmental and tool design-specific conditions that influence the measurements. The initial base calibration only has to be performed once for all ECS tools produced to develop a tool response catalog for individual elements that the ECS is sensitive to.

The routine shop verification consists of taking measurements in a specially designed water tank to verify correct identification of the spectral hydrogen peak and performing detector electronic gain checks using the small cesium internal check source.

Well site before and after checks consist of background internal electronic checks.

TLD

Similar to the CNTG and NGS, the calibration and verification methodology for the TLD consists of an initial base calibration and verification, monthly shop verification, and a well site before and after verification. The initial base calibration constitutes the development of a measurement to bulk density algorithm for a certain set of environmental conditions. The calibration is based on Monte Carlo computer modeling and measurements in the Schlumberger EECF calibration models. This initial base calibration only has to be performed once for a certain set of conditions.

The routine shop verification consists of checking the TLD bulk density measurement for uncased borehole conditions by making the measurement in materials with known densities. In addition, a background check with the gamma source removed from the tool is performed to verify that the system response to the 622 keV ^{137}Cs stabilization source located on each of the two detectors is accurate.

The background check is also performed before and after every logging run of the TLD, constituting the well site before and after verifications.

AITH

The Schlumberger calibration and verification methodology for the AITH consists of an initial base calibration and verification, routine shop verification, and a well site before and after electronics verification. The initial base calibration constitutes the determination of electronic gains and offsets and hardware adjustments for each individual tool so that the tool electrical induction response can be used to generate accurate electrical resistivity measurements. The initial base calibration has to be performed only once for all AITH tools produced to develop a tool specific response catalog for electronic gains and offsets.

The routine shop verification consists of taking measurements with specially designed calibration sleeves to verify correct measurement response as well as internal electronic gain checks.

Well site before and after checks consist of internal electronic checks.

CMR

After an initial base calibration and intensive measurement and electronic system checks performed at the time of tool production, the CMR calibration and verification methodology consists of a routine shop (or master) calibration and well site before and after survey calibration/verification.

The shop calibration consists of a one-point calibration in which the signal amplitude at 100% water-filled porosity is found by placing a calibration jig filled with water in front of the tool sensor section. In addition, an electronic calibration of system gain is performed using an internal test loop located on the tool's antenna. The measured amplitude and electronic gain are saved as a lookup table in the internal memory of the individual CMR tool to be used when logging in the field for the calculation of CMR porosities.

The well site before survey calibration covers two procedures for tuning the sensor antenna to the magnetic resonance frequency of water (known as the Larmor Frequency), performed at the surface and downhole in the vicinity of the logging interval. This tuning procedure compensates the sensor response for the well specific effects of pressure, temperature, and metallic debris in the hole. In addition, a check of system noise is made.

At the completion of the CMR logging, one of the tuning procedures is repeated: the system search for the Larmor Frequency to verify that the log was run "in tune." This procedure constitutes the well site after survey verification.

3.3 Processing Procedure

After the geophysical logging job was completed in the field and the data archived, the data were downloaded to the Schlumberger processing center. There the data were processed, in the stated order to (1) correct the measurements for near-wellbore environmental conditions and redo the raw measurement field processing for certain tools using better processing algorithms, (2) depth match and merge the log curves from different logging runs, and (3) model the near-wellbore substrate lithology/mineralogy and pore fluids through integrated log analysis. Afterwards an integrated log montage was built to combine and compile all the processed log results.

Environmental Corrections and Raw Measurement Reprocessing

If required, the field log measurements were processed to correct for conditions in the well, including fluid type (water or air), presence of steel casing, and (to a much lesser extent) pressure and temperature. Basically these environmental corrections entail subtracting from the measurement response the known influences of the set of prescribed borehole conditions. In R-14 the log measurements requiring these corrections are the CNTG porosity and NGS spectral gamma ray logs.

The CNTG epithermal neutron moisture content measurement in air-filled hole is derived using an entirely different processing algorithm than applied in water-filled hole; this processing is performed in the field.

The NGS spectral gamma ray are affected by the material (fluid, air, casing) in the borehole because different types and amounts of these materials have different gamma ray shielding properties; the NGS measures incoming gamma rays emitted by radioactive elements in the formation surrounding the borehole. The processing algorithms try to correct for the damping influence (or lack thereof) of the borehole material.

The measurements cannot be corrected for borehole washouts, rugosity, and the annulus material (if any) between casing and the formation; thus, the effects of these conditions should be accounted for in the interpretation of the log results.

Depth-Matching

Once the logs were environmentally corrected for the conditions in the wellbore and the raw measurement reprocessing was completed, the logs from different logging runs were depth-matched to each other using the AIT tool run as the base reference. Gamma ray was used as the common correlation log measurement for depth-matching the different runs.

Integrated Log Analysis

This analysis was performed using the Elemental Log Analysis (ELAN*) program. ELAN is a petrophysical interpretation program (Mayer and Sibbit, 1980; Quieren et al, 1986) designed for quantitative formation evaluation of cased and open-hole logs level by level. Evaluation is done by optimizing simultaneous equations described by one or more interpretation models.

The primary purpose of ELAN is solving the inverse problem in which log measurements, or tools, and response parameters are used together in response equations to compute volumetric results for formation components. This relationship is often presented in the triangular diagram below (Figure 3.1).

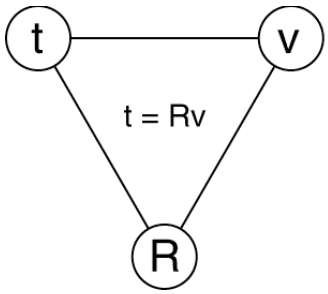


Figure 3.1. Schematic diagram of ELAN mathematical model

In this figure, t represents the tool vector—all logging instrument data and synthetic curves. The v is the volume vector, the volumes of formation components. R is the response matrix, containing the parameter values for what each tool would read, given 100% of each formation component. Given the data represented by any two corners of the triangle, ELAN can determine the third.

Additionally, ELAN includes methods by which individual models can be mixed and spliced to provide a combined model for more complex environments and large borehole extents. Each individual model is specified in a separate “Solve” process. The final result is produced by mixing and splicing the results from individual models in a “Combine” process.

The quality of the ELAN results can be assessed by reconstructing the individual geophysical logging curves from the solution and comparing them to the original data. However, a “good” fit does not

* Mark of Schlumberger

necessarily mean the correct ELAN, as the answer is non-unique. The degree of match between input and output curves is summarized as an error curve.

ELAN requires an a priori specification of the volume components present within the formation—fluids, minerals, and rocks. For each component, the relevant parameters for each tool are also required. For example, if one assumes that quartz is a volume component and the bulk density tool is used, then the bulk density parameter for this mineral is usually assumed to be 2.65 g/cc.

A key point in properly using ELAN is the input of the most representative parameter values possible. For certain minerals (e.g., quartz) most parameter values are fairly constant and easy to select; other mineral (e.g., clays) present the potential for wide variability in many parameters due to compaction (sonic slowness, bulk density) and minor changes in chemistry (Th, K, Fe, Al, H). Estimation of parameters, or their changes with depth, can be a major limitation to ELAN. Geochemical logs (acquired in R-14) are particularly helpful measurements for ELAN since they provide abundances of a number of important mineral forming elements.

ELAN simultaneously solves for multiple volume components using different tools. Some tools are highly influenced by parameters other than mineralogy and pore fluid (e.g., sonic), including geomechanical properties and borehole environmental conditions that cannot be corrected for in pre-processing. The dependency of the tool measurements on these conditions depends on the specific tool type and measurement. Including log measurements that are being highly influenced by these properties in the ELAN can significantly affect the solution, since variations in the logs are not only due to changes in mineralogy or pore fluid—what ELAN is trying to estimate. For example, if some of the logs are sensitive to washouts ELAN will try to match the log response in washed out zones by increasing the amount of porosity in the model, possibly at the expense of matching other log measurements used in the analysis that are not as sensitive to washouts (although the latter can be rectified by assigning more weight to the better logs). If some of the logs are affected by borehole conditions, or other properties not explicitly accounted for in the model (e.g. formation water salinity), while the others are not, often there is a poor match between modeled and actual log measurements in intervals where there are variations in these unaccounted for properties. Sometimes the solution can also become unstable—the model results change significantly due to only minor variations in log responses. In such cases it may be better to not include such measurements in the ELAN. In short, ELAN results are only as accurate at depicting true formation mineralogy and fluid content as the input logs are sensitive to the formation components included in the model—and insensitive to components/properties not included.

The tool measurements, volume components and parameters used in the ELAN analysis for R-14 are provided in Table 3.1. To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (13–1066 ft.), as many as possible of the processed logs were included in the analysis, with less weighting applied to less robust logs. Not all the tool measurements shown in these tables are used for the entire interval analyzed, as not all the measurements are available, or of good quality, across certain sections of the borehole.

The ELAN analysis was performed with as few constraints or prior assumptions as possible. A considerable effort was made to choose a set of minerals or mineral types for the model that is representative of Los Alamos area's geology and it's volcanic origins. No prior assumption is made about water saturation—where the boundary between saturated (if any) and unsaturated zones lies (e.g. the depth to the top of the regional aquifer or perched zones). Thus, the presence and amount of air in the pore space is unconstrained. Total porosity and water-filled porosity are also left unconstrained throughout the analysis interval. It was felt that the ELAN analysis should be performed with as few constraints as possible—even though the resulting model may show the effects of washouts and drilling

foam invasion (as elevated porosity and water content)—in order to guard against presumptions that the results are conclusive when in fact they may not be. Thus, interpretations should be made from the ELAN results with the understanding that the mineral-fluid model represents a mathematically optimized solution that is not necessarily a physically accurate representation of the native geologic formation, although in R-14 the results appear very well behaved. Within this context, the ELAN model is a robust estimate of the bulk mineral-fluid composition that accounts for the combined response from all the geophysical measurements.

Table 3.1
Tool measurements, volumes, and respective parameters used in the R-14 ELAN analysis .

Volume / Tool Measurement	Air	Capillary Bound Water	Water	Hornblende	Hypersthene	Labradorite	Silica Glass	Heavy Mafic Minerals	Augite	Montmorillinite	Pyrite	Orthoclase	Quartz
Bulk density (g/cc)	–0.19	1.00	1.00	3.11	3.55	2.65	2.2	4.0	3.08	2.02	4.99	2.58	2.64
Epithermal neutron porosity (ft^3/ ft^3)	-0.02	1.00	1.00	0.05	0.01	-0.01	0.0	0.02	-0.01	0.6	0.17	-0.01	0.0
Volumetric photoelectric effect	0	0	0.40	12	20.2	7	4.2	65.00	23.8	4.4	82.1	7.3	4.8
Total CMR water-filled porosity (ft^3/ ft^3)	0	1.0	1.0	0	0	0	0	0	0	0.425	0	0	0
CMR free fluid volume (ft^3/ ft^3)	0	0	1.0	0	0	0	0	0	0	0	0	0	0
Resistivity (ohm-m)	Very high	30	30	Very high	Very high	Very high	Very high	Very high	Very high	1.04	Very high	Very high	Very high
Dry weight silicon (lbf / lbf)	0.0	0.0	0.0	0.21	0.24	0.24	0.47	0.18	0.23	0.26	0	0.3	0.47
Dry weight calcium (lbf / lbf)	0.0	0.0	0.0	0.09	0.0	0.09	0.0	0.0	0.10	0.01	0.0	0.0	0.0
Dry weight iron (lbf / lbf)	0.0	0.0	0.0	0.07	0.20	0.0	0.0	0.22	0.11	0.02	0.47	0.0	0.0
Dry weight sulfur (lbf / lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.53	0.0	0.0
Dry weight titanium (lbf / lbf)	0.0	0.0	0.0	0.005	0.01	0.0	0.0	0.0	0.048	0.0	0.0	0.0	0.0
Wet weight potassium (lbf / lbf)	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.003	0.005	0.0	0.102	0.0
Weight water (lbf / lbf)	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.18	0.0	0.0	0.0
Wet weight thorium (ppm)	0.0	0.0	0.0	50	25	3	2	4	20	24	0	5.5	2

4.0 RESULTS

This section describes the final log results from the borehole geophysical logging performed by Schlumberger in R-14. These results have been processed, if required, to correct for the well environment and depth-match the logs from different tool runs in the well. Also, some of the results are not directly measured logs but are instead logs generated from integrated analysis of measured logs. In the following description of the results, an attempt is made to organize the discussion based on the evaluation needs addressed by the logs instead of describing each log independently.

The log results are presented as continuous curves of the processed measurement versus depth and are displayed as (1) summary log displays for selected directly related sets of measurements and (2) an integrated log montage that contains all the final log curves, on depth and side by side. The summary log displays address specific characterization needs, such as moisture content. The purpose of the integrated log montage is to present, side by side, all the most salient reprocessed logs and log-derived models, depth-matched to each other, so that correlations and relationships between the logs can be identified.

First the R-14 final processed log results are presented as a number of useful summary logs and described according to specific evaluation needs addressed by the geophysical logs. Next, the integrated log montage is described track by track.

4.1 Water-Filled Porosity

One of the primary objectives of the geophysical logging was to evaluate volumetric water content (water-filled porosity) to identify wet and porous water-producing zones. The CNTG neutron porosity, which measures water content in both open and cased hole above and below the borehole water level, was the primary service run for this purpose. The CMR was run to measure the water-filled pore size distribution and, most importantly, the amount of moveable water (effective water-filled porosity), which, in turn, provides valuable information on formation flow capacity (hydraulic conductivity). The TLD bulk density measurement provides useful information about total porosity—the sum of water-filled and air-filled porosity. The ECS geochemical measurement provides secondary information on water content through non-standard processing to obtain hydrogen weight fraction. In Well R-14 the CNTG neutron porosity and ECS hydrogen weight fraction appear to be adversely impacted by drilling foam that was present in the well at the time of logging, especially concentrated in the bottom section—yielding unrealistically high water content values across much of the logged interval. While standing water in the borehole has a large affect on these measurements, it is easily corrected for. The problem with the drilling foam is that it varies somewhere between air and water with regards to how the measurements respond and, thus, cannot be quantitatively corrected for. The CMR and TLD measurements are much less impacted by the foam filling the borehole because they are pad type tools that is pushed against the formation; however, they are shallow reading measurements and could be affected by invasion of the foam—whether it acts to wet or dry the near wellbore formation. It appears the CMR and TLD measurements are of good quality and not significantly affected by drilling foam invasion.

