1229219

[0081651H]

SGW-50194
Revision 0

Geophysical Logging Report for 200-DV-1 Operable Unit Waste Sites in the S Complex Area

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

RECEIVED
MAR 23 2015
EDMC

200-DV-1

Approved for Public Release;
Further Dissemination Unlimited

88

SGW-50194
Revision 0

Geophysical Logging Report for 200-DV-1 Operable Unit Waste Sites in the S Complex Area

Date Published
September 2011

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington

Release Approval Date 09/20/2011

Approved for Public Release;
Further Dissemination Unlimited

TRADEMARK DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy.

Printed in the United States of America

Contents

1 Introduction **1**

2 References **3**

Appendix

A Hanford Geophysical Logging Project S-SX Focus Area ..... **A-i**

Figure

Figure 1. 200-DV-1 Operable Unit Subregions in the S Complex Area, 200 West Area 2

Terms

OU	operable unit
Stoller	S.M. Stoller Corporation

1 Introduction

The 200-DV-1 (Deep Vadose Zone) Operable Unit (OU) consists of 44 liquid waste disposal sites located on the Hanford Site Central Plateau that have been grouped, based on geographic proximity, into subregions. This OU includes the waste sites with deep contamination that cannot be remediated using typical surface-based techniques. The decision process for the 200-DV-1 OU will investigate the nature and extent of deep vadose zone contamination; evaluate potential impacts on groundwater; and evaluate, select, and implement management strategies for addressing deep vadose zone threats to the environment (DOE/RL-2010-89, *Long-Range Deep Vadose Zone Program Plan*).

There are currently 20 200-DV-1 OU wastes sites in the 200 West Area; 17 are located in the T Complex Area, and 3 are located in the S Complex Area. The T Complex Area includes six subregions, and the S Complex Area includes three subregions. Waste sites in the 200-WA-1 (West Area) OU that are located in a subregion are also discussed. In support of the 200-DV-1 OU *Resource Conservation and Recovery Act of 1976* Facility Investigation/Corrective Measures Study and the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* Remedial Investigation/Feasibility Study Work Plan, S.M. Stoller Corporation (Stoller) was contracted to evaluate available geophysical logging data and existing geophysical interpretative reports within the two focus areas. The results for the T Complex Area are provided in SGW-49498, *Geophysical Logging Report for 200-DV-1 Operable Unit Waste Sites in the T Complex Area*, while this report provides the results for the S Complex Area.

Stoller prepared a 200-DV-1 OU waste site summary report (Appendix A) that provides the results of the borehole geophysical log evaluation, specifically focused on addressing the extent of gamma-emitting contamination within the vadose zone at 200-DV-1 OU waste sites in the S Complex Area (referred to as the S-SX Focus Area in Appendix A). The following two subregions (Figure 1) are included in this S Complex Area report:

- Subregion 1—216-S-9 Crib and 216-S-23 Crib (200-WA-1 OU waste site)
- Subregion 2—216-S-21 Crib and 216-S-25 Crib (200-WA-1 OU waste site)

The third subregion in the S Complex Area, the 216-S-13 Crib, was not included in the scope for this report.

The purpose of this report is to assemble and present the interpreted extent of gamma-emitting contamination using available geophysical logging data for the S Complex Area. For each subregion, all boreholes within 100 m (328.1 ft) of the waste site(s) were considered. The evaluation also was based on information about waste site history, well construction detail, and process waste history. These data were evaluated, along with the available geophysical borehole log data, to assess the nature and extent of gamma-emitting contamination in the vadose zone for each subregion and to interpret the historical context. Specific areas of inquiry include the following:

- Correlating between naturally occurring radionuclides and stratigraphy
- Evaluating the effects of stratigraphic boundaries on contaminant plumes
- Evaluating changes over time in the contaminant profile that may be attributed to decay and/or migration
- Comparing observed contaminant profiles with site characteristics and operational history
- Identifying potential data gaps and providing recommendations for future characterization

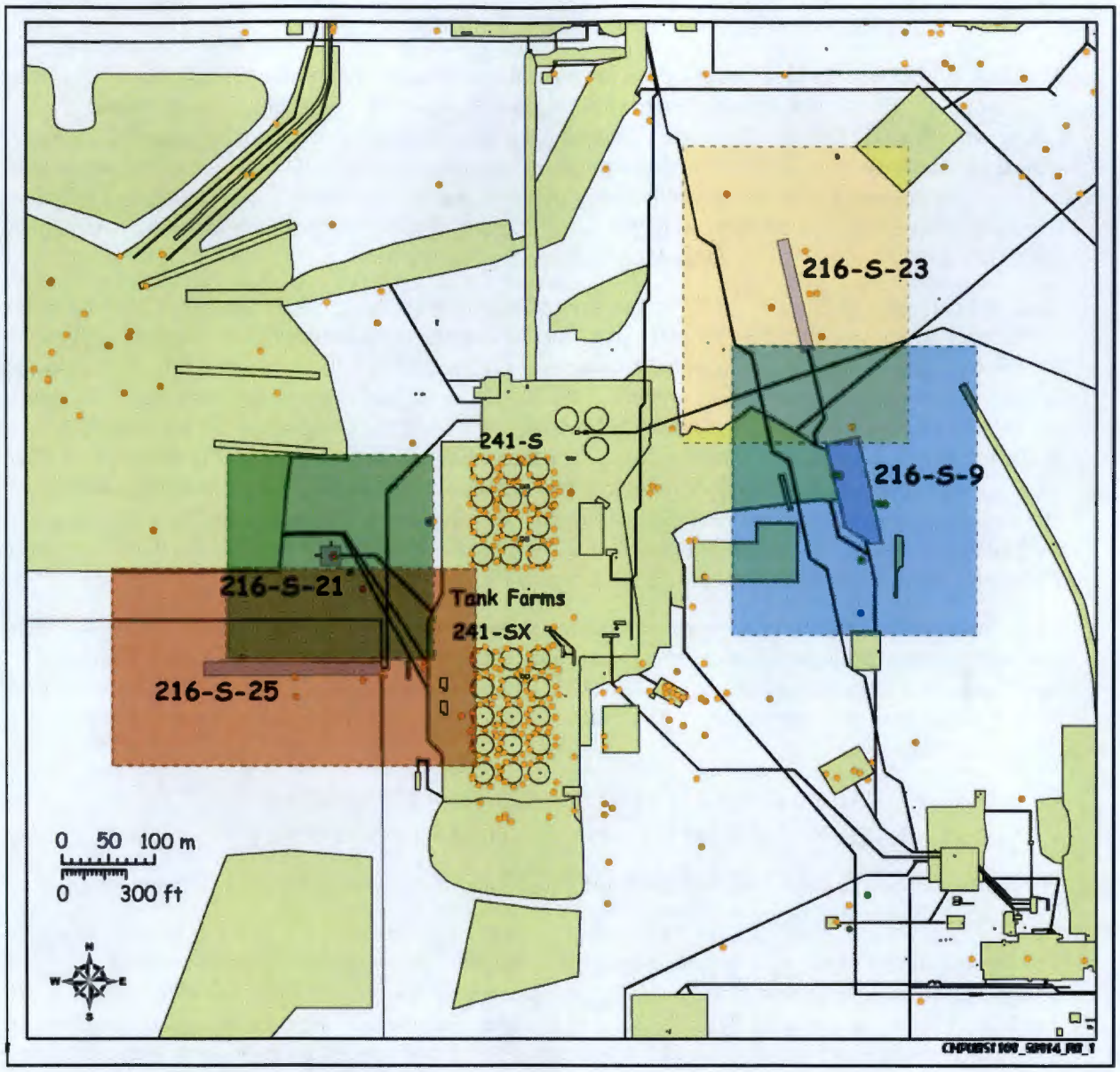


Figure 1. 200-DV-1 Operable Unit Subregions in the S Complex Area, 200 West Area

2 References

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9601, et seq., Pub. L. 107-377, December 31, 2002. Available at: http://epw.senate.gov/cercla.pdf.

DOE/RL-2010-89, 2010, *Long-Range Deep Vadose Zone Program Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0084131.

Resource Conservation and Recovery Act of 1976, 42 USC 6901, et seq. Available at: http://epw.senate.gov/rcra.pdf.

SGW-49498, 2011, *Geophysical Logging Report for 200-DV-1 Operable Unit Waste Sites in the T Complex Area*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

Appendix A

Hanford Geophysical Logging Project
S-SX Focus Area

This page intentionally left blank.

Appendix A

Hanford Geophysical Logging Project
S-SX Focus Area

This page intentionally left blank.

HANFORD GEOPHYSICAL LOGGING PROJECT

S-SX FOCUS AREA

September 2011

Prepared by
S.M. Stoller Corporation
Richland Office
Richland, Washington

TABLE OF CONTENTS

LIST OF TABLES ..... **iii**

LIST OF FIGURES ..... **iii**

HISTORY SHEET ..... **iv**

ACRONYMS AND ABBREVIATIONS ..... **v**

Executive Summary ..... **vi**

1.0 Introduction **1-1**
1.1 References 1-1

2.0 Log Measurements **2-2**
2.1 Total Gamma Logs 2-3
2.1.1 Geiger-Mueller 2-5
2.1.2 Scintillation Logs 2-6
2.2 Spectral Gamma Logs 2-6
2.2.1 Conventional Spectral Gamma Logs 2-7
2.2.2 High-Resolution Spectral Gamma Logs 2-7
2.3 Neutron Moisture Log 2-8
2.4 Passive Neutron Log 2-8
2.5 References 2-9

3.0 Background and Physical Setting **3-15**
3.1 Geology 3-15
3.1.1 Stratigraphy 3-15
3.1.2 Stratigraphy Interpreted Using Geophysical Log Data 3-15
3.2 Waste Site Descriptions 3-16
3.3 Waste Site Process History 3-16
3.4 References 3-17

4.0 216- S-9 and 216-S-23 Cribs **4-1**
4.1 Geology 4-1
4.2 Waste Site Process History 4-1
4.2.1 216-S-9 and 216-S-23 Cribs 4-1
4.3 Previous Investigations 4-2
4.4 Summary of Log Data 4-2
4.4.1 216-S-9 Crib 4-3
4.4.2 216-S-23 Crib 4-4
4.5 Summary of Subregion and Conclusions 4-5
4.6 Recommendations 4-5
4.7 References 4-5

5.0 216-S-21 and 216-S-25 Cribs **5-1**
5.1 Geology 5-1
5.2 Waste Site Process History 5-1
5.2.1 216-S-21 and 216-S-25 Cribs 5-1
5.3 Previous Investigation 5-2
5.4 Summary of Log Data 5-2
5.4.1 216-S-21 Crib 5-2
5.4.2 216-S-25 Crib 5-3
5.4.3 241-S and SX Farms 5-3

TABLE OF CONTENTS

5.5 Summary of Subregion and Conclusions 5-3
5.6 Recommendations 5-4
5.7 References 5-4

Appendix A - Geophysical Logs ..... A-i

LIST OF TABLES

Table 2-1. Hanford Borehole Calibration Models 2-11
Table 2-2. Man-made Gamma Emitting Radionuclides 2-12
Table 2-3. Naturally Occurring Radionuclides 2-13
Table 3-1. 200-DV-1 Suprabasalt-Sediment Lithostratigraphic Nomenclature 3-18
Table 4-1. Geophysical Log Data Acquired Since 1964 (Waste Sites Have A Prefix of 216-) 4-7
Table 5-1. Geophysical Log Data Acquired Since 1958 (Waste Sites Have A Prefix of 216-) 5-5

Table. A-1 200-DV-1 Operable Unit S-SX Focus Area Boreholes and Available Geophysical Log Data A-4

LIST OF FIGURES

Figure 2-1. Comparison of Gamma Energy Spectra 2-14
Figure 3-1. Stratigraphic Units at 216-T-3 and 216-T-6 Waste Sites 3-21
Figure 4-1. 216-S-9 Crib Under Construction 4-9
Figure 4-2. 216-S-9 and 216-S-23 Borehole and Cross Section Location Map 4-10
Figure 4-3. Scintillation Log Profiles (1964 to 1968) for Borehole 299-W22-25 (A7846) 4-11
Figure 4-4. Scintillation Log Profiles (1968 to 1976) for Borehole 299-W22-25 (A7846) 4-12
Figure 4-5. Borehole 299-W22-26 (A4968) Gross Gamma Log (1976) 4-13
Figure 4-6. Borehole 299-W22-34 (A7853) Gross Gamma Log (1976) 4-14
Figure 4-7. Borehole 299-W22-35 (A7854) Gross Gamma Log (1968) 4-15
Figure 4-8. 216-S-9 Crib Cross Section 4-16
Figure 4-9. Visualization of Cs-137 and Co-60 Contamination Near the 216- S-9 Crib Viewed from the West 4-17
Figure 4-10. Scintillation Log Profiles (1969 and 1970) for Borehole 299-W19-5 (A7734) Near 216-S-23 4-18
Figure 4-11. Scintillation Log Profiles (1969 and 1970) for Borehole 299-W19-6 (A4959) 4-19
Figure 4-12. 216-S-23 Crib Cross Section 4-20
Figure 4-13. 216-S-9 to 216-S-23 Cribs Cross Section 4-21
Figure 5-1. 216-S-21 and 216-S-25 Cribs Borehole and Cross Section Location Map 5-7
Figure 5-2. Cross Section from the 216-S-21 Crib to 241-SX Farm 5-8
Figure 5-3. Scintillation Log Profiles for 299-W23-4 near the 216-S-21 Crib 5-9
Figure 5-4. Visualization of Cs-137 and Co-60 Contamination for the 216-S-21 Crib 5-10
Figure 5-5. Visualization of Cs-137 and Co-60 Contamination for the 216-S-21 and 216-S-25 Cribs and West of 241-SX Farm 5-11

HISTORY SHEET

REV DATE	REV NO	REVISED BY	DESCRIPTION OF REVISION
06/17/11	0	P. Henwood	Initial Issue
09/07/11	1	P. Henwood	Minor Revisions

ACRONYMS AND ABBREVIATIONS

BGO	bismuth germanate
bgs	below ground surface
CCu	Cold Creek Unit
CCuc	Cold Creek Unit – calcic geosol
CCuz	Cold Creek Unit – silt dominated
CMS	Corrective Measures Study
cpm	counts per minute
cps	counts per second
DV-1 OU	Deep Vadose Zone Operable Unit
DVZ	Deep Vadose Zone
eCs	equivalent Cesium
eRa	Equivalent radium
eU	equivalent Uranium
FI	Facility Investigation
GM	Geiger-Mueller
HEIS-GPL	Hanford Environmental Information System- Geophysical Log database
HGU	Hanford Gamma Unit
HPGe	high-purity germanium
HRLS	High Rate Logging System
HSU	Hydrostratigraphic Unit
MCA	multi-channel analyzer
MDL	minimum detectable limit
MPC	maximum permissible concentration
MPT	Multi-Project Team
PW	process waste
REDOX	Reduction Oxidation
RFI/CMS	RCRA Facility Investigation/Corrective Measures Study
RFtf	Ringold Formation – Taylor Flat
RFwie	Ringold Formation – Wooded Island Unit E
RI/FS	Remedial Investigation/Feasibility Study
RLS	radionuclide logging system
SGLS	Spectral Gamma-ray Logging System
TRU	transuranic
TW	Tank Waste
VCT	vitrified clay tile
WIDL	Well Information Data Lookup
WIDS	Waste Information Data System

Executive Summary

An evaluation of geophysical log data to detect and assess deep vadose zone contamination in the vicinity of the S-SX Focus Area of the Deep Vadose Zone Operable Unit (200-DV-1 OU) has been performed. The S-SX Focus Area includes four liquid waste disposal sites assigned to the 200-DV-1 OU, and is in addition to the two single-shell tank farms (241-S and -SX). These four 200-DV-1 OU waste sites have been grouped into two subregions on the basis of proximity. Available geophysical logs from existing boreholes in or near each subregion have been evaluated in the context of geological conditions, site conditions, and operational history. Each subregion chapter (Sections 4 and 5) summarizes available site information and log data, defines current and past gamma-emitting radionuclide contaminant impacts, identifies data gaps, and provides recommendations for further investigation.

Boreholes and wells within 100 meters of the 200-DV-1 OU waste sites were identified. A master list (Table A-1) of available geophysical logs from these boreholes was created. The list includes information as to the form (electronic data or hard copy) of the log and its location (i.e., WIDL, HEIS_GPL, or hard copy files). As part of the tasks for this report, logs that were not already referenced in WIDL have been scanned and provided for downloading to WIDL.

Historical gross gamma logs provide a special insight into the disposal history of Hanford waste sites. Although they can be very difficult to interpret in their current form (typically paper strip charts with multiple scale changes to cope with a wide range of gamma activity), they allow interpretations to be made as to the time of arrival and depth and extent of gamma-emitting contamination. Qualitative comparison of total gamma logs over time provides information as to the half-life of dominant radionuclides, and can detect migration of contaminants. These interpretations can be critical in assessing potential impacts to the deep vadose zone and groundwater over the past sixty years. Development of high resolution spectral gamma logging in the early 1990s allows identification and assay of individual natural and manmade gamma emitting radionuclides. These data can be compared to historical gamma profiles. The geophysical logging data represents an important source of information because there is generally very little sediment sample data from the vadose zone within these areas. In some cases, geophysical log data is available both during and after 200-DV-1 waste site operational periods.

Spectral gamma logging also provides useful information for stratigraphic correlation. Concentrations of the naturally occurring radionuclides K-40, U-238, and Th-232 can be determined. Variations in these radionuclides can be used to identify and correlate stratigraphic units.

Brief summaries of the major findings for each subregion are provided below:

Sub Region 1

<u>216-S-9 and 216-S-23 Cribs</u>

- Based on geophysical borehole log data evaluation for wells near the 216-S-9 crib, there is a strong indication that gamma emitting contaminants impacted the deep vadose zone all the way to groundwater by February 1968. Significant decay had occurred by 1976, suggesting short-lived fission products such as Ru-106 as the dominant radionuclide. The current contaminant profile shows Cs-137 existing from approximately 30 to 60 ft (9.1 to 18.3 m) below ground surface with concentrations up to 50,000 pCi/g. This contamination remains above the Hf1/Hf2 geologic contact and near the vicinity of the crib. Most of the gamma emitting radionuclides that were evident in the deep vadose zone in 1968 have decayed away. Data also indicate that the upper unconfined aquifer became contaminated with gamma-emitting contamination around the same time as the vadose zone. These data indicate that mobile non-gamma emitting co-contaminants present in the waste stream could be present throughout the vadose zone down to the water table and above the CCU which may

act as a barrier to liquid migration. The presence and vertical extent of any non-gamma co-contaminants is a data gap for this crib.

- The 216-S-23 crib received similar waste as the 216-S-9 crib and was activated in 1969 after the 216-S-9 crib was closed. There is some evidence in two boreholes east of the crib that short-lived radionuclides contaminated the deep vadose zone to groundwater. Activity exhibited in these two boreholes was much less than shown in the vicinity of the 216-S-9 crib. This activity had decayed away by 1976 similar to the activity measured in the 216-S-9 crib. No significant Cs-137 is shown in any of the boreholes around this crib. At the time of logging in these two wells, groundwater contamination was noticeable at the artificially elevated water table.

Sub Region 2

<u>216-S-21 and 216-S-25 Cribs</u>

- The 216-S-21 crib is characterized by a borehole that was drilled directly through the center of the crib to 51 ft (15.5 m) bgs. Contamination was detected to the bottom of the borehole which reached total depth in the Hf2 sand. A nearby borehole (299-W23-4) southeast of the crib indicated potential contamination by short-lived radionuclides to at least 167 ft (50.9 m) bgs. Current log data indicate remnants of Co-60 near this depth.

The 216-S-21 crib is reasonably well characterized by a borehole that was drilled directly through the center of the crib to 51 ft (15.5 m) bgs. However, there is evidence from historical logs that the deep vadose zone may have been contaminated. Further characterization may be necessary to confirm or refute this possibility.

Total gamma logs in nearby boreholes in 1976 show no evidence of contamination from the 216-S-25 crib. Since 1976, there have been no further measurements acquired in the boreholes close to 216-S-25; however, the crib remained in service until 1985. Additional characterization will be necessary to confirm that no significant contamination was introduced into the crib since 1976.

1.0 INTRODUCTION

This work supports the 200-DV-1 OU RCRA Facility Investigation/Corrective Measures Study (RFI/CMS) and CERCLA Remedial Investigation/Feasibility Study (RI/FS) work plan for the 200-DV-1 (deep vadose zone) Operable Unit due September 30, 2012 (TPA milestone M-015-110A). Creation of the 200-DV-1 OU brings a centralized focus and systematic approach to the challenges presented by contamination in the deep vadose zone (CHPRC-01056-VA). This operable unit includes the waste sites that require specialized remediation approaches and cannot be remediated using typical surface-based techniques. The decision process for the 200-DV-1 OU will investigate the nature and extent of deep vadose zone contamination; evaluate potential impacts on groundwater; and evaluate, select, and implement management strategies for addressing deep vadose zone threats to the environment (CHPRC-01056-VA).

Forty-four waste sites are included in the 200-DV-1 operable unit. These waste sites previously were included in the tank waste (200-TW-1, 200-TW-2) and process waste (200-PW-5) operable units. The 200-DV-1 operable unit includes cribs and trenches associated with WMAs B-BX-BY and T and TX-TY along with a few reduction oxidation (REDOX) cribs located in the vicinity of the WMA S and SX. Geophysical log data associated with WMA B-BX-BY have been evaluated and reported in several waste site summary reports prepared by the Hanford Geophysical Logging Project in 2002. This report will address published log data associated with specific waste sites in the S and SX "Focus Area." This Focus Area has been further subdivided into two subregions:

Sub Region 1 - 216-S-9 and 216-S-23
Sub Region 2 - 216-S-21 and 216-S-25

The purpose of this report is to assemble available geophysical logging data and present the interpreted extent of gamma emitting contamination for the Focus area. For each subregion, all boreholes located within 100 meters of the waste site(s) are considered. This evaluation includes additional information about the waste sites' history, well construction detail, and process waste history. These data are evaluated to assess the nature and extent of gamma-emitting contamination in the vadose zone for each subregion, and to interpret the historical context. Specific areas of inquiry include: 1) correlations between naturally occurring radionuclides and stratigraphy; 2) evaluating the effects of stratigraphic boundaries on vadose zone contaminant migration; 3) evaluating changes over time in the contaminant profile that may be attributed to decay and/or migration; 4) comparing observed contaminant profiles with site characteristics and operational history; 5) identifying potential data gaps; and 6) providing recommendations for future characterization.

For each subregion, a brief background section is provided that includes waste site characteristics, process history, and geology. Cross sections that include the current contamination profile in relation to the waste site and lithostratigraphy are provided. Where appropriate and data are available, 3-dimensional visualizations and interpretations are provided. Appendix A includes a master list of all the geophysical logs used in the interpretations in this report.

1.1 REFERENCES

CHPRC-01056-VA. *Hanford Site – Deep Vadose Zone Cleanup Challenge, Rev. 3*. U.S. Department of Energy. Richland Operations Office. Richland, WA.

2.0 LOG MEASUREMENTS

Since the inception of the Hanford Site in World War II, borehole measurements have been used to assess and monitor subsurface radiological contamination. Over the years, a variety of geophysical log measurements have been made in boreholes, but the dominant measurements have been gamma activity and moisture content due to the cased nature of the boreholes and wells. Early measurements consisted of point by point measurements from instruments suspended in a borehole and recorded into log books or onto data sheets. As instrumentation and electronics have increased in sophistication and capability, logging equipment has also improved, from strip chart recordings to digital data acquisition. Although they may be considered crude by today's standards, early logs provide important information regarding the nature and extent of subsurface contamination throughout the operational history of the Hanford Site. Last and Horton (2000) provide a review of geophysical methods used at Hanford, including geophysical logging. Table 2 of their report includes a summary of significant logging activity up to 2000. A bibliography of publications related to surface and borehole geophysics is also provided.

Borehole geophysical logs provide a record of the nature and distribution of subsurface activity throughout Hanford's operational period to the present. Many boreholes that were logged in the early days are still available for logging, but the recent emphasis on decommissioning "unnecessary" boreholes means that opportunities to collect additional data may be limited. Gamma logs and moisture logs can be generated at regular intervals in a borehole and thus offer one of the few opportunities to monitor contaminant conditions over time in the vadose zone. An understanding of past and current geophysical logs is therefore important to evaluating the deep vadose zone.

The majority of waste disposal operations occurred in the Hanford 200 Areas (200W and 200E) where irradiated uranium was processed to recover plutonium. Depth to groundwater in this area is on the order of 240 feet. The Hanford formation and most of the Ringold Formation that comprise the vadose zone are poorly consolidated. Most boreholes and wells, particularly in or near areas of suspected contamination, are drilled with cable tool methods. Steel casing is required to maintain borehole integrity. Drilling methods involving mud to stabilize the borehole are not used because of the difficultly of dealing with radiological contamination and potential spreading. The presence of steel casing precludes the use of most electromagnetic logging methods. Acoustic logging methods require water or other fluid between the sonde and the borehole wall, and thus cannot function above groundwater level in most Hanford boreholes. A major exception is the borehole seismic survey, which employs a stationary geophone clamped to the casing and a surface seismic source to measure seismic wave velocities in the surrounding formation. The primary logging methods for vadose zone investigation rely on radiation transport. The steel casing blocks alpha and beta radiation, so only gamma rays and neutrons can be measured in most applications. Passive measurement of gamma activity is the most common logging method. Measurement of moisture content by neutron backscatter is also performed. Gamma density logs and neutron porosity logs have also been run, but interpretation of these logs is complicated by the presence of steel casing and annular material such as grout or bentonite. Since the gamma density log measures scattering of gamma rays from a Cs-137 source, its use in contaminated zones where Cs-137 is the dominant contaminant is problematic. Efforts have also been made to use neutrons from radioisotope sources (Am-241/be or Cf-252) or neutron generators to interrogate the vadose zone sediments. These include neutron capture logs, prompt fission logging, and neutron capture cross section logs. There has also been some success in using passive neutron logs to detect neutron activity originating from (α, n) reactions or spontaneous fission - this is interpreted as an indication of the presence of transuranic (TRU) elements, such as Pu-239, Pu-240, Pu-241, Np-237, or Am-241 (Bauer, et al, 2000). In some boreholes, high-resolution spectral gamma logs have also detected prompt gammas originating from (α, n) reactions or neutron capture (Henwood and McCain, 2009). At present, a subsurface probe using a scintillation detector to assay Tc-99 from in-situ measurement of beta activity is being developed (Skorska, 2010). This probe will be emplaced with a direct push drilling system. It will measure beta activity immediately below the direct push rods and thus provide a profile as the rods are withdrawn.

Gamma logs and moisture logs provide the bulk of available subsurface data for investigation of the deep vadose zone, and the remainder of this section will focus on those logs.

2.1 TOTAL GAMMA LOGS

Total gamma logs or gross gamma logs refer to passive measurement of gamma activity without regard to energy level. Naturally occurring radionuclides, such as K-40, U-238, and Th-232 contribute to background gamma activity in each measurement. These radionuclides have extremely long half lives, such that their activity or concentration can be considered constant over any time scale related to human activity. Variations in naturally occurring radionuclides result in detectable variations in background or natural gamma activity which can be used for lithologic identification and stratigraphic correlation.

Hanford waste includes fission products, uranium, and TRU radionuclides. Many of these emit detectable gamma rays. In general, the presence of gamma activity significantly in excess of a "typical" background count rate for a specific detector can be interpreted as a qualitative indication of the presence of Hanford related gamma-emitting contamination.

