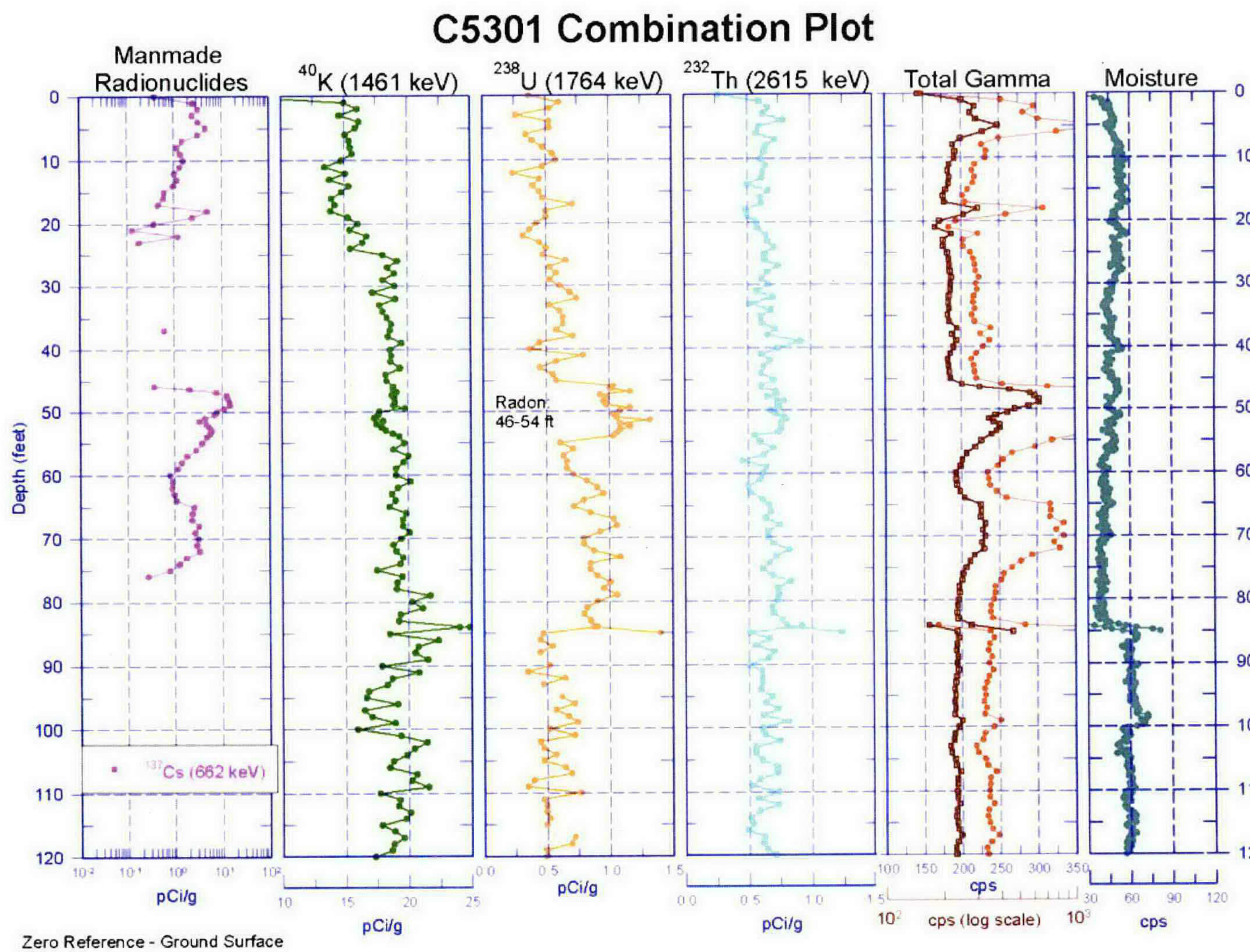
0085394

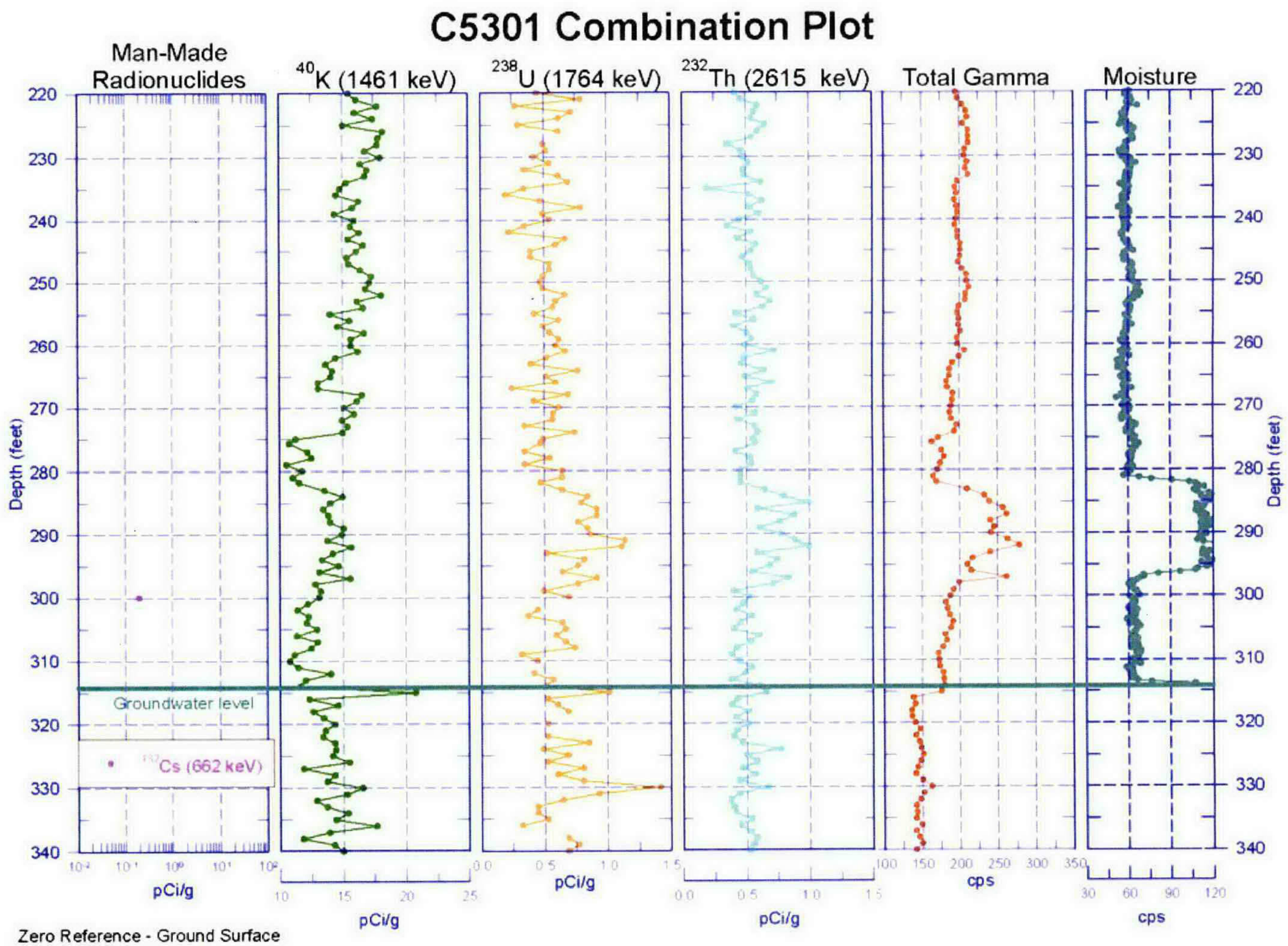
DOE/RL-2008-38

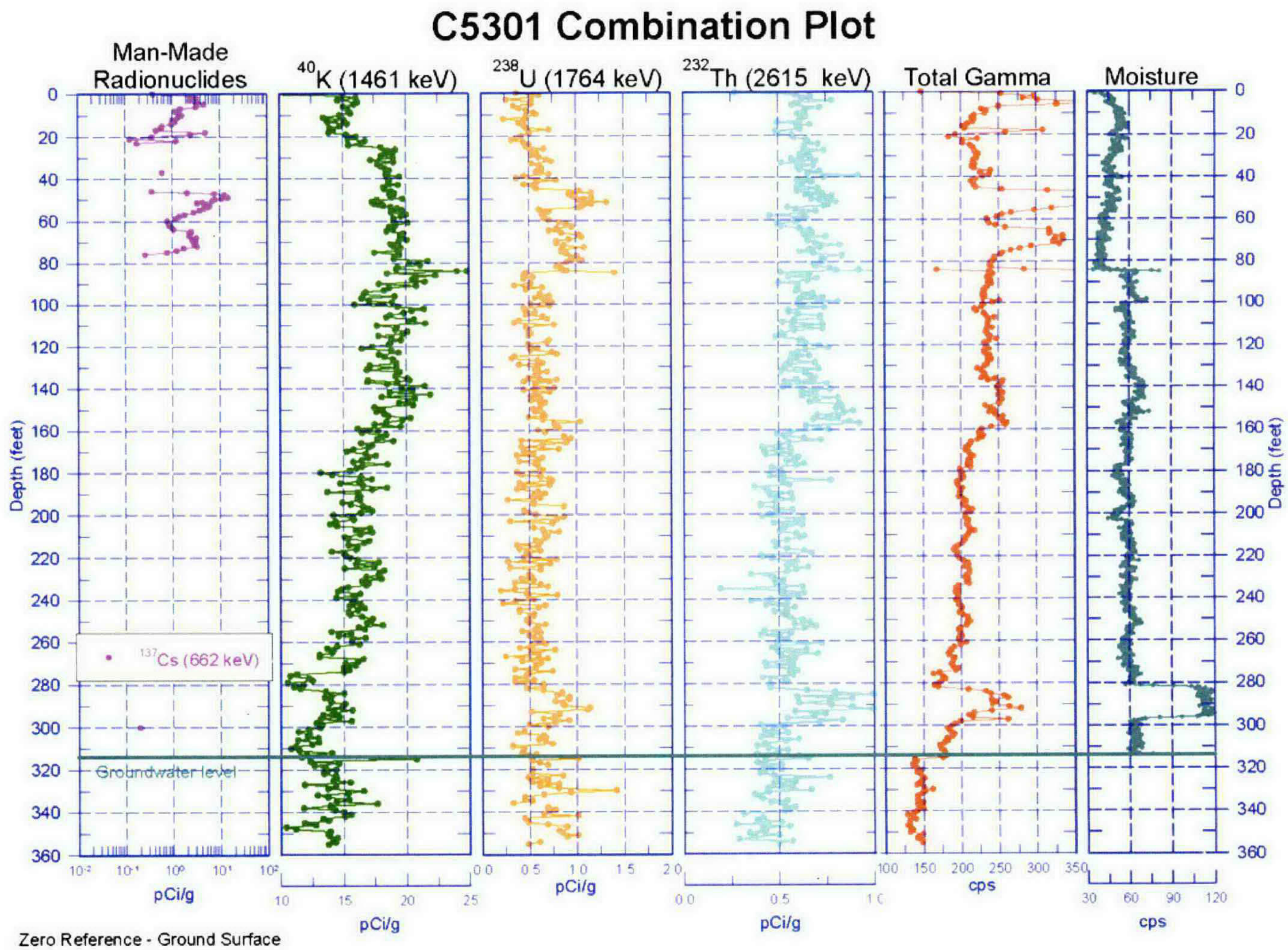
DRAFT A

SECTION

3 OF 3

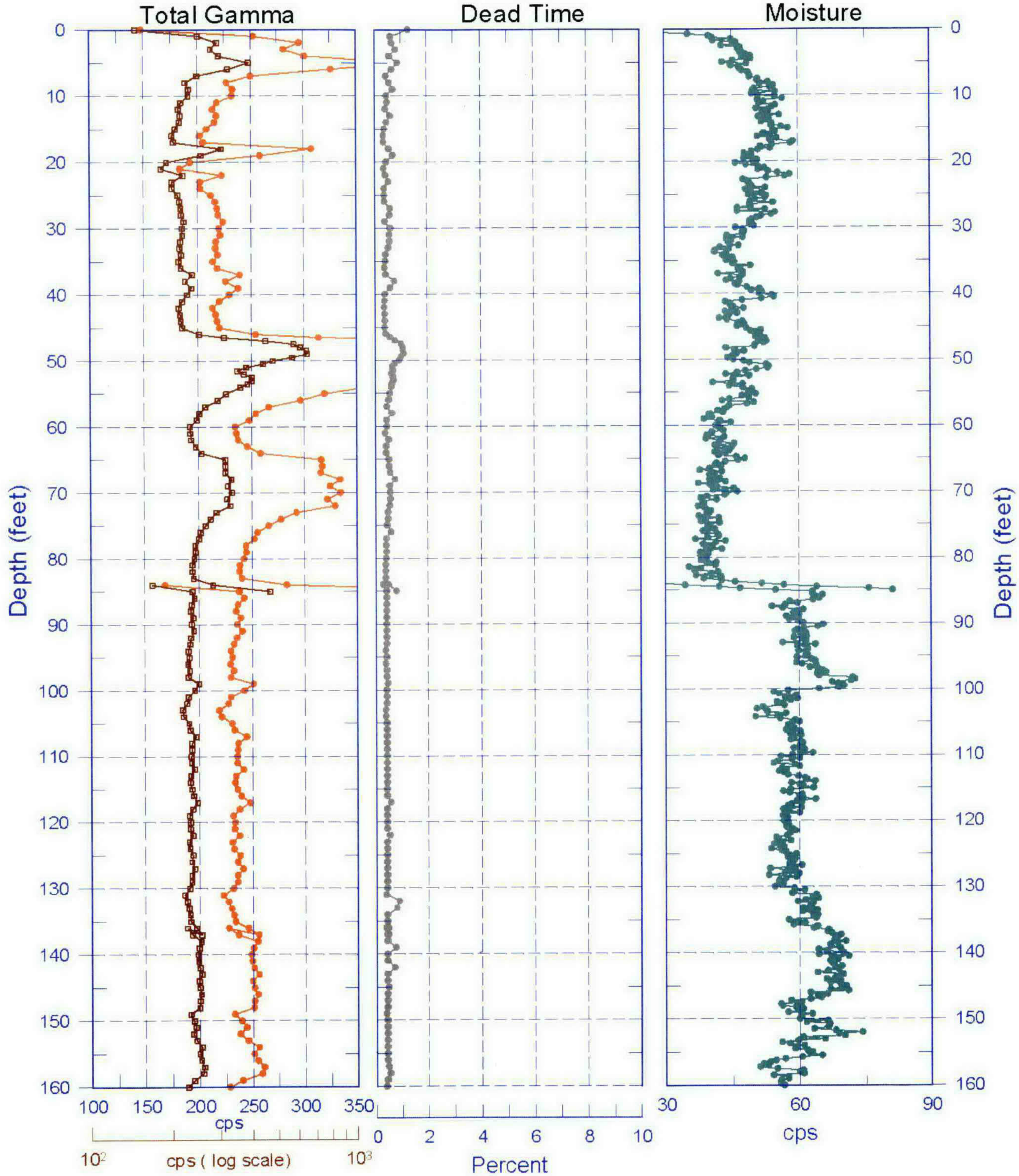

C5301 Combination Plot
Manmade Radionuclides
40K (1461 keV)
238U (1764 keV)
232Th (2615 keV)
Total Gamma
Moisture
Depth (feet)
137Cs (662 keV)
Radon
46-54 ft
pCi/g
cps
cps (log scale)
Zero Reference - Ground Surface


C5301 Combination Plot
Man-Made Radionuclides
^{40}K (1461 keV)
^{238}U (1764 keV)
^{232}Th (2615 keV)
Total Gamma
Moisture
Depth (feet)
Groundwater level
^{137}Cs (662 keV)
pCi/g
pCi/g
pCi/g
pCi/g
cps
cps
Zero Reference - Ground Surface


C5301 Combination Plot
Man-Made Radionuclides
40K (1461 keV)
238U (1764 keV)
232Th (2615 keV)
Total Gamma
Moisture
Depth (feet)
137Cs (662 keV)
Groundwater level
pCi/g
cps
Zero Reference - Ground Surface