The best estimate of true formation water content is obtained from the ELAN integrated log analysis, since none of these measurements actually directly measures volumetric water content. This analysis accounts for the individual measurement response to each matrix and pore volume constituent, as well as the relative uncertainty in the measurements, in solving for a single matrix-pore volume model at each depth that best accounts for the processed measurements results. To account for the erroneous CNTG neutron porosity and ECS hydrogen weight fraction values discussed above much greater weight was given to the CMR total water-filled porosity in the R-14 ELAN analysis.

The ELAN water-filled porosity results for R-14 are shown as part of the summary logs in Figure 4.1 (solid dark blue curve and blue shading in the second track from the right), and in expanded form, as part of the integrated log montage provided in Appendix E of the LANL R-14 Completion Report (compressed form shown in Figure 4.4). The summary log also displays

- ELAN moveable water volume fraction, or “effective porosity” (solid cyan curve and cyan shading in second track from right);
- ELAN bound water volume fraction (dotted blue shading in second track from right);
- ELAN total (water- and air-filled) porosity (red hashed curve in second track from right);
- Air-filled porosity (dotted red shading in second track from right);
- ELAN water saturation (dotted light blue curve in second track from right);
- CMR estimated tapered Timur-Coates equation hydraulic conductivity (solid blue curve and blue shading in first track from right);
- Gross gamma ray (solid brown curve in first track from left); and
- Caliper with measured washouts (dashed black curve with washouts shown by pink shading).

There was no standing water in R-14 at the time of the June 2002 geophysical logging, although there was concentrated wet drilling foam below 987 ft. There is uncertainty in determining whether 100% saturation of the virgin geologic formation occurs from the geophysical logs (corresponding to conditions within the regional aquifer or in perched zones above, where the entire pore space is filled with water)—due to the unknown effects of the drilling foam on the formation directly adjacent to the borehole and, ultimately, the log measurements. Even without such borehole conditions, the water saturation estimate from the geophysical logs is very sensitive to the matrix grain density. However, the processed log results do indicate well below full water saturation (mostly below 75%) across the entire depth section. These results, interpreted by themselves, suggest that the regional aquifer groundwater level lies below the bottom of the log interval (1068 ft) and that there are no significant perched water zones.

There are a few zones below 700 ft where the processed log results sporadically peak at or near 100% water saturation: 720–727 ft, 731–736 ft, 952 ft, 991 ft, 997 ft, 1032 ft. These increases in water saturation are surrounded by much lower water saturation (less than 60%) and, in the case of the two upper zones, are located within an interval containing very low total porosity and relatively constant water content—the high water saturation results from small fluctuations in air content. None of these zones clearly exhibit perched water and likely would not produce water. They could be very tight zones that are saturated, but do not flow, or simply the result of the uncertainty in the total and water-filled porosity estimates from the logs.

Other significant features of the R-14 porosity summary log are as follows:

- Below 535 ft, zones with highest water content:
  - 976–998 ft with a peak of 35%
  - 1060–1066 ft (bottom of hole) with a peak of 25%
- Below 535 ft, zones with higher total porosity and lower water saturation:
  - 540–614 ft
  - 782–890 ft

    - A thin zone of extremely high total porosity (70%) and relatively high water content (30%) from 524–535 ft. The zone also has a high moveable water content (20%) and estimated hydraulic conductivity. The zone is underlain by a thin clay bed that likely acts as a barrier to downward flow. Based on the spectral gamma ray and geochemical log response, the ELAN analysis, and experience from the log results in other wells, this zone likely corresponds to the bottom of the tuff/pumice sequence that is prevalent throughout the Los Alamos area—specifically probably the Guaje Pumice Bed.
- A thick section of high total porosity (45–55%) from 80–524 ft, likely corresponding to a tuff/pumice sequence. This section contains several interesting features, including:
    - 248–524 ft: slowly and consistently increasing water content, moveable water, and hydraulic conductivity
    - 218–248 ft: sharp increase in water content, moveable water, and hydraulic conductivity associated with a decrease in total porosity and the presence of two thin clay beds
    - 80–218 ft: slowly and consistently increasing water content, moveable water, and hydraulic conductivity
- Slightly higher water content (average 10%) and lower total porosity (35-40%), relative to the section immediately below, at the top of the borehole (13–80 ft).

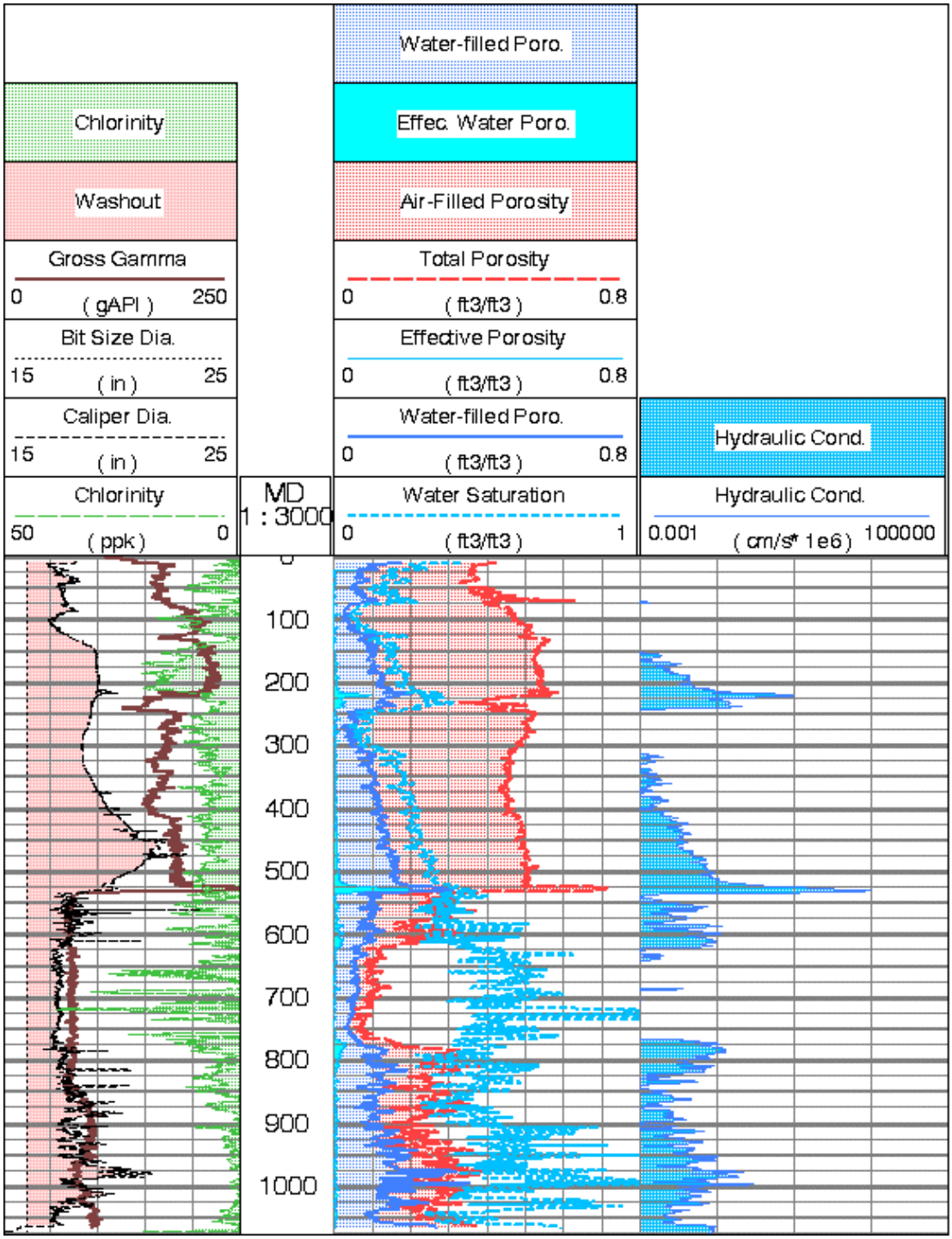


Figure 4.1. Summary porosity logs in R-14 borehole from processed geophysical logs, interval 13–1066 ft, with caliper, gross gamma, apparent chlorinity, water saturation, and hydraulic conductivity logs. Porosity and water saturation logs are derived from the ELAN integrated log analysis.

4.2 Density

Bulk density and P_e log measurements, obtained from the TLD geophysical tool in R-14, provide information about the formation total porosity (water and air) and lithology, respectively. The bulk density is the only measurement in the suite of logs run in R-14 (and most geophysical log measurements) that is directly sensitive to all formation components: air-filled porosity, water-filled porosity, and rock matrix. Total air plus water-filled porosity in the vadose zone can be estimated from density porosity when it is computed in conjunction with a water content measurement (e.g., neutron porosity or CMR total water-filled porosity) and an independent measurement/assumption of grain density. The processed bulk density and P_e curves (the latter referred to as "Pef" for photoelectric effect), as well as the apparent grain density derived from the ELAN analysis, are displayed as part of the summary logs (third track from left) for R-14 in Figure 4.2. Other applicable curves in the summary log are gross gamma ray (for stratigraphic correlation) and caliper (for identifying borehole washouts), shown in the farthest left track.

The bulk density and P_e measurements have a shallow depth of investigation and, thus, the measurements can be severely affected by borehole washouts and standoff from the formation, that is, measuring water/air density and P_e instead of the formation. The bulk density measurement is made using three detectors; the tool tries to compensate for differences in the near and far detector response by performing an internal processing correction, which is shown on logs as a density correction curve, flagged when it goes above/below quality cutoff thresholds. This flag is used as an indication when the TLD measurement quality may be compromised. In R-14 all indications are that the bulk density and P_e measurements are of very good quality, reflecting the limited amount and severity of borehole washouts and rugosity at the time of logging, especially compared to most other Los Alamos wells logged by Schlumberger. The density correction is flagged in relatively few places (see density track–fifth track from left–on the integrated log montage, Appendix E of the LANL R-14 Completion Report or Figure 4.4). Even in most of the flagged zones the density and P_e measurements appear to be reasonable and consistent with the other geophysical log measurements, suggesting the measurements have properly corrected for environmental conditions within these zones, despite the rather large corrections.

Total porosity was computed from the ELAN integrated analysis of all the log measurements, including bulk density as a crucial input, as displayed in the first track from the right on the summary log (Figure 4.2) and the second track from the right on the integrated log montage (inclusive of the depth track). In this analysis no constraints were placed on air or water-filled porosity through the entire depth section. As can be seen on the summary logs, the ELAN total porosity mimics bulk density since bulk density is the primary measurement providing information on air-filled porosity. Overall, the total porosity appears to be valid throughout much of the depth section.

The P_e measurement is a good indicator of lithologic changes. In this geologic setting, an increase in P_e above 3 is a good indicator of the presence of heavy, probably mafic, minerals; an increase to 5 is an indicator of a very heavy mineral-rich bed ("heavy" most likely corresponding to iron), such as a massive basalt lava flow. P_e increases to consistently above 3 in the interval 535–882 ft; in the interval 882–1068 ft P_e intermittently reaches to just above 3. The optimized ELAN mineral model results (see the integrated log montage, fourth track from the right) indicate that this zone contains small amounts (less than 10% by weight) heavy, iron-rich mafic minerals (such as magnetite and olivine), with consistently higher concentrations in the upper interval and less consistent, lower concentrations in the lower interval. The upper interval is probably a basaltic lava flow(s), with a massive, low porosity section from 622–765 ft, surrounded by higher porosity sections, likely corresponding to more fractured, broken up basalt zones.

Above the high P_e zone is a low P_e interval, averaging just above 2.5, that extends to the surface casing: 10–534 ft. The bulk density is very low across this interval as well, resulting in a very high ELAN total

porosity. As mentioned in the previous section, this section likely corresponds to a tuff/pumice sequence, with large amounts of quartz, orthoclase, and hornblende in the ELAN mineral model results indicative of a silica-rich volcanic tuff deposit. The ELAN results also indicate varying amounts of montmorillonite, as high as 20 weight%, particularly in the intervals 45–135 ft and 222–303 ft.

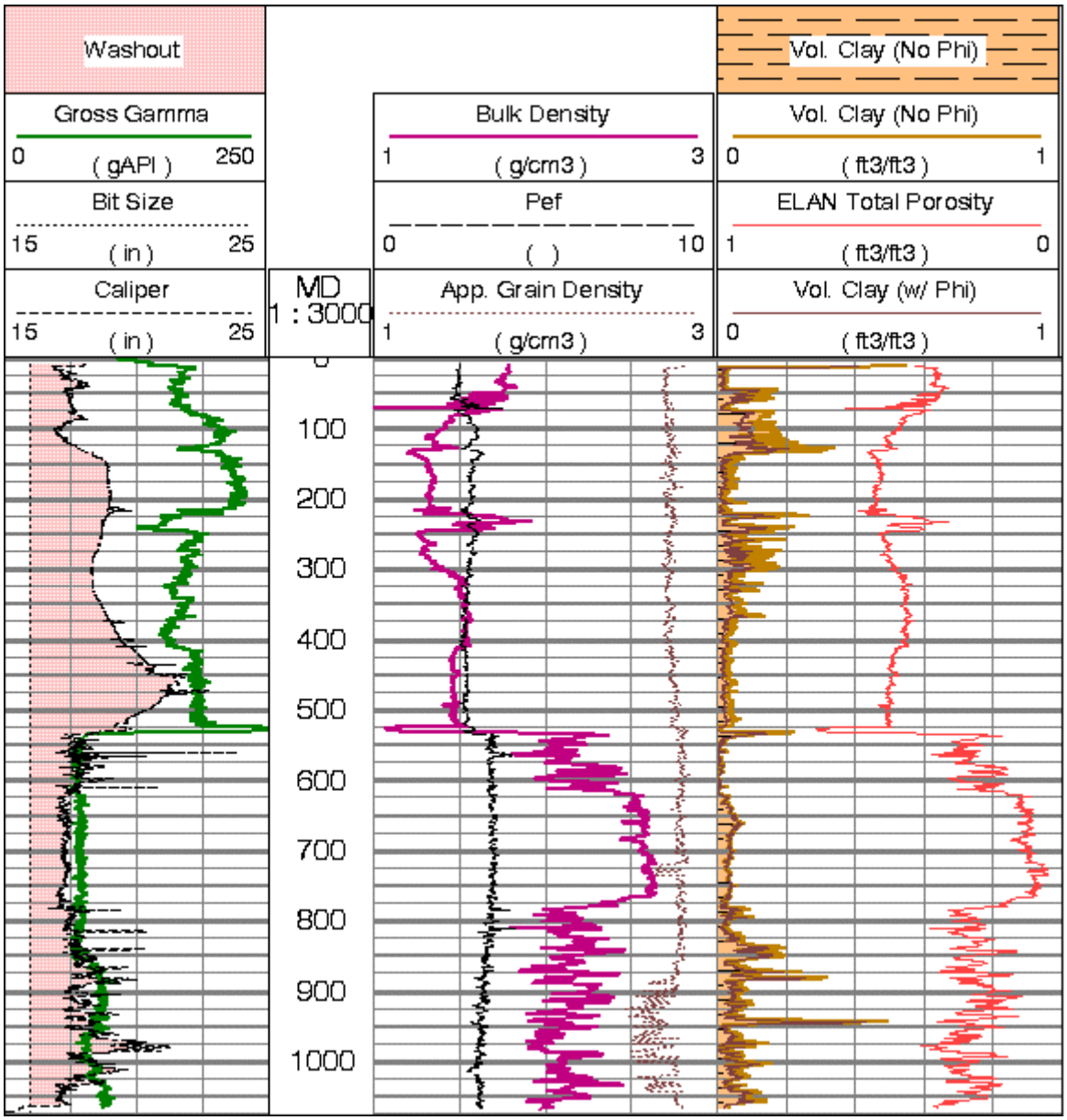


Figure 4.2. Summary bulk density and volume clay logs in R-14 borehole from processed geophysical logs, interval 28–764 ft. Also shown– caliper, gross gamma, apparent grain density, and total porosity logs.