Fission products are radionuclides created by fission of U-235 and less commonly Pu-239. When the U-235 atom undergoes fission, it tends to break up into two unequal fragments with atomic mass numbers of approximately 95 and 137, with the remainder of the mass as neutrons. Many fission fragments are highly unstable (short half life) and they undergo successive radioactive decay by beta emission or electron capture. Gamma rays are also emitted with most of these decay reactions. The short half lives associated with many fission fragments means that overall gamma activity will decrease rapidly over time. Where multiple logs are available over an extended time period, it may be possible to identify dominant radionuclides from the observed rate of decay. Typical short-lived radionuclides of interest that may be detectable by total gamma logs are listed below.

Radionuclide	Half-Life
Ru-106	371.8 days (1.018 years)
Cs-134	2.0652 years
Sb-125	2.75856 years
Co-60	5.271 years
Eu-154	8.601 years
Eu-152	13.537 years
Sr-90[a]	28.79 years
Cs-137	30.08 years

[a]Sr-90 does not emit gamma but its Bremstrahlung radiation is detected by gamma sondes as a broad peak.

When specific radionuclides are known or can be assumed to be present and sufficient data are available, it may be possible to use regression analysis of the decay curve to estimate the relative proportions of each radionuclide.

Manmade uranium and TRU are much less likely to be detected with total gamma logs because gamma emission rates associated with decay are very low. It is possible that significant concentrations of uranium or TRU may exist in intervals where total gamma activity is comparable to background levels. Since uranium and most TRU have much longer half-lives, radiation associated with these elements is more persistent.

Total gamma logs are generally reported in terms of count rate, which is determined by dividing total counts by the elapsed time over which the counts are accumulated. This may be reported in units of counts per minute (cpm) or counts per second (cps). It can be difficult to compare results between two different detectors, because the ability of a specific detector to count an incident gamma ray depends on the gamma

energy, attenuation through the sonde housing, any shielding or collimation, and the borehole environment (casing and the presence of water).

Most gamma detectors exhibit linear response, at least at low count rates. As radiation levels increase, count rates increase proportionally. However, at high count rates, detector response becomes increasingly non-linear. With each gamma interaction, there is a small time period during which the detector is unable to detect an additional gamma. This time period is known as the dead time (τ). The magnitude of τ is a characteristic of both the detector and associated pulse processing electronics. At low activity, it can be assumed that the measured count rate, m, is reasonably close to the "true" count rate, n. As gamma activity increases, the average time between gammas decreases so that the next gamma is more likely to arrive during a dead period and thus is not counted. At high activity, detector response becomes increasingly non-linear and the "true" count rate may be much higher than the measured count rate. In logging practice, a "dead time correction" based on the non-paralyzable model (Knoll, 2010) is applied:

$$n=m/(1-m\tau) \qquad (1)$$

The concept of dead time has implications regarding the maximum credible count rate from any logging system. Obviously, the maximum recordable count rate is $m = 1/\tau$. As the quantity $m\tau$ approaches 1, the "true" count rate (n) increases rapidly. Equation 1 is based on a hypothetical detector, with the basic assumption that gammas arriving during a dead period have no effect. In practice, it is reasonably reliable for values of $m\tau$ up to about 1/3. Therefore $m = 1/3\tau$ represents a credible maximum count rate for most detectors. Scott (1980) discusses the importance of accurate dead time values in correcting gamma logs, and provides equations to determine dead time using two sources of approximately equal magnitude. Unfortunately, dead time characteristics of older logging systems used at Hanford may not be known, and the systems are no longer available for testing. However, it is possible to make general assumptions based on detector type. Where response data exists, it is preferable to establish maximum credible count rates based on actual detector performance.

Dead time effects and behavior at high count rates are important factors in evaluating log data near Hanford waste sites. Radiation levels in contaminated intervals may range over about 9 to 10 orders of magnitude. This is well beyond the dynamic range of any single detector. Many detectors will become "saturated" or "paralyzed" in moderate to high levels of contamination.

Total gamma logs may be "standardized" in terms of equivalent concentrations of a specific radionuclide. By the early 1990's the scintillation logging system was calibrated in terms of "equivalent uranium" (eU) (Brodeur and Koizumi, 1989, Arthur, 1990, 1991, 1992, 1993). This calibration was based on the field calibration facilities developed by DOE (Steele and George, 1986). The borehole calibration models consisted of concrete cylinders 4 ft (1.2 m) in diameter and 4 ft (1.2 m) tall with a borehole along the axis. Uranium ore, monazite sand and/or orthoclase sand were used to provide varying concentrations of uranium, thorium, and potassium. The field calibration standards were originally located in Spokane. They were moved to Hanford in the early 1990's and are now installed at the Hanford Borehole Calibration Facility, located outside the 200W area near the central weather station. Table 2-1 provides information on the calibration models.

Use of "equivalent uranium" as a log unit at Hanford is not recommended, because it has the potential to be highly misleading. Nearly all gamma activity from "natural" uranium originates from Bi-214 or Pb-214. These daughters are located well down in the U-238 decay series. Secular equilibrium develops very slowly in the U-238 decay series, and gamma activity from Bi-214 or Pb-214 will require hundreds of thousands of years to reach equilibrium with the parent U-238. Uranium used as reactor fuel at Hanford was separated from the ore and enriched (generally to 2 wt% U-235 or less). During processing, the daughter radionuclides were removed, and the "processed" or "manmade" uranium actually exhibits significantly less gamma activity than "natural" uranium. Presenting log results in terms of eU will give the impression that uranium is present everywhere even though naturally occurring uranium in geologic materials is completely unrelated

to Hanford contamination. Moreover, the total gamma log results will seriously underestimate concentrations where uranium is present as a contaminant.

Recently, a convention has been established to report total gamma log results in terms of 'equivalent radium" (eRa). Ra-226 is a member of the U-238 decay series. With the exception of low intensity gammas from Pa-234m, nearly all gamma activity associated with the U-238 decay series originates from Ra-226 and subsequent daughters (notably Pb-214 and Bi-214). Even if secular equilibrium is not fully established in the calibration models, the decay series from Ra-226 to the stable end product Pb-206 will be in equilibrium. Ra-226 is not present at detectable levels in "manmade" or processed uranium and it was not produced at Hanford or used in significant quantities. eRa is therefore preferable to eU as a standard unit for total gamma logs. Background activity for total gamma logs should be on the order of 2.5 pCi/g eRa- this includes contributions from K-40 and the Th-232 decay series as well. Values above about 5 to 10 pCi/g eRa can be interpreted as an indication of contamination. However, anomalously high eRa levels may be misleading, because the observed gamma activity is almost certainly not related to radium; however, there are zones, such as the lower caliche in the Cold Creek unit, where high natural uranium levels exist. At the same time, eRa levels less than 5 pCi/g cannot be uniformly interpreted as "clean" because gamma activity from manmade uranium or TRU is relatively weak and may not contribute to a detectable difference in total gamma activity.

Cs-137 is the most common gamma emitting fission product remaining today at the Hanford Site, and total gamma logs may also be expressed in terms of "equivalent cesium" (eCs). This conversion is generally established by comparing the total gamma log with spectral gamma log results from the same borehole.

When total gamma logs are presented in terms of "equivalent concentrations" (eU, eRa, eCs), it must be understood that this in no way "confirms" that the indicated radionuclide is actually detected. The log should be interpreted to mean that the observed gamma activity is comparable to that associated with a uniform and homogeneous distribution of the indicated radionuclide.

One approach to standardize response of total gamma logs is to establish an empirical unit for gamma response. In well logging practice, the API gamma unit was established by the American Petroleum Institute for gamma logs. It is based on measurements in the API Calibration Facility at the University of Houston, Texas, where a concrete cylinder contains potassium, uranium, and thorium –bearing minerals at levels representing approximately twice the radioactivity of a typical midcontinent shale. The API gamma unit is defined as 1/200th of the difference in gamma activity between this cylinder and a similar cylinder of "barren" concrete. Since calibration models have been installed on the Hanford site, it is possible to define an empirical gamma unit on the basis of measurements in those models. The Hanford Gamma Unit (HGU) is defined on the basis of gamma activity at the midpoint between the SBT and SBK models. This was chosen because gamma activity at this point is very close to average background activity in shallow sediments. Converting total gamma log results to HGU thus expresses gamma activity in terms of multiples of background. This makes it relatively easy to identify intervals of possible contamination without providing any (possibly false) implication as to the source of the gamma activity. This simplifies comparisons of gamma measurements and trends over time using different sensors.

Two general types of detectors are used for total gamma logs. These are the Geiger-Mueller (GM) and scintillation detectors.

2.1.1 GEIGER-MUELLER

A GM detector is one of the oldest radiation detectors in existence, having been introduced in 1928. Simplicity, low cost, ruggedness, high-amplitude output, and ease of use make the GM detector useful in well logging applications. Because of the physical process inside a GM tube, all pulses are of the same amplitude, regardless of the energy level of the incident gamma. A major disadvantage of GM detectors is relatively high dead time. After a pulse is generated, a finite time period is required for the detector to recover. This time period is typically on the order of 20 to 100 microseconds. In a practical sense, GM detectors are

limited to a maximum count rates on the order of about 3400 to 20,000 cps (the exact value depends on the dead time). Because the high voltage across the GM tube must recover after each event, GM detectors may become paralyzed at high count rates. In detector paralysis, a gamma arriving during the dead time after a pulse is not counted but may extend the time necessary for the tube to recover. Count rates may become "saturated" or actually decrease with increasing gamma activity.

2.1.2 SCINTILLATION LOGS

In a scintillation detector, incident gamma rays create a brief flash of light, which is amplified and detected by a photomultiplier or photodiode. In logging applications, common scintillation materials include sodium iodide (NaI) or bismuth germanate (BGO). NaI crystals typically include trace amounts of thallium to improve response, and it should be understood that NaI is equivalent to the notation NaI(Tl) seen in other publications. Other scintillation materials that can be used in logging applications include cesium iodide (CsI) and lanthanum bromide (LaBr). The intensity of the light (and the voltage of the resultant output from the photomultiplier or photodiode) is proportional to the energy of the gamma ray. Depending on the electronics, it may be possible to capture spectral data. In other cases, the system may operate in a total count mode. In most systems, discriminators are used to reject pulses when the energy (voltage) is above or below a pre-set limit. Scintillation detectors generally have dead times on the order of 5 to 30 microseconds, meaning that the maximum credible count rate is on the order of 12,000 to 70,000 cps. Scintillation detectors may also become paralyzed in extremely high gamma activity.

2.2 SPECTRAL GAMMA LOGS

Spectral gamma logs provide information regarding the energy level of each of the detected gammas. Modern systems use a multi-channel analyzer (MCA) wherein individual pulses are counted and assigned to channels by energy level. When a gamma at a specific energy is detected, the value in the corresponding MCA channel is incremented. After the count time is completed, the resulting histogram of counts as a function of channel number (energy) is referred to as the gamma energy spectrum. Since radionuclides emit gammas at characteristic energy levels during decay, the gamma energy spectra can be used to identify and assay specific radionuclides.

As a historical note, some of the older scintillation total gamma logging systems had limited "spectral" capability as early as 1955. The "2nd generation scintillation logging system" and "3rd generation logging system" (Last and Horton, 2000) are described by Speer and Rankin (1956) and Raymond (1964). Both of these systems employed NaI detectors. Pulse height analyzers with adjustable discriminator circuits were used. In normal logging mode, the discriminators were off and total counts were recorded. Spectral information could be obtained by making stationary measurements and adjusting the discriminators to "bracket" energy ranges of interest. By today's standards, this method would be very cumbersome, and there is little evidence it was used extensively in the early logging at Hanford.

Spectral gamma logs can be classified as "conventional" or "high-resolution" depending on the energy resolution of the detector. Conventional spectral gamma logs employ scintillation detectors such as NaI or BGO. These systems are typically rugged and sensitive, but they have relatively poor energy resolution. Analysis is generally performed using relatively wide energy "windows" representing selected radionuclides. High resolution spectral gamma logs employ semiconductor detectors such as high-purity germanium (HPGe). Although these detectors are more difficult to employ in a logging environment and tend to be less sensitive than scintillators, they provide excellent energy resolution (2-4 keV peak width). Figure 2-1 shows a comparison between gamma energy spectra collected with a NaI detector (conventional log) and an HPGe detector (high resolution log).

2.2.1 CONVENTIONAL SPECTRAL GAMMA LOGS

Conventional spectral gamma logs have long been used for lithologic evaluation. Analysis and interpretation methods employed in the logging industry are based on the premise that gamma activity originates from natural sources (K-40, U-238 and Th-232, or "K U T"), and that variations in concentrations of these radionuclides are diagnostic of lithology. The logs generally include total count rate, with additional estimates for potassium, uranium, and thorium concentrations. These concentrations are computed from count rates in three or more relatively broad energy windows, using a coefficient matrix obtained from measurements in calibration models containing known amounts of potassium, uranium, and thorium-bearing minerals. In theory, windows can be added for additional radionuclides, but this poses practical problems. For one thing, only a relatively limited number of radionuclides can be added, and each additional radionuclide complicates calibration and analysis. Natural radionuclides are present in all sediments within a relatively limited range of concentrations. Manmade radionuclides are not present in uncontaminated sediments, but concentration values may vary over several orders of magnitude in contaminated intervals. The matrix approach will tend to generate false positives in uncontaminated intervals and may not accurately calculate concentrations in severely contaminated intervals. Other non-routine methods such as full spectrum analysis can be applied to achieve better results. Individual gamma energy spectra can be examined to identify radionuclides and calculations of equivalent concentration can be made from total count rate or window count rate.

Since the mid 1990's, high-resolution spectral gamma logging has been available at Hanford and these logs have displaced conventional spectral gamma logs from most applications. However, conventional spectral gamma logs still offer an important advantage: equipment required can be much smaller than that required for the high resolution logging equipment. The HPGe detectors and liquid nitrogen Dewar flasks that are required for high resolution spectral gamma logging constrain the minimum borehole diameter to about 4 inches. Increased use of small-diameter direct push units for shallow subsurface investigation has created a need for logging tools that can operate in borehole diameters as small as 2 inches, and this had led to deployment of small diameter conventional spectral gamma logging systems.

2.2.2 HIGH-RESOLUTION SPECTRAL GAMMA LOGS

The high resolution spectral gamma logging system (SGLS) employs cryogenically cooled HPGe detectors to acquire laboratory-quality gamma energy spectra in boreholes. The SGLS is a modification of the radionuclide logging system (RLS) that was deployed in the early 1990's. Both logging systems are very similar. The primary differences are in count time, data analysis, and log presentation.

Gamma energy resolution for the SGLS is between 2 and 4 keV. This allows natural and manmade radionuclides to be identified on the basis of characteristic decay gammas, and assay values are calculated from net counts for specific gamma peaks. Tables 2-2 and 2-3 lists prominent gamma energy lines for manmade and natural radionuclides. Because assay values are calculated from specific gamma energy peaks, the SGLS has the capability to detect contamination at levels well below those required to significantly affect total gamma counts.

The SGLS uses coaxial P-type HPGe detectors with relative efficiencies between 35% and 70% (100% is equivalent to a 2-inch by 2-inch NaI detector) for measurements from background levels up to the equivalent to several thousand pCi/g Cs-137. For high activity levels, a small planar HPGe detector, designated the high rate logging system (HRLS) is used. With additional shielding, the HRLS is capable of logging in Cs-137 levels up to 1 E8 pCi/g.

The SGLS is deployed in move-stop –acquire mode, meaning that the sonde is held stationary for a measurement and then moved up or down in the borehole casing to the next measurement point. Count times are typically between 100 and 200 seconds (clock time) but the detector can make much longer counts if necessary. The Dewar flask contains sufficient liquid nitrogen for 8 to 12 hours of operation: this represents

the practical maximum count time. Calibration is performed on an annual basis in the Hanford Borehole Calibration Models, where radionuclides in the U-238 and Th-232 decay series provide a wide range of gamma peaks between 185 and 2615 keV with well-known activity levels. The calibration data are used to define a calibration function ("inverse efficiency" or I(E)), which provides detector response as a function of gamma energy, under the assumption of a uniform distribution of the gamma source around the detector ("4-pi" geometry). Calibration of the SGLS and HRLS is described in McCain (2008).

The minimum detectable level (MDL) for the SGLS depends on background activity levels, detector efficiency, count time, and gamma yield (gammas per decay), as well as environmental factors such as casing thickness or the presence of water. An MDL can be calculated at each point for any energy, regardless of whether a gamma peak is detected. Table 2-2 shows typical MDLs for manmade radionuclides. For most fission products, the MDL is typically 1 pCi/g or better. For manmade uranium, the MDL is on the order of 10 to 20 pCi/g. (about 30 to 60 ppm U). For TRU, the MDL for individual radionuclides ranges from 10 to 50 nCi/g. The disparity in MDLs is related primarily to the wide range in gamma yields for the target radionuclides (see Table 2-2).

2.3 NEUTRON MOISTURE LOG

The neutron moisture probe bombards the formation with neutrons and measures the degree to which they are scattered back to the detector. The primary mechanism for neutrons scattering in geologic media is interaction with hydrogen atoms, so the neutron moisture log response is dominated by hydrogen. Since the hydrogen is primarily a constituent of water, the neutron moisture log effectively measures the moisture content. The neutron moisture probe currently in use at Hanford employs a 50 mCi Am-241/Be neutron source and a He-3 detector. Source to detector spacing is about 3 inches. For this system, count rates increase with increasing moisture. The probe responds to all hydrogen, including that contained in "bound" water associated with clays or bentonite, or water of hydration in cement. The moisture probe is sensitive to variations in moisture content associated with thin fine-grained layers, but depth of investigation is limited. Other than to assess the integrity of the annular seals, the neutron moisture detector cannot be run in borehole intervals where there is annular grout or bentonite, and it cannot be run below the water table. Neutron moisture log response is strongly affected by the casing inside diameter. Neutron moisture calibration models are available at the Hanford borehole calibration facility. These consist of large drums filled with a mixture of silica sand and hydrated alumina to provide equivalent moisture contents of approximately 5, 12, and 20 percent by volume (Englemann et al, 1995), with typical steel casings of 6-inch and 8-inch diameter. Since the moisture log is very sensitive to casing diameter, conversion of count rate to moisture content should only be made when borehole ID is close to either 6 or 8 inches. In most applications the neutron count rate is an excellent qualitative indicator of relative moisture content in the surrounding sediments. For a given moisture content, count rates decrease with increasing borehole diameter, and the log may not be effective in holes larger than 12 inches.

The neutron moisture log is calibrated to report moisture content in percent by volume. Most laboratory results for soil samples report moisture content in terms of percent by weight or gravimetric moisture content. If an accurate measure of the formation dry bulk density is available, the gravimetric moisture content can be converted to volumetric moisture content by the equation

$$MC_{vol} = MC_{grav} * \text{bulk density} \qquad (2)$$

2.4 PASSIVE NEUTRON LOG

The passive neutron log measures ambient neutron activity in the formation. In general, the log is run using the He-3 detector in the moisture gage without the Am-241/Be neutron source, with a longer count time and larger depth increment (60 to 100 sec count time and 1 ft (0.3 m) depth increment, compared to 15 sec count time and 0.25 ft (0.08 m) depth increment for the moisture log). (α, n) reactions occur when alpha particles

emitted from transuranic (TRU) elements (Pu-239, Pu-240, and Am-241) interact with light elements in the surrounding soil. To a lesser extent, spontaneous fission, primarily from Pu-240, may also contribute to neutron activity. Most TRU elements are present in the soil as oxides or nitrates, and the primary (α, n) reaction will tend to be with oxygen or nitrogen. Fluoride compounds are also possible, and fluorine has a much higher alpha capture cross section than either oxygen or nitrogen. Proof-of-principle tests carried out in the 216-Z-1A trench (Bauer et al, 2000) indicated very high neutron activity, and suggested that passive neutron logs could be used to detect TRU in the subsurface. Subsequent analysis of log data from 216-Z-1A (Henwood and McCain, 2009) indicates that at least part of the TRU contamination may be present in the form of fluoride compounds. Under normal circumstances, passive neutron activity in uncontaminated soil is an indication of TRU contamination, but it should only be used in a qualitative sense. It must also be noted that the He-3 detector may be subject to interference in intervals of extremely high gamma activity: measured passive neutron activity in a sediment zone where Cs-137 contamination is greater than about 100,000 pCi/g may not be indicative of TRU. For quantitative assay of highly contaminated sediments, the high resolution spectra gamma is recommended.

2.5 REFERENCES

Arthur, R.J. 1990. *1990 Yearly Calibration of Pacific Northwest Laboratory's Gross Gamma Borehole Geophysical Logging System*. PNL-7460. Pacific Northwest Laboratory. Richland, WA.

Arthur, R.J. 1991. *1991 Yearly Calibration of Pacific Northwest Laboratory's Gross Gamma Borehole Geophysical Logging System*. PNL-7785. Pacific Northwest Laboratory. Richland, WA.

Arthur, R.J. 1992. *1992 Yearly Calibration of Pacific Northwest Laboratory's Gross Gamma Borehole Geophysical Logging System*. PNL-8220. Pacific Northwest Laboratory. Richland, WA.

Arthur, R.J. 1993. *1993 Yearly Calibration of Pacific Northwest Laboratory's Gross Gamma Borehole Geophysical Logging System*. PNL-8895. Pacific Northwest Laboratory. Richland, WA.

Bauer, R., R. Randall, and R. Price. 2000. *Proof-of-Principle Demonstration of a Passive Neutron Tool for Detection of TRU-Contaminated Soil at the 216-Z-1A Tile Field*. BHI-01436. Bechtel Hanford Company. Richland, WA.

Brodeur, J.R. and C.J. Koizumi. 1989. *Base Calibration of Pacific Northwest Laboratory's Gross Gamma Borehole Geophysical Logging System*. WHC-EP-0246. Westinghouse Hanford Company. Richland, WA.

Gearhart Owen. 1975. "Instruction manual, Pulse Logging System." Gearhart Owen Industries, Inc, Fort Worth, Texas

Henwood, P.D. and R.G. McCain. August 2009. *Summary Report For Selected Boreholes Within The 216-Z-1A Tile Field, 216-Z-9 Trench and 216-Z-12 Crib*. HGLP-LDR-339, Rev. 2; SGW-42004. CH2M Hill Plateau Remediation Corp. Richland, WA.

Last, G.V and D.G. Horton. March 2000. *Review of Geophysical Characterization Methods Used at the Hanford Site*. PNNL-13149. Pacific Northwest National Laboratory. Richland, WA.

McCain, R.G. 2008; Calibration of High-Resolution Spectral Gamma Logging Systems; HGLP-MAN-005, Rev 2; Hanford Geophysical Logging Project, S M Stoller Corp, Richland, WA, Aug, 2008.

McCain, R.G. December 2009. *The Hanford Gamma Unit: A Means to Standardize Gamma Log Response at the Hanford Site*. HGLP-OTH-004. S M Stoller Corporation. Richland, WA.

Randall, R.R. 2000. *Dry Well Probe Calibration*.. HNF-3861. Fluor Hanford Corporation. Richland, WA.

Raymond, J.R. 1964. *A Gamma Scintillation Well Probe System*. HW-81972.

Skorska, M.B. 2010. *Test Work Plan for Further Laboratory Testing and Prototype Development of a Technetium-99 Beta Probe*. RPP-PLAN-45687. Washington River Protection Solutions LLC. Richland, WA.

Speer, W.G. and M.O. Rankin. 1956. *A Scintillation Well-Logging System*. HW-39273.

Steele, W.D, and D.C. George; 1986; Field Calibration Facilities for Environmental Measurement of Radium, Thorium and Potassium 2nd Edn; GJ/TMC-01 UC-70A, Bendix Field Engineering Corporation, Grand Junction, CO, Aug 1986

Strong, F.S. September1982. "Instrumentation Systems"; Appendix 1 in Isaacson, R.E. 1982. RHO-RE-EV-4 P. Rockwell Hanford Operations. Richland, WA.

Thomas, C.W., D.L. Reid, and H.A. Troiba. 1956. *Cobalt-60 in Ground Water and Separations Plant Waste Streams*. HW-42612. General Electric Company, Richland, WA.

TABLE 2-1. HANFORD BOREHOLE CALIBRATION MODELS

Gamma Calibration Models

Model	Radionuclide Content			eU	Total Gamma Activity	
	K-40	U-238	Th-232			
	pCi/g	pCi/g	pCi/g	ppm	mR/h	HGU
SBT	10.6 ± 1.3	10.02 ± 0.48	58.1 ± 1.4		0.298 ± 0.019	29.1 ± 2.8
barren					0.0102 ± 0.0009	**1.00**
SBK	53.5 ± 1.7	1.16 ± 0.11	0.11 ± 0.02		0.0187 ± 0.0014	1.83 ± 0.18
SBU	10.7 ± 0.8	190.5 ± 5.8	0.66 ± 0.06	567 ± 17	0.760 ± 0.096	74.3 ± 7.2
SBM	41.8 ± 1.8	125.8 ± 4.0	39.1 ± 1.1		0.664 ± 0.065	64.9 ± 6.2
SBL		324.0 ± 9.0		964 ± 27	1.351 ± 0.197	132 ± 13
SBH		3126 ± 180		9303 ± 536	10.86 ± 1.09	1062 ± 121
SBA		61.2 ± 1.7		182 ± 5	0.257 ± 0.037	25.1 ± 2.4
SBB		902.0 ± 27.0		2684 ± 80	3.59 ± 0.45	351 ± 34

Moisture Calibration Models

Model		Hole ID, in	Casing Thickness, in	vol % moisture	Density (g/cm^3)
A		8	0.32	5	1.76
B		8	0.32	19.7	1.70
C		8	0.32	11.9	1.76
D1	upper 2.25 ft	8	0.32	5.0	1.63
D2	middle 1.5 ft			40.9	1.32
D3	lower 2.25 ft			5.0	1.55
E		6	0.28	11.7	1.74
F		6	0.28	5.0	1.76
G		6	0.28	19.8	1.70

TABLE 2-2. MAN-MADE GAMMA EMITTING RADIONUCLIDES

RADIONUCLIDE	HALF LIFE (YEARS)	PRIMARY GAMMA RAYS		SECONDARY GAMMA RAYS		TYPICAL MDL, PCI/G
		E, KEV	YIELD (FRACTION)	E, KEV	YIELD (FRACTION)	
CO-60	5.2714	1332.50	0.9998	1173.24	0.9990	0.15
RU-106	1.0238	511.86	0.2040	621.93	0.0993	
SB-125	2.7582	427.88	0.2960	600.60 635.95 463.37	0.1786 0.1131 0.1049	
SN-126	1.E+05	414.50	0.86	666.10 694.80	0.86 0.8256	
CS-137	30.07	661.66	0.851			0.2
EU-152	13.542	1408.01	0.2087	344.28 964.13 1112.12 778.90	0.2658 0.1434 0.1354 0.1296	
EU-154	8.593	1274.44	0.3519	723.31 1004.73 873.19	0.2022 0.1801 0.1227	0.2
^{235}U	7.04E+08	185.72	0.5720	205.31	0.0501	0.6
PA-234M (U-238)[1]	4.47E+09	1001.03	0.0084	766.36	0.0029	10-15
NP-237[1]	2.14E+06	312.17	0.386	300.34 340.81 415.76	0.0662 0.0447 0.01745	1
PU-239	24110	375.05 413.71	1.554E-5 1.466E-5	203.55 345.01 332.85	5.69E-6 5.56E-6 4.94E-6	13000
PU-241 (U-237)	14.3 6.75D	159.96 208.005	6.54E-8 5.19E-6[3]	164.61 332.35	4.56E-7 2.94E-7	
AM-241[4]	432.2	208.01 335.37 662.40[4] 722.01	7.91E-6 4.96E-6 3.64E-6 1.96E-6	368.05 376.65 322.52 332.35	2.17E-6 1.38E-6 1.52E-6 1.49E-6	50000

MDL based on routine analysis with Spectral Gamma Logging System (SGLS).

