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Revision 0

BC Cribs and Trenches Excavation-Based Treatability Test - Phase 1 Report

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

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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Richland, Washington

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EXECUTIVE SUMMARY

Phase 1 of the excavation-based treatability test for the BC Cribs and Trenches Area waste sites (DOE/RL-2007-15, *Excavation-Based Treatability Test Plan for the BC Cribs and Trenches Area Waste Sites*[1]) was performed to assess the nature and extent of the near-surface contamination associated with the 216-B-26 Trench, estimate inventories of cesium-137 and strontium-90, and provide a preliminary update of the worker dose estimate for excavation/transportation/disposal of the near-surface contamination. Sixty-three shallow (approximately 7.6 m [25 ft] deep) direct-push technology holes were installed in the footprint and to the side of the trench to ascertain the extent of lateral contamination spread. Fifty-five of the boreholes were logged geophysically to estimate the cesium-137 concentration vs. depth. Eight of these boreholes were selected for soil sampling, leading to the installation of eight new boreholes adjacent those that were sampled. Twenty-four soil samples were collected from those boreholes at depths ranging from 2.4 to 5.2 m (8 to 17 ft).

A highly-contaminated region was found approximately 3.3 to 3.6 m (11 to 12 ft) deep that corresponds to the bottom of the trench during its period of operation. Thickness of this region is approximately 0.3 m (1 ft) with peak cesium-137 concentrations exceeding 1E+06 pCi/g. Cs-137 concentration varied considerably along the length of the trench with a maximum of ~2.9E+06 pCi/g observed near the west end of the center section of the trench. Estimated volume of soil contaminated with greater than 750 pCi/g Cs-137 (less than 4.6 m [15 ft] below ground surface) is 1,481 m^3. Contaminant distribution varied greatly among the three sections of the trench that are separated by berms. Cesium-137 inventories derived from logging data for the western, middle, and eastern sections of the trench are estimated at 28 Ci, 267 Ci, and 374 Ci, respectively, for a total inventory of 669 Ci. When sampling data is considered, the Cs-137 inventory is estimated at 569 Ci. Strontium-90 inventory based on sampling data is between 389 and 498 Ci. These values are in good agreement with RPP-26744, *Hanford Soil Inventory*

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[1] DOE/RL-2007-15, 2007, *Excavation-Based Treatability Test Plan for the BC Cribs and Trenches Area Waste Sites*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Model, Rev. 1,[2] inventories of 585 Ci and 488 Ci, respectively, for cesium-137 and strontium-90. The cesium-137 inventory is approximately half of the DOE/RL-2004-66, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites*,[3] prediction, which was based on limited logging and sampling data. With the reduced inventory and thinner layer of high contamination, worker dose for excavation/transportation/disposal activity is estimated at approximately half of the previously predicted dose.

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[2] RPP-26744, 2005, *Hanford Soil Inventory Model, Rev. 1*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

[3] DOE/RL-2004-66, 2005, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

CONTENTS

1.0 INTRODUCTION 1-1
- 1.1 BACKGROUND 1-1
- 1.2 PROJECT SCOPE 1-2

2.0 FIELD SAMPLING AND ANALYSIS 2-1
- 2.1 PHASE 1 CHARACTERIZATION SAMPLING DESIGN 2-1
- 2.2 SAMPLING HOLE INSTALLATION 2-2
- 2.3 GAMMA LOGGING 2-2
- 2.4 SOIL SAMPLING 2-4
- 2.5 SAMPLING LOCATIONS 2-4
  - 2.5.1 Initial Logging Boreholes 2-4
  - 2.5.2 Determination of the Lateral Extent of Contamination 2-7
  - 2.5.3 Laboratory Analysis of Soil Samples 2-8

3.0 RESULTS AND EVALUATION 3-1
- 3.1 NATURE AND EXTENT OF NEAR-SURFACE CONTAMINATION 3-1
  - 3.1.1 Logging Data 3-1
  - 3.1.2 Soil Sampling Data 3-5
- 3.2 INVENTORY 3-9
  - 3.2.1 Inventory Estimate Based on Logging Data 3-9
  - 3.2.2 Inventory Based on Sample Analysis 3-17
  - 3.2.3 Using the Cesium-137 Inventory Estimates to Generate an Overall Strontium-90 Inventory Estimate 3-19
  - 3.2.4 Comparison of inventory estimates 3-25
- 3.3 CORRELATION BETWEEN LOGGING AND SAMPLING DATA 3-25
- 3.4 WORKER DOSE ESTIMATE 3-28
- 3.5 ESTIMATED VOLUME OF SOIL EXCEEDING 750 pCi/g CESIUM-137 3-29

4.0 CONCLUSIONS 4-1

5.0 REFERENCES 5-1

APPENDICES

A BOREHOLE LOGGING DATA FOR THE 216-B-26 TRENCH ..... A-i

B DESCRIPTION OF BOREHOLE DATA USING MONTE CARLO N-PARTICLE CODE ..... B-i

FIGURES

Figure 1-1. Locations of the 200 West and 200 East Areas and the BC Cribs and Trenches Area Waste Sites on the Hanford Site. 1-4

Figure 1-2. Distribution, Layout, and Structure Type of the BC Cribs and Trenches Area Waste Sites. 1-5

Figure 1-3. Features of the BC Cribs and Trenches Area Waste Sites. 1-6

Figure 1-4. Construction of the BC Trenches in 1956. 1-7

Figure 2-1. Installation of Sampling Borehole. 2-3

Figure 2-2. Soil Sampling Tip. 2-4

Figure 2-3. Random and Adaptive Cluster Sampling Designs for the 216-B-26 Trench. 2-5

Figure 2-4. First Two Sample Node Lines and the Randomly Selected Nodes for Locating Boreholes in the Eastern Third of the 216-B-26 Trench. 2-5

Figure 3-1. Borehole Locations in the 216-B-26 Trench. 3-2

Figure 3-2. Soil Concentration with Depth Profiles at Borehole C5894. 3-4

Figure 3-3. Soil Concentration with Depth Profiles at Borehole C5875. 3-4

Figure 3-4. Soil Concentration with Depth Profiles at Borehole C5884. 3-5

Figure 3-5. Contaminated Layer Depth Estimated for the 216-B-26 Trench. 3-6

Figure 3-6. Estimated Depth of the Main Layer Across the 216-B-26 Trench. 3-7

Figure 3-7. Depth Integrals along the 216-B-26 Trench Using Density 1.9 kg/L. 3-10

Figure 3-8. Depth Integrals across the 216-B-26 Trench Using Density 1.9 kg/L. 3-11

Figure 3-9. Modified Depth Integrals across the 216-B-26 Trench. 3-13

Figure 3-10. Middle Third Gamma Log and Laboratory Sample Results at C5918. 3-23

Figure 3-11. Eastern Third Gamma Log and Laboratory Sample Results at C5921. 3-23

Figure 3-12. Eastern Third Gamma Log and Laboratory Sample Results at C5922. 3-24

Figure 3-13. Plot of Sr-90 and Cs-137 Soil Concentrations from the Laboratory Samples. 3-27

Figure 3-14. Plot of Cs-137 Soil Concentrations from Gamma Log and Laboratory Samples. 3-28

TABLES

Table 1-1. Summary of Remedial Investigation/Feasibility Study Work Plan Information for the 216-B-26 Trench Waste Site 1-8

Table 2-1. Data-Collection Design. 2-1

Table 2-2. Borehole Locations in the 216-B-26 Trench. 2-6

Table 2-3. Soil Sampling Locations and Depths. 2-8

Table 2-4. Duplicate Relative Percent Difference. 2-8

Table 3-1. Sample Results. 3-8

Table 3-2. Inventory Calculation for the Western Third of the 216-B-26 Trench. 3-14

Table 3-3. Inventory Calculation for the Middle Third of the 216-B-26 Trench. 3-15

Table 3-4. Inventory Calculation for the Eastern Third of the 216-B-26 Trench. 3-16

Table 3-5. Comparing Total Cs-137 Inventory Estimates for the 216-B-26 Trench. 3-17

Table 3-6. Calculated Inventory Based on Sample Data - Depth Averaged and Limited to Trench Footprint. 3-17

Table 3-7. Cesium-137 Sample Result Distribution by Depth. 3-18

Table 3-8. Strontium-90 Sample Result Distribution by Depth. 3-18

Table 3-9. Cesium-137 Inventory Distribution. 3-19

Table 3-10. Borehole Log and Laboratory Sample Results for the Western Third of the 216-B-26 Trench. 3-20

Table 3-11. Borehole Log and Laboratory Sample Results for the Middle Third of the 216-B-26 Trench. 3-21

Table 3-12. Borehole Log and Laboratory Sample Results for the Eastern Third of the 216-B-26 Trench. 3-22

Table 3-13. Estimate for the Sr-90 Inventory in the 216-B-26 Trench Based on Sr-90/Cs-137 Ratio. 3-24

Table 3-14. Inventory Comparison Between Borehole Logging and Sample Analysis. 3-25

Table 3-15. Numbers Used in Linear Correlations. 3-26

Table 3-16. Contaminated Soil Calculation for the Western Third of the 216-B-26 Trench. 3-30

Table 3-17. Contaminated Soil Calculation for the Middle Third of the 216-B-26 Trench. 3-31

Table 3-18. Contaminated Soil Calculation for the Eastern Third of the 216-B-26 Trench. 3-32

TERMS

bgs	below ground surface
DPT	direct-push technology
ERDF	Environmental Restoration Disposal Facility
ETF	Effluent Treatment Facility
FFTF	Fast Flux Test Facility
HHR	hydraulic hammer rig
MCNP	Monte Carlo N-Particle code
NA	not applicable
RPD	relative percent difference
SAP	sampling and analysis plan
SIM	RPP-26744, *Hanford Soil Inventory Model, Rev. 1*

METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If you know	*Multiply by*	*To get*	*If you know*	*Multiply by*	*To get*
Length			**Length**		
inches	25.40	millimeters	millimeters	0.0394	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles (statute)	1.609	kilometers	kilometers	0.621	miles (statute)
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.0929	sq. meters	sq. meters	10.764	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.591	sq. kilometers	sq. kilometers	0.386	sq. miles
acres	0.405	hectares	hectares	2.471	acres
Mass (weight)			**Mass (weight)**		
ounces (avoir)	28.349	grams	grams	0.0353	ounces (avoir)
pounds	0.454	kilograms	kilograms	2.205	pounds (avoir)
tons (short)	0.907	ton (metric)	ton (metric)	1.102	tons (short)
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.034	ounces (U.S., liquid)
tablespoons	15	milliliters	liters	2.113	pints
ounces (U.S., liquid)	29.573	milliliters	liters	1.057	quarts (U.S., liquid)
cups	0.24	liters	liters	0.264	gallons (U.S., liquid)
pints	0.473	liters	cubic meters	35.315	cubic feet
quarts (U.S., liquid)	0.946	liters	cubic meters	1.308	cubic yards
gallons (U.S., liquid)	3.785	liters			
cubic feet	0.0283	cubic meters			
cubic yards	0.764	cubic meters			
Temperature			**Temperature**		
Fahrenheit	(°F-32)*5/9	Centigrade	Centigrade	(°C*9/5)+32	Fahrenheit
Radioactivity			**Radioactivity**		
picocurie	37	millibecquerel	millibecquerel	0.027	picocurie

1.0 INTRODUCTION

This characterization report presents the results of soil sampling and borehole gamma logging in and around the 216-B-26 Trench. The field sampling was performed in accordance with DOE/RL-2007-14, *Sampling and Analysis Plan for Phase 1 of the BC Cribs and Trenches Area Waste Sites Excavation-Based Treatability Test*. This work was done as part of overall treatability test activities described in DOE/RL-2007-15, *Excavation-Based Treatability Test Plan for the BC Cribs and Trenches Area Waste Sites*. The BC Cribs and Trenches treatability test is required to support appropriate remedy selection for the near-surface contamination at the BC Cribs and Trenches Area waste sites described in DOE/RL-2004-66, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites*.

The data and interpretation in this report include determination of the nature and extent of Cs-137 and Sr-90 near-surface contamination, estimates of Cs-137 and Sr-90 inventory, estimates of the amount of material requiring removal, and validation of the existing excavation worker dose associated with the 216-B-26 Trench treatability test soil removal activities.

1.1 BACKGROUND

The BC Cribs and Trenches are located on the southern edge of the 200 East Area of the Hanford Site (Figure 1-1). Figures 1-2 and 1-3 provide details about the cribs and trenches. Figure 1-4 is an aerial photograph of the trenches during construction. The 216-B-26 Trench is one of the trenches that received scavenged waste from the uranium recovery process and the ferrocyanide processes at the 221/224-U Plant. The 216-B-26 Trench is the third trench from the bottom of Figure 1-4. The trench is roughly 152 m (500 ft) in length and 3.0 m (10 ft) in width at the floor, with ascending side berms. Summary information for the 216-B-26 Trench waste site is provided in Table 1-1. It is known that the length of the trench was divided into thirds by berms, which are visible in Figure 1-4. Therefore, it is possible that different amounts of waste were received in each third of the trench. No piping was left in place after closure of the 216-B-26 Trench. Because temporary piping was used for all of the BC trenches and was moved from one trench to another, it is not known where the exact discharge points in this trench were. A treatability test is required to improve the understanding of the nature and extent of the near-surface contamination and to aid in further defining the feasibility of this remedial-action alternative. DOE/RL-2007-15 describes several phases of work. The data collected during the treatability test will be used to ensure that the conceptual site model and conclusions of the focused feasibility study are accurate concerning removal, treatment, and disposal of contaminated soil at the BC Cribs and Trenches Area waste sites.

Results of the Previous 216-B-26 Trench Characterization

During earlier characterization activities conducted at the 216-B-26 Trench (DOE/RL-2004-66), six shallow (12.2 m [40 ft] deep) holes spaced evenly along the length of the trench were installed to locate the region of the trench with the highest contamination. High-resolution spectral gamma data were collected (i.e., logged) in these holes. Some portions of the trench appeared to be heavily contaminated, while other portions were slightly contaminated. One of the shallow boreholes showed no contamination, suggesting that it intersected one of the two

berms that divide the trench into thirds. Cesium-137 concentrations exceeding 1,000,000 pCi/g were observed in two boreholes. Two other logs exhibited maximum Cs-137 concentrations of 20,000 and 60,000 pCi/g, and a fifth borehole log indicated a maximum Cs-137 concentration of approximately 400,000 pCi/g. The complete results associated with this characterization are described in DOE/RL-2004-66, Appendix F.

Numerous soil samples were collected from a borehole drilled to groundwater at the place where the gamma-radiation logging showed the highest contamination. The borehole also was logged to assess residual gamma-emitting radionuclides and moisture concentrations.

The conclusions of the previous sampling include the following.

- High concentrations of Cs-137 and Sr-90 are present near the surface, approximately 3.7 to 4.6 m (12 to 15 ft) deep.
- Based on the shallow-borehole characterization, the spatial distribution of Cs-137 and Sr-90 is uneven.
- These Cs-137 and Sr-90 contaminants are relatively immobile and are confined to near-surface soil.
- Elevated concentrations of Tc-99 and nitrate were found in fine-grained soil layers 27.4 to 30.5 m (90 to 130 ft) deep.
- Essentially, no contamination was observed below 46 m (151 ft).

1.2 PROJECT SCOPE

The treatability study being conducted at the BC Cribs and Trenches Area waste sites will improve the revised feasibility study conclusions concerning remedy selection and enhance their validity. The treatability study consists of four phases.

- During Phase 1, data concerning the nature and extent of contamination in the 216-B-26 Trench will be collected. This trench is one of the 152 m (500 ft) trenches that received scavenged waste from the uranium recovery process and the ferrocyanide processes at the 221/224-U Plant. The collected data will be used to estimate the amount of material requiring removal (i.e., define the lateral and vertical extent of the excavations) and to calculate a predicted dose that remediation workers will receive in Phase 2 of the treatability study. Data from this phase of the study also will be used to correlate the total curie content of Cs-137 in the trench as determined by measurements and estimates of contaminated volume with the total curie content predicted by RPP-26744, *Hanford Soil Inventory Model, Rev. 1* (SIM).

  This report focuses on Phase 1.

- Phase 2 of the treatability study will involve excavation to test the process of removal, treatment, and disposal of the contaminated soil contained in the 216-B-26 Trench. Phase 2 of the study will begin with excavation of one third of the total trench length.

Data will be collected to ensure Environmental Restoration Disposal Facility waste acceptance criteria and transportation requirements are met and to validate dose estimates calculated using the data collected during Phase 1. The process of soil treatment (down-blending) to meet the dose rate requirements of transportation and Environmental Restoration Disposal Facility waste acceptance criteria will be refined during this phase of the study. Phase 2 of the treatability study will include the option to excavate more than one third of the trench if required.

- Phase 3 of the treatability study will involve characterization, similar to that conducted in Phase 1, followed by excavation to remove, treat, and dispose of soil and residual structures in the 216-B-14 Crib. Data will be collected for the same purposes as Phases 1 and 2. In addition, the potential for subsidence of the remnant crib structure will be evaluated.

- Phase 4 of the study will involve characterization followed by excavation, treatment, and disposal of contaminated soil in the 216-B-53A Trenches, formerly in the 200-LW-1 operable unit. Data collected in Phase 4 also will support initial site and waste characterization and validate dose measurements with predicted dose.

When sufficient data are collected to complete the assessment of the feasibility of the partial removal, treatment, and disposal remedial alternative, the treatability study may be concluded without completion and/or initiation of one or more of the listed phases.

Phase 1 Characterization Objectives

Data were collected in the 216-B-26 Trench concerning the nature and extent of Cs-137 and Sr-90 contamination. The data collected during Phase 1 will be used for the following.

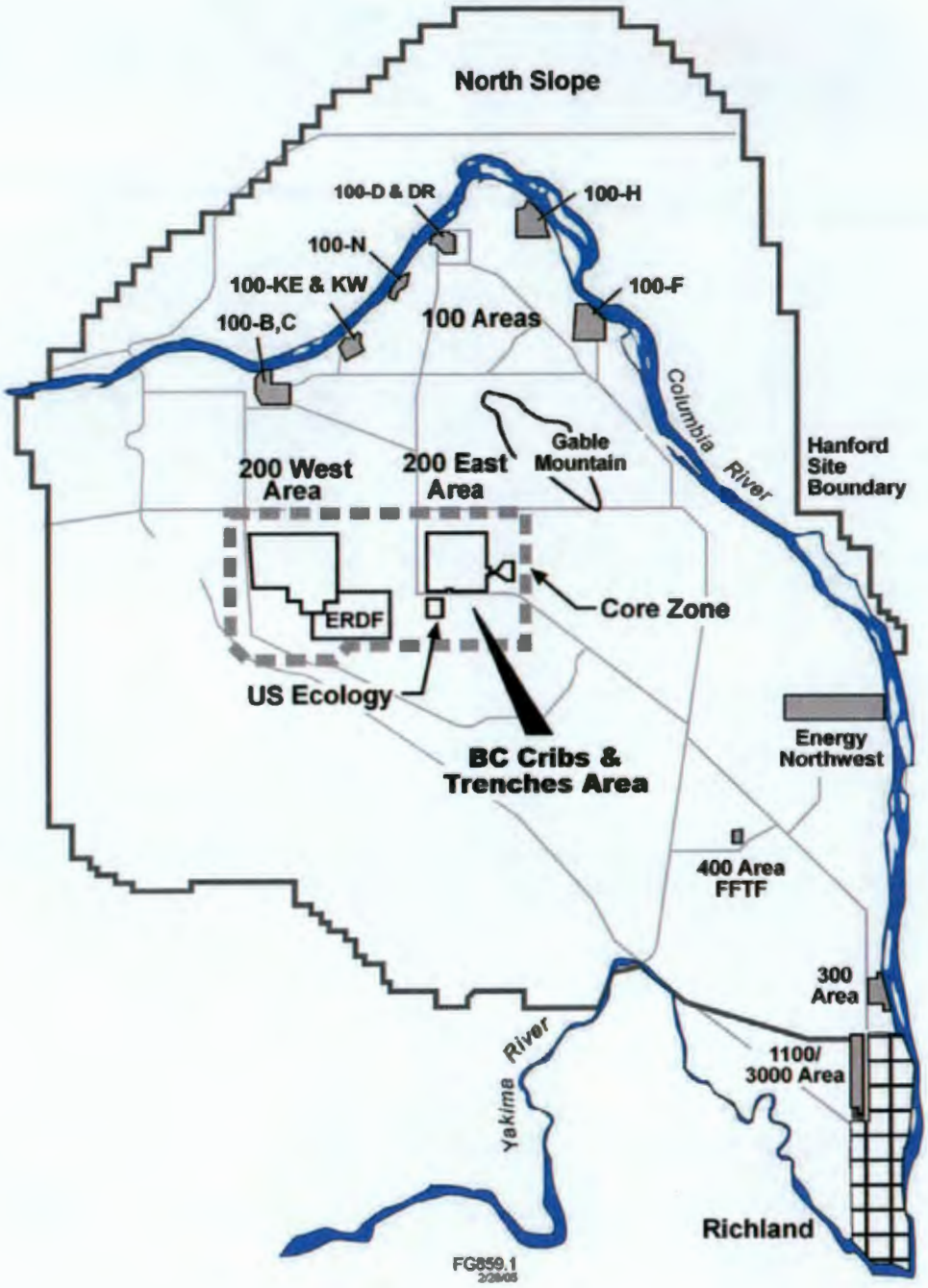
- Improve understanding of the nature and extent of the Cs-137 and Sr-90 contamination within the top 7.6 m (25 ft) of the 216-B-26 Trench footprint.

- Calculate the Cs-137 and Sr-90 inventories within the contaminated volume to determine the estimated amount of material requiring removal.

- Validate predicted Phase 2 remediation worker dose calculations.

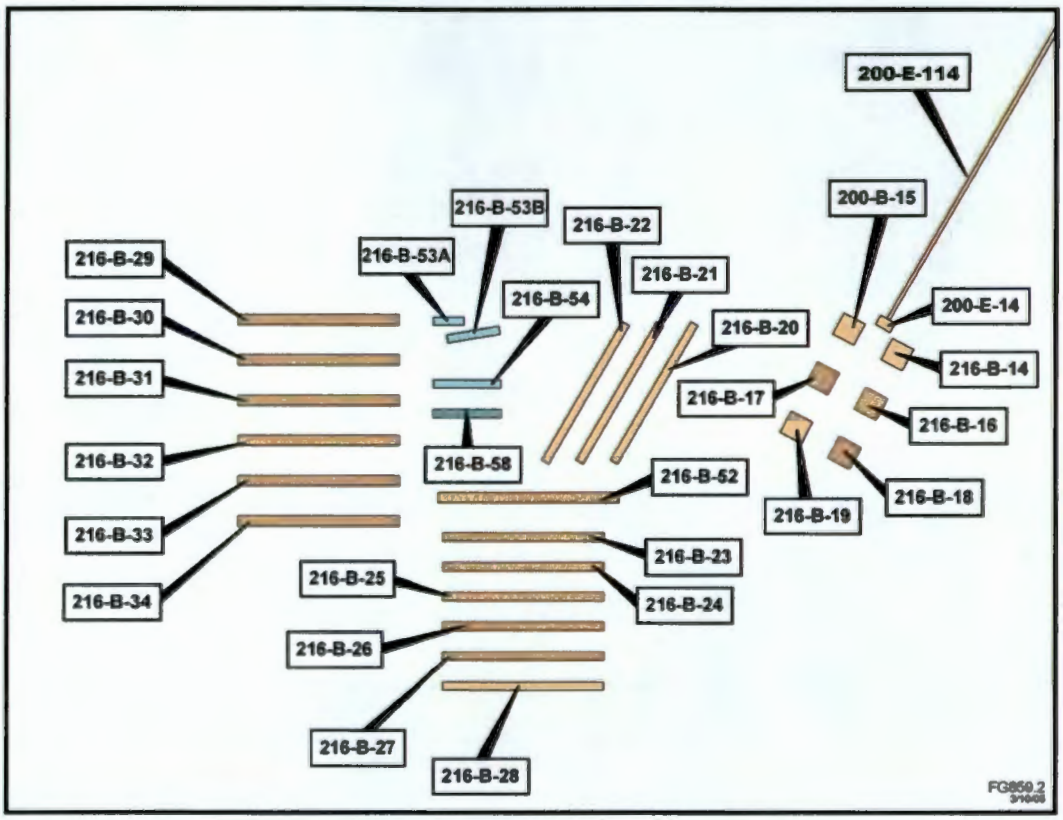
- Correlate the total curie contents of Cs-137 and Sr-90, determined by gamma logging and sampling, with the values predicted by the SIM.

Figure 1-1. Locations of the 200 West and 200 East Areas and the BC Cribs and Trenches Area Waste Sites on the Hanford Site.



ERDF = Environmental Restoration Disposal Facility.
FFTF = Fast Flux Test Facility.

Figure 1-2. Distribution, Layout, and Structure Type of the BC Cribs and Trenches Area Waste Sites.



Waste Site	Structure Type	Waste Site	Structure Type	Waste Site	Structure Type
216-B-14	Crib	216-B-24	Trench	216-B-34	Trench
216-B-15	Crib	216-B-25	Trench	216-B-52	Trench
216-B-16	Crib	216-B-26*	Trench	216-B-53A	Trench
216-B-17	Crib	216-B-27	Trench	216-B-53B	Trench
216-B-18	Crib	216-B-28	Trench	216-B-54	Trench
216-B-19	Crib	216-B-29	Trench	216-B-58	Trench
216-B-20	Trench	216-B-30	Trench	200-E-14	Siphon Tank
216-B-21	Trench	216-B-31	Trench	200-E-114	Pipeline
216-B-22	Trench	216-B-32	Trench		
216-B-23	Trench	216-B-33	Trench		

*The 216-B-26 Trench is the focus of Phase 1 for the treatability test.

Figure 1-3. Features of the BC Cribs and Trenches Area Waste Sites.

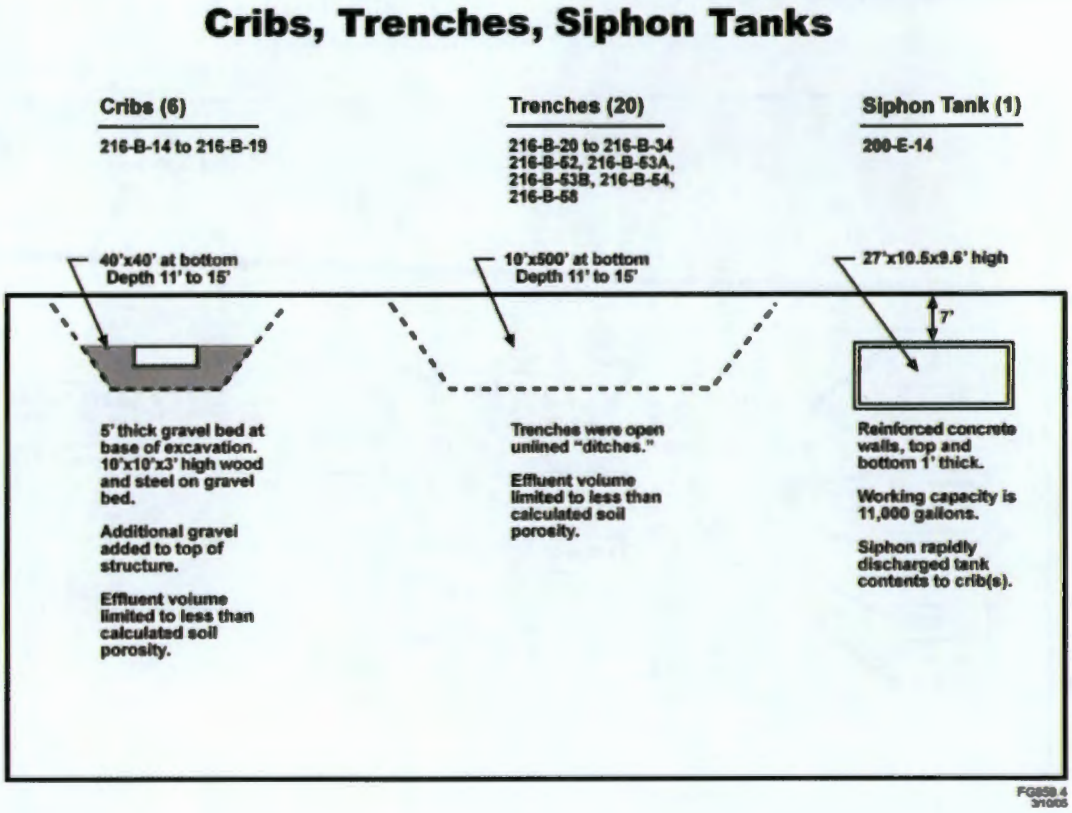


Figure 1-4. Construction of the BC Trenches in 1956.

Source: DOE/RL-2004-66, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites.*
The 216-B-26 Trench is the third trench up from the bottom of the figure.

Table 1-1. Summary of Remedial Investigation/Feasibility Study Work Plan Information for the 216-B-26 Trench Waste Site.

Site Code	Site Name	Location	Dates of Operation	Contaminant/Volume Released	Depth	General Description
216-B-26	216-B-26 Trench 216-BC-13 Trench	Directly south of the 216-B-25 Trench, south of the 200 East Area (across Route 4S)	December 1956 to February 1957	5,880,000 L with Fe, CN, Sr, PO_4, tributyl phosphate Surface radiological contamination	5.5 m (18 ft); 2.4 m (8 ft) is overburden	One of the unlined BC Trenches that was backfilled upon reaching capacity. The BC Trenches were stabilized together in 1969 with sand and gravel; in 1981 and1982 with clean soil. Concrete AC-540 markers outline the group of trenches. Uranium recovery process/scavenged liquid-extraction waste was routed to the trenches from the B, BX, and BY Tank Farms. Surface contamination spread through rabbits and vegetation has resulted in ongoing stabilization activities. Groundwater well 299-E13-12 monitors the site.

Source: DOE/RL-2000-38, *200-TW-1 Scavenged Waste Group Operable Unit and 200-TW-2 Tank Waste Group Operable Unit RI/FS Work Plan.*

2.0 FIELD SAMPLING AND ANALYSIS

More than five dozen direct push technology (DPT) holes were installed within the 216-B-26 Trench footprint and its periphery to improve understanding of the nature and extent of near-surface contamination, with focus on Cs-137 and Sr-90. DOE/RL-2007-14 defined 24 initial sampling locations within the trench footprint. These randomly selected locations were within each section of the trench to provide data along the trench length and across its width. Based on gamma logging data from those boreholes, additional boreholes were installed to locate the two berms that divided the trench into thirds and establish the extent of lateral contamination spread. Finally, soil sampling was performed at selected locations to further establish correlation between the logging data and Cs-137 concentrations, and to characterize the Sr-90 profile within the trench.

2.1 PHASE 1 CHARACTERIZATION SAMPLING DESIGN

The 216-B-26 Trench characterization design includes the following three elements:

1. Characterization of soil beneath the floor of the trench using borehole logging
2. A series of step-out boreholes to define the lateral extent of contamination around the trench and within the internal bermed areas separating the three sections of the trench
3. A series of 24 soil samples taken from eight boreholes within the footprint of the trench floor.

Table 2-1 summarizes the data-collection design for Phase 1 of the treatability test from the sampling and analysis plan (SAP).

Table 2-1. Data-Collection Design.