4.3 Volume of Clay

Volume of clay is of interest particularly because clay can have a large influence on hydraulic conductivity as well as the groundwater geochemistry. Unfortunately, there is no way to directly measure volume of clay from geophysical logging. It can only be derived indirectly from other log measurements, preferably a combination of measurements. Of the logging services run in R-14, the one that provides the most information about clay content is the NGS spectral gamma ray, since thorium and potassium are often associated with clays. However, because of the complex geologic history of the Los Alamos area, including many periods of volcanic activity, the geologic section contains numerous minerals other than clays that produce similar spectral gamma (and gross gamma) responses. This fact greatly complicates the estimate of clay volume directly from gamma ray measurements. The ECS provides important information about the collection of all minerals present since it measures the concentration of a number of important mineral-forming elements. Unfortunately, it cannot directly measure aluminum—the most important clay-forming element—although an indirect geochemical-derived estimate of aluminum can be made that is valid in siliciclastic rocks. The P_e measurement from the TLD provides additional information about bulk mineralogy, since it is sensitive to changes in the atomic number of mineral-forming elements, but it doesn't provide any specific information about clay minerals. The AIT resistivity measurement is sensitive to clay since clay has a low bulk resistivity; however, the measurement is also sensitive to pore water salinity and porosity. In addition, the CMR measures clay-bound water, which can be considered an indirect indicator of clay.

Considering the above-mentioned circumstances, the most robust way to estimate clay volume from the geophysical logs is to use all the logs together to solve for the full mineral and fluid volumetric composition of the formation. This type of analysis constitutes an inverse problem and can be performed using the ELAN program. Clay volume, along with the remaining matrix and fluid volumes, was estimated using the ELAN integrated log analysis approach with a fairly comprehensive mineral/fluid model containing montmorillonite, silica glass/quartz, orthoclase (representative of alkali feldspars), labradorite (representative of plagioclase feldspars), hypersthene, hornblende, augite, an analog representative of heavy mafic minerals (such as magnetite and olivine), water, and air. This set of volume constituents was chosen to provide a representative cross-section of possible major minerals in the R-14 geologic environment.

The ELAN volume model result, as well as the dry wt% model result, is shown as part of the integrated log montage, provided in Appendix E of the LANL R-14 Completion Report (and in Figure 4.4 in compressed form).

The volume of clay derived from these ELAN results for R-14, presented both as (1) fraction of the total (matrix plus pore space) volume and (2) fraction of just the matrix volume (pore space subtracted out), are shown as part of the summary logs (farthest track to the right) in Figure 4.2. The analysis predicts at least minor amounts of clay (montmorillonite) throughout much of the logged section—never reaching more than 50% by volume and mostly staying at less than 10%. The highest clay content (50%) occurs as a sharp peak (thin bed) at 945 ft. In the bottom higher porosity zone (below 770 ft) there is also higher clay content in the interval 830–886 ft, peaking at 30%, but mostly less than 20%. The ELAN clay volume is very consistent at about 4% across the very low porosity zone 623–770 ft (which likely corresponds to a massive basalt). In the higher porosity interval above this zone that is still within the basalt (540–623 ft) the ELAN results indicate very low clay content. At the top of this zone, and immediately below the very high porosity zone that likely corresponds to the Guaje Pumice Bed, there is a thin zone with higher clay content (20%) from 532–538 ft. This interpreted thin clay is characteristic of many of the Los Alamos wells logged by Schlumberger and likely acts as an inhibitor to download flow, as indicated by high water content directly above the bed. Above this depth, which likely corresponds to a tuff sequence, there are

two broad zones (45–135 ft and 222–303 ft) containing higher clay content, peaking at 30%, but mostly less than 20%.

4.4 Spectral Natural Gamma Ray

Natural gamma ray spectroscopy logs were acquired in R-14 for the purpose of

- identifying geologic/lithologic layer boundaries,
- correlating geologic/lithologic units with other wells, and
- helping in the evaluation of mineralogy, including clay content.

The processed spectral gamma log results are shown as summary logs in Figure 4.3 and in expanded form as part of the integrated log montage in Appendix E of the LANL R-14 Completion Report (shown compressed in Figure 4.4). On the summary log, gross gamma and gross gamma minus the uranium contribution are displayed in the first track (from left), useful radioisotope ratios are displayed in the third track, and the individual radioisotope concentrations–potassium (K), thorium (Th), and uranium (U)–are displayed in the fourth track.

The NGS spectral gamma measurements are of good quality throughout the log interval, valid for the purpose of interpretation. The raw field measurements were preprocessed to correct for borehole environmental conditions–mainly the lack of water in the well. The K and Th spectral components were used as valuable input to the ELAN analysis in R-14. If possible, it is not recommended to use U as an input to the ELAN model, because it can vary significantly for a particular mineral component due to independent processes (e.g. water flow, geochemical conditions); U was not used in the R-14 ELAN.

The R-14 spectral gamma ray logs have a number of distinct characteristics, which are described below:

- Overall across the logged interval there are two zones with a boundary at 535 ft that exhibit very different K, Th, and U characteristics.
    - The lower zone, likely corresponding to lava flow (mostly basalt) sequence based on the ELAN analysis results, has lower concentrations of the three elements (1.57 to 3.0 wet weight% K, 4 to 11 ppm Th, and 1 to 2.2 ppm U) and lower Th/K and U/K ratios (2 to 4 and 0.3 to 1, respectively).
    - The upper zone, likely corresponding to a tuff/pumice sequence, has ranges of 2.8 to 4.5 wet weight% K, 12 to 30 ppm Th, 3 to 12 ppm U, 2.5 to 9 for Th/K, and 0.7 to 4 U/K.
- A distinct peak in gross gamma, Th, U, and Th/K across the zone 524–534 ft, which likely corresponds to the bottom of the thick Bandelier Tuff sequence, delineating the Guaje Pumice Bed.
- A zone with lower K concentrations (1.75 wet weight%) from 960–1030 ft that also has higher total and water-filled porosity and higher hydraulic conductivity.

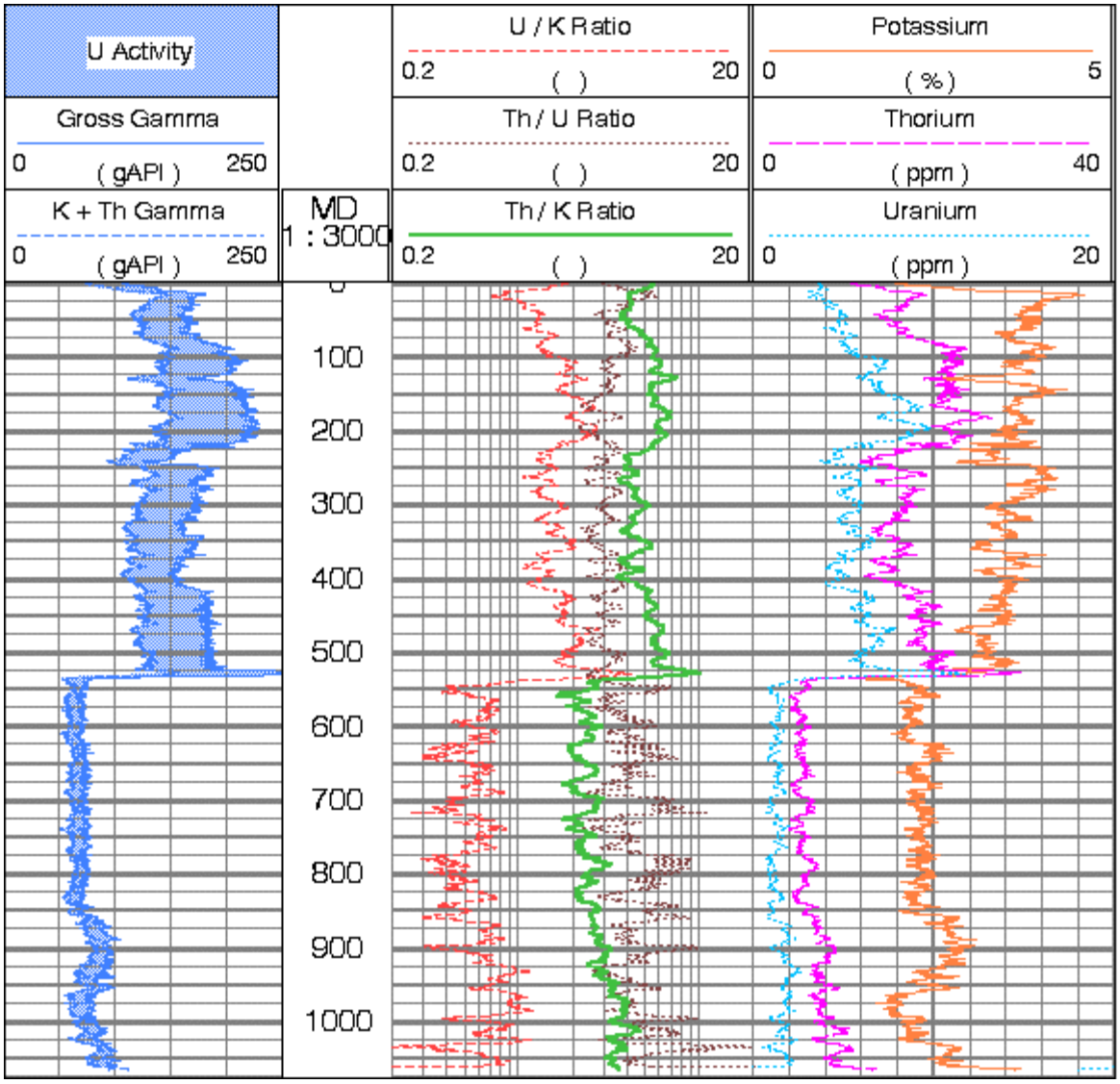


Figure 4.3. Summary spectral natural gamma ray logs from R-14 borehole, interval 28-764 ft

4.5 Integrated Log Montage

This section describes the integrated geophysical log montage for R-14: It includes a discussion of (1) what each log curve represents and how it was derived and (2) what are some of the most notable features in the displayed logs. The montage is provided in Appendix E of the LANL R-14 Completion Report and is shown compressed in Figure 4.4. A description of each log curve in the montage follows—organized under the heading of each track, starting from track 1 on the left-hand side of the montage. Note that the descriptions in this section focus on what the curves are and how they are displayed; the specific characteristics and interpretations of the R-14 geophysical logs are provided in the previous section.

Track 1–Depth

The first track on the left contains the depth below ground surface in units of feet, as measured by the geophysical logging system during the AITH logging run. All the geophysical logs are depth-matched to the gross gamma measurement run with the AITH.

Track 2–Basic Logs

The second track on the left (inclusive of the depth track) presents basic curves:

- gamma ray (thick black), recorded in API units and displayed on a scale of 0 to 250 API units;
- caliper (thin solid black) with bit size as a reference (dashed black) to show washout (pink shading), recorded in inches and displayed on a scale of 12 to 22 in;
- bulk chlorinity (dashed green with green shading), recorded in parts per thousand (ppk) and displayed on a scale of 50 to 0 ppk (left to right).

Two gamma ray curves from the NGS are presented:

- total gross gamma (thick solid black curve) and
- gross gamma minus the contribution of uranium (dashed black).

Gross gamma measurements are sensitive to radioactive elements in the near wellbore environment, which are potassium, thorium, and uranium—assuming the gamma activity is from naturally occurring sources. The response of the gross gamma curves is the result of the formation chemical makeup, including lithology/mineralogy. The gross gamma curve from the NGS is depth-matched to the gamma ray measurement from the AITH tool run.

The caliper curve is from the TLD tool, the single arm that is used to press the tool sensor against the borehole wall. It has been depth-matched to the AITH tool run using gross gamma ray as a reference. The caliper shows a significant amount of borehole enlargement and washout throughout, with borehole diameters as large as 22 in—well beyond the 16 in bit size. However, the washouts are generally not abrupt and sharp (i.e. the hole is washed out, but not especially rugose). Hole rugosity has the greatest negative impact on shallow-reading tools since it prevents the sensor section of the tool from contacting the borehole wall; “smooth” washouts do not cause this problem. Consequently, the overall impact of the washouts on log quality is minor.

The bulk chlorinity log is estimated from the ECS and is considered an experimental measurement of average water chlorine content seen by the tool—assuming all the chlorine is dissolved in water.

Track 3–Resistivity

The third track displays the resistivity measurements from the AITH, spanning most of the open hole section. All the resistivity logs are recorded in units of ohmmeters and displayed on a logarithmic scale of 2 to 2000 ohm-m.