1 Pa-234m is a short-term daughter of U-238. The yield is relatively low, and these gamma lines are generally not seen in "natural" uranium. Within the uranium decay series, secular equilibrium is achieved slowly, and gamma activity from Pb-214 or Bi-214 will not reach significant levels in less than several hundred thousand years. Hence, the presence of gamma activity originating from Pa-234m, without much higher levels of activity from Pb-214 and Bi-214 is an indication of the presence of anthropogenic U-238, which has been chemically separated from its decay products.

2 Np-237 is created by alpha decay of Am-241 and by successive neutron capture in U-235 during reactor operations. Np-237 may also have been used as a source material for production of P-238.

3 U-237 decay line corrected for branching ratio of 0.0000245

4 The intense 59.53 keV gamma from Am-241 is unlikely to penetrate steel casing. The 662 keV gamma line from Am-241 may be easily mistaken for Cs-137, a common fission product. Identification of Am-241 must be based on consideration of the waste stream involved and the presence of confirming gamma lines. Note that activity at 662 keV associated with 1 pCi/g Cs-137 is equivalent to234,000 pCi/g Am-241.

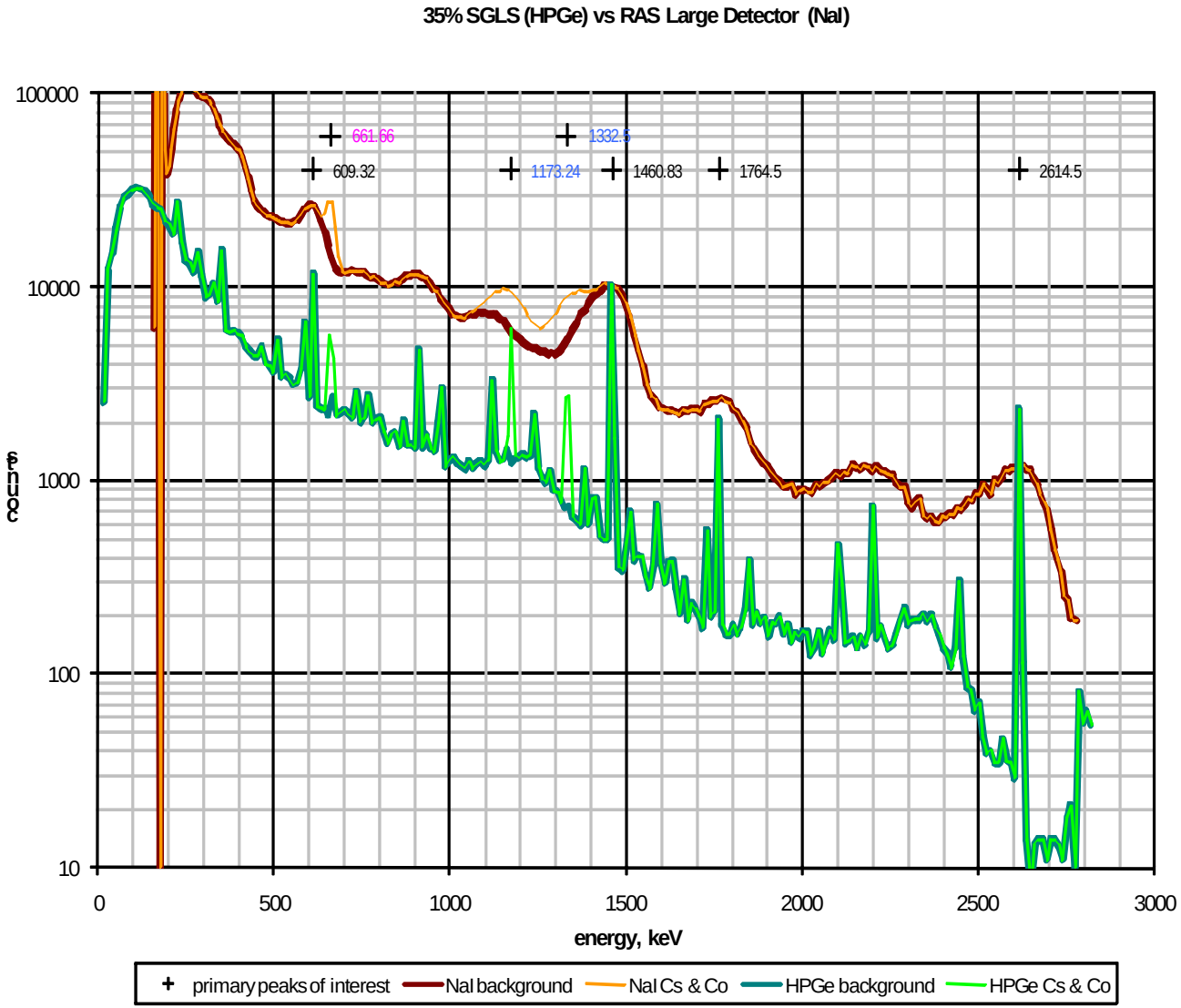
TABLE 2-3. NATURALLY OCCURRING RADIONUCLIDES

	PRIMARY GAMMA RAYS			SECONDARY GAMMA RAYS		
RADIONUCLIDE	DAUGHTER	E, KEV	Y	DAUGHTER	E, KEV	Y
K-40	AR-40	1460.83	0.1067			
TH-232[1]	TL -208	2614.53	0.3534	^{228}AC	911.21	0.266
	PB-212	238.63	0.433	^{228}AC	968.97	0.1617
	TL-208	583.19	0.3011	^{228}AC	338.32	0.1125
				^{208}TL	510.77	0.0806
U-238[2]	PB-214	351.92	0.358	^{214}PB	295.21	0.185
	BI-214	609.31	0.4479	^{214}BI	1120.29	0.148
	BI-214	1764.49	0.1536	^{214}PB	241.98	0.0750
				^{214}BI	1238.11	0.0586
				^{214}BI	2204.21	0.0486
				^{214}BI	2447.86	0.0150

1 Th-232 occurs naturally in geologic materials. At Hanford "background" values are generally in the range of 0.5 to 1 pCi/g. Th-232 will establish secular equilibrium throughout the decay series relatively quickly. Hence, anomalous values may indicate the presence of anthropogenic Th-232. Concentrations above 2 pCi/g warrant further evaluation.

2 U-238 occurs naturally in geologic materials. At Hanford "background" values are generally in the range of 0.5 to 2.5 pCi/g. For anthropogenic U-238, the decay series will not be in secular equilibrium, and the peaks shown above will not be elevated. Elevated Bi-214 and Pb-214 concentrations are an indication that radon Rn-222 may be present.

FIGURE 2-1. COMPARISON OF GAMMA ENERGY SPECTRA



3.0 BACKGROUND AND PHYSICAL SETTING

3.1 GEOLOGY

A discussion of geology in the area is provided in Appendix A of the Long Range Deep Vadose Zone Program Plan (U.S. Department of Energy 2010). Brief excerpts are included in this section and are included as they relate to geology that can be observed using geophysical logging data.

3.1.1 STRATIGRAPHY

Generally, the vadose zone beneath 200 West Area consists of the Hanford formation, Cold Creek unit, and Ringold Formation. The 200 West Area vadose zone ranges from 160 to 260 ft (49 to 79 m) thick. The recommended suprabasalt-sediment lithostratigraphic nomenclature for 200-DV-1 is shown in Table 3-1.

3.1.2 STRATIGRAPHY INTERPRETED USING GEOPHYSICAL LOG DATA

Borehole 299-W11-1 (A7275) located in 200 West near the 216-T-3 Reverse Well and the 216-T-6 cribs is used to illustrate a "type log" for identifying stratigraphic units (Figure 3-1). Naturally occurring K-40, U-238, and Th-232 concentrations in conjunction with total gamma data (and where available neutron moisture data) are invaluable for detecting variations in grain size or mineralogy. The units described in Table 3-1 are designated on the log and a short description of the radiological signature used for the selections is included below listed from oldest (deepest) to most shallow (i.e., most recent).

RFwie Ringold Formation member of Wooded Island – unit E: The top of this subunit is selected at a log depth of approximately 158 ft (48 m) bgs. It is characterized by decreases in the K-40 and Th-232 concentrations and slight decreases in total gamma from overlying finer-grained silty/sand sediments to more gravel dominated sediment below.

RFtf Ringold Formation member of Taylor Flat: The top of this unit is indicated at approximately 142 ft (43.3 m) bgs. An interval of finer-grained silt to sand size sediments occurs between 142 and 158 ft (43.3 and 48.2 m) bgs. K-40 and Th-232 concentrations both increase with a corresponding increase in total gamma.

CCu Cold Creek unit - undifferentiated: This unit consisting of two subunits occurs from 103 to 142 ft (31.4 to 43.3 m). The CCu represents one of the most significant barriers to fluid migration vertically beneath the 200 West Area and is a known perching horizon for large effluent disposal volumes. Within the 200 West Area, geophysical log signatures provide the best methodology for accurately defining the thickness and extent of this interval. The lower unit between 121 and 142 ft (36.9 and 43.3 m) bgs is referred to as the Cold Creek unit calcic geosol (caliche) (CCuc). The dominant features in geophysical logs are reflected by up to two caliche layers. These are shown by a 5 to 10 pCi/g decrease in K-40 and an approximate 0.5 pCi/g decrease in Th-232. The lower caliche layer is also characterized by a 2 to 3-fold increase in naturally occurring U-238. This increase causes the total gamma activity to increase even though the K-40 and Th-232 decrease. This is a consistent signature for the lower caliche layer throughout 200 West Area. The upper caliche reflects lower concentrations in K-40, Th-232, and the total gamma. The upper unit is defined by a predominance of silt and designated the Cold Creek silt dominated unit (CCuz) that is identified by an increase of Th-232 concentrations of 1 to 1.5 pCi/g.

Hf2 Hanford formation – unit 2 (sand dominated) is identified by moderate K-40 and Th-232 increases at the top of the formation at approximately 38 ft (11.6 m) bgs. This log type is reflective of the relatively thick sand-dominated sequence of unconsolidated basalt rich fine to coarse sand. It exhibits gradational characteristics that have been compared to grain-size increasing down to the top of the CCu.

Hf1 Hanford formation - unit 1 represents the youngest lithostratigraphic unit beneath the waste sites and is characteristically gravel to coarse sand dominant. The geophysical log inflection at the Hf1-Hf2 boundary can exhibit, gradational to sharp contact transitions dependent on grain size variability.

3.2 WASTE SITE DESCRIPTIONS

The S Plant Aggregate Area Management Study Report (U.S. Department of Energy 1992) addresses the two subregion waste sites subgroups. Subgroups and the number of waste sites applicable to this report include:

Tanks and Vaults –Selected single shell tanks in S and SX Farms

Cribs and Drains - 4 cribs

Reverse Wells - None

Ponds, Ditches, and Trenches - None

Septic Tanks - None

Transfer Facilities, Diversion Boxes, and Pipelines - Pipelines associated with identified sites

Unplanned Releases - One near the 216-S-9 crib

Only cribs are included in the 200-DV-1 OU in the S-SX Focus Area. Log data also will be evaluated for the single-shell tank boreholes that lie within 100 m of a 200-DV-1 waste site. Other published reports of log data within tank farms are referenced in Appendix A.

This report will focus specifically on the two S-SX Focus Area subregions. The impact of the single-shell tanks on the vadose zone, and the nature and extent of vadose zone contamination in the vicinity of the tank farms has been addressed in SST Baseline Tank Summary Data Reports, Tank Farm Reports and Addenda prepared by the Hanford Geophysical Logging Project, and in additional reports prepared by or for the tank farms contractor. Data from these reports and boreholes or drywells associated with the tanks will be discussed only in relation to subsurface conditions in or near the 200-DV-1 OU subregions. Table A-1 provides a listing of all logs assembled and evaluated for this report. In addition, the tank farm specific borehole logs and associated data are contained in referenced reports included in Appendix A.

There are four 200-DV-1 OU cribs identified for evaluation within the S-SX focus area. Cribs were designed to percolate wastewater into the ground without exposing it to the open air. Cribs are generally shallow excavations that are either backfilled with permeable material or held open by wood structures. Water flows directly into the backfilled material or open space and percolates into the vadose zone soils. Cribs typically received low-level liquid waste for disposal. Disposal operations to cribs were based on groundwater impact: "the amount of radioactive material that can be cribbed to any one site is limited by the concentration of any critical nuclide in the groundwater (Thomas 1956). A critical isotope may be defined as any radioactive isotope with a half-life greater than three years that exceeds one-tenth of the maximum permissible concentration (M.P.C.) in drinking water for occupational exposure." In accordance with waste management practices at the time, a crib was removed from service when the concentration of long-lived radioisotopes (e.g., Sr-90, Cs-137, and Co-60) in the groundwater beneath a disposal site reached one-tenth the maximum permissible concentration.

Pipelines transferred water and liquid wastes and are considered accessories to waste sites. They have the potential to leak, and must be considered when assessing a waste site. Pipeline leaks have been identified near the 216-S-9 crib.

3.3 WASTE SITE PROCESS HISTORY

The primary waste generating processes for the 200-DV-1 OU S-SX focus area are associated with the REDOX process. The REDOX process, used between 1951 and 1967, replaced the bismuth phosphate

process with lower costs, improved output, and enhanced recovery of uranium and plutonium. It was a solvent-extraction process that utilized methyl-isobutyl ketone (MIBK) as a solvent (DOE 1992). Various low-level waste streams and two high level waste streams were generated by the REDOX process. For the two S-SX subregions only low-level waste streams were distributed to the cribs. The following descriptions are derived from Williams (2001).

D-1 cell drainage and tank D-2 redistilled process condensate: The 216-S-9 and 216-S-23 cribs received this low level waste.

Single shell condensate: The SX tanks were specifically designed to accommodate self-boiling waste and incorporated underground duct headers connected to a common condenser/ventilation system. Tanks 241-SX-101 through 241-SX-106 were connected by a common vapor header. Tank SX-106 connected to the 241-SX-401 and 241-SX-402 condenser buildings. From these facilities condensate was sent to the 216-S-21 crib.

242-S Evaporator Waste: The evaporator was designed as a partial vacuum evaporator/crystallizer. The 216-S-25 crib was constructed to receive the process condensate.

Waste from the U-1/U-2 cribs pump and treat operation: Effluent extracted during a groundwater pump and treat operation was treated to remove uranium and was sent to the 216-S-25 crib in 1985.

3.4 REFERENCES

Thomas, C.W., D.L. Reid and H.A. Troiba. 1956. *Cobalt-60 in Ground Water and Separations Plant Waste Streams*. HW-42612. General Electric Company. Richland, WA.

Department of Energy. 1992. *S Plant Aggregate Area Maanagement Report*, DOE/RL-91-60 Revision 0, U.S. Department of Energy. Richland, WA.

Williams, J.C. 2001. *Historical Vadose Zone Contamination from S and SX Tank Farm Operations*, HNF-SD-WM-ER-560, Rev. 1. Fluor Federal Services. Richland, WA.

This page intentionally left blank.

TABLE 3-1. 200-DV-1 SUPRABASALT-SEDIMENT LITHOSTRATIGRAPHIC NOMENCLATURE

RECOMMENDED SUPRASALT-SEDIMENT LITHOSTRATIGRAPHIC NOMENCLATURE FOR 200-DV-1*									
	Group	*Formation or Equivalent Rank*	*Member or Unit Symbol*	*Submember or Subunit Symbol*	*Descriptive Name*	*Previous Designation(s)*	*Hydrostratigraphic Unit (HSU)*	*Basis for Recommended Name/Symbol Choice*	
Relative Stratigraphic Position		Holocene deposits	Hd		Holocene deposits - undifferentiated			Holocene is a formal geologic epoch (0 - 12,000 yrs B.P.) and therefore capitalized	Sequence boundary
			Hde		eolium	HD, eolian		Neither deposits nor eolium/ eolian are proper names and therefore lowercase	
			Hdb		backfill	HD, backfill		Neither deposits nor backfill are proper names and therefore lowercase	
		Hanford formation[1]	Hf		Hanford formation - undifferentiated	HF	Unit 1	Hanford is a proper geographic name and therefore capitalized; formation is an informal stratigraphic designation and therefore lowercase	Sequence boundary
			Hf1		Hanford formation - unit 1 (upper gravel-dominated unit)	H1, HF1			
			Hf2		Hanford formation - unit 2 (sand-dominated unit)	H2, HF2			
			Hf3		Hanford formation - unit 3 (lower gravel-dominated unit)	H3, HF3			
		Cold Creek unit[2]	CCu		Cold Creek unit - undifferentiated	CCU		Cold Creek is a proper geographic name and thus capitalized; the Cold Creek unit is an informal stratigraphic name and therefore "unit" is lowercase	Sequence boundary
			CCuz		Cold Creek unit - silt dominated	Early Palouse soil, CCUz, CCUu, PPUz, PPlz	Unit 2		

TABLE 3-1. 200-DV-1 SUPRABASALT-SEDIMENT LITHOSTRATIGRAPHIC NOMENCLATURE

RECOMMENDED SUPRASALT-SEDIMENT LITHOSTRATIGRAPHIC NOMENCLATURE FOR 200-DV-1*									
	Group	*Formation or Equivalent Rank*	*Member or Unit Symbol*	*Submember or Subunit Symbol*	*Descriptive Name*	*Previous Designation(s)*	*Hydrostratigraphic Unit (HSU)*	*Basis for Recommended Name/Symbol Choice*	
			CCuc		Cold Creek unit - calcic geosol (caliche)	caliche, calcrete, calcic paleosol, carbonate, CCUc, CCUl, PPUc, PPlc	Unit 3		
		Ringold Formation[3]	RF		Ringold Formation - undifferentiated	R, Rf		Ringold Formation is a **formalized** stratigraphic name and therefore always CAPITALIZED	Sequence boundary
			RFtf		Ringold Formation member of Taylor Flat	upper Ringold unit, Rtf	Unit 4	Ringold Formation members are informal and therefore "member" is lowercase; however Taylor Flat and Wooded Island are geographic features, recognized on published topographic maps, and therefore capitalized.	
			RFwi		Ringold Formation member of Wooded Island - undifferentiated	middle Ringold unit, Rwi			
				RFwie	Ringold Formation member of Wooded Island - unit e	Rwie, Unit E, Ringold E	Unit 5		
				RFlm	Ringold Formation - lower mud unit	Rlm, Ringold lower mud	Unit 8		
				RFwia	Ringold Formation member of Wooded Island - unit a	Rwia, Unit A, Ringold A	Unit 9		
	Columbia River Basalt (CRBG)	Saddle Mountains Basalt	Elephant Mountain Member		Basalt bedrock				Sequence boundary

TABLE 3-1. 200-DV-1 SUPRABASALT-SEDIMENT LITHOSTRATIGRAPHIC NOMENCLATURE

RECOMMENDED SUPRASALT-SEDIMENT LITHOSTRATIGRAPHIC NOMENCLATURE FOR 200-DV-1*									
	Group	*Formation or Equivalent Rank*	*Member or Unit Symbol*	*Submember or Subunit Symbol*	*Descriptive Name*	*Previous Designation(s)*	*Hydrostratigraphic Unit (HSU)*	*Basis for Recommended Name/Symbol Choice*	

[1] *Hanford formation,* first defined in Tallman et al. (1979) is an informal unit for deposits of the Ice Age floods on the Hanford Site. Codes of stratigraphic nomenclature strongly discourage using "formation" with informal units. Therefore, to be incompliance with stratigraphic standards "formation" should be replaced with something else. So far, PNNL has not arrived at a satisfactory alternate term to replace "formation". Another option is to formalize the unit but it does not appear to satisfy all the criteria of a "Formation" and if it did would require a major effort of time and resources to publish in a peer-reviewed journal - a requirement to formalization. For the time being PNNL recommends the continued informal use of Hanford formation until a satisfactory substitute is agreed upon by a majority of Hanford geologists.

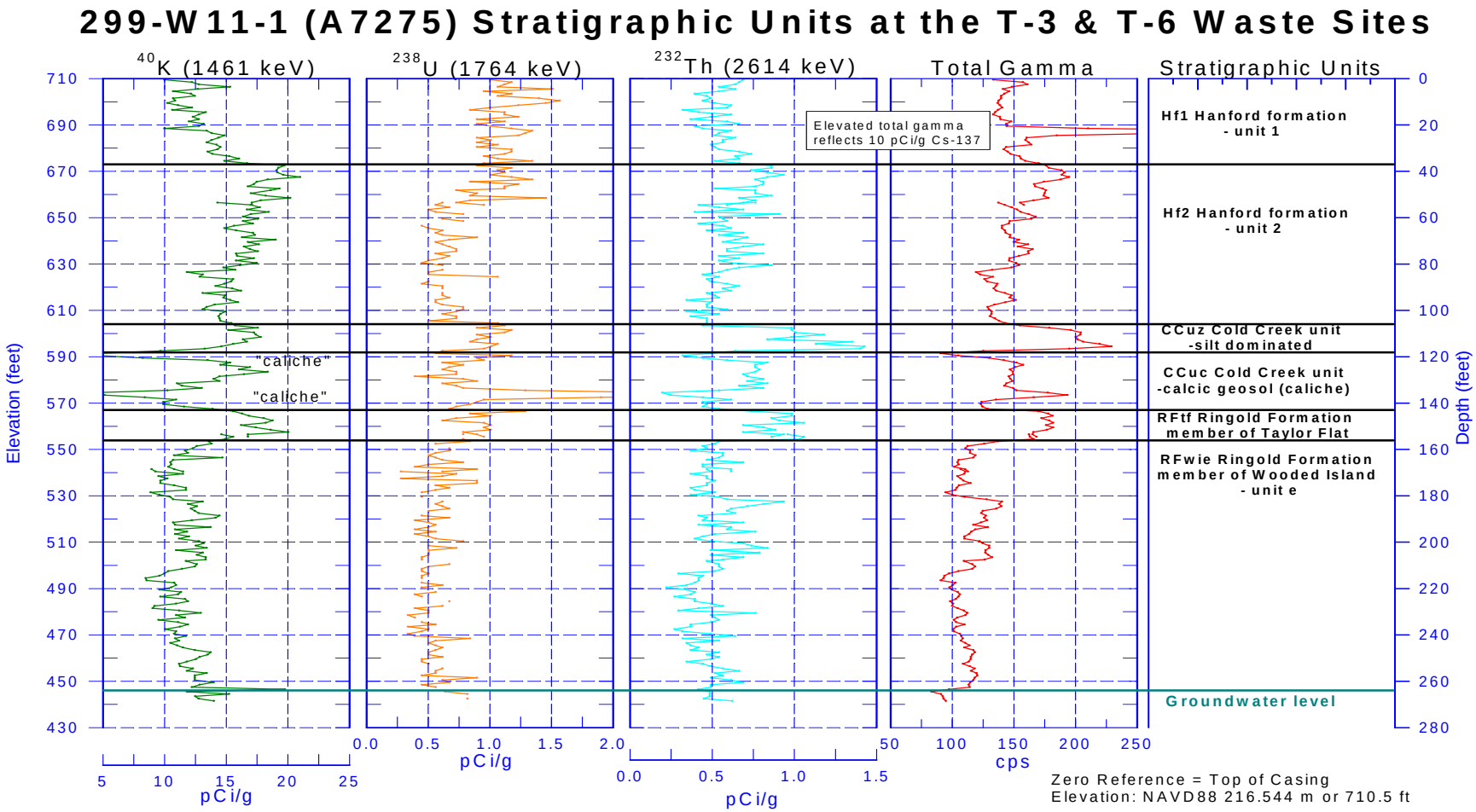
[2] Cold Creek unit first defined (informally) in DOE (2002)

[3] Ringold Formation formally defined in Newcomb (1958) and Newcomb, Strand and Frank (1972)

* This stratigraphic nomenclature conforms to most of the guidelines presented in:
(1) North American Stratigraphic Code (2005), *AAPG Bulletin*, v. 89, No. 11, pp. 1547-1591
(2) International Stratigraphic Guide (1994), International Subcommittee on Stratigraphic Classification, co-published International Union of Geological Sciences and Geological Society of America, 2nd edition
(3) Owen, DE (2009) "How to use stratigraphic terminology in papers, illustrations, and talks", *Stratigraphy*, v. 6, No. 2, p. 106-116.
(4) Stratigraphic Nomenclature and Description, http://www.nwrc.usgs.gov/techrpt/sta08.pdf

This page intentionally left blank.

FIGURE 3-1. STRATIGRAPHIC UNITS AT 216-T-3 AND 216-T-6 WASTE SITES



4.0 216- S-9 AND 216-S-23 CRIBS

Subregion 1 includes the 216-S-9 and 216-S-23 cribs. These sites are closely associated in terms of both proximity and process history. A brief background section is provided that includes waste site characteristics, process history, and geology. Cross sections that include the current contamination profile in relation to the waste site and stratigraphy, 3-dimensional data visualizations, and interpretations are provided in Section 4.4.

4.1 GEOLOGY

The general geology and stratigraphy for this area are described in Section 3.1. Stratigraphic relationships are depicted on cross sections of log data. Key stratigraphic intervals defined within the vadose zone, from shallowest to deepest include the Hf1, Hf2, CCu, RFtf, and RFwie. Overall, the vadose zone is approximately 240 ft (73.2 m) thick in this area. The contact between the Hf1 and Hf2 occurs relatively shallow and is usually situated approximately 30 ft (below the bottom of the facility. The top of the Hf2 (Hanford formation – unit 2) is at approximately 615 ft (188.4 m) in elevation or 75 ft (22.9 m) bgs and the CCu lies between elevations of approximately 545 ft (166.1 m) in elevation or 145 ft (44.2 m) bgs and 530 ft (161.5 m) in elevation or 160 ft (48.8 m) bgs. The Hf2 averages approximately 70 ft (21.3 m) in thickness and the CCu averages approximately 15 ft (4.6 m) in thickness beneath the area. The CCu contact is fairly flat over the subregion.

4.2 WASTE SITE PROCESS HISTORY

4.2.1 216-S-9 AND 216-S-23 CRIBS

The 216-S-9 crib is located east of the 241-S tank farm. The excavation for the site is 300 ft (91.4 m) long by 30 ft (9.1 m) deep by 30 ft (9.1 m) wide at the bottom (CHPRC 2011). Waste flowed into the unit through a distribution system that consists of 581 ft (177.1 m) of perforated 6-in. (15 cm) vitrified clay tile (VCT) pipe. According to as built drawing H-2-32363, a 3-in. (7.4 cm) schedule 10 steel inlet pipe feeds two parallel VCT pipes that are 15 ft (4.6 m) apart and extend 290 ft along the length of the crib near the bottom of the excavation. Figure 4-1 shows the 216-S-9 crib during construction and the header for the distribution system. The VCT pipes are approximately 20.3 ft (6.2 m) bgs and the bottom of the excavation is 24.3 ft (7.4 m) bgs. Gravel is placed in the excavation from 18.9 to 24.3 ft (5.8 to 7.4 m) that covers the VCT pipe with 1.4 ft (0.5 m) of gravel. A polyethylene barrier was placed on top of the gravel before backfilling the remainder of the excavation. There is a discrepancy of approximately 5.7 ft for the bottom of the excavation between CHPRC (2011) and the as built drawing H-2-32363. The reason for the discrepancy is unknown.

