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Completion Report for Well R-25b, Revision 1

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EXECUTIVE SUMMARY

This well completion report describes the drilling, installation, and testing of Los Alamos National Laboratory (the Laboratory) upper saturated zone well R-25b located on the mesa top in Technical Area 16 (TA-16), Los Alamos, New Mexico. This single-screen well is set at depth in the upper saturated zone to replace screen 1 in the existing R-25 well. R-25 was installed to provide hydrogeology and water-quality data as required by the March 1, 2005, Compliance Order on Consent for environmental remediation at the Laboratory. Well R-25b was installed to identify potential presence of perched groundwater and contamination in the upper saturated zone that may be associated with effluents containing high explosives discharged from the TA-16-260 Outfall.

The R-25b borehole was successfully drilled to a total depth (TD) of 786 ft below ground surface (bgs) and was terminated in the Otowi Member of the Bandelier Tuff. A well was installed with a screen interval of 750 to 770 ft bgs. Cuttings were collected at 10-ft intervals from the ground surface to TD and at 5-ft intervals within targeted zones where there was no recovery during completion of the companion borehole R-25c.

The drilling method for borehole R-25b was direct air rotary and casing hammer with water and foam assist, as needed, above the known saturation interval. Casing advance using the STRATEX system was used to drill below 524 ft to the TD of 786 ft bgs.

A cased-hole suite of geophysical logs was completed in R-25c (located 50 ft from R-25b) for hydrogeologic characterization. The logged interval coincides with the borehole interval for R-25b; therefore, the results of the logging are included in this report. No additional geophysical characterization was conducted in the R-25b borehole.

The well was completed in accordance with the New Mexico Environment Department–approved well design, with the screened interval installed to intercept the first water-bearing zone. The well has been developed, with a total of 5294 gal. removed as of November 6, 2008. Because of the persistence of elevated turbidity, an evaluation of potential causes of the turbidity was initiated in November 2008. Well development activities may be resumed, based on the results of this analysis, to attempt to reduce turbidity further.

Well surface completions were implemented following well development and consist of a 10 ft by 10 ft reinforced concrete pad surrounding a large-diameter protective steel casing. A brass survey monument was installed in the northwest corner of the pad. Four concrete-filled bollards were installed surrounding the pad.

A geodetic survey of wells R-25b and R-25c was completed on November 17, 2008. The elevation and location of a brass monument set in each concrete pad, along with the elevation and location of the rim of the inner and outer well casings, were recorded using a global positioning system.

Dedicated pressure transducer and well sampling pump systems are being installed in the casing to allow for ongoing groundwater sampling and water-level measurements. Investigation-derived waste management is being completed in accordance with the waste characterization plan. Site restoration activities will be completed as soon as weather allows.

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Abbreviations and Acronyms

µS	microsiemens
amsl	above mean sea level
API	American Petroleum Institute
APS	Acceleration Porosity Sonde
bgs	below ground surface
cu	capture units
DI	deionized
ECS	Elemental Capture Spectroscopy
ELAN	Elemental Log Analysis
GR	gamma ray
HE	high explosives
HNGS	Hostile Natural Gamma Spectroscopy
I.D.	inside diameter
I/S	illite/smectite
LANL	Los Alamos National Laboratory
lbf	pound force
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
O.D.	outside diameter

PVC	polyvinyl chloride
QC	quality control
RPF	Records Processing Facility
TD	total depth
TLD	Triple Lithodensity Detector
WDS	WDS Exploration & Wells
XRD	x-ray diffraction

1.0 INTRODUCTION

This monitoring well completion report summarizes the site preparation, drilling, well construction, aquifer evaluation, and related activities completed to date for monitoring well R-25b. Monitoring well R-25b was drilled and completed in October 2008 at Los Alamos National Laboratory (LANL or the Laboratory) for the Environmental Programs Water Stewardship Program.

The R-25 site is located on the mesa top in Technical Area 16 (TA-16) at the Laboratory (Figure 1.0-1). A detail of the R-25 site layout is shown in Figure 1.0-2. TA-16, also known as S-Site, contains many of the Laboratory's high explosives (HE) facilities, the Laboratory's state-of-the-art tritium facility, and several administrative support buildings. Activities involve fabricating and testing HE, plastics, and adhesives; conducting research in process development for manufacturing HE, plastics, adhesives, and other materials; and tritium processing.

The existing R-25 well was installed to monitor for potential contamination in groundwater associated with effluents containing HE discharged from an HE manufacturing facility outfall at TA-16-260 (Figure 1.0-1). R-25 was completed in 1999 and includes nine separate screened intervals. The first three screen intervals (screens 1, 2, and 3) of R-25 are believed to be compromised (screen 3 was drilled out because of damage during installation, and screened intervals 1 and 2 appear to be impacted by the activities conducted in screen 3).

R-25b is a replacement well for the first screened interval (screen 1). Well R-25b was designed to monitor upper saturated zone water-quality at 750 to 770 ft below ground surface (bgs). The purpose of monitoring well R-25b is to provide hydrogeology and water-quality data as required by the March 1, 2005, Compliance Order on Consent (the Consent Order) for environmental remediation at the Laboratory. A separate well (R-25c) was installed to monitor the screen 3 interval in R-25. Activities related to R-25c are detailed in a separate well completion report (LANL 2008, 103408). The location and placement of screened intervals in both wells (R-25b and R-25c) was at the direction of the New Mexico Environment Department (NMED), in accordance with the Consent Order.

The R-25b borehole was successfully drilled to a total depth (TD) of 786 ft bgs and was terminated in the Otowi Member of the Bandelier Tuff. A well was installed with a screen interval between 750 and 770 ft bgs. Cuttings were collected at 10-ft intervals from the ground surface to TD from the drill discharge hose, with samples at 5-ft intervals from those horizons in which no cuttings were recovered in borehole R-25c.

Postinstallation activities, including well development, surface completion, and geodetic surveying, were completed in October and November 2008. Well development activities included initial surging and bailing, followed by installation of a submersible pump and continued pumping and surging from October 13 to November 6, 2008. The geodetic survey of wells R-25b and R-25c was completed on November 17, 2008, following installation of the concrete pads and protective well casings. A dedicated In-Situ Level Troll pressure transducer and Bennett sampling pump system are being installed in the well in accordance with the approved design. Investigation-derived waste disposal is ongoing; disposition of the cuttings and purged groundwater will be completed in accordance with approved plans. Site restoration activities have been initiated and will be completed as weather allows.

The information presented in this report was compiled from field reports and activity summaries. Records, including the field reports, field logs, and survey information are on file at the Environmental Programs Directorate's Records Processing Facility (RPF). This report contains brief descriptions of all activities associated with the R-25b project as well as supporting figures, tables, and appendixes.

2.0 PRELIMINARY ACTIVITIES

Preliminary activities included preparing administrative planning documents and improvements to the drill site (Figure 1.0-2).

2.1 Administrative Preparation

The following documents were used to guide the implementation of the scope of work for this well:

- “Drilling Work Plan for Well R-25b” (LANL 2008, 100696)
- “Storm Water Pollution Prevention Plan for R-25b and R-25c Well Drilling Construction Site,” which is an addendum to “Storm Water Pollution Prevention Plan for SWMUs and AOCs (Sites) and Storm Water Monitoring Plan” (LANL 2006, 092600)
- “Waste Characterization Strategy Form for the R-25 Monitoring Well Installation” (June 2008, EP2008-0340)
- “Drilling Work Plan for Intermediate Aquifer Well R-25b” (LANL 2007, 098121), which includes the NMED-approved well completion design

2.2 Site Preparation

Site preparation was performed from June 18 to June 30, 2008, and included implementation of best management practices in accordance with the Storm Water Pollution Prevention Plan. This included minimal clearing of vegetation and expansion of the existing R-25 pad and lay-down areas; excavating and lining cuttings containment pits; and installing berms, silt fences, and straw wattles to control stormwater runoff and minimize erosion. An office trailer, sanitary facilities, and other field equipment were also moved to the site during this time. The drill pad measured approximately 60 ft × 220 ft and is covered with base-course gravel.

Two cuttings pits were constructed on the R-25 site, one each for R-25c and R-25b. Each of these pits was constructed with a central berm so cuttings from above the saturated interval could be segregated from those below. This was done to potentially minimize the volume of cuttings requiring off-site disposal because there is a reasonable expectation that the formation above saturation is not contaminated. The two R-25b cells each measured approximately 45 ft × 30 ft with an 8-ft average depth. The two pits were lined with plastic sheeting,10 mil in thickness.

Radiation control technicians from the Laboratory’s Radiation Protection Group-1 performed radiological screening of all construction equipment entering the S-Site limited access area, as necessary. All equipment or vehicles that were taken off-road or otherwise came into contact with soils were screened for HE by representatives from TA-16 Access Control before exiting from the S-Site limited access area.

Potable water used for drilling, dust suppression, and well installation was obtained from an existing Laboratory fire hydrant (#618), approximately 500 ft west of the site on Burning Grounds Road. The water was temporarily contained in a 2500-gal. water tank in the hull of the rod truck at the site.

Safety barriers and signs were installed around the borehole cuttings containment pits and at the pad entrance.

On June 30, 2008, WDC Exploration & Wells (WDC) mobilized drilling equipment to the site. On July 1, 2008, a decontamination pad was constructed, and downhole equipment that would be used to advance the borehole was pressure-washed with a steam cleaner using the potable water source. The

Laboratory conducted a mast-up drill rig equipment inspection at the site before drilling activities began on July 2, 2008. Borehole R-25c was completed first, and then the drill rig was moved to the R-25b location on September 11, 2008. All downhole tools and equipment were pressure-washed before use in borehole R-25b to prevent potential cross-contamination.

3.0 DRILLING ACTIVITIES

The proposed drilling method for borehole R-25b was direct air rotary and casing hammer with water and foam assist, as needed, above the expected saturation interval. Foam was not used to advance the borehole within approximately 150 ft of the first saturated interval. The borehole was completed using a Failing Co. Speedstar 50K drill rig (WDC Rig 111). Air used for drilling the borehole was provided by one deck-mounted 900 ft3/min compressor and three trailer-mounted auxiliary air compressors.

On September 11, 2008, a 16-in.-outside diameter (O.D.) permanent surface conductor casing (¼-in.-thick steel) was set to 18.7 ft bgs and was grouted in place. A bentonite plug was set at the base of the borehole, which was subsequently drilled out as the borehole was advanced. On September 12, 2008, the 14 ¾-in.-diameter open borehole was advanced to 145 ft bgs with a tricone button bit, roller stabilizer, and drill collar assembly using air and water to lift the drill cuttings. From September 13 to September 16, 2008, the open hole was advanced from 145 to 524 ft bgs with the same equipment; however, approved drilling foam (Baroid AQF-2) was added to the injected water to aid in lifting the drill cuttings to the surface. No drilling fluid other than water was used below 524 ft bgs (approximately 150 ft above the potential saturated horizon). See Table 3.0-1 for fluid quantities used.

To minimize circulation and borehole stability problems as encountered in R-25c, steel casing (11 ¾-in.-O.D.) was set from the surface to 524 ft bgs in the open borehole. From September 24 to September 27, 2008, the WDC crew advanced casing using a STRATEX drive shoe to total borehole depth of 786 ft bgs. The STRATEX casing bit overreams the borehole to approximately 13 ¼-in.-diameter. Upon reaching borehole TD, the casing was then retracted to 724 ft for video logging.

On September 28 and again on September 29, 2008, the Laboratory ran a video survey of the borehole to a depth of approximately 775 ft to confirm the presence of saturation in the borehole below the bottom of the casing and to observe the condition of the formation in the interval targeted for screening. The camera confirmed the bottom of the casing shoe at 724 ft bgs and also confirmed the tagged water level at 750 ft bgs on September 28 and at 759 ft bgs on September 29. There was no visual evidence of water seepage from the borehole wall between the standing water level and the bottom of the casing shoe on either date. One other observation from the video survey was that a borehole wall “skin” was apparent in the open interval between the bottom of the casing and the standing water level. This skin was likely the result of smearing of the formation (Otowi Member of the Bandelier Tuff) during borehole advancement.

Based on the observed static water levels during borehole completion, the well design was finalized with the screened interval from 750 to 770 ft bgs to ensure this water-bearing zone is within the screened interval. Well construction activities commenced on September 29, 2008.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities at R-25b.

4.1 Cuttings Sampling

Cuttings samples were collected from R-25b at approximately 10-ft intervals from the ground surface to the TD of 786 ft bgs, except for collection at 5-ft intervals at depths where there was no recovery in borehole R-25c. Bulk samples of varying volumes were collected from the discharge hose and retained as an unsieved (whole rock) fraction. For those intervals with no recovery in R-25c, sieved fractions (>#10 and >#35 mesh) were also collected at 5-ft intervals and retained in chip trays along with an unsieved (whole rock) fraction. All unsieved material was sealed in labeled Ziploc bags for eventual transfer to the Laboratory Sample Management Office. No cuttings samples were submitted for laboratory analysis.

4.2 Water Sampling

No water samples were collected during the drilling of monitoring well R-25b.

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at R-25b is presented below.

The Laboratory's geology task leader and site geologists used cuttings examination along with Laboratory and Schlumberger geophysical logs collected in borehole R-25c to determine the geologic contacts at this location. While cuttings were collected from borehole R-25b to augment data and observations already reported for R-25c, no changes were made to the lithology and contacts as reported in the R-25c lithologic log (LANL 2008, 103408, Appendix A). Drilling observations, video logging, water-level measurements, and geophysical logs were used to describe groundwater characteristics encountered at both R-25b and R-25c.

5.1 Stratigraphy

Borehole stratigraphy for the R-25b borehole is presented below in order of youngest to oldest geologic units. Figure 5.1-1 illustrates the stratigraphy at R-25b. A detailed lithologic log (based on samples from R-25b and R-25c) is presented in Appendix A.

Quaternary Alluvium, Qal (0 to 5 ft bgs)

Quaternary alluvium, consisting of poorly to moderately sorted loose sand, was encountered from 0 to 5 ft bgs. No evidence of alluvial groundwater was observed.

Tshirege Member of the Bandelier Tuff, Qbt (5 to 384 ft bgs)

Four subunits of the Tshirege Member of the Bandelier Tuff—Qbt 1, Qbt 2, Qbt 3, and Qbt 4—were encountered at R-25c from 5 to 384 ft bgs. Qbt 1 and Qbt 3 have been further subdivided, as indicated below.

Qbt 4 was present from 0 to 84 ft bgs. It consisted of a pale yellowish brown to light brownish gray, nonwelded to moderately welded crystal-rich devitrified ash-flow tuff. Cuttings from this interval typically contained fine ash matrix material with abundant quartz and sanidine crystals, and minor intermediate composition volcanic lithics.

The interval from 84 ft to 228 ft bgs includes an upper subunit Qbt 3t, with chemical properties that are transitional between lower Qbt 3 and Qbt 4. Qbt 3t and Qbt 3 were present in the R-25c borehole from 84 to 155 ft bgs and from 155 to 228 ft bgs, respectively. Both units are composed of a pale yellowish brown, brownish black, or medium gray, nonwelded to moderately welded, devitrified, crystal-rich ash-flow tuff and are mineralogically and texturally similar. Cuttings samples contained abundant welded, crystal-rich tuff with quartz and sanidine phenocrysts and generally minor quantities of intermediate composition volcanic lithics and feldspar crystals.

Qbt 2, from 228 to 332 ft bgs, is a grayish-brown to grayish-red, moderately to strongly welded, crystal-rich devitrified ash-flow tuff. Samples are generally composed of crystal-rich tuff fragments and quartz and sanidine crystals. Occasional intermediate to mafic composition volcanic lithics and vapor-phase altered pumice fragments are also observed.

The basal cooling unit of the Tshirege Member is divided into upper devitrified (Qbt 1v) and lower glassy (Qbt 1g) subunits (Broxton and Reneau 1995, 049726). Qbt 1v was present from 332 to 369 ft bgs as a grayish-brown to dusky brown, nonwelded to partially welded, devitrified, ash-flow tuff. Matrix tuff fragments are crystal rich with quartz and sanidine crystals. Rare mafic composition volcanic lithic fragments and minor vapor-phase altered pumice were observed. Qbt 1g was present from 369 to 384 ft bgs as a medium gray, nonwelded, vitric ash-flow tuff. Pinkish-gray fibrous vitric pumice was common.

Cerro Toledo Interval, Bandelier Tuff, Qct (384 to 740 ft bgs)

Volcaniclastic sedimentary and tephra deposits of the Cerro Toledo interval separate the Tshirege and Otowi Members of the Bandelier Tuff. The Cerro Toledo interval occurred in borehole R-25c from 384 to 740 ft bgs.

This interval contained poorly sorted uncemented fine to coarse-grained deposits of sand and fine gravel. Clasts are predominantly angular to rounded fragments from dacitic and rhyolitic flows, vitric pumice, nonwelded tephras, and abundant felsic crystals including bipyramidal quartz and sanidine. Rare fine sandstone was also observed. Clasts are generally light to dark gray and reddish brown. Pumice and tephras are light brown and white or orange where oxidized. The presence of quartz and sanidine crystals, up to 2 mm in diameter, indicates that the Cerro Toledo interval includes a component of reworked Otowi Member tuff.

Otowi Member of the Bandelier Tuff, Qbo (740 to 843 ft bgs)

The Otowi Member of the Bandelier Tuff is present in R-25c from 740 to 843 ft bgs. The depth interval for the Otowi Member is constrained primarily by natural gamma logs collected in R-25c. The Otowi Member is a lithic-bearing, partly pumiceous, and nonwelded ash-flow tuff. It contains reddish gray to gray, subangular to subrounded, intermediate composition volcanic rocks up to 15 mm. Pale yellow to white pumice lapilli are vitric and contain conspicuous phenocrysts of quartz and sanidine. Borehole R-25b was completed in this unit.

5.2 Groundwater

Groundwater was first recognized in R-25b during drilling at approximately 750 ft bgs in the Otowi Member of the Bandelier Tuff. This depth is similar to that encountered in R-25 but is significantly higher than that encountered in R-25c. The water level measured during drill casing advance ranged from 749 to 759.1 ft bgs.

Because of the proximity of R-25 to the new monitoring wells, pressure responses at adjacent screens in R-25b, CdV-16-1(i), and CdV-16-2(i)r were monitored during drilling of R-25b and R-25c. The collected pressure information suggests that (1) the vadose zone near CdV-16-1(i), R-25, R-25b, and R-25c is hydraulically well connected and (2) R-25b and R-25c are in good hydraulic contact with the formation. A synthesis of groundwater observations in these nearby wells is included as Appendix B.

Turbidity in water pumped during development of well R-25b has persisted. The Laboratory initiated an evaluation of water and well construction material samples in an attempt to isolate the source of the turbidity. Elevated turbidity in water produced from the screen at R-25b is caused by a very smectitic illite/smectite clay mineral typical of bentonite sources. The likeliest source of this clay mineral is from either annular fill bentonite chips or high-solids bentonite grout. A summary of the evaluation is included as Appendix C.

6.0 BOREHOLE LOGGING

A suite of cased-hole geophysical logs (conducted by Schlumberger; Appendix D) and multiple downhole video and natural gamma surveys (conducted by the Laboratory) were run during the drilling and installation of R-25c. The logs from these surveys are included in the R-25c well completion report (LANL 2008, 103408, Appendix A). No geophysical logging was conducted during drilling of R-25b; however, video logging was conducted in R-25b to evaluate borehole conditions in the vicinity of the first water-bearing horizon. A summary of video (R-25b only) and geophysical logging (R-25c only) runs is presented in Table 6.0-1, and described in the following sections.

6.1 Video Logging

Video logs were collected to evaluate borehole conditions and confirm water-bearing horizons during advancement of R-25b but are not presented in this report because they provided no additional detail on geological and groundwater features. Table 6.1-1 details individual video logging runs pertinent to the R-25b borehole interval.

- The Laboratory completed a video survey of R-25b on September 28, 2008, to verify depths to water (as documented by tagline) and to the casing shoe, to observe the condition of the borehole wall below the casing shoe, and to determine if there was any evidence of water seepage from the formation between the casing and the apparent static water level of 750 ft. The casing shoe was noted at 724 ft bgs, and there was no evidence of water seepage between the casing shoe and the standing water level. An approximately ¼-in. borehole wall “skin” of apparent smeared formation was observed in this interval.
- On September 29, 2008, the Laboratory ran a second video survey of R-25b. The water level in the borehole was observed at 759 ft bgs and no seepage below the casing was noted.

6.2 Geophysical Logging

While no geophysical logging was conducted in borehole R-25b, logging activities by the Laboratory and Schlumberger in borehole R-25c were conducted within the interval common to R-25b. The logs relevant to R-25b are summarized below.

On July 12, 2008, the Laboratory ran a natural gamma ray and an induction log of the uncased R-25c borehole to 609.1 ft bgs (in addition to performing a video log of the borehole).

- A suite of Schlumberger geophysical logs was run inside the drill casing of R-25c on August 13 and August 14, 2008. At the time of logging, the bottoms of the two casing strings in the R-25c borehole were located at the following depths:
    - bottom of 16-in. casing: 19.8 ft bgs
    - bottom of 11.75-in. casing: 848.5 ft bgs
- On August 13, 2008, the Schlumberger geophysical suite included Hostile Natural Gamma Spectroscopy (HNGS) and Elemental Capture Spectroscopy (ECS). HNGS was run uphole inside the casing from 850 to 700 ft bgs. ECS was run uphole inside the casing from 850 to 600 ft bgs.
- On August 14, 2008, the geophysical suite included Triple Lithodensity Detector (TLD) and Accelerator Porosity Sonde (APS). Both were run uphole inside the casing from 850 to 600 ft bgs.

The final Schlumberger logs and report from the R-25c survey are amended to this report (Appendix D), because they are pertinent to the screened interval of well R-25b.

7.0 WELL INSTALLATION

R-25b well casing and annular fill were installed between September 29 and October 13, 2008.