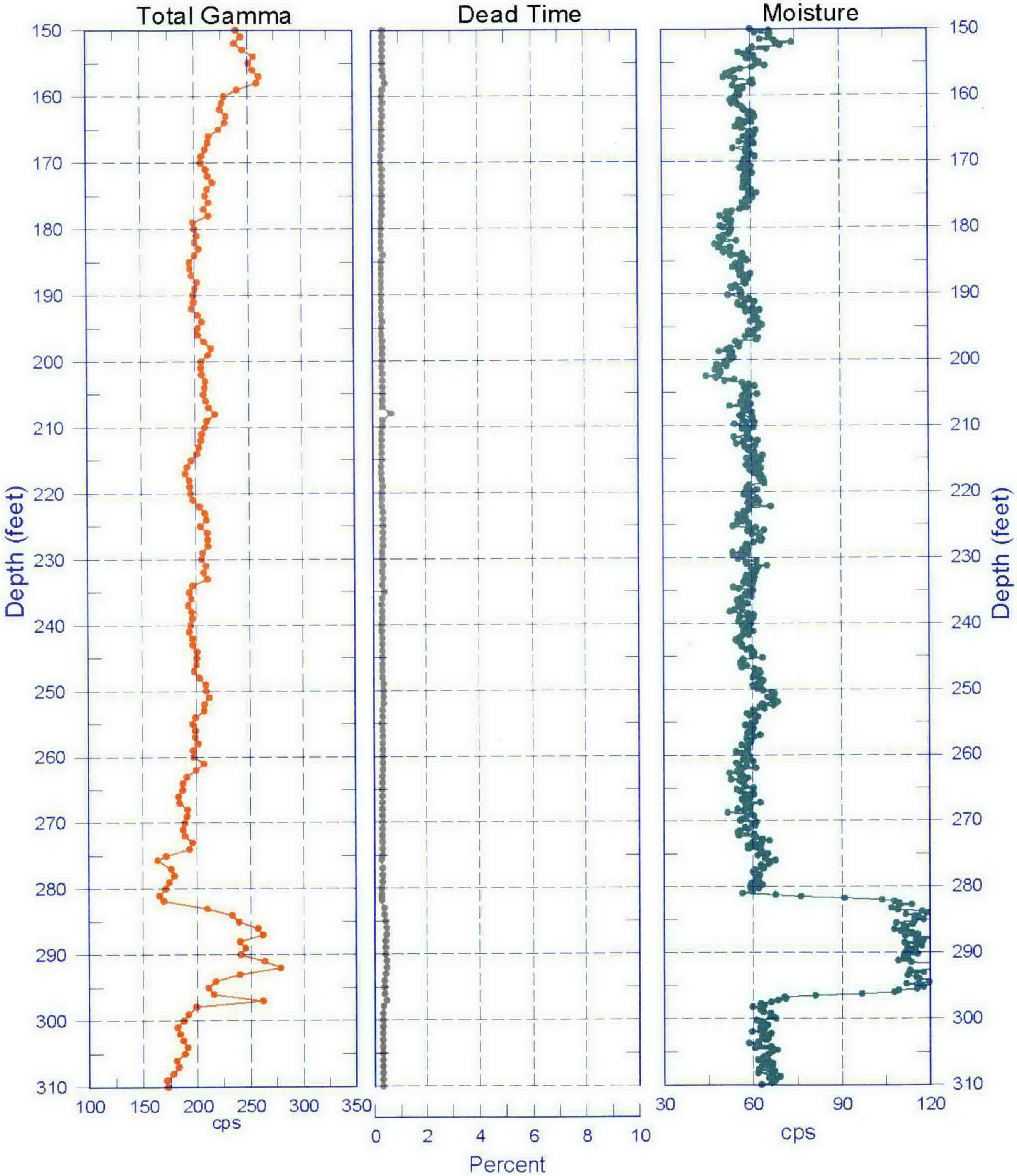
C5301

Total Gamma, Dead Time & Moisture



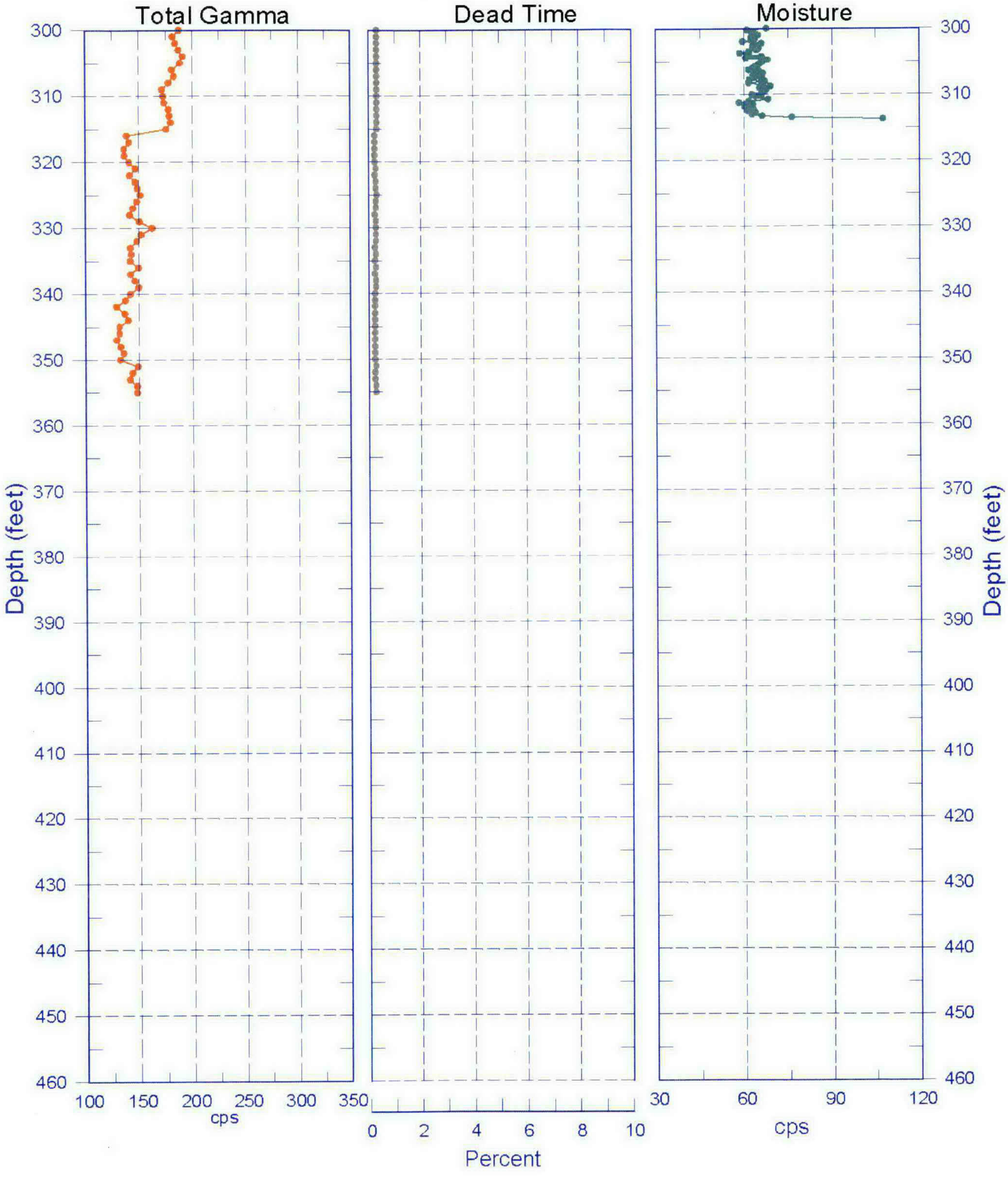
1 Reference - Ground Surface

C5301
Total Gamma, Dead Time & Moisture



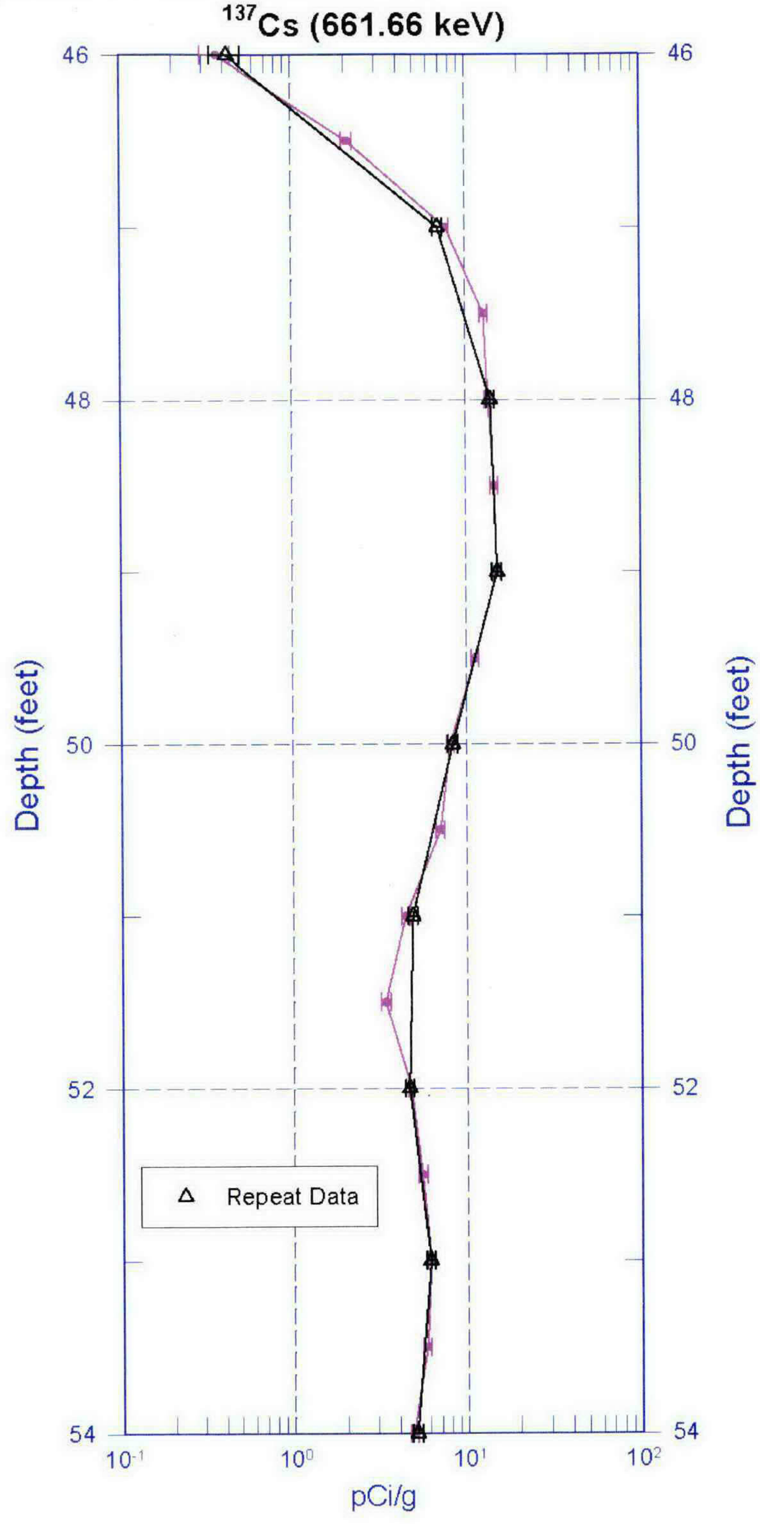
Reference - Ground Surface

C5301
Total Gamma, Dead Time & Moisture



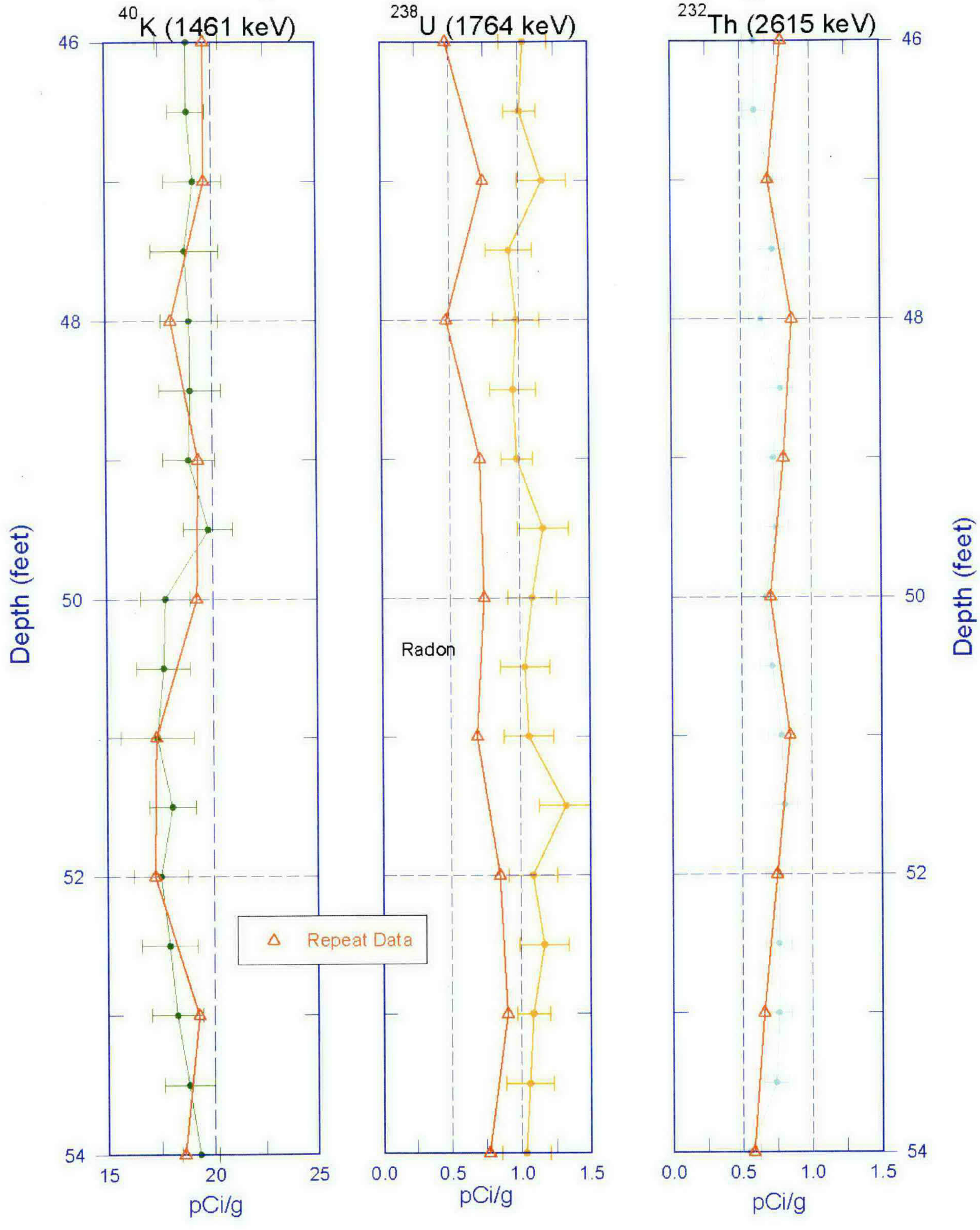