Six electrical resistivity logs from the AITH are displayed:

- Borehole fluid resistivity (solid orange curve)

- Bulk electrical resistivity at five median depths of investigation–10 in. (black solid), 20 in. (long-dashed blue), 30 in. (short-dashed red), 60 in. (dashed-dotted green), and 90 in. (solid purple)–each having a two-foot vertical resolution.

The area between the 10 in. and 90 in. resistivity curves, representing radial variations in bulk resistivity (potentially from invasion of drilling fluids), is shaded:

- blue when the 10 in. resistivity is greater than the 90 in. resistivity (labeled “resistive invasive”) and
- yellow when the 90 in. resistivity is greater than the 10 in. resistivity (labeled “conductive invasive”).

The resistivity logs vary between 10 and 2000 ohm-m (the upper limit of the AITH), exhibiting a lot of character up and down the borehole. Zones where all the resistivity logs shift left significantly, corresponding to relative low resistivity readings, are likely associated with intervals where clay is present in the formation; in general, the lower resistivities correlate quite well with increases in the CMR clay-bound moisture measurement. Conversely, zones where the resistivity logs shift right significantly, corresponding to relative high resistivity readings, are likely associated with intervals where clay is not present in significant amounts and the average pore size is larger or there is not much moisture present in the pore space.

Track 4–Porosity

The fourth track displays the primary porosity log results. All the porosity logs are recorded in units of volumetric fraction and displayed on a linear scale of 0.75 (left side) to negative 0.1 (right side). Specifically, these logs consist of

- CNTG water-filled epithermal neutron porosity (dotted sky blue curve)–a merged log of epithermal neutron porosity processed for water-filled borehole and epithermal neutron porosity processed for air-filled hole;
- CNTG water-filled thermal neutron porosity (dashed light blue curve at bottom)–thermal neutron porosity valid (and visible) only in the water-filled borehole (below 689 ft)
- Geochemical estimated water-filled porosity derived from the ECS hydrogen weight % measurement (dotted purple);
- CMR total water-filled porosity (solid black), which is probably the best estimate of this property in R-14;
- CMR effective water-filled porosity (dashed green);
- CMR bound water porosity (light blue area shading)–representing by the area between the CMR total and effective water-filled porosities; and
- Total porosity derived from bulk density and neutron porosity using 2.65 g/cc grain density (thick long dashed red), 2.25 g/cc (thin dashed red), and 3.05 g/cc (thin dotted red)–with red shading between the 2.25 g/cc and 3.05 g/cc curves; and
- ELAN total water and air-filled porosity (dashed-dotted cyan)–derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

The CNTG logs are environmentally corrected for borehole conditions–particularly borehole fluid (air). The ELAN results are based on fully corrected logs. All the porosity logs are depth matched to the AITH log using the gross gamma ray measurement obtained in every logging run.

Track 5–Density

The fifth track displays the:

- bulk density (thick solid maroon curve) on a scale of 1 to 3 grams per cubic centimeter (g/cc);
- P_e (long-dashed black curve) on a scale of 0 to 10 non-dimensional units;
- density correction (dashed orange curve) on a scale of -0.75 to 0.25 g/cc; and
- apparent grain density (dashed-dotted brown curve), derived from the ELAN analysis, on a scale of 2 to 4 g/cc.

Grey area shading is shown where the P_e increases above 3 (indicating the presence of heavy, possibly mafic, minerals) and orange shading is shown where the density correction is greater than the absolute value of 0.25 (indicating the density processing algorithm had to perform a major correction to the bulk density calculation). These logs have been depth matched to the AITH using gross gamma ray.

Track 6–NGS Spectral Gamma

The sixth track from the left displays the spectral components of the NGS measurement results as wet weight concentrations:

- potassium (solid green curve) in units of percent and on a scale of –10 to 10 percent;
- thorium (dashed brown) in units of parts per million (ppm) and on a scale of 50 to –50 ppm; and
- uranium (dotted blue) in units of parts per million (ppm) and on a scale of 20 to -20 ppm.

The log results are environmentally corrected for borehole conditions (particularly borehole size and fluid properties). Potassium and thorium are presented in such a way that they increase to the right and the left from the center of the track, respectively, with gray shading between the two curves to qualitatively show changes in both concentration values. Uranium is plotted increasing to the left from the middle.

Track 7–CMR Porosity

Track 7 displays various CMR water-filled porosities along with measurement quality flags. The porosity and measurement quality logs are presented on a scale of 0.5 to zero volume fraction and discrete blocks originating from the left side, respectively. Specifically, the CMR logs shown in this track are

- Total water-filled porosity (solid black curve)–representing the total water volume fraction measured by the CMR;
- Three millisecond (ms) porosity (short-dashed brown)–representing the water volume fraction corresponding to the portion of the CMR measured T2 distribution that is above 3 ms, a cutoff that is considered to be representative of the break between clay-bound water (less than 3 ms) and all other types of water (greater than 3 ms);
- Effective water-filled, or free fluid, porosity (solid pink)–representing the water volume fraction that is moveable (can flow), based on a 33 ms T2 distribution cutoff that is considered

representative of the break between bound water (less than 33 ms) and moveable water (greater than 33 ms) in clastic rocks;

- Clay-bound water (brown area shading between total and 3 ms porosity logs)–representing the water volume fraction that is bound within clays;
- Capillary-bound water (pink area shading between 3 ms and effective porosity logs)–representing the water volume fraction that is bound within matrix pores by capillary forces;
- CMR wait-time flag (red area shading)–activates when there is significant measurement response at late T2 times, corresponding to large amounts of completely free ("bathtub") water and often associated with washouts or very large pores;
- CMR measurement noise flag (yellow and orange area shading)–activates when there is potentially detrimental amounts of measurement noise detected by the tool, at moderate (yellow) and high (orange) levels.

All these CMR logs have been reprocessed from the field measurements to ensure proper and consistent processing algorithms are applied. The reprocessed logs are depth matched to the AITH tool run using gross gamma.

The CMR logs exhibit variability throughout the measured interval, indicating hydrogeologic heterogeneity (variability in pore-size distribution).

Track 8 –Pore Size Distribution

Track 8 displays the water-filled pore size distribution as determined by the CMR–shown as binned water-filled porosities. The binned porosity logs are presented on a scale of 0.5 to zero volume fraction with colored area shading corresponding to the different bins:

- Clay-bound water–brown area shading;
- Micro pore and small pore water (the sum comprising capillary-bound water)–gray and blue area shading, respectively;
- Medium pore, large pore, and late decay (the sum comprising effective water-filled porosity)–yellow, red, and green area shading, respectively.

Track 9–CMR T2 Distribution (Waveforms)

The CMR T2 distribution is displayed in Track 9 as green waveform traces at discrete depths. The horizontal axis, corresponding to relaxation time in milliseconds, is on a logarithmic scale from 0.3 to 3000 ms. Also plotted are the:

- T2 logarithmic mean (solid blue curve) and
- T2 cutoff time used for differentiating between bound and free water (solid red line)–a constant 33 ms in this case.

Track 10–CMR T2 Distribution (Heated Amplitude)

Track 10 displays the T2 distribution in another way–on a heated color scale where progressively "hotter" color (green to yellow to red) corresponds to increasing T2 amplitude. The remaining aspects of the display are the same as in Track 9, except that the T2 logarithmic mean is shown as a solid white curve and the T2 cutoff is not displayed.

Track 11–CMR Hydraulic Conductivity

Track 11 displays several estimates of hydraulic conductivity (K) from the CMR measurements, as well as one derived from the ELAN analysis, presented on a logarithmic scale of 10^{-3} to 10^{7} centimeters per second (cm/s) multiplied by 10^{6}:

- A K versus depth estimate derived from using the SDR permeability equation, converted to hydraulic conductivity (dashed purple curve);
- A K versus depth estimate derived from using the Timur-Coates permeability equation applied to a tapered T2 cutoff, converted to hydraulic conductivity (solid blue curve); and
- An intrinsic K versus depth estimate (assuming full saturation) derived from the ELAN analysis, converted to hydraulic conductivity (dotted pink).

The hydraulic conductivity values have been multiplied by 10^{6} to reduce the number of significant figures, since in cm/s the values are very small. Thus, when using these hydraulic conductivity estimates for quantitative analysis, the values should be divided by10^{6} or converted to other units.

Area color shading has been applied from the left side of the track up to the Timur-Coates equation K estimate, with different colors corresponding to ranges of K with representative clastic grain sizes:

- Grey–Clay K range (10^{-9} to 10^{-7} cm/s)
- Brown–silt K range (10^{-7} to 10^{-5} cm/s)
- Orange–silty-sand K range (10^{-5} to 10^{-3} cm/s)
- Yellow–clean sand K range (10^{-3} to 10^{-1} cm/s)
- Blue–gravel K range (10^{-1} to 10 cm/s)

Tracks 12 to 16– Geochemical Elemental Measurements

The narrow tracks 12 to 16 present the geochemical measurements iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), potassium (K) and estimated aluminum (Al), titanium (Ti) and gadolinium (Gd), and hydrogen (H) and bulk chlorinity (Cl) —from left to right respectively, in units of dry matrix weight fraction (except H and K in wet weight fraction, Cl in ppk). All these measurements were obtained from the ECS except K, which is from the NGS. All these measurements are depth matched to the AITH.

Track 17–ELAN Mineralogy Model Results (Dry Weight Fraction)

Track 17 displays the results from the ELAN integrated log analysis (the matrix portion)–presented as dry weight fraction of mineral types chosen in the model:

- Montmorillonite clay (brown/tan)
- Quartz (yellow with small black dots)
- Silica glass (orange)
- Orthoclase or other potassium feldspar (lavender)
- Labradorite or other plagioclase feldspar (pink)
- Hypersthene (purple)
- Hornblende (forest green)

- Augite (maroon)
- Heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green)
- Pyrite (cross-hatched red).

Track 18–ELAN Mineralogy-Pore Space Model Results (Wet Volume Fraction)

Track 18 displays the results from the ELAN integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- Montmorillonite clay (brown/tan)
- Clay-bound water (checkered gray-black)
- Quartz (yellow with small black dots)
- Silica glass (yellow with large black dots)
- Orthoclase or other potassium feldspar (lavender)
- Labradorite or other plagioclase feldspar (pink)
- Pyrite (tan with large black squares).
- Hypersthene (purple)
- Hornblende (forest green)
- Augite (maroon)
- Heavy mafic minerals, such as magnetite (dark army green)
- Air (red)
- Moveable water (white)
- Capillary-bound water (light blue).

Track 19–Summary Logs

Track 17, the second track from the right, displays several summary logs that describe the fluid and air-filled volume measured by the geophysical tools, including water saturation:

- Optimized estimate of total volume fraction water from the ELAN analysis (solid dark blue curve and area shading);
- Optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading);
- Optimized estimate of water saturation (percentage of pore space filled with water) from the ELAN analysis (dashed-dotted purple curve);
- Water saturation as calculated directly from the bulk density and geochemical estimated porosity using a grain density of 3.05 g/cc (dotted light blue curve), 2.65 g/cc (long-dashed light blue curve), and 2.25 g/cc (dashed light blue curve)–with light blue shading between the 2.25 and 3.05 g/cc saturation curves to show the range;
- Potential for water flow indicator from the CMR log (block green cross-hatched shading coming from the right-hand side of the track).

The water and porosity curves scale from 0 to 0.5 volume fraction, left to right; the water saturation scales from 0 to 1, from left to right. The flow indicator is a binary-valued flag that rises to halfway through the first division from the right on the x-axis when the CMR measurement indicates a potential for flow.

Track 20–Depth

The final track on the right, same as the first track on the left, displays the depth below ground surface in units of feet, as measured by the geophysical logging system during the AITH logging run.

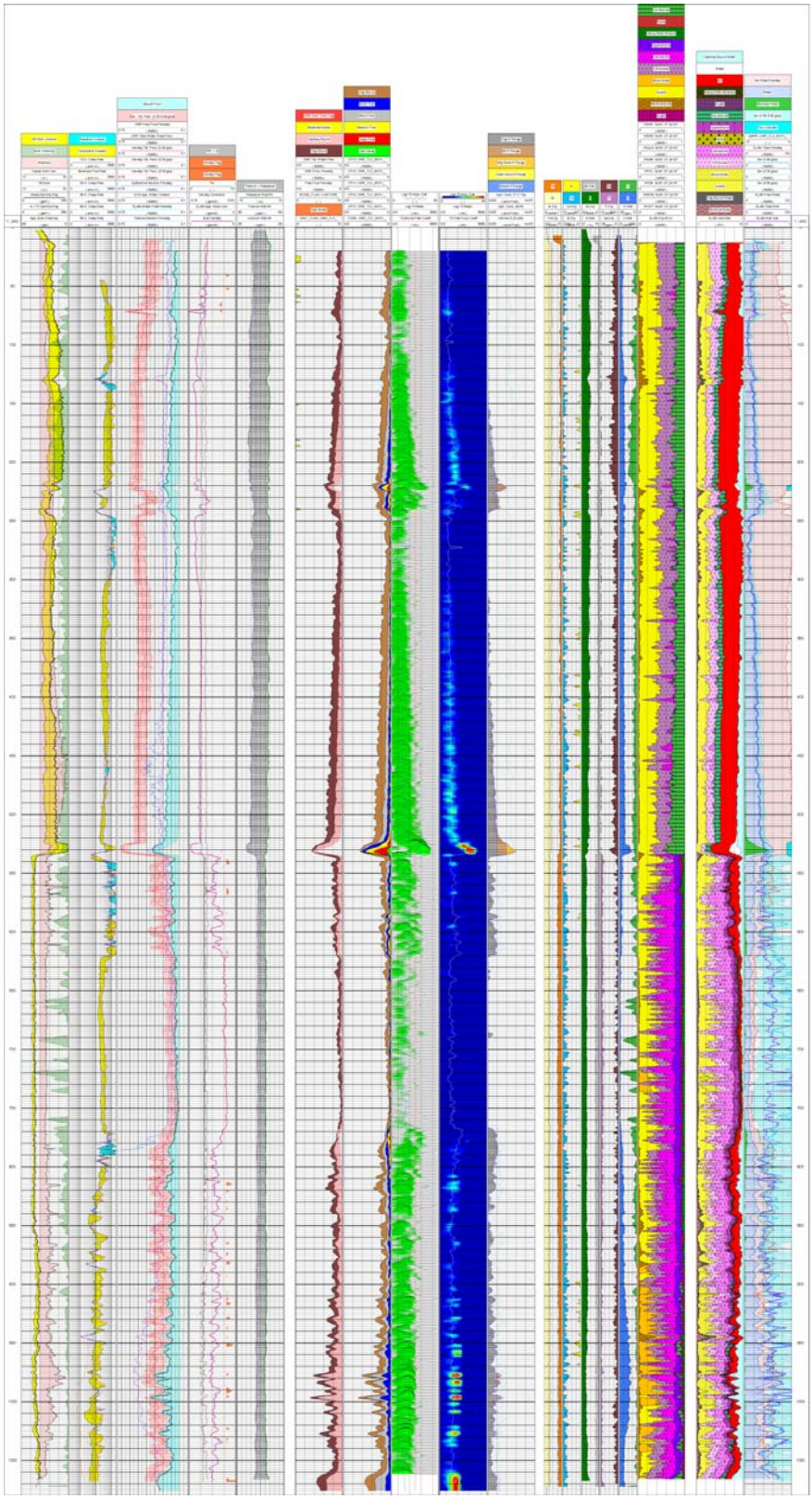


Figure 4.4. Geophysical log montage showing a compressed composite of all processed logs, including ELAN models, from borehole R-14.