7.1 Well Design

The well design was submitted as part of R-25b screen replacement work plan and approved by NMED (2007, 098996). The original proposed screen interval was 738 to 758 ft bgs; however, R-25b was constructed with a screened interval of 750 to 770 ft bgs. The shift downhole of 12 ft was based on observations made during drilling and downhole video logging conducted on September 28 and 29, 2008 (see section 6.1 for further discussion).

7.2 Well Construction

The R-25b well casing was constructed of 5.0-in.-inside diameter (I.D.)/5.563-in.-O.D. 304 (non–American Petroleum Institute [API]) stainless-steel blank casing joints fabricated to American Society for Testing and Materials A312 standards. Casing ends, screen ends, and couplings were threaded with 5-in. eight round short-casing threads in compliance with API Standard 5B. The well screen consists of two consecutive 10-ft lengths of 5.0-in.-I.D./5.563-in.-O.D. rod-based 0.020-in. (slot-size) wire-wrapped well screen. The casing and screen were factory cleaned and also steam-cleaned onsite. R-25b was constructed with a screened interval from 750 to 770 ft bgs. A 10.44-ft long piece of blank well casing was placed below the well screen for a sump. Figure 7.2-1 shows construction details for the completed well.

On September 29, 2008, well construction began with the placement of a 2-in.-I.D. steel integral joint tremie pipe in the borehole to a depth of 750 ft bgs. The tremie pipe was used to deliver annular fill materials during well construction.

The borehole was backfilled to approximately 778 ft bgs with 10/20 Colorado silica sand to provide a stable base for the well string. A 2-ft seal consisting of ⅜-in. bentonite chips was installed around the well sump from 778 to 776 ft bgs.

The primary filter pack of 10/20 silica sand was placed from 6 ft below the bottom of the screened interval to 5 ft above the top of the screen (776 to 745 ft bgs). The screened interval was set from 750.0 to 770.8 ft bgs. A transition sand collar of 20/40 silica sand was then placed above the primary filter pack from 745 to 742.5 ft bgs. Following placement of the fine sand collar, the drill crew installed another ⅜-in. bentonite chip seal from 742.5 to 718 ft bgs to protect the well screen from the bentonite slurry being placed above the seal.

Upon completing the placement of the bentonite chip seal to 718 ft bgs, the drill crew began backfilling the annular space from 718 to 574 ft bgs with a high-solids bentonite grout. In response to problems with grout emplacement in R-25c, a small quantity of soda ash was added to the first two lifts of high solids bentonite slurry from approximately 718 to 684 ft bgs. Addition of the soda ash was not beneficial; therefore, its use was discontinued above 684 ft. High-solids bentonite grout emplacement continued to 574 ft to bring the backfill to depth. To seal the borehole more effectively, from 574 to 84 ft bgs, bentonite chips were placed in the annulus and hydrated after approximately every 10-ft lift. A Portland cement seal with 2% bentonite was placed from 84 to approximately 8 ft bgs. The well casing was cut approximately 3 ft bgs to facilitate well completion. Well construction was completed on October 13, 2008, at which time the water level was measured at 759.1 ft bgs. Figure 7.2-1 depicts depths and volumes of materials used in each interval. Table 7.2-1 details volumes of materials used during well construction.

8.0 POSTINSTALLATION ACTIVITIES

A wellhead surface pad was installed at the well location, and a geodetic survey was performed on November 17, 2008. Site restoration activities will commence once the final disposition of drill cuttings and groundwater is determined in accordance with the NMED-approved waste decision trees.

8.1 Well Development

Well development began on October 13, 2008. Initially, the screen was bailed and swabbed to remove formation fines in the filter pack. Bailing and swabbing continued until October 15, with a total of approximately 740 gal. of water removed by bailing. Well response suggested that the well could be pumped at a reduced flow rate, and a 1 HP pump was installed on October 16, 2008. Water-quality parameters (pH, specific conductance, temperature, turbidity, oxygen, and redox potential) were monitored periodically during development. The results are summarized in Table 8.1-1. Well development continued for approximately 150 hours due to the continued presence of elevated turbidity. Development was terminated on November 6, 2008. To date, 5294 gallons have been removed from the well. A total of 2740 gal. of potable water was introduced during drilling activities within the saturated zone. While water-quality parameters have stabilized as of the report date (Figure 8.1-1), the water remains turbid. An evaluation of the nature of the turbidity is included in Appendix C. The Laboratory is currently considering more aggressive development methods in an attempt to clear the suspended material from the well.

8.2 Dedicated Monitoring System Installation

A dedicated In-Situ LevelTroll 500 transducer will be installed in a polyvinyl chloride (PVC) tube to continuously monitor water levels. The transducer tube is 1.0-in.-I.D. flush-threaded PVC with a 6-in. 0.010-in. screen-slot interval at the bottom of the tube. The transducer tube is capped on the bottom below the screen. A dedicated Bennett Model 1800 submersible piston pump will be installed for the purpose of groundwater sampling. The Bennett system consists of a sample pump, a tube bundle including a stainless-steel cable core, polypropylene air supply, exhaust tubes, and water discharge tube, and an electric cord for the water-level indicator. A well casing plate will be installed to anchor the tube bundle and transducer tube. Postinstallation construction and monitoring component installation details for R-25b are included in Figure 8.2-1.

8.3 Wellhead Completion

A reinforced concrete surface pad, 10 ft × 10 ft and 6 in. thick, was installed at R-25b, following completion of well development activities. The pad will provide long-term structural integrity for the well. A brass survey pin was embedded in the northwest corner of the pad. A 10-in.-I.D. steel protective casing with a locking lid was installed around the well riser. The concrete pad is slightly elevated above the ground surface, with base-course gravel graded up around the edges, to minimize potential for infiltration within the borehole annulus. Concrete-filled bollards, painted caution yellow were installed on each side of the pad to protect the well head from vehicular traffic. Refer to Figure 8.2-1 for completion details.

8.4 Geodetic Survey

The location and elevation of wells R-25b and R-25c were determined by geodetic survey on November 17, 2008. Data were collected with a Topcon Hyper+ differential GPS. Geodetic survey data for the well casing rim, protective casing, brass monument, and ground surface at R-25b were collected. The survey data is presented in Table 8.4-1.

Horizontal well coordinates are New Mexico State Plane Grid Coordinates, Central Zone (North American Datum of 1983) and are expressed in feet. Horizontal coordinates are based on GPS localization derived from the following LANL lab-wide control network monuments: A0001, A0002, A0003, A0006, A0009, A0306, B0001, B0004, B3303, BC1709, A-NMSR4-2, NMSR4-25, PAJ16, and PAJ10.

Elevation is expressed in feet above Mean Sea Level relative to the National Geodetic Vertical Datum of 1929. Vertical coordinates are based on GPS localization derived from the following Laboratory-wide control network monuments: A0003, A0006, A0306, A0602, B0001, B0004, B3303, BC1709, NMSR4-2, PAJ10, PAJ16.

8.5 Site Restoration and Waste Management

Fluids and cuttings produced during drilling and development were containerized and sampled in accordance with the 2008 “Waste Characterization Strategy Form for the R-25 Monitoring Well Installation” (LANL 2008, EP2008-0340), prepared for the R-25 well drilling at the Laboratory. Characterization samples of the various waste streams have been collected, and the waste managed in accordance with the waste characterization and strategy form.

Fluids and solids produced during drilling and well development will be land-applied after review of associated analytical results per the waste characterization strategy form and the Laboratory Environmental Protection Directorate Standard Operating Procedure 010.0, Land Application of Groundwater in accordance with the notice of intent decision tree (revised July 26, 2006). NMED approval was received via a letter dated November 21, 2006 (“NOI Decision Tree: Drilling, Development, Rehabilitation and Sampling Purge Water”), and/or “NOI Decision Tree for Management of Investigation-Derived Waste Solids from Drilling Operations,” November 2007. In the event water does not meet land application criteria, waste profiles will be prepared and the waste disposed in accordance with waste acceptance criteria of the receiving facility. Solids produced during drilling will be used to restore the areas of the cuttings pits to grade if they meet decision-tree criteria. Both liquid and solid land application will be conducted in accordance with the approved decision trees.

Waste generation and characterization for the R-25b project include a small quantity of contact waste, decontamination fluids, cuttings, discharged drilling water, and purged groundwater. Additionally, one drum of New Mexico special waste was generated following a diesel refueling overfill event on one of the air compressors. The waste material consisted of adsorbent cloth and diesel-contaminated soil. The waste profile has been finalized and the drum is scheduled for pickup and disposal as New Mexico special waste.

Site restoration activities will include removing water from the cuttings containment pits and land-applying it on-site, in accordance with the decision tree; removing cuttings from the cuttings containment pits; removing the polyethylene liner; removing the containment area berms and backfilling; and regrading the containment area. Cuttings will be used in accordance with governing documents outlined above. The site will be reseeded with a native seed mix consisting of Indian rice grass, mountain broam, blue stem, sand drop, and slender wheat grass seed. The seed mix will be applied at a rate of 20 lb/acre. Biosol fertilizer will be applied at a rate of 80 lb/acre.

9.0 DEVIATION FROM PLANNED ACTIVITIES

In general, drilling, sampling, and well construction at R-25b was performed as specified in the “Drilling Work Plan for Intermediate Aquifer Well R-25b” (LANL 2007, 098121). However, the screened interval was shifted downhole 10 ft (top of screen from 740 to 750 ft bgs) from the proposed well design (LANL 2007, 098121) to address the measured standing water-level fluctuations as observed during casing advance below 750 ft.

10.0 ACKNOWLEDGMENTS

Cabrera Services, Inc., provided management and oversight on all preparatory, reporting, and field-related activities.

EnviroWorks prepared the site for drilling activities and installed wellhead completion components.

Kleinfelder provided geologic field support and technical oversight and input related to drilling and aquifer evaluation, as well as preliminary report preparation.

Schlumberger conducted cased-borehole geophysical surveys.

WDC Exploration & Wells drilled the R-25 borehole and installed and developed the well.

Precision Surveys completed the geodetic survey.

11.0 REFERENCES AND MAP DATA SOURCES

11.1 References

The following list includes all documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate’s RPF and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; DOE-Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

Broxton, D.E., and S.L. Reneau, August 1995. "Stratigraphic Nomenclature of the Bandelier Tuff for the Environmental Restoration Project at Los Alamos National Laboratory," Los Alamos National Laboratory report LA-13010-MS, Los Alamos, New Mexico. (Broxton and Reneau 1995, 049726)

LANL (Los Alamos National Laboratory), March 2006. "Storm Water Pollution Prevention Plan for SWMUs and AOCs (Sites) and Storm Water Monitoring Plan," Los Alamos National Laboratory document LA-UR-06-1840, Los Alamos, New Mexico. (LANL 2006, 092600)

LANL (Los Alamos National Laboratory), June 2007. "Drilling Work Plan for Intermediate Aquifer Well R-25b," Los Alamos National Laboratory document LA-UR-07-3952, Los Alamos, New Mexico. (LANL 2007, 098121)

LANL (Los Alamos National Laboratory), February 2008. "Drilling Work Plan for Well R-25c," Los Alamos National Laboratory document LA-UR-08-0337, Los Alamos, New Mexico. (LANL 2008, 100696)

LANL (Los Alamos National Laboratory), September 2008. "Completion Report for Well R-25c," Los Alamos National Laboratory document LA-UR-08-5878, Los Alamos, New Mexico. (LANL 2008, 103408)

NMED (New Mexico Environment Department), November 2, 2007. "Approval of the Drilling Work Plan for Regional Aquifer Well R-25b," New Mexico Environment Department letter to D. Gregory (DOE-LASO) and D. McInroy (LANL) from J.P. Bearzi (NMED-HWB), Santa Fe, New Mexico. (NMED 2007, 098996)

11.2 Map Data Sources

Spatial data sources for map # 07-0071-3:

Locations for proposed wells are approximate and not yet surveyed. Locations provided by Los Alamos National Laboratory, Environmental Programs Directorate, Water Stewardship Project, February 2008.

Hypsography, 20 and 100 Foot Contour Intervals; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program; 1991.

Modeled Surface Drainage, 1991; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program, ER2002-0591; 1:24,000 Scale Data; Unknown publication date.

Paved and Dirt Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 10 September 2007.

Penetrations (Wells); Los Alamos National Laboratory, Environment and Remediation Support Services, EP2007-0442; 1:2,500 Scale Data; 16 July 2007.

Potential Release Sites; Los Alamos National Laboratory, Waste and Environmental Services Division, GIS/Geotechnical Services Group, EP2007-0682; 1:2,500 Scale Data; 29 October 2007.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 27 April 2007.

Technical Area Boundaries; Los Alamos National Laboratory, Site Planning & Project Initiation Group, Infrastructure Planning Division; 19 September 2007.