Element	Approach	Type of Data	Rationale
1	Systematic random statistical-sampling design to determine mean concentration of the contaminant of concern	Logging	Determining the mean concentration in a given volume of soil (by understanding the vertical and lateral extent of contamination) and knowing the density of the soil allows calculation of the total inventory of the contaminant of concern present in a trench. This measured inventory then can be compared to inventory predicted by the soil-inventory model, and a determination of the soil-inventory model's accuracy can be made. Also, the random sampling design provides information on the variability of contaminants to support dose estimates based on these measurements.
2	Adaptive-cluster sampling design	Logging	The need to determine the lateral extent will be met using a form of biased sampling aimed at identifying the maximum lateral extent of contamination. The vertical extent of contamination also will be determined in the sampling design selected for addressing decision rule #2. Therefore, a separate sampling design to resolve vertical extent is not required.
3	Random systematic sampling design	Soil Samples	Actual soil samples will be collected from 8 randomly-selected boreholes advanced adjacent to logging boreholes from element 1. The soil samples will be submitted for laboratory analysis of Cs-137 and Sr-90. These laboratory numbers will be used to develop correlations between laboratory and logging data for Cs-137 and between laboratory Cs-137 and Sr-90 data to independently calculate inventory or support inventory calculations based on the borehole logging data.

For the purposes of this data-collection activity, contamination was defined within the data quality objective process (DOE/RL-2007-15, Appendix A) as soil contaminated with Cs-137 at greater than 750 pCi/g and/or Sr-90 at greater than 90,000 pCi/g. These values represent maximum concentrations that are protective of human health 150 years from the present under an industrial scenario. This action level only applies to the soil down to 4.6 m (15 ft) below ground surface (bgs), because that depth is the point of compliance for human-health exposure.

Another use for the data from measurements conducted on soil samples from boreholes installed to estimate the mean concentration of contaminants in the trench will be to determine if a correlation between Cs-137 and Sr-90 activity can be established as a function of depth.

2.2 SAMPLING HOLE INSTALLATION

Each borehole, whether for logging or soil sampling, was installed using a hydraulic hammer rig (HHR) called Eurodrill,[1] provided and operated by Energy Solutions, Inc., down to an ultimate depth of approximately 7.6 m (25 ft). The borehole diameter was approximately 6.67 cm (2.63 in.). Borehole installation was relatively rapid using this technology, with up to five boreholes installed per day in the sandy soil. The HHR was mounted on a backhoe tractor, which facilitated movement between drilling locations. Because the HHR/backhoe combination was lightweight compared to some drilling equipment, it was not necessary to construct a penetration-resistant pad prior to installing the boreholes. Figure 2-1 shows installation of one of the boreholes.

Soil samples were collected using an inner string of casing that was inserted after the outer string was driven to the sampling depth. After removing the dummy point from the outer string, the inner string, including sample collection tool, was inserted to collect the soil sample.

2.3 GAMMA LOGGING

Installed boreholes were logged by Stoller, Inc.,[2] using a 2GHA-1000 Triple Gamma[3] logging tool to measure total gamma activity. Three detectors were mounted on the tool: one sodium iodide detector and two Geiger-Müller detectors. Data was collected at 15 cm (6-in.) intervals in an attempt to sharply define regions of high activity within the trench.

The 2GHA-1000 Triple Gamma tool is a component of the slim hole logging system. This logging system uses commercially available logging equipment capable of logging in a 4.44 cm (1.75-in.) diameter borehole. High-resolution spectral gamma logs commonly run in Hanford Site boreholes are constrained to a borehole diameter of at least 10 cm (4 in.) because of the detector size and the accompanying dewar flask needed to store liquid nitrogen for detector cooling. It is not possible to collect high-resolution gamma energy spectra in a small-diameter borehole so an alternative approach was developed to estimate Cs-137 concentrations.

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[1] Eurodrill is owned by Colcrete Eurodrill, Derbyshire, United Kingdom.

[2] Stoller is a trademark of S. M. Stoller Corporation, Lafayette, Colorado.

[3] 2GHA-1000 Triple Gamma tool is a product of Mount Sopris Instrument Co., Inc, Golden Colorado.

High-resolution spectral gamma log data collected in boreholes drilled in 2003 indicated that gamma activity was dominated by Cs-137, with concentrations (specific activities) as high as several million picocuries per gram. No other gamma-emitting radionuclides were detected. Strontium-90 is a known contaminant, and bremsstrahlung from high-energy betas caused by Sr-90 decay interacting with the steel casing will result in additional gamma activity. However, anomalous gamma activity observed in the cased holes can be attributed primarily to Cs-137.

Figure 2-1. Installation of Sampling Borehole.

Count rates are recorded for each of the 3 detectors in the 2GHA-1000 Triple Gamma tool, corrected for dead time (assuming a non-paralyzable response model), and converted to gamma dose rate at the axis (in units of millirem per hour), using individual detector dead times and response factors determined from calibration activities. Corrections also were made for background, so that only anomalous gamma activity was converted to gamma dose rate.

Model studies were conducted to estimate the gamma dose rate associated with a uniformly distributed concentration of Cs-137, taking into account the effects of borehole diameter and attenuation through sediments and the borehole casing. This factor was used to convert the estimated gamma dose rate to units of equivalent Cs-137.

2.4 SOIL SAMPLING

Soil samples were collected from selected locations using the HHR. A separate borehole was installed adjacent to the logging borehole to avoid contaminating the logging tool by residual soil from the sampling activity. Sampling tooling was designed to limit the quantity of soil to approximately 30 g to avoid potential for worker exposure to larger quantities of high-activity soil. Soil samples were removed from the sampling tip within a glovebox and transferred to bottles for transport to the analytical laboratory. Figure 2-2 is a photograph of the soil sampling tip.

Figure 2-2. Soil Sampling Tip.

2.5 SAMPLING LOCATIONS

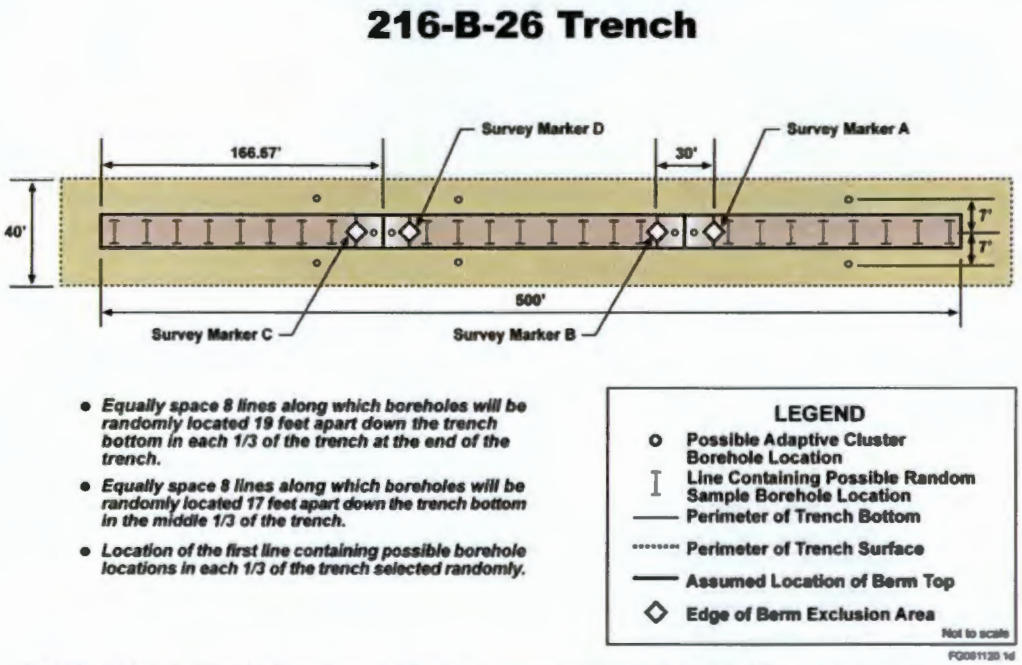
Phase 1 activities involve the characterization of the 216-B-26 Trench using boreholes in accordance with the three-element design described in Section 2.1.

2.5.1 Initial Logging Boreholes

Eight boreholes were drilled through the bottom of each third of the trench, in accordance with the design described in DOE/RL-2007-14. Systematic random sampling ensures large portions of the trench floor would not go unrepresented by the collected samples. To ensure any variability associated with lateral distance from the center-line of the trench bottom was characterized adequately by the sample, a random component also was added to the sampling design in these directions. The boreholes were located every 5.8 m (19 ft) along the centerline of the eastern and western third of the trench, and every 5.2 m (17 ft) along the middle third. At each centerline location a random perpendicular offset was applied. Figure 2-3 shows the general borehole locations in the trench. Figure 2-4 shows two node lines and the potential

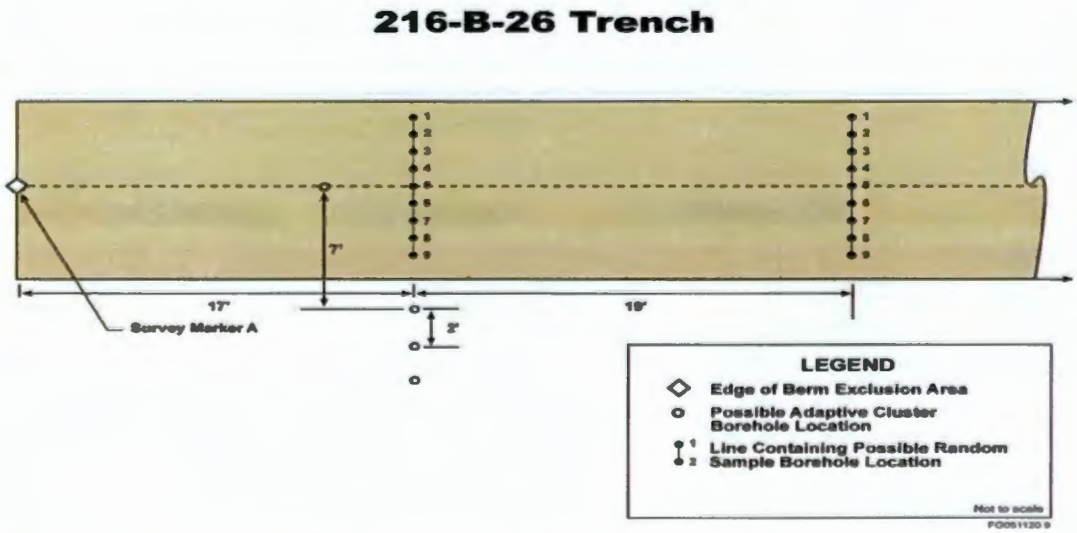
places of the nine random, perpendicular, offset locations. Table 2-2 shows the actual sampling locations, including the random offsets from the center-line.

Figure 2-3. Random and Adaptive Cluster Sampling Designs for the 216-B-26 Trench.



Source: DOE/RL-2007-14, *Sampling and Analysis Plan for Phase 1 of the BC Cribs and Trenches Area Waste Sites Excavation-Based Treatability Test.*

Figure 2-4. First Two Sample Node Lines and the Randomly Selected Nodes for Locating Boreholes in the Eastern Third of the 216-B-26 Trench.



Source: DOE/RL-2007-14, *Sampling and Analysis Plan for Phase 1 of the BC Cribs and Trenches Area Waste Sites Excavation-Based Treatability Test.*

Table 2-2. Borehole Locations in the 216-B-26 Trench.

Borehole Locations in the Eastern Third of the 216-B-26 Trench			
Distance of Node Line from Survey Marker A (ft)	**Sample Node**	**Distance From Center-Line Node 5 (ft)**	**Direction From Center-Line Node 5**
17.0	8	3	South
36.0	4	1	North
55.0	2	3	North
74.0	2	3	North
93.0	9	4	South
112	5	0	NA
131	7	2	South
150	8	3	South
Borehole Locations in the Center Third of the 216-B-26 Trench			
Distance of Node Line from Survey Marker B (ft)	**Sample Node**	**Distance From Center-Line Node 5 (ft)**	**Direction From Center-Line Node 5**
15.0	3	2	North
32.0	5	0	NA
49.0	3	2	North
66.0	6	1	South
83.0	5	0	NA
100	2	3	North
117	2	3	North
134	6	1	South
Borehole Locations in the Western Third of the 216-B-26 Trench			
Distance of Node Line from Survey Marker C (ft)	**Sample Node**	**Distance From Center-Line Node 5 (ft)**	**Direction From Center-Line Node 5**
13.0	8	3	South
32.0	6	1	South
51.0	4	1	North
70.0	8	3	South
89.0	7	2	South
108	2	3	North
127	5	0	NA
146	1	4	North

NA = not applicable.

2.5.2 Determination of the Lateral Extent of Contamination

When the data from all boreholes drilled through the bottom of the trench were reviewed, the location exhibiting the highest activity was used for a set of adaptive cluster sampling boreholes for each third of the trench. The first two adaptive cluster sampling boreholes were drilled approximately 2.1 m (7.0 ft) away from and perpendicular to the center-line of the trench. If Cs-137 activity was detected by the sodium iodide gamma ray logging instrument at a concentration greater than 750 pCi/g in the 0 to 4.6 m (0 to 15 ft) bgs interval, another borehole would be drilled along the same line as the high concentration, adaptive cluster sampling borehole, approximately 1.2 m (4 ft) further from the center-line of the trench. This protocol was adjusted based on data review (i.e., the distance from the previous borehole to the next borehole was adjusted subjectively depending on the activity observed). Drilling continued until an adaptive cluster sampling borehole was drilled where Cs-137 was not detected at greater than approximately 750 pCi/g in the 0 to 4.6 m (0 to15 ft) bgs interval. Only gamma ray logging measurements were collected in each of the adaptive cluster boreholes. No soil samples were collected from the adaptive cluster boreholes.

In addition to the lateral extent boreholes, the same approach was used to define the locations of the two internal trench berms that separate the three trench sections. Additional adaptive cluster sampling boreholes were drilled along the centerline of the trench away from the centerline closest to the berm in each end section of the trench. These boreholes were drilled in the direction toward the berm until the Cs-137 concentration did not exceed approximately 750 pCi/g in the 0 to 4.6 m (0 to 15 ft) bgs interval.

Soil Sampling

Soil sampling was performed at eight locations, with three samples collected from each location. One of the locations was associated with the trench footprint DPT hole near the eastern end of the trench from which the highest Cs-137 activity was observed (based on initial logging results). The other seven locations were selected from the other twenty-three DPT holes explicitly located in the SAP using a random number generator available on the internet. Random sampling depths were selected for the locations. Based on the initial logging data, the original 0.15 m (0.5-ft) -sampling depth was selected from the first 0.76 m (2.5-ft) interval exhibiting significant activity. Then, two additional samples were collected at 0.76 m (2.5-ft) intervals in the same DPT hole. This combination of random depth selection and sampling holes selection spanned a broad range of expected Cs-137 activities and depths. Twenty-four soil samples were collected from the eight DPT holes. In each case, the sampling holes were located approximately 0.40 m (1.3 ft) toward the axis of the trench from its associated logging hole. Table 2-3 lists the sampling locations and depths.

Table 2-3. Soil Sampling Locations and Depths.

Logging Hole	Sampling Hole	Initial Sampling Interval	1st Sample Depth	2nd Sample Depth	3rd Sample Depth
C5893	C5915	11.0 - 13.0	11.0	13.5	16.0
C5894	C5916	10.5 - 12.5	12.0	14.5	17.0
C5898	C5917	10.5 - 12.5	11.5	14.0	16.5
C5899	C5918	10.0 - 12.0	12.0	14.5	17.0
C5876	C5919	9.5 - 11.5	11.5	14.0	16.5
C5881	C5920	9.0 - 11.0	10.0	12.5	15.0
C5885	C5921	9.0 - 11.0	9.5	12.0	14.5
C5886	C5922	NA - focused sampling	8.1	9.6	11.6

NA = not applicable.

2.5.3 Laboratory Analysis of Soil Samples

The soil samples were described, packaged, and labeled in accordance with the SAP. The samples were submitted to Eberline Analytical Services of Richmond, California for gross alpha, gross beta, total strontium, and gamma emitters (including Cs-137). Twenty-four soil samples collected between October 3 and October 22, 2007 were received at the Eberline laboratory on November 15, 2007. Eberline selected two samples to duplicate. The laboratory also reported method blanks and laboratory control samples.

Laboratory Sample Quality

A review of the laboratory results concluded that the performance of the laboratory is within expectations and the data meet most of the SAP requirements. Minor deviations from the SAP requirements generally are caused by very high contamination levels. These deviations do not impact the usefulness of the data for the identified project purposes.

The laboratory reported no problems in the soil sample determinations for total strontium and gamma-emitters analysis. The method blank showed no evidence of any contaminant; all parameters were below minimum detectable activity. Laboratory control samples were recovered between 99 and 119 percent, which is within both laboratory statistical and administrative recovery limits.

For the parameters of interest, duplicate relative percent differences met SAP requirements and demonstrate that the analytical system was reproducible (Table 2-4).

Table 2-4. Duplicate Relative Percent Difference.

Parameter	Duplicate 1 RPD (low level)	Duplicate 2 RPD (high level)
Gross alpha	18	6
Gross beta	3	0
Total Strontium	2	3
Cs-137	17	0

RPD = relative percent difference.

Strontium tracer yield was 80 to 100, which is well within the 30 to 105 internal laboratory administrative limits.

All Cs-137 minimum detectable activity exceeded the reported method detection limit of 0.1 pCi/g. Generally this was caused by the high Cs-137 content that reduced counting times or the presence of other gamma emitters elevated the minimum detection level for Cs-137. This did not impact the value of the data for project use.

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3.0 RESULTS AND EVALUATION

Gamma logging and sampling data were collected from sixty-three boreholes to refine the nature and extent of near-surface contamination in the 216-B-26 Trench. The data also refine the inventory and worker dose estimates previously reported in the BC Cribs and Trenches focused feasibility study (DOE/RL-2004-66).

3.1 NATURE AND EXTENT OF NEAR-SURFACE CONTAMINATION

The locations of the boreholes are shown in Figure 3-1. The trench is about 152 m (500 ft) long and 3.0 m (10 ft) wide. In this figure, the trench is broken into three sections approximately equal in length (52 m [170 ft]). The grid is 1 by 1 m (3 by 3 ft).

Each section has largely uncontaminated soil at both ends. Generally, the boreholes are in a line running west to east along the centerline of the trench. Each section has a set of boreholes installed across the axis of the trench to ascertain the extent of the contamination to the south and north.

3.1.1 Logging Data

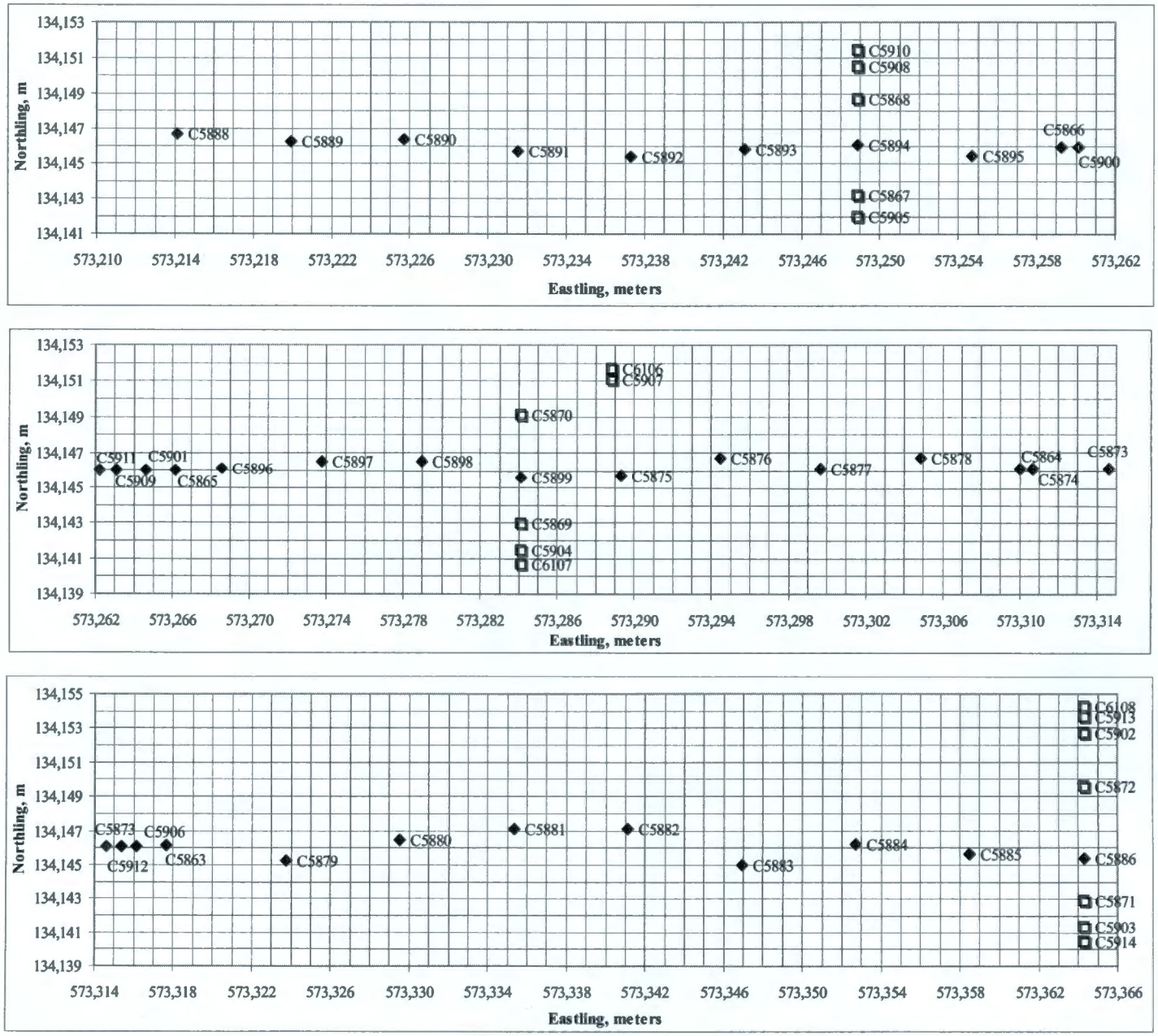
Borehole logging was accomplished using the 2GHA-1000 Triple Gamma logging tool described in Section 2.3. The probe was lowered to the bottom of the borehole, and then was raised at a continuous rate of 0.7 m/min (2 ft/min). The counting time was 15 seconds, with data acquired at 0.15 m (0.5 ft) intervals. All of the detectors experienced significant dead-time losses while passing through the highly contaminated soil layer.

The instrument with the largest depth integral (either the sodium iodide scintillation crystal or the ZP1320 Geiger-Müller counter) was used in later calculations of waste thickness and total inventory. Data from Geiger-Müller ZP1200 was ignored because of dead time issues. Equivalent Cs-137 activity was estimated assuming that all gamma activity above background was caused by a uniform distribution of Cs-137 in the surrounding soil. The estimated soil Cs-137 concentrations for each borehole are listed in Appendix A, along with the detector used, the borehole coordinates, the peak soil Cs-137 concentration measured, the depth integral, and the average waste thickness.

The depth integrals are shown in two sets of units. The simple form has units of inch times picocuries per gram and is computed using the trapezoid rule. Because all the readings are 15 cm (6 in.) apart and the soil concentration at the top and bottom of the borehole is zero, the depth integral can be calculated as 15 cm (6 in.) times the sum of the soil concentration readings.

The depth integral also can be expressed in units of microcuries per meter squared through multiplication of an assumed soil density. For the depth integrals shown in Appendix A, a soil density of 1.9 kg/L was used. The assumed soil density was based on parallels with the Monte Carlo N-Particle (MCNP) runs of Appendix B. The selection of soil density is described in more detail in Appendix A.

Figure 3-1. Borehole Locations in the 216-B-26 Trench.



Example logs for three boreholes are shown in Figures 3-2, 3-3, and 3-4. A linear scale is used to illustrate that most of the contaminated soil is found in a thin layer 3.4 to 3.7 m (11 to 12 ft) bgs.

Figure 3-2 shows the soil concentration in Borehole C5894 which is located near the centerline of the western third of the 216-B-26 Trench. Figure 3-3 shows the soil concentration in Borehole C5875 located near the center of the middle third. Figure 3-4 shows the soil concentration in Borehole C5884 located along the centerline in the eastern third. In all three figures the solid lines show borehole log data while dashed lines show a step function approximation of the highly contaminated layer. Note that the soil concentration used for the step function is the peak value measured.

The depth profiles illustrate the rapid change in the soil concentration above the highly contaminated layer. When the observed soil concentration changes by almost an order of magnitude in the space of 15 cm (6 in.), the lower reading is likely because of penetrating gamma radiation from the hot layer. In other words, the lower reading is probably larger than it should be. In some boreholes the observed soil concentration above and below the peak value decrease rapidly, as illustrated in Figures 3-2 and 3-3. For these boreholes the hot layer is relatively thin and the step function approximation is reasonable. In other boreholes the soil concentration decreases more gradually with depth, as illustrated by Figure 3-4. In these boreholes much of the contamination has migrated to greater depths. The step function also adequately represents this distribution.

An estimate of the average contaminated soil layer thickness was derived from the depth integral and the peak Cs-137 concentration. In effect, the layer is uniformly contaminated at the peak soil concentration. It likely errs on the thin side by ignoring the real-world variation in Cs-137 activity concentration that exists in the contaminated soil layer. For example, the first inch of contaminated soil probably has a higher concentration than all lower depths because of Cs-137 adsorption by the soil.

The thickness of the highly contaminated layer is the depth integral (units of inch times picocuries per gram) divided by the peak soil concentration (units of picocuries per gram). Numeric values for these two numbers are listed in Appendix A for each borehole. This thickness is corrected to account for the detector underestimating the soil concentration near thin layers. This correction is derived in Appendix B using a MCNP simulation. For an average layer thickness of 30.5 cm (12 in.), the correction reduces the thickness to 21.6 cm (8.5 in.), a 30 percent reduction. Most thicknesses are greater than 30.5 cm (12 in.) and have smaller corrections.

In Figures 3-2, 3-3, and 3-4 the step function approximation uses the thickness of the highly contaminated layer. The upper boundary of the highly contaminated layer is constrained to be no more than 15 cm (6 in.) above the depth observed for the peak concentration. This constraint comes from the spacing between measured soil concentrations in the borehole log. With a 15 cm (6-in.) mesh, the highest reading could miss the actual peak by as much as 7.6 cm (3 in.). Because the gammas being detected are mostly energetic photons from the decay of Cs-137, this is a small effect.

Figure 3-2. Soil Concentration with Depth Profiles at Borehole C5894.

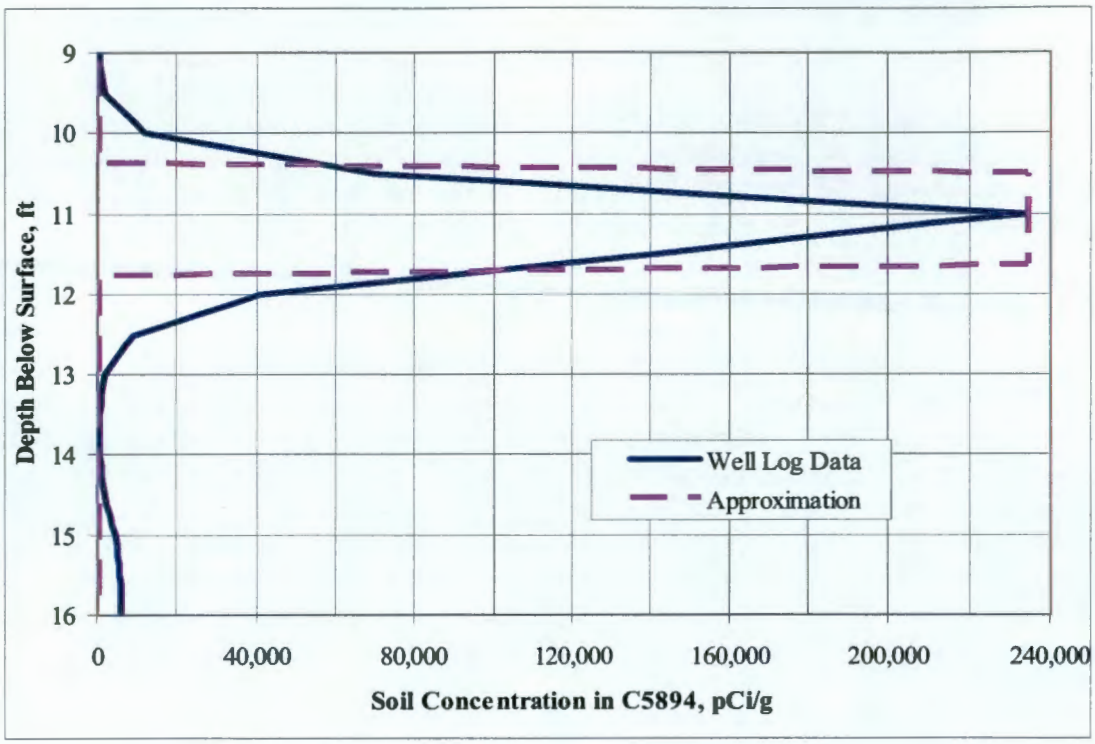


Figure 3-3. Soil Concentration with Depth Profiles at Borehole C5875.

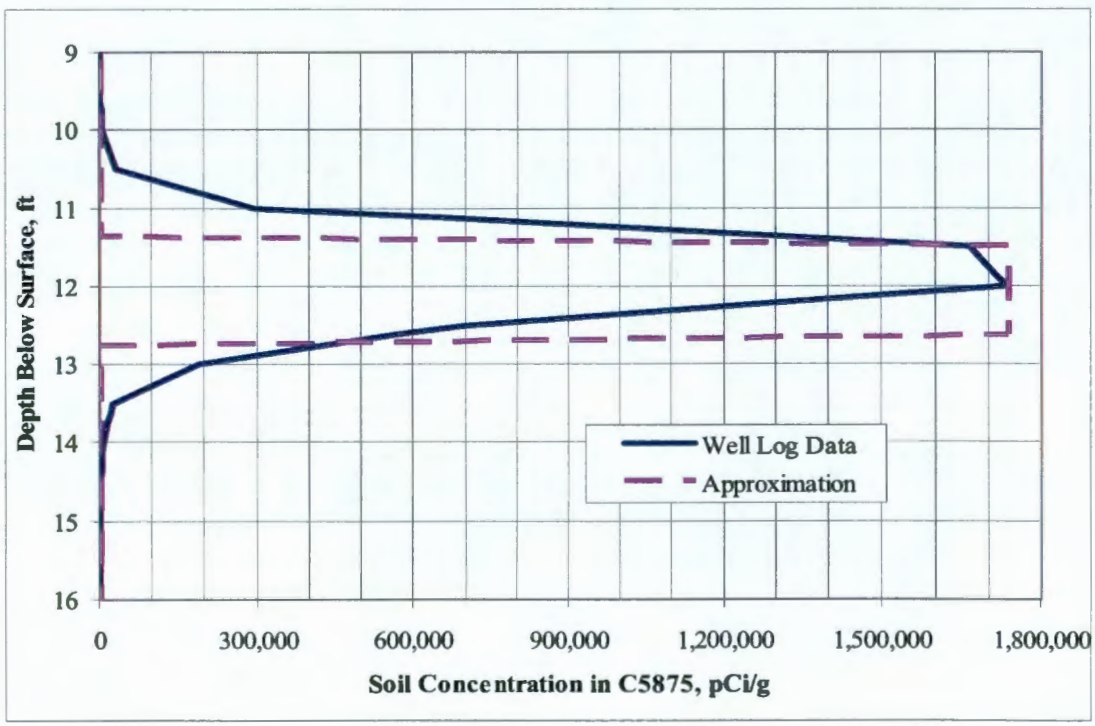


Figure 3-4. Soil Concentration with Depth Profiles at Borehole C5884.