The above depths described as bgs are derived from drawing H-2-32363. In 1995, contaminated soil from the southern portion of the unplanned release UN-216-W-30 was placed on the 216-S-9 crib (Smith 1995). Eighteen (0.5 m) to 24 in. (0.6 m) of clean backfill material was placed over the contaminated soil. The precise amount of backfill and contaminated soil is not documented. This interim stabilization raised the elevation of the ground surface so that the depths bgs reported in drawings must be adjusted. With interim stabilization, casings for groundwater wells were extended to account for anticipated grade changes. Most recent log data are reported in terms of depth from a specific reference, generally top of casing (TOC), and elevations reported are correct. In the case of depths below ground surface for older log data or waste site details, the presence of variable amounts of fill introduce some degree of error. This error will generally not be significant in the context of the deep vadose zone.

The 216-S-23 crib is located approximately 400 ft (121.9 m) northwest of the 216-S-9 crib. It was built to replace the 216-S-9 crib and was placed in service in January 1969. The crib is 360 ft (91.4 m) long by 28 ft (8.5 m) deep by 10 ft (3.1 m) wide (CHPRC 2011). According to design drawing SK-2-21845

(LaRiviere 1968), approximately 5 ft (1.5 m) of gravel was to be placed in the bottom of the excavation to 1 ft (0.3 m) above the distribution pipe. The distribution pipe is approximately 4 ft (1.2 m) from the bottom of the excavation and follows the center of the excavation. A polyethylene barrier was placed on top of the gravel before backfilling the excavation. The supply line for the crib was to connect to a 3-in. (7.6 cm) stainless steel pipe stub located 38 ft 11.6 m) south of the head of the 216-S-9 crib.

Contaminated soil from the northern portion of unplanned release UN-216-W-30 was placed on the 216-S-23 crib and was also interim stabilized in 1992 as described above for the 216-S-9 crib (Smith 1995).

The design flow for the system was 36,000 gallons (136,260 L) per day and the crib distribution system was designed to uniformly distribute a flow of 5 to 75 gallons (18.9 to 283.9 L) per minute over the entire length of the crib (LaRiviere 1968).

The 216-S-9 and 216-S-23 waste sites both received REDOX process condensate from the D-2 Receiver Tank in the 202-S Building (WIDS). According to DOE (1992) the waste was radioactive and acidic, mainly composed of nitric acid. The 216-S-9 crib received waste from 1965 to 1969 and the 216-S-23 crib from January 1, 1969 to January 1, 1972.

An unplanned release UPR-200-W-108 was discovered on January 8, 1969. During the tie-in of the 216-S-9 waste line to the new 216-S-23 crib, contaminated water was encountered coming from a break at the junction of the two crib lines. Further excavation disclosed a severed expansion buckle in the line at that point. There was no way of determining how long the line had been leaking or how much waste was discharged to the ground (WIDS).

4.3 PREVIOUS INVESTIGATIONS

Fecht et al. (1977) evaluated scintillation log profiles of four boreholes in the vicinity of the 216-S-9 crib. The boreholes are 299-W22-25 (A7846), 299-W22-26 (A4968), 299-W22-34 (A7853), and 299-W22-35 (A7854). Fecht et al. concluded that radioactive contaminants were detected from the crib bottom to the water table. It was also noted that the radiation intensity in these monitoring wells had been decreasing with time due to radionuclide decay. It was stated that the data indicate breakthrough to groundwater could have occurred.

Further evaluation of log data for the 216-S-9 crib was conducted in DOE (1992). That evaluation was in agreement with Fecht et al. (1977) in regard to possible breakthrough of contamination to groundwater and that gamma activity was declining due to radionuclide decay. It was also concluded that most of the waste disposed in the crib percolated into the vadose zone at the southern end of the crib and that the areal extent of elevated gamma activity is not known due to a lack of wells further from the crib boundaries.

Fecht et al. (1977) also evaluated the borehole log data around the 216-S-23 crib. In 1976, the scintillation probe profiles from five boreholes showed near background levels of radiation indicating no breakthrough to the groundwater.

An evaluation reported in DOE (1992) concurred with the Fecht et al. (1977) conclusions. There has been no geophysical logging in the vicinity of the 216-S-23 crib since 1976.

4.4 SUMMARY OF LOG DATA

Evaluating the "historical" geophysical record is important to determine the past existence of very short-lived radionuclides, the maximum extent of contamination at depth, and whether any influx or migration of contaminants has occurred over time since active disposal stopped.

Figure 4-2 shows the location of 12 boreholes relative to the two waste sites that have been evaluated for this subregion. All geophysical logging data acquired since 1964 have been considered and are included in Table 4-2. A review of these logging data was performed to qualitatively evaluate significant changes in the gamma profile (i.e., activity and vertical location) over time. Although beyond the scope of the current effort, a more accurate quantitative analysis would require detailed comparison of the historical logs, taking into account the relative efficiencies of the various detection systems. This effort would not be insignificant and would require a detailed assessment of the older logging systems, which are often difficult to locate in the historical records.

The locations of cross sections A-C are shown in Figure 4-2. The cross sections (Figures 4-8, 4-12, and 4-13 are included to depict important relationships between stratigraphy and the detected gamma contamination.

4.4.1 216-S-9 CRIB

There are four of five boreholes in the immediate vicinity of the 216-S-9 crib and one south of the crib that had available data to assess the gamma contamination in the area (Figure 4-2). The boreholes are 299-W22-25 (A7846), 299-W22-26 (A4968), 299-W22-34 (A7853), and 299-W22-35 (A7854); borehole 299-W22-27 (A7847) had no available gamma data. The sixth borehole is (299-W22-69 {C4969}). Boreholes 299-W22-25 (A7846), 299-W22-26 (A4968), and 299-W22-27 (A7847) were drilled from 12/63 to 04/64 prior to the 216-S-9 crib receiving waste. Boreholes 299-W22-34 (A7853), and 299-W22-35 (A7854) were drilled in August and September 1966 after the crib was activated. Borehole 299-W22-69 (C4969) was drilled in 2006.

It is important to consider the historical gamma contamination in boreholes around the 216-S-9 crib. Figures 4-3 to 4-7 are provided for discussion and interpretation. The most contaminated borehole near the 216-S-9 crib is 299-W22-25 (A7846) depicted in Figures 4-3 and 4-4. In 1964, before the crib was operational, background levels reflecting natural gamma levels are indicated, followed by more recent logs showing contamination. The driller's log reports groundwater level at 214 ft (65.2 m) bgs. The borehole gamma logs in 1964 and 1965 appear to be consistent with that groundwater level as indicated by reduced gamma activity at that depth. By August of 1965, some increased gamma activity is shown, although it could be the result of different detectors having been used. The obvious increase relative to 1964 at approximately 45 ft (13.7 m) is the first indication of activity in this borehole. By February 1966, significant activity is shown from approximately 25 to 140 ft (7.6 to 42.7 m) essentially all above the CCu. Also, the gamma activity increase at the bottom of the logged interval near 200 ft (61 m) may be indicating contaminated groundwater. Two years later, the February 1968 log suggests contamination throughout the vadose zone from 25 ft (7.6 m) to groundwater at approximately 200 ft (61 m). Gamma emitting radionuclides appear to occur in the saturated zone from the water table to the bottom of the borehole at approximately 300 ft (91.4 m) bgs. Figure 4-4 includes logs from 1970 and 1976. These logs indicate significant decay to near background levels by 1976 between 65 ft (19.8 m) and groundwater level at approximately 200 ft (61 m) bgs. Gamma-emitting radionuclides were also measured in the saturated zone in 1976 but at significantly less activity than in 1968. An interval from approximately 25 to 65 ft (7.6 to 19.8 m) bgs (within the Hf1 coarse grained facies of the Hanford formation) had not significantly decayed away during this time span.

Borehole 299-W22-25 (A7846) is located near the UPR-200-W-108 where contaminated water leaked into the vadose zone in January 1969 (Section 4.2.1). The location of this release lies between the borehole and the 216-S-9 crib at the junction of the 216-S-9 and 216-S-21 crib lines (Figure 4-2). The amount of waste released is unknown. This borehole has shown gamma contamination throughout the vadose zone.

Figures 4-5, 4-6, and 4-7 suggest a similar history for boreholes 299-W22-26 (A4968), 299-W22-34 (A7853), and 299-W22-35 (A7854), although the activity levels appear to be somewhat less. In general, there are three common characteristics in all of these boreholes: High gamma activity exists at varying thicknesses in all the boreholes between approximately 25 and 60 ft (7.6 and 18.3 m) primarily within the Hf1. A second interval of relatively higher gamma activity exists from approximately 136 to 149 ft (41.5 to 45.4 m) within the Hf2 and CCu. A third zone of higher activity is what appears to be the depth of groundwater at approximately 200 ft (61 m) bgs. Cross section A-A' (Figure 4-8) can be used to illustrate the current gamma contamination and stratigraphic relationships that most likely created these common characteristics.

Figure 4-8 shows the interpreted stratigraphy, contaminant profile at the current time (i.e., 2006 and 2007), the general groundwater level at the time of drilling (Chamness and Merz 1993), interpreted groundwater from gamma activity data while the crib was in use in about 1968, and the groundwater level in 2006 and 2007. The Cs-137 exists in the aforementioned depth interval discussed for historical logs from approximately 25 to 60 ft (7.6 to 18.3 m) and resides above the Hf1 and Hf2 contact interface. Relatively high activity in the historical logs between 136 to 149 ft (41.5 to 45.4 m) bgs appears to be associated with the CCu and perhaps the RFtf finer- grained sediments. The groundwater level appears to be at approximately 242 ft (73.7 m) depth bgs in 2006. This depth is in contrast to approximately 212 ft (64.6 m) bgs (Chamness and Merz 1993) when the boreholes were drilled in December 1963 and January 1964 and a depth of approximately 200 ft (61 m) in 1968 that is interpreted by gamma activity data. Also of note, are remnants of Cs-137, Co-60, and Eu-154 at various locations in the vadose zone where historical gamma logs suggested extensive contamination. In particular, the numerous detections of Cs-137 and Co-60 beginning at about the 1968 groundwater level and extending to the bottom of the logged interval may have an explanation. It is interpreted that these detections are the result of formerly contaminated groundwater that contained these radionuclides along with other shorter-lived radionuclides. It is hypothesized the contaminants adsorbed to the steel casing and remained fixed to the casing as the groundwater level receded. This phenomenon has been referred to as a 'bathtub ring" and is observed in older wells throughout Hanford. Although borehole 299-W22-69 (C4969) only shows a total gamma log, it was screened for gamma emitting contaminants and none were detected. This borehole, located south of the 216-S-9 crib, suggests lateral spread of Cs-137 was not significant in this direction but it cannot be used to definitively suggest the dominant short-lived contaminants did not invade the area in the 1960s. A visualization of the current contaminant distribution is shown in Figure 4-9.

4.4.2 216-S-23 CRIB

The 216-S-23 crib was constructed in 1968 to replace the 216-S-9 crib and was placed in service in January 1969 (WIDS). In accordance with waste management practices at the time, a crib was removed from service when the concentration of long-lived radioisotopes (e.g., Sr-90, Cs-137, and Co-60) in the groundwater beneath the disposal site reached one-tenth the maximum permissible concentration (MPC_W). Analysis of groundwater samples taken near the 216-S-9 crib indicated Sr-90 and Co-60 at 0.1 MPC_W in the groundwater on several occasions (LaRiviere 1968).

Five boreholes were drilled during November and December 1968 to monitor the new 216-S-23 crib. These boreholes were designated as 299-W22-37 (A7856), 299-W22-38 (A7857), 299-W19-5 (A7734), 299-W19-6 (A4959), and 299-W19-7 (A7735). The borehole locations are shown in Figure 4-2. At the time of drilling, these boreholes indicated the groundwater level to be at approximately 216 ft (65.8 m) bgs. None of these boreholes indicated any contamination in the vadose zone or elevated activity in the groundwater in January 1969, when they were first logged.

Fifteen months later in March 1970, only two boreholes (299-W19-5 and 299-W19-6) indicated any increased gamma activity and are included as Figures 4-10 and 4-11, respectively. Contamination may be indicated from approximately 72 ft (22 m) to the probable groundwater level at approximately 207 ft

(63.1 m). By 1976, the gamma activity had decayed to near background levels in the vadose zone and in the groundwater.

Cross section B-B' (Figure 4-12) shows log data acquired in 2003 near the 216-S-23 crib. No gamma emitting contamination was detected in the deep vadose zone.

Cross section C-C' (Figure 4-13) shows the current (radionuclides decayed to September 30, 2010) gamma profile from the 216-S-23 crib south to the 216-S-9 crib.

4.5 SUMMARY OF SUBREGION AND CONCLUSIONS

The 216-S-9 crib has exhibited significant contamination throughout the vadose zone from near the bottom of the crib at approximately 25 ft (7.6 m) bgs to the groundwater that was at approximately 200 ft (61 m) bgs in 1968. Although no boreholes are placed directly in the 30 ft (9.1 m) wide crib, every borehole drilled outside the crib boundaries where log data were available, showed similar occurrences of gamma-emitting radionuclide contamination. An interval of longer-lived radionuclides, i.e., Cs-137, is shown from approximately 25 ft (7.6 m) to the Hf1/Hf2 contact boundary at approximately 60 ft (18.3 m) bgs. A second relatively high contamination interval coincides with the CCu between approximately 136 and 149 ft (41.5 and 45.4 m). Gamma activity is observed in groundwater as early as February 1966. With the exception of the interval from 25 to 60 ft (7.6 to 18.3 m) that now exhibits Cs-137 concentrations up to 50,000 pCi/g; almost all of the gamma emitting radionuclides that were detected in the 1960s had decayed away by 1976. The duration from the time when the crib ceased operation in 1969 until 1976 is approximately seven years. If the dominant radionuclide were Ru-106 (half life of 1.02 years), it would have largely decayed away in seven years. Based on the relative activity levels in boreholes along the profile of the 216-S-9 crib, it appears most of the contamination infiltrated into the southern portion of the crib.

The vadose zone and groundwater below the 216-S-23 crib, which is approximately 400 ft (121.9 m) north of the 216-S-9 crib, did not appear to be impacted by contamination from the 216-S-9 crib prior to the time of its activation in January 1969. Five boreholes drilled at the time of construction of the crib exhibited no contamination. However, two boreholes (299-W19-5 and 299-W19-6) indicated contamination in the deep vadose zone to groundwater and within the groundwater within 15 months after the start date for the crib. This interpretation appears to conflict with Fecht et al. (1977) that suggested no evidence of impacts to groundwater. However, only 1976 log data were evaluated. Log data acquired in 1969 and 1970 (Figures 4-10 and 4-11) suggest contamination may have reached groundwater in 1970. Similar to the gamma activity in the deep vadose zone (i.e., greater than 60 ft (18.2 m) bgs associated with the 216-S-9 crib, the gamma activity decayed away quickly. Currently, boreholes in the vicinity of the 216-S-23 crib exhibit no long-lived gamma emitting contaminants.

4.6 RECOMMENDATIONS

Although the historical gross gamma logs provide compelling evidence that the 216-S-9 and 216-S-23 cribs contaminated the vadose zone to groundwater, the chemical nature and lateral extent of the contamination is not known. Both sets of crib data provide adequate characterization near the inlet or southern end of the cribs and indicate that significant contamination occurred throughout the vadose zone. Additional characterization within the northern ends of the cribs would provide data to evaluate the lateral as well as the vertical extent of contaminants remaining within the vadose zone.

4.7 REFERENCES

Additon, M.K., K.R. Fecht, T.L. Jones, and G.V. Last. 1978. *Scintillation Probe Profiles 200 West Area Crib Monitoring Wells*. RHO-LD-29. Rockwell Hanford Operations. Richland, WA.

Chamness, M.A. and Merz, J.K. 1993. *Hanford Wells.* PNL-800. Pacific Northwest Laboratory. Richland, WA.

Department of Energy. 1992. *S Plant Aggregate Area Maanagement Report.* DOE/RL-91-60, Rev. 0. U.S. Department of Energy. Richland, WA.

CHPRC 2011. *Central Plateau Waste Site Dimensions.* CP-49279, Rev. 0. CHPRC. Richland, Washington.

Fecht, K.R., G.V Last, and K.R. Price. 1977. *Evaluation of Scintillation Probe Profiles From 200 Area Crib Monitoring Well,s* Volume III. ARH-ST-156. Atlantic Richfield Hanford Company. Richland, WA.

LaRiviere, J.R. 1968. *Design Criteria 202-S building Waste Disposal Crib 216-S-23.* ARH-329. Atlantic Rchfield Hanford Company. Richland, WA.

Smith, D.L. 1995. *UN-216-W-24 and UN-216-W-30 Interim Stabilization Final Report.* BHI-00257 Rev. 0. Bechtel Hanford, Inc. Richland, Washington.

This page intentionally left blank.

TABLE 4-1. GEOPHYSICAL LOG DATA ACQUIRED SINCE 1964 (WASTE SITES HAVE A PREFIX OF 216-)

Waste Site	Well Name	Well ID	Alias	IDMS	Total Depth	Date	Log Type	Contamination History	Summary
S-9	299-W22-25	A7846		Submitted	320	03/19/64	GG	no visible signs of contamination	No man-made radionuclides were detected in the 1964 logging event, however by 1965, it was apparent that the crib was receiving waste. Maximum levels were reached in 1968, with decay since that time. In the 2007 SGLS logging event, Cs-137 was detected from 31 to 68 ft and at lower levels from 208 to 240 ft. The maximum concentration was 46,000 pCi/g at 33 ft. Co-60 was detected potentially in this high rate zone. Both Cs and Co were detected from 180 to 240 feet. Groundwater was not encountered at the time of logging in 2007; however detections of Cs and Co at 208 ft may be associated with the historical contamination in ground water that receded, leaving behind a "bathtub ring". GWL in W22-26 (two hundred feet north of W22-25) was 242 ft in 2007.
	299-W22-25	A7846		Submitted	240	04/24/64	N	possible water level at ~210 ft.	
	299-W22-25	A7846		Submitted	180	08/03/65	N	not interpreted	
	299-W22-25	A7846		Submitted	260	08/13/65	GG	10,000 cpm peak at approximately 30 ft	
	299-W22-25	A7846		Submitted	180	08/20/65	N	possible water level at ~208 ft.	
	299-W22-25	A7846		Submitted	260	10/21/65	GG	not interpreted	
	299-W22-25	A7846		Submitted	260	07/02/65	GG	not interpreted	
	299-W22-25	A7846		YES	208	02/21/65	N	possible water level at ~208 ft.	
	299-W22-25	A7846		Submitted	210	02/08/66	GG	high dead time and contamination from 20-125 ft, with increasing gamma at 210 ft (end of logging event)	
	299-W22-25	A7846		Submitted	320	02/22/68	GG	high dead time and contamination from 20-125 ft; from 210- end of logging event at 310 ft.	
	299-W22-25	A7846		Submitted	312	03/03/70	GG	similar contamination profile to 1968 GG log, with slight decay indicated from 210-310 ft.	
	299-W22-25	A7846		YES	210	03/04/74	TEMP	not interpreted	
	299-W22-25	A7846		YES	320	02/23/76	GG	similar contamination profile to 1970 GG log, with overall decay indicated from 50-310 ft.	
	299-W22-25	A7846		YES	320	11/19/76	DEN	not interpreted	
	299-W22-25	A7846		YES	235	02/23/77	N	possible water level at ~205 ft.	
	299-W22-25	A7846		YES	340	09/23/86	GG	maximum 400 cps at 42 ft, with strong decay throughout the borehole from 1976.	
	299-W22-25	A7846		YES	340	08/19/87	GG	similar profile to 1986 GG data.	
	299-W22-25	A7846		YES	335	03/19/07	SGLS	Cs-137 was detected from 31-68 ft; with max 46,000 pCi/g at 33 ft. Co-60 may also exist at these depths. Low level detections of Cs-137 and Co-60 from 208-240 ft may be related to contamination in previous GWL.	
S-9	299-W22-26	A4968		Submitted	230	07/02/65	GG	low levels of elevated gamma associated with man-made radionuclides was detected from 0-213 ft.	Maximum contamination levels were reached in 1966 with contamination reaching the ground water. The 2007 SGLS log shows the Cs-137 from 30-58 ft, with the maximum concentration measured at 1250 pCi/g at 38 ft. <1 pCi/g Co-60 was detected from 196 and 241 ft. Eu-154 was detected from 31 to 46 ft, with maximum concentration measured at 2 pCi/g at 39 ft. Logging was terminated at the water level at 242 ft.
	299-W22-26	A4968		Submitted	288	08/02/65	GG	low levels of elevated gamma associated with man-made radionuclides was detected from 0-213 ft and at 288	
	299-W22-26	A4968		Submitted	208	08/03/65	N	possible water level at 210 ft	
	299-W22-26	A4968		Submitted	206	08/20/65	N	possible water level at 205 ft.	
	299-W22-26	A4968		YES	300	10/21/65	N	possible water level at 205 ft.	
	299-W22-26	A4968		Submitted	200	03/07/66	GG	elevated gamma associated with man-made radionuclides was detected from 27 - 200 ft (end of logging event)	
	299-W22-26	A4968		Submitted	280	03/03/70	GG	similar profile to 1966 GG with possible decay	
	299-W22-26	A4968		YES	300	05/14/76	GG	similar profile to 1970 with visible signs of decay.	
	299-W22-26	A4968		YES	280	11/19/76	DEN	not interpreted	
	299-W22-26	A4968		Submitted	280	02/23/77	N	possible water level at 204 ft.	
	299-W22-26	A4968		YES	300	09/25/07	SGLS	Cs-137 - 30 to 58 ft and 75 ft, Co-60 and Cs-137 from 196-241 ft, Eu-154 from 31 to 46 ft, and 76 ft.	
S-9	299-W22-27	A7847		YES	572	02/21/74	TEMP	Hosted Piezometer - not interpreted	Temperature data only.
S-9	299-W22-34	A7853		YES	210	02/07/67	N	not interpreted	Contamination profiles from the 1976 to 1987 are similar with signs of decay from 1976 to 1987. The maximum depth of contamination was approximately 40 ft. The contamination appears to have reached ground water at approximately 200 ft. No recent data is available.
	299-W22-34	A7853		YES	216	05/14/76	GG	elevated gamma from 26 -213 ft with ~20,000,000 cpm at 33 ft.	
	299-W22-34	A7853		YES	216	11/19/76	DEN	not interpreted	
	299-W22-34	A7853		YES	200	02/23/77	N	possible water level at ~203 ft.	
	299-W22-34	A7853		YES	216	09/22/86	GG	contamination similar profile to 1976 GG data with signs of decay. Possible ground water contamination at 200 ft.	
	299-W22-34	A7853		YES	216	08/19/87	GG	contamination similar profile to 1986 GG data with signs of decay. Possible ground water contamination at 200 ft.	
S-9	299-W22-35	A7854		YES	200	02/07/67	N	possible water level at 200 ft.	The 1968 GG log shows the greatest amount of gamma activity, with signs of decay into 1987.
	299-W22-35	A7854		Submitted	200	02/22/68	GG	elevated gamma from 29-200 ft with max 30,000,000 cpm at 30 ft, possible contamination in gw at approximately 200 ft.	
	299-W22-35	A7854		YES	215	05/14/76	GG	similar profile to 1968 data with decay, max 700,000 at 29 ft. possible contamination in gw at approximately 200 ft.	
	299-W22-35	A7854		YES	215	11/19/76	DEN	not interpreted	

TABLE 4-1. GEOPHYSICAL LOG DATA ACQUIRED SINCE 1964 (WASTE SITES HAVE A PREFIX OF 216-)

Waste Site	Well Name	Well ID	Alias	IDMS	Total Depth	Date	Log Type	Contamination History	Summary
	299-W22-35	A7854		YES	200	02/23/77	N	possible water level at 202 ft.	
	299-W22-35	A7854		YES	215	09/22/86	GG	similar profile to 1976 data, with signs of decay, max less than 200 cps at 166 ft, possible ground water contamination.	
	299-W22-35	A7854		YES	215	08/19/87	GG	less than 100 cps throughout borehole with possible ground water contamination.	
S-9	299-W22-69	C4969		YES	377	02/09/06	SGLS	Total Gamma indicates no anomalous gamma activity.	No anomalous gamma activity.
S-23	299-W19-6	A4959		NO	420	01/09/69	GG	Near background levels indicated.	Contamination may have entered the vadose zone and groundwater in 1970. Subsequent profiles show decay to near background levels. The contamination appears to have reached ground water in 1970, with signs of decay by 1976.
	299-W19-6	A4959		YES	210	01/09/69	N	possible ground water level at 210 ft.	
	299-W19-6	A4959		NO	430	03/03/70	GG	Elevated gamma from 65 ft to groundwater at 207 ft.	
	299-W19-6	A4959		YES	420	05/13/76	GG	Decayed to near background levels.	
	299-W19-6	A4959		YES	430	06/23/76	OTH	not interpreted	
	299-W19-6	A4959		YES	420	02/24/77	N	possible ground water level at 210 ft.	
	299-W19-6	A4959		NO	168	04/15/85	OTH	not interpreted	
S-23	299-W19-5	A7734		YES	235	01/09/69	N	not interpreted	Contamination may have entered the vadose zone and groundwater in 1970. Subsequent profiles show decay to near background levels. The contamination appears to have reached ground water in 1970, with signs of decay by 1976. The 2003 log detected Cs-137 near the MDL from 2-9 ft. The 2003 logging event was terminated 1 ft above ground water.
	299-W19-5	A7734		NO	210	01/09/69	GG	Near background levels indicated.	
	299-W19-5	A7734		NO	230	03/02/70	GG	Elevated gamma from 65 ft to groundwater at 207 ft.	
	299-W19-5	A7734		YES	230	05/13/76	GG	Decayed to near background levels	
	299-W19-5	A7734		YES	230	06/23/76	OTH	not interpreted	
	299-W19-5	A7734		YES	210	02/24/77	N	possible ground water level at 210 ft.	
	299-W19-5	A7734		YES	235	07/28/03	HG	Cs-137 was detected near the MDL from 2-9 ft.	
S-23	299-W19-7	A7735		YES	210	01/09/69	N	not interpreted	No visible signs of contamination were detected before the 2003 logging event. Cs-137 was detected near the MDL from 4-5 ft in 2003. The 2003 logging event was terminated 1 ft above ground water.
	299-W19-7	A7735		NO	220	03/03/70	GG	no visible signs of contamination	
	299-W19-7	A7735		YES	220	05/13/76	GG	no visible signs of contamination	
	299-W19-7	A7735		YES	220	06/23/76	OTH	not interpreted	
	299-W19-7	A7735		YES	210	02/24/77	N	possible ground water level at 210 ft.	
	299-W19-7	A7735		YES	235	07/21/03	HG	Cs-137 was detected near the MDL from 4-5 ft.	
S-23	299-W19-10	A7738		YES	530	06/23/76	OTH	not interpreted	No GG data available for interpretation. Possible ground water level at 204 ft in 1977.
	299-W19-10	A7738		YES	410	02/24/77	N	possible ground water level at 204 ft.	
	299-W19-10	A7738		YES	460	06/24/81	OTH	not interpreted	
	299-W19-10	A7738		YES	660	05/18/82	OTH	not interpreted	
	299-W22-37	A7856		YES	210	01/09/69	N	not interpreted	No visible signs of contamination in historical data. The 2003 log detected Cs-137 near the MDL at 4 ft. The 2003 logging event was terminated at 243 feet, 1 ft above ground water.
	299-W22-37	A7856		NO	270	01/09/69	GG	no visible signs of contamination	
	299-W22-37	A7856		NO	270	03/02/70	GG	no visible signs of contamination	
	299-W22-37	A7856		YES	270	05/13/76	GG	no visible signs of contamination	
	299-W22-37	A7856		YES	270	06/23/76	OTH	not interpreted	
	299-W22-37	A7856		YES	275	02/24/77	N	possible water level at 210 ft	
	299-W22-37	A7856		YES	243	10/10/03	HG	Cs-137 was detected near the MDL at 4 ft.	
S-23	299-W22-38	A7857		NO	230	01/09/68	GG	no visible signs of contamination	No visible signs of contamination in historical data. The 2003 log detected Cs-137 near the MDL from 3-8 ft. The 2003 logging event was terminated at 224 feet, 1 ft above ground water.
	299-W22-38	A7857		YES	230	01/09/69	N	possible water level at 210 ft.	
	299-W22-38	A7857		NO	230	03/02/70	GG	no visible signs of contamination	
	299-W22-38	A7857		YES	224	05/13/76	GG	no visible signs of contamination	
	299-W22-38	A7857		YES	224	06/23/76	OTH	not interpreted	
	299-W22-38	A7857		YES	224	02/24/77	N	possible water level at 210 ft.	
	299-W22-38	A7857		YES	224	09/15/03	HG	Cs-137 was detected near the MDL from 3-8 ft.	