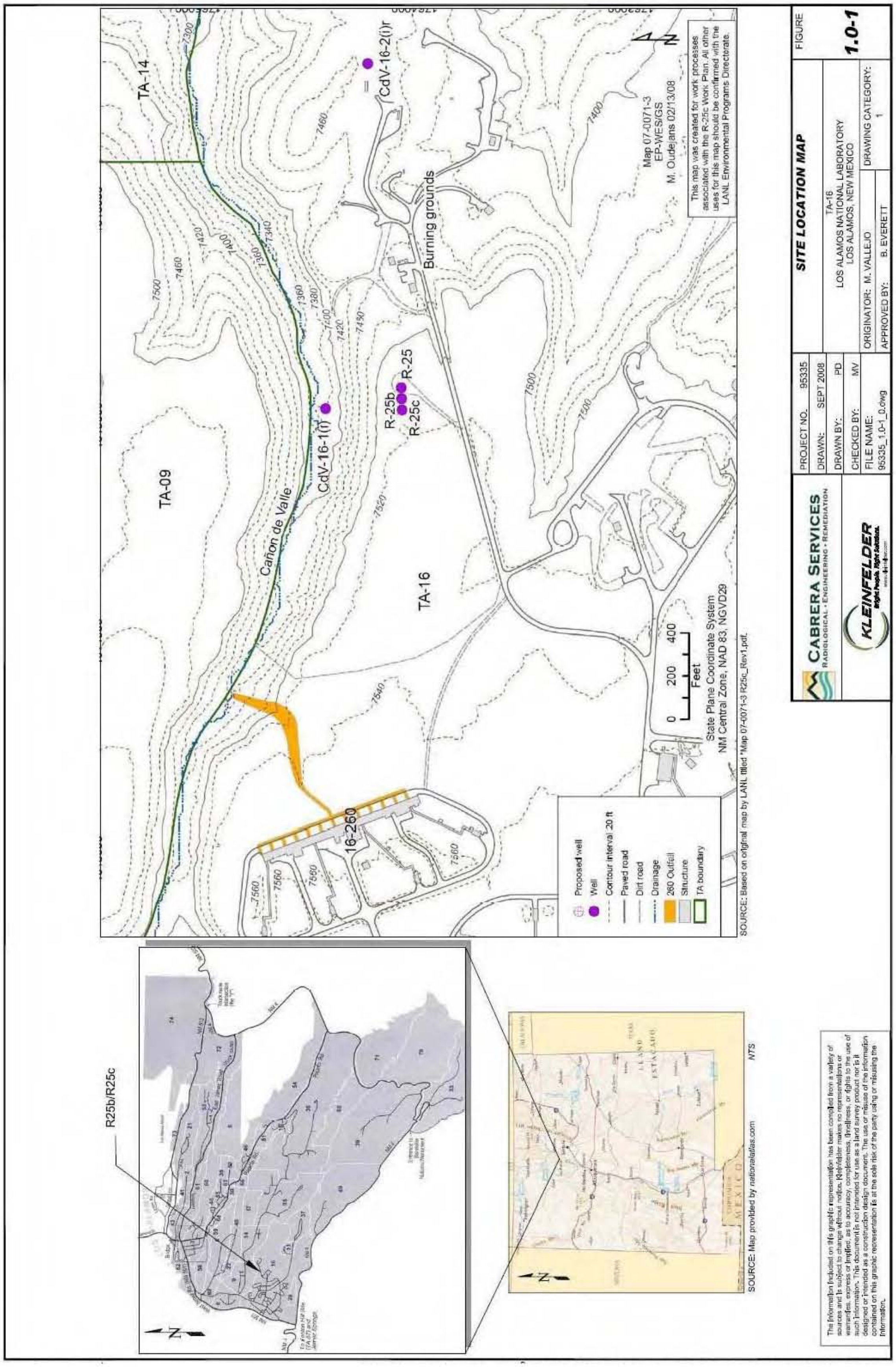

Figure 1.0-1 Site location

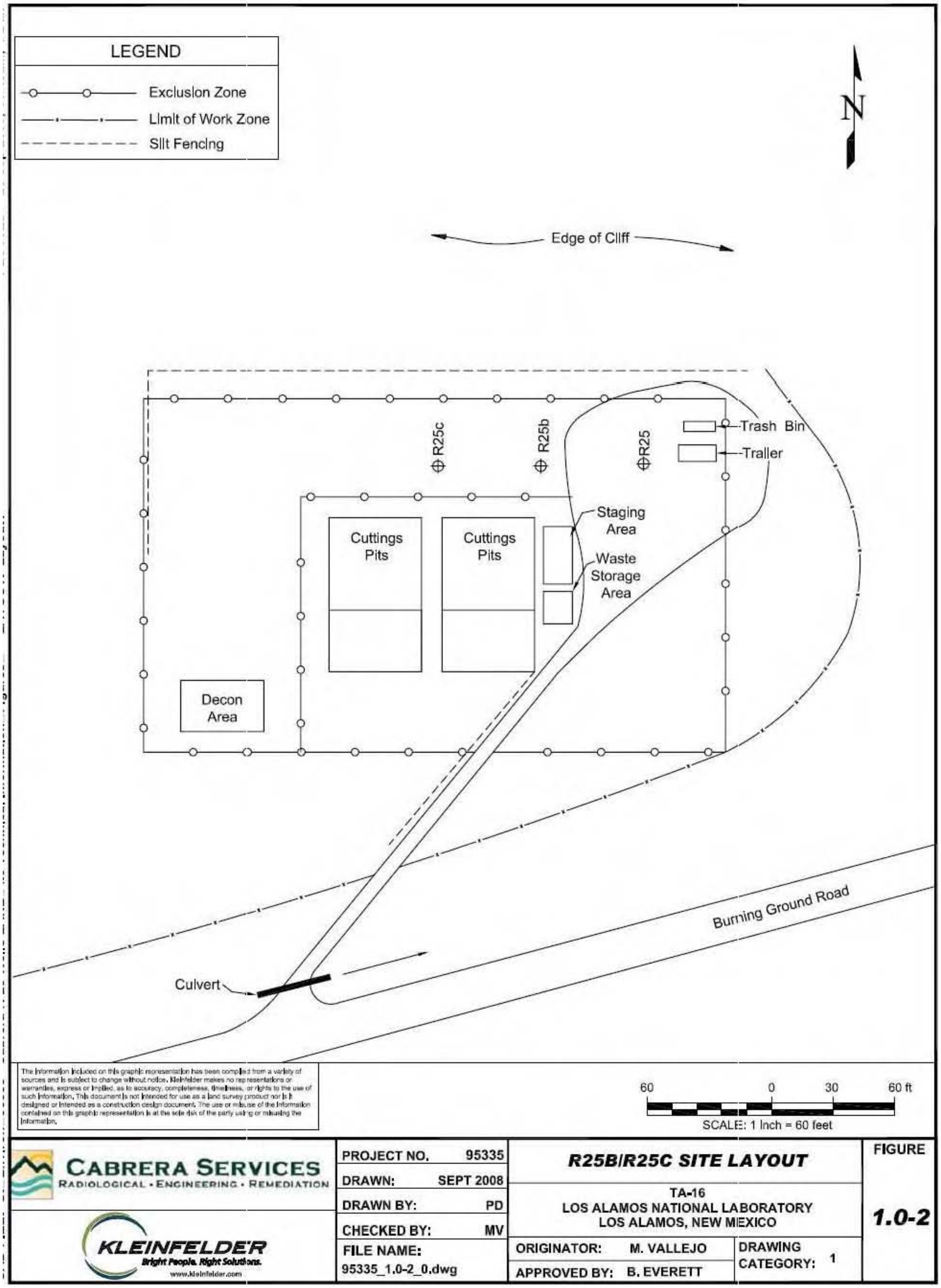

Figure 1.0-2 Site layout

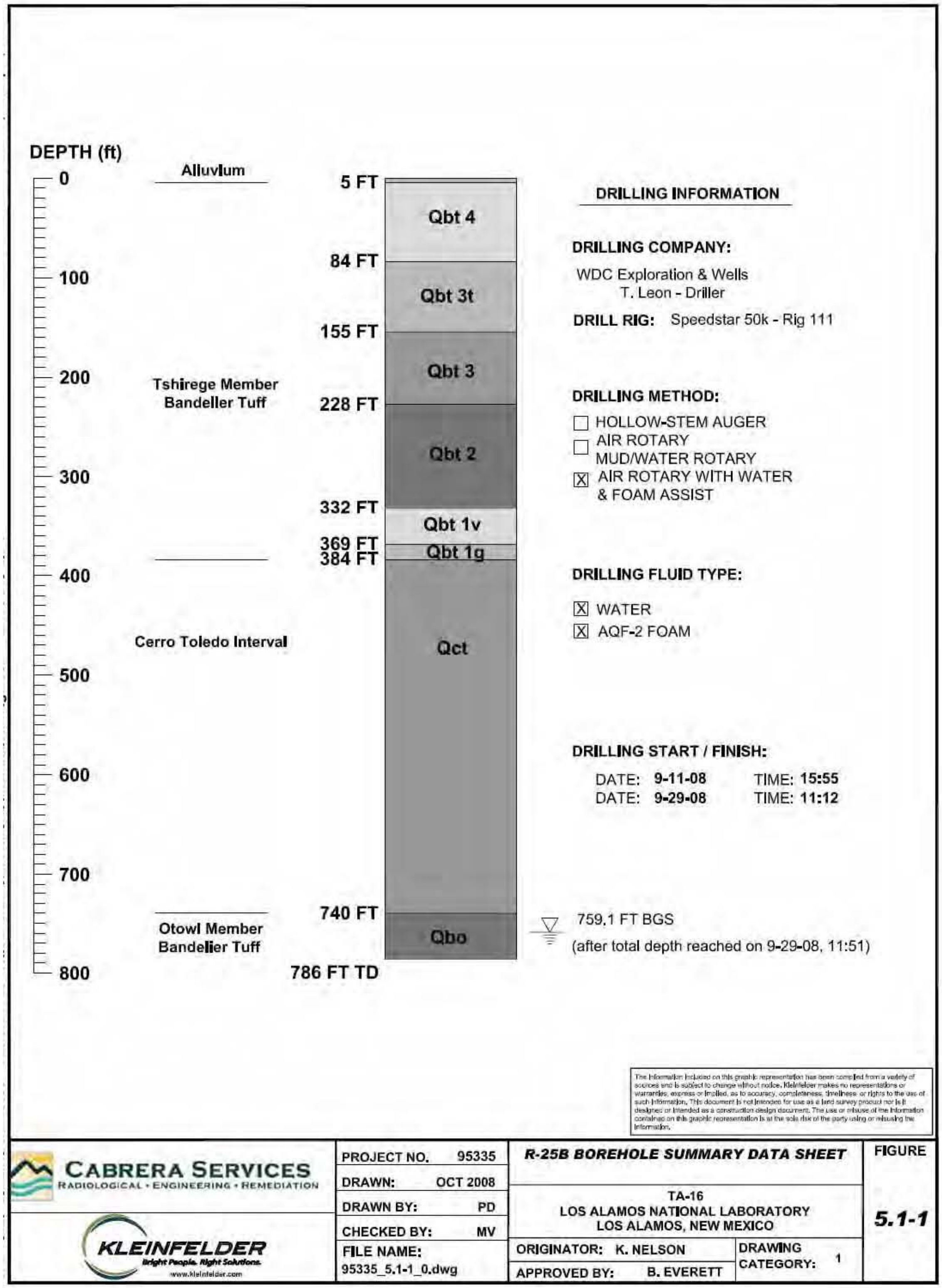

Figure 5.1-1 R-25b borehole summary data sheet

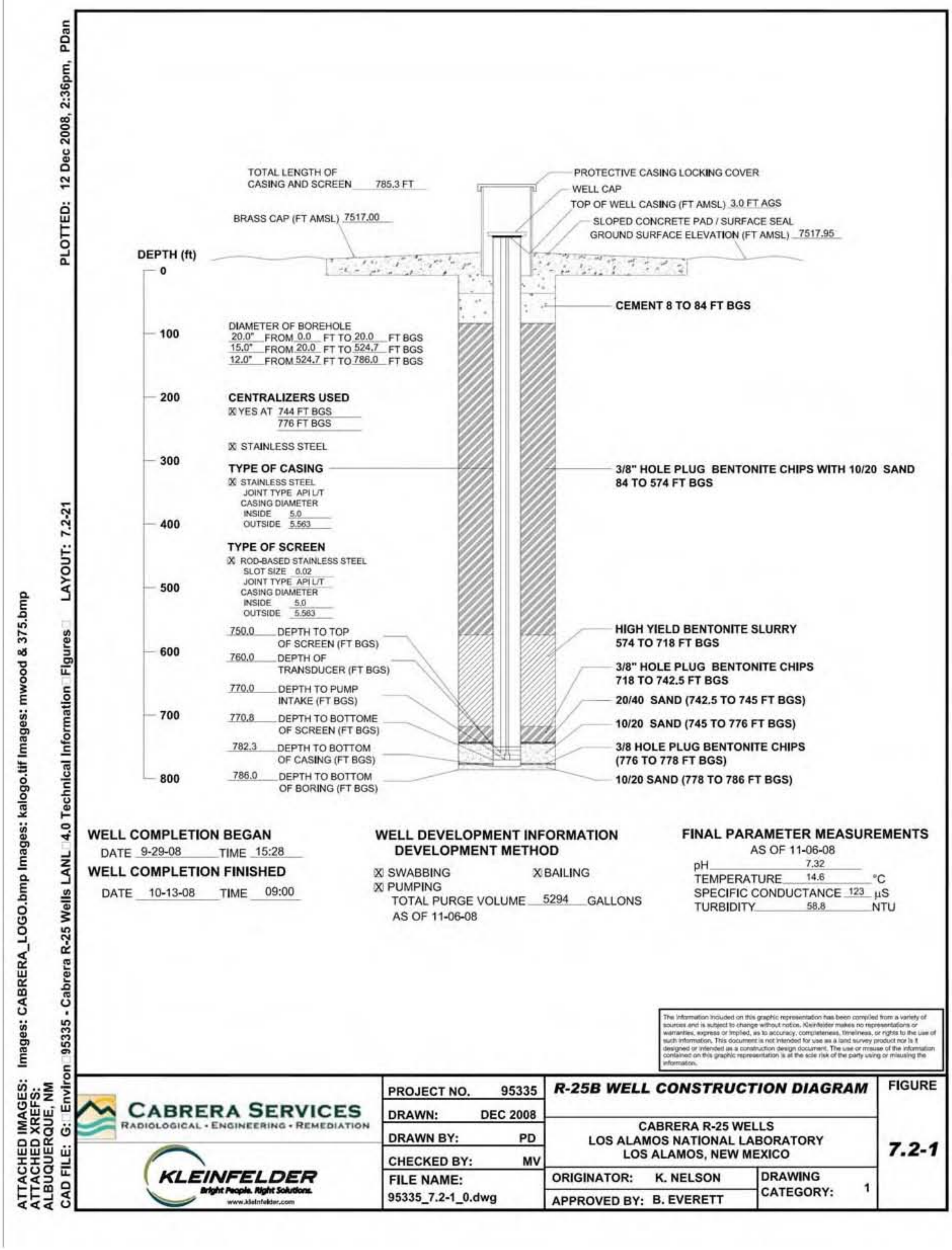

Figure 7.2-1 R-25b well construction diagram

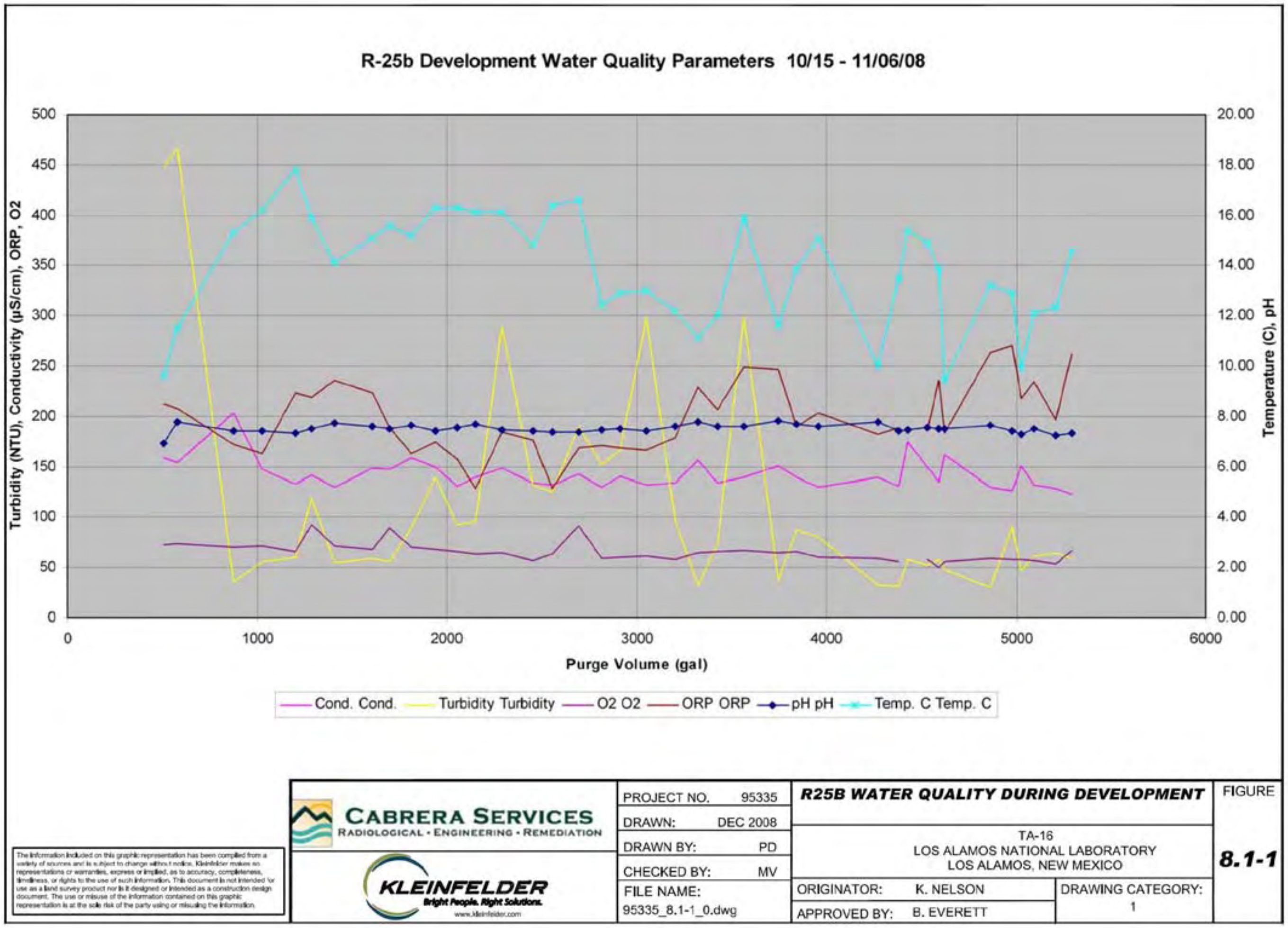

Figure 8.1-1 R-25b water-quality data through November 6, 2008

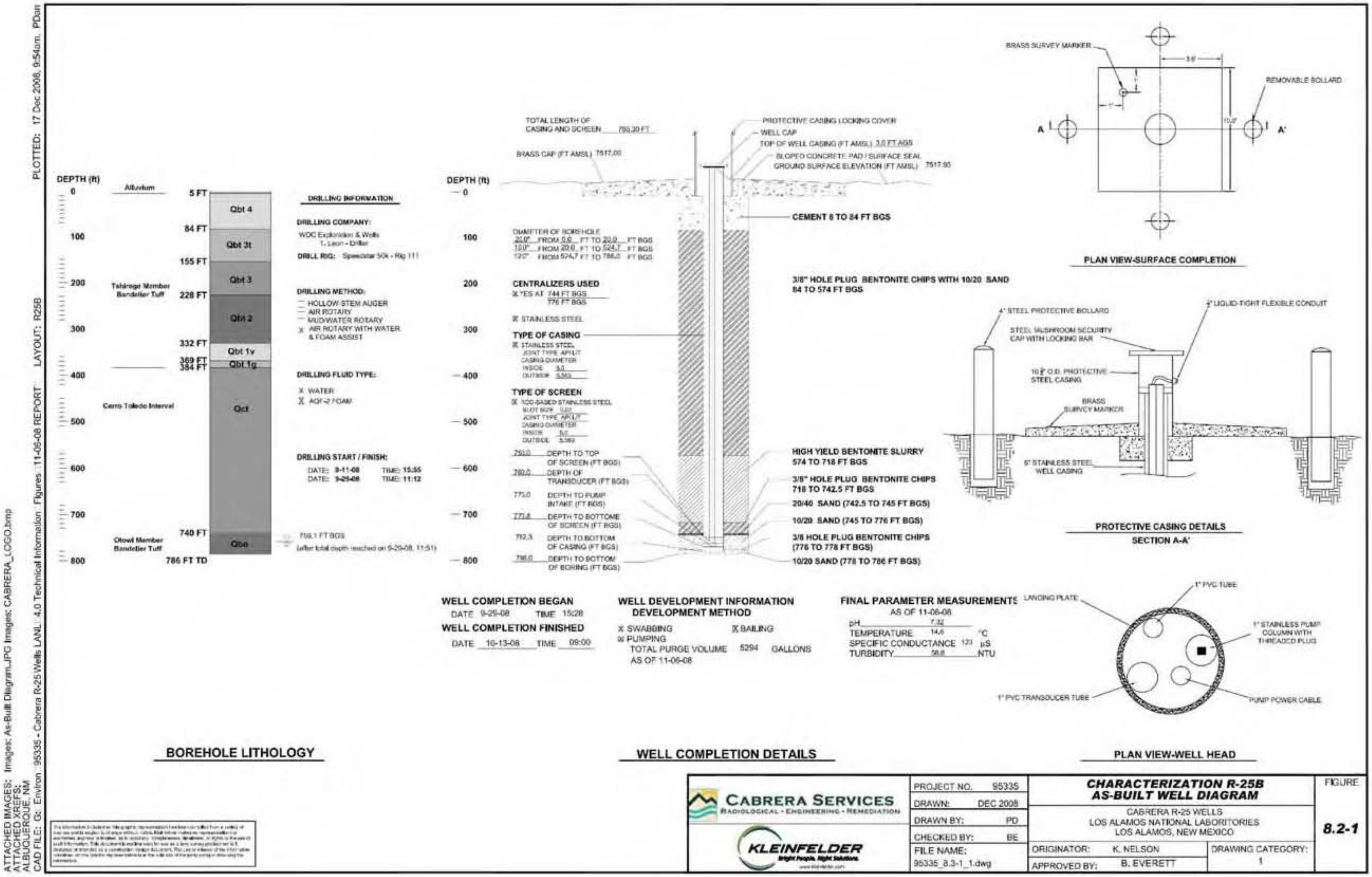

Figure 8.2-1 R-25b as-built well diagram

TECHNICAL NOTES FOR FIGURE 8.2-1[1]:

Survey Information[2]

Brass Marker

Northing: 1764074.69900

Easting: 1615125.59800

Elevation: 7517.000

Well Casing (top of stainless steel)

Northing: 1764069.36800

Easting: 1615128.48300

Elevation: 7519.634

BOREHOLE GEOPHYSICAL LOGS

Schlumberger Water Services natural gamma ray, induction, neutron (ECS) and APS, gamma-gamma density (TLD)

DRILLING INFORMATION

Drilling Company

WDC Exploration & Wells

Drill Rig

Failing Co. SpeedStar 50K WDC Rig #111

Drill Methods

Air rotary with water and foam assist

Drilling Fluids

0–524 ft Baroid AQF-2 foaming agent, air, and potable water

524–786 ft air and potable water

MILESTONE DATES

Drilling

Start: 09/11/2008

Finished: 09/29/2008

Well Completion

Start: 09/29/2008

Finished: 10/13/2008

WELL DEVELOPMENT/AQUIFER EVALUATION

Development Methods

Performed swabbing, bailing, –740 gal. removed

Total volume purged (as of 11/0608): 5294 gal.

Parameter Measurements (on 11/06/08)

pH: 7.32

Temperature: 14.6^{o}C

Specific Conductance: 123 µS

Turbidity: 58.8 nephelometric turbidity units (NTUs)

NOTES

1 Additional information available in “Final Completion Report, Characterization Wells R-25b, Los Alamos National Laboratory, Los Alamos, New Mexico, December 2008.

2. Coordinates based on New Mexico State Plane Grid Coordinates, Central Zone (NAD83); elevation expressed in feet above mean sea level using the National Geodetic Vertical Datum of 1929.

Table 3.0-1
Fluid Quantities Used during Drilling and Well Construction

Borehole	Date	Water (gal.)	Cumulative Water (gal.)	Foam (gal.)	Cumulative Foam (gal.)	Cumulative Returns in Pit: Fluids (gal.)
Drilling						
R-25b	09/11/08	300	300	0	0	—[a]
	09/12/08	0	300	0	0	—
	09/13/08	4000	4300	10	10	—
	09/14/08	1000	5300	0	10	—
	09/15/08	2000	7300	15	25	—
	09/16/08	2000	9300	25	50	—
	09/17/08	No drilling	9300	0	50	—
	09/18/08	No drilling	9300	0	50	—
	09/19/08	No drilling	9300	0	50	—
	09/20/08	No drilling	9300	0	50	—
	9/21/2008	No drilling	9300	0	50	—
	9/22/2008	0	9300	0	50	—
	9/23/2008	0	9300	0	50	9575
	9/24/2008	2000	11300	0	50	—
	9/25/2008	70	11370	0	50	—
	9/26/2008	0	11370	0	50	—
	9/27/2008	0	11370	0	50	—
	9/28/2008	0	11370	0	50	—
	9/29/2008	300	11670	0	50	—
Well Construction						
R-25b	9/29/2008	0	11670	n/a[b]	n/a	n/a
	9/30/2008	150	11820	n/a	n/a	n/a
	10/01/2008	2000	13820	n/a	n/a	n/a
	10/02/2008	250	14070	n/a	n/a	n/a
	10/03/2008	0	14070	n/a	n/a	n/a
	10/04/2008	0	14070	n/a	n/a	n/a
	10/05/2008	0	14070	n/a	n/a	n/a
	10/06/2008	0	14070	n/a	n/a	n/a
	10/07/2008	500	14570	n/a	n/a	n/a
	10/08/2008	1000	15570	n/a	n/a	n/a
	10/09/08	3000	18570	n/a	n/a	n/a
	10/10/2008	1200	19770	n/a	n/a	n/a
	10/11/2008	7500	27270	n/a	n/a	n/a

Table 3.0-1 (continued)

Borehole	Date	Water (gal.)	Cumulative Water (gal.)	Foam (gal.)	Cumulative Foam (gal.)	Cumulative Returns in Pit: Fluids (gal.)
R-25b	10/12/2008	0	27270	n/a	n/a	n/a
	10/13/2008	0	27270	n/a	n/a	n/a
Total (gal.)			27270		50	9575
Total Volume R-25b (gal.)		**27,270**				

Note: Foam use and pit use discontinued after drilling activities; therefore, no additional fluids were produced.

[a] — = No observations were taken.

[b] n/a = Not applicable.

Table 6.1-1
R-25b Video and R-25c Geophysical Logging Runs Relevant to R-25b

Date	Depth (ft)	Description
07/12/08	0–609.2	LANL video, natural gamma ray, and induction surveys run through open hole. Less than 1 ft of water (likely, fluids were introduced during drilling) was observed in bottom of the borehole.
08/13/08	850–700	Schlumberger HNGS survey run uphole in cased borehole (16-in.-steel casing from surface to 19.8 ft bgs; 11.75-in.-steel casing from surface to 848.5 ft bgs).
08/13/08	850–700	Schlumberger ECS survey run uphole in cased hole (16-in.-steel casing from surface to 19.8 ft bgs; 11.75-in.-steel casing from surface to 848.5 ft bgs). Poor quality log because instrument would not sit on casing wall. A bow spring centralizer was installed on the instrument, and the hole was successfully ECS logged.
08/14/08	850–600	Schlumberger TLD survey run uphole in cased hole (16-in. steel casing from surface to 19.8 ft bgs; 11.75-in.-steel casing from surface to 848.5 ft bgs; open hole (10-in.-diameter) from 848.5 to 1140 ft bgs).
08/14/08	850–600	Schlumberger APS survey run uphole in cased hole (16-in.-steel casing from surface to 19.8 ft bgs; 11.75-in.-steel casing from surface to 848.5 ft bgs; open hole (10-in.-diameter) from 848.5 to 1140 ft bgs).
09/28/08	0–782	LANL conducted a video survey of the borehole. The casing shoe was noted at 724 ft bgs and there was no evidence of water seepage between the casing shoe and the standing water level of 750 ft bgs. An approximately ¼-in. borehole wall “skin” of apparent smeared formation was observed in this interval.
09/29/08	0–782	LANL conducted a video survey of the borehole to confirm depth to water and look for evidence of seepage from formation. Water level was observed to be 759 ft bgs, and there was still no evidence of seepage between the bottom of the casing shoe (724 ft) and the standing water level.

Table 7.2-1
Annular Fill Materials

Material	Volume in R-25b
Surface seal: cement slurry	76 ft^3
Bentonite seal: bentonite chips	490 ft^3
Bentonite seal: high solids bentonite grout	144 ft^3
Upper annular seal: bentonite chips	17.8 ft^3
Fine sand collar: 20/40 silica sand	1.3 ft^3
Primary filter: 10/20 silica sand	23.5 ft^3
Lower annular seal: bentonite chips	4.0 ft^3
Backfill material: 10/20 silica sand	3.5 ft^3
Potable water	15, 600 gal.

Table 8.1-1
R-25b Water-Quality Data during Well Development (through November 6, 2008)

Date	Cumulative Purge Volume (gal.)	pH	Cond. (µS)	Turbidity (NTU)	Temperature (C)	O_2 (%)	ORP (mV)
10/15/08	505	6.90	158	448.0	9.6	72.0	212
	580	7.76	154	467.0	11.5	74.0	208
10/17/08	875	7.42	203	36.2	15.3	70.0	172
	1030	7.43	147	56.2	16.2	71.9	163
	1200	7.33	133	60.4	17.8	65.3	223
10/18/08	1290	7.48	142	119.0	15.9	92.2	219
	1405	7.74	130	54.9	14.1	71.8	236
	1606	7.61	148	58.9	15.1	68.2	223
10/19/08	1700	7.51	147	56.0	15.6	89.1	189
	1815	7.62	158	89.0	15.2	70.2	163
	1937	7.41	149	140.0	16.3	68.2	174
10/20/08	2054	7.56	131	92.6	16.3	66.0	157
	2152	7.66	139	96.0	16.1	63.9	128
	2289	7.44	148	289.0	16.1	64.9	184
10/21/08	2454	7.43	134	132.0	14.8	57.0	176
	2555	7.36	132	125.0	16.4	63.3	128
	2692	7.36	143	190.0	16.6	91.7	168
10/22/08	2816	7.47	130	152.0	12.4	59.2	171
	2914	7.49	141	166.0	12.9	60.2	168
	3050	7.42	132	298.0	13.0	61.1	166
10/23/08	3110	7.59	134	97.2	12.2	57.8	159

Table 8.1-1 (continued)

Date	Cumulative Purge Volume (gal.)	pH	Cond. (µS)*	Turbidity (NTU)	Temperature (C)	O_2 (%)	ORP (mV)
10/24/08	3325	7.76	156	32.7	11.1	65.2	229
	3425	7.58	134	73.8	12.0	65.7	207
	3562	7.57	140	298.0	15.9	66.8	249
10/27/08	3745	7.80	151	37.5	11.6	64.8	247
	3845	7.70	140	87.0	13.9	65.7	190
	3960	7.61	130	80.7	15.1	60.1	203
10/28/08	4274	7.76	139	32.2	10.0	59.7	182
	4380	7.42	131	31.1	13.5	56.3	189
11/04/08	4430	7.46	174	58.2	15.4	No data	No data
	4534	7.56	149	52.5	14.9	58.2	186
	4590	7.50	135	57.9	13.9	50.2	235
11/05/08	4620	7.49	162	48.5	9.4	55.5	183
	4862	7.65	130	30.4	13.2	58.6	263
	4980	7.42	126	90.4	12.9	57.6	270
11/06/08	5030	7.28	151	46.6	9.9	57.8	218
	5096	7.52	132	61.3	12.1	56.7	234
	5210	7.24	128	65.0	12.3	53.6	196
	5294	7.32	123	58.8	14.6	66.5	262

* µS = Microsiemens.