5.0 REFERENCES

Kenyon, B., R. Kleinberg, C. Straley, G. Gubelin, and C. Morris: 1995. “Nuclear Magnetic Resonance Imaging— Technology for the 21st Century.” Oilfield Review, v. 7, n. 3, p. 19–33.

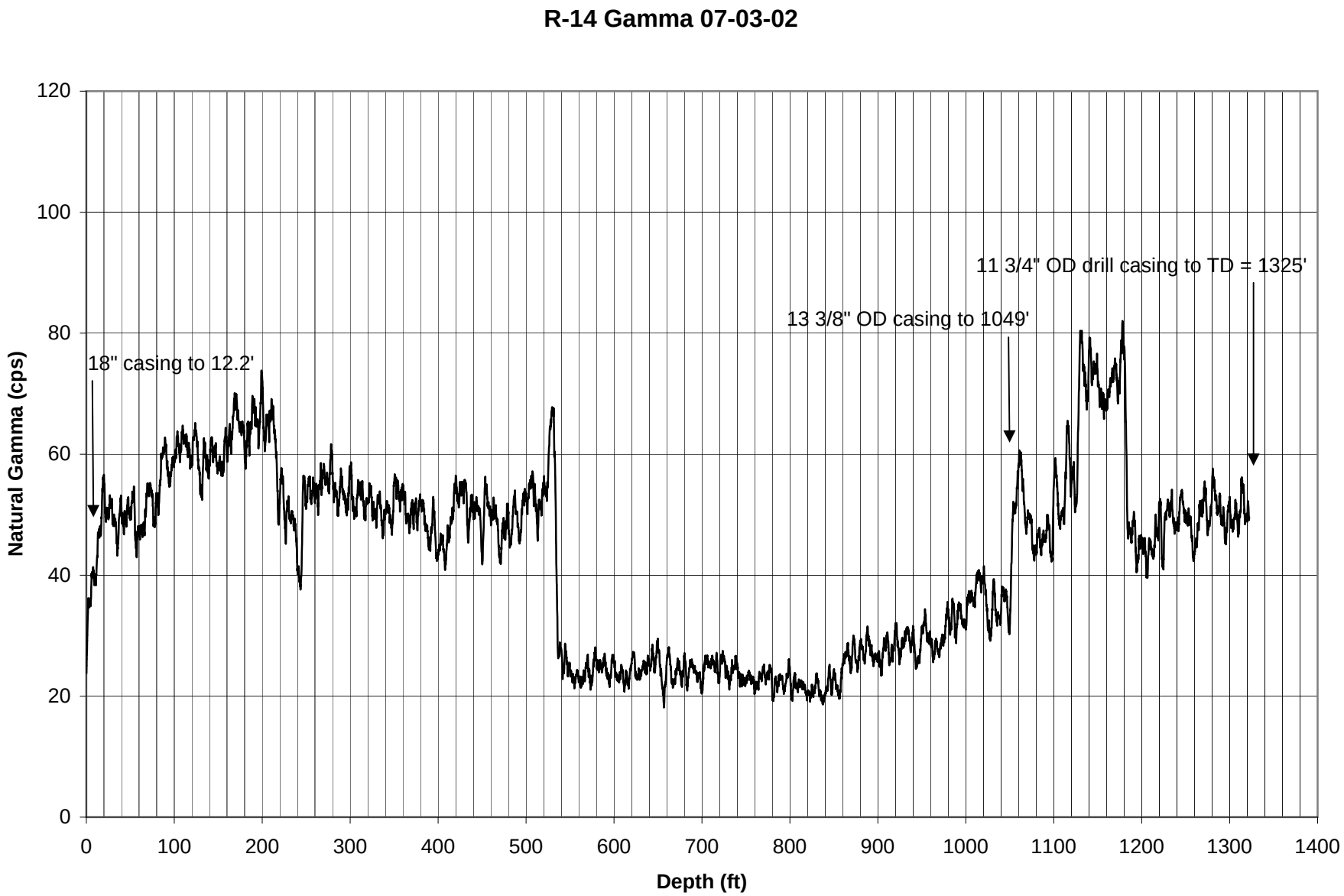
Mayer, C. and A. Sibbit, 1980. “GLOBAL, A New Approach to Computer-Processed Log Interpretation.” Paper SPE 9341 presented at the 1980 SPE Annual Technical Conference and Exhibition.

Quirein, J., S. Kimminau, J. LaVigne, J. Singer, and F. Wendel. 1986. “A Coherent Framework for Developing and Applying Multiple Formation Evaluation Models.” Paper DD in 27th Annual Logging Symposium Transactions: Society of Professional Well Log Analysts.

Schlumberger, Log Interpretation Charts 1998 (SMP-7006).

Schlumberger, Log Interpretation Principles/Applications 1989 (SMP 7017)

Schlumberger, Log Quality Control Manual. 1997


R-14 Gamma 07-03-02
Natural Gamma (cps)
Depth (ft)
18" casing to 12.2'
13 3/8" OD casing to 1049'
11 3/4" OD drill casing to TD = 1325'
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400

CHEMICAL PROCESSING PLTS			
0.00000	0.00		1700-1750, 1800-1870,1900,1940-1950,1970-2 0
0.00000	0.00		1700-1750, 1800-1870,1900,1940-1950,1970-2
CHEMICAL PROCESSING PLTS			
0.00000	0.00		
0.00000	0.00	0.00000	0.00000 0.00000
0.00000	0.00	0.00000	0.00000 0.00000

974.500	20.000	
976.000	10.000	
976.000	10.000	
976.000	10

974.641 - 15.243
1.05.70 - 16.748
974.641 - 15.243
974.641 - 15.243
974.641 - 15.243

994.841 - 1.0.1.0.0.0
998.0.0.0 - 1.0.1.0.0.0
1.0.1.0.0.0 - 1.0.1.0.0.0
1.0.1.0.0.0 - 1.0.1.0.0.0
1.0.1

Appendix F

Westbay™ Multi-Level Sampling Diagram
(CD attached to inside back cover)

DRAFT Summary Casing Log

Company: Los Alamos National Lab
Well: R14
Site: LANL
Project: Hydrogeology Study

Job No: WB777
Author: DL/GG

Well Information

Reference Datum: Ground Level
Elevation of Datum: 0.00 ft.
MP Casing Top: 0.00 ft.
MP Casing Length: 1312.75 ft.

Borehole Depth: 1315.00 ft.
Borehole Inclination: vertical
Borehole Diameter: 5.00 in.

Well Description:
PlasticMP55
Other References:
Pipe-based wire-wrapped screens.
BF and screens after LANL 07/10/02

File Information

File Name: 777_R14.WWD
Report Date: Fri Aug 02 12:13:03 2002

File Date: Aug 02 12:08:51 2002

Sketch of Wellhead Completion

Legend

(Qty) MP Components

(Library - WD Library 7/27/00)

(2) 0603 - MP55 End Plug

(10) 0601M15 - MP55 Casing, 1.5 m, PVC

(1) 0601M10 - MP55 Casing, 1.0 m, PVC

(124) 0601M30 - MP55 Casing, 3.0 m, PVC

(8) 0612 - MP55 Packer, Stiffened, SS

(133) 0602 - MP55 Regular Coupling

(10) 0605 - MP55 Measurement Port

(2) 0607 - MP55 Hydraulic Pumping Port

(6) 0608 - MP55 Magnetic Location Collar

Geology

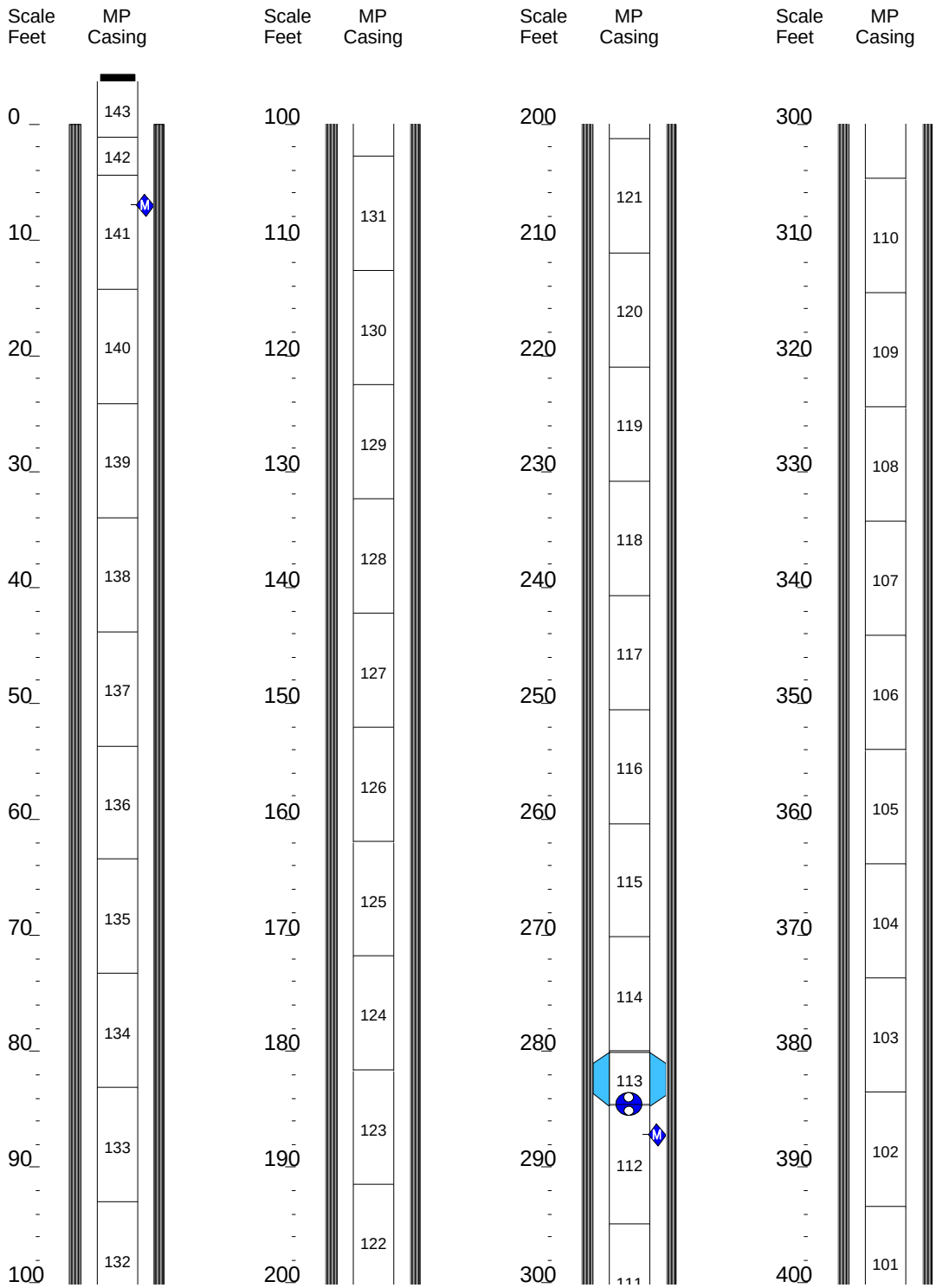
Backfill/Casing

Stainless Steel

Well Screen

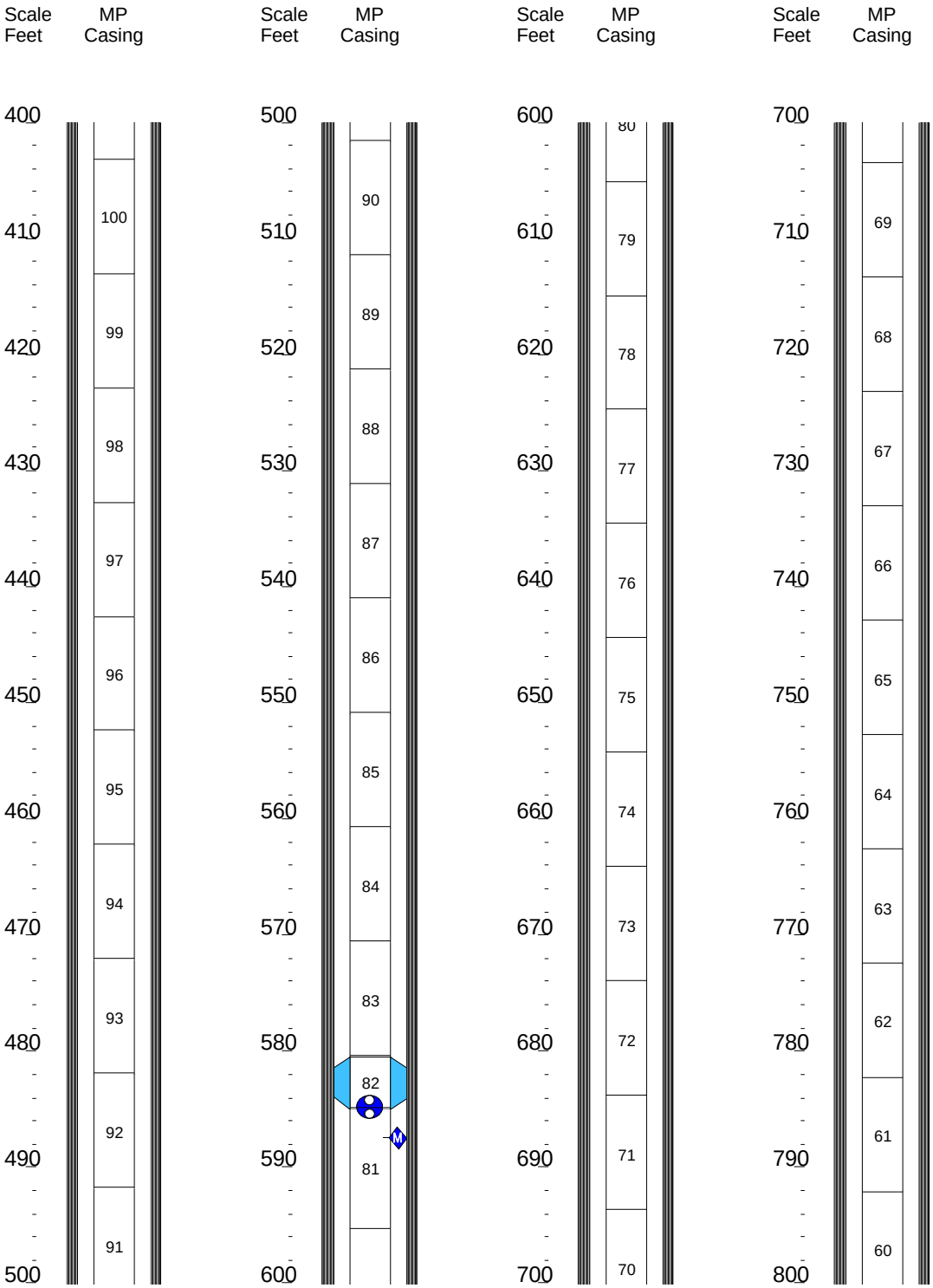
DRAFT Summary MP Casing Log
Los Alamos National Lab