1 Reference - Ground Surface

C5301
Repeat of Manmade Radionuclides



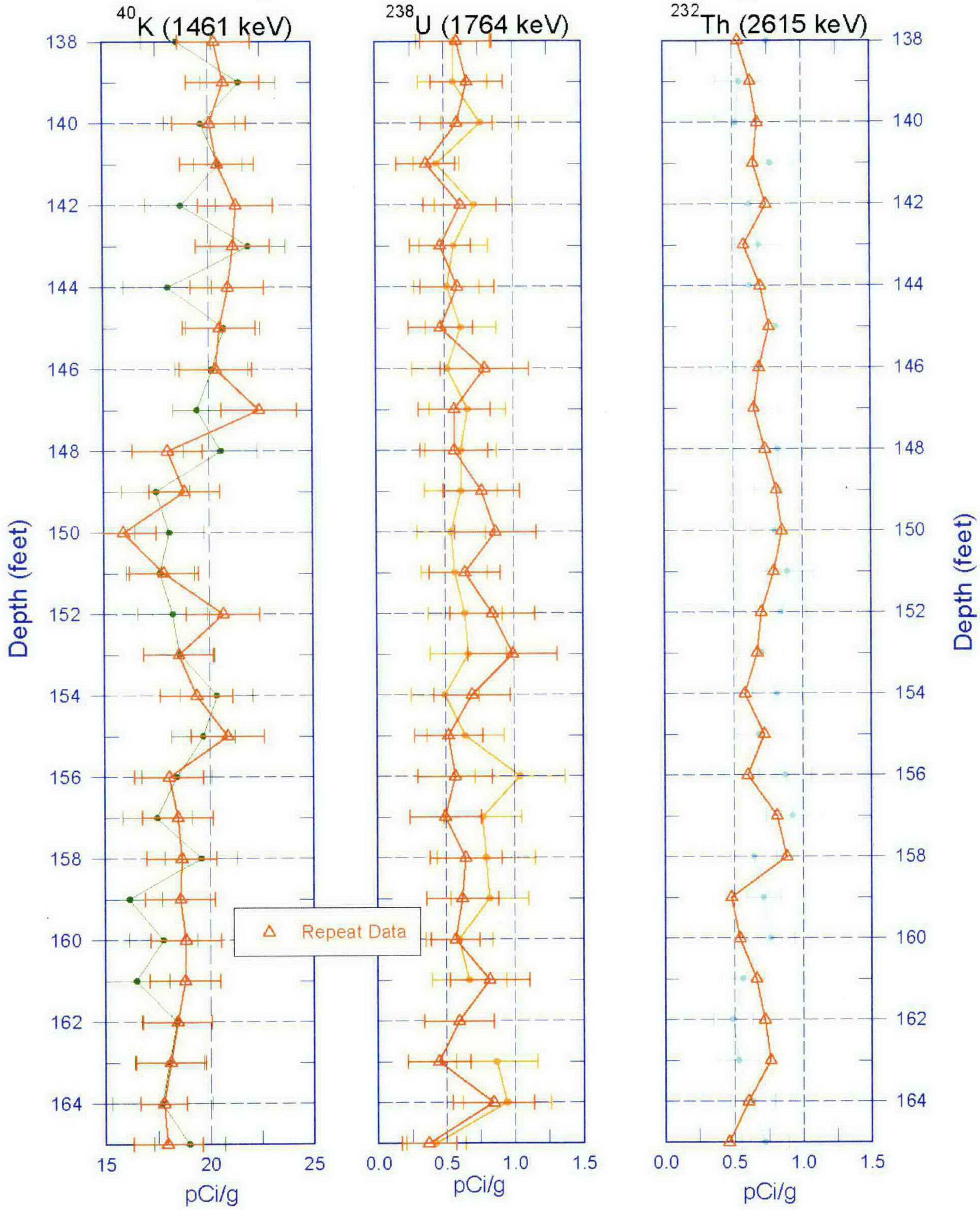
1 Zero Reference - Ground Surface

C5301
Repeat of Natural Gamma Logs



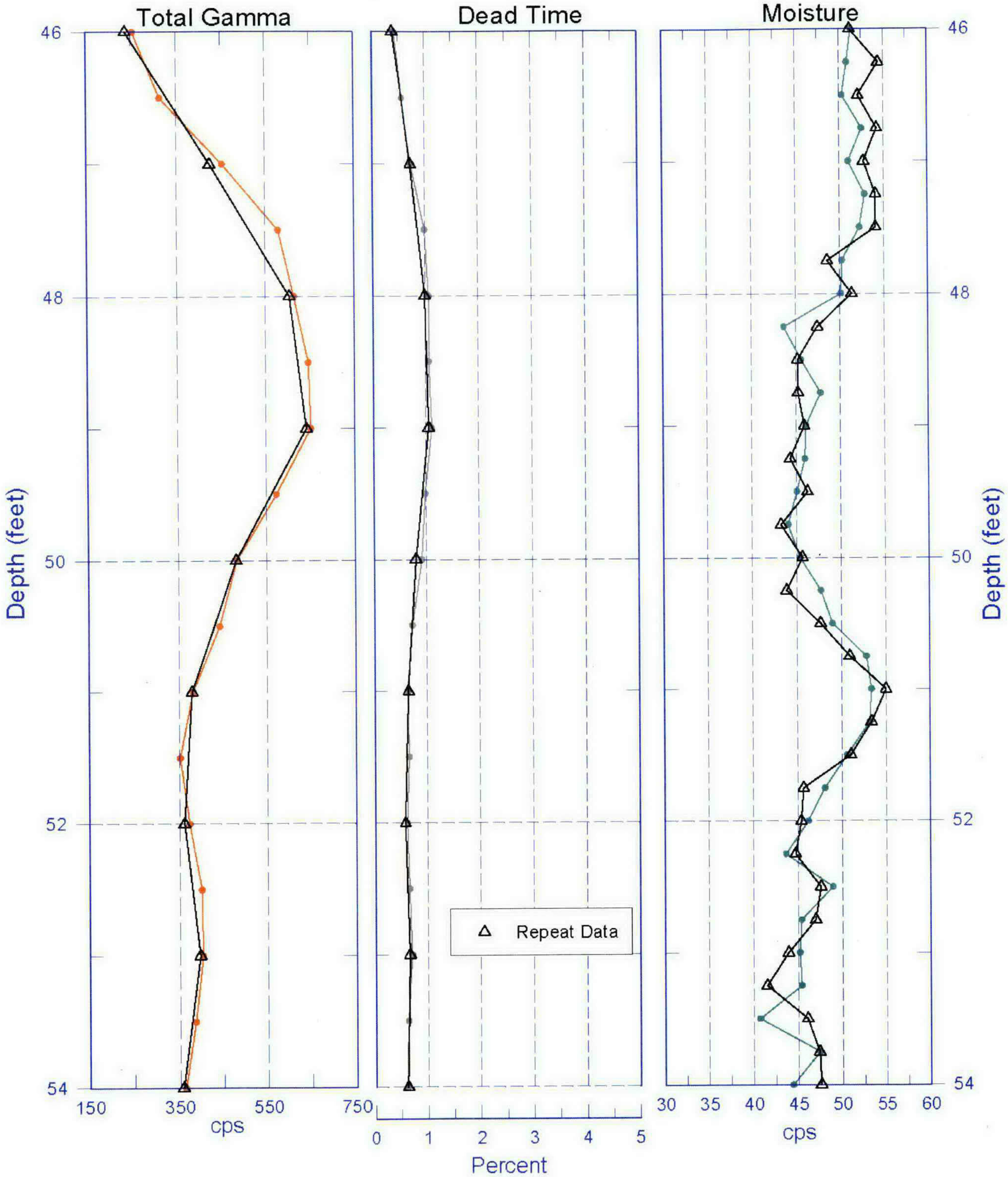
Zero Reference = Ground Surface

C5301
Repeat of Natural Gamma Logs



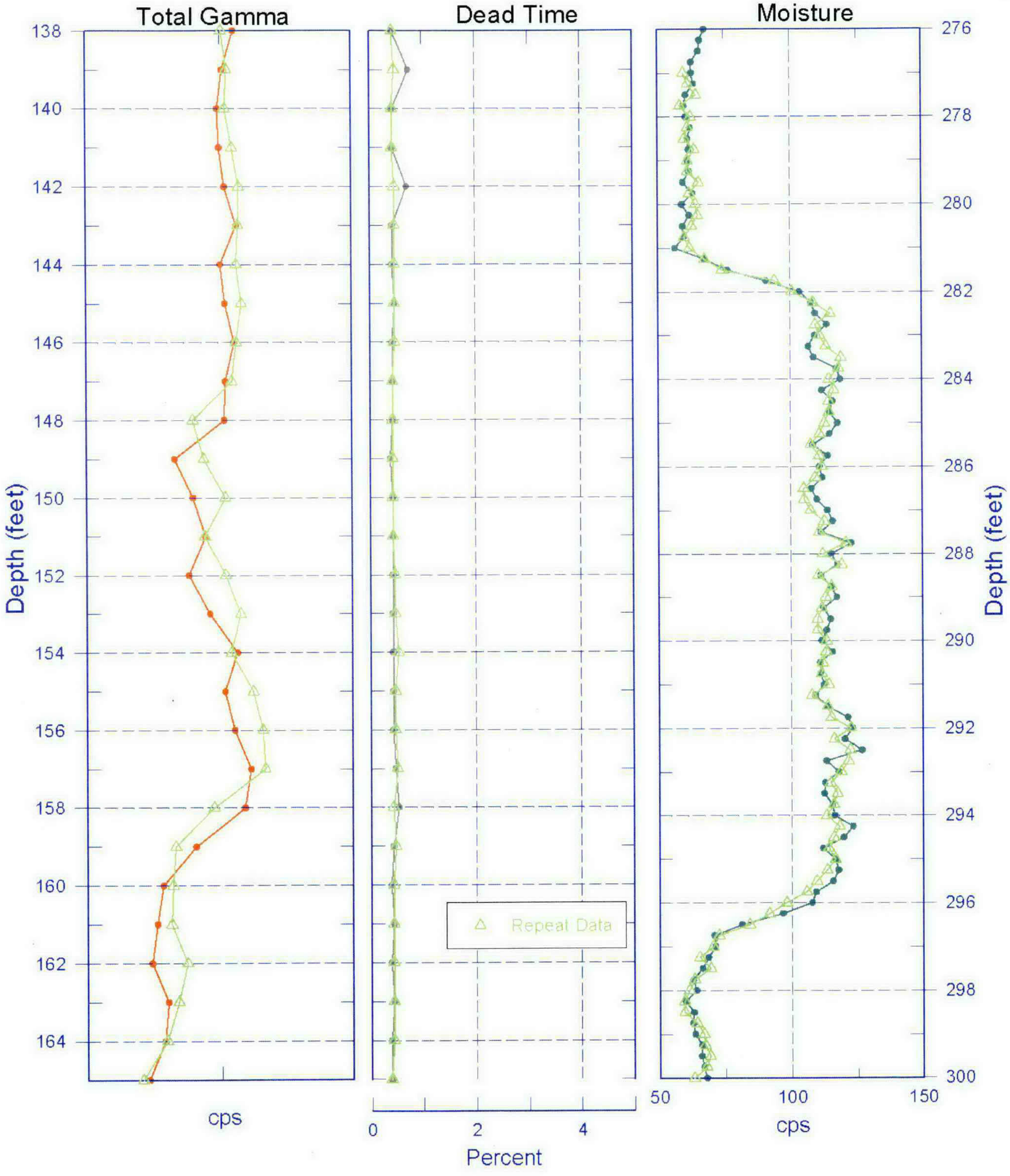
Zero Reference = Ground Surface

C5301
Repeat of Total Gamma, Dead Time & Moisture



1 Reference - Ground Surface

C5301
Repeat of Total Gamma, Dead Time & Moisture



Reference - Ground Surface

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Attachment B-6. Geophysical Log – Borehole 299-E24-54 (proximal to 216-A-4 Crib)