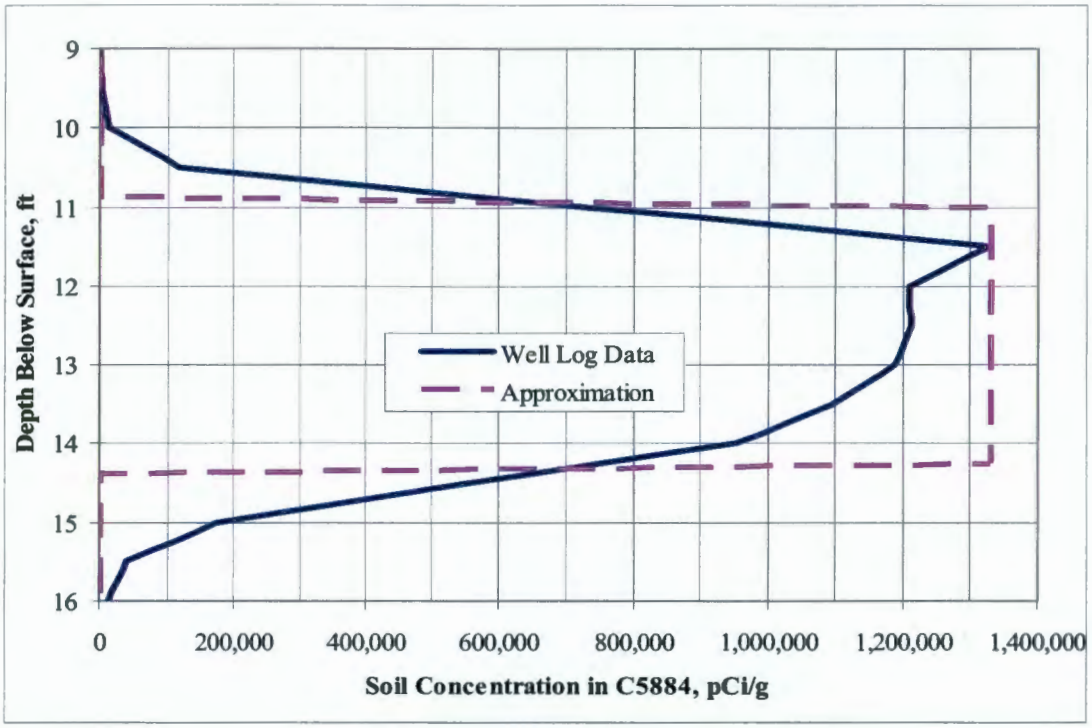


Figure 3-5 shows the upper and lower boundaries of the hot layer for the entire length of the 216-B-26 Trench. The solid line in Figure 3-5 is at the depth of the peak concentration in the borehole log. The majority of the contaminated soil is confined to a layer roughly 0.3 m (1 ft) thick over most of the trench. The only exception is the eastern third of the 216-B-26 Trench, for which the highly contaminated layer thicknesses ranges from 0.6 to 0.9 m (2 to 3 ft) over a distance of several meters.

Figure 3-6 shows the upper and lower boundaries of the main contaminant layer in a line across the trench (south to north). The soil concentrations are small on the sides of the trench and large in the middle. In the eastern section of the trench at Borehole C5886 the highest soil concentration also is found at the smallest depth. Note that Figures 3-5 and 3-6 exaggerate the vertical scale. Each square in the coordinate grid is 1 m (3 ft) wide but only 0.3 m (1 ft) tall.

3.1.2 Soil Sampling Data

Soil samples were collected from seven randomly selected locations and one focused location (associated with the highest contamination level observed by logging). Each of the sampling boreholes was located approximately 0.4 m (1.3 ft) from its associated logging. Soil sample results are shown in Table 3-1.

Figure 3-5. Contaminated Layer Depth Estimated for the 216-B-26 Trench.

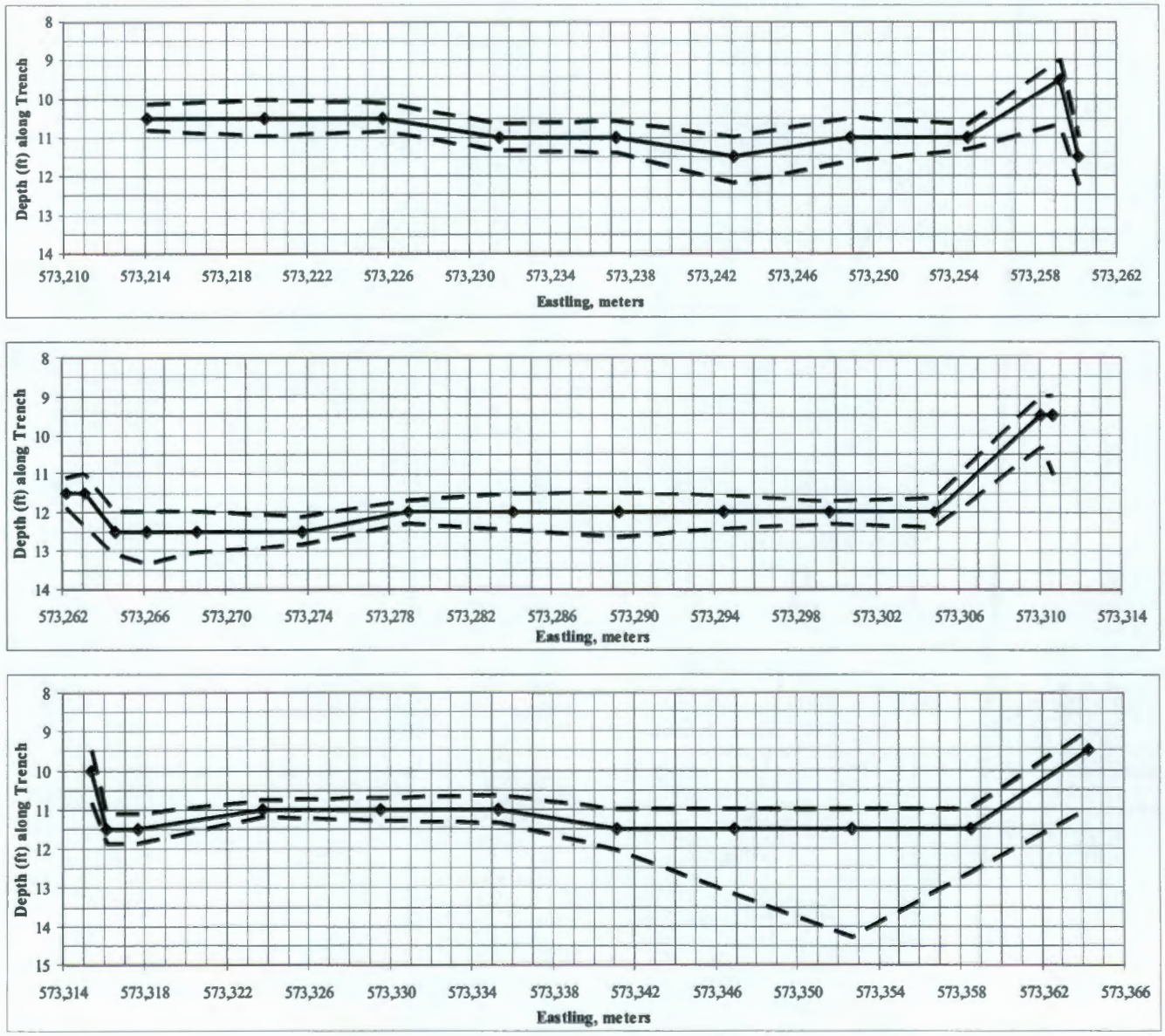


Figure 3-6. Estimated Depth of the Main Layer Across the 216-B-26 Trench.

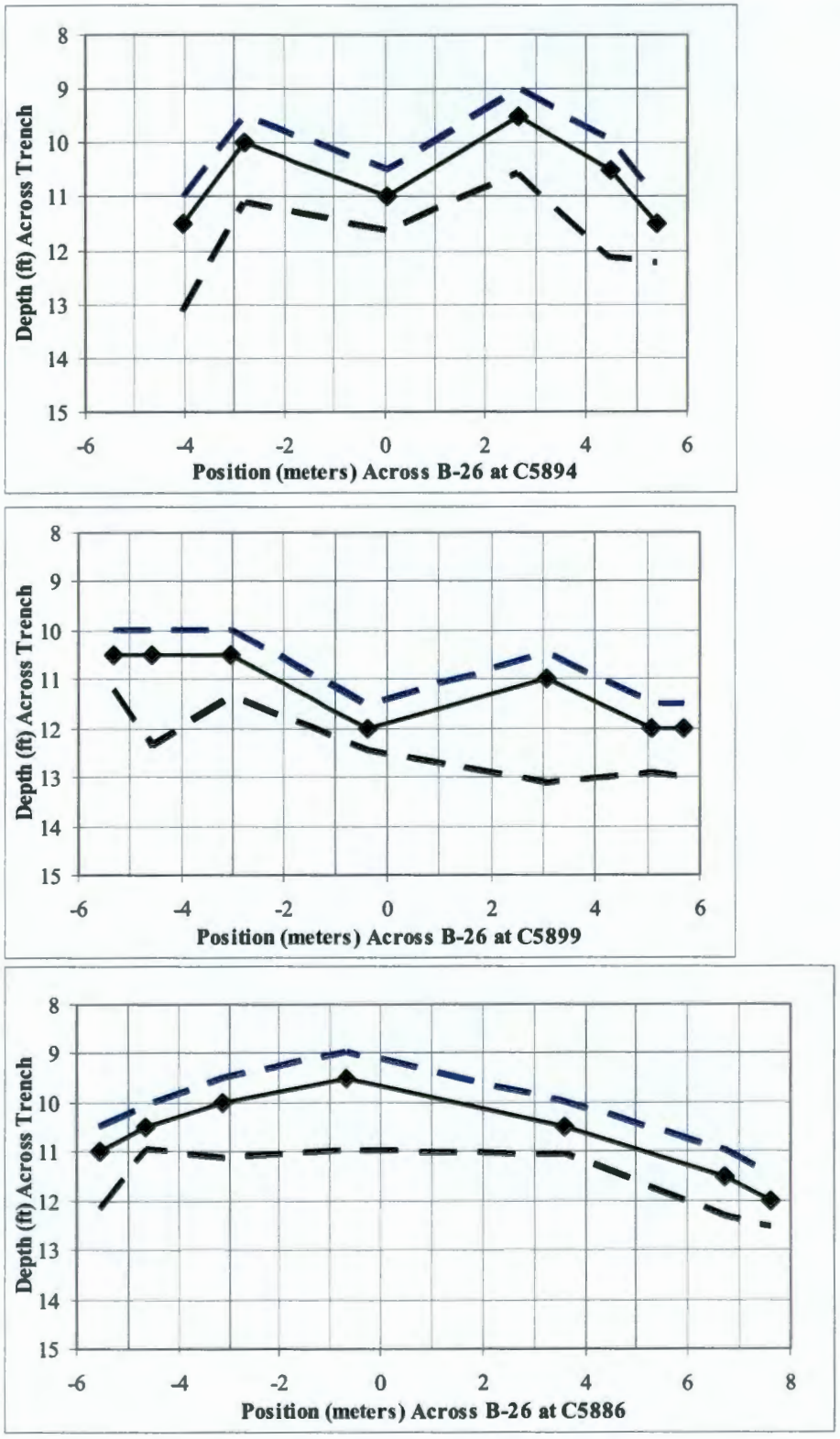


Table 3-1. Sample Results.

Sampling Hole	Logging Hole	Depth (ft)	Cs-137 (pCi/g)	Sr-90 (pCi/g)
C5915	C5893	11.0-11.5	U	9.83
		13.5-14.0	27,600	77,300.0
		16.0-16.5	194	445.0
C5916	C5894	12.0-12.5	0.43	219.0
		14.5-15.0	336	3,050.0
		17.0-17.5	3.60	21.4
C5917	C5898	11.5-12.0	0.567	45.0
		14.0-14.5	5,740	3,970
		16.5-17.0	6,020	1,580
C5918	C5899	12.0-12.5	2,210,000	1,410,000
		14.5-15.0	9,100	6,760
		17.0-17.5	2,950	823
C5919	C5876	11.5-12.0	U	2,710
		14.0-14.5	2,630	6,960
		16.5-17.0	198	512
C5920	C5881	10.0-10.5	U	40.1
		12.5-13.0	22.6	91,200
		15.0-15.5	172	2,310
C5921	C5885	9.6-10.0	U	10.2
		11.9-12.4	1,420,000	561,000
		14.5-15.0	483	6,630
C5922	C5886	8.0-8.5	0.793	13.3
		9.6-10.1	2,620	35,700
		11.5-12.0	692,000	646,000

U = not detected.

3.2 INVENTORY

Inventory estimates were based on the logging data and sampling data. Correlation between the two approaches was made. Also, inventory values were compared with past estimates.

3.2.1 Inventory Estimate Based on Logging Data

The total inventory of Cs-137 in the 216-B-26 Trench is estimated from the vertical depth integral (units of microcuries per meter squared) and the horizontal extent of the soil contamination (units of meters squared). This approach has the following characteristics.

- The depth integral is largely independent of the contaminated layer thickness, as shown in Appendix B. Thus, no corrections for layer thickness are needed.
- The estimated inventory is proportional to the soil density. Because the assumed soil density was selected from a range of possible values, the total inventory also should be considered as a range of possible values.
- The horizontal extent of the contaminated soil layer is important. The total inventory is proportional to the total horizontal area.

The 216-B-26 Trench was divided into three sections of approximately equal length. Each third of the trench has boreholes along the length and one transverse row of boreholes. The activity integration begins with the transverse boreholes to define the contaminant distribution in the north-south direction. It is assumed that the activity per unit length varies along the length of the trench, but is proportional to the depth integral along the midline of the trench. The proportionality constant is termed the effective width of the contamination because it has units of length (meters). The effective width parameter is calculated for the transverse row of boreholes in each section. It is applied to each borehole in the east-west direction to arrive at the total inventory in that section of the trench. Each third of the trench has a different value for effective width.

The depth integral and peak soil concentration at each borehole along the 216-B-26 Trench is shown in Figure 3-7. The location of the transverse row of boreholes is indicated in Figure 3-7 with a circle around the depth integral. The depth integral and peak soil concentration at each of the boreholes in the north-south direction is shown in Figure 3-8. In Figure 3-8 the midline of the trench (134,146 m northling) is at 0 m. Note that the vertical scales differ from graph to graph. Peak Cs-137 concentration in the western third is roughly an order of magnitude less than the other two thirds.

Note that Figure 3-8 does not show the expected outline of the trench, namely, a flat bottom area about 3 m (10 ft) wide. This indicates that the boreholes were not well spaced. There is one borehole near the centerline and the next borehole is in the side wall of the trench. An additional borehole on either side of the mid-line borehole would have better defined the bottom of the trench.

Figure 3-7. Depth Integrals along the 216-B-26 Trench Using Density 1.9 kg/L.

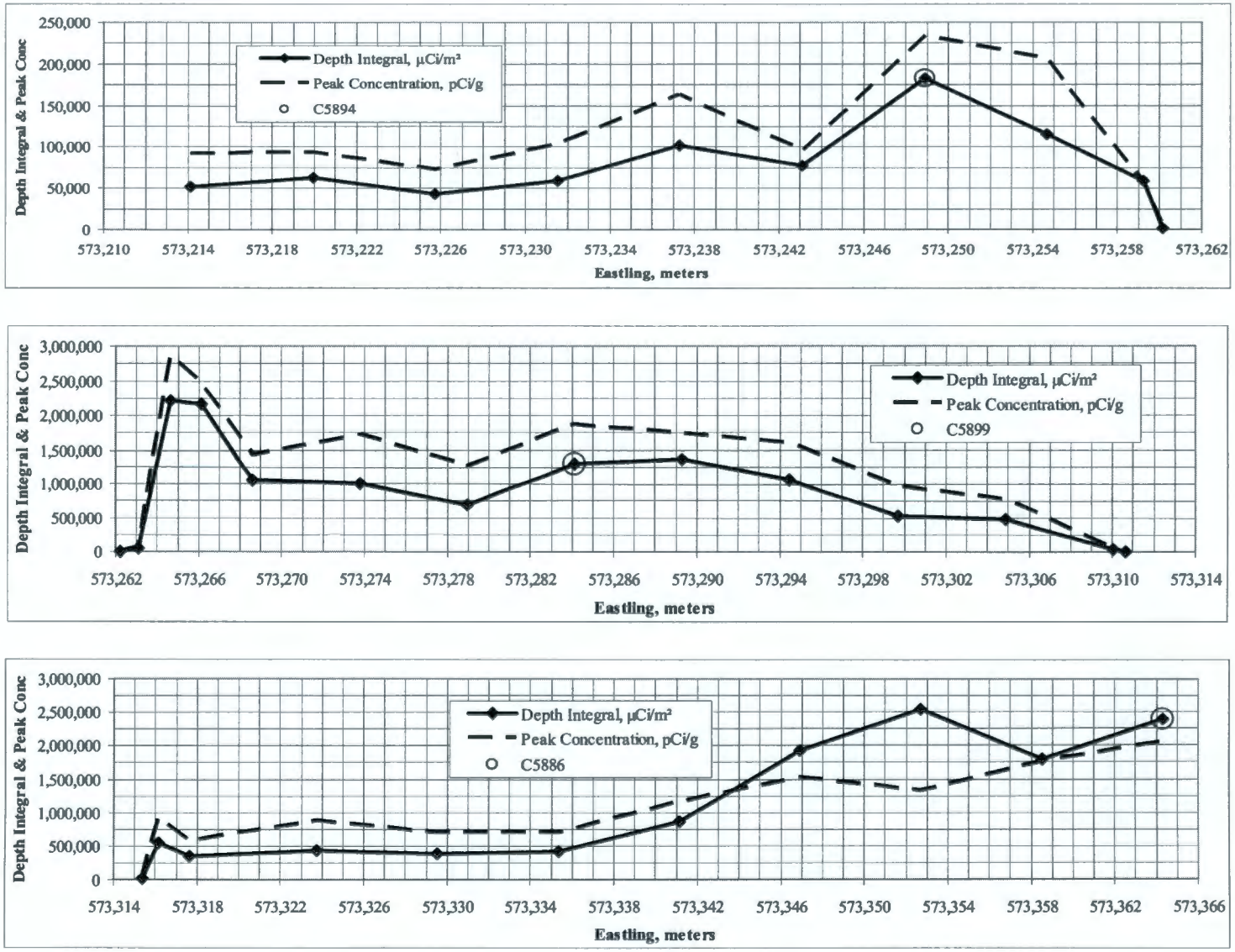
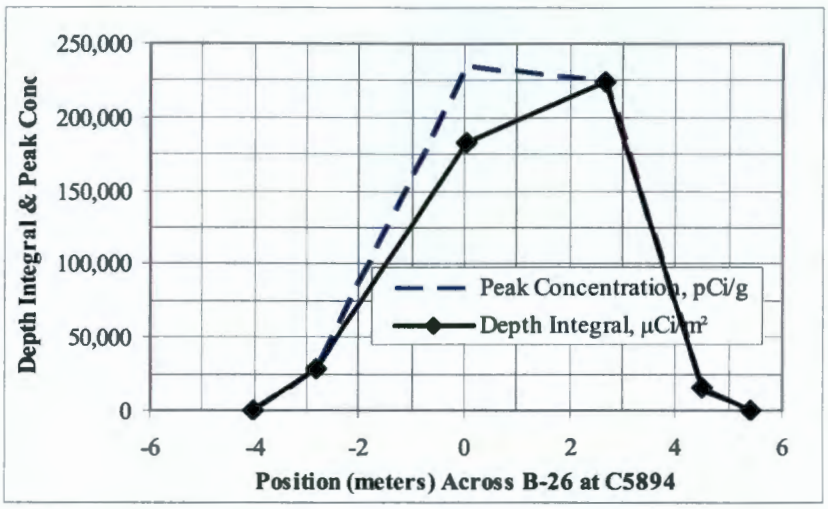
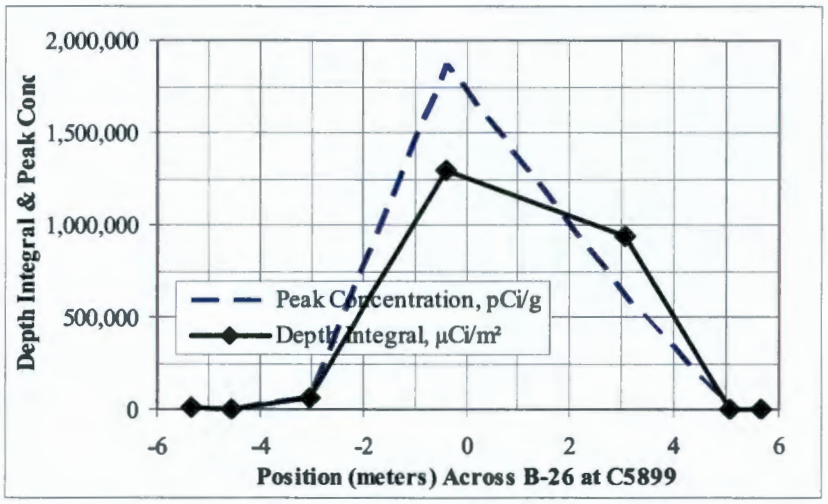
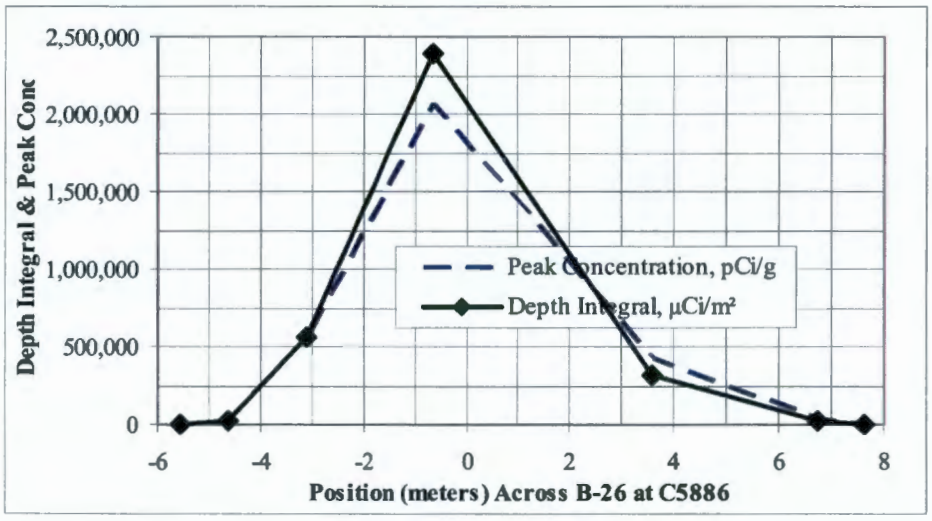


Figure 3-8. Depth Integrals across the 216-B-26 Trench Using Density 1.9 kg/L.







The soil concentration profile shown in Figure 3-8 underestimates the inventory. Because the soil concentration in the bottom of the trench was only measured at one point, the integration across the trench follows a triangular shape rather rising to a peak that is at least 3 m (10 feet) wide. For this reason, the borehole log data was modified to add fictitious boreholes near the sides of the trench. The fictitious boreholes use the same borehole log data as the borehole near the centerline. The midline of the trench is taken to be at northling 134,146 m. Assuming the trench is 3.048 m (10.0 ft) wide, the sides of the trench are at 134,144.48 m and 134,147.52 m. The soil Cs-137 concentrations and fictitious borehole locations are shown in Figure 3-9.

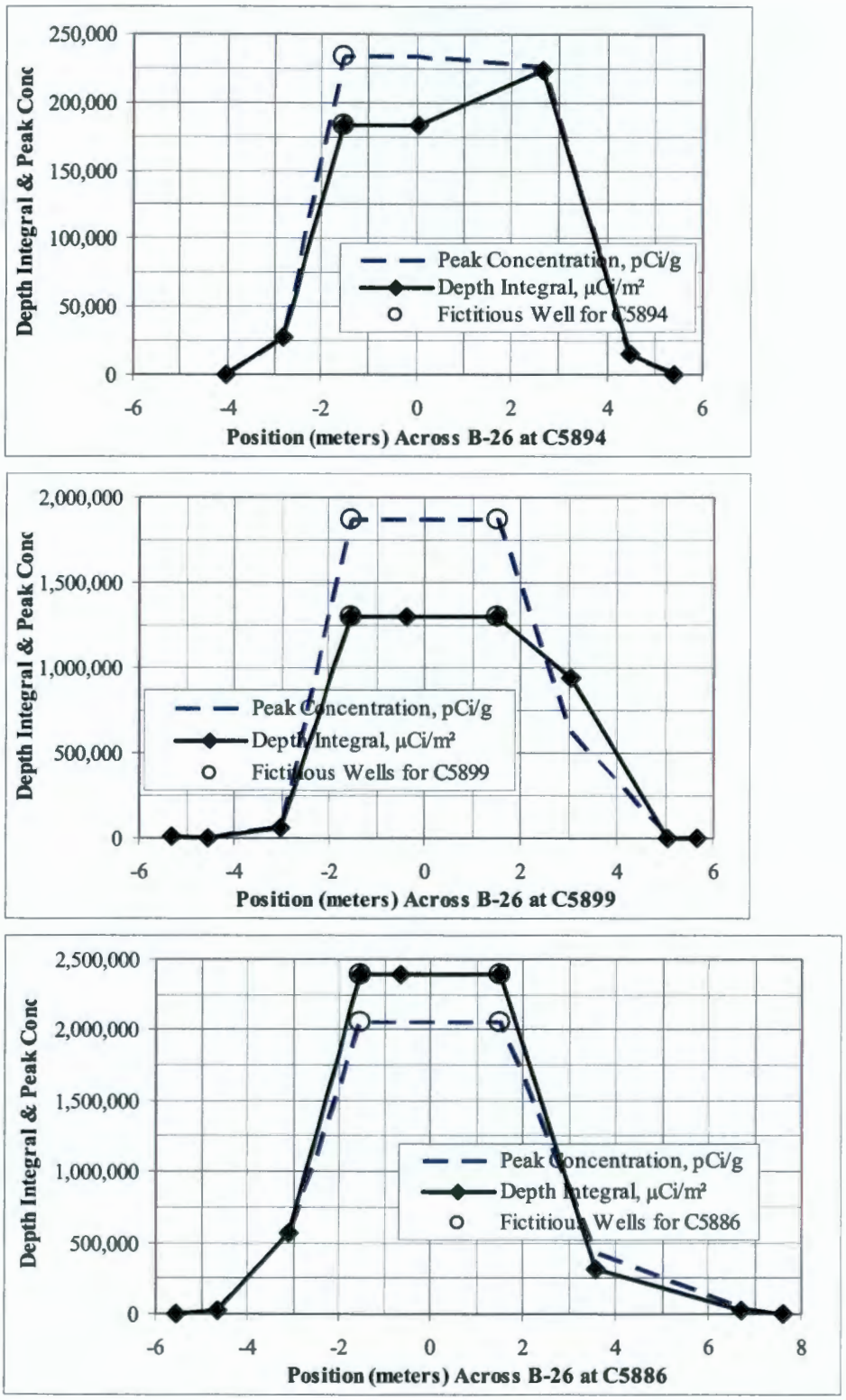
The data shown in Figure 3-9 was used in the estimate of radionuclide inventory. Only one borehole was added to the western section of the trench because of the shape of the peak concentration curve. The middle and eastern thirds received two fictitious boreholes to better define the bottom of the trench.

The calculation of the total inventory in the 216-B-26 Trench is shown in Tables 3-2, 3-3, and 3-4. The fictitious boreholes are indicated with a letter after the borehole number. The total activity of Cs-137 in each section of the 216-B-26 Trench is calculated separately. The depth integrals are listed in Appendix A for each borehole. The next step is to combine boreholes to cover the horizontal footprint of the trench. Because most of the boreholes are along the length of the trench (west to east) near the center, the boreholes along lines running from south to north were used to define the shape of the Cs-137 distribution. The same distribution is assumed to apply to all the boreholes in that third of the trench. The borehole data in the south to north direction defines a parameter termed the effective width for the soil contamination in that section of the trench. The effective width is then applied to the log data along the trench centerline to give the total activity in that section.

Tables 3-2 to 3-4 have two parts. The upper portion shows the transverse (south to north) integration. The lower portion shows the west to east integration. Both parts have the same calculation of total activity along a string of boreholes. The first two columns show the identification numbers of the boreholes used for that segment. The third column shows the space between the two boreholes. Distances marked with asterisks are located at the boundary. They are estimates of the likely horizontal extent of contamination. There is no contamination beyond this boundary. The fourth column shows the average value of the depth integral for the two boreholes. It is half the sum of the depth integrals for the two boreholes shown in the first two columns. The depth integrals are listed in Appendix A.

The last column shows the product of the distance (third column) and the average depth integral (fourth column). It represents the average activity per unit length or width for the space between two boreholes. The sum of the values is shown in the "Totals" row with the units "microcuries per meter". The "Effective Contamination Width" is the total activity per unit length divided by the centerline depth integral. This value is assumed to exist at each borehole along the axis of the trench.

Figure 3-9. Modified Depth Integrals across the 216-B-26 Trench.



The lower portion of Tables 3-2 to 3-4 follows the calculation in the upper portion. The space between boreholes was multiplied by the average value for the depth integral. The inventory in each third of the trench was calculated as the product of the effective contamination width and the west to east total. The sum of these three totals is the Cs-137 inventory estimated for the 216-B-26 Trench (e.g., 28 + 267 + 374 = 669 Ci). The western third of the trench has just 4 percent of the total activity. The majority (56 percent) of the Cs-137 activity is in the eastern third of the trench although the maximum activity was observed in the center section just east of the western berm. Table 3-5 provides comparisons to other estimates.

Table 3-2. Inventory Calculation for the Western Third of the 216-B-26 Trench.

South Borehole	North Borehole	Space Between Boreholes (m)	Average Vertical (μCi/m²) [a]	Transverse Segment (μCi/m) [b]
NA	C5905	2 [c]	109	217
C5905	C5867	1.22	14,155	17,235
C5867	C5894a	1.29	105,643	136,108
C5894a	C5894	1.56	183,192	286,513
C5894	C5868	2.63	203,660	535,140
C5868	C5908	1.83	119,792	219,505
C5908	C5910	0.91	8,033	7,310
C5910	NA	2 [c]	305	609
Totals		NA	NA	1,202,637
Effective Contamination Width: [d] 6.56 m				
West Borehole	**East Borehole**	**Space Between Boreholes (m)**	**Average Vertical (μCi/m²) [a]**	**West to East Segment (μCi/m) [b]**
NA	C5888	6 [c]	51,585	309,508
C5888	C5889	5.79	57,343	332,018
C5889	C5890	5.79	52,991	306,815
C5890	C5891	5.79	50,571	292,804
C5891	C5892	5.79	80,018	463,305
C5892	C5893	5.80	89,385	518,435
C5893	C5894	5.79	130,095	753,247
C5894	C5895	5.79	149,476	865,464
C5895	C5866	4.57	87,469	399,731
C5866	C5900	0.91	30,480	27,737
Totals		NA	NA	4,269,065
Total Cs-137 in Western Third: [e] 28.03 Ci				

[a] The average value of the depth integrals for the two boreholes shown in the first two columns (values for depth integrals are given in Appendix A).
[b] The product of the distance (third column) and the depth integral (fourth column).
[c] Estimated from the likely horizontal extent of contamination.
[d] The sum of the transverse segment values (1,202,637 μCi/m) divided by the centerline depth integral (183,192 μCi/m²).
[e] The product of the Effective Contamination Width (6.56 m) and the West to East Segment Total (4,269,065 μCi/m).
NA = not applicable.