Job No: WB777
Well: R14



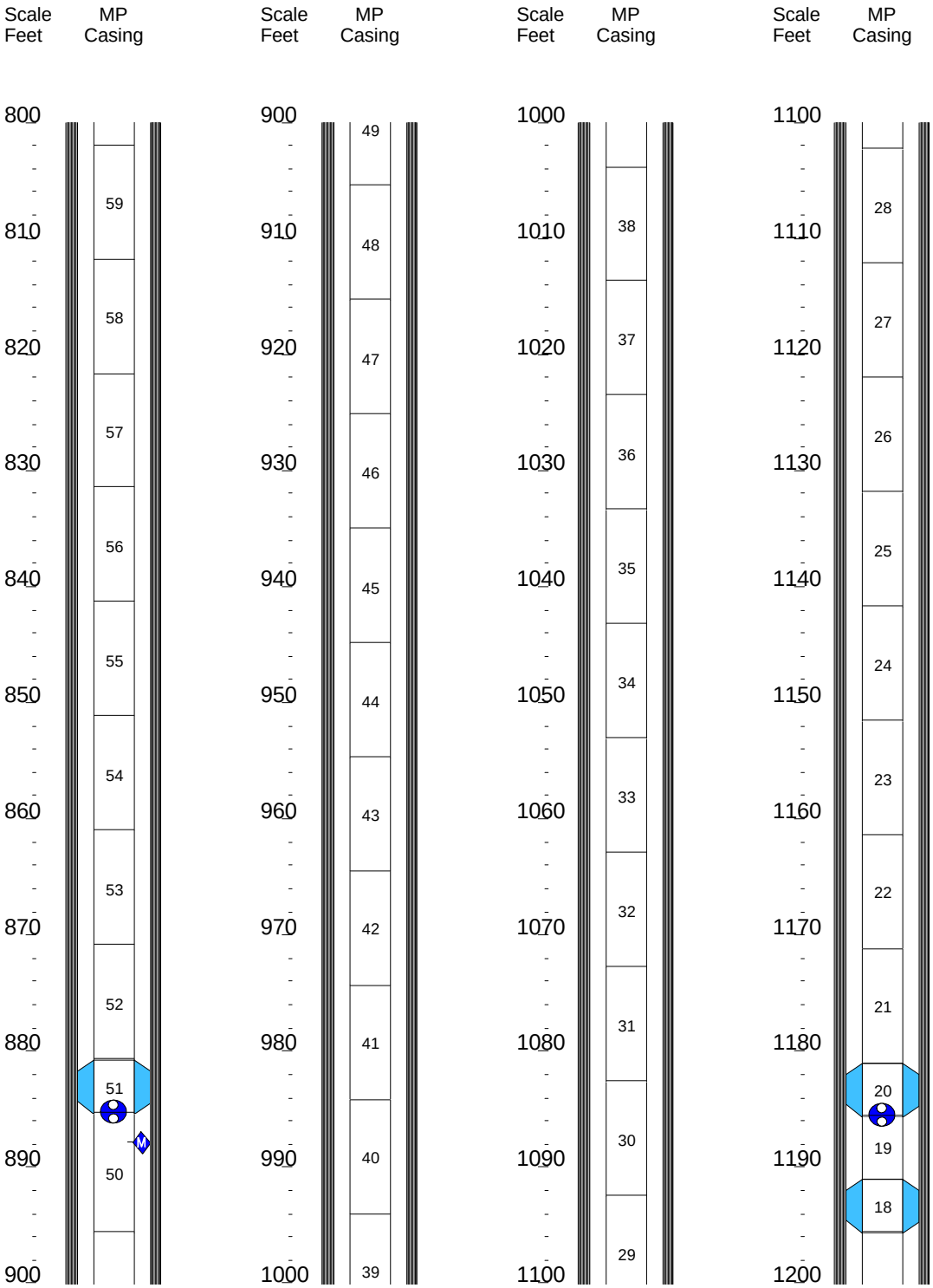
DRAFT Summary MP Casing Log
Los Alamos National Lab

Job No: WB777
Well: R14



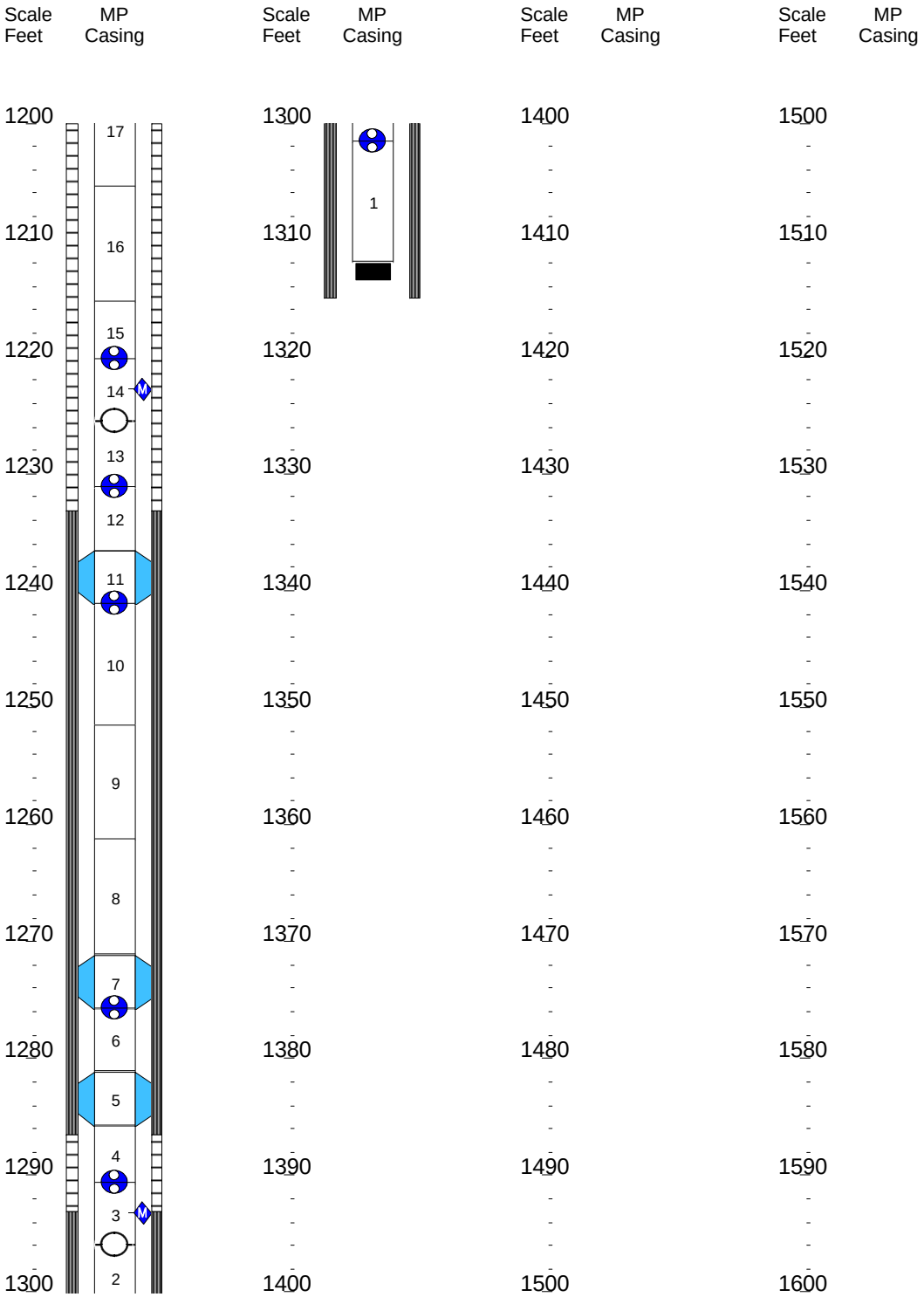
DRAFT Summary MP Casing Log
Los Alamos National Lab

Job No: WB777
Well: R14



DRAFT Summary MP Casing Log
Los Alamos National Lab

Job No: WB777
Well: R14



Appendix G

Waste Characterization Data

Los Alamos
NATIONAL LABORATORY

Risk Reduction & Environmental Stewardship Division
Water Quality & Hydrology Group (RRES-WQH)
PO Box 1663, MS K497
Los Alamos, New Mexico 87545
(505) 667-7969/Fax: (505) 665-9344

Date: July 16, 2002
Refer to: RRES-WQH: 02-273

Mr. Curt Frischkorn
Pollution Prevention Section
Ground Water Quality Bureau
New Mexico Environment Department
P.O. Box 26110
Santa Fe, New Mexico 87502

SUBJECT: NOTICE OF INTENT TO DISCHARGE, HYDROGEOLOGIC WORKPLAN WELLS

Dear Mr. Frischkorn:

At our July 11, 2002, meeting at your Santa Fe office (Attendees: Mike Saladen (RRES-WQH), Roy Bohn (RRES-R), Bob Beers (RRES-WQH), John Young (NMED-HWB), and Curt Frischkorn (NMED-GWQB)), we reviewed the Notice of Intent to Discharge (NOI) submitted by Los Alamos National Laboratory to your agency on August 2, 2001, for the Hydrogeologic Workplan Wells. In addition to our general review of the NOI, we discussed the Laboratory's immediate need to discharge approximately 50,000 gallons of containerized drilling fluid from Hydrogeologic Workplan Well R-14. I have addressed both of these topics below.

It was my understanding from our July 11th meeting that both you and Mr. Young were satisfied with the Laboratory's NOI for the Hydrogeologic Workplan Wells with the exception of the NOI Decision Tree (Figure 1.0). Per your request, attached is a revised NOI Decision Tree that incorporates a reference to applicable RCRA regulatory limits' into the decision process. In addition, it was also my understanding that your agency would not require a ground water discharge plan for the discharge of drilling fluid, development water, and purge water from Hydrogeologic Workplan Wells as long as all discharges were compliant with the terms and conditions of the NOI.

In addition to our general discussions about the Hydrogeologic Workplan NOI, we discussed the discharge of approximately 50,000 gallons of containerized drilling fluid produced during the drilling of Hydrogeologic Workplan Well R-14. Per your request, please find the following enclosed water quality data and Material Safety Data Sheets (MSDSs) for the drilling fluid produced from R-14.

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Mr. Curt Frischkorn - 2 - July 16, 2002
RRES-WQH:02-273

Water Quality Data. Attachment 1.0 contains water quality data (metals, general chemistry, SVOA, VOA, perchlorate, nitrate, and tritium) for the approximately 50,000 gallons of containerized drilling fluid produced during the drilling of R-14. It should be noted that the data table titled, "ER Water Samples" contains analytical results from two samples, GW14-02-46382 and GW14-02-46383, submitted for metals analysis. These samples were collected from the upper and lower portion of the storage tanks, respectively. Both samples were filtered prior to analysis.

The approximately 50,000 gallons of containerized drilling fluid from R-14 is compliant with New Mexico Water Quality Control Commission (NM WQCC) Regulation 3103 ground water standards with the exception of the following three contaminants:

Contaminant	Max. Result (mg/L)	Min. Result (mg/L)	WQCC ground water standard (mg/L)
Al	42.0	7.69	5.0
Fe	9.25	1.51	1.0
Mn	0.36	0.13	0.2

With the exception of acetone, no VOA or SVOA compounds were detected in R-14 drilling fluids. Acetone, detected at 1.6 mg/L, is present as a byproduct of the drilling additives. No perchlorate or tritium were detected in the R-14 drilling fluid at concentrations greater than analytical laboratory's Method Detection Limits (MDLs). Nitrate/nitrite (as N) was detected at 0.56 mg/L.

MSDS Information. Attachment 2.0 contains Material Safety Data Sheets (MSDSs) for the drilling fluid additives used in the top 1068 feet of the R-14 borehole including the formulation quantities for each product.

The Laboratory requests your agency's permission to discharge the approximately 50,000 gallons of drilling fluid from R-14 in accordance with the August 2, 2001, NOI. Please call me at (505) 667-6969 or Roy Bohn of the Laboratory's Environmental Restoration Project (RRES-R) at (505) 665-5138 if additional information is required.