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DOE-EM/GJ878-2005

299-E24-54 (A5911)
Log Data Report

Borehole Information:

Borehole: 299-E24-54 (A5911)			Site: 216-A-4 Crib		
Coordinates (WA St Plane)		GWL[1] (ft): None		GWL Date: 04/07/05	
North (m)	East (m)	Drill Date	Ground Level Elevation (ft)	Total Depth (ft)	Type
135536.193	575224.407	01/55	716.0	102	Cable

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Top (ft)	Bottom (ft)
Welded Steel	2.05	6 5/8	6 1/8	1/4	2.05	102
Welded Steel	0	8 5/8	8	unknown	0	50

Borehole Notes:

The logging engineer measured the 6-in. casing and stickup using a steel tape. Measurements were rounded to the nearest 1/16 in. The 8-in. casing was not visible at the ground surface. Casing depths are derived from HWIS[2], which reports the borehole was originally drilled in 1955 to a depth of 50 ft. In 1982, the borehole was deepened to 102 ft with a 6-in. casing placed to total depth. The annulus between the 6-in. and 8-in. casings was grouted from 0 to 50 ft. The bottom 2 ft (100-102 ft) of the borehole was plugged with grout.

Logging Equipment Information:

Logging System:	Gamma 1E		Type:	SGLS (70%) SN: 34TP40587A
Calibration Date:	04/05	Calibration Reference:	DOE-EM/GJ865-2005	
		Logging Procedure:	MAC-HGLP 1.6.5, Rev. 0	

Spectral Gamma Logging System (SGLS) Log Run Information:

Log Run	1	2 Repeat	3		
Date	04/07/05	04/11/05	04/11/05		
Logging Engineer	Spatz	Spatz	Spatz		
Start Depth (ft)	99.5	50.5	38.5		
Finish Depth (ft)	39.5	39.5	2.5		
Count Time (sec)	100	100	100		
Live/Real	R	R	R		
Shield (Y/N)	N	N	N		
MSA Interval (ft)	1.0	1.0	1.0		
ft/min	N/A[3]	N/A	N/A		

Log Run	1	2 Repeat	3		
Pre-Verification	AE048CAB	AE049CAB	AE049CAB		
Start File	AE048000	AE049000	AE049012		
Finish File	AE048060	AE049011	AE049048		
Post-Verification	None	AE049CAA	AE049CAA		
Depth Return Error (in.)	0	N/A	0		
Comments	No fine gain adjustment.	No fine gain adjustment.	No fine gain adjustment.		

Logging Operation Notes:

Logging was conducted with a centralizer on the sonde. Logging data acquisition is referenced to the top of casing. Before logging the borehole was swabbed by the Health Physics Technician (HPT); no contamination was detected. An industrial hygiene technician checked for organic vapors at the well head and reported no hazardous vapors. A repeat section was collected in this borehole to evaluate system performance.

Analysis Notes:

Analyst:	Henwood	Date:	04/21/05	Reference:	GJO-HGLP 1.6.3, Rev. 0

Pre-run and post-run verifications for the logging system were performed before and after each day's data acquisition. The acceptance criteria were met. On April 7, 2005, the post-run verification spectra were collected but inadvertently not saved to a disk.

A combined casing correction for 0.572-in.-thick casing was applied to the log data between the ground surface and 50 ft. Below 50 ft a correction for 0.322-in.-thick casing was applied.

SGLS spectra were processed in batch mode using APTEC SUPERVISOR to identify individual energy peaks and determine count rates. Concentrations were calculated with an EXCEL worksheet template identified as G1EOct04.xls using efficiency functions and corrections for casing, water, and dead time as determined from annual calibrations. No corrections for dead time or water were necessary.

Log Plot Notes:

Separate log plots are provided for the man-made radionuclides (^{137}Cs and ^{60}Co) detected in the borehole, naturally occurring radionuclides (^{40}K, ^{238}U, ^{232}Th [KUT]), a combination of man-made, KUT, and dead time, and total gamma plotted with dead time. For each radionuclide, the energy value of the spectral peak used for quantification is indicated. Unless otherwise noted, all radionuclides are plotted in picocuries per gram (pCi/g). The open circles indicate the minimum detectable level (MDL) for each radionuclide. Error bars on each plot represent error associated with counting statistics only and do not include errors associated with the inverse efficiency function, dead time correction, casing corrections, or water corrections.

A plot of data acquired by Waste Management Federal Services Northwest in 1999, using the Radionuclide Logging System (RLS), is shown that provides a comparison to the current SGLS data. An historical gross gamma log acquired in 1963 (Additon et al. 1978) was re-digitized and included for comparison with the current total gamma log data.

Repeat log sections for the naturally occurring and man-made radionuclides are also included.

Results and Interpretations:

^{137}Cs and ^{60}Co were the man-made radionuclides detected in this borehole. ^{137}Cs was detected in two primary depth intervals between approximately 29 and 36 ft and between 64 and 91 ft. ^{137}Cs was also detected at approximately 1 pCi/g and below at a few other locations in the borehole. The maximum concentration was measured at approximately 55 pCi/g at 65.5 ft.

^{60}Co was detected between 29 and 54 ft and between 65 and 69 ft. The maximum concentration was measured at 2 pCi/g at 45.5 ft.

The comparison of RLS and SGLS data indicates good agreement and suggests no contaminant movement has occurred since 1999.

The historical gross gamma log showed elevated gamma activity between 28 and 45 ft. At the time of logging in 1963, the borehole was only 50 ft deep. ^{137}Cs and ^{60}Co were detected in this interval in 2005.

The repeat sections generally indicate good agreement of the naturally occurring KUT and man-made radionuclides.

References:

Additon, M.K., K.R. Fecht, T.L. Jones, and G.V. Last, 1978. *Scintillation Probe Profiles From 200 East Area Crib Monitoring Wells*, RHO-LD-28, Rockwell Hanford Operations, Richland, Washington.

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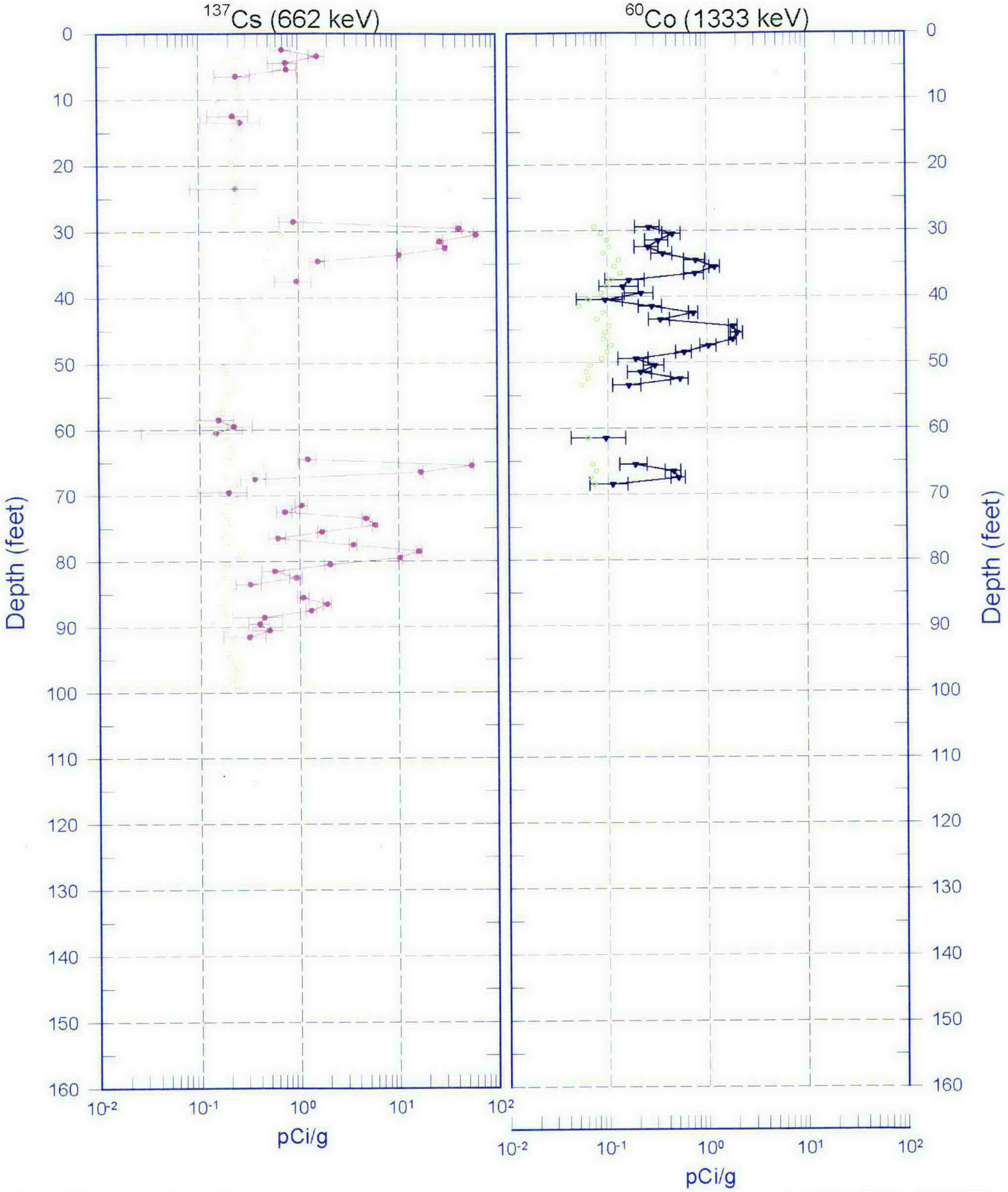
[1] GWL – groundwater level