Table 8.4-1
R-25b and R-25c Geodetic Survey Data

Northing	Easting	Elevation	R-25b Identification
1764074.69900	1615125.59800	7517.000	Brass cap embedded in pad
1764069.39900	1615128.24900	7520.120	Top of protective casing
1764069.36800	1615128.48300	7519.634	Top of well cap
Northing	**Easting**	**Elevation**	**R-25c Identification**
1764083.07100	1615073.71900	7517.589	Brass cap embedded in pad
1764077.75600	1615076.53200	7520.481	Top of protective casing
1764077.71500	1615076.70800	7519.952	Top of well cap

Appendix A

Lithologic Logs

Los Alamos National Laboratory
Regional Hydrogeologic Characterization Project
Borehole Lithologic Log

BOREHOLE IDs: R-25b and R-25c	**TECHNICAL AREA (TA):** 16	**PAGES: 5**
DRILLING COMPANY: WDC	**START DATE/TIME:** 07/07/08:1425	**END DATE/TIME:** 08/22/08:1755
DRILLING METHOD: Air Rotary	**MACHINE:** Failing Co. SpeedStar 50K	**SAMPLING METHOD:** Drill Cuttings
GROUND ELEVATION: **** ft above mean sea level (amsl)	**TOTAL DEPTH (TD):** 1140 ft below ground surface (bgs)	
DRILLERS: J. Leon/S. Huston	**LOGGERS:** M. Ivers/M. Pitterle	

DEPTH (ft)	LITHOLOGY	LITHOLOGIC SYMBOL	Notes
0–5	**ALLUVIUM:** Predominantly silt and fine sand (SM), with <5% medium to coarse sand, brown (5YR 4/4). Dry.	-	**Alluvium:** (0–5 ft bgs) Cuttings are very dirty; was not possible to distinguish individual components.
5–35	**TSHIREGE MEMBER, BANDELIER TUFF:** Pale yellowish brown (10YR 6/2), nonwelded to partially welded, devitrified ash-flow tuff. WR: Fine ash matrix with sparse crystals of quartz and sanidine, <1 mm, rare pumice, and rare dark, volcanic lithics of intermediate composition. +35F: Predominantly crystals, <1 mm. Dry.	Qbt 4	**Qbt 4 Tshirege Member of Bandelier Tuff:** (5–84 ft bgs) Samples from 20 to 50 ft are contaminated with bentonite pellets used to set seal at the bottom of the surface casing before grouting.
35–55	**35–55 ft bgs:** Light brownish gray (5YR 6/1) to light gray (10YR 7/1), nonwelded to moderately welded, devitrified ash-flow tuff. WR: Sparse crystals of sanidine and quartz, rare pumice, lithics not observed (cuttings are coated with dust). +35F: Predominantly crystals, 1 mm or less. Dry.		
55–84	**55–84 ft bgs:** Pale yellowish brown (10YR 6/2) to medium gray (N5), nonwelded to partially welded, devitrified ash-flow tuff. WR: Fine ash matrix with abundant felsic crystals of sanidine and quartz, mostly 2–3 mm, up to 5 mm at the base of the interval, common white pumice, and minor volcanic lithics of intermediate composition up to 2 cm. +35F: Predominantly crystals. Wet. 55–60 ft bgs: predominantly crystals, up to 2 mm. Many appear rounded.		

BOREHOLE IDs: R-25b and R-25c	**TECHNICAL AREA (TA):** 16	**PAGES: 5**	
84–105	**TSHIREGE MEMBER, BANDELIER TUFF:** Brown (5YR 4/4), nonwelded, devitrified ash-flow tuff. WR: Matrix of fine ash (95%) with minor crystals of sanidine and quartz, minor dark volcanic lithics of intermediate composition, mostly <3 mm, and rare pumice. +10F: Rounded tuff clasts (matrix) with minor crystals. +35F: 95% crystals, 5% tuff clasts and lithics. Dry to wet.	Qbt 3t	**Qbt 3t Tshirege Member of Bandelier Tuff:** (84–155 ft bgs)
105–145	**105–145 ft bgs:** Pale yellowish brown (10YR 6/2), nonwelded, devitrified ash-flow tuff. WR: Matrix of fine ash (80%–90%), abundant crystals of sanidine, quartz and feldspar, rare pumice, minor volcanic lithics of crystal-rich tuff of intermediate composition. +10F: Predominantly lithics up to 12 mm. +35F: Roughly equal proportions of lithics and crystals. Dry		
145–155	**145–155 ft bgs:** Brownish black (5YR 2/1) to medium gray (N5), moderately welded, devitrified ash-flow tuff. WR: Ash matrix with abundant (18%–20%) crystals of sanidine and quartz, 2–3 mm, rare pumice, very light gray (N8) to white, minor light brown (5YR 5/6) and reddish brown volcanic lithics. +10F: Tuff matrix clasts. +35F: Predominantly crystals, with lesser tuff clasts and lithics. Wet.		
155–215	**TSHIREGE MEMBER, BANDELIER TUFF:** Nonwelded, devitrified, ash-flow tuff. WR: Predominantly crystals, light gray (N8) tuff clasts, lithics and rare pumice. +10F: Tuff clasts and lithics. +35F: 95% crystals.	Qbt 3	**Qbt 3 Tshirege Member of Bandelier Tuff:** (155–228 ft bgs)
215–225	**215–225 ft bgs:** No recovery.		
225–228	**225–228 ft bgs:** Nonwelded, devitrified, ash-flow tuff. WR: Predominantly crystals, light gray (N8) tuff clasts, lithics and rare pumice. +10F: Tuff clasts and lithics. +35F: 95% crystals. **Note:** Poorly recovered. An increase in the penetration rate indicates soft formation, possibly the white, nonwelded tuff at the base of Qbt 3.		Poorly recovered. An increase in the penetration rate indicates soft formation, possibly the white, nonwelded tuff at the base of Qbt 3.

BOREHOLE IDs: R-25b and R-25c	**TECHNICAL AREA (TA):** 16	**PAGES: 5**	
228–240	**TSHIREGE MEMBER, BANDELIER TUFF:** Grayish red (10R 4/2), moderately to strongly welded, devitrified ash-flow tuff. WR: Recovered >75% crystals of sanidine and quartz, lesser tuff clasts, lithics and rare pumice. +35F: 90%–95% crystals.	Qbt 2	**Qbt 2 Tshirege Member of Bandelier Tuff:** (228–332 ft bgs) **Note:** The very low penetration rate through the interval suggests a moderately to strongly welded tuff; however, the lack of recovery of tuff (matrix) may indicate a nonwelded tuff.
240–305	**240–305 ft bgs:** Grayish brown (5YR 3/2), partially to moderately welded, devitrified ash-flow tuff. WR: Tuff matrix is crystal-rich, 20%+ sanidine and quartz, light gray (N8) to white, vapor-phase altered pumice are common, minor dark, volcanic lithics. +10F: Tuff clasts (matrix) with minor lithics. +35F: 80%–90% crystals with lesser tuff clasts and minor lithics. **270–280 ft bgs:** Matrix is yellowish brown (10YR 6/2), nonwelded to partially welded (very poor recovery of matrix).		
305–332	**305–332 ft bgs:** Grayish brown (5YR 3/2), moderately welded, devitrified ash-flow tuff. WR: Tuff matrix is crystal-rich, 20%+ sanidine and quartz, minor light gray (N8) to white, vapor-phase altered pumice, rare dark, volcanic lithics. +10F: Tuff clasts (matrix) with minor lithics. +35F: 80%–90% crystals with lesser tuff clasts and minor lithics.		
332–355	**TSHIREGE MEMBER, BANDELIER TUFF:** Grayish brown (5YR 3/2) to dusky brown (5YR 2/2), nonwelded to partially welded, devitrified ash-flow tuff. WR: Tuff matrix is crystal rich (+30%). Vapor-phase alteration of the matrix is not readily apparent in the cuttings, although the color is lighter. Minor vapor-phase altered pumice (sugary texture), and rare dark volcanic lithics. +10F: Tuff clasts (matrix) with minor lithics. +35F: 80%–90% crystals with lesser tuff clasts and minor lithics.	Qbt 1v	**Qbt 1v Tshirege Member of Bandelier Tuff:** (332–369 ft bgs)
355–369	**355–369 ft bgs:** Very poor recovery of the matrix (recovered mostly crystals) indicates the tuff may be nonwelded or could to vapor-phase alteration of the matrix.		
369–384	**TSHIREGE MEMBER, BANDELIER TUFF:** Medium gray (N5), nonwelded, devitrified ash-flow tuff. WR: Recovery consists predominantly of crystals of sanidine and quartz, and abundant dark gray to reddish brown volcanic lithics of intermediate compositions, up to 16 mm. Pinkish gray, vitric pumice with fibrous textures are common. +10F: Predominantly lithics. +35F: Predominantly crystals with minor lithics and tuff matrix. **380–382 ft bgs:** Increase in vitric pumice, pale yellowish brown (10YR 6/2) to grayish orange pink (5YR 7/2), up to 1 cm; higher concentration of volcanic lithics.	Qbt 1g	**Qbt 1g Tshirege Member of Bandelier Tuff:** (369–384 ft bgs)

BOREHOLE IDs: R-25b and R-25c	**TECHNICAL AREA (TA):** 16	**PAGES: 5**	
384–385	**CERRO TOLEDO INTERVAL:** Volcaniclastic sediments. WR: Poorly sorted, fine to coarse sand and fine gravel size clasts, predominantly angular to subangular, locally subrounded (especially pumice and nonwelded tephras). Clasts are predominantly volcanic tuffs and lavas of rhyolitic to intermediate compositions, pumice (mostly vitric), nonwelded tephras, abundant felsic crystal fragments (noted bipyramidal quartz), and rare siltstones. Clasts are generally light to dark gray (N8-4) and reddish brown. Pumice and tephras are light brown to white and orange where altered (oxidized).	Qct	**Cerro Toledo Interval:** (384–740 ft bgs)
385–395	**385–395 ft bgs:** No recovery.		
395–500	**415–430 ft bgs:** Decrease in pumice, less orange coloration (oxidation); pumice are generally white. **430–435 ft bgs:** No recovery. **440–445 ft bgs:** Interval contains approximately 75% white to slightly orange, vitric pumice.		
500–520	**500–515 ft bgs:** Crystal-rich tephra (very poor recovery of the tuff matrix). WR: White to light gray and grayish pink, moderately indurated ash. +10F: Tephra clasts. +35F: +95% felsic crystal fragments. **515–520 ft bgs:** No recovery.		
520–591	**520–591 ft bgs:** Volcaniclastic sediments. Same as above, with an increase in mafic volcanics, very dark gray (N3) to black (N2.5), andesites, dacites, and rare volcanic siltstones. **530–535 ft bgs:** No recovery.	Qct	
591–610	**591–616 ft bgs:** Brown (10YR 5/3) to dark yellow (10YR 3/4) (wet), nonwelded, devitrified ash-flow tuff. WR: Ash matrix with rare light gray (N7-8) to dark yellowish orange (10YR 6/6), vitric pumice, common felsic crystals, sparse dark volcanic lithics of intermediate composition. +10F: Predominantly tuff matrix (rounded clasts) with minor lithics. +35F: Tuff clasts, pumice, minor lithics and crystals.		
610–640	**610–640 ft bgs:** No recovery.		
640–650	**640–650 ft bgs:** Very light gray (N9) to dark yellow orange (10 YR 6/6) medium–coarse sand size pumice fragments, subround, trace clear phenocrysts.		
650–690	**650–690 ft bgs:** No recovery.		

BOREHOLE IDs: R-25b and R-25c	TECHNICAL AREA (TA): 16	PAGES: 5	
690–740	**690–740 ft bgs:** Yellowish orange (10YR 6/4) (check color), nonwelded, vitric ash-flow tuff. WR: Fine ash matrix with common pumice, vitric, vesicular/frothy textures, white (N9) to light gray (10YR 7/2) and yellowish orange (10YR 6/4), common sanidine and quartz, minor volcanic lithics of intermediate compositions, dark gray to very dark gray (N5-3) and yellowish red (5YR 4/4). Pumice have very fine mafic crystals. +10F: Vitric pumice and lesser tuff clasts, and minor lithics. +35F: Predominantly crystals with roughly equal parts of tuff matrix and pumice, and common lithics.		
740–843	**OTOWI MEMBER, BANDELIER TUFF:** White, partially welded, vitric ash-flow tuff. WR: Fine ash with abundant vitric pumice, white (N9), porous, vesicular textures (difficult to distinguish between tuff matrix and pumice in cuttings), minor to common sanidine and quartz, common dark volcanic lithics of intermediate compositions. +10F: Predominantly pumice with lesser tuff matrix clasts, and common lithics. +35F: Generally equal parts pumice/tuff clasts, crystals and lithics.		
843–850	**GUAJE PUMICE BED:** Cannot be readily distinguished from the Otowi in cuttings. However, a marked increase in larger, rounded pumice in the +10F from 840 to 845 ft may represent the top of the Guaje Pumice Bed. Otherwise, the interval is the same as the Otowi Member above.	Qbo g	**Guaje Pumice Bed:** (843–850 ft bgs)
850–1045	**PUYE FORMATION:** Volcaniclastic sediments. WR: Poorly sorted, medium to coarse sand and fine gravel size clasts (up to 3.5 cm) of angular to subangular, and rarely subrounded volcanic flows and tuffs of intermediate composition. Clasts range from very light gray (N8) to dark gray (N4), with lesser dusky red (2.5YR 3-4/4), light brown (7.5YR 6/4) and light gray (5YR 7/1). Tuffs and rhyolite flows are generally lighter in color, are partially to densely welded, often crystal rich, and occasionally vitric. +35F: Generally the same as WR but includes minor amounts of felsic crystal fragments, <5%.	Tpf	**Puye Formation:** (850–1140 ft bgs) **Note:** Sample recovery through the interval was very poor. Because of the large volumes air needed to drill and the large quantities of water produced from the formation, it was not possible to recover the fines, and sample quality is poor.
1045–1140	**1045–1140 ft bgs:** Volcaniclastic sediments, as above. Noted an increase in darker intermediate volcanic clasts, and a decrease in clast size; fine gravel is rare to absent. Felsic crystal fragments are rare to absent.		

Appendix B

Evaluation of Pressure Responses in R-25 Screens during Drilling of R-25b and R-25c

R-25b and R-25c are replacement wells for screens 1 and 3 of R-25, respectively. R-25c is located 100 ft to the west of R-25 and R-25b is located between R-25c and R-25 and 50 ft to the west of R-25 (Figure 1.0-1, main text). Because of the close distance between R-25 and the new monitoring wells, pressure responses at adjacent screens in R-25, CdV-16-1(i), and CdV-16-2(i)r were monitored during drilling of the intermediate monitoring wells R-25b and R-25c. The elevations of the top and bottom of the R-25 screens are screen 1: 6757.7 and 6778.5 ft, screen 3: 6451.5 and 6461.5 ft. The pressure responses in nearby intermediate screens could be a result of (1) stresses induced on the strata and (2) addition of fluids during drilling and well completion. The pressure responses at R-25 screens 1, 2, 3, and 4, and intermediate monitoring well CdV-16-1(i) during the drilling of R-25c and R-25b are analyzed.

Screen 1 at R-25 and the CdV-16-1(i) screen are located at the approximate same elevation about 370 ft apart, but the intermediate zone water level at CdV-16-1(i) is about 20 ft higher than at R-25 screen 1. The screen at CdV-16-2(i)r is about 20 ft lower in elevation than R-25 screen 2 and about 1500 ft to the east of R-25, but the water level at CdV-16-2(i)r is about 130 ft lower than at R-25 screen 2; no water level responses were observed at CdV-16-2(i)r during the drilling of R-25c and R-25b.

The pressure data (in terms of water-level elevations) collected from July 1 to September 30, 2008, at R-25 intermediate screens 1 through 4 and intermediate well CdV-16-1(i) is presented in Figure B-1. Note that data obtained for R-25 screen 3 are from Westbay port MP3B, which is located about 20 ft below screen 3. All pressure fluctuations observed at this zone were in sump water below the screen; water has not been observed within the interval of R-25 screen 3. The figure shows that the pressures at screen 2 were the most affected by the drilling activities in August 2008. The apparent water level in this screen fluctuated substantially; the maximum increase is about 100 ft and the maximum decrease is about 80 ft. However, the fluctuations observed at screen 2 could have been the result of pressures induced by drilling and not actual water-level fluctuations in the formation.

Figure B-2 shows the pressure data at R-25 screens 1 and 2 and CdV-16-1(i) between August 1 and September 30. Note the difference in the y-axis scales. Regardless of the substantial difference in the magnitude of pressure fluctuations (screen 1: ~2 ft; screen 2: ~180 ft, CdV-16-1(i) ~2 ft), the fluctuations show similar temporal patterns. Figures B-3 and B-4 present analysis of the pressure fluctuations at screens 1 and 2 in relation to the drilling activities at R-25c. The pressures were affected once R-25c was drilled to depth of 1080 ft below ground surface (bgs). After that time, the drilling and development activities appear to be producing well-correlated responses to the pressures at screens 1 and 2. This suggests a good hydraulic connection of the intermediate groundwater and vadose zone near R-25, CdV-16-1(i) and R-25c.

Figure B-5 shows the water level responses at R-25 screens 1 and 2 during drilling and completion of R-25b. During drilling of R-25b on September 13, 2008, 4000 gal. was introduced into the borehole, which caused a concurrent water-level rise of about 0.1 ft at R-25 screen 1 and short-term water-level spike at R-25 screen 2 of about 6 ft. Analyses of the CdV-16-1(i) water-level data show about 0.1 ft water-level rise September 13, 2008, similar to that observed at R-25 screen 1. A water-level rise of about 0.1 ft at R-25 screen 1 on September 26 and September 27 is not correlated with water use at R-25b but may be associated with well drilling activities on September 27, 2008, when reaming the borehole to total depth of 786 ft bgs.

Figure B-6 shows the pressure data at screens 3 and 4 of R-25 between August 1 and September 30. The water level increased by about 2 ft and 0.08 ft on August 12 in screens 3 (sump) and 4, respectively. This may be coinciding with the advancing of R-25c to a depth of 1080 ft bgs (Figure B-3). This may suggest that drilling produced short-term vertical water flow that was detected at screens 3 and 4 of R-25. On August 22, the water level of screen 3 sump rose again by 0.5 ft. It may be associated with the redrilling of R-25c down to 1080 ft (Figure B-4). On September 24 after the well was completed, 966 gal.

of water was introduced in R-25c and was lost to the formation before the well could be tagged. Coinciding with this event, there is 0.1 ft increase of water level at screen 3 sump that may be result of water injection at R-25c. This information again suggests a good hydraulic connection within the vadose zone near R-25.

In conclusion, the drilling and well development activities at R-25b and R-25c produced pressure responses at all the intermediate screens of R-25 (screens 1 through 4) and nearby intermediate monitoring well CdV-16-1(i). The collected pressure information is very valuable and it suggests that (1) the vadose zone near CdV-16-1(i), R-25, R-25b and R-25c is hydraulically well connected and (2) R-25b and R-25c are in good hydraulic contact with the formation.