Sincerely,

Bob Beers
Water Quality & Hydrology Group

BB/am

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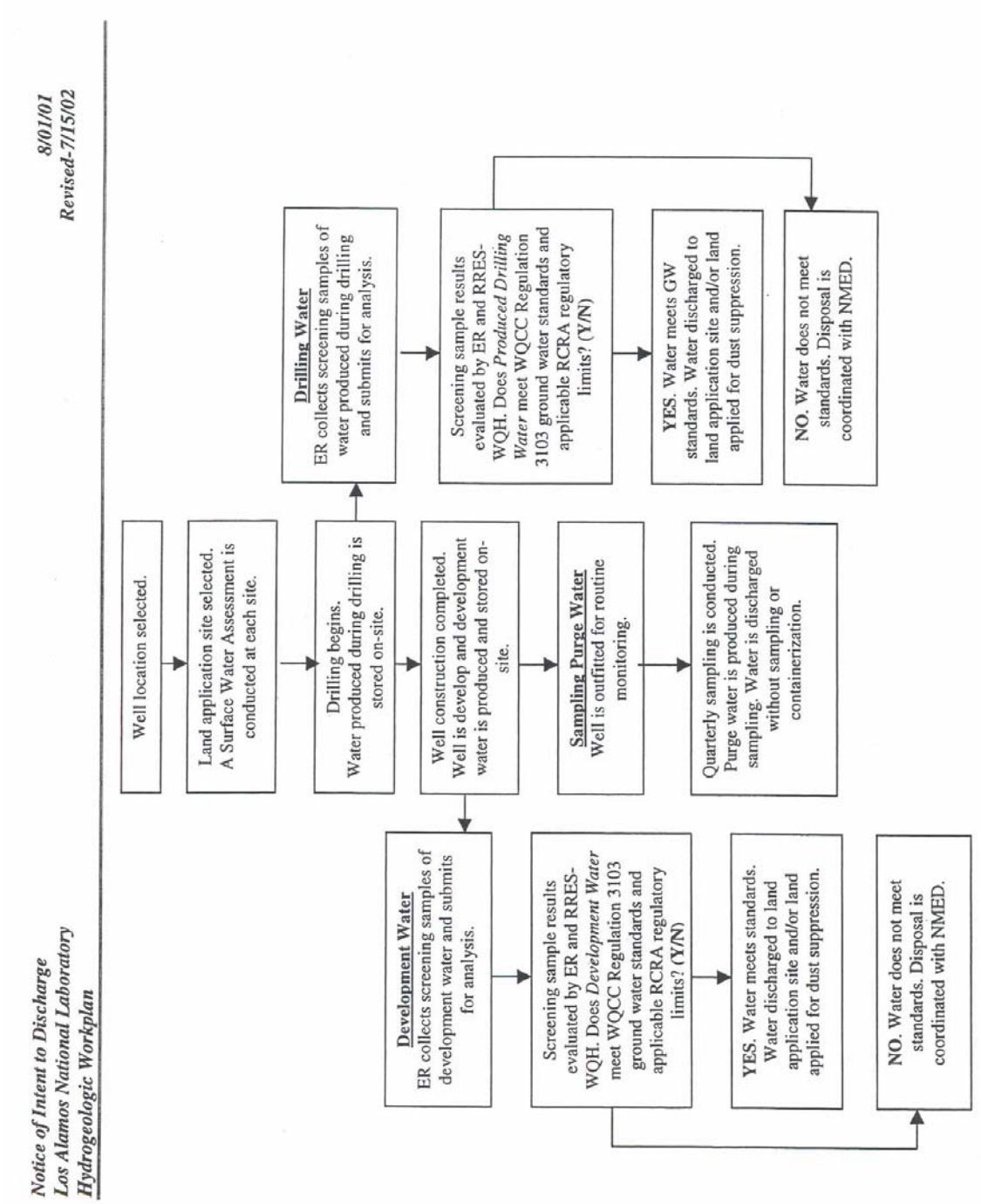

Figure 1.0. Workplan NOI Decision Tree

Los Alamos National Laboratory/University of California
Risk Reduction & Environmental Stewardship (RRES)
Groundwater Protection Program (GPP), MS M992
Los Alamos, New Mexico 87545
(505) 665-4681/FAX (505) 665-4747

National Nuclear Security Administration
Los Alamos Area Office, MS A316
Environmental Restoration Program
Los Alamos, New Mexico 87544
(505) 667-7203/FAX (505) 665-4504

Date: January 22, 2003
Refer to: RRES-GPP:03-006

Mr. John Young, Corrective Action Project Leader
Permits Management Program
NMED – Hazardous Waste Bureau
2905 Rodeo Park Drive East
Building 1
Santa Fe, NM 87505-6303

Butch Tongate
Bureau Chief
NMED-Solid Waste Bureau
P.O. Box 26110
Santa Fe, NM 87502

SUBJECT: MANAGEMENT OF DRILL CUTTINGS FROM HYDROGEOLOGIC WORKPLAN WELLS (R-WELLS)

Dear Messrs. Young and Tongate:

The purpose of this letter is to inform the New Mexico Environment Department Hazardous Waste Bureau (NMED-HWB) and Solid Waste Bureau (NMED-SWB) that the Los Alamos National Laboratory (LANL) will use the cuttings from the drilling of regional aquifer wells for restoration of the drilling site upon completion of drilling activities. The decision to use the cuttings for this purpose is supported by the information included below.

LANL will remove the drill pit liner and leave the cuttings in place as fill for the drill pit upon completion of drilling activities. The drill pits will then be filled to ground level with original site material. The sites will be revegetated and appropriate Best Management Practices will be put in place to prevent erosion. This practice has been used successfully at LANL at all previous regional well drill sites. Unlike previous wells, however, R-Wells 14, 16, 20, 23 and 32 were drilled using drilling fluids, and residuals remain in the cuttings. The attachment to this letter includes data demonstrating that the residuals in the cuttings do not constitute a waste management concern.

Management of the cuttings as part of site restoration is appropriate because the analytical results for the cuttings are consistent with that of purged water being discharged to the ground, per the conditions of Notices of Intent (NOIs) approved by the NMED-Groundwater Bureau (GWB) for R-Wells 14, 16, 20, 23, and 32. The analytes detected in wet cuttings from R-Wells 14 and 32, the minimum, maximum, and mean values, soil geochemical background values, screening levels, and TCLP regulatory limits are shown in the attachment. The screening levels are from "NMED Soil Screening Levels," Revision 1.0, December 18, 2000, with the exception of acetone, 4-methyl-2-pentanone, n-propylbenzene, and 1,2,4-trimethylbenzene, which are Environmental Protection Agency (EPA) screening levels. ESLs are from the ECORISK database, version 1-5, September 2002. Analytes are compared to background values, where available. If background values are unavailable,

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Attachment

Analytes Detected in Wet Cuttings for Wells (R-14, R-32)

Detected Analyte	Minimum Value	Maximum Value	Mean Value	Soil Geochemical Background Value	Screening Action Levels	Ecological Screening Levels	TCLP Regulatory Limit
Radionuclides (pCi/g):							
Am-241 (alpha spec)	0	0	0	0.013	NA	NA	NA
Cs-137 (gamma spec)	0	0	0	1.65	NA	NA	NA
Pu-238 (alpha spec)	0	0	0	0.023	NA	NA	NA
Pu-239 (alpha spec)	0	0	0	0.054	NA	NA	NA
Sr-90 (proportional counting)	0	0	0	1.31	NA	NA	NA
Tritium (liquid scintillation)	0.035	31.860	10.6	0.17 (Qbt 3)*	890	36,000	NA
Th-232 (gamma spec)	0	1.25	0.417	2.33	NA	NA	NA
U-234 (alpha spec)	1.10	1.28	1.19	2.59	NA	NA	NA
U-235 (alpha spec)	0	0.073	0.037	0.2	NA	NA	NA
U-238 (alpha spec)	1.13	1.23	1.19	2.29	NA	NA	NA
Organics (EPA 8260-B & 8270-C, mg/kg):							
Acetone (isopropyl alcohol)	2.9	17.6	14.7	Unavailable	1,600	3.8	NA
Benzene	0	0.010	0.002	Unavailable	6.4	55	0.5 mg/L
Bromomethane	0	0.620	0.160	Unavailable	3.7	NA	NA
Chloroform	0	0.0078	0.0018	Unavailable	0.38	28	6 mg/L
Chloromethane	0	0.0079	0.0026	Unavailable	12.0	NA	NA
Ethylbenzene	0	0.015	0.003	Unavailable	68	NA	NA
4-Methyl-2-pentanone	0	0.033	0.007	Unavailable	790	NA	NA
Methylene chloride	0	0.710	0.182	Unavailable	8.9	7.1	NA
n-Propylbenzene	0	0.0065	0.001	Unavailable	140	NA	NA
Toluene	0	0.510	0.138	Unavailable	180	70	NA
1,2,4-Trimethylbenzene	0	0.038	0.008	Unavailable	52	NA	NA
Xylenes (total)	0	0.064	0.013	Unavailable	63	5.4	NA
High Explosives (EPA 8330, mg/kg) :							
No compounds were detected.							
PCBs (EPA 8082, mg/kg):							
No compounds were detected.							
Total Inorganics (EPA 6010-B, mg/kg):							
Aluminum	1.93	9,670	3,228	29,200	NA	NA	NA
Antimony	0	0.068	0.023	0.83	NA	NA	NA
Arsenic	0.005	1.57	0.528	8.17	NA	NA	NA
Barium	0.018	61.3	20.5	295	NA	NA	NA
Beryllium	0	0.333	0.111	1.83	NA	NA	NA
Cadmium	0	0.285	0.095	0.40	NA	NA	NA
Calcium	45.2	9,370	3,392	6,120	NA	NA	NA
Chromium	0.0034	29.7	10.2	19.3	NA	NA	NA
Cobalt	0	15.9	5.3	8.64	NA	NA	NA
Copper	0.008	24.3	8.1	14.7	NA	NA	NA
Iron	0	28,170	9,390	21,500	23,000	NA	NA
Lead	0	2.69	0.898	22.3	NA	NA	NA
Magnesium	0.08	14,390	4,800	4,610	NA	NA	NA
Manganese	0	501	167.3	671	NA	NA	NA
Mercury	0	0.0011	0.0004	0.1	NA	NA	NA
Nickel	0.004	48.1	16.0	15.4	1,500	NA	NA
Potassium	37.3	733	390.8	3,460	NA	NA	NA
Selenium	0	1.75	0.59	1.52	NA	NA	NA
Silver	0	0.084	0.028	1	NA	NA	NA
Sodium	227	2,620	1,260	915	NA	NA	NA
Thallium	0	0.107	0.036	0.73	NA	NA	NA
Vanadium	0	54.8	18.3	39.6	NA	NA	NA
Zinc	0	42	14.0	48.8	NA	NA	NA
TCLP Inorganics (EPA 1311/6010-B, mg/L):							
Arsenic	0	0	0	NA	NA	NA	5
Barium	0.152	0.241		NA	NA	NA	100
Cadmium	0	0	0	NA	NA	NA	1
Chromium	0	0.0169		NA	NA	NA	5
Lead	0	0.003		NA	NA	NA	5
Mercury	0	0	0	NA	NA	NA	0.2
Selenium	0	0	0	NA	NA	NA	1
Silver	0	0	0	NA	NA	NA	5

* Background value is calculated from Bandelier Tuff unit 3 (Qbt 3) value of 0.3 pCi/mL at 18.5% moisture concentration.

HYDROGEOLOGIC WORKPLAN
WELL R-14

CONTAINERIZED DRILLING FLUIDS

Contents:

ANALYTICAL REPORTS

- GENERAL CHEMISTRY
- METALS
- PERCHLORATE
- NITRATE/NITRITE
- TRITIUM
- VOA
- SVOA

Hydrogeologic Workplan Well R-14
Water Quality Data-Drilling Fluid

ER

ER WATER SAMPLES

SAMPLE ID	DESCRIPTION	DATE MM/DD/YY	ER Req#	Ag ppm	Al ppm	Std.D. +/-	As ppm	Std.D. +/-	B ppm	Std.D. +/-	Ba ppm
GW14-02-46328	Frac tank mud sample, anions	06/21/02	889S	---	---	---	---	---	---	---	---
GW14-02-46382	Frac tank mud sample, metals	06/26/02	897S	<0.001	7.69	0.02	0.0081	0.0001	0.08	0.01	0.042
GW14-02-46383	Frac tank mud sample, metals	06/26/02	897S	<0.001	42.0	0.1	0.0069	0.0002	0.10	0.01	0.15

Page 1

Hydrogeologic Workplan Well R-14
Water Quality Data-Drilling Fluid

ER

SAMPLE ID	Std.D. +/-	Be ppm	Br ppm	Ca ppm	Std.D. +/-	Cd ppm	Cl ppm	ClO3 ppm	ClO4 ppm	Co ppm	Std.D. +/-	Cr ppm	Std.D. +/-	Cs ppm
GW14-02-46328	---	---	0.27	---	---	---	5.59	<0.05	<0.01	---	---	---	---	---
GW14-02-46382	0.001	<0.001	---	12.9	0.1	<0.001	---	---	---	0.0022	0.0001	0.015	0.001	0.0017
GW14-02-46383	0.01	<0.001	---	29.6	0.2	<0.001	---	---	---	0.009	0.001	0.016	0.001	0.0012

Page 2

Hydrogeologic Workplan Well R-14
Water Quality Data-Drilling Fluid

ER

SAMPLE ID	Std.D. +/-	Cu ppm	Std.D. +/-	F ppm	Fe ppm	Std.D. +/-	Hg ppm	Std.D. +/-	K ppm	Std.D. +/-	Li ppm	Std.D. +/-	Mg ppm	Std.D. +/-	Mn ppm
GW14-02-46328	---	---	---	0.48	---	---	---	---	---	---	---	---	---	---	---
GW14-02-46382	0.0001	0.027	0.001	---	1.51	0.01	0.0020	0.0001	13.8	0.2	0.15	0.01	3.76	0.05	0.13
GW14-02-46383	0.0001	0.025	0.001	---	9.25	0.07	0.0008	0.0001	16.5	0.1	0.13	0.01	11.4	0.1	0.36