Table 3-3. Inventory Calculation for the Middle Third of the 216-B-26 Trench.

South Borehole	North Borehole	Space Between Boreholes (m)	Average Vertical (µCi/m²) [a]	Transverse Segment (µCi/m) [b]
NA	C6107	2 [c]	3,352	6,705
C6107	C5904	0.76	3,498	2,658
C5904	C5869	1.53	30,567	46,831
C5869	C5899a	1.50	680,598	1,023,563
C5899a	C5899	1.14	1,300,354	1,487,605
C5899	C5899b	1.90	1,300,354	2,475,874
C5899b	C5870	1.55	1,119,511	1,733,095
C5870	C5907	2.00	470,497	940,014
C5907	C6106	0.61	1,328	810
C6106	NA	2 [c]	165	330
Totals		NA	NA	7,717,484
Effective Contamination Width: [d] 5.93 m				
West Borehole	**East Borehole**	**Space Between Boreholes (m)**	**Average Vertical (µCi/m²) [a]**	**West to East Segment (µCi/m) [b]**
C5900	C5911	2.05	993	2,036
C5911	C5909	0.90	28,573	25,715
C5909	C5901	1.53	1,137,572	1,740,485
C5901	C5865	1.52	2,194,986	3,336,378
C5865	C5896	2.44	1,610,386	3,929,342
C5896	C5897	5.18	1,023,556	5,302,021
C5897	C5898	5.18	842,753	4,365,459
C5898	C5899	5.18	993,875	5,148,271
C5899	C5875	5.18	1,329,724	6,887,970
C5875	C5876	5.18	1,209,897	6,267,269
C5876	C5877	5.19	790,179	4,101,029
C5877	C5878	5.18	497,422	2,576,648
C5878	C5864	5.18	253,616	1,313,731
C5864	C5874	0.61	16,143	9,847
C5874	C5873	3.95	121	476
Totals		NA	NA	45,006,678
Total Cs-137 in MiddleThird: [e] 267.11 Ci				

[a] The average value of the depth integrals for the two boreholes shown in the first two columns (values for depth integrals are given in Appendix A).
[b] The product of the distance (third column) and the depth integral (fourth column).
[c] Estimated from the likely horizontal extent of contamination.
[d] The sum of the transverse segment values (7,717,484 µCi/m) divided by the centerline depth integral (1,300,354 µCi/m²).
[e] The product of the Effective Contamination Width (5.93 m) and the West to East Segment Total (45,006,678 µCi/m).

NA = not applicable.

Table 3-4. Inventory Calculation for the Eastern Third of the 216-B-26 Trench.

South Borehole	North Borehole	Space Between Boreholes (m)	Average Vertical (μCi/m²) [a]	Transverse Segment (μCi/m) [b]
NA	C5914	2 [c]	81	161
C5914	C5903	0.91	9,602	8,738
C5903	C5871	1.53	291,638	445,305
C5871	C5886a	1.59	1,477,283	2,347,533
C5886a	C5886	0.87	2,390,332	2,089,150
C5886	C5886b	2.17	2,390,332	5,196,581
C5886b	C5872	2.06	1,351,905	2,788,861
C5872	C5902	3.13	170,306	533,583
C5902	C5913	0.91	15,752	14,334
C5913	C6108	0.61	2,268	1,384
C6108	NA	2 [c]	83	166
Totals		NA	NA	13,425,795
Effective Contamination Width:[d] 5.62 m				
West Borehole	**East Borehole**	**Space Between Boreholes (m)**	**Average Vertical (μCi/m²) [a]**	**West to East Segment (μCi/m) [b]**
C5873	C5912	0.76	10,247	7,788
C5912	C5906	0.76	286,749	217,929
C5906	C5863	1.53	453,843	694,380
C5863	C5879	6.10	389,294	2,374,693
C5879	C5880	5.79	399,501	2,313,113
C5880	C5881	5.79	391,628	2,267,524
C5881	C5882	5.80	632,299	3,667,335
C5882	C5883	5.79	1,390,443	8,050,667
C5883	C5884	5.79	2,228,715	12,904,261
C5884	C5885	5.79	2,159,317	12,502,447
C5885	C5886	5.79	2,087,991	12,089,468
C5886	NA	4 [c]	2,390,332	9,561,326
Totals		NA	NA	66,650,931
Total Cs-137 in Eastern Third:[e] 374.36 Ci				

[a] The average value of the depth integrals for the two boreholes shown in the first two columns (values for depth integrals are given in Appendix A).
[b] The product of the distance (third column) and the depth integral (fourth column).
[c] Estimated from the likely horizontal extent of contamination.
[d] The sum of the transverse segment values (13,425,795 μCi/m) divided by the centerline depth integral (2,390,332 μCi/m^2).
[d] The product of the Effective Contamination Width (5.62 m) and the West to East Segment Total (66,650,931 μCi/m).

NA= not applicable.

Table 3-5. Comparing Total Cs-137 Inventory Estimates for the 216-B-26 Trench.

Reference	Cs-137 Inventory	Decayed to 8/1/2007 [a]	Ratio with Current Report
Current Report	669 Ci on 8/1/07	669 Ci	1.00
DOE/RL-2004-66 Draft A	1500 Ci on 1/1/01	1288 Ci	1.93
SIM 2005 (RPP-26744) [b]	585 Ci on 1/1/01	503 Ci	0.75

[a] The radioactive decay half life for Cs-137 is 30 years.
[b] The SIM 2005 value shown is the mean.
DOE/RL-2040-66, *Focused Feasibility study for the BC Cribs and Trenches Area Waste Sites.*
RPP-26744, *Hanford Soil Inventory Model, Rev. 1.*

The personnel exposure assessment in DOE/RL-2004-66 is based on the estimated inventory being located in a contaminated soil layer from 3.0 to 4.0 m (10 to 13 ft) bgs. The logging results show that the layer is much thinner and the total activity is less. Thus, the estimated personnel dose can be reduced by a factor of two.

3.2.2 Inventory Based on Sample Analysis

As previously described, 24 samples were collected from eight boreholes associated with specific logging boreholes and analyzed for Cs-137 and Sr-90.

The Cs-137 and Sr-90 inventory within the soil underneath the 216-B-26 Trench can be selected through a simple arithmetic treatment of the analytical results of the 24 soil samples (Table 3-6). Since the samples were located randomly, one may take the average value of the samples at each depth interval and apply it to the volume within which the samples were selected.

Table 3-6. Calculated Inventory Based on Sample Data - Depth Averaged and Limited to Trench Footprint.

Constituent	Calculated inventory (Ci/) [a, b]
Cs-137	300.4
Sr-90	205.6

[a] Average of laboratory results for depth interval averages.
[b] Calculation performed using the average concentration and the following volume assumptions:
Upper extent of sampled volume = 8 ft bgs
Lower extent of sampled volume = 18 ft bgs
Width of sampled volume = 10 ft
Longitudinal extent of trench = 500 ft
Calculated sampled volume = 50,000 ft^3
Soil density = 1.9g/cc
No accounting for contaminants outside of the sampled volume
No correction for reductions in contaminant concentrations within berm areas.

The results confirm that a large percentage of the Cs-137 and Sr-90 contamination exists within a thin layer just below the original floor of the 216-B-26 Trench. Tables 3-7 and 3-8 display results of calculations of the average concentration with depth and the contribution of each depth interval to the total. Nearly all of the contamination exists between 3.3 to 4.0 m (11 to 13 ft) bgs.

Table 3-7. Cesium-137 Sample Result Distribution by Depth.

Depth (ft bgs)	Sample Results (pCi/g)					Sum (pCi/g)	Average (pCi/g)	Contribution (%)
8-9	0.793	NA	NA	NA	NA	0.793	1	0.0
9-10	2620	0	NA	NA	NA	2620	1310	0.1
10-11	0	NA	NA	NA	NA	0	0	0.0
11-12	0	0.567	0	692000	NA	692000.6	173000.1	15.5
12-13	2210000	22.6	1420000	0.43	NA	3630023	907505.8	81.3
13-14	27600	NA	NA	NA	NA	27600	27600	2.5
14-15	336	5740	9100	2630	483	18289	3657.8	0.3
15-16	172	NA	NA	NA	NA	172	172	0.0
16-17	194	6020	198	NA	NA	6412	2137.333	0.2
17-18	3.6	2950	NA	NA	NA	2953.6	1476.8	0.1
Total	NA	NA	NA	NA	NA	NA	1116861	100.0

NA = not applicable.

Table 3-8. Strontium-90 Sample Result Distribution by Depth.

Depth (ft bgs)	Sample Results (pCi/g)					Sum	Average	Contribution (%)
8-9	13.3	NA	NA	NA	NA	13.3	13.3	0.0
9-10	10.2	35700	NA	NA	NA	35710.2	17855	2.3
10-11	40.1	NA	NA	NA	NA	40.1	40.1	0.0
11-12	9.83	45	2710	646000	NA	648764.8	162191	21.2
12-13	219	1410000	91200	561000	NA	2062419	515605	67.5
13-14	77300	NA	NA	NA	NA	77300	77300	10.1
14-15	3050	3970	6760	6960	6630	27370	5474	0.7
15-16	2310	NA	NA	NA	NA	2310	2310	0.3
16-17	445	1580	512	NA	NA	2537	846	0.1
17-18	21.4	823	NA	NA	NA	844.4	422	0.1
Total	NA	NA	NA	NA	NA	NA	764148	100.0

NA = not applicable.

3.2.3 Using the Cesium-137 Inventory Estimates to Generate an Overall Strontium-90 Inventory Estimate

The direct comparison of Cs-137 estimates from the two independent data sets detailed in this section provides some confidence in the inventory numbers. The Cs-137 distribution shows that contamination extends significantly beyond the volume for which soil samples are available. The borehole logging tools cannot directly observe Sr-90 concentrations; however, the soil samples can provide data that can be use for Sr-90 inventory estimates.

Using the soil data, the limited-volume estimate of Sr-90 can be expanded to the entire contaminated zone under the assumption that the relative percentage in the limited volume versus the entire contaminated volume is the same for Sr-90 as Cs-137. Using the borehole logging estimates from Table 3-9, the overall inventory exceeds the limited-volume inventory by a factor of 1.89. Applying this factor to the Sr-90 limited-volume inventory estimate (Table 3-6), results in a total soil sample derived Sr-90 estimated inventory of 389 Ci.

Table 3-9 shows the logging data estimate of the Cs-137 inventory limited to the volume of soil directly beneath the floor of the trench (i.e., the sampled volume). Columns labeled "Overall" show the original calculation, including contributions from all of the s; while columns labeled "Limited" show the inventory calculation within the limited width of the trench footprint.

Table 3-9. Cesium-137 Inventory Distribution.

Location	Length Integral [a] (Ci/m)	Width of 216-B-26 (m)		Cs-137 Inventory (Ci)	
		Overall [b]	Limited [c]	Overall [b]	Limited [c]
Western Third	4.27	6.56	3.05	28	13.0
Middle Third	45.01	5.93	3.05	267	137.2
Eastern Third	66.65	5.62	3.05	374	203.2
Whole Trench	NA	NA	NA	669	353.3

[a] Integrals were computed in Tables 3-2 to 3-4 from the depth integrals and the spacing of the boreholes along the 216-B-26 Trench.
[b] Width based on the transverse logs.
[c] Width is the width of the bottom of the trench (10 ft).
The Cs-137 inventories are the product of the length integral and the width for each portion of the trench.
NA = not applicable.

An alternative method of estimating the overall Sr-90 inventory used the relative concentrations of Cs-137 and Sr-90 for each section of the trench, based on soil sampling data. Tables 3-10 to 3-12 list the borehole logging data and sampling data for the western, middle, and eastern sections of the trench, respectively. Note that sample analysis data is represented to cover a 6-in. depth range. These data are depicted in Figures 3-10 to 3-12.

Table 3-10. Borehole Log and Laboratory Sample Results for the Western Third of the 216-B-26 Trench.

Depth (ft)	Borehole C5893	Borehole C5915		Borehole C5894	Borehole C5916	
	NaI (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)	NaI (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)
9.5	0.0			0.0		
10	21.6			54.0		
10.5	62.9			281.0		
11	343.4	0	9.83	1,802.2		
11.5	2,209.9	0	9.83	11,758.9		
12	14,882.9			69,418.3	0.43	219
12.5	87,991.8			233,976.1	0.43	219
13	95,480.8			142,255.1		
13.5	30,002.0	27,600	77,300	40,696.2		
14	8,855.8	27,600	77,300	9,133.3		
14.5	3,493.7			1,614.9	336	3050
15	2,979.5			617.2	336	3050
15.5	3,317.7			522.7		
16	2,451.6	194	445	1,600.5		
16.5	2,107.2	194	445	4,528.2		
17	1,522.7			5,595.2	3.6	21.4
17.5	970.0			5,949.4	3.6	21.4
18	683.1			5,581.2		

The gamma logs are shown for push Boreholes C5893 and C5894. The laboratory samples were collected at nearby Boreholes C5915 and C5916. The laboratory sample results are shown at the range of depths they were collected.

Table 3-11. Borehole Log and Laboratory Sample Results for the Middle Third of the 216-B-26 Trench.

Depth (ft)	Borehole C5898	Borehole C5917		Borehole C5899	Borehole C5918		Borehole C5876	Borehole C5919	
	ZP1320 (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)	ZP1320 (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)	ZP1320 (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)
9	0.0			0.0			0.0		
9.5	0.0			391.8			341.8		
10	602.3			2,554.6			1,496.8		
10.5	4,210.5			18,655.2			10,599.6		
11	32,971.8			157,999			100,304		
11.5	272,503	0.567	45	1,174,927			805,662	0	2710
12	1,265,617	0.567	45	1,867,541	2,210,000	1,410,000	1,602,344	0	2710
12.5	592,047			735,972	2,210,000	1,410,000	570,336		
13	129,475			227,304			102,763		
13.5	19,917.0			39,234.0			18,527.3		
14	5,745.3	5740	3970	5,639.3			8,056.7	2630	6960
14.5	6,102.4	5740	3970	1,528.2	9100	6760	5,827.0	2630	6960
15	4,866.0			1,771.4	9100	6760	12,322.6		
15.5	794.3			2,674.1			12,325.5		
16	224.2			3,757.6			6,060.3		
16.5	480.0	6020	1580	9,213.9			11,235.0	198	512
17	2,286.4	6020	1580	21,254.7	2950	823	4,906.2	198	512
17.5	5,459.5			26,175.6	2950	823	2,658.4		

The gamma logs are shown for push Boreholes C5898, C5899, and C5876. The laboratory samples were collected at nearby Boreholes C5917, C5918, and C5919. The laboratory sample results are shown at the range of depths they were collected.

Table 3-12. Borehole Log and Laboratory Sample Results for the Eastern Third of the 216-B-26 Trench.

Depth (ft)	Borehole C5881	Borehole C5920		Borehole C5885	Borehole C5921		Borehole C5886	Borehole C5922	
	ZP1320 (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)	ZP1320 (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)	ZP1320 (pCi/g)	Cs-137 (pCi/g)	Sr-90 (pCi/g)
7.5	0.0			0.0			1,918.5		
8	0.0			0.0			14,337.2	0.793	13.3
8.5	0.0			0.0			147,611	0.793	13.3
9	360.8			366.0			1,064,440		
9.5	2,216.5			1,782.0	0	10.2	2,057,776	2,620	35,700
10	12,878.4	0	40.1	11,960.4	0	10.2	656,000	2,620	35,700
10.5	102,151	0	40.1	83,347.5			648,631		
11	703,335			568,213			969,770		
11.5	491,355			1,764,358			974,930	692,000	646,000
12	80,235.3			1,528,388	1,420,000	561,000	703,212	692,000	646,000
12.5	13,103.0	22.6	91200	1,222,438	1,420,000	561,000	359,993		
13	2,145.5	22.6	91200	502,173			142,646		
13.5	613.7			141,161			80,277.8		
14	367.1			76,720.8			68,408.7		
14.5	193.4			68,998.7	483	6630	54,572.5		
15	0.0	172	2310	60,159.4	483	6630	48,014.5		
15.5	0.0	172	2310	44,312.9			82,483.0		
16	209.0			28,246.0			29,780.6		

The gamma logs are shown for push Boreholes C5881, C5885, and C5886. The laboratory samples were collected at nearby Boreholes C5920, C5921, and C5922. The laboratory sample results are shown at the range of depths they were collected.

Figure 3-10. Middle Third Gamma Log and Laboratory Sample Results at C5918.

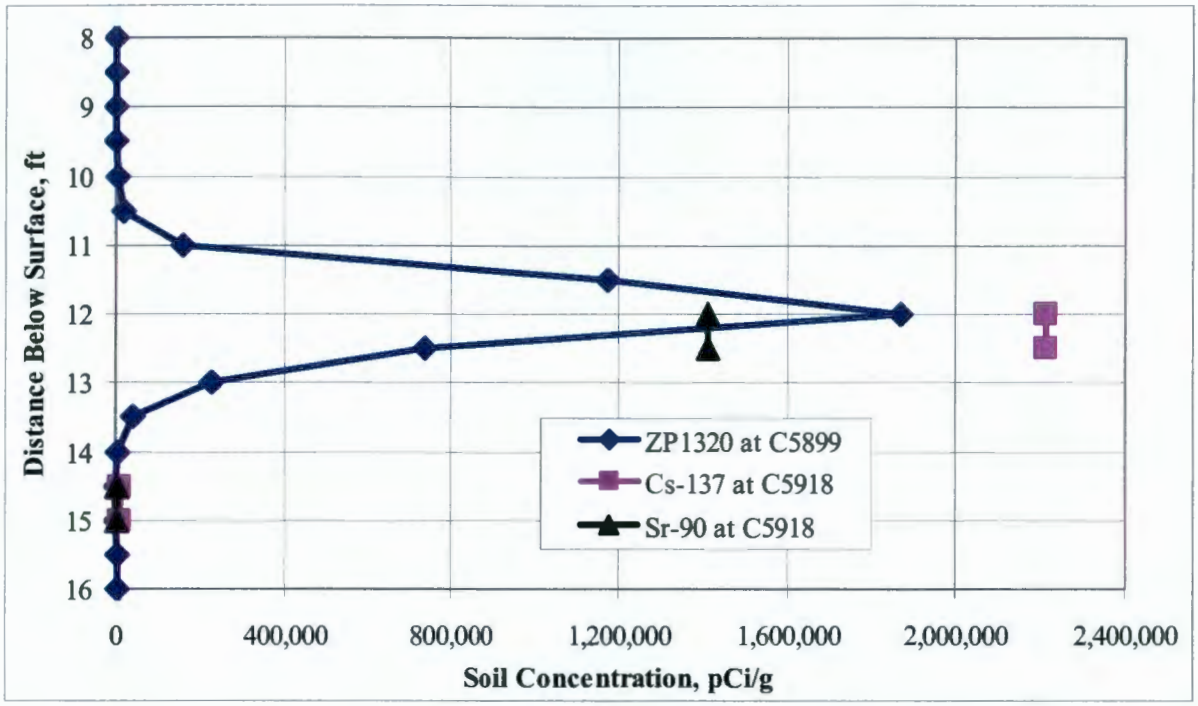


Figure 3-11. Eastern Third Gamma Log and Laboratory Sample Results at C5921.

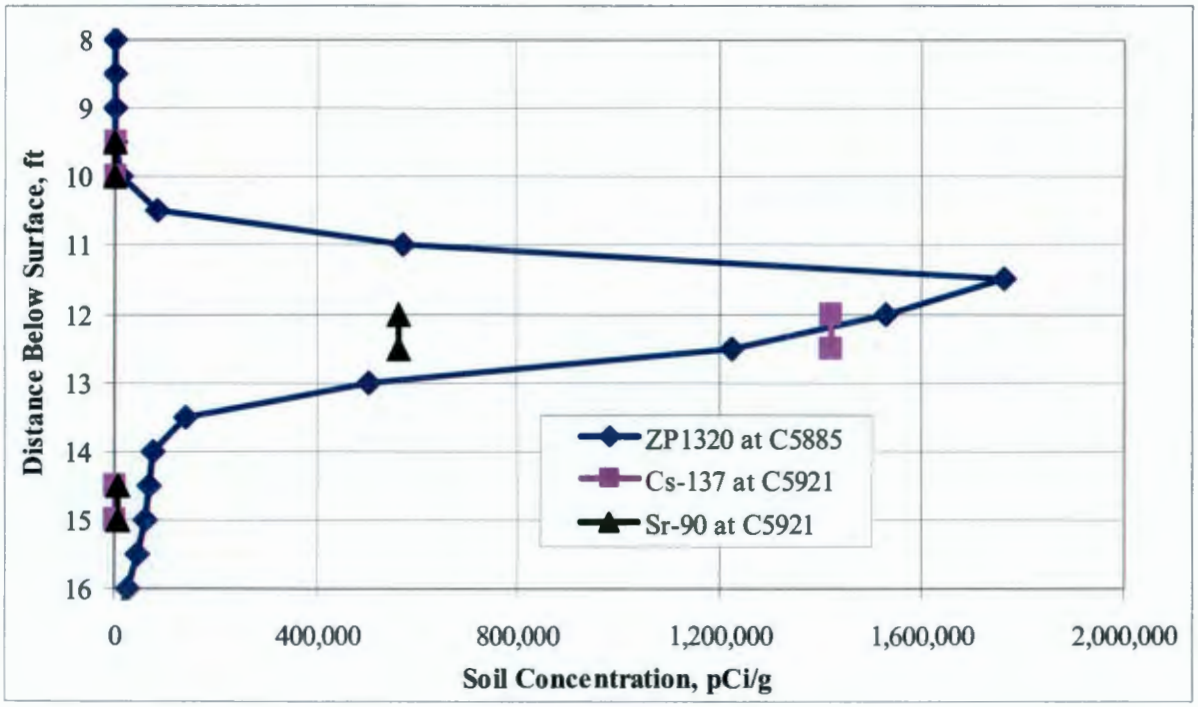
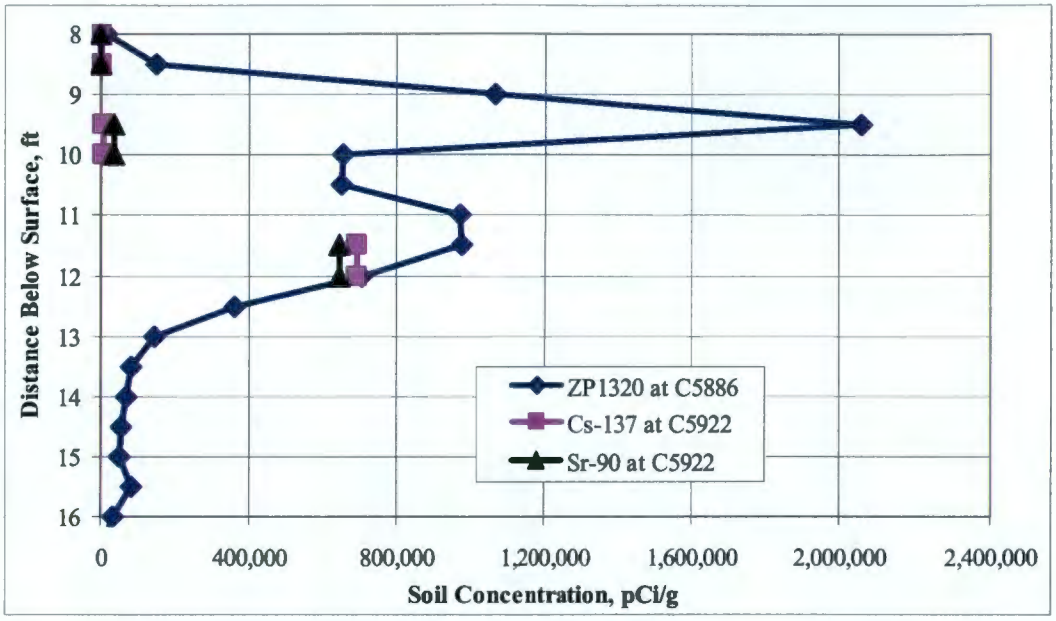


Figure 3-12. Eastern Third Gamma Log and Laboratory Sample Results at C5922.



An estimate for the Sr-90 inventory will be made using the relative amounts of Cs-137 and Sr-90 in each portion of the trench. This calculation is summarized in Table 3-13. The observed inventory of Cs-137 is shown in the first column of numbers. The approximate ratio of Sr-90 to Cs-137 is shown in the second column of numbers. The final column shows the product of the first two columns, with the total estimated Sr-90 inventory at the bottom.

The relative amounts of Cs-137 and Sr-90 are not well defined by the laboratory samples. In the western third, the ratio is based on the largest laboratory sample result, Borehole C5915 at a depth from 4.1 to 4.3 m (13.5 to 14 ft). The ratio assumed for the western third is 77,300 pCi/g divided by 27,600 pCi/g, or 2.80. For the middle third the ratio also is based on the largest laboratory sample result, Borehole C5918 at a depth from 3.6 to 3.8 m (12 to 12.5 ft) and shown in Figure 3-10. The eastern third uses the average ratio for the two largest laboratory sample results shown in Figures 3-11 and 3-12.

Table 3-13. Estimate for the Sr-90 Inventory in the 216-B-26 Trench Based on Sr-90/Cs-137 Ratio.

	Cs-137 Ci	Sr-90/Cs-137	Sr-90 Ci
Western Third	28	2.80	78
Middle Third	267	0.638	170
Eastern Third	374	0.664	249
Total	**669**	**NA**	**498**
SIM 2005 Mean [a]	503	NA	416
Ratio with SIM [b]	1.33	NA	1.20

[a] Values have been decayed to 8/1/2007 for comparison with the estimated inventories.
[b] The present estimate divided by the value from the SIM.

SIM = RPP-26744, *Hanford Soil Inventory Model, Rev. 1.*

3.2.4 Comparison of inventory estimates

Inventory estimates for Cs-137 were developed using borehole logging data and soil sampling data. Because the soil sampling data was limited to the trench footprint, that data was extrapolated to consider the entire contaminated volume based on the fraction of the contamination observed beneath the trench footprint, according to logging data.

When the Cs-137 inventories obtained by borehole logging (353 Ci) and soil sample analysis (300 Ci) are normalized to the same soil volume, the values differ by approximately 15 percent. Ratioing the Cs-137 inventory value obtained by soil sample analysis to the entire volume of contaminated soil obtained via borehole logging results in 569 Ci Cs-137.

The Sr-90 inventory was estimated primarily from the soil sampling data, because the logging did not detect it. Two approaches were employed. One involved extrapolating the calculated volume beneath the trench footprint to the entire contaminated volume, similar to that done for the Cs-137 soil sampling data, resulting in 389 Ci Sr-90. The other was based on ratios of Sr-90 to Cs-137 for each third of the trench that were obtained from the soil sampling data and applied those ratios to the Cs-137 inventories developed from the logging, resulting in 498 Ci Sr-90. Table 3-14 compares inventory values obtained by borehole logging and soil sample analysis.

Table 3-14. Inventory Comparison Between Borehole Logging and Sample Analysis.

Constituent	Calculated inventory (Ci)	
	Borehole Logging	Soil Sampling
Cs-137	669	569 [a]
Sr-90	NA	389 [a] - 498 [b]

[a] Based on relative soil volume beneath trench footprint and total contaminated region.
[b] Based on Cs-137/Sr-90 ratio.

3.3 CORRELATION BETWEEN LOGGING AND SAMPLING DATA

There is a linear correlation function in Excel[7] that can be applied to the gamma log and laboratory sample results to look for general correlations. The numbers used in the correlation calculations are shown in Table 3-15.

The first correlation is between Sr-90 and Cs-137 in the laboratory samples (Figure 3-13). The function LINEST was used to calculate the slope, intercept, and R^2 (Table 3-15, "Laboratory Sample" column). The linear correlation equation is the following:

$$\text{Sr-90} = \text{Cs-137} \times 0.5836 + 12{,}546 \text{ pCi/g}$$

where

$R^2 = 0.936$.

[7] Excel is a trademark of Microsoft Corporation, Redmond, Washington.

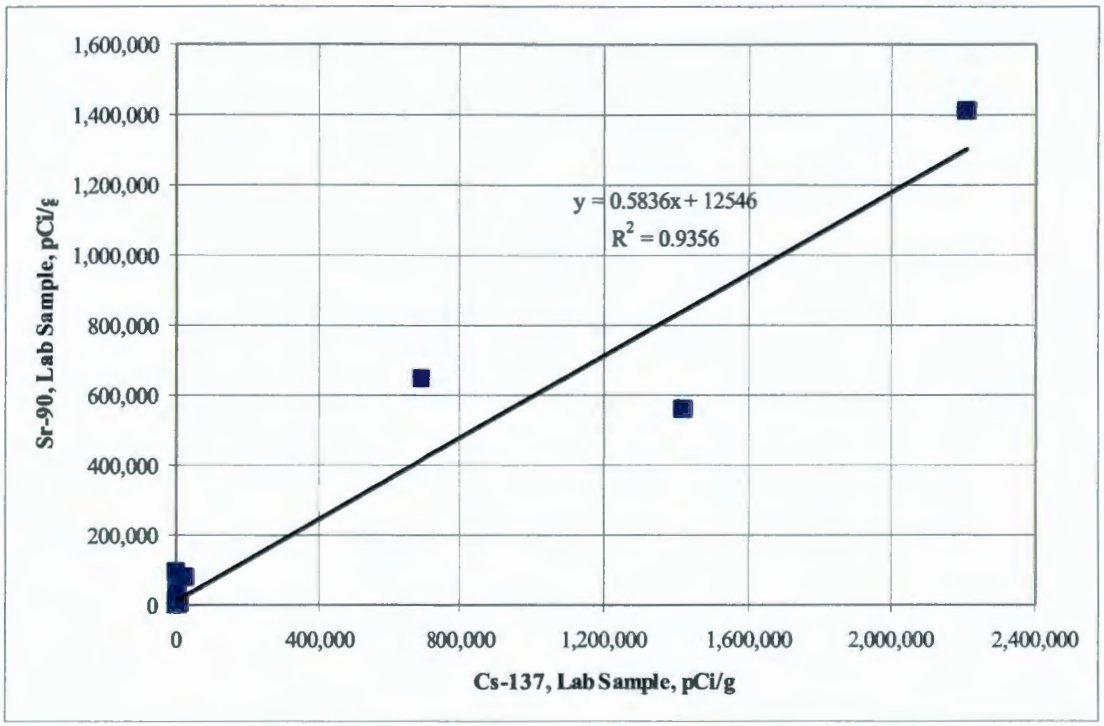
The laboratory sample data is plotted in Figure 3-13. From the graph it is clear the correlation is determined by the three samples that were near the hot layer (noted in bold type in Table 3-15) and a point near the origin. The numerous samples with little contamination have little effect on the overall Sr-90 to Cs-137 correlation.