[2] HWIS – Hanford Wells Information System

[3] N/A – not applicable

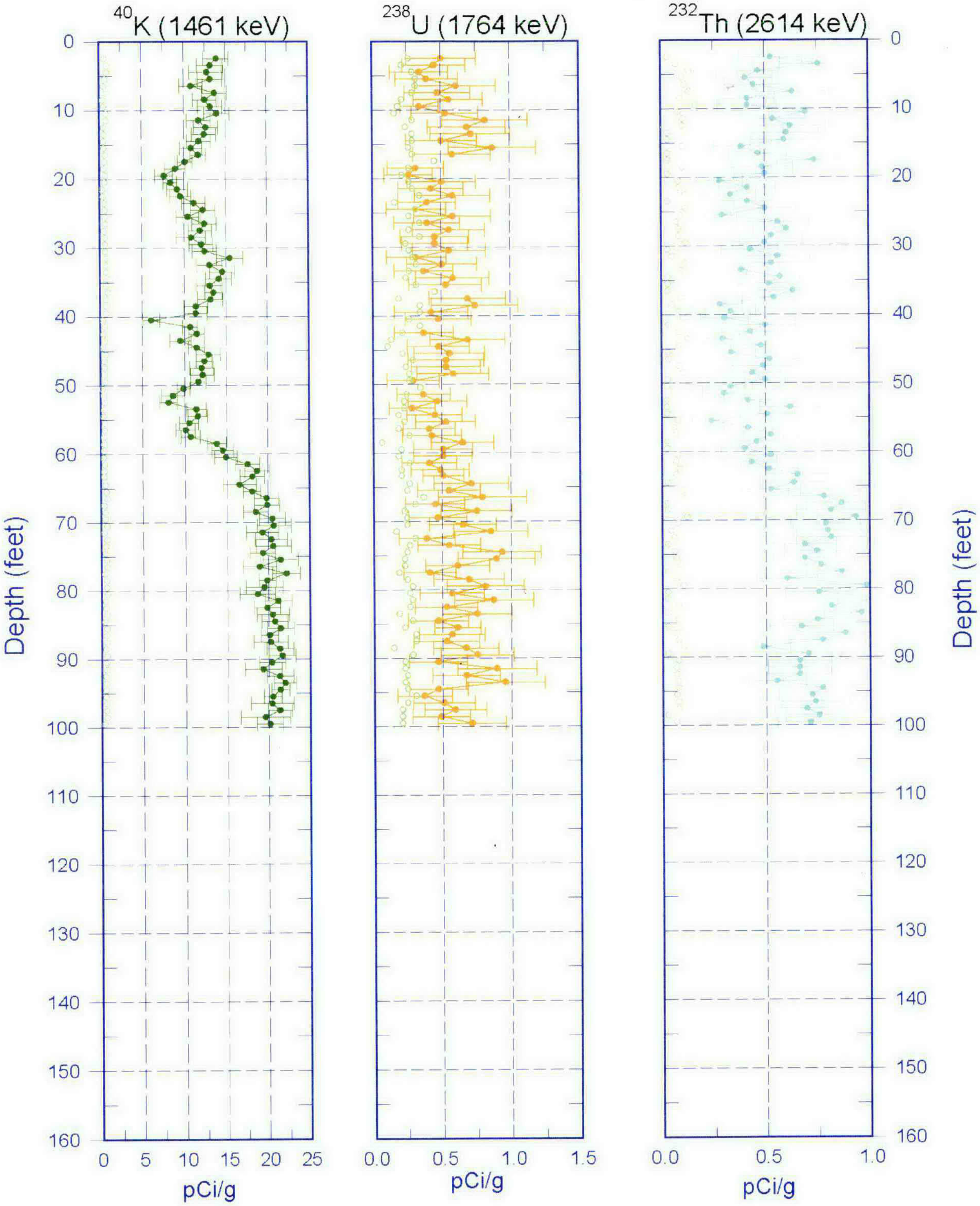
299-E24-54 (A5911)
Man-Made Radionuclides