Hydrogeologic Workplan Well R-14
Water Quality Data-Drilling Fluid

ER

SAMPLE ID	Std.D. +/-	Mo ppm	Std.D. +/-	Na ppm	Std.D. +/-	Ni ppm	Std.D. +/-	NO2 ppm	NO3 ppm	Oxalate ppm	Pb ppm	Std.D. +/-	pH Lab	PO4 ppm
GW14-02-46328	---	---	---	---	---	---	---	1.64	0.27	<0.05	---	---	---	0.50
GW14-02-46382	0.01	0.13	0.01	285	2	0.008	0.001	---	---	---	0.0047	0.0001	6.73	---
GW14-02-46383	0.01	0.20	0.01	374	1	0.018	0.001	---	---	---	0.011	0.001	6.72	---

Page 4

Hydrogeologic Workplan Well R-14
Water Quality Data-Drilling Fluid

ER

SAMPLE ID	Rb ppm	Rb Std.D. +/-	Sb ppm	Sb Std.D. +/-	Se ppm	Se Std.D. +/-	Si ppm	Si Std.D. +/-	Sn ppm	Sn Std.D. +/-	Sr ppm	Sr Std.D. +/-	Th ppm	Th Std.D. +/-	Ti ppm
GW14-02-46328	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
GW14-02-46382	0.030	0.001	0.0040	0.0001	0.004	0.001	37.4	0.6	<0.001		0.16	0.01	0.014	0.001	0.092
GW14-02-46383	0.026	0.001	0.0031	0.0001	0.003	0.001	114	2	0.0031	0.0001	0.43	0.01	0.030	0.001	0.45

Hydrogeologic Workplan Well R-14
Water Quality Data-Drilling Fluid

ER

SAMPLE ID	Std.D. +/-	Tl ppm	U ppm	Std.D. +/-	V ppm	std.D. +/-	Zn ppm	Std.D. +/-
GW14-02-46328	---	---	---	---	---	---	---	---
GW14-02-46382	0.001	<0.001	0.0059	0.0001	0.013	0.001	0.022	0.001
GW14-02-46383	0.01	<0.001	0.010	0.001	0.016	0.001	0.039	0.001

Page 6

LOS ALAMOS NATIONAL LABORATORY

Preliminary

Client Sample ID: GW14-02-46382

Severn Trent Laboratories - Radiochemistry

Lab Sample ID: F2F260140-001
Work Order: E3PPG
Matrix: WATER

Date Collected: 06/21/02 0000
Date Received: 06/26/02 0900

Parameter	Result	Qual	Total Uncert. (2 σ+/-)	MDC	Prep Date	Analysis Date	Batch #	Yld %
TRITIUM (Distill) by EPA 906.0 MOD				pCi/L	906.0 MOD			
Tritium	20	U	140	230	07/08/02	07/08/02	2189221	

NOTE(S)

Data are incomplete without the case narrative.

MDC is determined by instrument performance only.

Bold results are greater than the MDC

U Result is less than the sample detection limit.

SEVERN TRENT LABORATORIES, INC.

PRELIMINARY DATA SUMMARY

The results shown below may still require additional laboratory review and are subject to change. Actions taken based on these results are the responsibility of the data user.

Los Alamos National Laboratory
Los Alamos Non-Rad
Project Number: 888S

PAGE 3

Lot #: F2F260137 Date Reported: 7/10/02

Client Sample ID: GW14-02-46328
Sample #: 001 Date Sampled: 06/21/02 Date Received: 06/26/02 Matrix: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD	Reviewed
Volatile Organics by GC/MS					
Dichlorodifluoromethane	ND	50	ug/L	SW846 8260B	
Chloromethane	5.9 J	50	ug/L	SW846 8260B	
Vinyl chloride	ND	50	ug/L	SW846 8260B	
Bromomethane	ND	50	ug/L	SW846 8260B	
Chloroethane	ND	50	ug/L	SW846 8260B	
Trichlorofluoromethane	ND	50	ug/L	SW846 8260B	
Trichlorotrifluoroethane	ND	25	ug/L	SW846 8260B	
Acetone	1600 E	250	ug/L	SW846 8260B	
1,1-Dichloroethene	ND	25	ug/L	SW846 8260B	
Iodomethane	ND	25	ug/L	SW846 8260B	
Methylene chloride	29	25	ug/L	SW846 8260B	
Carbon disulfide	ND	25	ug/L	SW846 8260B	
1,1-Dichloroethane	ND	25	ug/L	SW846 8260B	
2-Butanone	ND	120	ug/L	SW846 8260B	
2,2-Dichloropropane	ND	25	ug/L	SW846 8260B	
1,2-Dichloroethene (total)	ND	25	ug/L	SW846 8260B	
Chloroform	ND	25	ug/L	SW846 8260B	
Bromochloromethane	ND	25	ug/L	SW846 8260B	
1,1,1-Trichloroethane	ND	25	ug/L	SW846 8260B	
1,1-Dichloropropene	ND	25	ug/L	SW846 8260B	
Carbon tetrachloride	ND	25	ug/L	SW846 8260B	
1,2-Dichloroethane	ND	25	ug/L	SW846 8260B	
Benzene	ND	25	ug/L	SW846 8260B	
Trichloroethene	ND	25	ug/L	SW846 8260B	
1,2-Dichloropropane	ND	25	ug/L	SW846 8260B	
Bromodichloromethane	ND	25	ug/L	SW846 8260B	
Dibromomethane	ND	25	ug/L	SW846 8260B	
4-Methyl-2-pentanone	ND	120	ug/L	SW846 8260B	
cis-1,3-Dichloropropene	ND	25	ug/L	SW846 8260B	
Toluene	ND	25	ug/L	SW846 8260B	
1,1,2-Trichloroethane	ND	25	ug/L	SW846 8260B	
2-Hexanone	ND	120	ug/L	SW846 8260B	
1,3-Dichloropropane	ND	25	ug/L	SW846 8260B	
Tetrachloroethene	ND	25	ug/L	SW846 8260B	
Chlorodibromomethane	ND	25	ug/L	SW846 8260B	
1,2-Dibromoethane	ND	25	ug/L	SW846 8260B	

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SEVERN TRENT LABORATORIES, INC.

PRELIMINARY DATA SUMMARY

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Los Alamos National Laboratory
Los Alamos Non-Rad
Project Number: 888S

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Lot #: F2F260137 Date Reported: 7/10/02

Client Sample ID: GW14-02-4632B
Sample #: 001 Date Sampled: 06/21/02 Date Received: 06/26/02 Matrix: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD	
Volatile Organics by GC/MS					Reviewed
Chlorobenzene	ND	25	ug/L	SW846 8260B	
1,1,1,2-Tetrachloroethane	ND	25	ug/L	SW846 8260D	
Ethylbenzene	ND	25	ug/L	SW846 8260B	
Xylenes (total)	ND	25	ug/L	SW846 8260B	
Styrene	ND	25	ug/L	SW846 8260B	
Bromoform	ND	25	ug/L	SW846 8260B	
Isopropylbenzene	ND	25	ug/L	SW846 8260B	
1,1,2,2-Tetrachloroethane	ND	25	ug/L	SW846 8260B	
1,2,3-Trichloropropane	ND	25	ug/L	SW846 8260B	
n-Propylbenzene	ND	25	ug/L	SW846 8260B	
trans-1,3-Dichloropropene	ND	25	ug/L	SW846 8260B	
Bromobenzene	ND	25	ug/L	SW846 8260B	
2-Chlorotoluene	ND	25	ug/L	SW846 8260B	
1,3,5-Trimethylbenzene	ND	25	ug/L	SW846 8260B	
4-Chlorotoluene	ND	25	ug/L	SW846 8260B	
tert-Butylbenzene	ND	1200	ug/L	SW846 8260B	
1,2,4-Trimethylbenzene	ND	25	ug/L	SW846 8260B	
sec-Butylbenzene	ND	25	ug/L	SW846 8260B	
p-Isopropyltoluene	ND	25	ug/L	SW846 8260B	
1,3-Dichlorobenzene	ND	25	ug/L	SW846 8260B	
1,4-Dichlorobenzene	ND	25	ug/L	SW846 8260B	
n-Butylbenzene	ND	25	ug/L	SW846 8260B	
1,2-Dichlorobenzene	ND	25	ug/L	SW846 8260B	
1,2-Dibromo-3-chloro-propane	ND	25	ug/L	SW846 8260B	

J Estimated result. Result is less than RL.
E Estimated result. Result concentration exceeds the calibration range.

Semivolatile Organic Compounds by GC/MS					In Review
3-Methylphenol & 4-Methylphenol	ND	20	ug/L	SW846 8270C	
Pyridine	ND	20	ug/L	SW846 8270C	
N-Nitrosodimethylamine	ND	20	ug/L	SW846 8270C	
Phenol	ND	10	ug/L	SW846 8270C	
Aniline	ND	20	ug/L	SW846 8270C	
bis(2-Chloroethyl)-ether	ND	10	ug/L	SW846 8270C	

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SEVERN TRENT LABORATORIES, INC.

PRELIMINARY DATA SUMMARY

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Los Alamos National Laboratory
Los Alamos Non-Rad
Project Number: 8888

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Lot #: F2F260137

Date Reported: 7/10/02

Client Sample ID: GW14-02-46328
Sample #: 001 Date Sampled: 06/21/02 Date Received: 06/26/02 Matrix: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
Semivolatile Organic Compounds by GC/MS				In Review
2-Chlorophenol	ND	10	ug/L	SW846 8270C
1,3-Dichlorobenzene	ND	10	ug/L	SW846 8270C
1,4-Dichlorobenzene	ND	10	ug/L	SW846 8270C
Benzyl alcohol	ND	10	ug/L	SW846 8270C
1,2-Dichlorobenzene	ND	10	ug/L	SW846 8270C
2-Methylphenol	ND	10	ug/L	SW846 8270C
2,2'-oxybis(1-Chloropropane)	ND	10	ug/L	SW846 8270C
N-Nitrosodi-n-propyl-amine	ND	10	ug/L	SW846 8270C
Hexachloroethane	ND	10	ug/L	SW846 8270C
Nitrobenzene	ND	10	ug/L	SW846 8270C
Isophorone	ND	10	ug/L	SW846 8270C
2 Nitrophenol	ND	10	ug/L	SW846 8270C
2,4-Dimethylphenol	ND	10	ug/L	SW846 8270C
bis(2-Chloroethoxy) methane	ND	10	ug/L	SW846 8270C
Benzoic acid	ND	20	ug/L	SW846 8270C
2,4-Dichlorophenol	ND	10	ug/L	SW846 8270C
1,2,4-Trichloro-benzene	ND	10	ug/L	SW846 8270C
Naphthalene	ND	10	ug/L	SW846 8270C
4-Chloroaniline	ND	20	ug/L	SW846 8270C
Hexachlorobutadiene	ND	10	ug/L	SW846 8270C
4-Chloro-3-methylphenol	ND	20	ug/L	SW846 8270C
2-Methylnaphthalene	ND	10	ug/L	SW846 8270C
Hexachlorocyclopenta-diene	ND	10	ug/L	SW846 8270C
2,4,6-Trichloro-phenol	9.5 J	10	ug/L	SW846 8270C
2,4,5 Trichloro phenol	5.0 J	10	ug/L	SW846 8270C
2-Chloronaphthalene	ND	10	ug/L	SW846 8270C
2-Nitroaniline	ND	50	ug/L	SW846 8270C
Dimethyl phthalate	ND	10	ug/L	SW846 8270C
Acenaphthylene	110	10	ug/L	SW846 8270C
2,6-Dinitrotoluene	ND	10	ug/L	SW846 8270C
3-Nitroaniline	ND	50	ug/L	SW846 8270C

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SEVERN TRENT LABORATORIES, INC.

PRELIMINARY DATA SUMMARY

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Los Alamos National Laboratory
Los Alamos Non-Rad
Project Number: 888S

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Lot #: F2F260137

Date Reported: 7/10/02

Client Sample ID: GW14-02-46328
Sample #: 001 Date Sampled: 06/21/02 Date Received: 06/26/02 Matrix: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD	
Semivolatile Organic Compounds by GC/MS					In Review
Acenaphthene	ND	10	ug/L	SW846 8270C	
2,4-Dinitrophenol	ND	50	ug/L	SW846 8270C	
4-Nitrophenol	ND	50	ug/L	SW846 8270C	
Dibenzofuran	ND	10	ug/L	SW846 8270C	
2,4-Dinitrotoluene	ND	10	ug/L	SW846 8270C	
Diethyl phthalate	ND	10	ug/L	SW846 8270C	
Fluorene	ND	10	ug/L	SW846 8270C	
4-Chlorophenyl phenyl ether	ND	10	ug/L	SW846 8270C	
4-Nitroaniline	ND	20	ug/L	SW846 8270C	
4,6-Dinitro-2-methylphenol	ND	50	ug/L	SW846 8270C	
N-Nitrosodiphenylamine	ND	10	ug/L	SW846 8270C	
Azobenzene	ND	20	ug/L	SW846 8270C	
4-Bromophenyl phenyl ether	ND	10	ug/L	SW846 8270C	
Hexachlorobenzene	ND	10	ug/L	SW846 8270C	
Pentachlorophenol	ND	50	ug/L	SW846 8270C	
Phenanthrene	ND	10	ug/L	SW846 8270C	
Anthracene	ND	10	ug/L	SW846 8270C	
Fluoranthene	ND	10	ug/L	SW846 8270C	
Pyrene	ND	10	ug/L	SW846 8270C	
Butyl benzyl phthalate	ND	10	ug/L	SW846 8270C	
Benzo(a)anthracene	ND	10	ug/L	SW846 8270C	
3,3'-Dichlorobenzidine	ND	20	ug/L	SW846 8270C	
Chrysene	ND	10	ug/L	SW846 8270C	
bis(2-Ethylhexyl) phthalate	7.7 J	10	ug/L	SW846 8270C	
Di-n-butyl phthalate	ND	10	ug/L	SW846 8270C	
Di-n-octyl phthalate	ND	10	ug/L	SW846 8270C	
Benzo(b)fluoranthene	ND	10	ug/L	SW846 8270C	
Benzo(k)fluoranthene	ND	10	ug/L	SW846 8270C	
Benzo(a)pyrene	ND	10	ug/L	SW846 8270C	
Indeno(1,2,3-cd)pyrene	ND	10	ug/L	SW846 8270C	
Benzo(ghi)perylene	ND	10	ug/L	SW846 8270C	
Dibenz(a,h)anthracene	ND	10	ug/L	SW846 8270C	

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