Table 3-15. Numbers Used in Linear Correlations.

Laboratory Sample Borehole	Depth Below Grade (ft)		Laboratory Sample (pCi/g)		Gamma Log Borehole	Gamma Log (pCi/g)	
	Upper	Lower	Cs-137	Sr-90		Upper	Lower
C5915	11	11.5	0	9.83	C5893	343	2,210
C5915	13.5	14	27,600	77,300	C5893	30,002	8,856
C5915	16	16.5	194	445	C5893	2,452	2,107
C5916	12	12.5	0.43	219	C5894	69,418	233,976
C5916	14.5	15	336	3,050	C5894	1,615	617
C5916	17	17.5	3.6	21.4	C5894	5,595	5,949
C5917	11.5	12	0.567	45	C5898	272,503	1,265,617
C5917	14	14.5	5,740	3,970	C5898	5,745	6,102
C5917	16.5	17	6,020	1,580	C5898	480	2,286
C5918	**12**	**12.5**	**2,210,000**	**1,410,000**	**C5899**	**1,867,541**	**735,972**
C5918	14.5	15	9,100	6,760	C5899	1,528	1,771
C5918	17	17.5	2,950	823	C5899	21,255	26,176
C5919	11.5	12	0	2,710	C5876	805,662	1,602,344
C5919	14	14.5	2,630	6,960	C5876	8,057	5,827
C5919	16.5	17	198	512	C5876	11,235	4,906
C5920	9.9	10.4	0	40.1	C5881	12,878	102,151
C5920	12.5	13	22.6	91,200	C5881	13,103	2,145
C5920	15	15.5	172	2,310	C5881	0	0
C5921	9.6	10	0	10.2	C5885	1,782	11,960
C5921	**11.9**	**12.4**	**1,420,000**	**561,000**	**C5885**	**1,528,388**	**1,222,438**
C5921	14.5	15	483	6,630	C5885	68,999	60,159
C5922	8	8.5	0.793	13.3	C5886	14,337	147,611
C5922	9.6	10.1	2,620	35,700	C5886	2,057,776	656,000
C5922	**11.5**	**12**	**692,000**	**646,000**	**C5886**	**974,930**	**703,212**

Numbers on this table are taken from Tables 3-10, 3-11, and 3-12.

Figure 3-13. Plot of Sr-90 and Cs-137 Soil Concentrations from the Laboratory Samples.

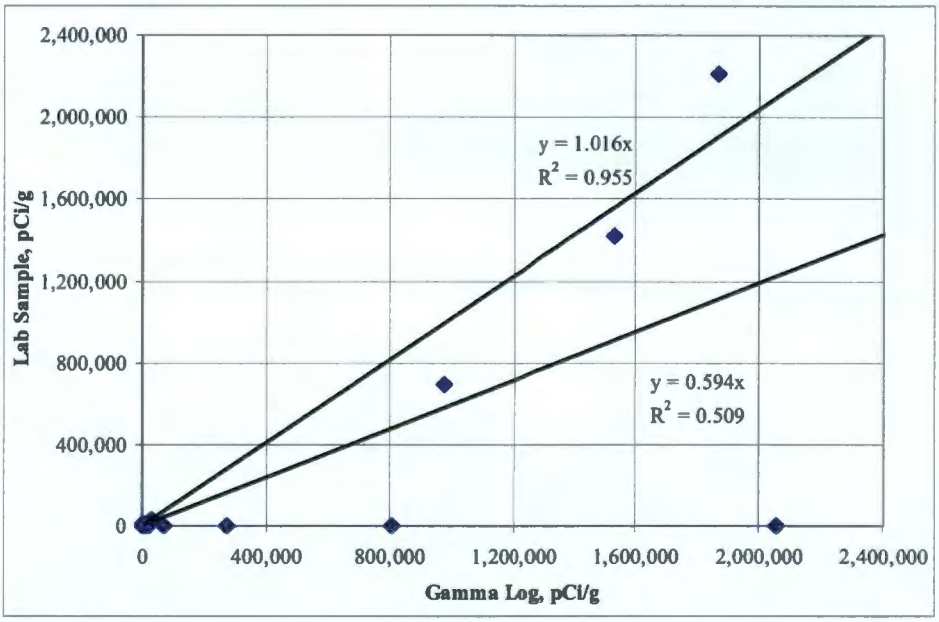


The second correlation is between the Cs-137 concentrations observed in the borehole logs and the Cs-137 concentration measured in the laboratory samples. Because of uncertainties in the depth of the laboratory sample measurements, two values for the gamma log were used for each laboratory sample result. The Upper Depth gamma log result is at the shallow depth and the Lower Depth gamma log is 0.15 m (0.5 ft) deeper.

It is assumed that the function passes through the origin.

The upper gamma log data yields a better correlation with the laboratory sample results (Figure 3-14). Note that the correlation coefficient ($R^2 = 0.509$) indicates a poor correlation. The points along the horizontal axis are locations where the gamma log instrument registered high count rates, but the soil at the same depth in a nearby borehole had almost no contamination. Much of this difference is caused by the laboratory samples missing the hot layer by a small distance. The laboratory results are then very small, however the gamma instrument was registering the penetrating gammas coming from the hot layer. Because of the inherently poor match between the sampling approach and the abrupt, highly contaminated layer misrepresented by logging, further sampling was not conducted.

Figure 3-14. Plot of Cs-137 Soil Concentrations from Gamma Log and Laboratory Samples.



It should be noted that if the points near the horizontal axis are dropped based on the sample location being above or below the hot layer, then the correlation is improved. This is shown in the Figure 3-14 on the upper line.

The result for the upper depth indicates excellent agreement between laboratory samples and gamma log results. The challenge is to obtain the laboratory sample at the depth of the hot layer.

3.4 WORKER DOSE ESTIMATE

One of the objectives of this report is to revise the worker dose estimate, as appropriate. The initial estimate was provided in DOE/RL-2004-66, Appendix F, which broke down individual work activities of excavation, transportation, and disposal into specific scenarios. Using a radioactive source term based on samples from a single borehole and logging data from that borehole and six others, protected workers (i.e., workers provided shielding and controls to minimize exposure to ionizing radiation) were predicted to receive a dose of 8.0 person-rem to excavate, transport, and dispose the 216-B-26 Trench near-surface contamination.

The revised inventory, based on the logging data, is approximately half of the inventory assumed in the calculation reported in DOE/RL-2004-66. The personnel exposure assessment in DOE/RL-2004-66 is based on the estimated inventory being located in a contaminated soil layer from 3.0 to 4.0 m (10 to 13 ft) bgs. The borehole logging results show that the layer is much thinner and the total activity is less. Thus the estimated personnel dose can be reduced by a factor of two.

3.5 ESTIMATED VOLUME OF SOIL EXCEEDING 750 pCi/g CESIUM-137

The estimated volume of soil contaminated above 750 pCi/g is shown in Tables 3-16 to 3-18. The soil volume is calculated for each section of the 216-B-26 Trench down to a depth of at most 4.6 m (15 ft). The calculation uses the transverse boreholes to define a depth profile to the south and north of each Borehole along the east-west centerline of the trench.

The soil concentration rises rapidly as the hot layer is encountered. The depth at which the transition from clean to contaminated occurs can be estimated using the linear slope of the soil concentration. This slope reaches a maximum near the transition. This is the best physical estimate that can be made for the upper depth for the contaminated layer. Values are listed in Appendix A in the row labeled "WAC Upper Depth."

At depths below the hot layer the soil concentration decreases. In some boreholes (e.g., Borehole C5890 in Table A-1) the decrease is rapid, consistent with little spread of contamination below the hot layer. In other boreholes (e.g., Borehole C5866 in Table A-1) the decrease is slow enough to indicate the contaminated soil extends from the hot layer to depths below 4.6 m (15 ft).

To define the lower depth of the contaminated layer, the depth at which the soil concentration drops below 750 pCi/g is used. If this depth is below 4.6 m (15 ft), then that depth is used instead. The assumed lower boundary of the contaminated soil layer is shown in Appendix A in the row labeled "WAC Lower Depth." The contaminated soil thickness is shown in Appendix A in the row labeled "WAC Thickness."

Tables 3-16 to 3-18 have two parts. The upper portion shows the transverse (south to north) integration to obtain the north-south shape factor shown on the tables as "Average Contamination Width" because it has units of length. The lower portion shows the west to east integration. Both parts have the same type of calculation along a string of boreholes. The first two columns show the ID numbers of the boreholes used for that segment. The third column shows the space between the two boreholes. Distances marked with asterisks are located at the outer boundary. They are estimates of the horizontal extent of contamination beyond the last borehole. The fourth column shows the average thickness of the layer contaminated above 750 pCi/g for the boreholes identified in the first two columns.

The last column shows the product of the distance (third column) and the average waste thickness (fourth column). It represents the vertical area of contaminated soil in the space between two boreholes.

The "Average Contamination Width" is the total vertical area divided by the centerline waste thickness. This ratio is assumed to hold at each borehole along the centerline of the trench. It is called a width because it has units of length.

The lower portion of Tables 3-16 to 3-18 follows the calculation in the upper portion. The space between boreholes is multiplied by the average value for the waste thickness between two boreholes. The weighted total vertical area is the sum. The volume of soil in each third of the trench is calculated as the product of the "Average Contamination Width" and the West to East Total meter-inch. The sum of these three totals is the contaminated soil volume estimated for the 216-B-26 Trench (460 + 415 + 606 = 1481 m^3).

While the majority of the inventory is in the eastern third of the trench, the soil volume is much more evenly distributed (note that the highest activity was observed in the center third). Thus, the average soil concentration in the eastern third is considerably higher than in the western third.

Table 3-16. Contaminated Soil Calculation for the Western Third of the 216-B-26 Trench.

South Borehole	North Borehole	Space Between Boreholes (m)	Waste Thickness (in.)[a]	Transverse Area (m-in.)[b]
NA	C5905	2[c]	0.0	0.0
C5905	C5867	1.22	22.5	27.4
C5867	C5894a	1.29	40.5	52.2
C5894a	C5894	1.56	36.0	56.3
C5894	C5868	2.63	45.0	118.2
C5868	C5908	1.83	48.0	88.0
C5908	C5910	0.91	21.0	19.1
C5910	NA	2[c]	0.0	0.0
Totals		NA	NA	361
Average Contamination Width:[d] 10.03 m				
West Borehole	**East Borehole**	**Space Between Boreholes (m)**	**Waste Thickness (in.)[a]**	**West to East Area (m-in.)[b]**
NA	C5888	6[c]	34.0	204.1
C5888	C5889	5.79	37.8	218.8
C5889	C5890	5.79	35.0	202.5
C5890	C5891	5.79	28.2	163.3
C5891	C5892	5.79	31.4	182.1
C5892	C5893	5.80	33.9	196.8
C5893	C5894	5.79	34.5	199.8
C5894	C5895	5.79	35.0	202.6
C5895	C5866	4.57	44.0	201.0
C5866	C5900	0.91	37.5	34.1
Totals:		52.02 m		1805 m-in.
Total Soil in Western Third:[e] 460.0 m^3				

The entire length of the western third is assumed to follow this transverse pattern.

[a] Average value of the waste thickness for the two boreholes shown in the first two columns. Values for waste thickness are given in Appendix A.

[b] The product of the distance between boreholes and the waste thickness. It is the vertical cross-section.

[c] Distances are located at the outer boundary and estimated from the likely horizontal extent of contamination.

[d] The sum of the transverse areas (361 m-in.) divided by the centerline waste thickness (36.0 in.).

[e] The product of the Average Contamination Width (10.03 m) and the West to East Segment Total (1,805 m-in.).

Table 3-17. Contaminated Soil Calculation for the Middle Third of the 216-B-26 Trench.

South Borehole	North Borehole	Space Between Boreholes (m)	Waste Thickness (in.)[a]	Transverse Area (m-in.)[b]
NA	C6107	2[c]	12.0	24.0
C6107	C5904	0.76	12.0	9.1
C5904	C5869	1.53	21.0	32.2
C5869	C5899a	1.50	43.5	65.4
C5899a	C5899	1.14	45.0	51.5
C5899	C5899b	1.90	45.0	85.7
C5899b	C5870	1.55	42.0	65.0
C5870	C5907	2.00	30.0	59.9
C5907	C6106	0.61	10.5	6.4
C6106	NA	2[c]	0.0	0.0
Totals		NA	NA	399
Average Contamination Width:[d] 8.87 m				
West Borehole	**East Borehole**	**Space Between Boreholes (m)**	**Waste Thickness (in.)[a]**	**West to East Area (m-in.)[b]**
C5900	C5911	2.05	10.5	21.5
C5911	C5909	0.90	15.0	13.5
C5909	C5901	1.53	34.5	52.8
C5901	C5865	1.52	37.5	57.0
C5865	C5896	2.44	37.5	91.5
C5896	C5897	5.18	36.6	189.7
C5897	C5898	5.18	37.0	191.5
C5898	C5899	5.18	42.3	219.3
C5899	C5875	5.18	45.0	233.1
C5875	C5876	5.18	43.2	223.6
C5876	C5877	5.19	37.5	194.5
C5877	C5878	5.18	33.3	172.5
C5878	C5864	5.18	33.0	170.9
C5864	C5874	0.61	16.5	10.1
C5874	C5873	3.95	0.0	0.0
Totals		NA	NA	1,842
Total Soil in MiddleThird:[e] 415.0 m^3				

The entire length of the western third is assumed to follow this transverse pattern.

[a] Average value of the waste thickness for the two boreholes shown in the first two columns. Values for waste thickness are given in Appendix A.

[b] The product of the distance between boreholes and the waste thickness. It is the vertical cross-section.

[c] Distances are located at the outer boundary and estimated from the likely horizontal extent of contamination.

[d] The sum of the transverse areas (399 m-in.) divided by the centerline waste thickness (45.0 inches).

[a] The product of the Average Contamination Width (8.87 m) and the West to East Segment Total (1,842 m-in.).

Table 3-18. Contaminated Soil Calculation for the Eastern Third of the 216-B-26 Trench.

South Borehole	North Borehole	Space Between Boreholes (m)	Waste Thickness (in.)[a]	Transverse Area (m-in.)[b]
NA	C5914	2[c]	0.0	0.0
C5914	C5903	0.91	14.6	13.3
C5903	C5871	1.53	38.6	59.0
C5871	C5886a	1.59	60.0	95.3
C5886a	C5886	0.87	72.0	62.9
C5886	C5886b	2.17	72.0	156.5
C5886b	C5872	2.06	57.0	117.6
C5872	C5902	3.13	36.0	112.8
C5902	C5913	0.91	24.0	21.8
C5913	C6108	0.61	9.0	5.5
C6108	NA	2[c]	0.0	0.0
Totals		NA	NA	645
Average Contamination Width: 8.96 m				
West Borehole	**East Borehole**	**Space Between Boreholes (m)**	**Waste Thickness (in.)[a]**	**West to East Area (m-in.)[b]**
C5873	C5912	0.76	13.5	10.3
C5912	C5906	0.76	36.0	27.4
C5906	C5863	1.53	45.0	68.9
C5863	C5879	6.10	45.0	274.5
C5879	C5880	5.79	48.0	277.9
C5880	C5881	5.79	42.6	246.8
C5881	C5882	5.80	42.6	247.2
C5882	C5883	5.79	51.0	295.3
C5883	C5884	5.79	51.0	295.3
C5884	C5885	5.79	49.5	286.6
C5885	C5886	5.79	60.0	347.4
C5886	NA	4[c]	72.0	288.0
Totals		NA	NA	2665
Total Soil in Eastern Third: 606.3 m^3				

The entire length of the western third is assumed to follow this transverse pattern.

[a] Average value of the waste thickness for the two boreholes shown in the first two columns. Values for waste thickness are given in Appendix A.

[b] The product of the distance between boreholes and the waste thickness. It is the vertical cross-section.

[c] Distances are located at the outer boundary and estimated from the likely horizontal extent of contamination.

[d] The sum of the transverse areas (645 m-in.) divided by the centerline waste thickness (72.0 inches).

[a] The product of the Average Contamination Width (8.96 m) and the West to East Segment Total (2,665 m-in.).

Most of the contaminated soil is in the eastern third of the trench. An unusual feature of the eastern third is that most of the activity appears to be in the eastern half of the eastern third.

4.0 CONCLUSIONS

As a result of installing approximately five dozen shallow boreholes in the 216-B-26 Trench, collecting gamma logging data, and analyzing two dozen samples, the following have been concluded.

- A highly contaminated region of Cs-137 and Sr-90 is confined to a relatively thin layer corresponding to the bottom of the trench. The thickness of this layer is estimated to average approximately 0.3 m (1 ft) thick. Cs-137 concentration varied considerably along the length of the trench with a maximum of ~2.9E+06 pCi/g observed near the west end of the center section of the trench.

- Based on the logging data, the Cs-137 inventory is estimated at 569 to 669 Ci. This value is roughly half of the inventory previously calculated, based on limited data and comparable to the value predicted by the SIM (503 Ci, decayed to common date).

- Based on sampling data, the Sr-90 inventory is estimated at 389 to 498 Ci.

- Estimated volume of soil contaminated with greater than 750 pCi/g Cs-137 (less than 4.6 m [15 ft] bgs) is 1,481 m^3.

- The worker dose estimate to excavate, transport, and dispose of the 216-B-26 Trench near-surface contamination is estimated to be approximately 4.0 man-rem or half of that previously calculated, based on the source term being reduced by that amount.

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5.0 REFERENCES

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APPENDIX A

BOREHOLE LOGGING DATA FOR THE 216-B-26 TRENCH

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APPENDIX A

BOREHOLE LOGGING DATA FOR THE 216-B-26 TRENCH

The borehole log results used in this report are shown in the tables below. The first three tables describe boreholes located along the length of the trench from west to east. Table A-1 is the western third of the trench, Table A-2 is the middle third, and Table A-3 is the eastern third. Boreholes exhibiting negligible activity were not included.

The heading rows show the borehole identification number, the eastling and northling coordinates, the maximum soil concentration and the depth at which it was measured. The depth integral is shown in units of microcuries per meter squared and inch times picocuries per gram. The average thickness of the waste is the value corrected for thin layers using the formula shown in Appendix B. The final row of the header information shows which detector has the largest depth integral, which was used in this report. There were only two, sodium iodide (scintillation) or ZP1320 (Geiger-Müller).

All of the borehole logs started at ground level and went down 7.3 to 7.9 m (24 to 26 ft). The tables omit rows at the top or bottom of the borehole that have zero for the measured soil concentration. Soil concentrations are all given in units of picocuries per gram based on calibration with equivalent Cs-137. Because nearly all the gamma emitting isotopes in the waste are Cs-137, the soil concentrations are effectively picocuries per gram Cs-137.

The last three tables describe the boreholes located across the trench from south to north. Table A-4 is the south to north line in the western third at Borehole C5894. Table A-5 is the line in the middle third at Borehole C5899. Table A-6 is the line in the eastern third at Borehole C5886. The same table headings are used. Table A-7 shows details for the header portions of Tables A-1 to A-6.

The depth integral in units of inch times picocuries per gram was calculated using the trapezoid rule to integrate the soil concentration with depth. The depth integral in microcuries per meter squared was computed from the first form through multiplication by an assumed soil density. For the soil surrounding the push s, a density of 1.9 kg/L was consistent with the Monte Carlo simulations in Appendix B. The log slope was used for this determination. The bottom two rows in each table show a representative log slope near the peak soil concentration and the depth at which this occurs. The depth numbers are all midpoints between the borehole log points. The log slopes assume a sharp boundary between the clean soil and the contaminated soil. Where the transition is more gradual, the log slopes will be smaller (less change in soil concentration with depth).

In Appendix B a density of 1.7 kg/L gives a log slope of about 0.78 while a density of 2.1 kg/L gives a log slope of about 0.92. The range of slopes in the borehole log data points to densities in this range. Note that the insertion of the borehole casing is expected to increase the soil density near the borehole. Hence, the middle value of 1.9 kg/L was selected for soil density for the entire trench

Table A-1. Log Results along the Western Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification									
	C5888	C5889	C5890	C5891	C5892	C5893	C5894 [b]	C5895	C5866	C5900
Eastling (m)	573,214.1	573,219.9	573,225.7	573,231.5	573,237.3	573,243.1	573,248.9	573,254.7	573,259.2	573,260.2
Northling (m)	134,146.6	134,146.3	134,146.4	134,145.7	134,145.4	134,145.8	134,146.0	134,145.4	134,146.0	134,146.0
Peak Concentration (pCi/g)	91,382	92,884	72,789	102,942	163,147	95,481	233,976	205,873	56,982	2,119
Depth at Peak (ft)	12	12	12	12.5	12.5	13	12.5	12.5	11	13
Depth Integral ($\mu Ci/m^2$)	51,585	63,102	42,879	58,262	101,774	76,997	183,192	115,759	59,178	1,782
Depth Integral (inch*pCi/g)	1,068,892	1,307,541	888,502	1,207,259	2,108,866	1,595,460	3,795,942	2,398,656	1,226,231	36,932
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
5.5	0.0	0.0	44.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	55.6	48.6	0.0	0.0	0.0	0.0	0.0	0.0
6.5	0.0	0.0	23.5	141.3	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	93.6	0.0	0.0	0.0	0.0	0.0	0.0
7.5	0.0	0.0	0.0	118.2	0.0	24.7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	34.6	0.0	32.0	0.0	0.0	0.0	0.0
8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	72.3	0.0
9.5	26.1	24.9	23.7	0.0	0.0	0.0	0.0	0.0	490.6	0.0
10	97.9	91.4	90.6	42.0	55.1	21.6	54.0	54.1	3,413.7	0.0
10.5	566.0	520.0	485.2	180.1	300.8	62.9	281.0	276.9	20,838.8	0.0
11	3,537.2	3,124.4	2,736.7	918.7	1,929.4	343.4	1,802.2	1,730.7	56,981.6	0.0
11.5	22,494.9	18,827.5	17,043.9	4,651.4	12,341.9	2,209.9	11,758.9	11,019.7	23,548.1	70.2
12	91,382.0	92,883.8	72,788.7	24,888.1	75,052.4	14,882.9	69,418.3	71,346.1	10,371.1	365.5
12.5	38,493.1	70,195.7	43,255.4	102,942.4	163,146.8	87,991.8	233,976.1	205,872.6	18,325.1	1,402.4
13	11,892.9	18,291.8	9,065.0	54,663.0	62,031.3	95,480.8	142,255.1	68,493.8	31,833.4	2,118.5
13.5	6,237.7	6,330.2	1,190.2	9,490.8	19,231.6	30,002.0	40,696.2	15,986.7	12,480.6	1,283.2
14	2,380.6	2,480.2	233.7	1,659.6	3,979.0	8,855.8	9,133.3	7,306.3	2,768.9	378.4
14.5	356.1	1,400.2	82.7	430.9	1,349.9	3,493.7	1,614.9	1,426.3	3,300.2	172.8

Table A-1. Log Results along the Western Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification									
	C5888	C5889	C5890	C5891	C5892	C5893	C5894 [b]	C5895	C5866	C5900
Eastling (m)	573,214.1	573,219.9	573,225.7	573,231.5	573,237.3	573,243.1	573,248.9	573,254.7	573,259.2	573,260.2
Northling (m)	134,146.6	134,146.3	134,146.4	134,145.7	134,145.4	134,145.8	134,146.0	134,145.4	134,146.0	134,146.0
Peak Concentration (pCi/g)	91,382	92,884	72,789	102,942	163,147	95,481	233,976	205,873	56,982	2,119
Depth at Peak (ft)	12	12	12	12.5	12.5	13	12.5	12.5	11	13
Depth Integral ($\mu Ci/m^2$)	51,585	63,102	42,879	58,262	101,774	76,997	183,192	115,759	59,178	1,782
Depth Integral (inch*pCi/g)	1,068,892	1,307,541	888,502	1,207,259	2,108,866	1,595,460	3,795,942	2,398,656	1,226,231	36,932
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
15	86.0	1,267.2	37.9	159.1	842.8	2,979.5	617.2	412.7	1,455.0	71.7
15.5	52.8	1,042.7	38.3	98.2	870.9	3,317.7	522.7	161.7	1,162.1	65.3
16	37.8	596.2	61.6	67.4	858.4	2,451.6	1,600.5	42.8	1,521.0	43.8
16.5	49.3	231.1	33.8	67.2	858.0	2,107.2	4,528.2	55.7	1,361.5	43.5
17	66.3	166.1	29.8	66.4	381.0	1,522.7	5,595.2	66.3	1,453.4	35.3
17.5	63.2	147.0	30.4	93.8	391.9	970.0	5,949.4	88.9	1,639.0	29.7
18	49.3	123.7	39.7	36.3	626.8	683.1	5,581.2	114.9	1,719.0	23.5
18.5	56.7	102.3	22.6	23.6	722.4	1,262.8	8,508.5	52.4	1,561.4	25.8
19	25.0	77.1	22.0	22.5	703.1	1,986.8	9,904.4	36.0	1,415.9	25.9
19.5	0.0	0.0	32.1	27.0	668.2	2,002.2	17,483.6	78.8	1,436.3	0.0
20	0.0	0.0	57.2	31.2	830.5	1,978.6	13,176.0	161.2	1,259.8	0.0
20.5	0.0	0.0	107.3	23.6	1,248.6	1,119.6	11,255.9	547.1	1,013.8	0.0
21	34.8	0.0	89.4	0.0	1,505.1	104.3	10,233.9	1,624.9	1,074.7	0.0
21.5	33.9	0.0	91.4	24.0	386.1	22.4	7,713.3	1,652.0	740.7	0.0
22	32.9	0.0	43.1	25.1	220.1	0.0	7,072.6	1,168.8	298.6	0.0
22.5	35.8	0.0	31.7	31.1	238.2	0.0	4,108.6	916.3	193.4	0.0
23	36.1	0.0	31.0	29.2	348.8	0.0	2,084.1	1,172.6	131.8	0.0
23.5	24.2	0.0	37.5	27.5	268.0	0.0	2,228.0	1,314.6	178.4	0.0
24	0.0	0.0	41.4	29.9	68.9	0.0	1,834.9	1,412.6	195.2	0.0
24.5	0.0	0.0	51.5	23.1	21.7	0.0	1,514.8	2,118.4	111.8	0.0

Table A-1. Log Results along the Western Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification									
	C5888	C5889	C5890	C5891	C5892	C5893	C5894 [b]	C5895	C5866	C5900
Eastling (m)	573,214.1	573,219.9	573,225.7	573,231.5	573,237.3	573,243.1	573,248.9	573,254.7	573,259.2	573,260.2
Northling (m)	134,146.6	134,146.3	134,146.4	134,145.7	134,145.4	134,145.8	134,146.0	134,145.4	134,146.0	134,146.0
Peak Concentration (pCi/g)	91,382	92,884	72,789	102,942	163,147	95,481	233,976	205,873	56,982	2,119
Depth at Peak (ft)	12	12	12	12.5	12.5	13	12.5	12.5	11	13
Depth Integral ($\mu Ci/m^2$)	51,585	63,102	42,879	58,262	101,774	76,997	183,192	115,759	59,178	1,782
Depth Integral (inch*pCi/g)	1,068,892	1,307,541	888,502	1,207,259	2,108,866	1,595,460	3,795,942	2,398,656	1,226,231	36,932
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
25	0.0	0.0	35.3	0.0	0.0	0.0	154.1	2,021.7	24.5	0.0
25.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,042.5	0.0	0.0
Hot Upper Depth (ft)	11.7	11.5	11.6	12.2	12.1	12.5	12.0	12.2	10.5	12.5
Hot Lower Depth (ft)	12.3	12.5	12.4	12.8	12.9	13.7	13.1	12.8	12.2	13.8
Hot Thickness (in.)	8.0	11.1	8.7	8.1	9.7	14.3	13.7	8.0	20.1	15.2
WAC Upper Depth (ft)	11.7	11.5	11.6	12.2	12.1	12.3	12.0	12.2	10.5	12.3
WAC Lower Depth (ft)	14.5	15.0	14.0	14.5	15.0	15.0	15.0	15.0	15.0	14.0
WAC Thickness (in.)	34.0	41.6	28.4	28.0	34.8	33.0	36.0	34.0	54.0	21.0
Peak Log Slope	0.803	0.780	0.794	0.728	0.806	0.828	0.815	0.811	0.842	0.716
Depth for Log Slope (ft)	11.25	11.25	11.25	11.75	11.25	11.75	11.25	11.75	9.75	11.75

[a] Table A-7 shows details about each of the parameters.
[b] Borehole is common to both the transverse strings and the east-west strings.

NaI = sodium iodide.