ft to m = ft x 0.3048

Log Type
- HG High Resolution Spectral Gamma (HPGe) e.g. SGLS, HRLS, RLS
- SG "Conventional" Spectral Gamma e.g. NaI, BGO, CsI
- GG Gross Gamma e.g. GM, GG, Scintillation
- NM Neutron Moisture
- N Neutron (unspecified)
- PN Passive Neutron
- OTH Other (Density, Temperature, Caliper)

FIGURE 4-1. 216-S-9 CRIB UNDER CONSTRUCTION

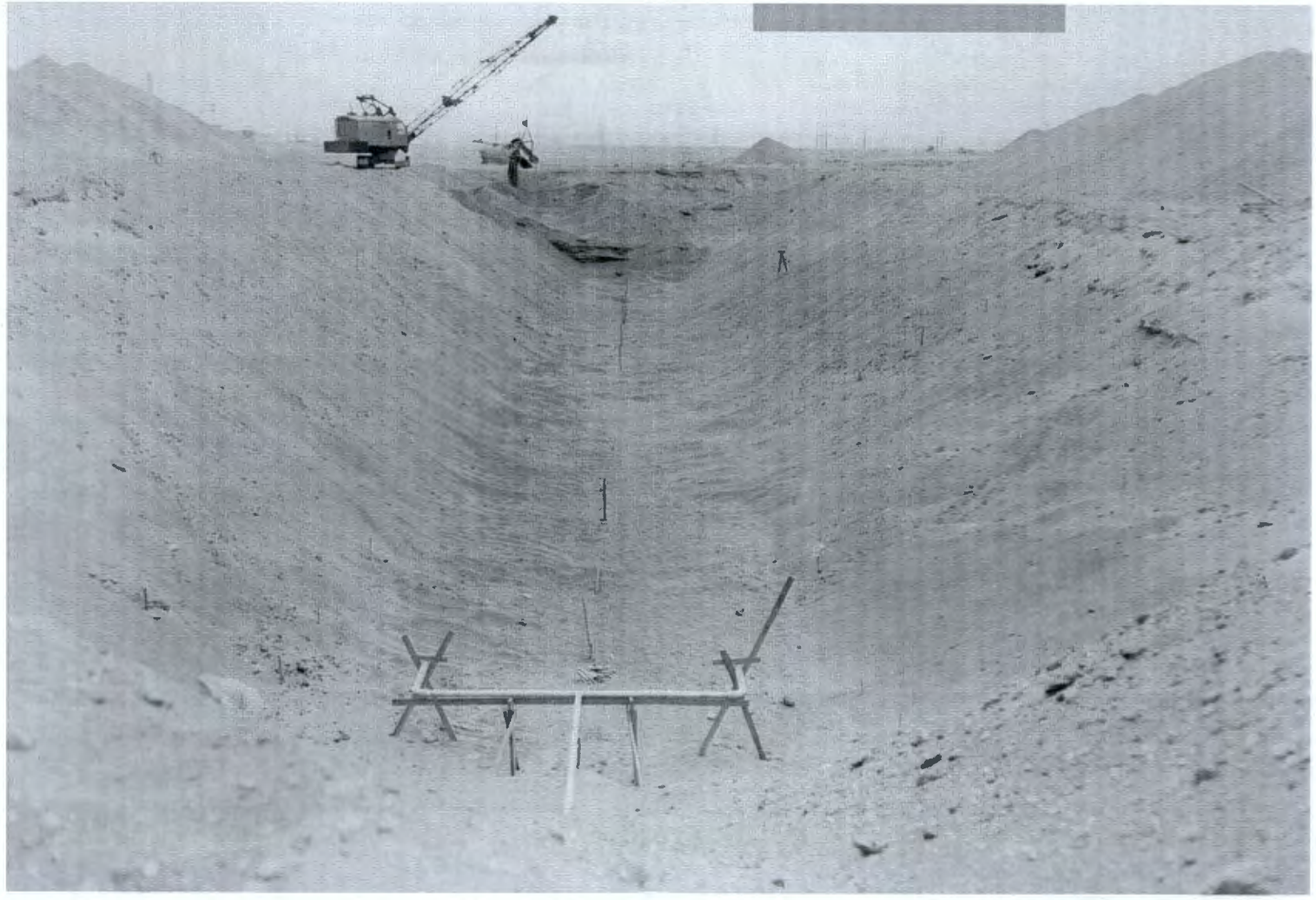


FIGURE 4-2. 216-S-9 AND 216-S-23 BOREHOLE AND CROSS SECTION LOCATION MAP

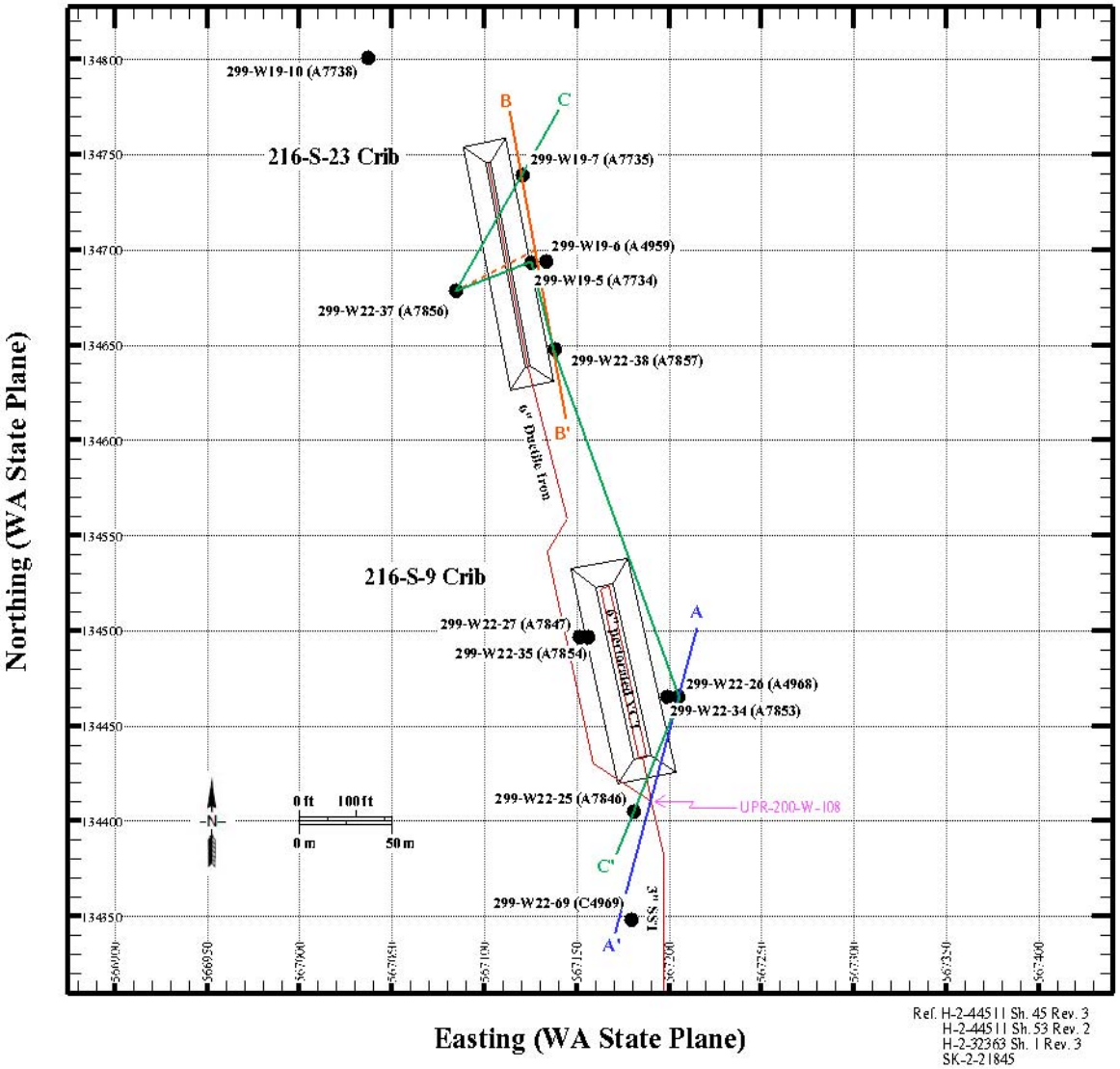


FIGURE 4-3. SCINTILLATION LOG PROFILES (1964 TO 1968) FOR BOREHOLE 299-W22-25 (A7846)

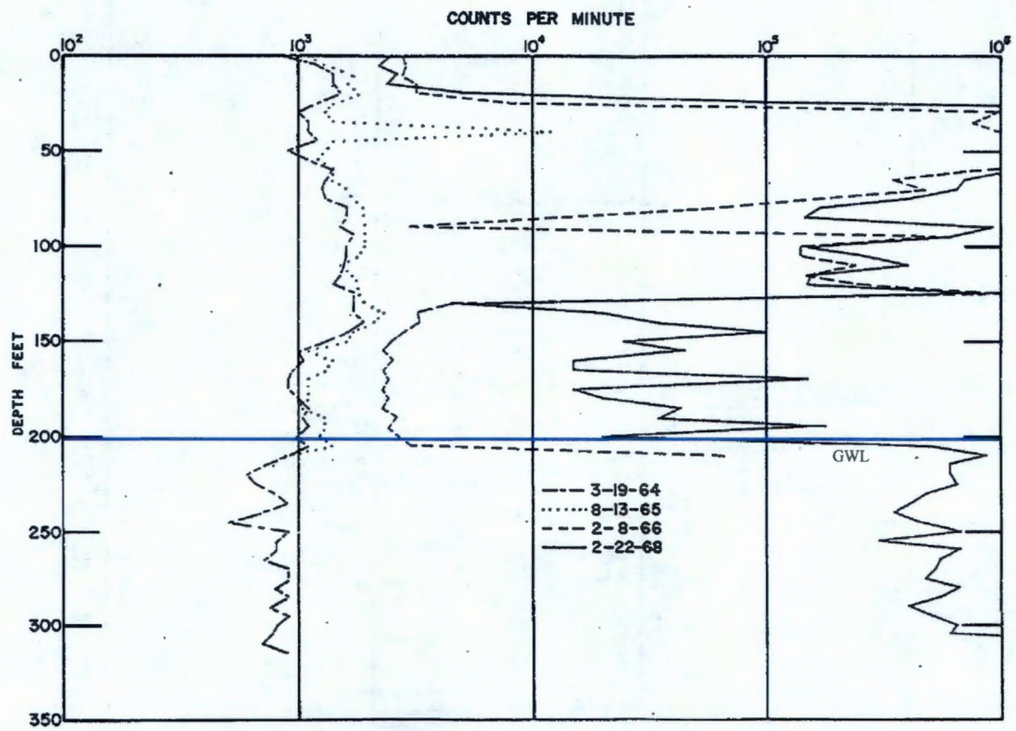


FIGURE B-10. WELL W22-25 SCINTILLATION LOG

UNCLASSIFIED

FIGURE 4-4. SCINTILLATION LOG PROFILES (1968 TO 1976) FOR BOREHOLE 299-W22-25 (A7846)

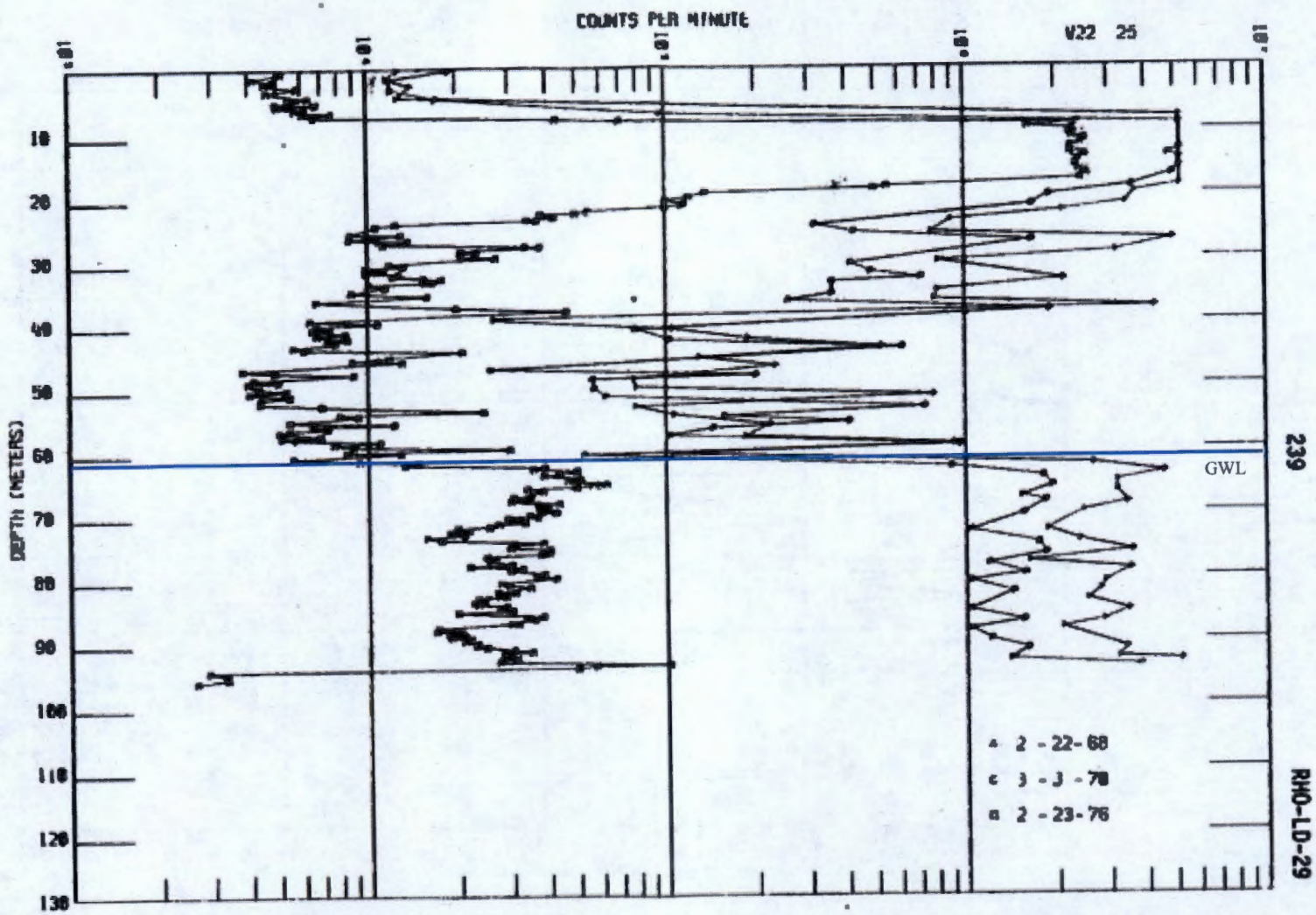


FIGURE 4-5. BOREHOLE 299-W22-26 (A4968) GROSS GAMMA LOG (1976)

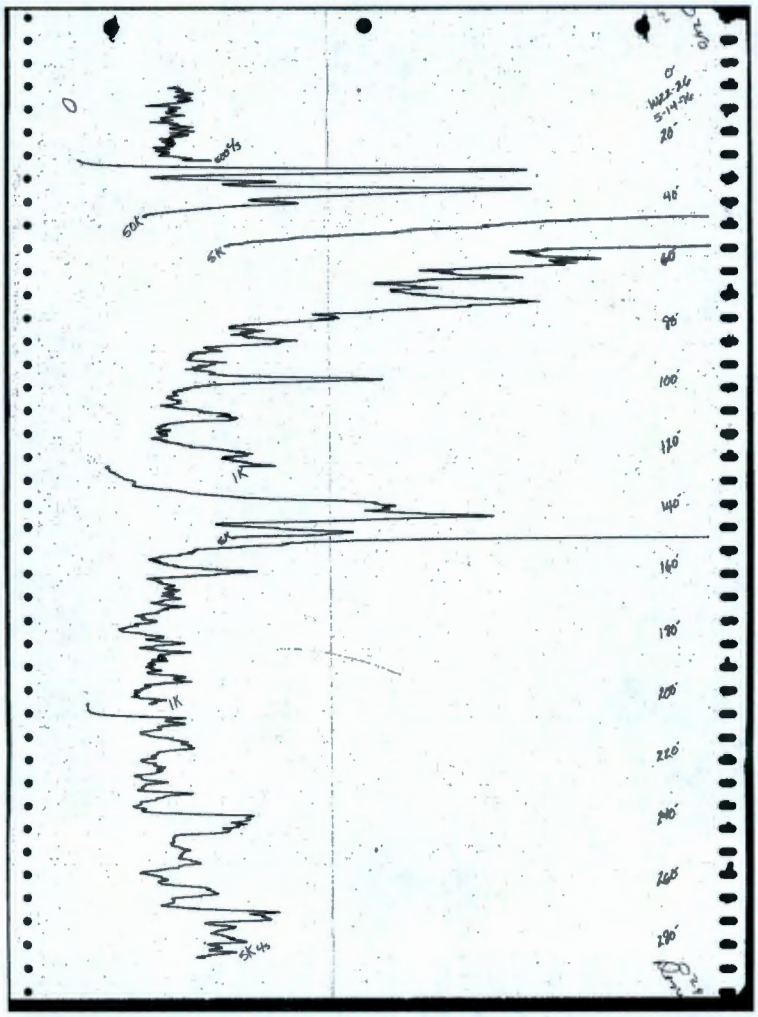


FIGURE 4-6. BOREHOLE 299-W22-34 (A7853) GROSS GAMMA LOG (1976)

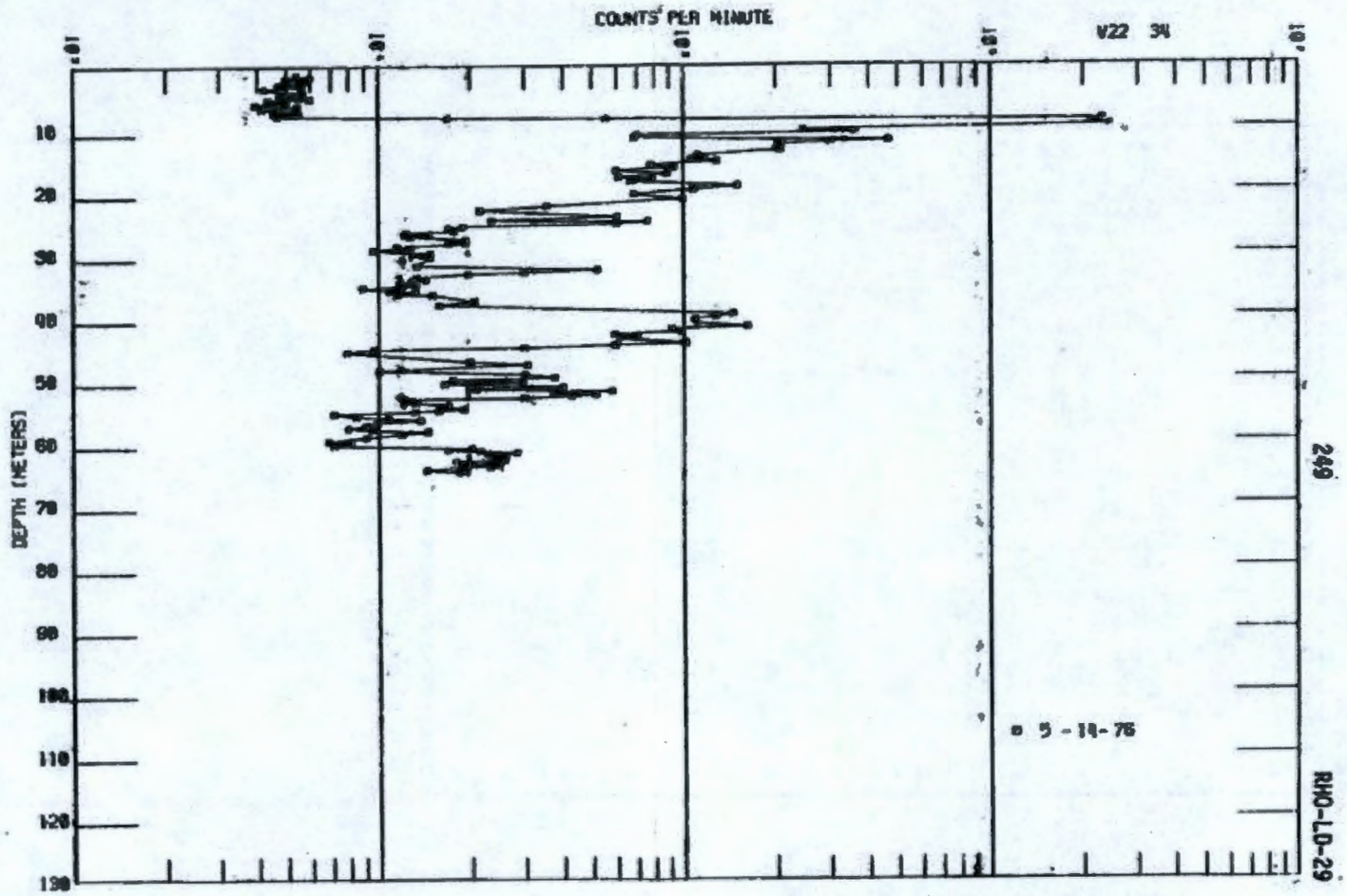


FIGURE 4-7. BOREHOLE 299-W22-35 (A7854) GROSS GAMMA LOG (1968)

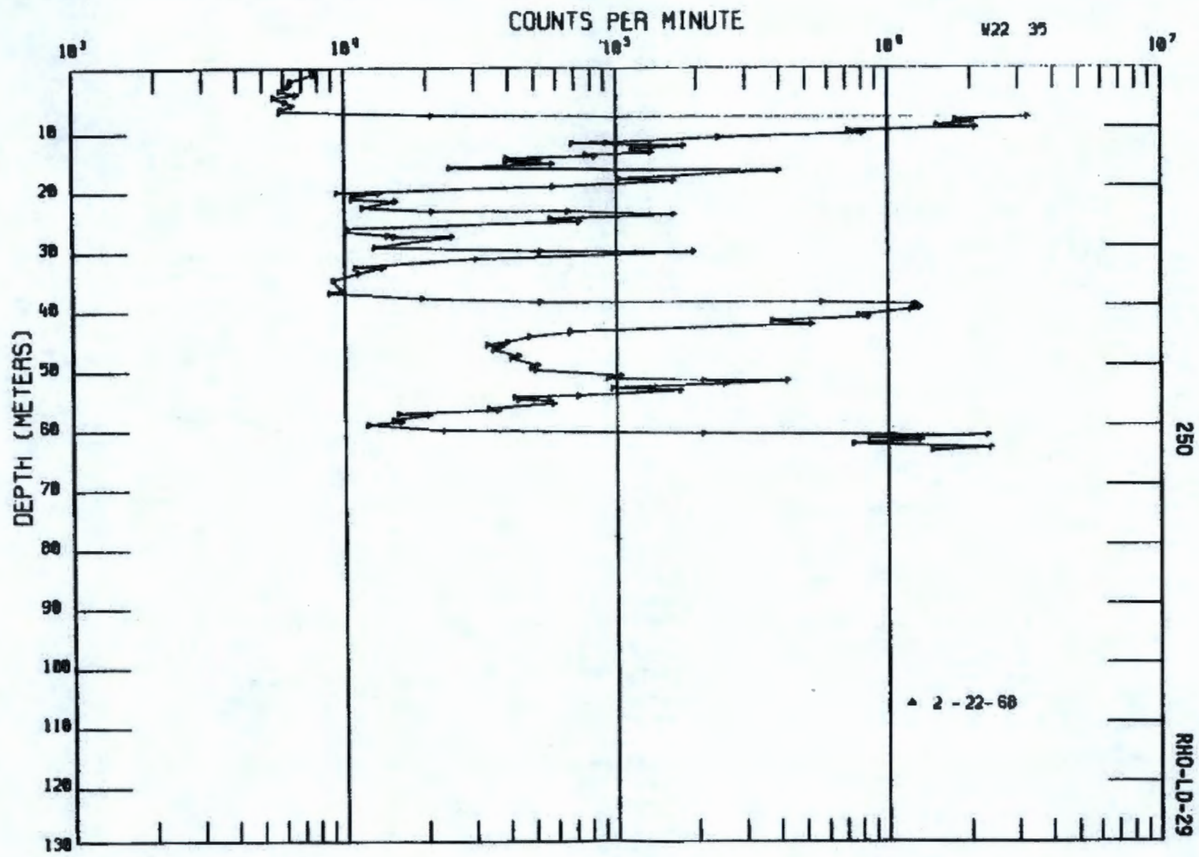
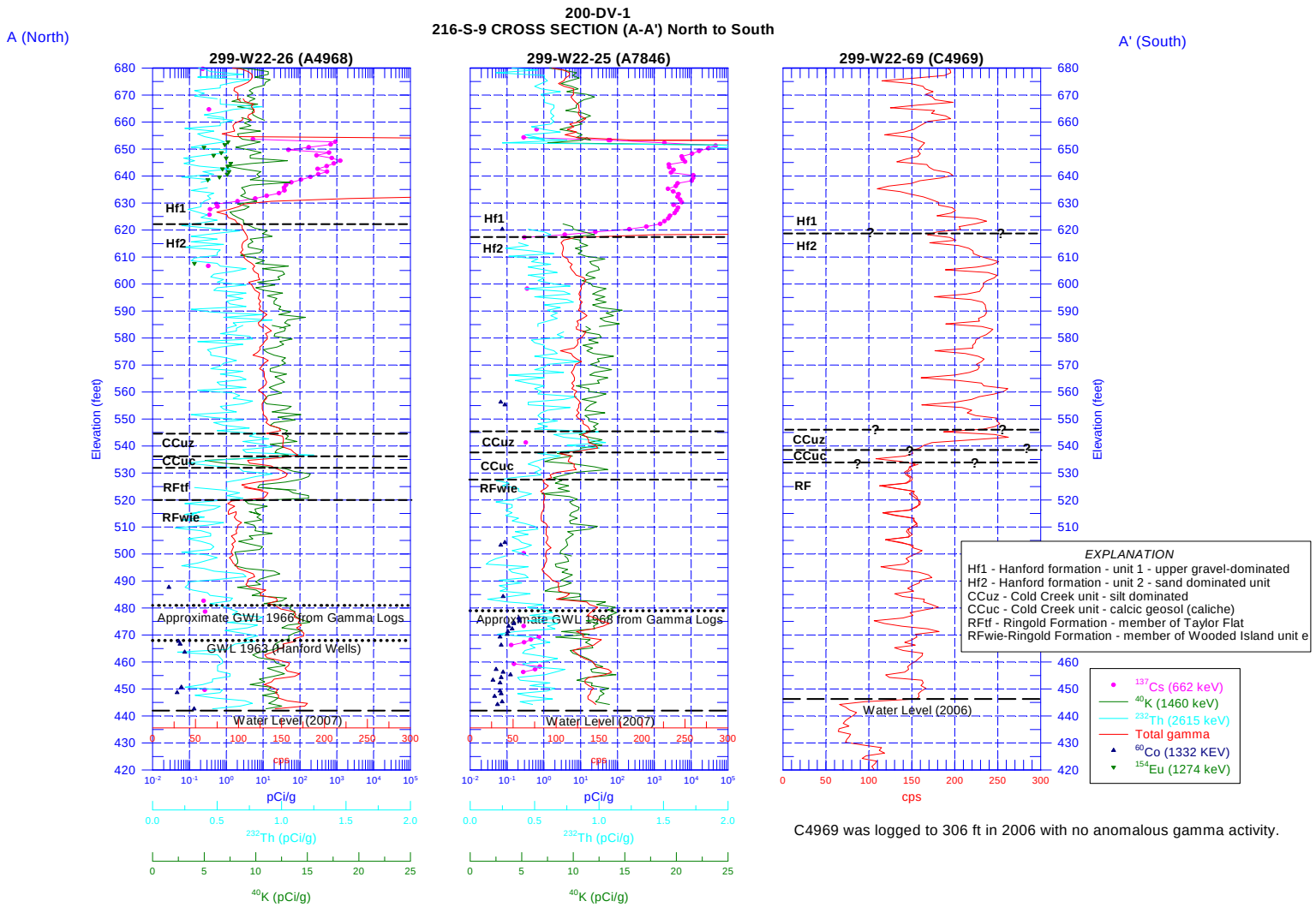


FIGURE 4-8. 216-S-9 CRIB CROSS SECTION



C4969 was logged to 306 ft in 2006 with no anomalous gamma activity.