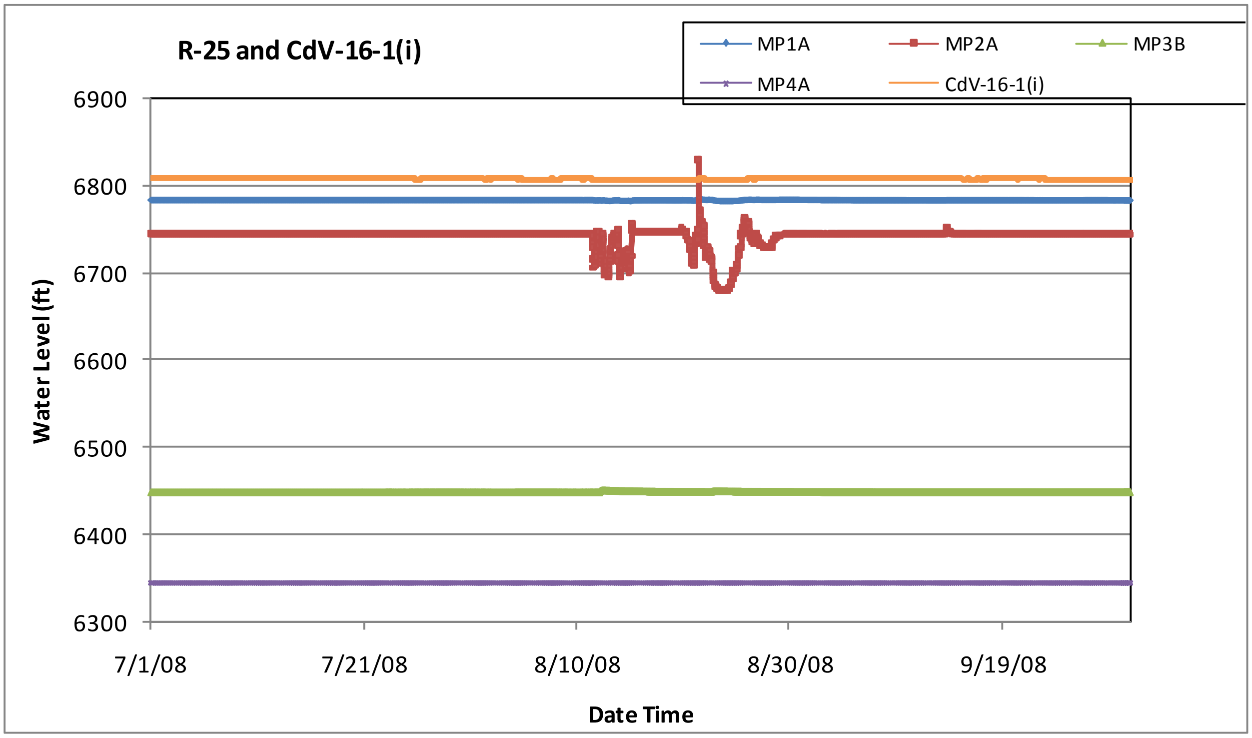

Figure B-1 Water-level elevations observed at R-25 intermediate screens CdV-16-1(i)

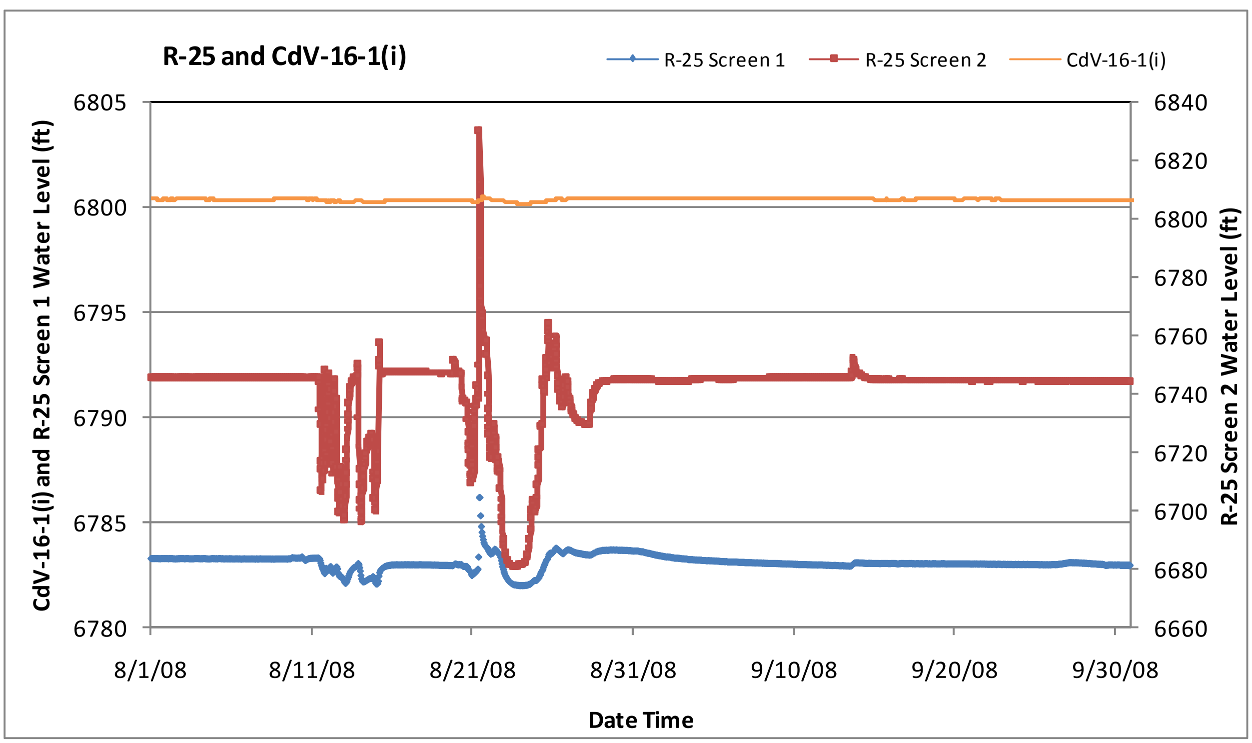

Figure B-2 Water-level elevations observed at R-25 screens 1 and 2 and CdV-16-1(i)

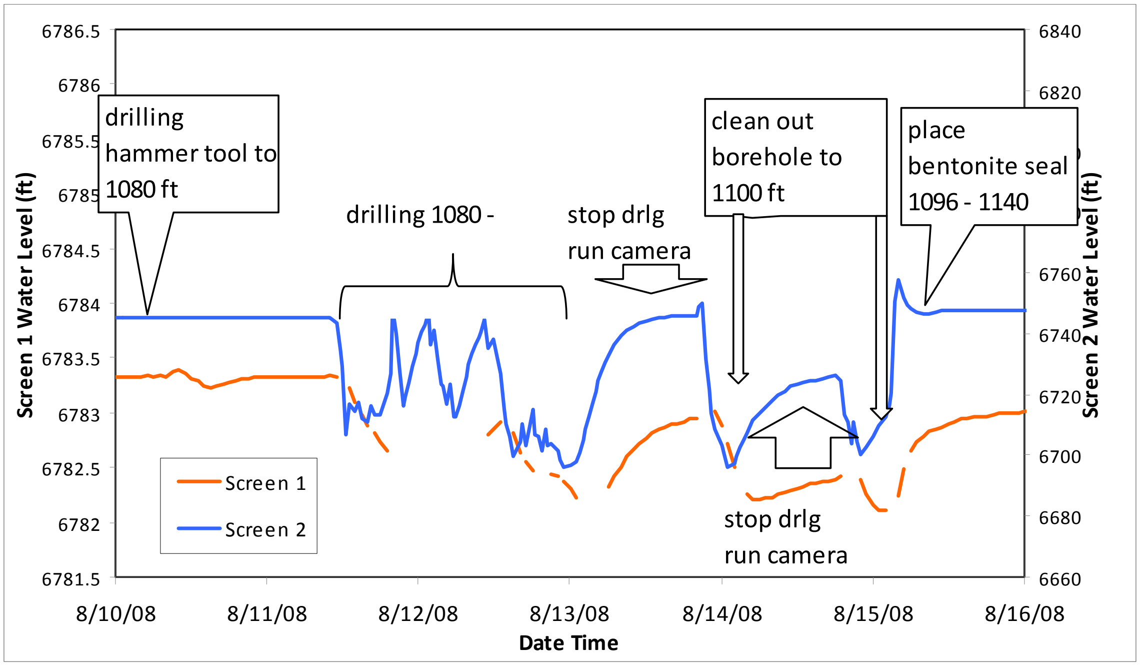

Figure B-3 **Water-level elevations observed at R-25 screens 1 and 2. The figure relates drilling activities at R-25c to observed pressure responses August 10 and August 16.**

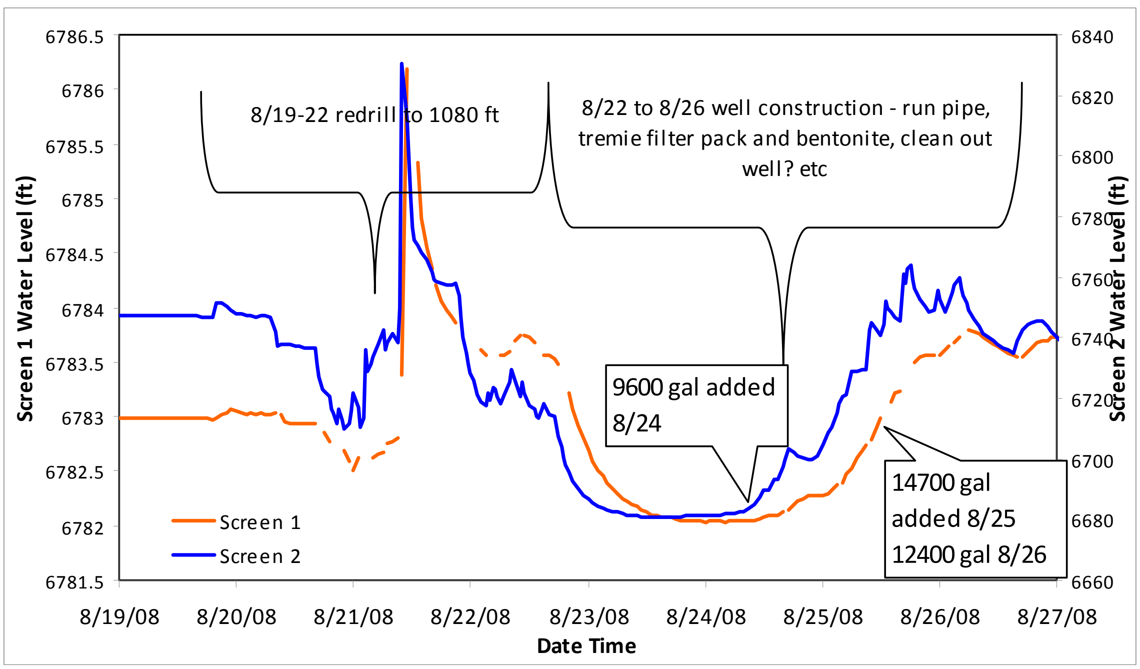

Figure B-4 **Water-level elevations observed at R-25 screens 1 and 2. The figure relates drilling activities at R-25c to observed pressure responses August 19 and August 27.**

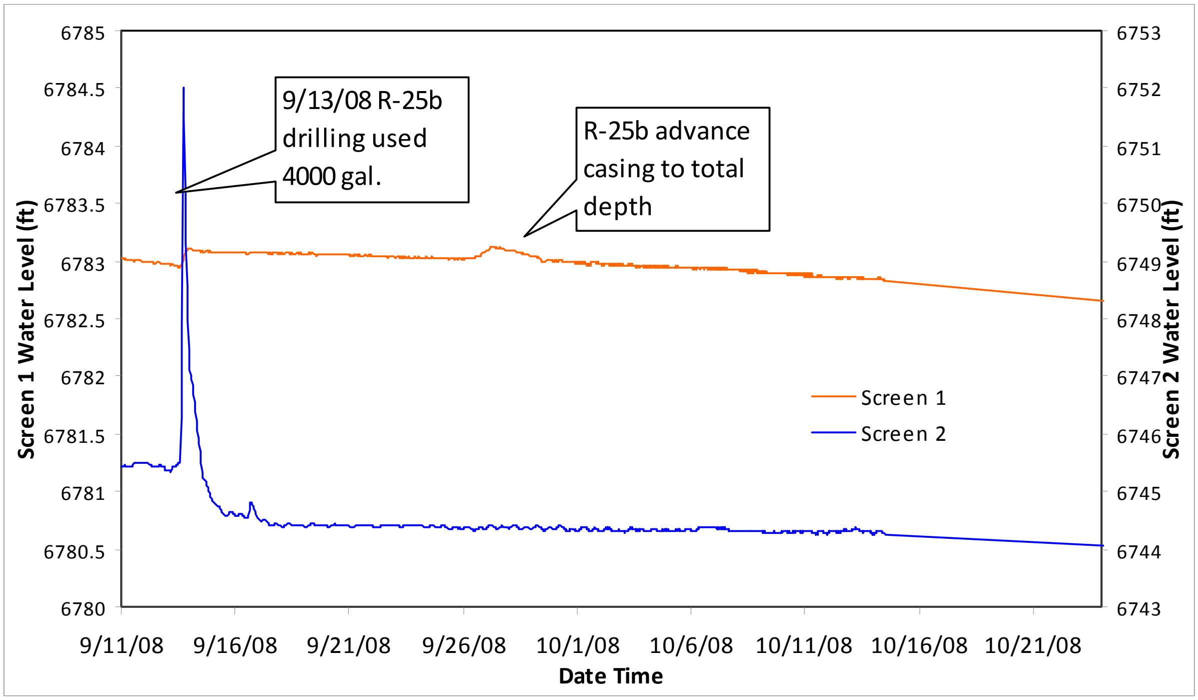

Figure B-5 **Water-level elevations observed at R-25 screens 1 and 2. The figure relates drilling activities at R-25b to observed pressure responses September 11 and October 24.**

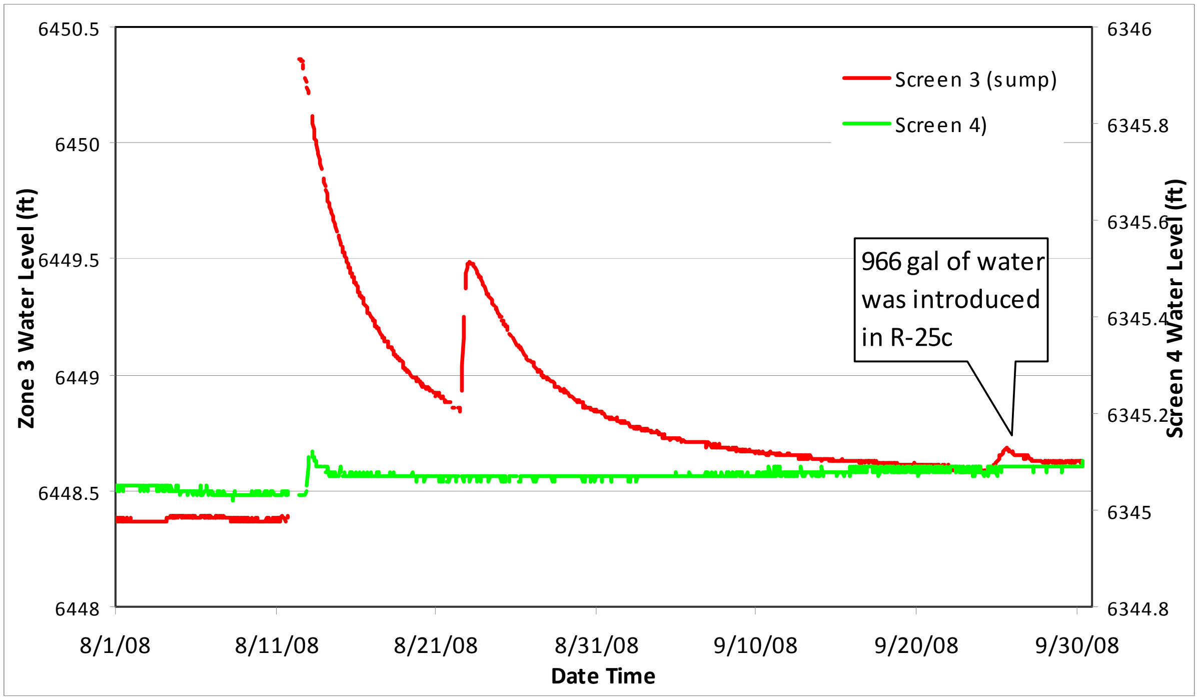

Figure B-6 **Water-level elevations observed at R-25 screens 3 and 4. The figure relates drilling activities at R-25c to observed pressure responses September 11 and October 24.**

Appendix C

Evaluation of Turbid Suspension during Well Development

C-1.0 INTRODUCTION

While developing R-25b, it became apparent that, although other water-quality parameters had stabilized over time, (pH, specific conductance, temperature, etc.), turbidity values remained elevated (i.e., between 50 and 100 nephelometric turbidity units). To identify the potential source of the persistent turbidity, Los Alamos National Laboratory (the Laboratory) undertook a geochemical investigation of the groundwater itself, along with samples of the formation, and all materials introduced to the borehole in the process of well completion.

Source of Turbid Suspension during the Development of Well R-25b

Turbidity in water pumped during development of well R-25b has been persistent. A sample was collected for analysis; a portion of this sample was dried and the sedimented or precipitated solids were analyzed optically (grain mount) and by x-ray diffraction (XRD). In addition, samples were collected of bentonite chips from the seal below the screen, from the seal above the screen, and from the high-solids bentonite grout used above the upper bentonite chip seal. Since soda ash (Na-carbonate) was added to two batches of bentonite grout (from the interval of 584 to 614 ft), samples of this material were used to examine their effect on the grout. Soda ash is routinely added to grout that is being placed at depth, as a means of inhibiting hydration of the grout.

Baseline analysis of evaporated turbid water and of suspensions from bentonite annular materials

A split of the turbid development water from R-25b was evaporated to obtain a total sample of all suspended solids and dissolved salts. Analysis of the dried sample by XRD shows an illite/smectite (I/S) with small (001) spacing (9.9 Å), quartz, and trace kaolinite; calcite is the only detected salt and is abundant in this sample. To obtain comparable baseline samples from the lower seal, upper seal, and bentonite grout, each of these was hydrated with deionized (DI) water and allowed to swell for several hours; the samples were then agitated and allowed to settle overnight. The mobile fines were then collected from the upper portion of each and evaporated. Figure C-1.0-1 compares the XRD data for all four of the dried samples.

The XRD data show that the (001) diffraction of the dried I/S from the turbid water from the R-25b screen collapses to a lower spacing (higher 2θ) than the dried suspension from the high-solids bentonite grout or from the upper seal, but not from the bottom seal. The turbid water from the R-25b screen also produces a significant amount of calcite that is not produced by the dried suspensions from any of the annular fill bentonites, but those suspensions were created with DI water. Calcite precipitated from the screen water is therefore believed to be primarily a product of evaporation of the carbonate component of the native water at R-25b. When examined optically as grain mounts the calcite crystals occur as <1-µm subhedral grains in a web of fibrous clay accumulations. All of the samples in Figure C-1.0-1 contain quartz grains that are too small for optical identification.

Although most of the calcite produced from the evaporated development water at R-25b could be precipitated from carbonate in native groundwater, some may be attributed to interaction with soda ash (Na carbonate) by exchange of Ca from smectite for Na from the soda ash, producing Ca-carbonate on evaporation. The cation exchange in this reaction is typical of reaction between smectite and soda ash (Klimosh and Levitskii 2004, 103852), and in fact, is the reason that soda ash is used as an additive in grout injections. To test the possible formation of calcite as a development from soda ash interaction with the grout, a portion of the grout was mixed with soda ash dissolved in DI water and evaporated. X-ray diffraction analysis showed that a small amount of calcite was formed, along with thermonatrite ($NaCO_3 \cdot H_2O$) from the excess of soda ash. This result suggests that some of the calcite observed could be formed by such a reaction but does not rule out the possibility that most may actually be formed from Ca and carbonate in native groundwater.

A notable change in the clay mineral component of the grout was observed in reaction with the soda ash. Figure C-1.0-2 shows that the broad I/S (001) diffraction of untreated grout splits into two different clay mineral components with different (001) spacing after treatment with soda ash and evaporation. Treatment with soda ash also removes the small amount of gypsum observed in precipitation of the suspension from untreated grout; the alternative form of the sulfate component on evaporation may be an Na-sulfate that is not evident in the XRD data.

Characterization of the clay mineral component from the screen at R-25b

An oriented mount was prepared of the evaporated solids from the R-25b screen to determine whether or not the clay mineral component consists of a smectitic clay typical of bentonites. The wetting of the sample to prepare the smear mount expands the (001) spacing from 9.9 to 12.3 Å. Glycolation overnight at 40 °C further expands the (001) spacing to 17.2 Å, indicative of a fully expandable smectite with only a minor illite component (Figure C-1.0-3).

These results are typical of Na-smectites with little interstratified illite common to bentonites. The symmetric and well-formed (001) peaks of the smear mount and its glycolated equivalent, with little indication of interstratified illite, are not typical of most native clays analyzed from the Labratory site, which are principally Ca-K illite-smectites with relatively low content of interlayer Na and without the well-developed, symmetrical (001) diffraction seen in the glycolated sample of Figure C-1.0-3.

Characterization of the clay mineral component following soda-ash treatment of the high solids bentonite grout

A smear mount of the soda-ash exposed high-solids bentonite grout was prepared to determine whether either of the two (001) peaks observed in that sample may be related to the clay mineral collected at the R-25b screen. This may help to determine whether treatment with soda ash can release readily transported smectite as a consequence of reactions that occur along with the lowering of viscosity that occurs as a result of soda ash treatment. Figure C-1.0-4 shows that glycolation of grout that was split into two clay mineral components by soda ash (Figure C-1.0-3) has produced a minor component that does not expand on glycolation (illitic, or possibly a mica) and a major component that fully expands to 5.2º (smectitic). The smectitic component matches the clay mineral that is produced from turbid water entering the R-25b screen (compare the 5.2º green peak in Figure C-1.0-3 and the 5.2º green peak in Figure C-1.04).

C-2.0 SUMMARY

Elevated turbidity in water produced from the screen at R-25b is caused by a very smectitic I/S clay mineral typical of bentonite sources. The likeliest source of this clay mineral is from high-solids bentonite grout.

The host rock at the screen in R-25b consists of vitric silicic ash of the Otowi Member of the Bandelier Tuff. Alteration of vitric tuff can produce a smectitic I/S that is similar to that in the high-solids bentonite grout. However, cuttings of the Otowi observed in both R-25b and R-25c are of essentially unaltered vitric ash, indicating that this unit is unlikely to produce the quantity or quality of smectitic I/S entering the screen at R-25b.