Table A-2. Log Results along the Middle Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification												
	C5911	C5909	C5901	C5865	C5896	C5897	C5898	C5899 [b]	C5875	C5876	C5877	C5878	C5864
Eastling (m)	573,262.2	573,263.1	573,264.6	573,266.2	573,268.6	573,273.8	573,279.0	573,284.1	573,289.3	573,294.5	573,299.7	573,304.9	573,310.0
Northling (m)	134,146.0	134,146.0	134,146.0	134,146.0	134,146.1	134,146.5	134,146.5	134,145.6	134,145.7	134,146.7	134,146.1	134,146.7	134,146.1
Peak Concentration (pCi/g)	344	64,587	2,866,366	2,475,971	1,419,771	1,721,248	1,265,617	1,867,541	1,733,445	1,602,344	964,759	785,551	36,673
Depth at Peak (ft)	13	13	12.5	12.5	12.5	12.5	12	12	12	12	12	12	11
Depth Integral ($\mu Ci/m^2$)	204	56,942	2,218,202	2,171,769	1,049,003	998,110	687,396	1,300,354	1,359,094	1,060,701	519,657	475,187	32,045
Depth Integral (inch*pCi/g)	4,227	1,179,891	45,963,576	45,001,431	21,736,483	20,681,927	14,243,590	26,944,752	28,161,916	21,978,882	10,767,867	9,846,404	664,001
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**NaI (pCi/g)**
6 ft	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.5 ft	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	26.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.8
8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	130.4
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	678.0
9.5	0.0	30.2	232.3	0.0	0.0	0.0	0.0	391.8	820.0	341.8	0.0	271.2	3,107.6
10	0.0	50.3	985.3	415.4	326.9	220.1	602.3	2,554.6	4,286.0	1,496.8	987.6	1,666.1	10,895.4
10.5	0.0	86.3	5,454.2	2,661.2	2,300.6	2,080.2	4,210.5	18,655.2	30,806.3	10,599.6	8,202.7	9,765.1	25,771.4
11	0.0	162.1	37,228.2	18,498.0	16,820.9	12,703.5	32,971.8	157,999	293,460	100,304	62,306.6	76,159.9	36,672.6
11.5	0.0	432.1	314,946	147,114	150,539	106,388	272,503	1,174,927	1,662,748	805,662	491,440	580,889	23,967.9
12	22.0	2,147.1	1,631,747	1,022,811	997,999	789,522	1,265,617	1,867,541	1,733,445	1,602,344	964,759	785,551	7,172.3
12.5	99.7	17,865.1	2,866,366	2,475,971	1,419,771	1,721,248	592,047	735,972	693,727	570,336	219,122	162,614	1,722.5
13	344.0	64,586.6	1,177,715	1,504,997	548,705	576,242	129,475	227,304	188,661	102,763	28,011.5	20,592.1	387.6

Table A-2. Log Results along the Middle Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification												
	C5911	C5909	C5901	C5865	C5896	C5897	C5898	C5899 [b]	C5875	C5876	C5877	C5878	C5864
Eastling (m)	573,262.2	573,263.1	573,264.6	573,266.2	573,268.6	573,273.8	573,279.0	573,284.1	573,289.3	573,294.5	573,299.7	573,304.9	573,310.0
Northling (m)	134,146.0	134,146.0	134,146.0	134,146.0	134,146.1	134,146.5	134,146.5	134,145.6	134,145.7	134,146.7	134,146.1	134,146.7	134,146.1
Peak Concentration (pCi/g)	344	64,587	2,866,366	2,475,971	1,419,771	1,721,248	1,265,617	1,867,541	1,733,445	1,602,344	964,759	785,551	36,673
Depth at Peak (ft)	13	13	12.5	12.5	12.5	12.5	12	12	12	12	12	12	11
Depth Integral ($\mu Ci/m^2$)	204	56,942	2,218,202	2,171,769	1,049,003	998,110	687,396	1,300,354	1,359,094	1,060,701	519,657	475,187	32,045
Depth Integral (inch*pCi/g)	4,227	1,179,891	45,963,576	45,001,431	21,736,483	20,681,927	14,243,590	26,944,752	28,161,916	21,978,882	10,767,867	9,846,404	664,001
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**NaI (pCi/g)**
13.5	167.2	55,066.1	881,754	1,053,959	169,942	122,047	19,917.0	39,234.0	25,157.4	18,527.3	5,749.9	2,981.3	93.4
14	47.3	24,054.0	420,365	479,073	47,452.7	18,904.3	5,745.3	5,639.3	5,270.6	8,056.7	3,509.2	577.4	33.0
14.5	24.4	9,677.5	106,355	207,551	47,436.0	2,848.5	6,102.4	1,528.2	804.3	5,827.0	449.8	0.0	0.0
15	0.0	6,186.7	38,093.1	58,328.6	43,512.6	4,378.0	4,866.0	1,771.4	232.9	12,322.6	357.0	0.0	0.0
15.5	0.0	4,144.8	34,569.9	48,327.8	37,041.9	2,107.4	794.3	2,674.1	346.4	12,325.5	908.6	0.0	0.0
16	0.0	2,395.9	20,140.8	54,668.6	21,711.4	3,641.3	224.2	3,757.6	637.1	6,060.3	2,824.7	0.0	0.0
16.5	0.0	1,909.1	20,265.5	52,269.5	22,587.2	7,441.5	480.0	9,213.9	1,338.1	11,235.0	3,914.3	0.0	0.0
17	0.0	1,059.2	16,346.7	54,407.9	22,236.8	5,128.9	2,286.4	21,254.7	3,072.4	4,906.2	467.1	0.0	0.0
17.5	0.0	844.6	18,406.3	45,658.3	18,842.3	1,260.8	5,459.5	26,175.6	1,406.0	2,658.4	0.0	0.0	0.0
18	0.0	1,573.3	17,700.4	47,045.7	21,802.6	2,258.7	733.7	20,057.8	1,659.1	1,935.7	0.0	0.0	0.0
18.5	0.0	527.9	17,213.7	42,137.7	10,552.1	2,717.3	331.1	17,487.6	1,135.1	1,758.6	0.0	0.0	0.0
19	0.0	538.8	9,651.4	36,385.1	4,917.7	2,024.9	255.4	18,444.6	1,671.4	2,078.9	0.0	0.0	0.0
19.5	0.0	615.3	6,916.5	35,358.2	1,349.4	1,096.4	189.1	18,240.2	2,040.5	2,361.3	0.0	0.0	0.0
20	0.0	657.7	6,789.3	34,237.1	454.4	1,287.2	270.5	19,163.7	573.0	10,738.6	0.0	0.0	0.0
20.5	0.0	463.3	3,380.0	28,477.8	2,720.1	1,901.9	842.1	23,454.9	738.8	48,690.6	0.0	0.0	0.0
21	0.0	225.1	4,842.8	26,395.1	2,088.1	3,078.1	4,905.5	16,973.2	1,046.4	44,323.9	348.0	0.0	0.0
21.5	0.0	190.8	2,500.0	8,405.5	1,824.2	4,745.8	8,116.3	17,431.3	2,191.2	46,800.6	410.4	0.0	0.0

Table A-2. Log Results along the Middle Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification												
	C5911	C5909	C5901	C5865	C5896	C5897	C5898	C5899 [b]	C5875	C5876	C5877	C5878	C5864
Eastling (m)	573,262.2	573,263.1	573,264.6	573,266.2	573,268.6	573,273.8	573,279.0	573,284.1	573,289.3	573,294.5	573,299.7	573,304.9	573,310.0
Northling (m)	134,146.0	134,146.0	134,146.0	134,146.0	134,146.1	134,146.5	134,146.5	134,145.6	134,145.7	134,146.7	134,146.1	134,146.7	134,146.1
Peak Concentration (pCi/g)	344	64,587	2,866,366	2,475,971	1,419,771	1,721,248	1,265,617	1,867,541	1,733,445	1,602,344	964,759	785,551	36,673
Depth at Peak (ft)	13	13	12.5	12.5	12.5	12.5	12	12	12	12	12	12	11
Depth Integral ($\mu Ci/m^2$)	204	56,942	2,218,202	2,171,769	1,049,003	998,110	687,396	1,300,354	1,359,094	1,060,701	519,657	475,187	32,045
Depth Integral (inch*pCi/g)	4,227	1,179,891	45,963,576	45,001,431	21,736,483	20,681,927	14,243,590	26,944,752	28,161,916	21,978,882	10,767,867	9,846,404	664,001
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**NaI (pCi/g)**
22	0.0	296.1	631.9	1,894.1	451.1	15,291.9	8,244.9	16,709.8	3,646.2	50,927.0	0.0	0.0	0.0
22.5	0.0	219.1	0.0	1,174.2	3,126.5	22,071.8	3,709.1	11,259.0	3,603.0	57,341.2	313.5	0.0	0.0
23	0.0	44.6	0.0	8,110.0	5,260.9	10,922.2	1,113.7	8,463.7	7,737.9	61,383.2	269.7	0.0	0.0
23.5	0.0	247.7	0.0	3,906.9	975.8	3,431.4	1,918.0	6,512.8	21,391.1	59,040.6	293.2	0.0	0.0
24	0.0	263.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.5	0.0	61.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hot Upper Depth (ft)	12.6	12.5	12.0	12.0	12.0	12.1	11.7	11.5	11.5	11.6	11.7	11.6	10.5
Hot Lower Depth (ft)	13.4	13.9	13.1	13.3	13.1	12.9	12.3	12.5	12.6	12.4	12.3	12.4	11.8
Hot Thickness (in.)	8.9	16.2	13.5	16.1	12.6	8.5	7.4	11.6	13.7	10.7	7.2	9.2	16.0
WAC Upper (ft)	12.6	12.5	11.8	12.0	11.8	12.1	11.7	11.3	11.3	11.6	11.7	11.3	10.3
WAC Lower (ft)	NA	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	14.5	14.0	13.0
WAC Thickness (in.)	0.0	30.0	39.0	36.0	39.0	34.2	39.7	45.0	45.0	41.3	33.6	33.0	33.0
Peak Log Slope	0.657	0.920	0.927	0.901	0.952	0.923	0.917	0.928	0.979	0.976	0.897	0.892	0.545
Depth Log Slope (ft)	12.25	12.25	11.25	11.25	11.25	11.25	11.25	10.75	10.75	10.75	11.25	10.75	9.75

[a] Table A-7 shows details about each of the parameters.
[b] Borehole is common to both the transverse strings and the east-west strings.

NaI = sodium iodide.

Table A-3. Log Results along the Eastern Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification										
	C5912	C5906	C5863	C5879	C5880	C5881	C5882	C5883	C5884	C5885	C5886 [b]
Eastling (m)	573,315.4	573,316.1	573,317.7	573,323.8	573,329.5	573,335.3	573,341.1	573,346.9	573,352.7	573,358.5	573,364.3
Northling (m)	134,146.1	134,146.1	134,146.1	134,145.2	134,146.5	134,147.1	134,147.1	134,145.0	134,146.2	134,145.6	134,145.4
Peak Concentration (pCi/g)	23,347	922,469	579,250	877,734	700,464	703,335	1,153,853	1,522,315	1,326,973	1,764,358	2,057,776
Depth at Peak (ft)	11.5	11.5	11.5	11	11	11	11.5	11.5	11.5	11.5	9.5
Depth Integral ($\mu Ci/m^2$)	20,494	553,003	354,683	423,905	375,097	408,158	856,440	1,924,447	2,532,984	1,785,651	2,390,332
Depth Integral (inch*pCi/g)	424,666	11,458,829	7,349,411	8,783,782	7,772,426	8,457,483	17,746,374	39,876,642	52,486,196	37,000,633	49,530,286
Depth Below Grade (ft)	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	329.5
7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,918.5
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14,337.2
8.5	45.4	0.0	0.0	0.0	0.0	0.0	0.0	257.6	0.0	0.0	147,611
9	168.2	582.0	0.0	606.5	779.3	360.8	370.4	1,175.9	335.1	366.0	1,064,440
9.5	812.6	3,083.9	1,050.7	5,132.2	4,708.7	2,216.5	2,344.7	6,681.5	2,125.4	1,782.0	2,057,776
10	3,120.8	17,111.4	7,237.7	34,840.9	39,403.1	12,878.4	14,776.6	37,346.6	14,269.3	11,960.4	656,000
10.5	10,474.9	107,930	54,401.0	276,979	378,678	102,151	113,934	229,086	118,294	83,347.5	648,631
11	23,256.5	627,695	472,120	877,734	700,464	703,335	757,767	1,040,584	739,224	568,213	969,770
11.5	23,346.6	922,469	579,250	222,633	136,063	491,355	1,153,853	1,522,315	1,326,973	1,764,358	974,930
12	7,510.6	201,154	80,741.5	30,122.8	18,153.7	80,235.3	366,635	1,021,017	1,207,859	1,528,388	703,212
1	1,600.5	23,479.5	11,071.7	5,786.6	3,969.0	13,103.0	60,348.3	877,421	1,211,401	1,222,438	359,993
13	333.9	4,173.2	2,171.3	2,602.4	1,420.4	2,145.5	19,174.9	701,193	1,188,329	502,173	142,646
13.5	78.2	1,356.1	1,848.4	1,024.2	991.3	613.7	10,096.0	367,043	1,093,078	141,161	80,277.8

Table A-3. Log Results along the Eastern Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification										
	C5912	C5906	C5863	C5879	C5880	C5881	C5882	C5883	C5884	C5885	C5886 [b]
Eastling (m)	573,315.4	573,316.1	573,317.7	573,323.8	573,329.5	573,335.3	573,341.1	573,346.9	573,352.7	573,358.5	573,364.3
Northling (m)	134,146.1	134,146.1	134,146.1	134,145.2	134,146.5	134,147.1	134,147.1	134,145.0	134,146.2	134,145.6	134,145.4
Peak Concentration (pCi/g)	23,347	922,469	579,250	877,734	700,464	703,335	1,153,853	1,522,315	1,326,973	1,764,358	2,057,776
Depth at Peak (ft)	11.5	11.5	11.5	11	11	11	11.5	11.5	11.5	11.5	9.5
Depth Integral ($\mu Ci/m^2$)	20,494	553,003	354,683	423,905	375,097	408,158	856,440	1,924,447	2,532,984	1,785,651	2,390,332
Depth Integral (inch*pCi/g)	424,666	11,458,829	7,349,411	8,783,782	7,772,426	8,457,483	17,746,374	39,876,642	52,486,196	37,000,633	49,530,286
Depth Below Grade (ft)	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**
14	29.3	771.5	1,666.8	1,068.3	841.9	367.1	15,692.4	135,240	952,607	76,720.8	68,408.7
14.5	0.0	0.0	337.5	311.3	492.0	193.4	17,079.4	76,903.0	557,268	68,998.7	54,572.5
15	0.0	0.0	869.3	204.0	303.9	0.0	39,470.5	61,277.9	173,622	60,159.4	48,014.5
15.5	0.0	0.0	873.1	232.6	672.3	0.0	40,268.2	56,184.6	40,385.8	44,312.9	82,483.0
16	0.0	0.0	648.7	330.5	735.9	209.0	35,799.4	45,829.1	12,950.1	28,246.0	29,780.6
16.5	0.0	0.0	685.1	710.8	770.0	0.0	28,724.3	49,191.0	17,991.9	8,097.4	3,196.1
17	0.0	0.0	1,348.9	265.7	835.4	0.0	34,271.2	93,689.5	18,821.6	3,179.5	29,276.6
17.5	0.0	0.0	2,113.8	265.5	864.1	0.0	37,644.1	86,646.4	30,935.8	14,119.0	34,431.1
18	0.0	0.0	4,067.1	192.2	1,031.7	0.0	23,954.9	54,403.4	29,786.9	8,353.5	20,519.1
18.5	0.0	0.0	2,108.2	0.0	815.9	0.0	9,517.4	50,672.0	6,713.1	6,797.8	26,576.5
19	0.0	0.0	291.3	330.5	638.0	217.5	24,048.4	58,878.0	4,436.4	9,863.6	10,150.7
19.5	0.0	0.0	0.0	198.4	768.4	199.5	59,949.7	36,563.3	294.2	4,773.8	7,413.2
20	0.0	0.0	0.0	0.0	341.5	0.0	52,460.3	13,427.4	0.0	2,854.5	8,621.6
20.5	0.0	0.0	0.0	0.0	297.1	0.0	29,582.5	5,953.3	0.0	1,800.4	6,924.0
21	0.0	0.0	0.0	0.0	253.3	0.0	9,553.9	7,728.7	0.0	1,915.7	2,352.8
21.5	0.0	0.0	0.0	416.7	479.5	0.0	413.5	8,081.4	0.0	1,046.7	456.0
22	0.0	0.0	0.0	323.4	370.3	0.0	0.0	1,315.9	0.0	662.0	0.0

Table A-3. Log Results along the Eastern Third of the 216-B-26 Trench. (3 Pages)

Borehole Parameters [a]	Borehole Identification										
	C5912	C5906	C5863	C5879	C5880	C5881	C5882	C5883	C5884	C5885	C5886 [b]
Eastling (m)	573,315.4	573,316.1	573,317.7	573,323.8	573,329.5	573,335.3	573,341.1	573,346.9	573,352.7	573,358.5	573,364.3
Northling (m)	134,146.1	134,146.1	134,146.1	134,145.2	134,146.5	134,147.1	134,147.1	134,145.0	134,146.2	134,145.6	134,145.4
Peak Concentration (pCi/g)	23,347	922,469	579,250	877,734	700,464	703,335	1,153,853	1,522,315	1,326,973	1,764,358	2,057,776
Depth at Peak (ft)	11.5	11.5	11.5	11	11	11	11.5	11.5	11.5	11.5	9.5
Depth Integral ($\mu Ci/m^2$)	20,494	553,003	354,683	423,905	375,097	408,158	856,440	1,924,447	2,532,984	1,785,651	2,390,332
Depth Integral (inch*pCi/g)	424,666	11,458,829	7,349,411	8,783,782	7,772,426	8,457,483	17,746,374	39,876,642	52,486,196	37,000,633	49,530,286
Depth Below Grade (ft)	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**	**ZP1320 (pCi/g)**
22.5	0.0	0.0	0.0	597.2	262.6	0.0	0.0	0.0	0.0	385.1	0.0
23	0.0	0.0	0.0	632.8	0.0	0.0	0.0	0.0	0.0	298.0	0.0
23.5	0.0	0.0	0.0	423.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hot Upper Depth (ft)	11.0	11.1	11.1	10.8	10.7	10.6	11.0	11.0	11.0	11.0	9.0
Hot Lower Depth (ft)	12.3	11.9	11.9	11.2	11.3	11.4	12.1	13.2	14.3	12.6	11.0
Hot Thickness (in.)	16.1	9.0	9.4	5.3	7.1	8.5	12.7	26.2	39.6	19.5	24.1
WAC Upper (ft)	10.8	10.8	10.8	10.8	10.3	10.6	10.8	10.8	10.8	11.0	9.0
WAC Lower (ft)	13.0	14.5	14.5	14.5	14.5	13.5	15.0	15.0	15.0	15.0	15.0
WAC Thickness (in.)	27.0	45.0	45.0	45.0	51.0	34.2	51.0	51.0	51.0	48.0	72.0
Peak Log Slope	0.526	0.800	0.938	0.900	0.983	0.899	0.887	0.788	0.919	0.843	1.013
Depth Log Slope (ft)	10.25	10.25	10.75	10.25	10.25	10.25	10.25	10.25	10.25	10.25	8.25

[a] Table A-7 shows details about each of the parameters.
[b] Borehole is common to both the transverse strings and the east-west strings.

NaI = sodium iodide.

Table A-4. Borehole Log Results across the Western Third of the 216-B-26 Trench at C5894. (2 Pages)

Borehole Parameters [a]	Borehole Identification					
	C5905	C5867	C5894 [b]	C5868	C5908	C5910
Eastling (m)	573,248.9	573,248.9	573,248.9	573,248.9	573,248.9	573,248.9
Northling (m)	134,142.0	134,143.2	134,146.0	134,148.7	134,150.5	134,151.4
Peak Concentration (pCi/g)	176	27,913	233,976	226,031	12,483	734
Depth at Peak (ft)	13	11.5	12.5	11	12	13
Depth Integral ($\mu Ci/m^2$)	217	28,093	183,192	224,128	15,456	609
Depth Integral (inch*pCi/g)	4,497	582,114	3,795,942	4,644,177	320,264	12,623
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
5	0.0	0.0	0.0	0.0	0.0	0.0
5.5	0.0	0.0	0.0	0.0	24.8	0.0
6	0.0	0.0	0.0	0.0	23.1	0.0
6.5	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	39.6	0.0	0.0	0.0	0.0
7.5	0.0	35.2	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
8.5	0.0	0.0	0.0	30.6	0.0	0.0
9	0.0	37.4	0.0	142.7	0.0	0.0
9.5	0.0	177.2	0.0	984.0	0.0	0.0
10	0.0	1,057.4	54.0	6,715.6	24.9	0.0
10.5	0.0	5,823.2	281.0	52,043.5	91.1	0.0
11	0.0	25,783.3	1,802.2	226,031	561.4	21.6
11.5	31.6	27,912.8	11,758.9	179,109	3,416.8	73.1
12	77.9	8,814.3	69,418.3	72,639.7	12,483.3	163.4
12.5	120.3	9,841.6	233,976	40,323.5	11,760.9	271.4
13	175.7	10,438.6	142,255	76,967.8	10,265.6	734.3
13.5	156.3	3,843.8	40,696.2	61,904.4	7,913.2	336.6
14	103.6	1,002.8	9,133.3	15,844.3	2,356.8	115.1
14.5	36.8	343.5	1,614.9	2,789.4	946.4	56.4
15	25.1	230.6	617.2	2,201.8	487.0	47.5
15.5	0.0	228.4	522.7	2,753.9	304.6	39.4
16	0.0	201.4	1,600.5	2,833.4	224.0	43.8
16.5	0.0	157.0	4,528.2	2,765.9	219.7	39.8
17	0.0	162.3	5,595.2	2,678.7	212.9	33.5
17.5	0.0	150.1	5,949.4	2,464.0	232.8	25.4
18	22.2	132.5	5,581.2	2,823.8	221.4	32.1
18.5	0.0	69.3	8,508.5	3,063.7	193.6	25.9
19	0.0	28.8	9,904.4	4,291.5	342.3	22.9
19.5	0.0	27.3	17,483.6	3,237.9	327.6	21.6

Table A-4. Borehole Log Results across the Western Third of the 216-B-26 Trench at C5894. (2 Pages)

Borehole Parameters [a]	Borehole Identification					
	C5905	C5867	C5894 [b]	C5868	C5908	C5910
Eastling (m)	573,248.9	573,248.9	573,248.9	573,248.9	573,248.9	573,248.9
Northling (m)	134,142.0	134,143.2	134,146.0	134,148.7	134,150.5	134,151.4
Peak Concentration (pCi/g)	176	27,913	233,976	226,031	12,483	734
Depth at Peak (ft)	13	11.5	12.5	11	12	13
Depth Integral ($\mu Ci/m^2$)	217	28,093	183,192	224,128	15,456	609
Depth Integral (inch*pCi/g)	4,497	582,114	3,795,942	4,644,177	320,264	12,623
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
20	0.0	0.0	13,176.0	2,444.1	275.7	0.0
20.5	0.0	56.7	11,255.9	2,188.2	230.8	0.0
21	0.0	78.7	10,233.9	2,077.3	87.2	0.0
21.5	0.0	73.6	7,713.3	1,834.9	41.4	0.0
22	0.0	71.0	7,072.6	709.6	38.6	0.0
22.5	0.0	89.4	4,108.6	72.2	42.3	0.0
23	0.0	61.3	2,084.1	27.4	26.7	0.0
23.5	0.0	26.4	2,228.0	36.0	0.0	0.0
24	0.0	23.6	1,834.9	0.0	0.0	0.0
24.5	0.0	0.0	1,514.8	0.0	0.0	0.0
25	0.0	0.0	154.1	0.0	0.0	0.0
25.5	0.0	0.0	0.0	0.0	0.0	0.0
Hot Upper Depth, ft	12.5	11.0	12.0	10.5	11.5	12.5
Hot Lower Depth, ft	14.6	12.6	13.1	12.1	13.6	13.7
Hot Thickness, in.	25.6	19.4	13.7	19.0	25.7	14.9
WAC Upper Depth, ft:	12.5	10.8	12.0	10.5	11.5	12.5
WAC Lower Depth, ft:	NA	14.5	15.0	15.0	15.0	NA
WAC Thickness, in:	0.0	45.0	36.0	54.0	42.0	0.0
Peak Log Slope:	0.391	0.741	0.815	0.889	0.790	0.432
Depth for Log Slope, ft:	11.75	10.25	11.25	10.25	10.75	12.75

[a] Table A-7 shows details about each of the parameters.
[b] Borehole is common to both the transverse strings and the east-west strings.
NaI = sodium iodide.

Table A-5. Borehole Log Results across the Middle Third of the 216-B-26 Trench at C5899. (2 Pages)

Borehole Parameters [a]	Borehole Identification						
	C6107	C5904	C5869	C5899 [b]	C5870	C5907	C6106
Eastling (m)	573,284.1	573,284.1	573,284.1	573,284.1	573,284.1	573,288.9	573,288.9
Northling (m)	134,140.7	134,141.4	134,143.0	134,145.6	134,149.1	134,151.1	134,151.7
Peak Concentration (pCi/g)	8,276	214	69,151	1,867,541	615,179	2,516	347
Depth at Peak (ft)	12	12	12	12	12.5	13.5	13.5
Depth Integral ($\mu Ci/m^2$)	6,705	291	60,842	1,300,354	938,668	2,326	330
Depth Integral (inch*pCi/g)	138,926	6,032	1,260,720	26,944,752	19,450,221	48,197	6,835
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	24.6	0.0	0.0
8.5	0.0	0.0	0.0	0.0	73.5	0.0	0.0
9	0.0	0.0	0.0	0.0	360.9	0.0	0.0
9.5	0.0	0.0	49.1	391.8	1,639.0	0.0	0.0
10	23.7	0.0	196.0	2,554.6	6,417.2	0.0	0.0
10.5	83.1	0.0	834.7	18,655.2	19,048.0	0.0	0.0
11	520.3	25.6	4,559.8	157,999	61,574.2	0.0	0.0
11.5	3,725.2	93.7	26,288.7	1,174,927	277,370	27.1	0.0
12	8,276.2	213.6	69,150.7	1,867,541	587,450	101.0	0.0
12.5	3,364.3	173.0	33,103.8	735,972	615,179	455.0	39.8
13	753.0	37.8	8,085.7	227,304	547,834	1,676.5	177.6
13.5	324.4	0.0	3,485.7	39,234.0	327,319	2,515.7	347.3
14	239.6	0.0	2,571.0	5,639.3	96,572.7	821.7	144.5
14.5	234.0	0.0	2,824.5	1,528.2	66,251.5	374.4	46.9
15	245.9	23.5	2,102.1	1,771.4	48,066.7	149.3	25.7
15.5	281.4	0.0	2,605.4	2,674.1	47,194.5	89.7	22.2
16	237.5	21.9	2,956.6	3,757.6	33,782.5	101.7	0.0
16.5	229.7	21.9	2,683.7	9,213.9	31,612.1	106.2	0.0
17	188.0	27.6	2,935.4	21,254.7	30,785.2	106.9	0.0
17.5	152.0	23.6	3,586.9	26,175.6	32,938.2	97.2	23.6
18	129.6	21.4	3,225.9	20,057.8	37,325.6	117.9	21.9
18.5	150.5	27.4	2,873.0	17,487.6	24,717.3	114.3	22.9
19	198.5	25.6	2,568.4	18,444.6	25,230.9	117.0	24.8
19.5	219.7	21.2	2,748.1	18,240.2	27,497.7	96.9	0.0
20	247.6	0.0	2,870.4	19,163.7	29,308.0	98.4	25.5
20.5	206.1	0.0	3,411.3	23,454.9	27,287.7	128.2	27.7
21	241.2	24.8	2,828.9	16,973.2	22,622.7	108.0	24.2
21.5	285.8	25.2	3,419.2	17,431.3	20,956.9	73.4	26.6
22	322.9	29.1	3,742.0	16,709.8	22,103.7	59.0	25.0
22.5	355.1	29.9	3,254.4	11,259.0	24,257.0	74.7	22.2
23	412.5	28.1	3,105.0	8,463.7	23,527.2	113.2	23.4
23.5	372.5	27.8	2,294.9	6,512.8	25,471.8	111.8	23.2
24	333.2	27.2	1,687.2	0.0	30,598.9	89.6	21.7

Table A-5. Borehole Log Results across the Middle Third of the 216-B-26 Trench at C5899. (2 Pages)

Borehole Parameters [a]	Borehole Identification						
	C6107	C5904	C5869	C5899 [b]	C5870	C5907	C6106
Eastling (m)	573,284.1	573,284.1	573,284.1	573,284.1	573,284.1	573,288.9	573,288.9
Northling (m)	134,140.7	134,141.4	134,143.0	134,145.6	134,149.1	134,151.1	134,151.7
Peak Concentration (pCi/g)	8,276	214	69,151	1,867,541	615,179	2,516	347
Depth at Peak (ft)	12	12	12	12	12.5	13.5	13.5
Depth Integral ($\mu Ci/m^2$)	6,705	291	60,842	1,300,354	938,668	2,326	330
Depth Integral (inch*pCi/g)	138,926	6,032	1,260,720	26,944,752	19,450,221	48,197	6,835
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
24.5	401.8	28.7	2,085.0	0.0	32,183.0	67.7	22.4
25	398.9	26.8	1,986.5	0.0	37,122.7	40.8	0.0
Hot Upper Depth (ft)	11.5	11.5	11.5	11.5	12.0	13.0	13.0
Hot Lower Depth (ft)	12.7	13.9	12.8	12.5	14.6	14.4	14.5
Hot Thickness (in.)	14.4	28.2	16.2	11.6	31.6	17.3	17.9
WAC Upper Depth (ft)	11.5	11.5	11.5	11.3	11.8	12.8	13.0
WAC Lower Depth (ft)	13.5	NA	15.0	15.0	15.0	14.5	NA
WAC Thickness (in.)	24.0	0.0	42.0	45.0	39.0	21.0	0.0
Peak Log Slope	0.855	0.564	0.761	0.928	0.654	0.654	0.649
Depth for Log Slope (ft)	11.25	11.25	11.25	10.75	11.25	12.25	12.75

[a] Table A-7 shows details about each of the parameters.
[b] Borehole is common to both the transverse strings and the east-west strings.

NaI = sodium iodide.