FIGURE 4-9. VISUALIZATION OF CS-137 AND CO-60 CONTAMINATION NEAR THE 216- S-9 CRIB VIEWED FROM THE WEST

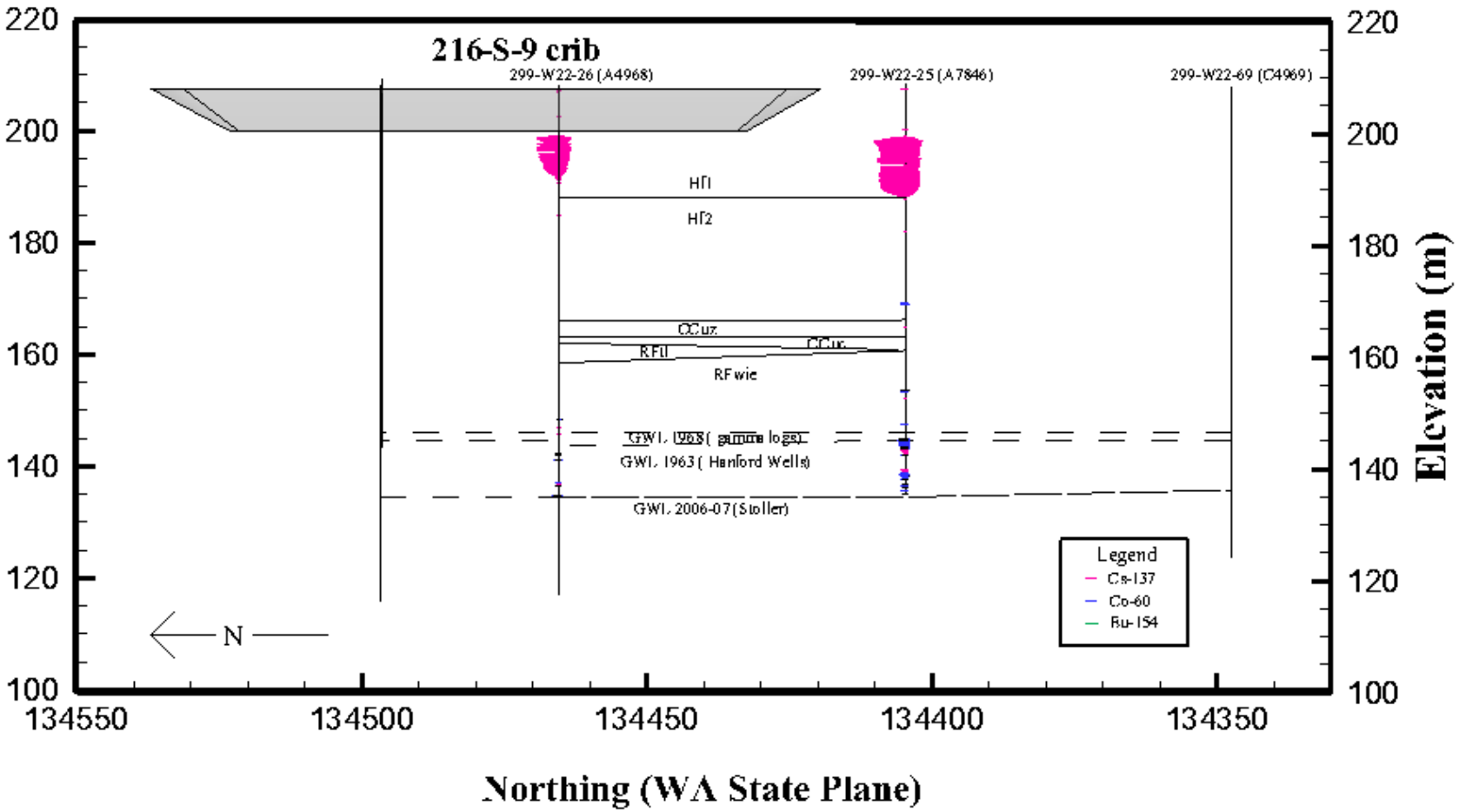


FIGURE 4-10. SCINTILLATION LOG PROFILES (1969 AND 1970) FOR BOREHOLE 299-W19-5 (A7734) NEAR 216-S-23

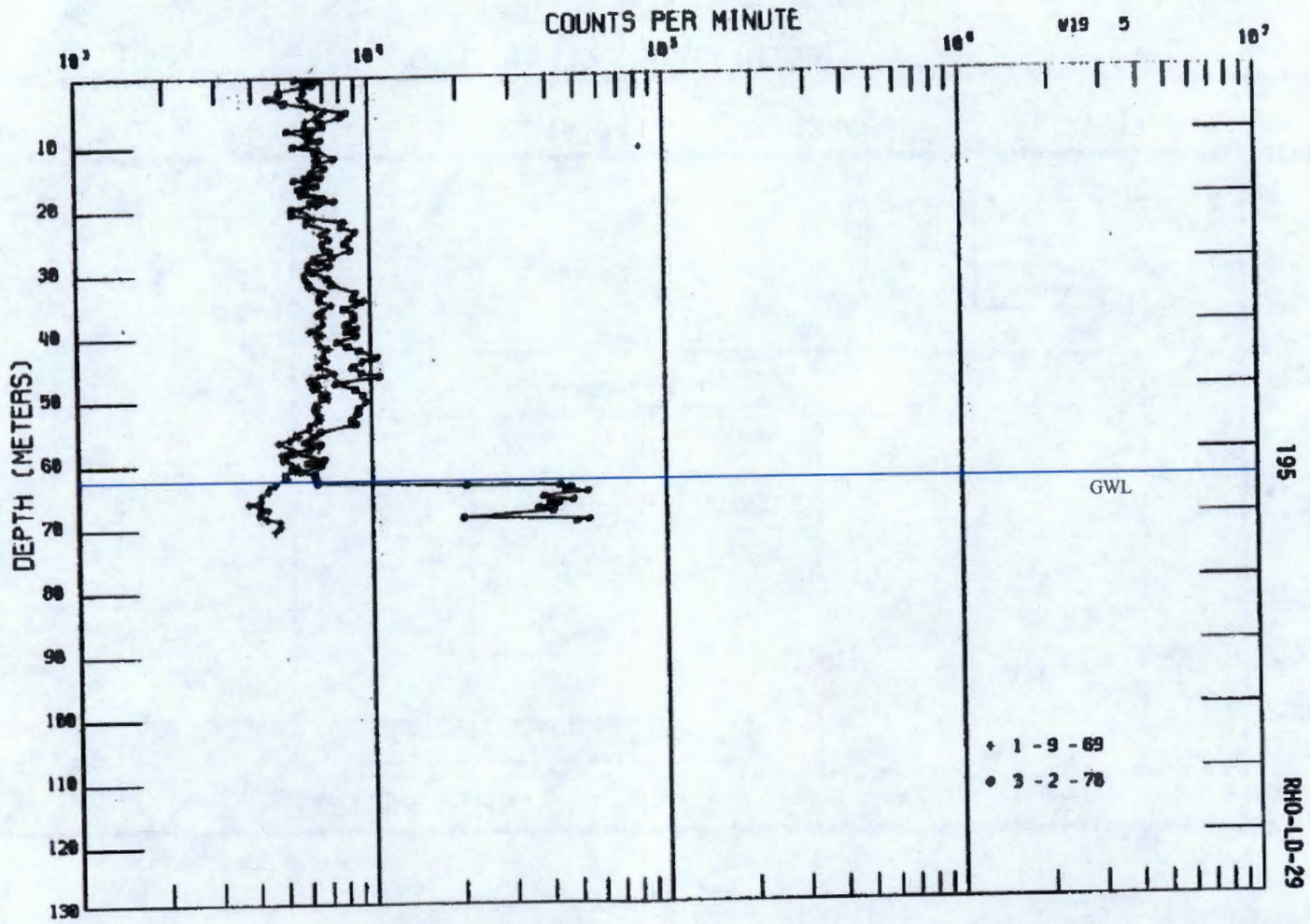
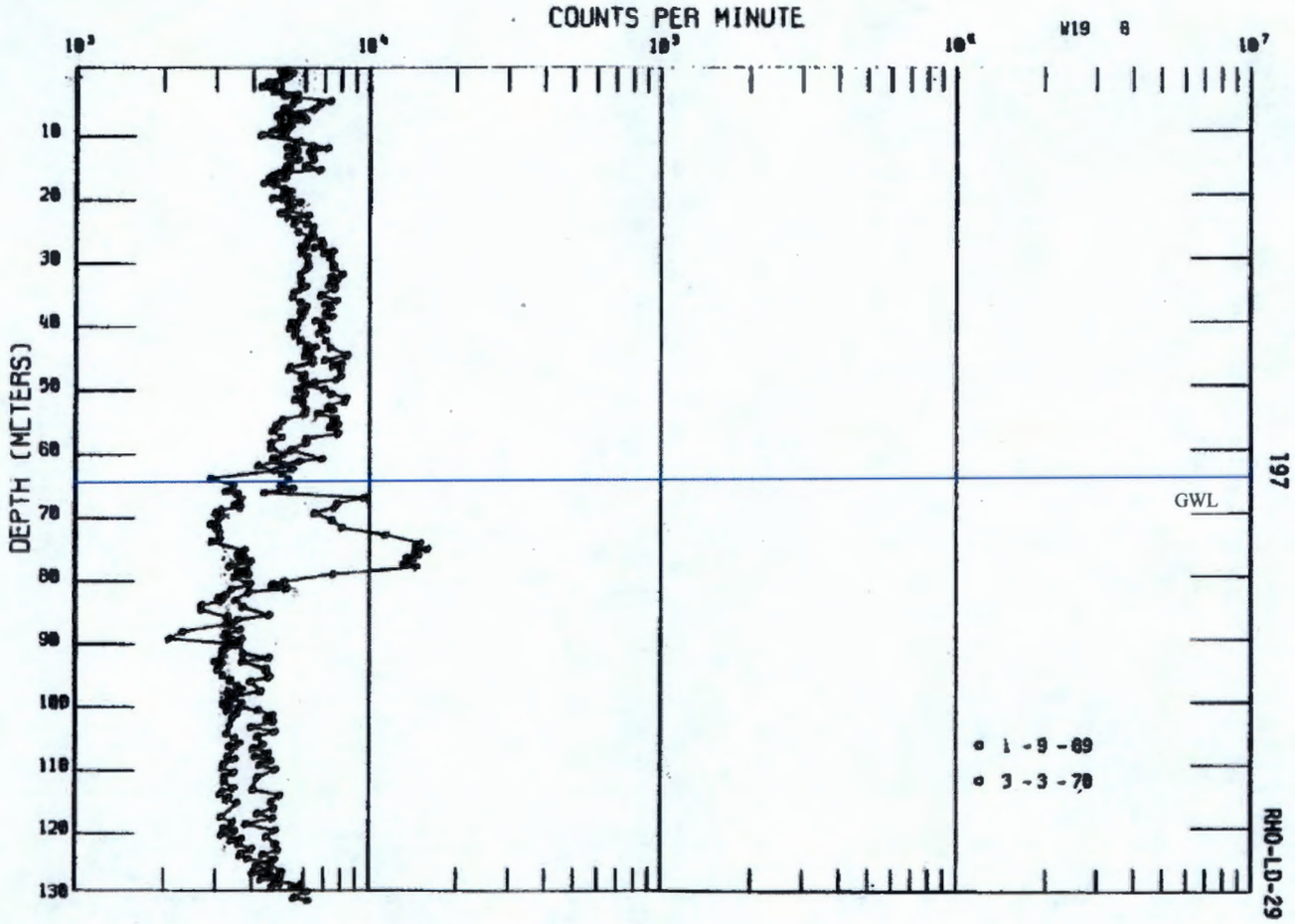


FIGURE 4-11. SCINTILLATION LOG PROFILES (1969 AND 1970) FOR BOREHOLE 299-W19-6 (A4959)



This page intentionally left blank.

FIGURE 4-12. 216-S-23 CRIB CROSS SECTION

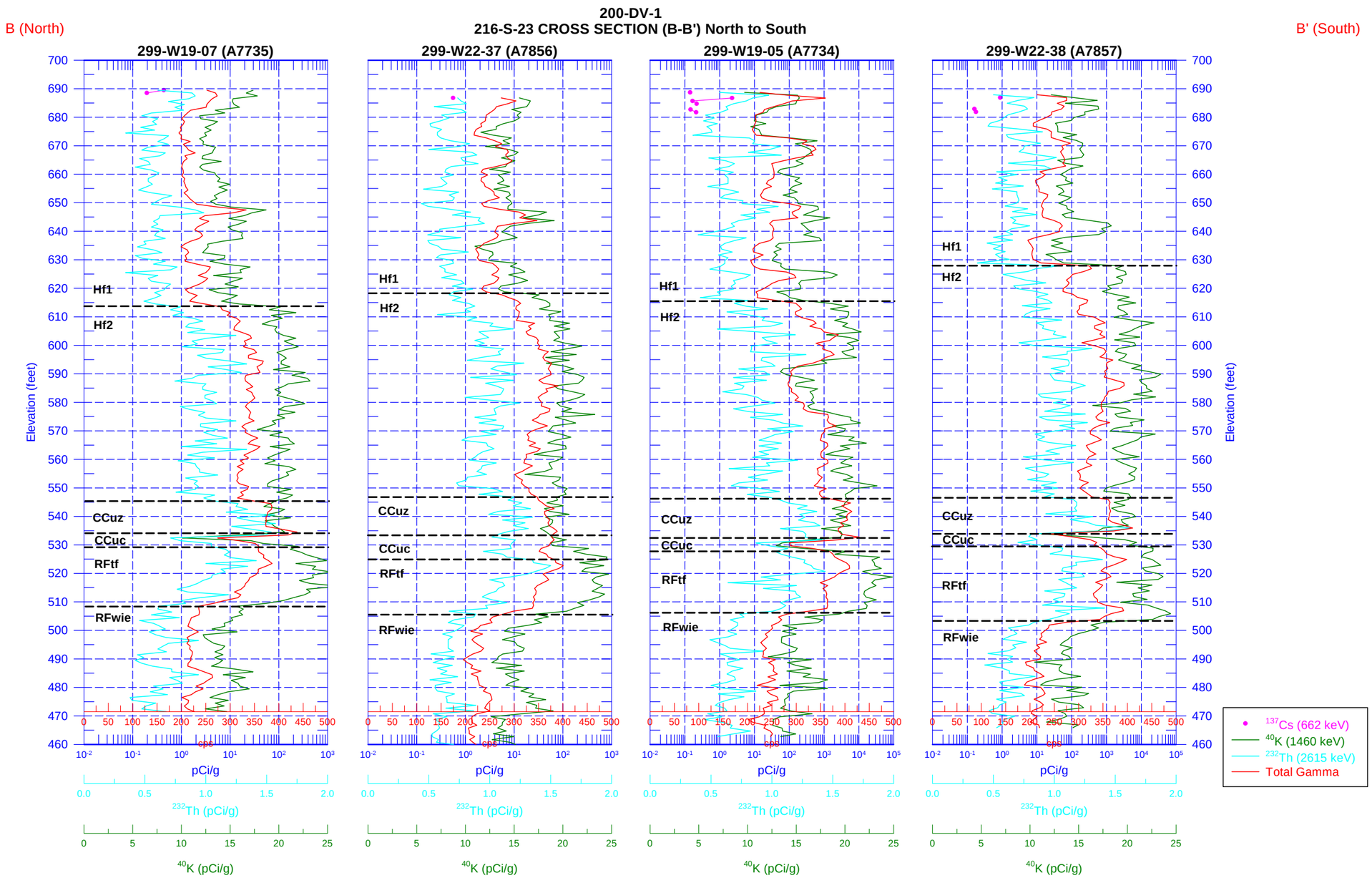
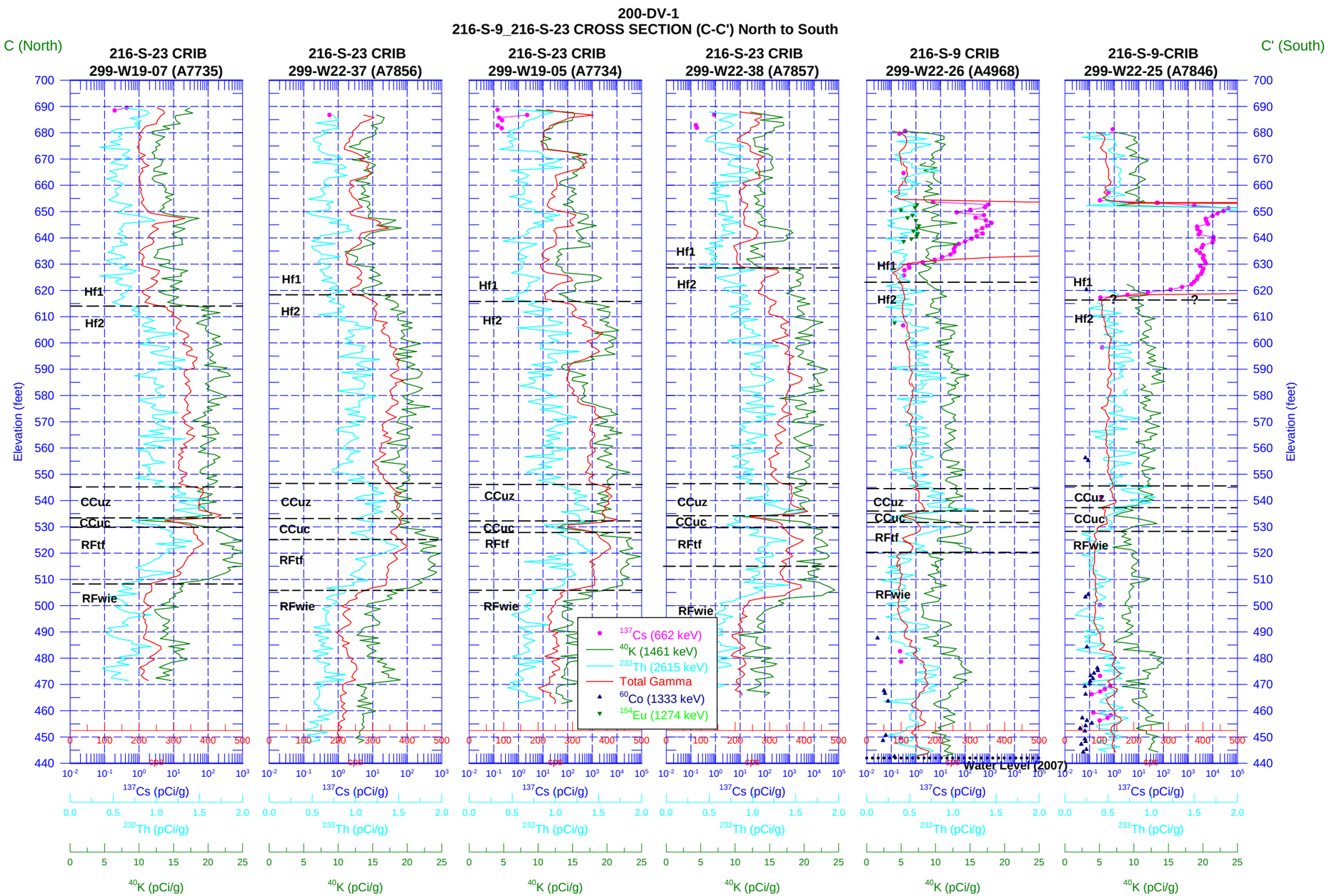


FIGURE 4-13. 216-S-9 TO 216-S-23 CRIBS CROSS SECTION



5.0 216-S-21 AND 216-S-25 CRIBS

This subregion includes the 216-S-21crib and the 216-S-25 crib (Figure 5-1). These waste sites are related in geographic proximity and geology. Process history and the size of the cribs differ. 241-SX-Farm lies immediately to the east of 216-S-25 and southeast of 216-S-21. A brief background section is provided that includes waste site characteristics, process history, and geology. Cross sections that include the current contamination profile in relation to the waste site and stratigraphy, 3-dimensional data visualizations, and interpretations are provided in Section 5.4.

5.1 GEOLOGY

The general geology and stratigraphy for this area are described in Section 3.1. Stratigraphic relationships are depicted on a cross section presenting log data. Key Stratigraphic intervals defined within the vadose zone, from shallowest to deepest include the Hf1, Hf2, CCu, RFtf, and RFwie. Overall, the vadose zone is approximately 220 ft (68.6 m) thick in this area. The contact between the Hf1 and Hf2 occurs relatively shallow and is usually situated approximately 45 ft below the facilities. The top of the Hf2 (Hanford formation – unit 2) is at approximately 600 ft (182.9 m) in elevation (65 ft or 19.8 m bgs) and the CCu lies between approximately 550 ft (167.6 m) in elevation or 110 ft (33.5 m) bgs and 505 ft (153.9 m) in elevation or 160 ft (48.8 m) bgs. The Hf2 averages greater than 50 ft (15.2 m) in thickness and the CCu averages 45 ft (13.7 m) in thickness beneath the area.

5.2 WASTE SITE PROCESS HISTORY

5.2.1 216-S-21 AND 216-S-25 CRIBS

The 216-S-21 crib is located north of the 216-S-25 crib, northwest of the 241-SX Tank Farm, and due west from the 241-S Tank Farm. This waste site consists of a 16 square ft (1.5 square meters) wooden crib box. The bottom dimensions of the excavation for the crib are 50 ft (15.2 m) by 50 ft (15.2 m) by 22.1 ft (6.7 m) deep. There is 8.25 ft (2.5 m) of backfill above the crib which is laid in gravel (WIDS). According to WIDS, the site was interim stabilized in 1991 that suggests 1 to 2 ft (0.3 to 0.6 m) of contaminated material and clean backfill may have been placed over the crib. It is not known if the reported 8.25 ft (2.5 m) of backfill reported in WIDS includes the possible additional backfill material. The crib received waste through an 8-in. (20.3 cm) schedule 40 carbon steel pipeline originating from the 241-SX-401 condenser facility that lies west of the 241-SX-106 tank (Figure 5-1). A borehole (299-W23-63 {A7899}) has been drilled through the center of the crib.

The 216-S-25 crib is located west of the 241-SX tank farm and south of the 216-S-21 crib. The bottom dimensions of the waste site excavation are 575 ft (175.3 m) long by 10 ft (3.1 m) wide and 10 ft (3.1 m) deep. The slope of the excavation is 1:1 (WIDS). A 6-in. (15.2 cm) perforated PVC pipe serves as the distributor pipe throughout the length of the excavation and lies in gravel fill approximately 7 ft (2.1 m) bgs. Above the gravel fill is backfill. An underground 4-in. (10.1 cm) pipeline from the 242-S evaporator building enters the crib at the east end. In 1984, the pipeline from the 241-SX-402 condenser was tied into the 216-S-25 pipeline (WIDS).

According to WIDS, the 216-S-21 crib may have received waste from 1954 to 1970 although Cramer (1987) indicates the site was retired in February 1969 (Corbin et al. {2005} reports 1969). The site received 241-SX condensate from the condensers in the 241-SX-401 Condenser Facility.

The 216-S-25 crib operated from 1973 to 1985 (Corbin et al. 2005). The crib received waste from the 242-S Evaporator building and the 241-SX-402 Condenser facility after 1984. In 1985, the crib also received effluent from a pump and treat effort to extract U-238 from groundwater underneath the 216-U-1 and -2 cribs.

5.3 PREVIOUS INVESTIGATION

Fecht et al. (1977) evaluated scintillation log profiles from borehole 299-W23-4 (A4987) that lies just southeast from the center of the 216-S-21 crib. Fecht et al. stated radioactive contaminants were detected from 3.7 m (12 ft) below the crib bottom (9.8 m or 32 ft bgs) to 42.7 m (140 ft) below the crib (essentially above the CCu). It was observed that the maximum radiation intensity located 5.5 m (18 ft) below the crib had been increasing since waste discharges to the crib had been terminated. It was postulated the liquid effluent discharged to the nearby 216-U-10 pond could have provided the sediment moisture needed to move low levels of radiation from the sediments beneath the 216-S-21 crib toward well 299-W23-4. Fecht et al. observed that data indicate no breakthrough to groundwater from this site.

Fecht et al. also evaluated the 216-S-25 crib. Boreholes 299-W23-9 (A7883), 299-W23-10 (A7884), and 299-W23-11 (A4980) were logged and showed near background levels of activity in 1976. It was concluded breakthrough to groundwater had not occurred. DOE (1992) evaluated the same boreholes and concurred with the Fecht et al. assessment. There had been no additional geophysical data acquired since 1976.

5.4 SUMMARY OF LOG DATA

Figure 5-1 shows the location of boreholes relative to the two waste sites that have been evaluated for this subregion. All geophysical logging data acquired since 1964 have been considered and are included in Table 5-1. A brief evaluation of the significance of each log as compared to earlier logs in the same borehole is made. This evaluation is intended to describe any significant changes in the gamma profile during intervening years. A more accurate quantitative analysis will require detailed comparison, taking into account the relative efficiencies of the various detection systems. This will require a detailed assessment of the older logging systems, which depends on reports and other information that are difficult to locate. This is beyond the scope of the current effort. The "historical" record is important to determine the past existence of very short-lived radionuclides, the maximum extent of contamination at depth, and whether any influx or migration of contaminants has occurred over time since active disposal stopped.

The location of cross section A-A' is shown in Figure 5-1. The cross section (Figure 5-2) is included to depict important relationships between stratigraphy and the detected gamma contamination. With the exception of the tank farm boreholes, these boreholes are the only ones that have digitized geophysical log data available. The remaining boreholes in the area have historical total gamma logs that were reviewed but have not been digitized for evaluation and presentation.