C-3.0 REFERENCE

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

Klimosh, Y.A., and I.A. Levitskii, 2004. "Rheological Properties of Slips Based on Polymineral Clays with Electrolyte Additives," *Glass and Ceramics,* Vol. 61, No. 11–12, pp. 375–378. (Klimosh and Levitskii 2004, 103852)

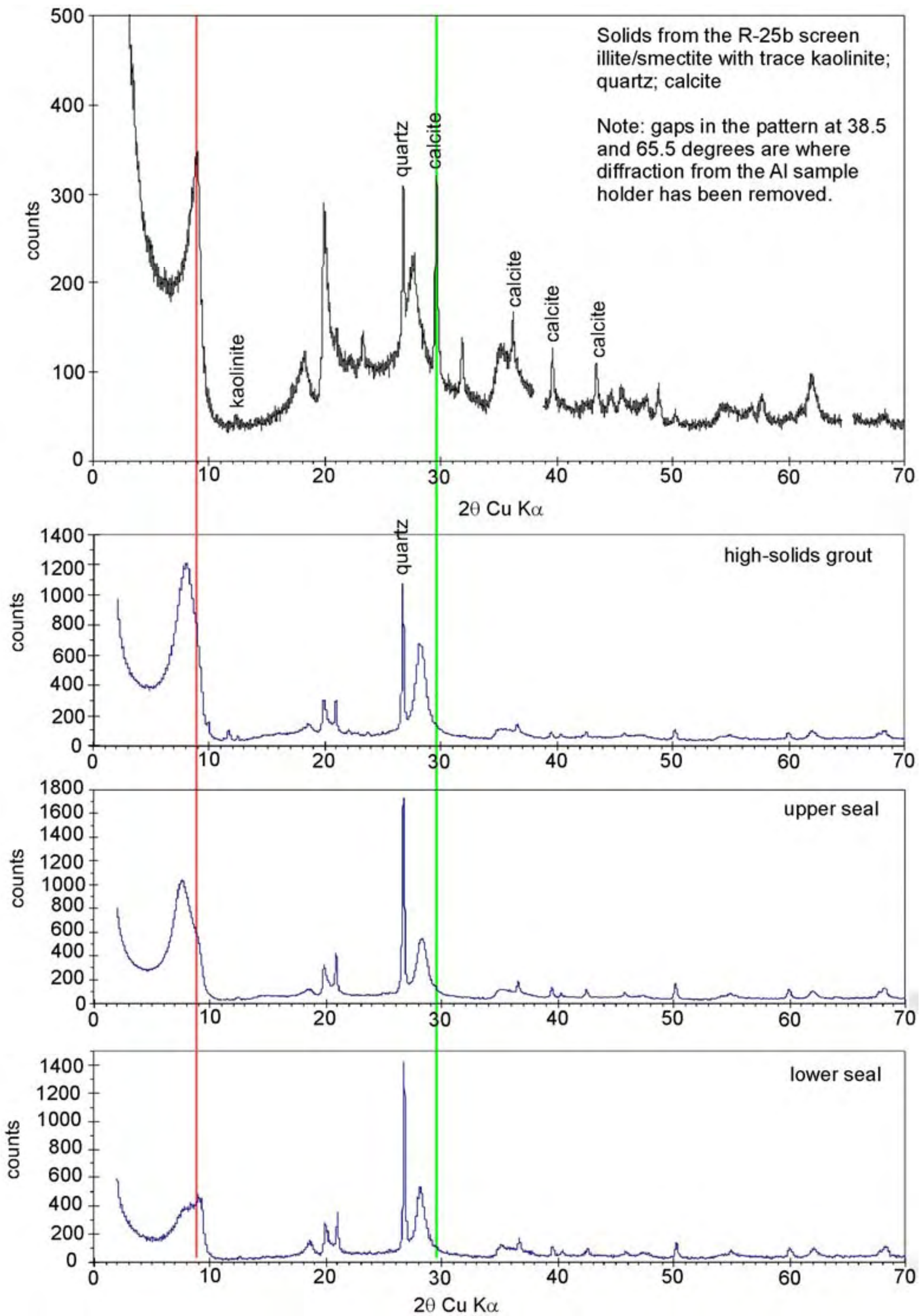

Figure C-1-0.1 X-ray diffraction analyses of evaporated turbid development water from the screen at R-25b and of three DI water suspensions from annular fill materials: high-solids bentonite grout, the upper seal bentonite chips, and the lower seal bentonite chips. The red line is aligned with the (001) maximum of dried I/S from the development water and the green line is aligned with the major calcite peak in the dried sample from the development water.

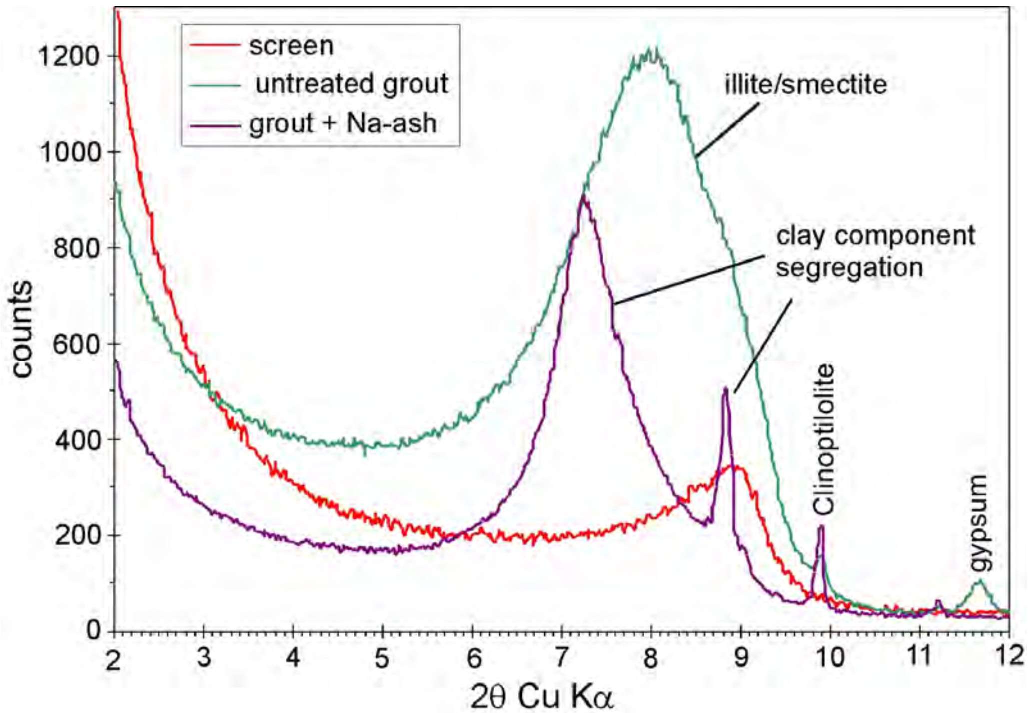

Figure C-1.0-2 Comparison of the low-angle diffraction from a dried sample of the R-25b screen turbid water with dried suspensions from the high-solids bentonite grout (untreated with soda ash) and of the same grout after exposure to a solution with soda ash. Note the small amount of zeolite (probably clinoptilolite) in the grout (whether treated or untreated) and the gypsum present in only the untreated grout.

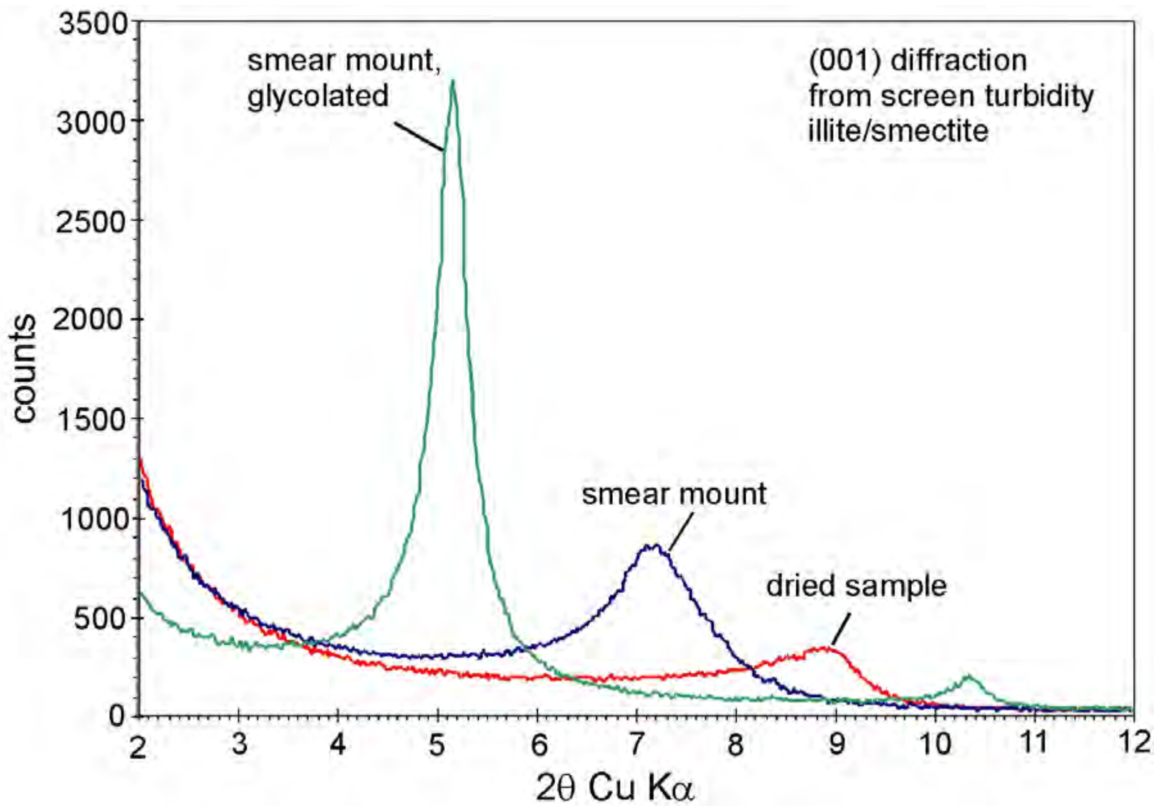

Figure C-1.0-3 Low-angle diffraction of the clay mineral collected from turbid screen samples at R-25b.

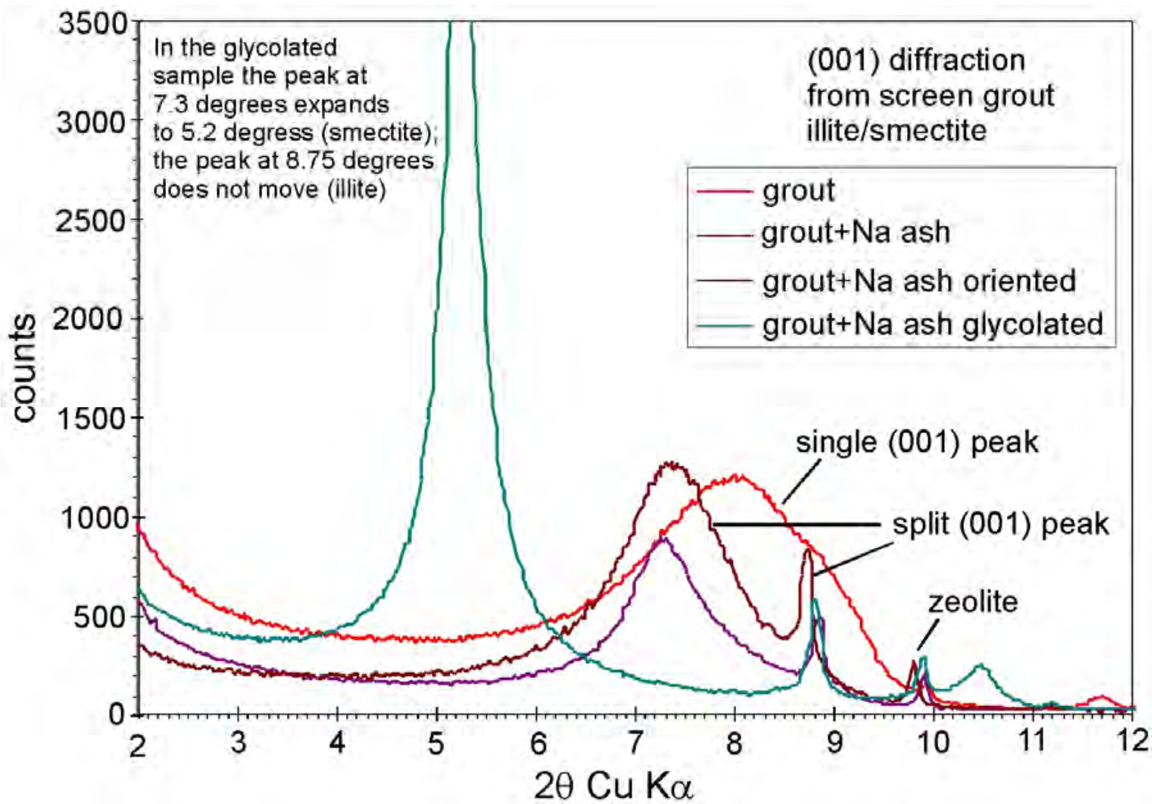

Figure C-1.0-4 Low-angle diffraction of (1) the original sample of dried, untreated high-solids bentonite grout (red); (2) a dried sample of the grout following treatment with soda ash, showing the split of the clay mineral component into two (001) peaks (purple); (3) the oriented smear mount prepared from the soda-ash exposed grout (brown); and (4) glycolation of the oriented smear mount (green).

Appendix D

Geophysical Logging Report

D-1.0 INTRODUCTION

In August 2008, geophysical logging was performed by Schlumberger Water Services in characterization well R-25c before well completion. The logging measurements were acquired from 566 to 850 ft below ground surface (bgs), when the borehole contained 11.75 in.-outside diameter (O.D.) freestanding steel casing from ground surface to 850 ft, drilled with an approximately 12 in.-diameter bit size. Access with the logging tools into the uncased borehole below 850 ft could not be achieved because of an obstruction in the borehole.

The primary purpose of the geophysical logging was to characterize the geology and hydrogeology across the depth section where well screens were being considered, with emphasis on determining upper saturated zone groundwater levels, relative water saturation, depths of porous aquifer zones, and stratigraphy/lithology of geologic units. These objectives were accomplished by measuring, nearly continuously, along the length of the well (1) total water-filled porosity from which an indirect estimate of hydraulic conductivity (production capacity) is made in combination with lithologic composition estimated from the other logs; (2) bulk density (sensitive to total water plus air-filled porosity and grain density); (3) neutron-induced gamma ray (GR) spectroscopy, providing bulk concentrations of a number of important mineral-forming elements, as well as hydrogen; and (4) spectral natural gamma ray, including potassium, thorium, and uranium concentrations.

The following Schlumberger geophysical logging tools were used in the project (see Table D-1.0-1):

- Accelerator Porosity Sonde (APS)
- Triple Detector Litho-Density (TLD)
- Elemental Capture Spectroscopy (ECS)
- Hostile Natural Gamma Spectroscopy (HNGS) and GR

Once the Cabrera Services well drilling project team provided Schlumberger final notification that R-25c was ready for geophysical well logging, the Schlumberger district in Farmington, New Mexico, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and the crew to the job site. Cabrera asked Schlumberger to bring both the open and cased hole geophysical logging tool suites, with the hope of running the open hole suite if the borehole remained stable enough. However, because of an obstruction in the open borehole below the bottom of the casing, the open hole suite could not be run and the cased hole suite was run instead. The Schlumberger logging crew first ran the HNGS and ECS logging tools then rigged down and moved off the site to allow the drilling crew to try and drill out the obstruction. The drilling crew was not immediately successful, so the logging crew returned the next day to complete the cased hole logging suite. Table D-1.0-2 summarizes the geophysical logging runs performed in R-25c.

Preliminary results of these measurements were generated in the logging truck when the geophysical services were performed and are documented in field logs provided on-site. However, the measurements presented in the field results are not fully corrected for borehole conditions (particularly casing) and are provided as separate, individual logs. Schlumberger reprocessed the field results 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 provide consistent hydrogeologic and geologic results; 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, relative hydraulic conductivity, and lithology).

The geophysical log measurements from well R-25c provide overall, good quality results that are consistent with each other across the logged interval. However, the existence, extent, and effect on the geophysical logs of a water or air-filled annulus between the casing and the borehole wall (voids behind the casing) is difficult to determine and thus there is uncertainty about how well some of the log measurements represent true geologic formation conditions (unaffected by drilling). The distance between the logging tool sensor and formation is unknown and thus difficult to account for or correct for. The measurements most affected by voids behind the casing were ones that have a shallow depth of investigation and that require close contact to the uncased borehole wall: the bulk density and the neutron porosity measurements. One indicator that the bulk density is being adversely affected by voids behind the casing is when the computed density porosity is unrealistically high. Where the total porosity estimated from the processed logs reaches above 55%, the bulk density measurement is likely being affected by voids.

Important results from the processed geophysical logs in R-25c include the following.

1. The standing water level in R-25c dropped from 778 ft bgs during the first logging run to 810 ft bgs the next day during the last logging run. The significantly changing well water level creates difficulties for interpretation of the geophysical logs due to draining of the near-borehole geologic formation, thus changing the natural hydrogeologic conditions that the logging tools measure.

2. The processed logs indicate fairly high water content throughout the logged interval, ranging from a low of approximately 12% of total rock volume at 694 ft bgs to a high of around 40% at various depths below 810 ft bgs. It is important to note that the low water content at 694 ft correlates with unrealistically high density porosity (over 80%), which, as described above, indicates a large void behind casing, likely resulting in a lower water content than is representative of the formation. Overall, water content increases with depth, particularly below 694 ft.

3. The total porosity estimated from the processed logs is very high throughout the logged interval, averaging about 40% below 650 ft bgs and 52% above. While the log estimate (primarily derived based on the bulk density measurement) is likely elevated in certain sections due to annular voids between the free-standing casing and the borehole wall (mostly air-filled across the logged section), it is unlikely there is a consistent gap between the casing and the borehole wall that causes the entire log to be biased high. The geology is most likely volcanic tuff, which is known to have high porosity from many other Los Alamos National Laboratory (Laboratory) wells that have been logged (uncased and cased). The naturally high porosity could enable the rock in the immediate vicinity of the borehole to drain when the well water level dropped, a possible explanation for why the geophysical logs are indicating unsaturated conditions and a water table is much lower than anticipated.

4. Conclusions that can be drawn from the processed log results are that the depth of full water saturation is above 824 ft, but the actual depth cannot be conclusively determined from the logs due to the influence of the lowering well water level on the measurements (likely causing the logs to underestimate water content and thus water saturation). It is possible the top of the first saturated horizon could be as high as 695 ft where the processed logs indicate a significant decrease in water content and saturation.

5. The predicted relative flow capacity profile generated from the integrated log analysis results indicate that the most productive interval is at the bottom of the logged section (827–840 ft bgs), with a number of other productive zones up to 710 ft.

6. The integrated log mineral and porosity analysis indicates that the composition of most of the logged section of the borehole (605–842 ft bgs) is conducive to volcanic tuff. However, compositional change is indicated below 762 ft (increase in iron and possibly feldspar) that may represent the presence of alluvium/fanglomerate or altered volcanic tuff.

D-2.0 GEOPHYSICAL LOGGISNG SERVICES AND TOOLS

Schlumberger performed geophysical logging services in characterization well R-25c in August 2008 before initial well completion. The purpose of these services was to acquire in situ measurements to help characterize the near-borehole 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 used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to help design the well completion, to better understand subsurface site conditions, and to assist in overall decision-making.

The primary geophysical logging tools used by Schlumberger in well R-25c were the

- APS, which measures through casing and in water or air-filled hole volumetric water content of the formation at several depths of investigation to evaluate moist/porous zones using a pulsed epithermal neutron measurement, as well as neutron capture cross-section, which is sensitive to water and clay content;
- TLD, which measures formation bulk density through casing to estimate total porosity;
- HNGS, which measures gross natural gamma and spectral natural GR activity, including potassium, thorium, and uranium concentrations, to evaluate geology/lithology, particularly the amount of thorium and potassium-bearing minerals; and
- ECS, which measures neutron-induced spectral GR activity, which determines elemental weight fraction concentrations of a number of key rock-forming elements used to characterize geochemistry, mineralogy, and lithology of the formation, as well as hydrogen content (closely related to water content).

In addition, calibrated gross GR was recorded with every service for the purpose of correlating depths between the different logging runs. Table D-2.0-1 summarizes the geophysical logging runs performed in R-25c.

A more detailed description of these geophysical logging tools can be found on the Schlumberger website (http://www.slb.com/content/services/evaluation/index.asp?).

D-3.0 METHODOLOGY

This section describes the methods Schlumberger employed for geophysical logging of well R-25c, including the following stages/tasks:

- measurement acquisition at the well site
- quality assessment of logs
- reprocessing of field data

D-3.1 Acquisition Procedure

Once the well drilling project team notified Schlumberger that R-25c was ready for geophysical well logging, the Schlumberger district in Farmington, New Mexico, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Upon arriving at the Laboratory site, the crew completed site-entry paperwork and received a site-specific safety briefing.

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

- parking and stabilizing the logging truck in a position relative to the borehole that is best for performing the surveys;
- setting up a lower and an upper sheave wheel (the latter attached to, and hanging above, the borehole from the drilling rig/mast truck);
- threading the wireline cable through the sheaves; and
- attaching to the end of the cable the appropriate sonde(s) for the first run.

Next, prelogging 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 ECS and TLD, respectively), the sources were taken out of their carrying shields and placed in the appropriate tool source-holding locations using special source-handling tools just before lowering the tool string. 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 were returned to their appropriate storage shields, thus eliminating any radiation hazards. Any postlogging measurement checks were performed as part of log quality control (QC) and assurance. The tool string was cleaned as it was pulled out of the hole, separated, and disconnected.

The second tool string was attached to the cable for another logging run, followed by subsequent tool strings and logging runs. After the final logging run was completed, the cable and sheave wheels were rigged down.

Before departure, the logging engineer printed field logs and created a compact disk containing the field log data for on-site distribution and sent the data via satellite to the Schlumberger data storage center. The Schlumberger data processing center was alerted that the data were ready for postacquisition processing.

D-3.2 Log QC 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 full 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.

A tool-specific base calibration that directly relates the tool response to the physical measurement using the designed measurement principle is performed on all Schlumberger logging tools when first assembled in the engineering production centers. This is accomplished through a combination of computer modeling and controlled measurements in calibration models with known chemical and physical properties.