Table A-6. Borehole Log Results across the Eastern Third of the 216-B-26 Trench at C5886. (3 Pages)

Borehole Parameters [a]	Borehole Identification							
	C5914	C5903	C5871	C5886 [b]	C5872	C5902	C5913	C6108
Eastling (m)	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3
Northling (m)	134,140.5	134,141.4	134,142.9	134,145.4	134,149.6	134,152.7	134,153.6	134,154.2
Peak Concentration (pCi/g)	159	29,045	551,530	2,057,776	426,217	30,989	6,017	169
Depth at Peak (ft)	12.5	12	11.5	9.5	12	13	13.5	14
Depth Integral ($\mu Ci/m^2$)	161	19,042	564,233	2,390,332	313,479	27,133	4,370	166
Depth Integral (inch*pCi/g)	3,345	394,569	11,691,534	49,530,286	6,495,620	562,226	90,559	3,445
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.5	0.0	0.0	28.0	0.0	0.0	0.0	0.0	0.0
3	24.2	42.1	29.9	0.0	0.0	0.0	0.0	0.0
3.5	27.8	73.0	0.0	0.0	0.0	0.0	0.0	0.0
4	31.6	43.5	0.0	0.0	0.0	0.0	0.0	0.0
4.5	33.6	37.7	45.3	0.0	0.0	0.0	0.0	0.0
5	0.0	34.7	118.4	0.0	0.0	0.0	0.0	0.0
5.5	0.0	0.0	39.4	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	329.5	0.0	0.0	0.0	0.0
7.5	0.0	0.0	0.0	1,918.5	30.1	0.0	0.0	0.0
8	0.0	0.0	22.9	14,337.2	0.0	0.0	0.0	0.0
8.5	0.0	0.0	72.7	147,611	25.0	0.0	0.0	0.0
9	0.0	0.0	338.7	1,064,440	62.1	0.0	0.0	0.0
9.5	0.0	0.0	1,811.2	2,057,776	240.5	0.0	0.0	0.0
10	0.0	60.5	9,883.6	656,000	1,213.8	0.0	0.0	0.0
10.5	0.0	290.5	54,007.5	648,631	7,221.9	0.0	0.0	0.0
11	0.0	1,672.3	278,830	969,770	40,664.2	63.0	0.0	0.0
11.5	45.4	8,816.1	551,530	974,930	205,652	341.6	27.2	0.0

Table A-6. Borehole Log Results across the Eastern Third of the 216-B-26 Trench at C5886. (3 Pages)

Borehole Parameters [a]	Borehole Identification							
	C5914	C5903	C5871	C5886 [b]	C5872	C5902	C5913	C6108
Eastling (m)	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3
Northling (m)	134,140.5	134,141.4	134,142.9	134,145.4	134,149.6	134,152.7	134,153.6	134,154.2
Peak Concentration (pCi/g)	159	29,045	551,530	2,057,776	426,217	30,989	6,017	169
Depth at Peak (ft)	12.5	12	11.5	9.5	12	13	13.5	14
Depth Integral ($\mu Ci/m^2$)	161	19,042	564,233	2,390,332	313,479	27,133	4,370	166
Depth Integral (inch*pCi/g)	3,345	394,569	11,691,534	49,530,286	6,495,620	562,226	90,559	3,445
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
12	120.8	29,044.9	410,780	703,212	426,217	1,603.3	81.5	0.0
12.5	158.5	14,586.2	196,475	359,993	176,422	7,711.5	363.2	0.0
13	83.4	3,160.6	104,710	142,646	34,337.4	30,988.6	1,944.9	54.5
13.5	32.1	1,405.8	46,644.0	80,277.8	6,835.3	27,586.9	6,016.5	168.0
14	0.0	591.3	59,586.9	68,408.7	3,486.4	6,478.6	2,720.7	168.5
14.5	0.0	514.9	66,788.0	54,572.5	3,870.1	2,385.3	459.3	50.1
15	0.0	738.3	30,292.5	48,014.5	7,213.1	1,655.3	193.3	22.8
15.5	0.0	834.4	26,998.0	82,483.0	8,281.9	1,292.9	109.2	0.0
16	0.0	2,175.4	34,652.2	29,780.6	9,164.7	838.3	88.8	0.0
16.5	0.0	771.8	30,848.2	3,196.1	12,216.4	1,028.1	87.0	20.3
17	0.0	151.9	21,967.4	29,276.6	11,212.9	1,393.7	119.7	0.0
17.5	0.0	406.1	8,960.0	34,431.1	7,916.8	971.3	150.2	0.0
18	0.0	225.7	4,409.0	20,519.1	7,675.3	601.0	122.4	0.0
18.5	0.0	57.1	4,897.3	26,576.5	12,908.5	570.3	143.7	0.0
19	0.0	26.8	2,695.3	10,150.7	11,701.6	574.9	189.3	0.0
19.5	0.0	0.0	750.5	7,413.2	8,753.2	512.9	150.8	0.0
20	0.0	0.0	58.2	8,621.6	6,309.9	770.1	142.9	0.0
20.5	0.0	0.0	24.8	6,924.0	7,580.0	790.7	132.1	0.0
21	0.0	0.0	0.0	2,352.8	10,917.6	688.5	158.3	0.0
21.5	0.0	0.0	21.8	456.0	10,980.2	644.3	189.1	0.0

Table A-6. Borehole Log Results across the Eastern Third of the 216-B-26 Trench at C5886. (3 Pages)

Borehole Parameters [a]	Borehole Identification							
	C5914	C5903	C5871	C5886 [b]	C5872	C5902	C5913	C6108
Eastling (m)	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3	573,364.3
Northling (m)	134,140.5	134,141.4	134,142.9	134,145.4	134,149.6	134,152.7	134,153.6	134,154.2
Peak Concentration (pCi/g)	159	29,045	551,530	2,057,776	426,217	30,989	6,017	169
Depth at Peak (ft)	12.5	12	11.5	9.5	12	13	13.5	14
Depth Integral ($\mu Ci/m^2$)	161	19,042	564,233	2,390,332	313,479	27,133	4,370	166
Depth Integral (inch*pCi/g)	3,345	394,569	11,691,534	49,530,286	6,495,620	562,226	90,559	3,445
Depth Below Grade (ft)	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**ZP1320 (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**	**NaI (pCi/g)**
22	0.0	0.0	25.3	0.0	10,583.5	560.6	155.2	0.0
22.5	0.0	0.0	43.9	0.0	9,889.3	846.5	163.2	20.6
23	0.0	0.0	90.9	0.0	8,432.8	1,036.3	195.6	0.0
23.5	0.0	0.0	41.5	0.0	8,355.5	818.1	183.5	19.9
24	0.0	0.0	27.5	0.0	5,320.8	555.8	208.3	0.0
24.5	0.0	0.0	22.0	0.0	843.0	346.4	250.9	22.1
25	0.0	0.0	22.3	0.0	67.5	49.5	346.5	27.5
Hot Upper Depth (ft)	12.0	11.6	11.0	9.0	11.5	12.5	13.0	13.5
Hot Lower Depth (ft)	13.6	12.4	12.6	11.0	12.5	13.8	14.0	15.1
Hot Thickness (in.)	19.6	10.5	19.8	24.1	12.5	16.0	12.3	18.9
WAC Upper Depth (ft)	11.8	11.6	11.0	9.0	11.5	12.5	13.0	13.3
WAC Lower Depth (ft)	NA	14.0	15.0	15.0	15.0	15.0	14.5	NA
WAC Thickness (in.)	0.0	29.3	48.0	72.0	42.0	30.0	18.0	0.0
Peak Log Slope	0.425	0.760	0.738	1.013	0.751	0.682	0.729	0.489
Depth for Log Slope (ft)	11.75	10.75	10.25	8.25	10.75	12.25	12.75	13.25

[a] Table A-7 shows details about each of the parameters.
[b] Borehole is common to both the transverse strings and the east-west strings.

NaI = sodium iodide.

Table A-7. Explanation of Lines in Tables A-1 to A-6.

Row Label	Description of Row
Eastling (m)	East-west position of the borehole on the Washington State survey grid in meters.
Northling (m)	North-south position of the borehole on the Washington State survey grid in meters.
Peak Concentration (pCi/g)	Largest soil concentration measured in the borehole in picocuries per gram. Most of this is Cs-137.
Depth at Peak (ft)	Depth corresponding to the largest soil concentration in feet below grade.
Depth Integral ($\mu Ci/m^2$)	Sum of the soil concentrations from grade to 24 ft multiplied by the space between readings (6 inches) multiplied by an assumed soil density (1.9 kg/L). Unit conversions are applied so the final units are microcuries per meter squared.
Depth Integral (in.*pCi/g)	The depth integral in simpler units. This is the sum of the soil concentrations from grade to 24 ft multiplied by the space between readings (6 in.).
Hot Upper Depth (ft)	This is a column heading for the rows listing the borehole log results. The other column headings in this row of the table show which detector result is being reported. "NaI" refers to the sodium iodide scintillation counter, while "ZP1320" refers to a Geiger counter.
Hot Lower Depth (ft)	The depth of the upper surface of the hot layer ignoring the effect of penetrating gamma radiation. It is calculated as the "Depth at Peak" minus half the "Hot Thickness". If half the "Hot Thickness" exceeds 6 inches, then 6 inches is used rather than half the "Hot Thickness".
Hot Thickness (in.)	The depth of the lower surface of the hot layer based on the thickness at the peak concentration that will give the Depth Integral.
WAC Upper Depth (ft)	The depth integral divided by the peak soil concentration. In addition, the thickness is reduced due to calibration issues as described in the last section of Appendix B.
WAC Lower Depth (ft)	The smaller of the Hot Upper Depth or the depth with the largest rate of change in the soil concentration. The rate of change is soil concentration with depth will reach a maximum near the boundary between clean and contaminated soil.
WAC Thickness (in.)	The lower depth of contamination that exceeds 750 pCi/g. If the lower depth exceeds 15 ft then the "WAC Lower Depth" is set to 15 ft.
Hot Upper Depth (ft)	The thickness of soil that exceeds 750 pCi/g, inches. Calculated as the difference between the WAC upper and lower depths.
Peak Log Slope	The largest logarithmic slope observed at depths above the peak concentration. The logarithmic slopes are calculated as the common log (base 10) of the ratio of adjacent soil concentrations. The 6 inch gap between readings is not included.
Depth for Log Slope (ft)	Midpoint of the depth range selected for the peak slope. This is generally unrelated to either of the upper boundary definitions (Hot Layer or WAC Layer).

APPENDIX B

DESCRIPTION OF BOREHOLE LOGGING DATA USING MONTE CARLO N-PARTICLE CODE

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APPENDIX B

DESCRIPTION OF BOREHOLE LOGGING DATA USING MONTE CARLO N-PARTICLE CODE

B1.0 OBJECTIVE

Appendix B represents the borehole total gamma logs using Monte Carlo N-Particle code (MCNP). The change in detector count rate as it approaches a relatively thin layer of contaminated soil is of particular interest with regard to the method used to estimate total activity in the contaminated soil.

B1.1 GEOMETRY

The boreholes are steel pipes that were represented using an internal diameter of 5.1 cm (2 in.) with a wall thickness of 0.952 cm (0.375 in.).

The soil was represented using densities of 1.7 kg/L and 2.1 kg/L to observe the effect of soil density on the inferred radionuclide concentration and total inventory. The contaminated layers were centered at a depth of 3.8 m (12.5 ft) from the ground surface.

The sodium iodide (NaI) detector was represented as a cylinder with an outside diameter of 4.29 cm (1.69 in.) and a stainless steel wall thickness of 0.079 cm (0.031 in.). The NaI crystal has a length of 3.81 cm (1.5 in.). The top and bottom metal container thickness is 0.318 cm (0.125 in.). Thus, the overall length of the NaI detector is 4.445 cm (1.75 in.). The NaI detector is centered in the borehole.

The center of the detector was positioned at various elevations relative to the horizontal centerline of the contaminated soil layer. These elevations are listed in Tables B-1 and B-2. Table B-1 shows the elevations above waste centerline in units of inches; Table B-1 shows the detector elevations relative to the ground surface in units of centimeters.

Table B-1. Detector Elevations (in Inches) Relative to the Soil Layer Centerline. (2 Pages)

File ID	Case 1 2 Inch[a]	Case 2 4 Inch[a]	Case 3 6 Inch[a]	Case 4 8 Inch[a]	Case 5 12 Inch[a]	Case 6 18 Inch[a]	Case 7 24 Inch[a]
Case A[b]	0	0	0	0	0	0	0
Case B	1	1	2	2	2	5	6
Case C	3	2	3	4	4	7	8
Case D	5	4	5	6	6	9	10
Case E	7	6	7	8	8	11	12
Case F	13	8	9	10	10	13	14
Case G	19	14	15	16	12	15	16

Table B-1. Detector Elevations (in Inches) Relative to the Soil Layer Centerline. (2 Pages)

File ID	Case 1 2 Inch[a]	Case 2 4 Inch[a]	Case 3 6 Inch[a]	Case 4 8 Inch[a]	Case 5 12 Inch[a]	Case 6 18 Inch[a]	Case 7 24 Inch[a]
Case H	25	20	21	22	18	21	18
Case I	NA	26	27	28	24	27	24
Case J	NA	NA	NA	NA	30	33	30
Case K	NA	NA	NA	NA	NA	NA	36

[a] Shows the contaminated soil layer thickness.
[b] The center of the detector at the same elevation as the horizontal centerline of the contaminated soil layer. The row with the detector at the boundary between contaminated and uncontaminated soil depends on the soil thickness. For example, the 12 in. layer (Case 5) has the boundary at 6 in. from the centerline (Case D).
For each contaminated soil layer thickness the vertical distance away from the contaminated soil is the same, namely, 2, 4, 6, 12, 18, and 24 in.
NA = not applicable.

In Tables B-1 and B-2 the identity of the cases depends on the column and row designators. For example, the input and output files for the 6 in. soil layer at the contaminated soil boundary (3 in. from the centerline) are designated "3C."

The first row in each table is the elevation of the waste centerline (12.5 ft below the ground surface). The row at the boundary between contaminated and clean soil depends on the layer thickness. The detector positions above the waste and relative to this boundary are all the same, namely, 2, 4, 6, 12, 18, 24 in. from the boundary.

Table B-2. Detector Elevations (in Centimeters) Relative to the Ground Surface.

File ID	Case 1 2 Inch[a]	Case 2 4 Inch[a]	Case 3 6 Inch[a]	Case 4 8 Inch[a]	Case 5 12 Inch[a]	Case 6 18 Inch[a]	Case 7 24 Inch[a]
Case A[b]	-381.00	-381.00	-381.00	-381.00	-381.00	-381.00	-381.00
Case B	-378.46	-378.46	-375.92	-375.92	-375.92	-368.30	-365.76
Case C	-373.38	-375.92	-373.38	-370.84	-370.84	-363.22	-360.68
Case D	-368.30	-370.84	-368.30	-365.76	-365.76	-358.14	-355.60
Case E	-363.22	-365.76	-363.22	-360.68	-360.68	-353.06	-350.52
Case F	-347.98	-360.68	-358.14	-355.60	-355.60	-347.98	-345.44
Case G	-332.74	-345.44	-342.90	-340.36	-350.52	-342.90	-340.36
Case H	-317.50	-330.20	-327.66	-325.12	-335.28	-327.66	-335.28
Case I	NA	-314.96	-312.42	-309.88	-320.04	-312.42	-320.04
Case J	NA	NA	NA	NA	-304.80	-297.18	-304.80
Case K	NA	NA	NA	NA	NA	NA	-289.56

[a] Shows the contaminated soil layer thickness.
[b] The center of the detector at the same elevation as the horizontal centerline of the contaminated soil layer, which is 12.5 ft below the ground surface.
The listed detector positions are above the contaminated layer centerline. The detector positions below the waste centerline are assumed to have the same results as those above the waste centerline.
For each contaminated soil layer thickness the vertical distance above the contaminated soil is the same, namely, 2, 4, 6, 12, 18, and 24 in.
NA = not applicable.

B1.2 COMPOSITIONS

The NaI detector has trace amounts of thallium iodide to improve scintillation light yield. The thallium was ignored and NaI (Tl) was modeled as pure NaI. For input to MCNP, the atom fraction of sodium is 50 percent and the atom fraction of iodine is 50 percent. The NaI crystal has a density of 3.67 kg/L.

The stainless steel surrounding the NaI detector was represented using weight percents of 1 percent silicon, 19 percent chromium, 2 percent manganese, 68 percent iron, and 10 percent nickel. The stainless steel density was 8 kg/L.

The borehole casing was represented as pure iron with a density of 7.86 kg/L.

Air was represented using the US Standard Atmosphere at a temperature of 20°C and a relative humidity of 40 percent. The weight percents of each element are 0.064 percent hydrogen, 75.101 percent nitrogen, 23.552 percent oxygen and 1.283 percent argon. The density of the air was 0.0012 kg/L.

The final material was the soil surrounding the borehole casing. The soil composition is shown in Table B-3. It was taken from WHC-SD-HWV-TI-020, *Soil Density and Mass Attenuation Coefficients for use in Shielding Calculations at HWVP*. Densities of 1.7 kg/L and 2.1 kg/L were used.

Table B-3. Assumed Soil Composition.

Element	Weight Fraction		Element	Weight Fraction
Hydrogen	0.617%		Phosphorus	0.222%
Oxygen	47.331%		Potassium	1.068%
Sodium	1.678%		Calcium	5.969%
Magnesium	2.722%		Titanium	1.425%
Aluminum	6.864%		Manganese	0.151%
Silicon	22.889%		Iron	9.064%

The composition shown uses the average basalt concentration given in WHC-SD-HWV-TI-020, *Soil Density and Mass Attenuation Coefficients for use in Shielding Calculations at HWVP*, adding only moisture.

B1.3 PHOTON SOURCE

The main source of photon radiation is Cs-137. About 94.43 percent of the Cs-137 decays end with Ba-137 in an excited nuclear state (Ba-137m). Ba-137m decays to its ground state by emitting a photon with energy 661.7 keV. About 9.9 percent of the photons interact with the orbital electrons. Thus the rate at which 662 keV photons are emitted from a 1 μCi source of Cs-137 is calculated:

$$(37{,}000 \text{ decays/s per } \mu\text{Ci})(0.9443)(0.901) = 31{,}480 \text{ photon/s per } \mu\text{Ci Cs-137}$$

Because of the limited range of the photons in soil, the region of contaminated soil that contributes to the detector reading was taken to be 60 cm for the low density soil (1.7 kg/L) and 50 cm for the high density soil (2.1 kg/L). This was based on a few cases with different soil thickness to find the smallest thickness adequate to represent the much larger thickness around the borehole.

Table B-4 shows the total photon source strength used in the MCNP input for the various soil layers and thicknesses. The assumed soil concentration is 1 x 10^{-6} Ci/g Cs-137 with Ba-137m in secular equilibrium.

Table B-4. Total Source Strength for Soil with 1 μCi/g Cs-137.

Thickness of Soil, inches	Density: 1.7 g/cc Outer radius: 60 cm	Density: 2.1 g/cc Outer radius: 50 cm
2	3.067E+09	2.627E+09
4	6.133E+09	5.253E+09
6	9.200E+09	7.880E+09
8	1.227E+10	1.051E+10
12	1.840E+10	1.576E+10
18	2.760E+10	2.364E+10
24	3.680E+10	3.152E+10

The total source strength is 662 keV photons per second.
The soil inner radius is 3.493 cm (1.375 in.).

B1.4 PHOTON FLUENCE TO EXPOSURE RATE CONVERSION

For comparison with calibration work done with the actual NaI detector used in the borehole logging, the exposure rates at each elevation were computed for each waste thickness. These calculations required conversion of the photon flux into an exposure rate using the point detector tally (Tally 5) in MCNP. The conversion factors given in Goldstein, 1959, *Fundamental Aspects of Reactor Shielding*, were used (Table B-5).

Table B-5. Exposure Rate per Unit Photon Flux. (2 Pages)

Photon Energy, MeV	mR/h per photon/cm^2/s	Photon Energy, MeV	mR/h per photon/cm^2/s	Photon Energy, MeV	mR/h per photon/cm^2/s
0.0100	3.051E-03	0.100	1.524E-04	1.000	1.833E-03
0.0115	2.264E-03	0.115	1.778E-04	1.145	2.044E-03
0.0131	1.713E-03	0.131	2.079E-04	1.311	2.269E-03
0.0150	1.282E-03	0.150	2.460E-04	1.501	2.511E-03
0.0172	9.556E-04	0.172	2.917E-04	1.719	2.769E-03

Table B-5. Exposure Rate per Unit Photon Flux. (2 Pages)

Photon Energy, MeV	mR/h per photon/cm^2/s	Photon Energy, MeV	mR/h per photon/cm^2/s	Photon Energy, MeV	mR/h per photon/cm^2/s
0.0197	7.139E-04	0.197	3.449E-04	1.968	3.046E-03
0.0225	5.371E-04	0.225	4.052E-04	2.254	3.343E-03
0.0258	4.025E-04	0.258	4.763E-04	2.581	3.665E-03
0.0296	3.040E-04	0.296	5.580E-04	2.955	4.010E-03
0.0338	2.353E-04	0.338	6.469E-04	3.384	4.389E-03
0.0387	1.856E-04	0.387	7.488E-04	3.875	4.805E-03
0.0444	1.515E-04	0.444	8.649E-04	4.437	5.262E-03
0.0508	1.307E-04	0.508	9.906E-04	5.080	5.771E-03
0.0582	1.197E-04	0.582	1.131E-03	5.817	6.346E-03
0.0666	1.175E-04	0.666	1.285E-03	6.661	6.987E-03
0.0763	1.225E-04	0.763	1.454E-03	7.627	7.719E-03
0.0873	1.342E-04	0.873	1.635E-03	8.733	8.550E-03

Values are from Goldstein, 1959, *Fundamental Aspects of Reactor Shielding*, page 17.

B1.5 MCNP RESULTS

MCNP Version 4c was used in these calculations. This software comes from Los Alamos National Laboratory and meets current Fluor Hanford Software Quality Assurance requirements as described in HNF-26564, *Requirements and Management Plan: Use of MCNP Version 4C for Safety Significant and Safety Class Applications at Fluor Hanford.* The default photon interaction libraries were used in the calculations.

For the NaI detector each detector elevation required a different input file. The 1.7 kg/L cases begin with the letter "W" while the 2.1 kg/L cases begin with the letter "Z". For example, the file name "Z3C" indicates the soil density is 2.1 kg/L, layer thickness is 6 in., and the detector elevation is 3 in. above the waste centerline. A sample NaI detector input file is shown in Attachment A.

The detector tally (Tally 8, or energy distribution of pulses in a detector) was used for the NaI detector. Results were tallied in two energy bins, 0 to 0.01 MeV and 0.01 to 0.7 MeV. Only the second bin was used to indicate the detector response results shown in Tables B-6 and B-7.

Table B-6. NaI Detector Response at Density 1.7 kg/L. (2 Pages)

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
Centerline	3.01E+06	5.23E+06	6.91E+06	8.11E+06	9.70E+06	1.08E+07	1.10E+07
Near Center	NA	NA	NA	NA	9.32E+06	9.79E+06	1.06E+07
Between	NA	4.97E+06	6.09E+06	7.61E+06	NA	NA	1.01E+07

Table B-6. NaI Detector Response at Density 1.7 kg/L. (2 Pages)

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
Near Boundary	NA	NA	NA	NA	8.09E+06	8.56E+06	8.55E+06
Boundary	2.65E+06	4.13E+06	4.87E+06	5.29E+06	5.64E+06	5.89E+06	5.86E+06
2 Inch	1.48E+06	2.24E+06	2.65E+06	2.91E+06	3.20E+06	3.17E+06	3.16E+06
4 Inch	7.66E+05	1.20E+06	1.46E+06	1.57E+06	1.66E+06	1.71E+06	1.70E+06
6 Inch	4.28E+05	6.63E+05	7.83E+05	8.52E+05	9.16E+05	9.25E+05	9.42E+05
12 Inch	6.79E+04	1.07E+05	1.29E+05	1.38E+05	1.58E+05	1.56E+05	1.60E+05
18 Inch	1.14E+04	1.87E+04	2.33E+04	2.56E+04	2.59E+04	2.81E+04	2.91E+04
24 Inch	2.28E+03	3.60E+03	4.05E+03	4.56E+03	5.43E+03	5.21E+03	5.97E+03
Relative Errors Reported by MCNP							
Centerline	1.01%	1.08%	1.15%	1.23%	1.38%	1.60%	1.83%
Near Center	NA	NA	NA	NA	1.41%	1.68%	1.86%
Between	NA	1.11%	1.23%	1.27%	NA	NA	1.35%
Near Boundary	NA	NA	NA	NA	1.07%	1.27%	1.04%
Boundary	1.08%	0.86%	1.12%	1.08%	1.04%	1.25%	0.95%
2 Inch	1.02%	0.96%	1.08%	1.18%	1.20%	1.21%	1.08%
4 Inch	1.16%	1.30%	1.26%	1.40%	1.36%	1.42%	1.04%
6 Inch	1.34%	1.52%	1.40%	1.55%	1.42%	1.22%	0.81%
12 Inch	2.12%	2.39%	2.67%	2.98%	2.41%	2.10%	1.60%
18 Inch	3.67%	4.05%	4.45%	4.90%	3.44%	4.05%	3.75%
24 Inch	4.74%	5.33%	6.15%	6.70%	6.51%	8.14%	8.28%

NaI Detector response is measured in cps per μCi/g.
The MCNP Tally 8 was used over the energy range 0.01 to 0.7 MeV.
The row with the detector at the boundary is highlighted.
NA = not applicable.

Table B-7. NaI Detector Response at Density 2.1 kg/L. (2 Pages)

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
Centerline	3.34E+06	5.79E+06	7.53E+06	8.80E+06	1.02E+07	1.11E+07	1.15E+07
Near Center	NA	NA	NA	NA	9.89E+06	1.03E+07	1.10E+07
Between	NA	5.49E+06	6.64E+06	8.22E+06	NA	NA	1.03E+07
Near Boundary	NA	NA	NA	NA	8.55E+06	8.82E+06	8.81E+06
Boundary	2.96E+06	4.42E+06	5.11E+06	5.43E+06	5.73E+06	5.87E+06	5.85E+06
2 Inch	1.50E+06	2.21E+06	2.59E+06	2.76E+06	2.88E+06	2.91E+06	2.85E+06

Table B-7. NaI Detector Response at Density 2.1 kg/L. (2 Pages)

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
4 Inch	7.22E+05	1.09E+06	1.26E+06	1.32E+06	1.37E+06	1.40E+06	1.42E+06
6 Inch	3.57E+05	5.15E+05	6.01E+05	6.32E+05	6.75E+05	6.94E+05	6.96E+05
12 Inch	4.15E+04	6.30E+04	7.25E+04	7.60E+04	8.30E+04	8.28E+04	8.51E+04
18 Inch	5.53E+03	9.01E+03	1.05E+04	1.19E+04	1.27E+04	1.26E+04	1.50E+04
24 Inch	1.03E+03	1.79E+03	2.36E+03	2.66E+03	3.33E+03	3.81E+03	4.24E+03
Relative Errors Reported by MCNP							
Centerline	0.89%	0.95%	1.02%	1.09%	1.24%	1.46%	1.66%
Near Center	NA	NA	NA	NA	1.26%	1.52%	1.69%
Between	NA	0.98%	1.09%	1.13%	NA	NA	1.24%
Near Boundary	NA	NA	NA	NA	0.96%	1.16%	1.09%
Boundary	0.94%	0.77%	0.88%	0.98%	0.96%	1.16%	1.04%
2 Inch	0.94%	0.89%	1.01%	1.13%	1.17%	1.43%	1.18%
4 Inch	1.10%	1.10%	1.25%	1.41%	1.38%	1.55%	1.05%
6 Inch	1.36%	1.60%	1.48%	1.66%	1.53%	1.30%	1.06%
12 Inch	2.52%	2.89%	3.30%	3.72%	2.52%	2.67%	2.49%
18 Inch	4.87%	5.40%	6.13%	5.42%	4.54%	5.58%	4.84%
24 Inch	6.52%	6.98%	7.45%	8.11%	7.69%	8.30%	9.09%

NaI Detector response is measured in cps per μCi/g.
The MCNP Tally 8 was used over the energy range 0.01 to 0.7 MeV.
The row with the detector at the boundary is highlighted.
NA = not applicable.

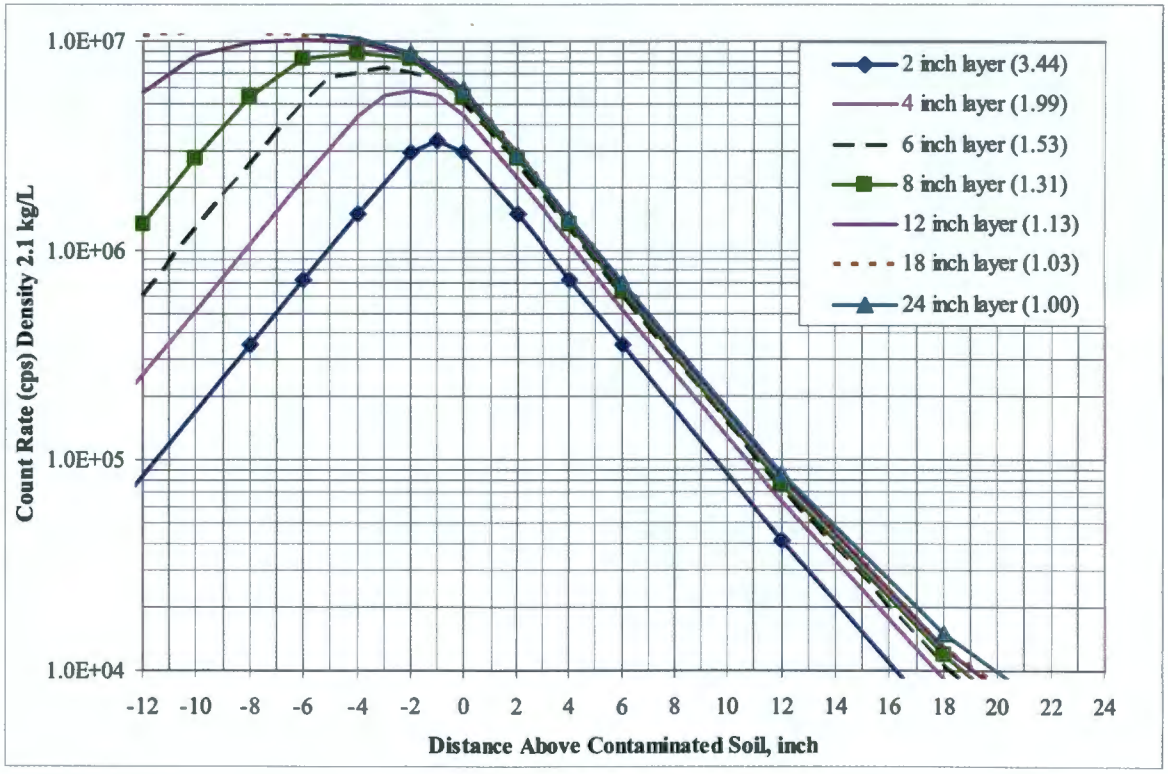
The NaI detector response results are graphed in Figures B-1 and B-2. Note that the curves are lined up relative to the boundary between contaminated and clean soil. The two graphs are similar, differing mainly in the logarithmic slope above the contaminated soil.

The 24 in. thick layer was assumed to be infinitely thick because the detector reading changes less than 5 percent when the detector is 6 in. from the waste centerline. Also, the real NaI detector was calibrated using an effectively infinite source. The 24 in. MCNP results will be used to represent the detector calibration.

To observe the effect of soil density, Table B-8 shows the ratios of the MCNP results. The detector response numbers in Table B-6 are divided by the corresponding numbers in Table B-7. The ratios near the contaminated soil are close to 1 and become larger as the detector moves away from the waste. Thus the local soil density has little effect on the detector response as long as the detector is near the contaminated soil layer.

Figure B-1. NaI Detector Response per Unit Soil Concentration, Soil Density is 1.7 kg/L.

Figure B-2. NaI Detector Response per Unit Soil Concentration, Soil Density is 2.1 kg/L.



Note that the centerline results for the 24 in. thick layer are largely independent of soil density. Table B-8 shows a 4 percent difference for the Tally 8 results and a 0.3 percent difference for the Tally 5 results. This means the translation of instrument readings (counts per second) into soil concentration (microcuries per gram) is largely independent of the soil density.

The contaminated layer thickness has an appreciable effect on the detector response. The numbers shown in parentheses in the legends of Figures B-1 and B-2 are the scale factors needed to correct an instrument calibrated for an infinite thickness. They are calculated as the ratio of centerline results. For example, the soil concentration near a layer 4 in. thick should be adjusted upward by a factor of 2.11 (soil density 1.7 kg/L) or 1.99 (soil density 2.1 kg/L).

Table B-8. Effect of Soil Density on MCNP Results.

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
Ratio of Tally 8 Results (cps per µCi/g)							
Centerline	0.90	0.90	0.92	0.92	0.95	0.97	0.96
Near center	NA	NA	NA	NA	0.94	0.95	0.97
Between	NA	0.91	0.92	0.93	NA	NA	0.97
Near boundary	NA	NA	NA	NA	1.06	1.03	1.03
Boundary	0.90	0.94	0.95	0.97	0.99	1.00	1.00
2 Inch	0.99	1.02	1.03	1.06	1.11	1.09	1.11
4 Inch	1.06	1.11	1.15	1.19	1.21	1.22	1.20
6 Inch	1.20	1.29	1.30	1.35	1.36	1.33	1.35
12 Inch	1.64	1.70	1.78	1.81	1.91	1.89	1.88
18 Inch	2.06	2.07	2.22	2.15	2.03	2.22	1.94
24 Inch	2.22	2.00	1.71	1.71	1.63	1.37	1.41
Ratio of Tally 5 Results (mR/h per µCi/g)							
Centerline	0.90	0.92	0.95	0.94	0.96	0.99	1.00
Near center	NA	NA	NA	NA	0.95	1.00	0.97
Between	NA	0.94	0.93	0.94	NA	NA	0.97
Near boundary	NA	NA	NA	NA	0.95	0.99	0.95
Boundary	0.91	0.92	0.97	0.97	0.99	1.01	1.02
2 Inch	0.99	1.03	1.07	1.06	1.10	1.11	1.09
4 Inch	1.09	1.15	1.16	1.19	1.23	1.21	1.24
6 Inch	1.26	1.27	1.30	1.29	1.38	1.38	1.36
12 Inch	1.69	1.80	1.81	1.84	1.86	1.88	1.88
18 Inch	2.22	2.35	2.62	2.31	2.05	2.17	2.14
24 Inch	2.32	2.23	1.98	2.11	1.92	1.84	1.65

The ratios are calculated as the 1.7 kg/L result divided by the 2.1 kg/L result.
The row with the detector at the boundary is highlighted.
NA = not applicable.