5.4.1 216-S-21 CRIB

There are two boreholes in the immediate vicinity of the 216-S-21 crib where current borehole geophysical data (acquired in 1995 and 2006) are available to evaluate. Log data acquired from borehole 299-W23-63 (A7899) in 2006 and 299-W23-4 (A4987) in 1995 are included in cross section A-A' (Figure 5-2). Historical logs for 299-W23-4 (A4987) are included in Figure 5-3. Borehole 299-W23-63 (A7899) indicates Cs-137 concentrations up to 40 million pCi/g along with Co-60, Eu-154, and Sn-126. It is likely these latter contaminants exist in the high activity Cs-137 interval although not detected because the MDL is significantly increased for these radionuclides in the high Cs-137 interval. Unfortunately, this borehole was only drilled to 50 ft (15.2 m) bgs so that the maximum depth where contaminants existed is not known. Borehole 299-W23-4 (A4987) southeast of the center of the crib, indicates Co-60 contamination beginning at approximately 36 ft (11 m) bgs. Figure 5-3 shows the early historical record from Fecht et al. for this borehole. As summarized in Section 5-3, Fecht et al. concluded contaminants did not extend deeper than 140 ft (42.7 m) below the crib or approximately 162 ft (49.3 m) bgs. The driller's log from May 1957, suggests elevated gamma activity from 40 to 75 ft (12.2 to 22.9 m) at the time of drilling.

However, another interpretation is that contamination existed to 51 m (167 ft) bgs in 1958 with a high activity interval at approximately 11 m (36 ft) bgs. By 1968, significant decay of the gamma activity had occurred but appears to remain above background levels to 77 m (253 ft) bgs. In 1976, background gamma activity is indicated except for the interval from 12 to 14 m (39 to 46 ft) bgs. In this interval, gamma activities attributed to Co-60 (based on log data acquired in 1991) had increased since 1968. It is possible this new interpretation of the historical logs is not correct because the characteristics of the possibly different gamma detectors between 1968 and 1976 were not normalized properly for direct comparison. However, the existence of remnant Co-60 in current logs to a depth of at least 165 ft (50 m) bgs would suggest contamination consisting of relatively short-lived radionuclides may have extended into the deep vadose zone.

Fecht et al. (1977) also observed that the maximum radiation intensity located 5.5 m (18 ft) below the crib had been increasing in borehole 299-W23-4 since waste discharges to the crib had been terminated. It was postulated by Fecht et al.(1977) the liquid effluent discharged to the nearby 216-U-10 pond could have provided the sediment moisture needed to move low levels of radiation from the sediments beneath the 216-S-21 crib toward well 299-W23-4. Unknown to Fecht et al. (1977) was that this increase in radiation intensity was likely caused by Co-60 rather than the more common gamma emitter Cs-137. Co-60 is generally considered more mobile than Cs-137. It is not unusual to observe migration of this contaminant in the vadose zone and it may not be related to the 216-U-10 pond.

A visualization of current contaminants that have been measured near the 216-S-21 crib is indicated in Figure 5-4.

5.4.2 216-S-25 CRIB

Boreholes surrounding the 216-S-25 crib do not have digital data or current log data for presentation. Boreholes 299-W23-9 (A7883), 299-W23-10 (A7884), and 299-W23-11 (A4980), closest to the crib, indicated near background levels of activity in 1976. A cluster of three boreholes, located between the crib and the 241-SX farm and two boreholes in the west side of 241-SX farm, are included in cross section A-A' (Figure 5-2). Boreholes 299-W23-14 (A4983), 299-W23-21 (C3113), and 299-W23-8 (A4991) indicate no contamination. This suggests contamination has not reached this area from either the 216-S-25 crib or the 241-SX tank farm. A visualization of current contamination near the 216-S-21 and 216-S-25 cribs and boreholes near tanks 241-SX-106 and 241-SX-109 near the western edge of the 241-SX tank farm is included as Figure 5-5. There appears to be no commingling of wastes originating from the cribs or tank farm.

5.4.3 241-S AND SX FARMS

Numerous reports have been issued regarding contamination from various sources in the 241-SX and 241-S tank farms. Figure 5-2 suggests there is no contamination in the deep vadose zone west of the 241-SX and S farms that can be attributed to the cribs or the tank farm. Two boreholes adjacent to 241-SX-106 and 241-SX-109 tanks are included in Figure 5-2 to further validate that no probable impact occurred from west of the 241-SX tank farm. Refer to Appendix A for a list of references for all borehole geophysical logging data that have been acquired in 241-SX Farm. Knepp (2002) contains a comprehensive evaluation of contamination in 241-S and -SX-Farms. Sobczyk (2000) correlated observed gamma-ray observations with the stratigraphy of the sediments underlying the 241-SX farm.

5.5 SUMMARY OF SUBREGION AND CONCLUSIONS

A borehole located in the center of the 216-S-21 crib indicates Cs-137 contamination up to 40 million pCi/g. Co-60, Eu-154, and Sn-126 were also detected near the bottom of the borehole at 51 ft (15.5 m). Although the borehole did not fully penetrate the contamination, activity decreases with depth below the highest activity detected at approximately 25 ft (7.6 m). A borehole located southeast of the crib

indicated Co-60 contamination from 37 to 60 ft (11.3 to 18.3 m) bgs. The Co-60 contamination suggests lateral and downward migration. In addition, Co-60 is detected at a few sporadic depths to a maximum depth of 165 ft (50.1 m) bgs. This depth of contamination is consistent with historical total gamma logs that suggest elevated gamma activity to at least 140 ft (42.3 m) bgs and possibly to groundwater. There are not enough boreholes with available data in the area to evaluate the full extent of potential lateral or vertical extent of contamination. Boreholes surrounding the 216-S-25 crib do not have current spectral gamma logging data to evaluate this crib. However, historical gamma data acquired in 1976 in three boreholes close to the crib indicate near background levels of activity. Boreholes that lie east of the crib midway between the crib and 241-SX farm indicate no contamination that could be attributed to either the tank farm or the crib.

5.6 RECOMMENDATIONS

The 216-S-21 crib is characterized by a borehole that was drilled directly through the center of the crib to 51 ft (15.5 m) bgs. However, there is evidence from historical logs from a borehole southeast of the crib that the deep vadose zone may have been contaminated. Further characterization may be necessary to confirm or refute this possibility.

The 216-S-25 crib indicated no evidence of contamination in nearby boreholes in 1976. Since 1976, there have been no further measurements acquired in the boreholes. However, the crib continued to be used until 1985. Additional characterization would be necessary to confirm that no significant contamination was introduced into the crib since 1976.

5.7 REFERENCES

Corbin, R.A. et al. 2005. *Hanford Soil Inventory Model, Rev. 1*. RPP-26744. CH2MHILL Hanford Group Inc. Richland, WA.

Cramer, K.H. 1987. *Hanford Site Waste Management Units Report*. 004690. U.S. Department of Energy. Richland, WA.

Department of Energy. 1992. *S Plant Aggregate Area Maanagement Report*. DOE/RL-91-60, Rev. 0. U.S. Department of Energy. Richland, WA.

Fecht, K.R., Last, G.V., and Price, K.R. 1977. *Evaluation of Scintillation Probe Profiles From 200 Area Crib Monitoring Wells* Volume III. ARH-ST-156. Atlantic Richfield Hanford Company. Richland, WA.

Knepp, A.J. 2002. *Field Investigation Report for Waste Management Area S-SX*, Vol. 1, Main Text and Appendices A-C. RPP-7884. CH2M Hill Hanford Group Inc. Richland, WA.

Cramer, K.H. 1987. *Hanford Site Waste Management Units Report*, 004690. U.S. Department of Energy. Richland, WA.

Sobczyk, S.M. 2000. *Subsurface Interpretation of the SX Tank Farm Hanford Site, Washington Based on Gamma-Ray Logging*. Nez Perce Tribe ERWM Program. Lapwai, ID 83540.

TABLE 5-1. GEOPHYSICAL LOG DATA ACQUIRED SINCE 1958 (WASTE SITES HAVE A PREFIX OF 216-)

Waste Site	Well Name	Well ID	Tank Farm	ALIAS	IDMS	Depth	Log Date	Log Type	CONTAMINATION HISTORY	SUMMARY
S-25	299-W23-11	A4980			NO	235	05/18/76	GG	no visible signs of contamination	no visible signs of contamination
S-21	299-W23-13	A4982				218	11/05/90	GG	no visible signs of contamination	
S-21	299-W23-13	A4982				218	11/30/90	GG	no visible signs of contamination	
S-25	299-W23-14	A4983			N/A	225	N/A	None	no data available	no data available
S-21	299-W23-4	A4987			NO	175	02/28/58	GG	elevated gamma from 0-170 ft, maximum activity at ~38 ft.	Elevated gamma was detected in the 1958 GG log to 170 ft bgs. Maximum activity occurred at approximately 38 ft. Significant decay had occurred by 1959 although the maximum activity was still prominent at 38 ft. An increase is observed between 1968 and 1976 at 38 ft although the remainder of the borehole is near background. Current logs suggest it may have been Co-60 migrating from the crib. Current data (1995) shows Co-60 at approximately 37 ft to 60 ft, with intermittent detections to ~165 ft. No other radionuclide contaminants were detected.
S-21	299-W23-4	A4987			NO	185	08/05/59	GG	decay since 1958 to near background levels, activity remains at 38 ft	
S-21	299-W23-4	A4987			NO	280	05/07/63	GG	similar profile as 1959 GG	
S-21	299-W23-4	A4987				180	04/09/65	N	possible water level at 180 ft	
S-21	299-W23-4	A4987			NO	250	02/22/68	GG	increase in activity at 38 ft, remainder of borehole near background	
S-21	299-W23-4	A4987				250	02/23/76	GG	similar profile as 1968, with signs of increased gamma at 38 ft.	
S-21	299-W23-4	A4987				260	02/23/76	OTH	not interpreted	
S-21	299-W23-4	A4987			NO	260	11/19/76	OTH	Density log without source; shows elevated gamma from 40 to 50 ft	
S-21	299-W23-4	A4987				255	02/23/77	N	possible water level at 180 ft	
S-21	299-W23-4	A4987			NO	253	12/09/91	HG	RLS -no Cs, Co-60 from 37-60 ft. Max. activity was 11 pCi/g at 39 ft.	
S-21	299-W23-4	A4987			NO	180	06/27/95	NM	not interpreted	
S-21	299-W23-4	A4987			NO	300	06/28/95	HG	elevated gamma from 40-46 ft	
S-21	299-W23-63	A7899		241-SX-1 #1	YES	51	12/27/06	HG	SGLS- Cs-137, Eu-154, Co-60 and Sn-126 contamination	Borehole drilled to 51 ft did not penetrate all the contamination. Cs-137 (max 45,000,000 pCi/g at 24.5 ft); Eu-154, Co-60, and Sn-126 were detected in 2006.
S-21	299-W23-63	A7899			YES	51	12/27/06	NM	not interpreted	
S-21	299-W23-63	A7899			YES	51	12/27/06	PN	No TRU detected.	
S-21	299-W23-71	A7907		241-SX-1T.H.	N/A	54	N/A	None	No data available	no data available
S-21	299-W23-210	A8045			N/A	100	N/A	None	No data available	no data available
S-21	299-W23-20	C3112			N/A	260	N/A	None	No data available	no data available
S-25	299-W23-21	C3113				258	10/31/00	HG	no detections; gamma attenuation due to dual casing (0-70 ft)	no visible signs of contamination, dual casing 0-70 ft.
S-21	C7901	C7901			N/A	N/A	N/A	None	proposed, awaiting drilling	proposed, awaiting drilling
S-25	299-W23-8	A4991				235	05/18/76	GG	no visible signs of contamination	No significant contamination in the borehole.
S-25	299-W23-8	A4991				235	06/24/76	OTH	not interpreted	
S-25	299-W23-8	A4991				240	02/23/77	N	possible water level at 180 ft	
S-25	299-W23-8	A4991			YES	235	10/06/03	HG	Cs-137 detected at 3,5,12,18,23,175 ft	
S-25	299-W22-53	A7860			N/A	N?A	N/A	None	no data available	no data available
S-25	299-W23-9	A7883				500	03/04/74	OTH	not interpreted	no apparent contamination
S-25	299-W23-9	A7883				230	06/24/74	OTH	not interpreted	
S-25	299-W23-9	A7883				230	02/23/76	GG	no visible signs of contamination	
S-25	299-W23-9	A7883				180	02/18/77	N	possible water level at 180 ft	
S-25	299-W23-10	A7884				230	03/04/74	OTH	not interpreted	no apparent contamination
S-25	299-W23-10	A7884				230	05/18/76	GG	no visible signs of contamination	
S-25	299-W23-10	A7884				230	06/24/76	OTH	not interpreted	
S-25	299-W23-10	A7884				230	02/18/77	N	possible water level at 180 ft	
S-25	299-W23-10	A7884			NO	150	10/08/80	GG	no visible signs of contamination	
S-25	299-W23-10	A7884			NO	150	01/09/81	GG	no visible signs of contamination	
S-25	299-W23-10	A7884			NO	150	04/14/81	GG	no visible signs of contamination	
SX-106	299-W23-144	A7980	41-06-09		TF	100	07/03/07	HG	Low levels (less than 10 pCi/g) of Cs-137 in backfill and at Hf1/Hf2 interface.	No significant contamination impact to the deep vadose zone
S-25	C4890	C4890			N/A	224	N/A	None	no data available	no data available
S-25	C4891	C4891			N/A	150	N/A	None	no data available	no data available
SX-109	299-W23-108	A7944	41-09-09		TF	130	12/31/95	HG	< 1 pCi/g Cs throughout borehole, 1000 pCi/g between 65 and 75 ft bgs	No deep vadose zone gamma activity
TANK FARM WELLS ON ORIGINAL LIST, NOT USED IN REPORT										
SX-106	299-W23-58	A7894	41-06-11	241-SX-1		101			tank farms	
SX-112	299-W23-65	A7901	41-00-08	241-SX-8		125			tank farms	
SX-109	299-W23-107	A7943	41-09-07			75			tank farms	

TABLE 5-1. GEOPHYSICAL LOG DATA ACQUIRED SINCE 1958 (WASTE SITES HAVE A PREFIX OF 216-)

Waste Site	Well Name	Well ID	Tank Farm	ALIAS	IDMS	Depth	Log Date	Log Type	CONTAMINATION HISTORY	SUMMARY
SX-109	299-W23-109	A7945	41-09-11			75			tank farms	
SX-112	299-W23-114	A7950	41-12-07			75			tank farms	
SX-112	299-W23-115	A7951	41-12-09			75			tank farms	
SX-112	299-W23-116	A7952	41-12-10			75			tank farms	
SX-115	299-W23-120	A7956	41-15-09			75			tank farms	
SX-115	299-W23-121	A7957	41-15-10			125			tank farms	
SX-103	299-W23-139	A7975	41-03-09			100			tank farms	
S-112	299-W23-176	A8012	40-12-09			100			tank farms	
SX-103	299-W23-196	A8032	41-03-10			100			tank farms	
S-112	299-W23-208	A8044	40-12-07			105			tank farms	
SX-106	299-W23-227	A8054	41-06-23			130			tank farms	

Log Type

HG High Resolution Spectral Gamma (HPGe) e.g. SGLS, HRLS, RLS
SG "Conventional" Spectral Gamma e.g. NaI, BGO, CsI
GG Gross Gamma e.g. GM, GG, Scintillation
NM Neutron Moisture
N Neutron (unspecified)
PN Passive Neutron
OTH Other (Density, Temperature, Caliper)