The base calibration for most Schlumberger tools is augmented through regular "master calibrations" typically performed every 1 to 6 mo in local Schlumberger shops (such as Farmington, New Mexico), depending on tool design. Master calibrations consist of controlled measurements using specially designed calibration tanks/jigs and internal calibration devices that are built into the tools, both with known physical properties. The measurements are used to fine-tune the tool's calibration parameters and to verify that the measurements are valid.

In addition, on every logging job, before and after on-site calibrations are executed for most Schlumberger tools directly before/after lowering/removing the tool string from the borehole. For most tools, these represent a measurement verification instead of an actual calibration used to confirm the validity of the measurements directly before acquisition and to ensure that they have not drifted or been corrupted during the logging job.

All Schlumberger logging measurements have a number of associated depth-dependent QC logs and flags to assist with identifying and determining the magnitude of log quality problems. These QC logs are monitored in real-time by the logging engineer during acquisition and are used in the postacquisition processing of the logs to determine the best processing approach for optimizing the overall validity of the property estimates derived from the logs.

Additional information on specific tool calibration procedures can be found on the Schlumberger web page (http://www.hub.slb.com/index.cfm?id=id11618).

D-3.3 Processing Procedure

After the geophysical logging job was completed in the field and the data were archived, the data were downloaded to the Schlumberger processing center. There the data were processed in the following sequence: (1) the measurements were corrected for near-wellbore environmental conditions and the measurement field processing for certain tools (i.e., the TLD, APS, and ECS) was redone using better processing algorithms and parameters; (2) the log curves from different logging runs were depth-matched and spliced, if required; and (3) the near-wellbore substrate lithology/mineralogy and pore fluids were modeling through integrated log analysis. Afterward, an integrated log montage was built to combine and compile all the processed log results.

D-3.3.1 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, temperature, and fluid salinity. Basically, these environmental corrections entail subtracting from the measurement response the known influences of the set of prescribed borehole conditions. In R-25c, the log measurements requiring these corrections are the APS porosity and neutron capture cross-section, CNT porosity, TLD bulk formation density, ECS elemental concentrations, and HNGS spectral GR logs.

Two neutron porosity measurements are available: one that measures thermal ("slow") neutrons (CNT tool) and one that measures epithermal ("fast") neutrons (the APS tool for R-25c). Measurement of epithermal neutrons is required to make neutron porosity measurements in air-filled holes. In water/mud-filled holes, both the epithermal and thermal neutron measurements are valid. Both measurements can be fully environmentally corrected for a single string of steel casing. Epithermal (APS) neutron porosity measurements were made in R-25c. The APS measurements were reprocessed for casing, borehole fluid type (air versus water), and other environmental conditions. The APS also measures neutron capture cross-section; this measurement was also corrected for well environmental conditions at the time of logging. For further processing and analysis (e.g., integrated log analysis), the reprocessed neutron porosity and neutron capture cross-section logs were used.

The raw ECS elemental yield measurements include the contribution of iron from steel casing and hydrogen from fluid in the borehole. The processing consists of subtracting this unwanted contribution from the raw normalized yield then performing the normal elemental yields-to-weight fraction processing. The contribution to subtract is a constant baseline amount (or zoned constant values if there are bit/casing size changes), usually determined by comparing the normalized raw yields in zones directly below/above the borehole casing/fluid change. Casing corrections were applied to the ECS logs across the entire log interval to account for one string of steel casing. During ECS logging in R-25c, the borehole contained water from the bottom to 779 ft; no hydrogen correction was required in the air-filled section above 779 ft, and the difference between the hydrogen yield above and below this depth was used to determine the baseline borehole hydrogen correction to apply below.

The HNGS spectral GR is affected by the material (fluid, air, and casing) in the borehole because different types and amounts of these materials have different GR-shielding properties; the HNGS measures incoming GRs emitted by radioactive elements in the formation surrounding the borehole. The processing algorithms try to correct for the damping influence of the borehole material. The HNGS logs from R-25c were reprocessed to account for the environmental effects of the casing, borehole fluid (water below 778 ft and air above), and hole size as best as possible.

The measurements cannot be fully corrected for borehole washouts or rugosity because the specific characteristics (e.g., geometry) of these features are unknown (especially in this scenario where they hidden by casing) and their effects on the measurements are often too significant to account for. Thus, the compromising effects of these conditions on the measurements should be accounted for in the interpretation of the log results.

D-3.3.2 Depth-Matching and Splicing

Once the logs were environmentally corrected for the conditions in the borehole and the raw measurement reprocessing was completed, the logs from different tool runs were depth-matched to each other using the HNGS tool run as the base reference. Gross GR was used as the common correlation log measurement for depth-matching the different runs. The depth reference for all the processed logs is ground surface.

D-3.3.3 Integrated Log Analysis

An integrated log analysis, using as many of the processed logs as possible, was performed to model the near-wellbore substrate lithology/mineralogy and pore fluids. This analysis was performed using the Elemental Log Analysis (ELAN) program (Mayer and Sibbit 1980, 103867; Quirein et al. 1986, 098043), a petrophysical interpretation program designed for depth-by-depth quantitative formation evaluation from borehole geophysical logs. ELAN estimates the volumetric fractions of user-defined rock matrix and pore constituents at each depth based on the known log measurement responses to each individual constituent by itself[1]. ELAN requires an a priori specification of the volume components present within the formation, i.e., fluids, minerals, and rocks. For each component, the relevant response parameters for each measurement are also required. For example, assuming that quartz is a volume component within the formation and the bulk density tool is used, then the bulk density parameter for this mineral is well known to be 2.65 g/cc.

[1]Mathematically, this corresponds to an inverse problem: solving for constituent volume fractions from an (over)determined system of equations relating the measured log results to combinations of the tool measurement response to individual constituents.

The logging tool measurements, volume components, and measurement response parameters used in the ELAN analysis for R-25c are provided in Table D-3.3-1. The final results of the analysis—an optimized mineral-fluid volume model—are shown on the integrated log montage (see Attachment D-1 [on CD], third track from the right inclusive of the depth track). In addition, the ELAN program provides a direct comparison of the modeled versus the actual measured geophysical logs, as well as a composite log of all of the key ELAN-derived results, including geologic/hydrogeologic properties computed from the mineral-fluid volume model (see Attachment D-2 [on CD]). To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (595 to 842 ft bgs), as many processed logs as possible were included in the analysis, with less weighting applied to less robust logs. Not all of the tool measurements shown in Table D-3.3-1 and the ELAN modeled versus measured log display are used for the entire interval analyzed because not all the measurements are available or of good quality, across certain sections of the borehole. To accommodate fewer tool measurements, certain model constituents are removed from the analysis in some intervals.

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 geology and its volcanic origins. For the ELAN analysis, the log interval from 595 to 762 ft bgs was assumed to be tuff, and a mineral suite considered representative of this volcanic tuff, based on Laboratory cuttings mineral analysis, was used (primary “minerals” silica glass/cristobalite/tridymite [indistinguishable from the log measurements], quartz, potassium feldspar, and augite, with accessory minerals calcite and pyrite). The results of laboratory analyses of Bandelier Tuff and Puye Formation samples from around the Laboratory site were also used to constrain the proportion of quartz versus the combination of glass/cristobalite/tridymite in the ELAN analysis. The log interval 762 to 842 ft bgs was assumed to possibly be fanglomerate/alluvium (although possibly tuff with slightly different composition from the tuff above), and a mineral suite considered representative of this geology, based on Laboratory cuttings mineral analysis, was used (primary “minerals” silica glass/cristobalite/tridymite [indistinguishable from the log measurements], plagioclase and potassium feldspar; quartz at a defined small fraction of the silica glass content; with possible accessory/trace minerals biotite, augite, hypersthene, heavy mafic minerals, and pyrite).

No prior assumption is made about water saturation—where the boundary between saturated 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, despite the obvious influence on the log response of borehole washouts and annular voids behind the casing. There is no way to objectively correct for the adverse effect on the log measurements from these borehole conditions; therefore, the decision was made to perform the ELAN analysis to honor the log measurements. Accordingly, 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. 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.

D-4.0 RESULTS

Preliminary results from the wireline geophysical logging measurements Schlumberger acquired in R-25c were generated in the logging truck when the geophysical services were performed and were documented in the field logs provided on-site. However, the measurements presented in the field results are not fully corrected for undesirable influence (from a measurement standpoint) of borehole and geologic conditions and are provided as separate, individual logs. The field log results have been processed to (1) correct/improve the measurements, as best as possible, for borehole/formation environmental conditions and (2) depth-match the logs from different tool runs in the well. Additional logs were generated from integrated analysis of processed measured logs, providing valuable estimates of key geologic and hydrologic properties.

The processed log results are presented as continuous curves of the processed measurement versus depth and are displayed as (1) a one-page, compressed summary log display for selected directly related sets of measurements (see Figures D-4.0-1, D-4.0-2, and D-4.0-3) and as (2) an integrated log montage that contains all the key processed log curves, on depth and side by side (see Attachment D-1). The summary log displays address specific characterization needs, such as porosity, production capacity, moisture content, water saturation, and lithologic changes. The purpose of the integrated log montage is to present, side by side, all the most salient processed logs and log-derived models, depth-matched to each other, so that correlations and relationships between the logs can be identified.

Important results from the processed geophysical logs in R-25c are described below.

D-4.1 Well Fluid Level

The standing water level in R-25c (within the freestanding 11.75 in.-O.D. casing) was changing during the August 13–14, 2008, logging, lowering from 778 ft bgs during the first logging run to 810 ft bgs during the final logging run. The significantly changing well water level creates difficulties for interpretation of the geophysical logs due to draining of the near-borehole geologic formation, thus changing the natural hydrogeologic conditions that the logging tools measure.

D-4.2 Upper Saturated Zone

The processed geophysical logs definitively indicate fully-water saturated conditions only at the very bottom of the log interval, below 824 ft bgs (see porosity summary display in Figure D-4.0-1 or integrated log montage in Attachment D-1). The estimated pore volume water saturation (fraction of the total pore volume containing water) computed from the ELAN analysis reaches above 80% below 824 ft. Above this depth, water content and water saturation decreases. Between 730 and 770 ft, the ELAN water saturation is higher than the rest of the upper section, reaching 75% in many places. Other interesting features of the processed logs that may provide information about the hydrogeology include a definitive decrease in water content above 710 ft and further, more significant, decrease at 695 ft, both of which are marked by decreases in estimated water saturation as well (particularly at 695 ft). Above 683 ft, water content increases slightly, resulting in an increase in water saturation, but decreases again above 653 ft (water saturation decreases significantly because of an increase in the total porosity log).

The ELAN estimated water content is fairly high throughout the logged interval, ranging from a low of approximately 12% of total rock volume at 694 ft bgs to a high of around 40% at various depths below 810 ft bgs (see porosity summary display in Figure D-4.0-1 or integrated log montage in Attachment D-1). It is important to note that the low water content at 694 ft correlates with unrealistically high density porosity (over 80%), which indicates a large void behind casing, likely resulting in a lower water content than is representative of the formation. Overall, water content increases with depth, particularly below 694 ft.

The total porosity estimated from the ELAN analysis is very high throughout the logged interval, averaging about 40% below 650 ft bgs and 52% above. While the log estimate (primarily derived based on the bulk density measurement) is likely elevated in certain sections due to annular voids between the freestanding casing and the borehole wall (likely mostly air-filled across the logged section), it is unlikely there is consistent gap between the casing and the borehole wall causing the entire log to be biased high. This would be unusual compared to previous Laboratory wells. The geology is likely mostly volcanic tuff, which is known to have high porosity from the many other Laboratory wells that have been logged (uncased and cased). The naturally high porosity could enable the rock in the immediate vicinity of the borehole to drain when the well water level dropped—a possible explanation for why the geophysical logs are indicating unsaturated conditions and a water table much lower than anticipated.

Conclusions that can be drawn from these geophysical log results are that the upper saturated zone water level (depth at which there is full water saturation) is above 824 ft, but the actual depth cannot be conclusively determined from the logs due to the influence of the lowering well water level on the measurements (likely causing the logs to underestimate water content and, thus, water saturation). It is possible the top of the upper saturated zone could be as high as 695 ft where the processed logs indicate a significant decrease in water content and saturation.

The predicted relative flow capacity profile generated from the ELAN integrated log analysis results (derived by integrating the hydraulic conductivity log and normalizing to one) potentially provides information about the depth and relative productivity of more permeable intervals within the logged interval. The flow profile logs (computed from two hydraulic conductivity estimates) suggest that the most productive interval is at the bottom of the logged section (827–840 ft bgs), with the other most productive zone also toward the bottom at 812–822 ft, 803–810 ft, 793–798 ft, 788–791 ft, 781–785 ft, 775–777 ft, 767–773 ft, 763–765 ft, and 710–713 ft (see porosity summary display in Figure D-4.0-1 or integrated log montage in Attachment D-1).

D-4.3 Vadose Zone Water

As mentioned above, the depth to the top of the upper saturated zone and thus the extent of vadose is difficult to assess from the geophysical logs due to the highly varying well water level before and during the time of the logging. Key features of the processed logs across the logged section that might provide information about saturated and unsaturated zone hydrogeology (porosity, water content, saturation) are described above. One of the more interesting characteristics of the log results is the high water content even at the top of the logged section, ranging 20%–25% above 673 ft bgs to the top of the logged interval at 566 ft. This suggests the vadose zone hydrogeologic system is quite wet at this site, at least at these depths.

D-4.4 Geology

The processed geophysical log results, particularly the matrix geochemistry logs, provide information on lithology and potential formation contacts intersected by R-25c across the log interval (from 605 to 842 ft bgs). The generalized geologic stratigraphy observed from the logs across the measured interval is as follows (depth below ground surface):

- 605–650 ft bgs (top of processed log interval): Very high porosity silicon rich material with significant amounts of calcium (likely volcanic tuff)—characterized by very high total porosity (48%–55% of total rock volume); high silica glass/tridymite/cristobalite content; moderate to high potassium feldspar content; moderate amounts of calcite (or other calcium-bearing minerals); and minor amounts of quartz and augite (or similar minerals)
- 650–690 ft bgs: High porosity silicon rich volcanic tuff—characterized by high total porosity (37%–44% of total rock volume); high silica glass/tridymite/cristobalite content; moderate to high potassium feldspar content; moderate amounts of calcite (or other calcium-bearing minerals); and minor amounts of quartz and augite (or similar minerals)
- 690–697 ft bgs: Very high porosity silicon rich volcanic tuff (likely washout behind casing)—characterized by very high total porosity (53% of total rock volume but likely associated with a void behind casing); high silica glass/tridymite/cristobalite content; moderate amounts of potassium feldspar and calcite (or other calcium-bearing minerals); and minor amounts of quartz and augite (or similar minerals)

- 697–708 ft bgs: High porosity silicon rich volcanic tuff/pumice—characterized by high total porosity (38%–43% of total rock volume); high silica glass/tridymite/cristobalite content; moderate amounts of potassium feldspar and calcite (or other calcium-bearing minerals); and minor amounts of quartz and augite (or similar minerals)
- 708–712 ft bgs: Very high porosity silicon rich volcanic tuff (likely washout behind casing)—characterized by very high total porosity (50% of total rock volume but likely associated with a void behind casing); high silica glass/tridymite/cristobalite content; moderate amounts of potassium feldspar and calcite (or other calcium-bearing minerals); and minor amounts of quartz and augite (or similar minerals)
- 712–762 ft bgs: High porosity silicon rich volcanic tuff—characterized by varying, high total porosity (34%–46% of total rock volume); high silica glass/tridymite/cristobalite content; moderate amounts of potassium feldspar and calcite (or other calcium-bearing minerals); and minor amounts of quartz and augite (or similar minerals)
- 762–778 ft bgs: Very high porosity, silicon-rich material with significant feldspar (possibly alluvium/fanglomerate or altered volcanic tuff)—characterized by potentially very high total porosity (34%–44%); high silica glass/tridymite/cristobalite or quartz content; moderate amounts of potassium and plagioclase feldspar and quartz; variably small to moderate amounts of calcite; variably trace to minor amounts of augite, biotite, hypersthene, pyrite and/or heavy mafic minerals
- 778–822 ft bgs: Variable, very high porosity, iron-rich material with significant feldspar (possibly alluvium/fanglomerate or altered volcanic tuff)—characterized by potentially very high total porosity (36%–50%); high plagioclase feldspar content; moderate silica glass/tridymite/cristobalite or quartz content and potassium feldspar; variably small to moderate amounts of calcite; variably trace to minor amounts of augite, biotite, hypersthene, pyrite and/or heavy mafic minerals
- 822–827 ft bgs: High porosity, iron-rich material with significant feldspar and potentially calcite (possibly alluvium/fanglomerate or altered volcanic tuff)—characterized by high total porosity (32%–44%); moderate to high calcite content (or other calcium-bearing minerals); moderate plagioclase and potassium feldspar content; moderate silica glass/tridymite/cristobalite or quartz content; variably trace to minor amounts of biotite and/or heavy mafic minerals
- 822–842 ft bgs (bottom of log interval): Variable, very high porosity, iron-rich material with significant feldspar (possibly alluvium/fanglomerate or altered volcanic tuff)—characterized by potentially very high total porosity (44%–55%, but highest porosity likely associated with voids behind casing); high plagioclase feldspar content; moderate silica glass/tridymite/cristobalite or quartz content and potassium feldspar; variably small to moderate amounts of calcite and augite; variably trace to minor amounts of hypersthene, biotite, pyrite and/or heavy mafic minerals

D-4.5 Summary Logs

Three summary log displays have been generated for R-25c to highlight the key hydrogeologic and geologic information provided by the processed geophysical log results.

- Porosity and hydrogeologic properties summary log showing continuous hydrogeologic property logs, including total porosity (water and air), water-filled porosity, water saturation, estimated hydraulic conductivity, transmissivity, and relative producibility (production capacity), highlights key derived hydrologic information obtained from the integrated log results (Figure D-4.0-1).
- Density and clay content summary showing a continuous logs of formation bulk density and estimated grain density, as well as estimated clay volume, highlights key geologic rock matrix information obtained from the log results (Figure D-4.0-2).

- Spectral natural GR and lithology summary showing a high vertical resolution, continuous volumetric analysis of formation mineral and pore fluid composition (based on an integrated analysis of the logs), and key lithologic/stratigraphic correlation logs from the spectral GR measurement (concentrations of gamma-emitting elements) highlights the geologic lithology, stratigraphy, and correlation information obtained from the log results (Figure D-4.0-3).

D-4.6 Integrated Log Montage

This section summarizes the integrated geophysical log montage for R-25c. The montage is provided in Attachment D-1. 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-25c geophysical logs are provided in the previous section

D-4.6.1 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 HNGS logging run. All the geophysical logs are depth-matched to the gross gamma log acquired with this logging run.

D-4.6.2 Track 2—Basic Logs

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

- GR (thick black), recorded in American Petroleum Institute (API) GR standard units (gAPI) and displayed on a scale of 0 to 200 gAPI units
- neutron-capture cross-section from the APS tool (long-dashed olive green), which is sensitive to water content and lithology, recorded in capture units (cu) and displayed on a scale of 0 to 25 cu
- single arm caliper from the TLD (thin solid pink) with nominal bit size as a reference (dashed-dotted black) to show nominal annular distance between inside of inner casing to borehole wall (pink shading), recorded as hole diameter in inches and displayed on a scale of 8 to 18 in.

Two GR curves from the HNGS are displayed:

- total gross gamma (thick solid black curve with thinner dashed black curve as backup representing the uncorrected SGT GR displayed on a scale to match the corrected HNGS gamma)
- gross gamma minus the contribution of uranium (dotted black)
- yellow shading between the two curves to show uranium contribution to the total GR response

D-4.6.3 Track 3—Porosity

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

- APS epithermal neutron porosity derived from near-far detector pairing (bold solid dark blue curve)—deepest reading epithermal neutron porosity from APS tool, processed for zoned air-filled and water-filled cased hole;

- APS epithermal neutron porosity derived from near-array detector pairing (solid sky blue curve)—medium depth of investigation epithermal neutron porosity from APS tool, processed for zoned air-filled and water-filled cased hole;
- APS slowing down time porosity derived from pulsed neutron time series in the array detectors (thin dotted green curve)—shallowest reading epithermal neutron porosity from APS tool, processed for zoned air-filled and water-filled cased hole;
- ECS bulk volumetric water content derived from hydrogen weight concentration measurement, corrected for water in casing, and converted to volume fraction (short-dashed pink);
- Total porosity derived from bulk density and ELAN water-filled porosity using a grain density of 2.25 g/cc (dashed red curve), 2.45 g/cc (long-dashed red curve), and 2.65 g/cc (dotted red curve),with red shading between the 2.25 g/cc and 2.65 g/cc porosity curves to show the range; and
- ELAN water-filled porosity (bold dashed-dotted cyan)—derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

D-4.6.4 Track 4—Density

The fourth track displays the

- bulk density, corrected for single string of steel casing (thick solid maroon curve) on a wrapping scale of 1 to 3 g/cc; and
- apparent grain density (dashed brown curve), derived from the ELAN analysis, on a scale of 2.4 to 3.2 g/cc.

D-4.6.5 Track 5—HNGS Spectral Gamma

The fifth track from the left displays the spectral components of the HNGS measurement results as wet-weight concentrations, corrected as best as possible for casing and borehole size and fluid:

- potassium (solid green curve) in units of percent weight fraction and on a scale of –2.5% to 2.5%
- thorium (dashed brown) in units of ppm and on a scale of 25 to –25 ppm
- uranium (dotted blue) in units of ppm and on a scale of 20 to 0 ppm

D-4.6.6 Tracks 6 to 11—Geochemical Elemental Measurements

The narrow tracks 6 to 11 present the geochemical measurements, along with their estimated one standard deviation uncertainty range: iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), estimated aluminum (Al) and potassium (K), titanium (Ti) and gadolinium (Gd), hydrogen (H) and apparent relative bulk chlorinity (Rela. Cl), and uranium (U) and carbon yield (C Yield) from left to right, respectively, in units of dry matrix weight fraction (except K and H in wet-weight fraction, Rela. Cl in ppk, U in wet-weight ppm, and C Yield in relative yield units).