For the exposure rate determinations, all 7 detector positions were run in one case using a point detector Tally 5. Results are listed in Tables B-9 and B-10. The file naming convention used was the letter "R" followed by the soil layer designator (1 to 7) and ending with either "A" or "C" to indicate which soil density. For example, the file name "R3A" indicates a soil density of 1.7 kg/L and a waste thickness of 6 in. A sample exposure rate calculation input file is shown in Attachment B. Table B-11 evaluates the effect of soil density.

Table B-9. Exposure Rates at Density 1.7 kg/L.

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
Centerline	2.33E+02	4.03E+02	5.31E+02	6.07E+02	7.04E+02	7.81E+02	8.08E+02
Near center	NA	NA	NA	NA	6.80E+02	7.22E+02	7.56E+02
Between	NA	3.83E+02	4.46E+02	5.52E+02	NA	NA	7.04E+02
Near boundary	NA	NA	NA	NA	5.95E+02	6.13E+02	6.07E+02
Boundary	2.01E+02	3.01E+02	3.58E+02	3.81E+02	4.00E+02	4.10E+02	4.13E+02
2 Inch	1.01E+02	1.51E+02	1.80E+02	1.91E+02	2.01E+02	2.06E+02	2.05E+02
4 Inch	4.98E+01	7.58E+01	8.98E+01	9.63E+01	1.03E+02	1.04E+02	1.05E+02
6 Inch	2.61E+01	3.89E+01	4.67E+01	5.03E+01	5.32E+01	5.53E+01	5.39E+01
12 Inch	3.77E+00	5.89E+00	6.99E+00	7.61E+00	8.10E+00	8.38E+00	8.40E+00
18 Inch	6.32E-01	1.03E+00	1.36E+00	1.31E+00	1.42E+00	1.42E+00	1.45E+00
24 Inch	1.15E-01	1.85E-01	2.24E-01	2.41E-01	2.90E-01	3.04E-01	2.81E-01
Relative Errors Reported by MCNP							
Centerline	0.41%	0.28%	1.40%	0.34%	0.35%	1.06%	0.98%
Near center	NA	NA	NA	NA	0.46%	1.73%	0.43%
Between	NA	1.85%	0.34%	0.25%	NA	NA	0.38%
Near boundary	NA	NA	NA	NA	0.35%	0.75%	0.49%
Boundary	0.23%	0.24%	1.28%	0.45%	0.51%	0.72%	1.94%
2 Inch	0.28%	0.40%	1.17%	0.70%	0.57%	0.79%	0.66%
4 Inch	0.37%	0.48%	0.59%	0.62%	1.55%	0.80%	1.00%
6 Inch	1.99%	0.56%	1.34%	0.74%	0.98%	1.23%	0.90%
12 Inch	0.82%	1.20%	1.12%	1.67%	1.57%	1.70%	1.70%
18 Inch	3.14%	8.72%	14.70%	2.94%	3.65%	2.74%	3.22%
24 Inch	3.62%	3.51%	4.08%	3.54%	4.21%	4.58%	3.23%

Exposure rates are shown in mR/h per μCi/g.
The MCNP point detector Tally 5 was used at each detector elevation.
The row with the detector at the boundary is highlighted.
NA = not applicable.

Table B-10. Exposure Rates at Density 2.1 kg/L.

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
Centerline	2.58E+02	4.41E+02	5.61E+02	6.46E+02	7.34E+02	7.93E+02	8.05E+02
Near center	NA	NA	NA	NA	7.16E+02	7.25E+02	7.77E+02
Between	NA	4.09E+02	4.78E+02	5.90E+02	NA	NA	7.26E+02
Near boundary	NA	NA	NA	NA	6.23E+02	6.22E+02	6.39E+02
Boundary	2.20E+02	3.26E+02	3.69E+02	3.93E+02	4.03E+02	4.06E+02	4.07E+02
2 Inch	1.01E+02	1.46E+02	1.69E+02	1.80E+02	1.83E+02	1.86E+02	1.87E+02
4 Inch	4.57E+01	6.61E+01	7.71E+01	8.06E+01	8.36E+01	8.63E+01	8.49E+01
6 Inch	2.08E+01	3.06E+01	3.58E+01	3.91E+01	3.85E+01	4.02E+01	3.98E+01
12 Inch	2.23E+00	3.26E+00	3.87E+00	4.14E+00	4.36E+00	4.46E+00	4.47E+00
18 Inch	2.85E-01	4.40E-01	5.21E-01	5.67E-01	6.91E-01	6.54E-01	6.76E-01
24 Inch	4.97E-02	8.30E-02	1.13E-01	1.14E-01	1.51E-01	1.65E-01	1.70E-01
Relative Errors Reported by MCNP							
Centerline	0.41%	0.34%	0.27%	0.28%	0.31%	0.60%	0.52%
Near center	NA	NA	NA	NA	0.99%	0.49%	0.79%
Between	NA	0.26%	0.31%	0.37%	NA	NA	0.38%
Near boundary	NA	NA	NA	NA	0.61%	0.29%	1.40%
Boundary	0.31%	1.12%	0.57%	1.13%	0.73%	0.61%	0.73%
2 Inch	0.41%	0.33%	0.89%	1.31%	0.36%	0.49%	0.99%
4 Inch	0.92%	0.51%	1.37%	0.47%	0.63%	1.14%	0.71%
6 Inch	0.99%	0.67%	0.92%	3.00%	0.63%	1.19%	1.07%
12 Inch	1.02%	1.38%	1.19%	1.26%	1.51%	2.28%	2.19%
18 Inch	2.62%	2.95%	3.55%	2.54%	5.42%	3.05%	3.91%
24 Inch	3.29%	2.94%	6.70%	2.27%	4.53%	5.59%	3.14%

Exposure rates are shown in mR/h per μCi/g.
The MCNP point detector Tally 5 was used at each detector elevation.
The row with the detector at the boundary is highlighted.
NA = not applicable.

Table B-11. Sodium Iodide Detector Response. (2 Pages)

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
Soil Density is 1.7 kg/L							
Centerline	1.29E+04	1.30E+04	1.30E+04	1.34E+04	1.38E+04	1.38E+04	1.37E+04
Near center	NA	NA	NA	NA	1.37E+04	1.36E+04	1.41E+04
Between	NA	1.30E+04	1.36E+04	1.38E+04	NA	NA	1.43E+04
Near boundary	NA	NA	NA	NA	1.36E+04	1.40E+04	1.41E+04
Boundary	1.32E+04	1.37E+04	1.36E+04	1.39E+04	1.41E+04	1.43E+04	1.42E+04

Table B-11. Sodium Iodide Detector Response. (2 Pages)

Detector Elevation	Thickness of the Contaminated Soil Layer						
	2 Inch	4 Inch	6 Inch	8 Inch	12 Inch	18 Inch	24 Inch
2 Inch	1.47E+04	1.48E+04	1.47E+04	1.52E+04	1.59E+04	1.54E+04	1.55E+04
4 Inch	1.54E+04	1.58E+04	1.62E+04	1.63E+04	1.62E+04	1.64E+04	1.62E+04
6 Inch	1.64E+04	1.70E+04	1.68E+04	1.69E+04	1.72E+04	1.67E+04	1.75E+04
12 Inch	1.80E+04	1.82E+04	1.85E+04	1.81E+04	1.96E+04	1.87E+04	1.90E+04
18 Inch	1.81E+04	1.81E+04	1.71E+04	1.95E+04	1.82E+04	1.97E+04	2.01E+04
24 Inch	1.98E+04	1.95E+04	1.81E+04	1.89E+04	1.87E+04	1.71E+04	2.12E+04
Soil Density is 2.1 kg/L							
Centerline	1.29E+04	1.31E+04	1.34E+04	1.36E+04	1.39E+04	1.41E+04	1.43E+04
Near center	NA	NA	NA	NA	1.38E+04	1.42E+04	1.41E+04
Between	NA	1.34E+04	1.39E+04	1.39E+04	NA	NA	1.42E+04
Near boundary	NA	NA	NA	NA	1.37E+04	1.42E+04	1.38E+04
Boundary	1.34E+04	1.35E+04	1.39E+04	1.38E+04	1.42E+04	1.44E+04	1.44E+04
2 Inch	1.48E+04	1.51E+04	1.53E+04	1.53E+04	1.57E+04	1.56E+04	1.52E+04
4 Inch	1.58E+04	1.64E+04	1.64E+04	1.64E+04	1.64E+04	1.62E+04	1.67E+04
6 Inch	1.71E+04	1.68E+04	1.68E+04	1.62E+04	1.75E+04	1.73E+04	1.75E+04
12 Inch	1.86E+04	1.93E+04	1.87E+04	1.84E+04	1.90E+04	1.86E+04	1.90E+04
18 Inch	1.94E+04	2.05E+04	2.01E+04	2.10E+04	1.84E+04	1.93E+04	2.21E+04
24 Inch	2.07E+04	2.16E+04	2.09E+04	2.34E+04	2.20E+04	2.30E+04	2.49E+04

Detector Response is measured in cps per mR/h.
The NaI response factor is calculated as the Tally 8 result (cps per μCi/g) divided by the Tally 5 result (mR/h per μCi/g).
The row with the detector at the boundary is highlighted.
NaI = sodium iodide.

If the exposure rates in Tables B-9 and B-10 were plotted, the graphs would be very similar to Figures B-3 and B-4. Ratios of Table B-9 numbers divided by Table B-10 numbers are shown in the lower half of Table B-8. For detectors located near the waste layer the ratios are close to 1. Soil density has little effect on the exposure rate unless the detector is more than a few inches from the contaminated layer. The layer thickness has the greatest effect on exposure rate.

The detector response can be restated in terms of counts per second per millirem per hour. This is calculated as the MCNP Tally 8 result (cps per μCi/g) divided by the Tally 5 result (mR/h per μCi/g). These numbers are shown in Table B-10 and plotted in Figures B-3 and B-4. When stated this way (cps per mR/h) the detector response is largely independent of both soil density and distance from the contaminated soil layer. Note that the numbers in parentheses in the legend in these figures are the calibration correction factors for thin slabs based on exposure rates. A complete listing of these correction factors is given in Table B-12.

Figure B-3. Detector Response per Unit Exposure Rate, Soil Density is 1.7 kg/L.

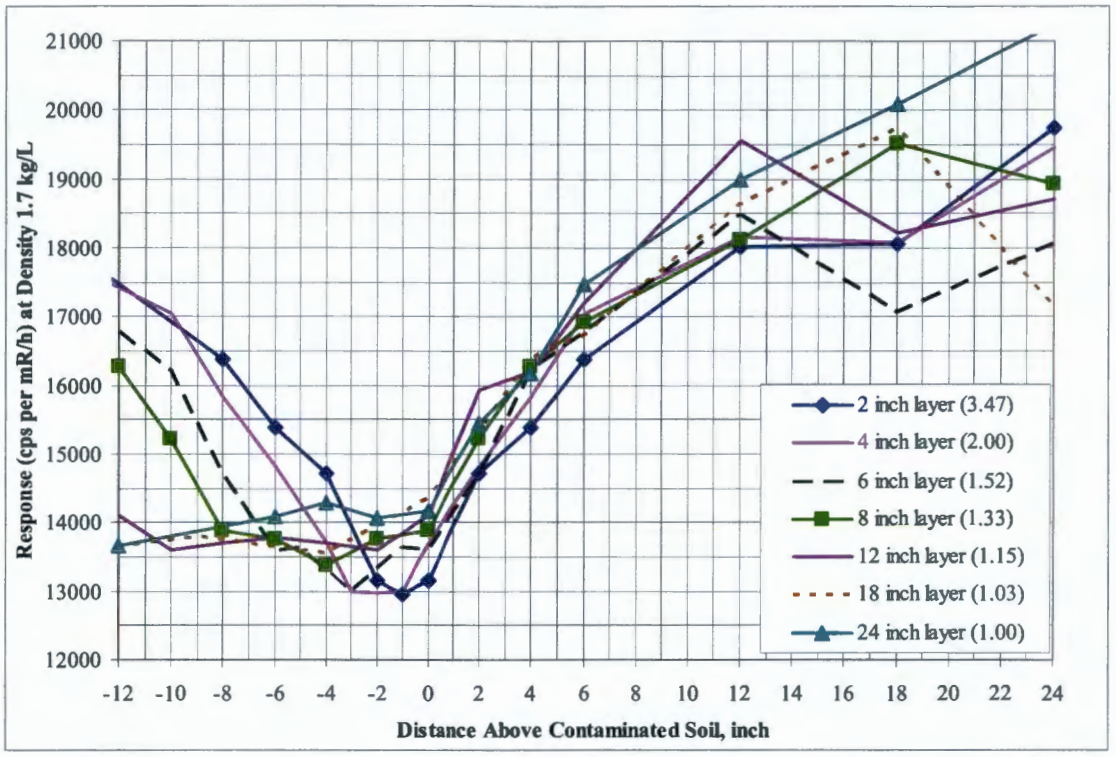


Figure B-4. Detector Response per Unit Exposure Rate, Soil Density is 2.1 kg/L.

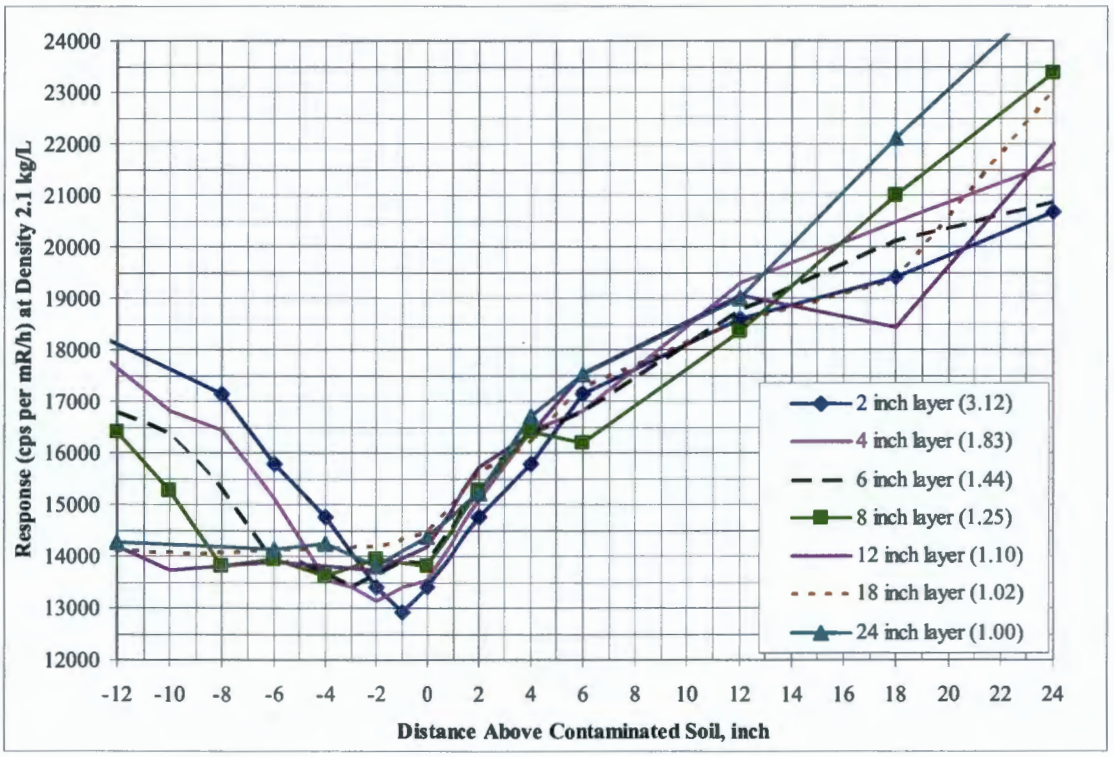


Table B-12. Summary of Calibration Correction Factors.

Soil Layer Thickness	Soil Density is 1.7 kg/L		Soil Density is 2.1 kg/L	
	NaI	Exposure	NaI	Exposure
2 Inch	3.66	3.47	3.44	3.12
4 Inch	2.11	2.00	1.99	1.83
6 Inch	1.60	1.52	1.53	1.44
8 Inch	1.36	1.33	1.31	1.25
12 Inch	1.14	1.15	1.13	1.10
18 Inch	1.02	1.03	1.03	1.02
24 Inch	1.00	1.00	1.00	1.00

The ratios on this table are computed using MCNP detector results at the waste centerline. The values are the 24-in. waste centerline result divided by the centerline result at the waste thickness shown in the first column.
MCNP = Monte Carlo N-Particle code.

B1.6 TOTAL INVENTORY IN A LAYER

The total inventory in a layer involves integration over depth and area. The area integration is based on several borehole logs spaced to define the extent and general horizontal trends in the amount of subsurface contamination. The integration with depth is described.

Because the source used in the MCNP calculations is a known quantity, the calculation of the integral based on the borehole log can be compared with the actual source. This comparison is shown in Table B-13.

Table B-13. Comparison of Depth Integration with Actual Source.

Soil Layer Thickness	Depth Integral, Ci/m^2			Percent Differences	
	Actual	NaI	Exposure	NaI	Exposure
Soil Density is 1.7 kg/L					
2 Inch	0.086	0.095	0.091	10.3%	5.3%
4 Inch	0.173	0.188	0.181	9.1%	4.5%
6 Inch	0.259	0.279	0.269	7.6%	3.8%
8 Inch	0.345	0.370	0.353	7.1%	2.3%
12 Inch	0.518	0.550	0.527	6.2%	1.7%
18 Inch	0.777	0.819	0.794	5.4%	2.2%
24 Inch	1.036	1.090	1.047	5.1%	1.0%
Soil Density is 2.1 kg/L					
2 Inch	0.107	0.114	0.113	6.6%	5.9%
4 Inch	0.213	0.223	0.224	4.7%	4.8%
6 Inch	0.320	0.332	0.330	3.7%	3.2%
8 Inch	0.427	0.439	0.440	2.9%	3.0%
12 Inch	0.640	0.652	0.654	1.9%	2.1%
18 Inch	0.960	0.976	0.969	1.6%	0.9%
24 Inch	1.280	1.302	1.298	1.7%	1.4%

The depth integral is the sum of the products of average soil concentration, the thickness of the soil represented by that average concentration, and the soil density.

In Table B-13 the detector readings are taken at face value and assumed to represent a particular soil concentration according to the infinite source calibration represented by the 24 in. waste thickness results. The measured soil concentration is then the borehole log result calculated by MCNP (counts per second or mR per hour) divided by the 24 in. layer result at the waste centerline (cps per μCi/g or mR/h per μCi/g). Thus, from Tables B-6 and B-7 or B-9 and B-10 these measured soil concentrations turn out to be less than 1 μCi/g.

The next step is a simple numeric integration using the trapezoid rule and integrating from the ground surface to a depth far below the contaminated soil layer. The average soil concentration is multiplied by the soil thickness and the products are summed. The sum is multiplied by the soil density to convert from units of (in. times microcuries per gram) to units of (curies per meter squared). The conversion factor follows:

$$(\text{soil density, kg/L})(0.0254\ \text{m/inch})(1000\ \text{g/kg})(1000\ \text{L/m}^3)(1 \times 10^{-6}\ \text{Ci/}\mu\text{Ci}) = 0.0254 \times \text{density}$$

The actual value for the depth integral is the product of the soil concentration (1 μCi/g), the layer thickness (in inches), the soil density (in kg/L), and the above conversion factor.

As shown in Table B-13, the depth integrals are within 10 percent of the actual depth integral independent of the layer thickness. Thus, there is no need to correct the borehole log for thin sources. Also, it is noteworthy that the depth integral is largely independent of the soil density.

B1.7 LAYER THICKNESS

The approximate thickness of the contaminated soil layer can be calculated from the depth integral (units of inch times microcuries per gram) and the peak value of the soil concentration (units of microcuries per gram). The ratio of depth integral to peak soil concentration is the thickness of soil at the observed peak concentration.

Because the soil concentrations need to be corrected for the finite thickness of contaminated soil, while the depth integral does not need this correction, the calculated soil thicknesses will depend on the soil thickness (Table B-14).

In Table B-14 the depth integral is shown the product of the soil concentrations and thicknesses down the borehole without conversion to units of microcuries per meter squared. Because a unit soil concentration was used in the MCNP calculations, the depth integral turns out to be close to the thickness of the contaminated soil layer. When the depth integrals shown in Table B-14 are divided by the peak soil concentrations, the results are the average waste thicknesses. As the waste layer thickness decreases, the apparent thickness of the waste becomes larger than the actual thickness. Most of this difference with the actual thickness comes from basing the calibration on an infinitely thick layer rather than the actual thickness.

A function was created to relate the waste thickness computed as the ratio of depth integral to peak concentration to the actual waste layer thickness. The numbers shown in Table B-14 for a soil density of 1.7 kg/L and the NaI detector were used in the least squares fit. The correction function is shown below. The fitting constants are A=-2.9606, B=33.509, C=-142.34, D=270.36,

and E=-192.04. This function should only be applied to uncorrected thicknesses ranging from 8 to 25 in.

Corrected Thickness Function :

$$T_{Corrected} = \mathrm{Exp}\left(A\,P^5 + B\,P^4 + C\,P^3 + D\,P^2 + E\right)$$

$$\text{where} \quad T_o = \frac{\text{Depth Integral}}{\text{Peak Concentration}} \quad \text{and} \quad P = \ln(T_o)$$

Table B-14. Calculation of Average Waste Layer Thickness.

Soil Layer Thickness	Peak Concentration (µCi/g)		Depth Integral (in.*µCi/g)		Waste Thickness (in.es)	
	NaI	Exposure	NaI	Exposure	NaI	Exposure
Soil Density is 1.7 kg/L						
2 Inch	0.273	0.288	2.21	2.11	8.08	7.31
4 Inch	0.474	0.499	4.37	4.18	9.21	8.37
6 Inch	0.626	0.658	6.46	6.23	10.32	9.47
8 Inch	0.735	0.751	8.57	8.18	11.65	10.89
12 Inch	0.879	0.872	12.74	12.21	14.50	14.01
18 Inch	0.977	0.967	18.97	18.39	19.43	19.02
24 Inch	1.000	1.000	25.23	24.24	25.23	24.24
Soil Density is 2.1 kg/L						
2 Inch	0.291	0.321	2.13	2.12	7.33	6.60
4 Inch	0.503	0.547	4.19	4.19	8.32	7.66
6 Inch	0.655	0.697	6.22	6.19	9.50	8.88
8 Inch	0.765	0.803	8.23	8.24	10.75	10.27
12 Inch	0.887	0.911	12.23	12.26	13.79	13.45
18 Inch	0.969	0.984	18.29	18.16	18.88	18.45
24 Inch	1.000	1.000	24.41	24.34	24.41	24.34

The peak soil concentration is the ratio of the centerline MCNP result with the centerline result for the 24 in. thick layer.
The depth integral follows the trapezoid rule without the conversion to units of Ci/m^2 described in the text. In these units, and with unit soil concentration, the depth integrals approximate the actual waste thickness.
The Waste Thickness columns are calculated as the Depth Integral divided by the Peak Concentration.
NaI = sodium iodide.

B2.0 CONCLUSIONS

From the MCNP calculations the following lessons were learned.

1. The soil density has little effect on the instrument readings at the depth of the waste. For depths above and below the waste, higher soil density reduces the readings.
2. The calibration thickness is important. When calibrating using an effectively infinite thickness, the soil concentrations inferred at thin layers are underestimated significantly.
3. The depth integral is not strongly affected by the thickness or density of the waste layer.

4. The average soil thickness calculated as the ratio of the depth integral divided by the peak concentration can be corrected to give a more accurate indication of the waste thickness.

B3.0 REFERENCES

Goldstein, H., 1959, *Fundamental Aspects of Reactor Shielding*, Addison Wesley Publishing Co., Inc., Reading, Massachusetts.

HNF-26564, 2005, *Requirements and Management Plan: Use of MCNP Version 4C for Safety Significant and Safety Class Applications at Fluor Hanford*, Fluor Hanford, Inc., Richland, Washington.

WHC-SD-HWV-TI-020, 1992, *Soil Density and Mass Attenuation Coefficients for use in Shielding Calculations at HWVP*, Westinghouse Hanford Company, Richland, Washington.

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ATTACHMENT A

EXAMPLE MCNP INPUT FILE FOR THE NAI DETECTOR RESPONSE (Z3C.IN)

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ATTACHMENT A

EXAMPLE MCNP INPUT FILE FOR THE NAI DETECTOR RESPONSE (Z3C.IN)

```
NaI Detector, 6-inch Waste Layer, 3 inches Above Center
c    cell definitions
  1  0                (10:51:-56)                 $ outside world
  2  1  -2.100        -10    24    -51    56      $ soil around borehole
  3  2  -7.860        -24    23    -51    56      $ borehole casing
  4  3  -0.0012       -23          -51    52      $ air above detector
  5  3  -0.0012       -23    22    -52    55      $ air beside detector
  6  3  -0.0012       -23          -55    56      $ air below detector
  7  4  -8.00         -22          -52    53      $ detector can above
  8  4  -8.00         -22    21    -53    54      $ detector can side
  9  4  -8.00         -22          -54    55      $ detector can below
 10  5  -3.67         -21          -53    54      $ NaI detector

c  surface definitions
 10   CZ      50.0    $  outer boundary (100 cm -- same results)
c  walls
 21   CZ     2.143   $ NaI detector
 22   CZ     2.223   $ detector can
 23   CZ     2.540   $ borehole inner wall
 24   CZ     3.493   $ borehole outer wall
c  horizontal surfaces
 51   PZ       0.00     $ ground surface
 52   PZ   -371.158     $ detector can top
 53   PZ   -371.475     $ NaI top
 54   PZ   -375.285     $ NaI bottom
 55   PZ   -375.603     $ detector can bottom
 56   PZ   -792.480     $ bottom of borehole

MODE p
M1    $  Hanford Soil with 0.10 ml/cc Water
         1000.       -0.00617    $  Hydrogen
         8000.       -0.47331    $  Oxygen
        11000.       -0.01678    $  Sodium
        12000.       -0.02722    $  Magnesium
        13000.       -0.06964    $  Aluminum
        14000.       -0.22889    $  Silicon
        15000.       -0.00222    $  Phosphorus
        19000.       -0.01068    $  Potassium
        20000.       -0.05969    $  Calcium
        22000.       -0.01425    $  Titanium
        25000.       -0.00151    $  Manganese
        26000.       -0.09064    $  Iron
M2     $  plain iron to represent steel pipe
```

```
        26000.        -1.000      $  Iron
        COND=1
M3     $  Air at 20 C and 40.0% Relative Humidity
         1000.        -0.00064    $  Hydrogen
         7000.        -0.75101    $  Nitrogen
         8000.        -0.23552    $  Oxygen
        18000.        -0.01283    $  Argon
        GAS=1

M4     $  stainless steel
        14000.        -0.010      $  Silicon
        24000.        -0.190      $  Chromium
        25000.        -0.020      $  Manganese
        26000.        -0.680      $  Iron
        28000.        -0.100      $  Nickel
        COND=1
M5     $  pure sodium iodide (NaI)
        11000.         0.5        $  Sodium
        53000.         0.5        $  Iodine
IMP:p    0  1  1  1  1  1  1  1  1  1
PRINT    40 50 60 80
c     contaminated soil layer 6-inch thick at 12.5 ft depth
SDEF     wgt=7.890E+09    erg=0.6615    cel=2
         pos=0 0 -381.00    rad=d2    ext=d3    axs= 0 0 1
SI2    L   3.493    50.0
SP2    D -21    1
SI3        7.62
FC9    NaI Detector Count Rate, cps
F8:p     10
E8      0    0.01    0.7
NPS     2E+7
```

ATTACHMENT B

EXAMPLE MCNP INPUT FILE FOR EXPOSURE RATES IN THE BOREHOLE (R3A.IN)

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ATTACHMENT B

EXAMPLE MCNP INPUT FILE FOR EXPOSURE RATES IN THE BOREHOLE (R3A.IN)

```
6-inch Waste Layer, 1.7 kg/L Soil
c    cell definitions
  1  0                (10:51:-56)              $ outside world
  2  1  -1.700      -10   24   -51   56       $ soil around borehole
  3  2  -7.860      -24   23   -51   56       $ borehole casing
  4  3  -0.0012     -23        -51   56       $ air inside borehole

c  surface definitions
 10   SZ     60.0   $  outer boundary (100 cm -- same results)
c  walls
 23   CZ    2.540  $ borehole inner wall
 24   CZ    3.493  $ borehole outer wall
c  horizontal surfaces
 51   PZ      0.00     $ ground surface
 56   PZ   -792.480   $ bottom of borehole

MODE p
M1   $  Hanford Soil with 0.10 ml/cc Water
        1000.       -0.00617   $  Hydrogen
        8000.       -0.47331   $  Oxygen
       11000.       -0.01678   $  Sodium
       12000.       -0.02722   $  Magnesium
       13000.       -0.06564   $  Aluminum
       14000.       -0.22888   $  Silicon
       15000.       -0.00222   $  Phosphorus
       19000.       -0.01063   $  Potassium
       20000.       -0.03969   $  Calcium
       22000.       -0.01425   $  Titanium
       25000.       -0.00151   $  Manganese
       26000.       -0.03064   $  Iron
M2    $  plain iron to represent steel pipe
       26000.       -1.000     $  Iron
       DENS=1
M3    $  Air at 20 C and 40.0% Relative Humidity
        1000.       -0.00064   $  Hydrogen
        7000.       -0.75101   $  Nitrogen
        8000.       -0.23552   $  Oxygen
       18000.       -0.01283   $  Argon
       GAS=1
IMP:p   0  1  1  1
PRINT   40 50 60 80
c    contaminated soil layer 6-inch thick at 12.5 ft depth
SDEF    wgt=9.201E-19   erg=0.6615   cel=2
        pos=0 0 -381.10   rad=d2   ext=d3   axs= 0 0 1
SI2   L   3.493   60.0
SP2   D -21   1
SI3       7.62
c  Photon Exposure Rate per Unit Flux, mR/h per photon/cm2-s
DE0   log    0.0100    0.0115    0.0131    0.0150    0.0172    0.0197    0.0225
             0.0258    0.0296    0.0339    0.0387    0.0444    0.0508    0.0582
             0.0666    0.0763    0.0873    0.100     0.115     0.131     0.150
             0.172     0.197     0.225     0.258     0.296     0.339     0.387
             0.444     0.508     0.582     0.666     0.763     0.873     1.000
DF0   log  9.051E-03 2.264E-03 1.715E-03 1.282E-03 9.556E-04 7.139E-04 5.371E-04
           4.028E-04 3.041E-04 2.299E-04 1.856E-04 1.515E-04 1.307E-04 1.187E-04
           1.178E-04 1.225E-04 1.342E-04 1.524E-04 1.778E-04 2.078E-04 2.460E-04
           2.917E-04 3.448E-04 4.052E-04 4.766E-04 5.550E-04 6.468E-04 7.485E-04
           8.649E-04 9.906E-04 1.131E-03 1.285E-03 1.454E-03 1.635E-03 1.838E-03
```

```
FC5   Exposure Rate from Detectors in Borehole
F5:p    0.0    0.0    -381.000    3.0    $ Centerline
        0.0    0.0    -375.920    3.0    $ 2 inch
        0.0    0.0    -373.380    3.0    $ 3 inch
        0.0    0.0    -368.300    3.0    $ 5 inch
        0.0    0.0    -363.220    3.0    $ 7 inch
        0.0    0.0    -358.140    3.0    $ 9 inch
        0.0    0.0    -342.900    3.0    $ 15 inch
        0.0    0.0    -327.660    3.0    $ 21 inch
        0.0    0.0    -312.420    3.0    $ 27 inch
NPS    1E+8
```

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