FIGURE 5-1. 216-S-21 AND 216-S-25 CRIBS BOREHOLE AND CROSS SECTION LOCATION MAP

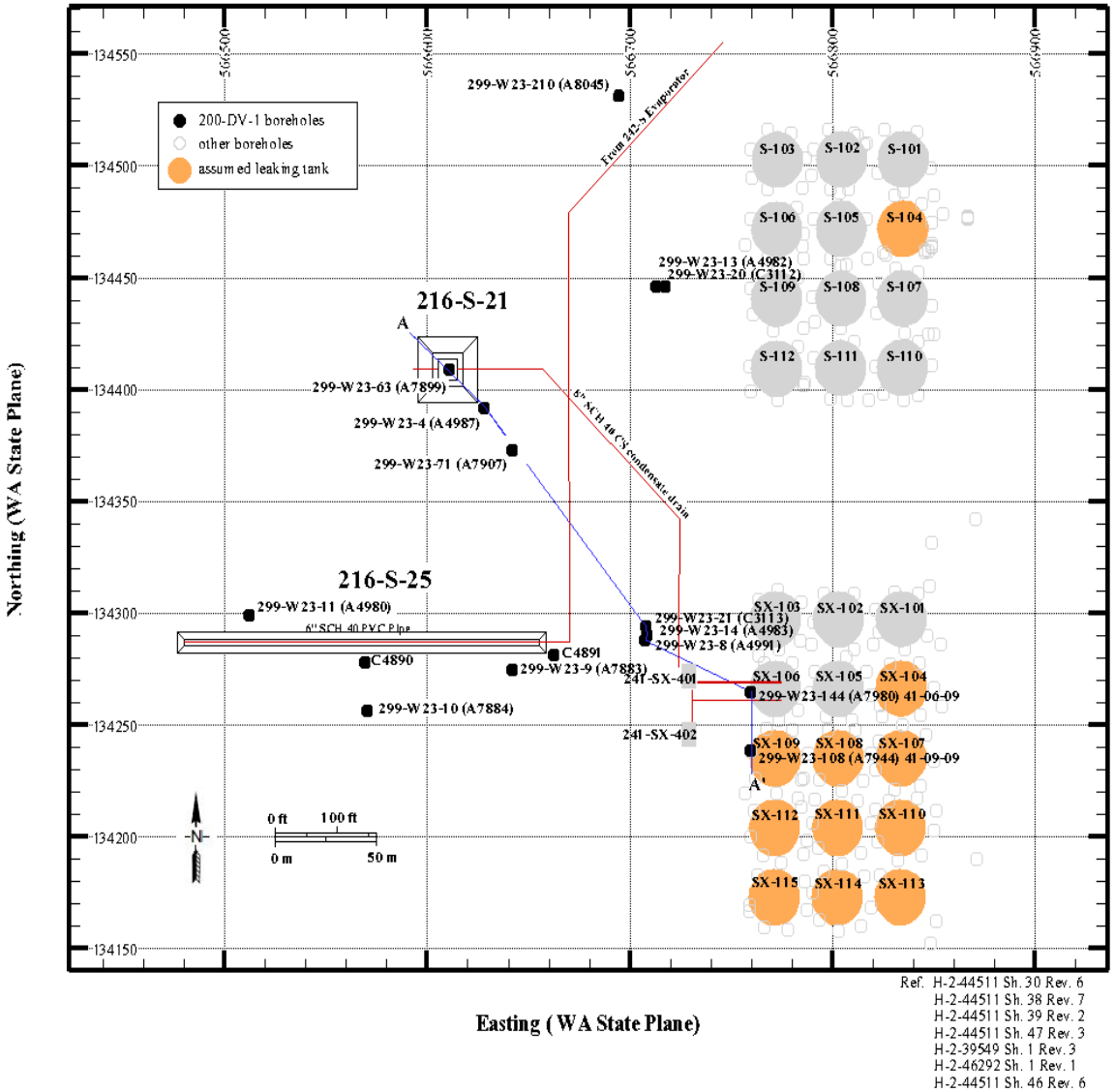


FIGURE 5-2. CROSS SECTION FROM THE 216-S-21 CRIB TO 241-SX FARM

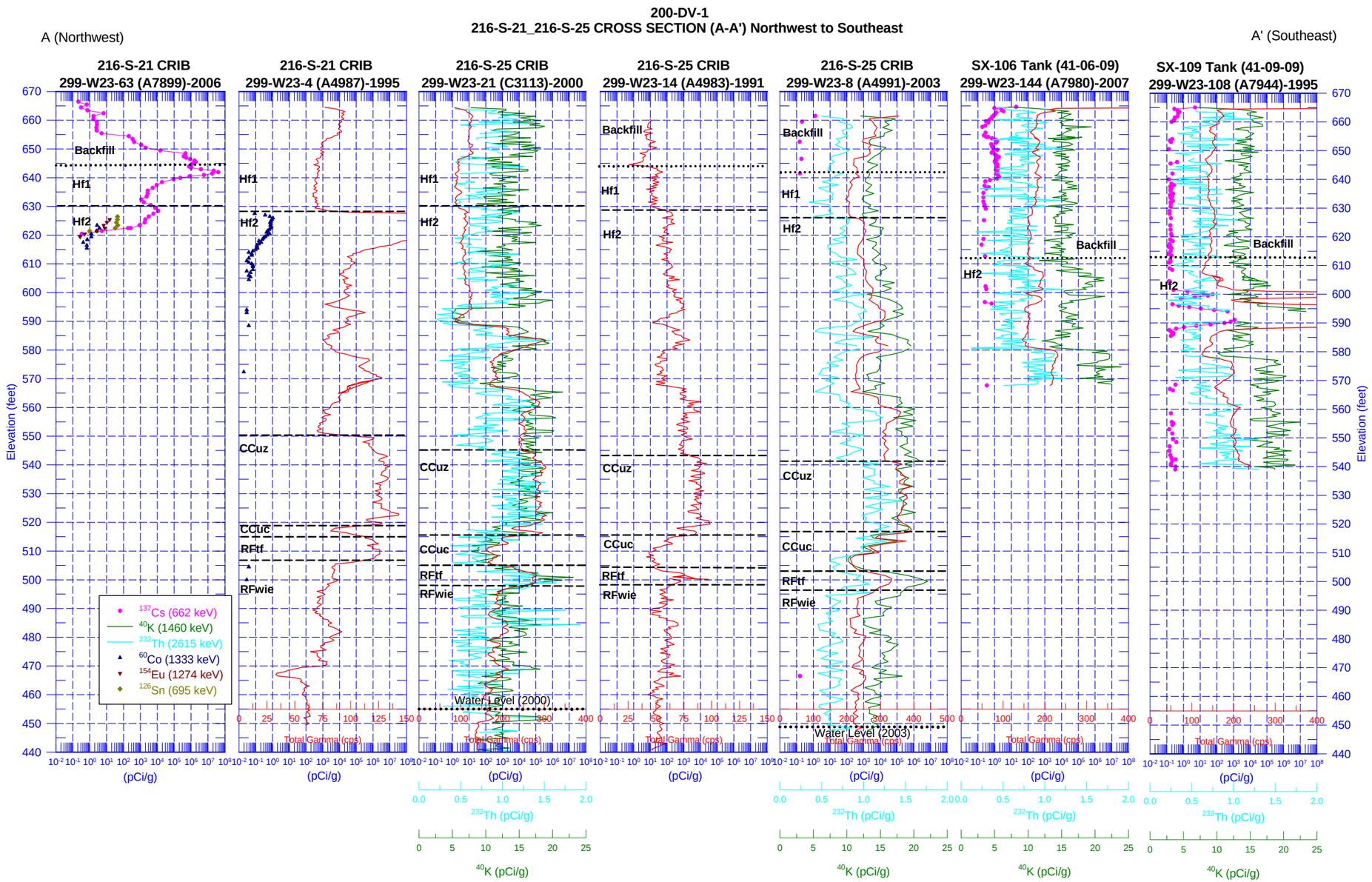


FIGURE 5-3. SCINTILLATION LOG PROFILES FOR 299-W23-4 NEAR THE 216-S-21 CRIB

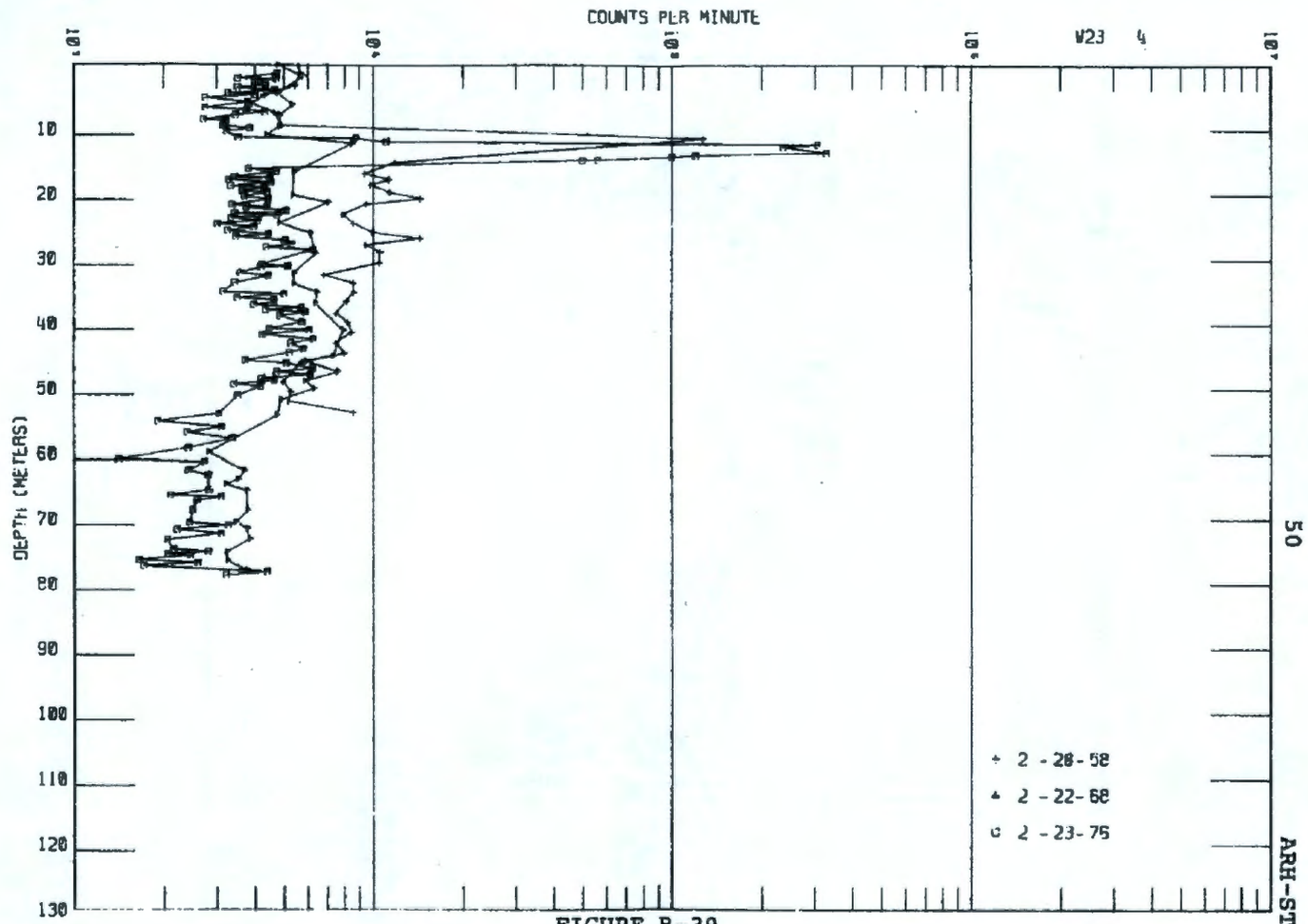


FIGURE B-39

WELL W23-4 SCINTILLATION PROBE PROFILES

ARH-ST-156

FIGURE 5-4. VISUALIZATION OF CS-137 AND CO-60 CONTAMINATION FOR THE 216-S-21 CRIB

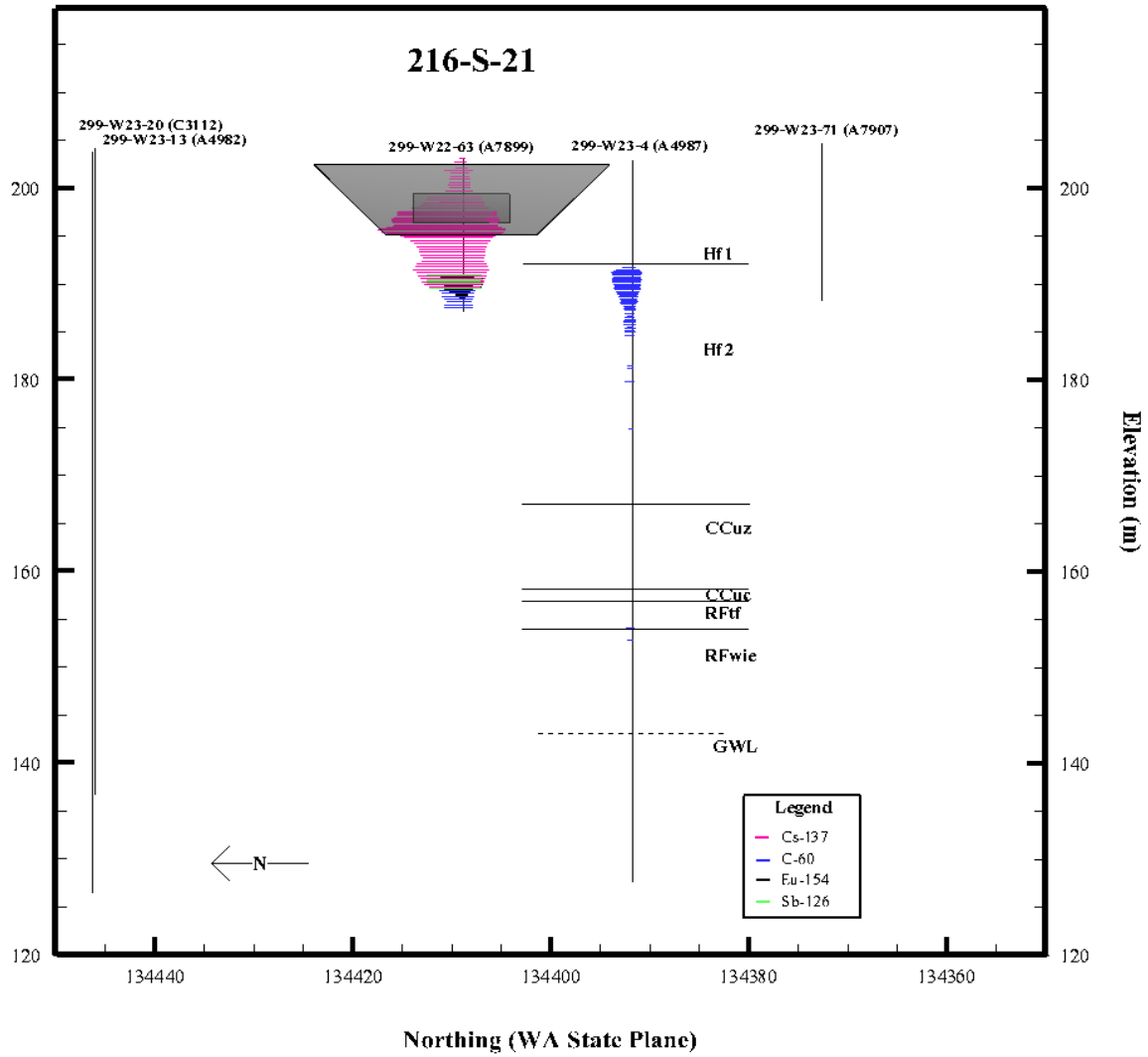
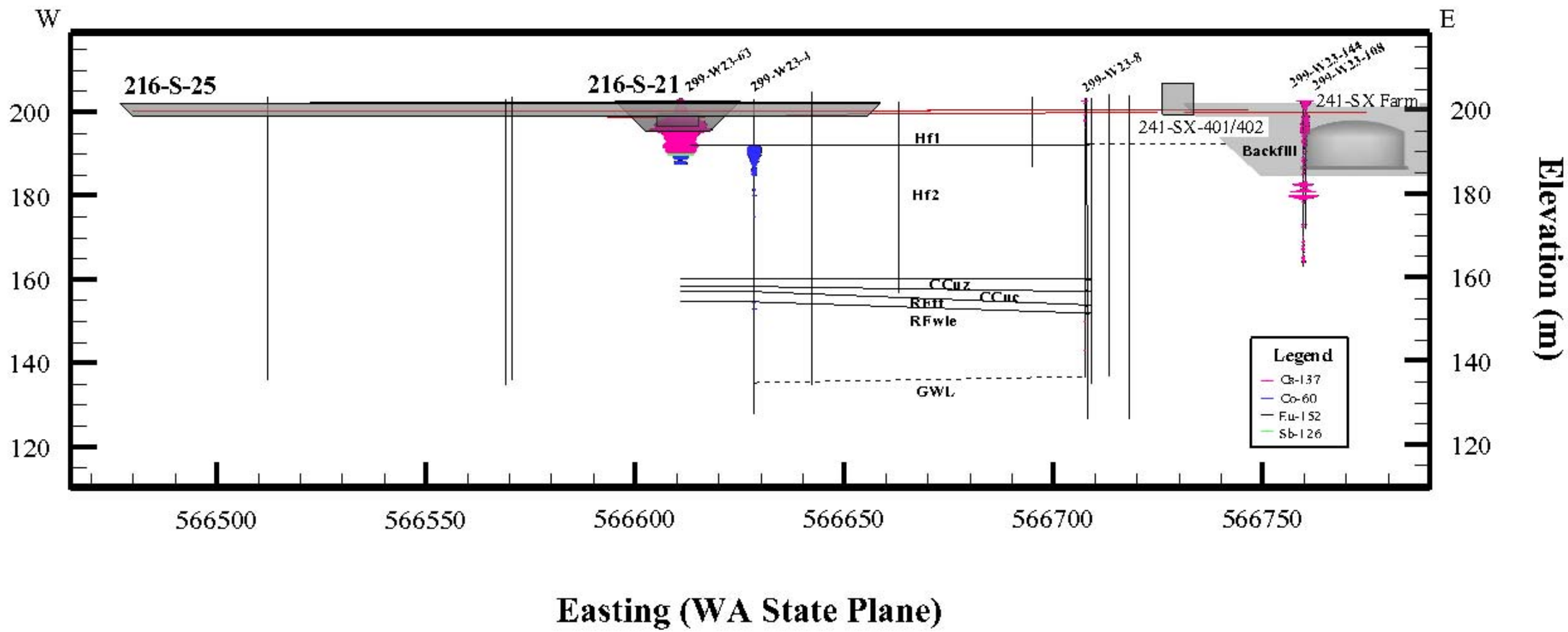


FIGURE 5-5. VISUALIZATION OF CS-137 AND CO-60 CONTAMINATION FOR THE 216-S-21 AND 216-S-25 CRIBS AND WEST OF 241-SX FARM



A

Appendix A - Geophysical Logs

A.1 Description of S-SX Focus Area for Boreholes

Table A-1 contains an inventory of 129 geophysical logs for the 30 boreholes and wells in the 200-DV-1, S-SX focus area. This list is based on the 2 sub-regions within the S-SX sites. The table below lists these sub region designations.

200-DV-1_S-SX Waste Sites by Sub region:

Sub Regions	Sub Region Waste Sites
1	216-S-9 and 216-S-23
2	216-S-21 and 216-S-25

Table A-1 includes the well identification number, well name, tank farm number, and alias for each of the 30 boreholes. The files were assigned a sub region number for sorting purposes. The "Depth" is the total logging depth or range for each logging event. The "Log Type" is identified with the following abbreviations:

LOG TYPE	EXPLANATION
HG	High Resolution Spectral Gamma (HPGe) e.g. SGLS, HRLS, RLS
SG	"Conventional "Spectral Gamma e.g. NaI, BGO, CsI
GG	Gross Gamma, e.g. GM, Scintillation
NM	Neutron Moisture
N	Neutron (unspecified)
PN	Passive Neutron
OTH	Other (Density, Temperature, Caliper)

The "Log sub type" is an explanation of the specific logs, e.g. scintillation, neutron, etc.

Descriptions of the logging methods are described in section 2 of this report.

The column labeled "IN IDMS" identifies 79 various borehole logs available in WIDL. An additional 40 logs have been copied or scanned and submitted to WIDL. No data were available for 8 boreholes within these waste sites. The data for the two tank farm boreholes are available in Tank Farm Summary Data Reports listed in Appendix A-2.

All of the SGLS logs in this list have been submitted to HEIS.

N/A is placed in the column of boreholes where no data is available.

A.2 Geophysical Borehole Logging Reports for the 241- S and -SX Tank Farms

SST Baseline Publications (by tank farm)

DOE-GJO. 1998. *Hanford Tank Farms Vadose Zone, S Tank Farm Report.* GJO-97-31-TAR, GJO-HAN-17. Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office.

DOE-GJO. 2000. *Hanford Tank Farms Vadose Zone, Addendum to the S Tank Farm Report.* GJO-97-31-TARA, GJO-HAN-17. Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office.

DOE/GJO. 1996. *Vadose Zone Characterization Project at the Hanford Tank Farms, SX Tank Farm Report.* DOE/ID/12584-268, GJPO-HAN-4. Prepared by Rust Geotech for the U.S. Department of Energy, Grand Junction Office.

DOE-GJO. 2000. *Hanford Tank Farms Vadose Zone, Addendum to the SX Tank Farm Report.* DOE/ID/12584-268A, GJPO-HAN-4. Prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office (tank designation has a prefix of 241-).

Tank Summary Data Reports

Tank Farm	Tank	Report Number	Date
S	S-101	GJ-HAN-70	5/97
	S-102	GJ-HAN-71	5/97
	S-103	GJ-HAN-72	5/97
	S-104	GJ-HAN-73	6/97
	S-105	GJ-HAN-74	6/97
	S-106	GJ-HAN-75	6/97
	S-107	GJ-HAN-76	6/97
	S-108	GJ-HAN-77	6/97
	S-109	GJ-HAN-78	6/97
	S-110	GJ-HAN-79	6/97
	S-111	GJ-HAN-80	6/97
	S-112	GJ-HAN-81	8/97
SX	SX-101	GJ-HAN-5	9/95
	SX-102	GJ-HAN-6	10/95
	SX-103	GJ-HAN-4	9/95
	SX-104	GJ-HAN-3	9/95
	SX-105	GJ-HAN-7	9/95
	SX-106	GJ-HAN-8	10/95
	SX-107	GJ-HAN-9	11/95
	SX-108	GJ-HAN-10	11/95
	SX-109	GJ-HAN-11	11/95
	SX-110	GJ-HAN-12	12/95
	SX-111	GJ-HAN-13	12/95
	SX-112	GJ-HAN-14	1/96
	SX-113	GJ-HAN-15	1/96
	SX-114	GJ-HAN-16	1/96
	SX-115	GJ-HAN-17	1/96

Other Publication:

Sobczyk, S.M. 2000. *Subsurface Interpretation of the SX Tank Farm Hanford Site, Washington Based on Gamma-Ray Logging.* Nez Perce Tribe ERWM Program. Lapwai, ID 83540.

Direct Push Characterization

Steffler, R.Z. 2009. *Completion Report for 241-SX Tank Farm Direct Push Barrier Characterization,* RPP-43548, Revision 0. Energy Solutions Federal Services, Inc. Richland, WA.

Sydnor, H.A. and R.Z. Steffler. 2010. *Completion Report for 241-S/SX Tank Farm Direct Push Barrier Characterization.* RPP-47274, Revision 0. Washington River Protection Solutions, LLC/Energy Solutions Federal Services, Inc., Northwest. Richland, WA.

SST Gross Gamma Log Summaries

200W	
Tank farm	**Report No**
S	HNF-4220
SX	HNF-3136

Summary of Tank Farms RCRA Facility Investigation and Supporting Data

Field, J.G. 2010. Hanford SX-Farm Leak Assessments Report. RPP-ENV-39658, Rev. 0. Washington River Protection Solutions LLC. Richland, Washington.

Knepp, A.J. 2002. Field Investigation Report for Waste Management Area S-SX, Vol. 1, Main Text and Appendices A-C. RPP-7884. CH2M Hill Hanford Group Inc. Richland, Washington.

Mann, F.M (editor) 2008. *Phase 1 RCRA Facility Investigation Report for the Hanford Single-Shell Tank Waste Management Areas.* (DVD-ROM) DOE/ORP-2008-001. U.S. Department of Energy, Office of River Protection. Richland, WA.

TABLE. A-1 200-DV-1 OPERABLE UNIT S-SX FOCUS AREA BOREHOLES AND AVAILABLE GEOPHYSICAL LOG DATA

Well ID	Well Name	Tank Farm #	Alias	Sub Regions 1-2	Depth (feet)	Log Type	Log Sub-Type	Log Date	IN IDMS	IDMS_ID	WIDL Data Available
A7846	299-W22-25			1	320	GG	scint	3/19/64	NO	SUBMITTED	
A7846	299-W22-25			1	240	N	neutron	4/24/64	NO	SUBMITTED	
A7846	299-W22-25			1	260	GG	scint	7/2/65	NO	SUBMITTED	
A7846	299-W22-25			1	180	N	neutron	8/3/65	NO	SUBMITTED	
A7846	299-W22-25			1	210	GG	scint	8/13/65	NO	SUBMITTED	
A7846	299-W22-25			1	240	N	neutron	8/20/65	NO	SUBMITTED	
A7846	299-W22-25			1	335	N	neutron	10/21/65	YES	153565727	Log Data Report - Neutron 299-W22-25 (A7846)
A7846	299-W22-25			1	260	GG	scint	10/21/65	NO	SUBMITTED	
A7846	299-W22-25			1	210	GG	scint	2/8/66	NO	SUBMITTED	
A7846	299-W22-25			1	320	GG	scint	2/22/68	NO	SUBMITTED	
A7846	299-W22-25			1	312	GG	scint	3/3/70	NO	SUBMITTED	
A7846	299-W22-25			1	210	OTH	temp	3/4/74	YES	154116452	Log Data Report - Temperature 299-W22-25 (A7846)
A7846	299-W22-25			1	320	GG	scint	2/23/76	YES	149928526	Log Data Report - GAMMA 299-W22-25 (A7846)
A7846	299-W22-25			1	320	OTH	density	11/19/76	YES	153786928	Log Data Report - Density 299-W22-25 (A7846)
A7846	299-W22-25			1	335	N	neutron	2/23/77	YES	153565919	Log Data Report - Neutron 299-W22-25 (A7846)
A7846	299-W22-25			1	340	GG	gamma	9/23/86	YES	149928527	Log Data Report - GAMMA 299-W22-25 (A7846)
A7846	299-W22-25			1	340	GG	gamma	8/19/87	YES	149928528	Log Data Report - GAMMA 299-W22-25 (A7846)
A7846	299-W22-25			1	335	HG	HRLS	9/19/07	YES	154378169(138882054)	Log Data Report 299-W22-25 (A7846)
A7846	299-W22-25			1	335	HG	SGLS	9/19/07	YES	154378169	Log Data Report 299-W22-25 (A7846)
A4968	299-W22-26			1	230	GG	scint	7/2/65	NO	SUBMITTED	
A4968	299-W22-26			1	288	GG	scint	8/2/65	NO	SUBMITTED	
A4968	299-W22-26			1	208	N	neutron	8/3/65	NO	SUBMITTED	
A4968	299-W22-26			1	206	N	neutron	8/20/65	NO	SUBMITTED	
A4968	299-W22-26			1	300	N	neutron	10/21/65	YES	153492060	Log Data Report - Neutron 299-W22-26 (A4968)
A4968	299-W22-26			1	200	GG	scint	3/7/66	NO	SUBMITTED	
A4968	299-W22-26			1	280	GG	scint	3/3/70	NO	SUBMITTED	
A4968	299-W22-26			1	300	GG	scint	5/14/76	YES	149198528	Log Data Report - Gamma 299-W22-26 (A4968)
A4968	299-W22-26			1	280	OTH	density	11/19/76	YES	153781145	Log Data Report - Density 299-W22-26 (A4968)
A4968	299-W22-26			1	280	N	neutron	2/23/77	YES	153492061	Log Data Report - Neutron 299-W22-26 (A4968)
A4968	299-W22-26			1	300	HG	SGLS	9/25/07	YES	154368602	Log Data Report 299-W22-26 (A4968)
A4968	299-W22-26			1	300	HG	SGLS	10/8/07	YES	138882051	Log Data Report
A7847	299-W22-27			1	572	OTH	TEMP	2/21/74	YES	154116453	Log Data Report - Temperature 299-W22-27 (A7847)
A7853	299-W22-34			1	110	N	neutron	2/7/67	YES	153565550	Log Data Report - Neutron 299-W22-34 (A7853)
A7853	299-W22-34			1	210	GG	scint	5/14/76	YES	149928546	Log Data Report - GAMMA 299-W22-34 (A7853)

TABLE. A-1 200-DV-1 OPERABLE UNIT S-SX FOCUS AREA BOREHOLES AND AVAILABLE GEOPHYSICAL LOG DATA

Well ID	Well Name	Tank Farm #	Alias	Sub Regions 1-2	Depth (feet)	Log Type	Log Sub-Type	Log Date	IN IDMS	IDMS_ID	WIDL Data Available
A7853	299-W22-34			1	216	OTH	density	11/19/76	YES	153787135	Log Data Report - Density 299-W22-34 (A7853)
A7853	299-W22-34			1	200	N	neutron	2/23/77	YES	153565624	Log Data Report - Neutron 299-W22-34 (A7853)
A7853	299-W22-34			1	216	GG	gamma	9/22/86	YES	149928547	Log Data Report - GAMMA 299-W22-34 (A7853)
A7853	299-W22-34			1	216	GG	gamma	8/19/87	YES	149928548	Log Data Report - GAMMA 299-W22-34 (A7853)
A7854	299-W22-35			1	200	N	neutron	2/7/67	YES	153565926	Log Data Report - Neutron 299-W22-35 (A7854)
A7854	299-W22-35			1	200	GG	scint	2/22/68	NO	SUBMITTED	
A7854	299-W22-35			1	215	GG	scint	5/14/76	YES	149928549	Log Data Report - GAMMA 299-W22-35 (A7854)
A7854	299-W22-35			1	215	OTH	density	11/19/76	YES	153787033	Log Data Report - Density 299-W22-35 (A7854)
A7854	299-W22-35			1	215	N	neutron	2/23/77	YES	153566020	Log Data Report - Neutron 299-W22-35 (A7854)
A7854	299-W22-35			1	200	GG	gamma	9/22/86	YES	149928550	Log Data Report - GAMMA 299-W22-35 (A7854)
A7854	299-W22-35			1	215	GG	gamma	8/19/87	YES	149928551	Log Data Report - GAMMA 299-W22-35 (A7854)
C4969	299-W22-69			1	377	HG	SGLS	2/9/06	YES	154309297(50386452)	Log Data Report 299-W22-69 (C4969)
A4982	299-W23-13			2	218	GG	gamma	11/5/90	YES	149198374	Log Data Report - Gamma 299-W23-13 (A4982)
A4982	299-W23-13			2	218	GG	gamma	11/30/90	YES	149198375	Log Data Report - Gamma 299-W23-13 (A4982)
C3112	299-W23-20			2	260	None	N/A	N/A	N/A	N/A	N/A
A8045	299-W23-210			2	100	None	N/A	N/A	N/A	N/A	N/A
A4987	299-W23-4			2	175	GG	scint	02/28/58	NO	SUBMITTED	
A4987	299-W23-4			2	185	GG	scint	08/05/59	NO	SUBMITTED	
A4987	299-W23-4			2	280	GG	scint	05/07/63	NO	SUBMITTED	
A4987	299-W23-4			2	180	N	neutron	4/9/65	YES	153492065	Log Data Report - Neutron 299-W23-4 (A4987)
A4987	299-W23-4			2	250	GG	scint	02/22/68	NO	SUBMITTED	
A4987	299-W23-4			2	250	GG	scint	2/23/76	YES	149206209	Log Data Report - Gamma 299-W23-4 (A4987)
A4987	299-W23-4			2	260	OTH	density	2/25/76	YES	153781416	Log Data Report - Density 299-W23-4 (A4987)
A4987	299-W23-4			2	260	OTH	density	11/19/76	NO	SUBMITTED	
A4987	299-W23-4			2	255	N	neutron	2/23/77	YES	153492066	Log Data Report - Neutron 299-W23-4 (A4987)
A4987	299-W23-4			2	253	HG	RLS	12/9/91	NO	SUBMITTED	
A4987	299-W23-4			2	180	NM	NMLS	06/27/95	NO	SUBMITTED	
A4987	299-W23-4			2	300	HG	NaI	6/28/95	NO	SUBMITTED	
A7899	299-W23-63		241-SX-1 #1	2	51	HG	HRLS	12/27/06	YES	154378170(50203998)	Log Data Report 299-W23-63 (A7899)
A7899	299-W23-63			2	51	HG	SGLS	12/27/06	YES	154378170	Log Data Report 299-W23-63 (A7899)
A7899	299-W23-63			2	51	NM	NMLS	12/27/06	YES	154378170	Log Data Report 299-W23-63 (A7899)
A7899	299-W23-63			2	51	PN	PNLS	12/27/06	YES	154378170	Log Data Report 299-W23-63 (A7899)
A7907	299-W23-71		241-SX-1T.H.	2	54	None	N/A	N/A	N/A	N/A	N/A
A7738	299-W19-10			1	530	OTH	density	06/23/76	YES		

TABLE. A-1 200-DV-1 OPERABLE UNIT S-SX FOCUS AREA BOREHOLES AND AVAILABLE GEOPHYSICAL LOG DATA

Well ID	Well Name	Tank Farm #	Alias	Sub Regions 1-2	Depth (feet)	Log Type	Log Sub-Type	Log Date	IN IDMS	IDMS_ID	WIDL Data Available
A7738	299-W19-10			1	410	N	neutron	02/24/77	YES		
A7738	299-W19-10			1	460	OTH	temp	06/24/81	YES		
A7738	299-W19-10			1	660	OTH	temp	05/18/82	YES		
A7734	299-W19-5			1	235	N	neutron	01/09/69	YES		
A7734	299-W19-5			1	210	GG	scint	01/09/69	NO	SUBMITTED	
A7734	299-W19-5			1	230	GG	scint	03/02/70	NO	SUBMITTED	
A7734	299-W19-5			1	230	GG	scint	05/13/76	YES		
A7734	299-W19-5			1	230	OTH	density	06/23/76	YES		
A7734	299-W19-5			1	210	N	neutron	02/24/77	YES		
A7734	299-W19-5			1	235	HG	SGLS	07/28/03	YES		
A4959	299-W19-6			1	420	GG	scint	01/09/69	NO	SUBMITTED	
A4959	299-W19-6			1	210	N	neutron	01/09/69	YES		
A4959	299-W19-6			1	430	GG	scint	03/03/70	NO	SUBMITTED	
A4959	299-W19-6			1	420	GG	scint	05/13/76	YES		
A4959	299-W19-6			1	430	OTH	density	06/23/76	NO	SUBMITTED	
A4959	299-W19-6			1	420	N	neutron	02/24/77	YES		
A4959	299-W19-6			1	168	OTH	density	04/15/85	NO	SUBMITTED	
A7735	299-W19-7			1	210	N	neutron	01/09/69	YES		
A7735	299-W19-7			1	220	GG	scint	03/03/70	NO	SUBMITTED	
A7735	299-W19-7			1	220	GG	scint	05/13/76	YES		
A7735	299-W19-7			1	220	OTH	density	06/23/76	YES		
A7735	299-W19-7			1	210	N	neutron	02/24/77	YES		
A7735	299-W19-7			1	235	HG	SGLS	07/21/03	YES		
A7856	299-W22-37			1	210	N	neutron	01/09/69	YES		
A7856	299-W22-37			1	270	GG	scint	01/09/69	NO	SUBMITTED	
A7856	299-W22-37			1	270	GG	scint	03/02/70	NO	SUBMITTED	
A7856	299-W22-37			1	270	GG	scint	05/13/76	YES		
A7856	299-W22-37			1	270	OTH	density	06/23/76	YES		
A7856	299-W22-37			1	275	N	neutron	02/24/77	YES		
A7856	299-W22-37			1	243	HG	SGLS	10/10/03	YES		
A7857	299-W22-38			1	230	GG	scint	01/09/68	NO	SUBMITTED	
A7857	299-W22-38			1	230	N	neutron	01/09/69	YES		
A7857	299-W22-38			1	230	GG	scint	03/02/70	NO	SUBMITTED	
A7857	299-W22-38			1	224	GG	scint	05/13/76	YES		

TABLE. A-1 200-DV-1 OPERABLE UNIT S-SX FOCUS AREA BOREHOLES AND AVAILABLE GEOPHYSICAL LOG DATA

Well ID	Well Name	Tank Farm #	Alias	Sub Regions 1-2	Depth (feet)	Log Type	Log Sub-Type	Log Date	IN IDMS	IDMS_ID	WIDL Data Available
A7857	299-W22-38			1	224	OTH	density	06/23/76	YES		
A7857	299-W22-38			1	210	N	neutron	02/24/77	YES		
A7857	299-W22-38			1	224	HG	SGLS	09/15/03	YES		
C7901	C7901			1	N/A	None	N/A	N/A	N/A	N/A	PROPOSED BOREHOLE-AWAITING DRILLING
A7860	299-W22-53			2	N/A	None	N/A	N/A	N/A	N/A	Borehole mis-located; REDOX #3 located at 202 S canyon facility
A7884	299-W23-10			2	230	OTH	temp	03/04/74	YES		
A7884	299-W23-10			2	230	GG	scint	05/18/76	YES		
A7884	299-W23-10			2	230	OTH	density	06/24/76	YES		
A7884	299-W23-10			2	230	N	neutron	02/18/77	YES		
A7884	299-W23-10			2	150	GG	gamma	10/08/80	NO	SUBMITTED	
A7884	299-W23-10			2	150	GG	gamma	01/09/81	NO	SUBMITTED	
A7884	299-W23-10			2	150	GG	gamma	04/14/81	NO	SUBMITTED	
A7944	299-W23-108	41-09-09		2	130	HG	SGLS	12/31/95	NO	TANK FARMS	TANK FARMS
A4980	299-W23-11			2	235	GG	scint	05/18/76	NO	SUBMITTED	
A4983	299-W23-14			2	225	HG	RLS	10/30/00	YES		
A7980	299-W23-144	41-06-09		2	100	HG	SGLS	07/03/07	NO	TANK FARMS	TANK FARMS
C3113	299-W23-21			2	258	HG	SGLS	10/31/00	YES		
A4991	299-W23-8			2	240	GG	scint	05/18/76	YES		
A4991	299-W23-8			2	235	OTH	density	06/24/76	YES		
A4991	299-W23-8			2	235	N	neutron	02/23/77	YES		
A4991	299-W23-8			2	235	HG	SGLS	10/06/03	YES		LDR SUBMITTED IN 2010
A7883	299-W23-9			2	500	OTH	temp	03/04/74	YES		
A7883	299-W23-9			2	230	OTH	density	06/24/74	YES		
A7883	299-W23-9			2	230	GG	scint	02/23/76	NO	SUBMITTED	
A7883	299-W23-9			2	180	N	neutron	02/18/77	YES		
C4890	C4890			2	224	None	N/A	N/A	N/A	N/A	N/A
C4891	C4891			2	150	None	N/A	N/A	N/A	N/A	N/A