D-4.6.7 Track 12—ELAN Mineralogy Model Results (Dry-Weight Fraction)

Track 12 displays the results from the ELAN integrated log analysis (the matrix portion) presented as dry-weight fraction of mineral types chosen in the model:

- quartz (yellow with closely spaced small black dots)
- combined silica glass, tridymite, and cristobalite (yellow with widely spaced large black dots)

- orthoclase or other potassium feldspar (lavender)
- labradorite or similar plagioclase feldspar (pink)
- biotite (light green)
- pyrite (orange-tan with black squares)
- hypersthene (purple)
- augite (maroon)
- heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green)
- calcite (cyan)

D-4.6.8 Track 13—ELAN Mineralogy and Pore Space Model Results (Wet-Volume Fraction)

Track 13 displays the results from the ELAN integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- quartz (yellow with closely spaced small black dots)
- combined silica glass, tridymite, and cristobalite (yellow with widely spaced large black dots)
- orthoclase or other potassium feldspar (lavender)
- labradorite or similar plagioclase feldspar (pink)
- biotite (light green)
- pyrite (orange-tan with black squares)
- hypersthene (purple)
- augite (maroon)
- heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green)
- calcite (cyan)
- air (red)
- water (white)
- moved air (orange)
- moved water (blue)

D-4.6.9 Track 14—Water Saturation

Track 14 displays the continuous-in-depth water saturation logs estimated from the processed logs, recorded in units of volumetric fraction of pore space filled with water (ratio of ft^3/ft^3) and presented on a scale of 0 to 1 ft^3/ft^3 (left to right):

- optimized estimate of water saturation (volumetric fraction of pore space filled with water) from the ELAN analysis (bold dashed-dotted purple curve with blue shading to the right and red shading to the left, corresponding to water-filled and air-filled pore space, respectively)

- water saturation as calculated directly from the bulk density and ELAN-estimated porosity using a grain density of 2.25 g/cc (dashed cyan curve), 2.45 g/cc (solid cyan curve), and 2.65 g/cc (dotted cyan curve) with stippled cyan shading between the 2.25 g/cc and 2.65 g/cc water saturation curves to show the range

D-4.6.11 Track 15—Hydraulic Conductivity

Track 15 displays several estimates of hydraulic conductivity (K) derived from the ELAN integrated log analysis (sensitive to the estimated porosities and mineral composition), presented on a logarithmic scale of 10^{-5} to 10^{5} ft/d:

- a K-versus-depth estimate derived from using the k-Lambda permeability equation with water-filled porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (bold solid blue curve with gradational coloring to represent the range of hydraulic conductivity relative to standard unconsolidated clastic sediments)
- an intrinsic K-versus-depth estimate (assuming full saturation) using the k-Lambda permeability equation with total porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (dotted cyan)
- an intrinsic K-versus-depth estimate (assuming full saturation) using the ELAN total porosity and mineral-based permeability equation with total porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (dotted purple)

In addition, estimates of cumulative transmissivity from the bottom of the log interval are displayed for the k-Lambda estimator (bold dashed-dotted bright green curve) and the ELAN mineral-based estimator (dashed dark green curve), computed by integrating from bottom to top the hydraulic conductivity estimates, presented on a logarithmic scale of 10^{-5} to 10^{5} ft^2/d.

D-4.6.12 Track 16—Predicted Flow (Production Potential) Profile

Track 16 displays the integrated predicted relative flow (production potential) profile from the permeability (hydraulic conductivity) logs that mimics a flow meter (spinner) acquired under flowing conditions:

- predicted relative water-flow profile derived from the k-Lambda water permeability log (bold solid blue curve), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate (ratio of flow rate to flow rate)
- predicted relative water-flow profile derived from the ELAN water permeability log (long-dashed blue), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate
- relative integrated intrinsic permeability profile derived by integrating the k-Lambda intrinsic permeability log (dashed-dotted red), displayed on a unitless linear scale of 0 to 1
- relative integrated intrinsic permeability profile derived by integrating the ELAN intrinsic permeability log (dashed red), displayed on a unitless linear scale of 0 to 1
- predicted hypothetical well water flow versus depth profile for the entire log interval (dotted green), assuming a well radius of 4 in., entirely open to flow, and pumping is occurring under steady state conditions with a drawdown of 25 ft (incremental flow computed using the Thiem steady state flow equation), derived from the k-Lambda water permeability log (bold solid blue), displayed on a scale of 0 to 50,000 gal./d

D-4.6.13 Track 17—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:

- optimized estimate of total volume fraction water from the ELAN analysis (solid blue curve and blue plus cyan area shading)
- optimized estimate of volume fraction intergranular water (nonclay-bound water-filled porosity) from the ELAN analysis (dashed cyan curve and cyan area shading)
- optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading)
- estimate of bulk volumetric water content from the ECS tool (thin dashed dark blue curve)

The porosity and volumetric water content scales are from 0 to 0.6 total volume fraction, left to right

D-4.6.14 Track 18—Depth

The final track on the right, the 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 HNGS logging run.

D-5.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

Mayer, C., and A. Sibbit, September 21–24, 1980. "Global, A New Approach to Computer-Processed Log Interpretation," 55th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers of AIME, September 21–24, 1980, Dallas, Texas. (Mayer and Sibbit 1980, 103867)

Quirein, J., S. Kimminau, J. LaVigne, J. Singer, and F. Wendel, June 9–13, 1986. "A Coherent Framework for Developing and Applying Multiple Formation Evaluation Models," SPWLA 27th Annual Logging Symposium, June 9–13, 1986, Schlumberger Well Services, Houston, Texas. (Quirein et al. 1986, 098043)

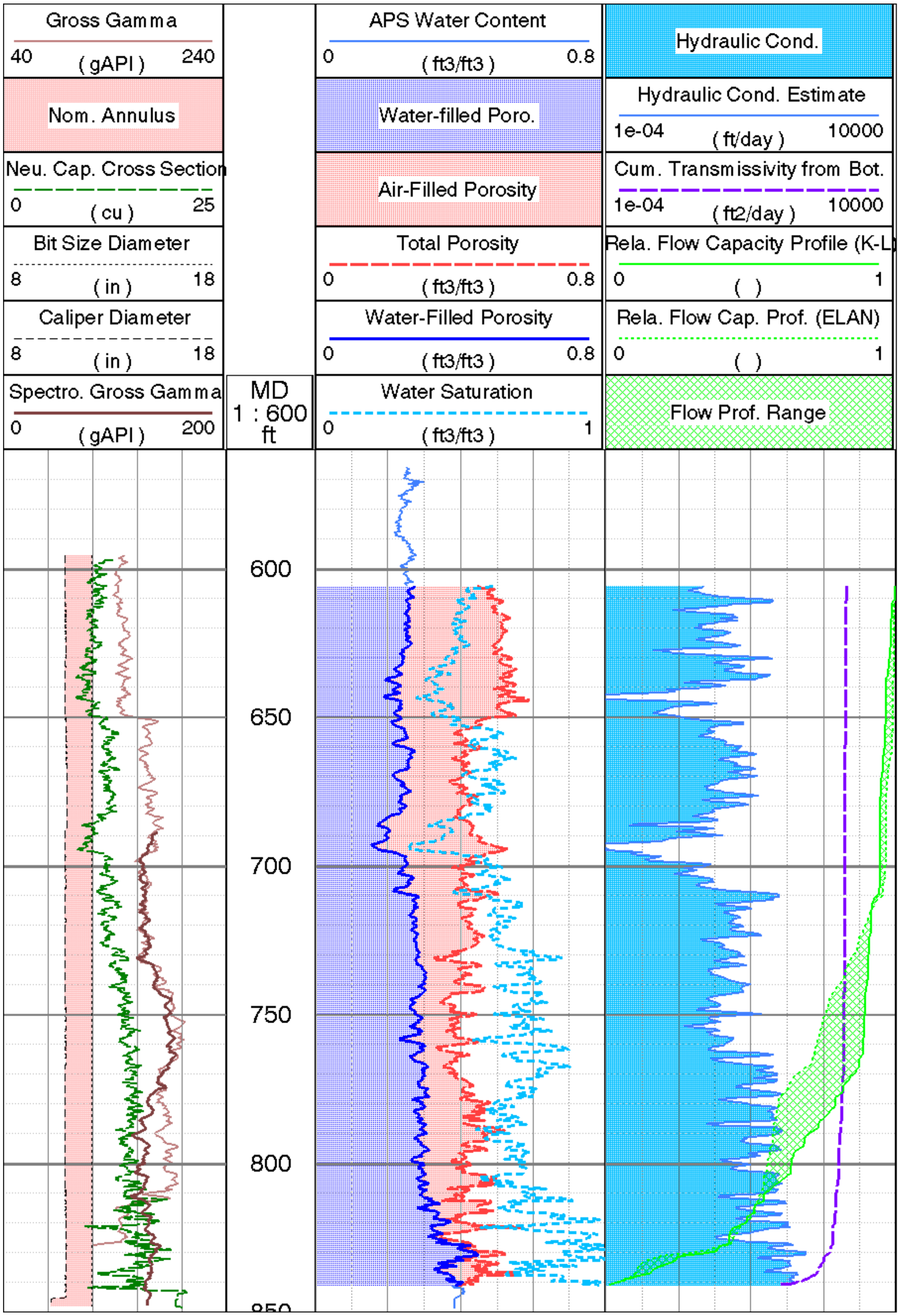

Figure D-4.0-1 Summary of porosity logs in R-25c borehole from processed geophysical logs, interval of 566 to 842 ft bgs, with caliper, gross gamma, neutron capture cross section, water saturation, estimated relative flow capacity profile, hydraulic conductivity, and transmissivity logs also displayed. Porosity, water saturation, and hydraulic conductivity logs are derived from the ELAN integrated log analysis.

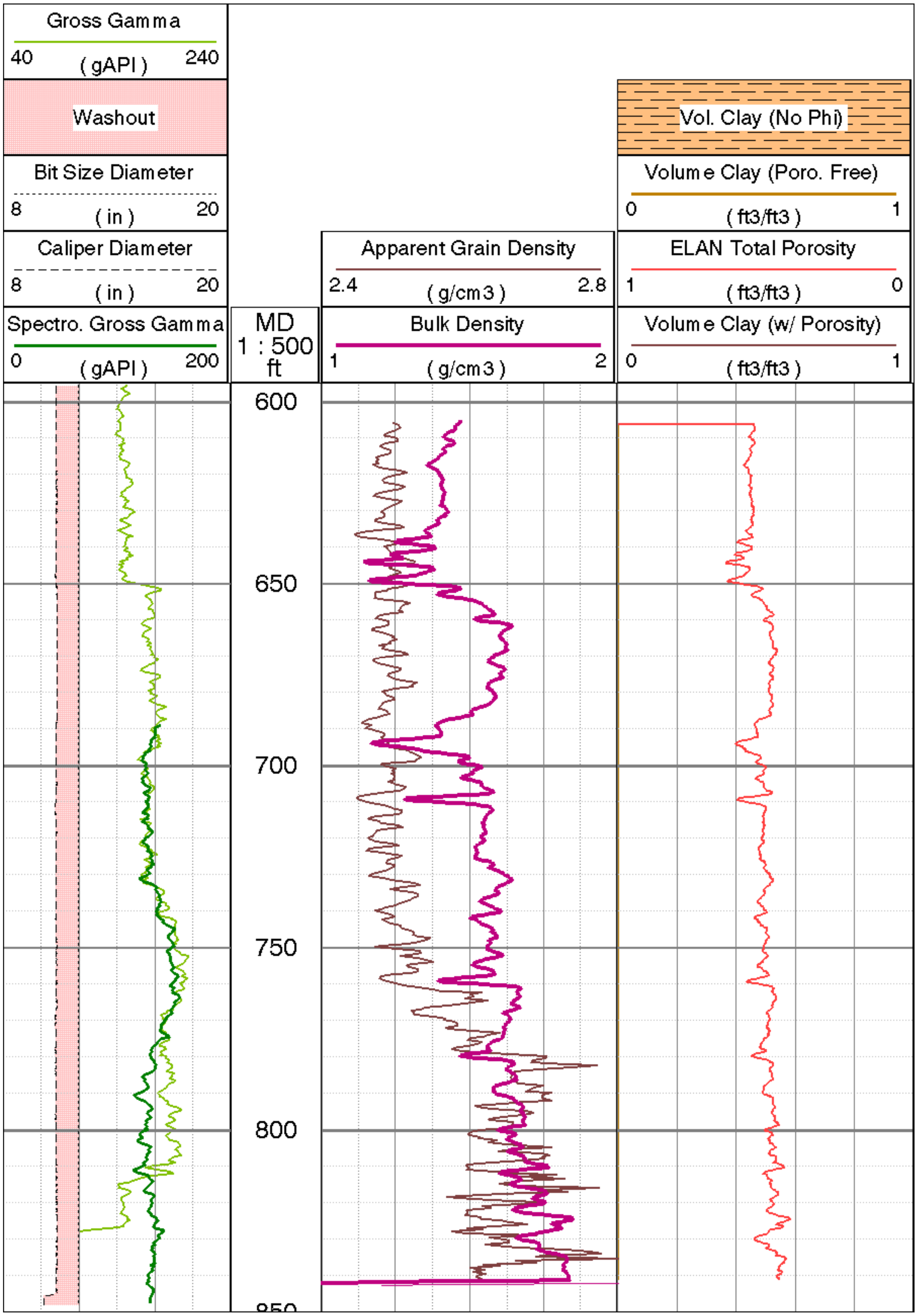

Figure D-4.0-2 Summary of bulk density and apparent grain density logs in R-25c borehole from processed geophysical logs, interval of 605 to 840 ft bgs. Also shown are caliper, gross gamma, volume of clay, and total porosity logs (the latter two are derived from the ELAN analysis; note that clay was not solved for).

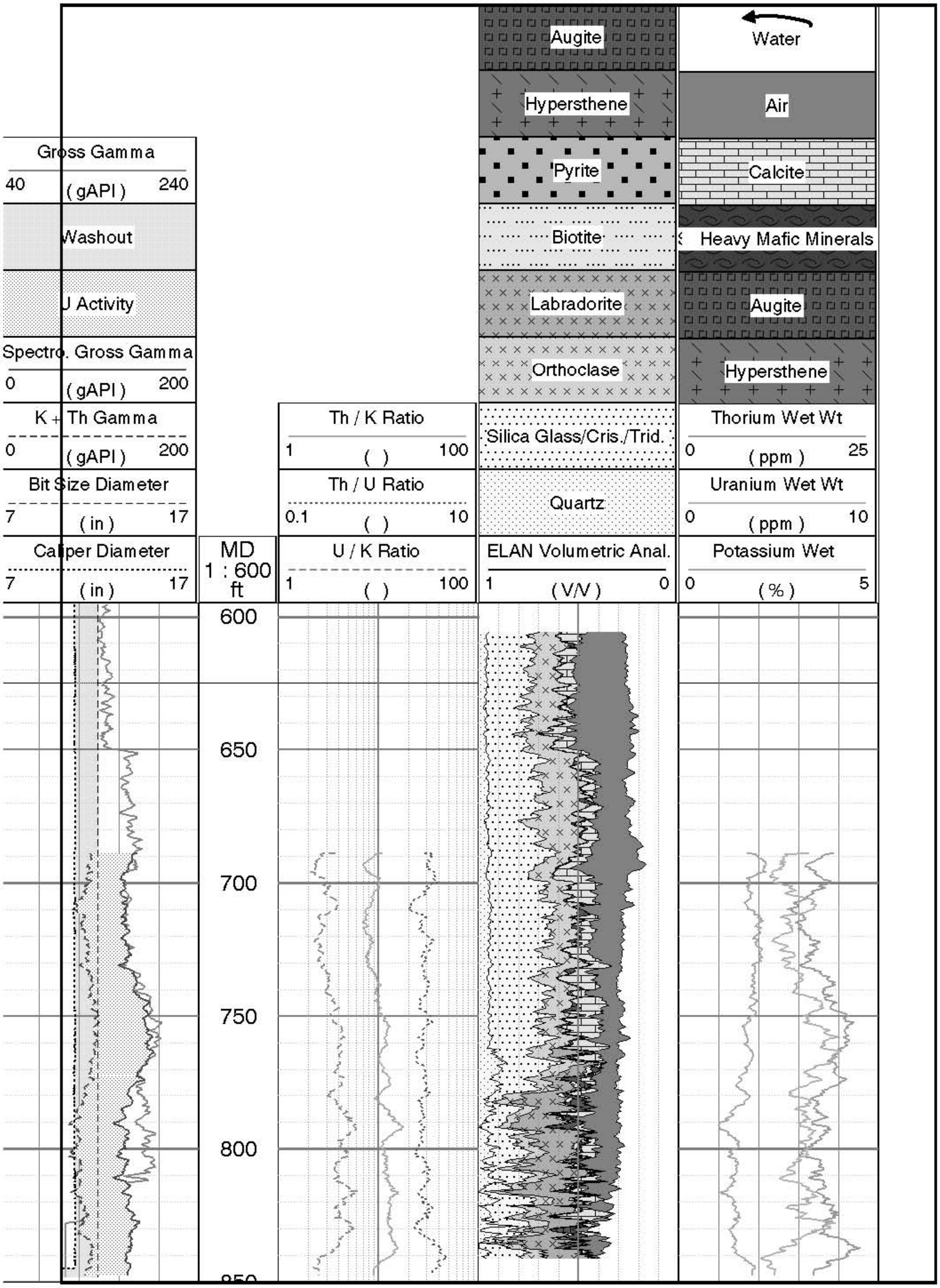

Figure D-4.0-3 Summary of spectral natural gamma ray logs and ELAN mineralogy/lithology and pore fluid model volumes derived from the ELAN integrated log analysis for R-25c borehole, interval 595 to 842 ft bgs. Caliper log is also shown.

Table D-1.0-1
Geophysical Logging Tool, Technology, Corresponding Measured Properties

Tool	Technology	Properties Measured
APS	Epithermal neutron porosity and neutron capture cross-section	Water/moisture content, lithologic variations
TLD	Gamma-gamma bulk density	Bulk density, total porosity, lithology
ECS	Neutron-induced GR spectroscopy	Formation matrix geochemistry, lithology and mineralogy, formation hydrogen content
HNGS and GR	Gross and spectral natural GR, including potassium, thorium, and uranium concentrations	Formation matrix geochemistry, lithology, and mineralogy

Table D-1.0-2
Geophysical Logging Services, Their Combined Tool Runs and Intervals Logged, as Performed by Schlumberger in Well R-25c

Date of Logging	Run #	Tool 1 (bottom)	Tool 2 (top)	Depth Interval (ft bgs)
13-Aug-2008	1	HNGS	GR	692–850
	2	ECS	GR	588–850
14-Aug-2008	3	TLD	GR	606–850
	4	APS	GR	566–850

Table D-2.0-1
Geophysical Logging Services, Their Combined Tool Runs and Intervals Logged, as Performed by Schlumberger in Borehole R-25c

Date of Logging	Borehole Status	Run #	Tool 1	Tool 2	Depth Interval (ft)
13-Aug-2008	Steel free-standing casing from surface to bottom. Single string of 11.75 in.-O.D. casing from surface to the bottom of the borehole at 850 ft, with bit size of ~12 in.	1	HNGS (Bottom)	GR (Top)	692–850
Same	Same	2	ECS	GR	588–850
14-Aug-2008	Same	3	TLD	GR	606–850
Same	Same	4	APS	GR	566–850

Table D-3.3-1
Tool Measurements, Volumes, and Respective Parameters Used in the R-25c ELAN Analysis

Volume Tool Measurement	Air	Water	Hypersthene	Labradorite	Silica Glass, Cristo., Tridy.	Heavy Mafic Minerals	Augite	Montmorillonite	Biotite	Pyrite	Orthoclase	Calcite	Quartz
Bulk density (g/cc)	–0.19	1.00	3.55	2.68	2.33	5.08	3.08	2.02	3.04	4.99	2.54	2.71	2.64
Epithermal neutron poro. (ft^3/ft^3)	0	1.00	0.012	-0.01	0.0	0.022	-0.01	0.6	0.14	0.165	-0.01	0.0	–0.05
Dry-weight silicon (lbf/lbf)*	0.0	0.0	0.24	0.247	0.468	0.184	0.225	0.242	0.178	0.0	0.3	0.0	0.468
Dry-weight calcium (lbf/lbf)	0.0	0.0	0.0	0.09	0.0	0.0	0.10	0.012	0.007	0.0	0.0	0.405	0.0
Dry-weight iron (lbf/lbf)	0.0	0.0	0.20	0.023	0.0	0.22	0.112	0.02	0.199	0.466	0.015	0.0	0.0
Dry-weight aluminum (lbf/lbf)	0.0	0.0	0.0	0.162	0.0	0.0	0.018	0.103	0.081	0.0	0.104	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	0.535	0.0	0.0	0.0
Dry-weight titanium (lbf/lbf)	0.0	0.0	0.01	0.0	0.0	0.0	0.048	0.001	0.016	0.0	0.0	0.0	0.0
Wet-weight potassium (lbf/lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.003	0.004	0.070	0.0	0.12	0.0	0.0
Weight hydrogen (lbf/lbf)	0.0	0.111	0.0	0.0	0.01	0.0	0.0	0.022	0.003	0.0	0.0	0.0	0.0
Wet-weight thorium (ppm)	0	0	13.5	1.75	2	4	13.5	24	25	0	5	0	0
Neutron capture cross-section (cu)	0	22.21	18.9	7.87	4	103	25.66	20	54.1	90	15.82	7.4	4.7

* lbf = Pound force.

Attachment D-1

Integrated Log Montage
(on CD included with this document)

Attachment D-2

Integrated Log Montage
(on CD included with this document)