Zero Reference - Top of Casing

Last Log Date - 04/11/05

299-E24-54 (A5911)
Natural Gamma Logs

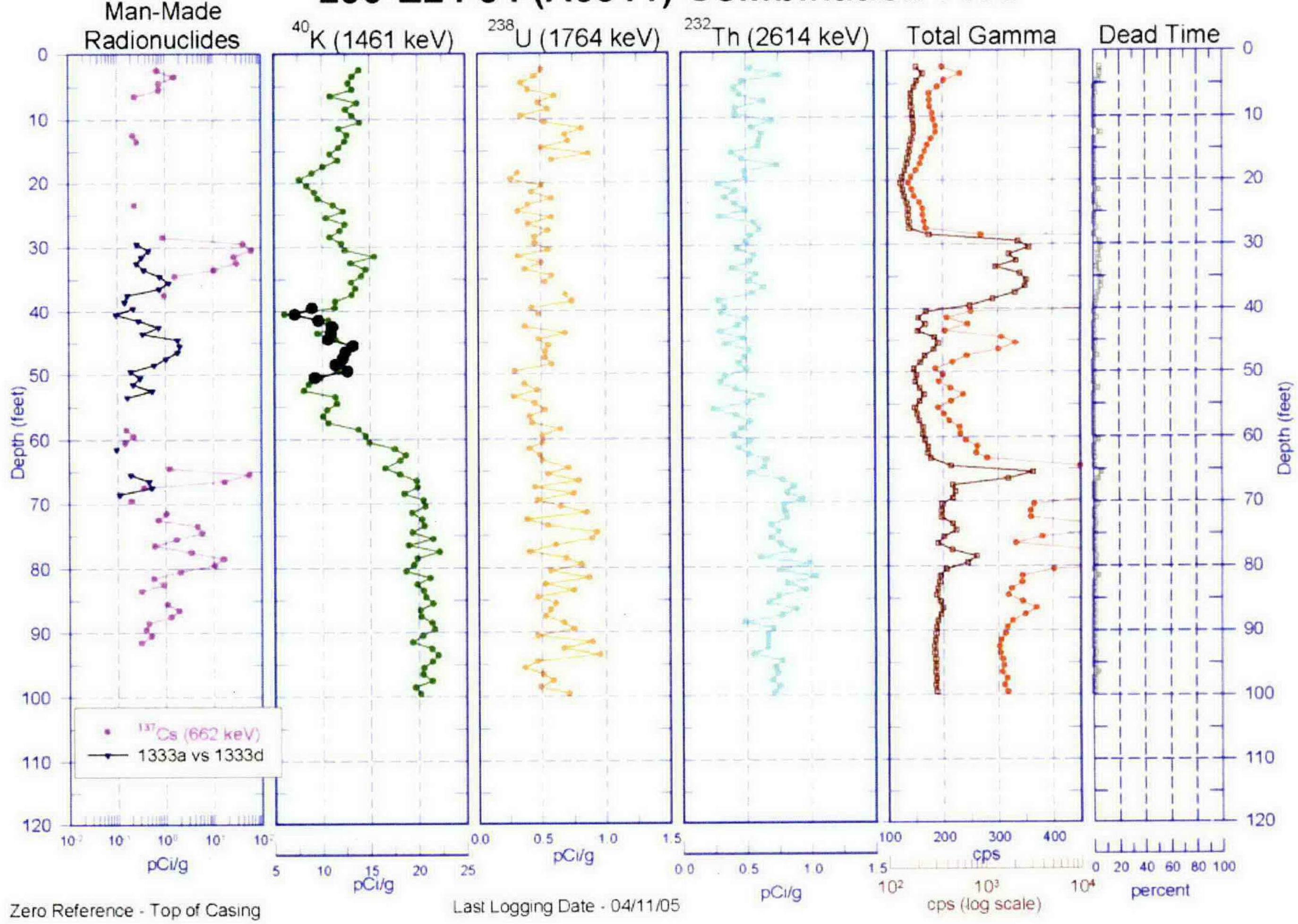


Zero Reference = Top of Casing

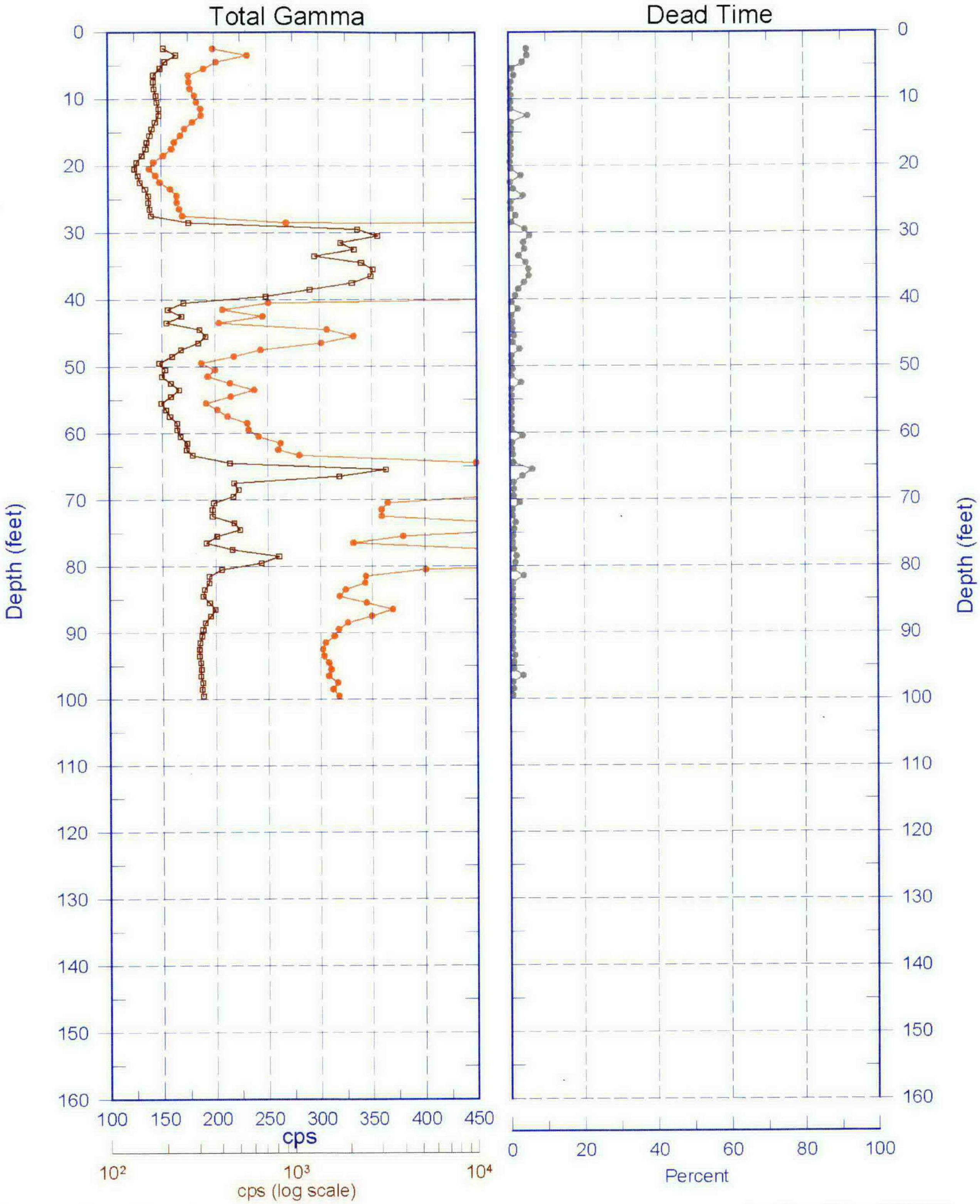
Last Log Date - 04/11/05

1

299-E24-54 (A5911) Combination Plot



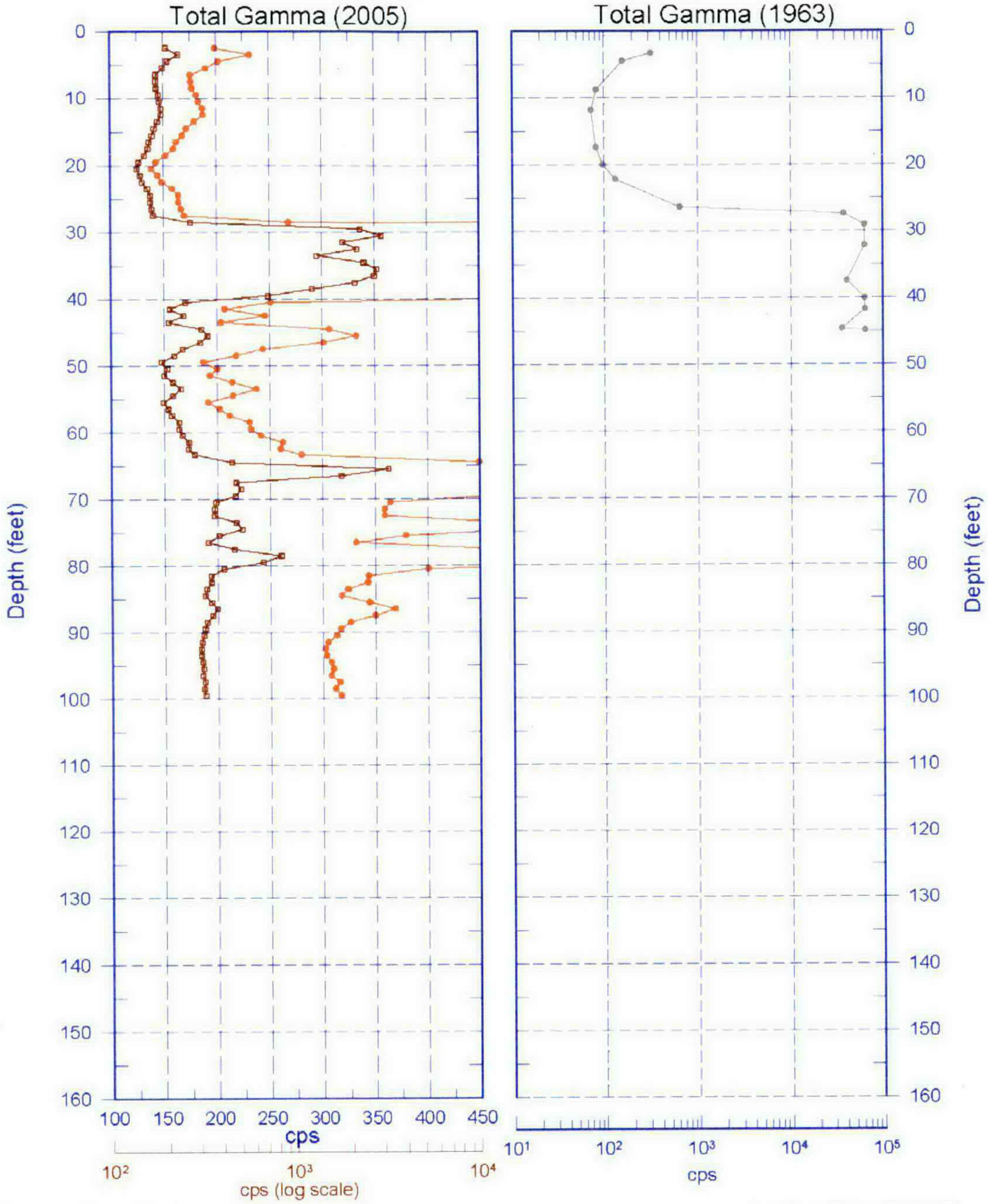
299-E24-54 (A5911)
Total Gamma & Dead Time



1 Reference - Top of Casing

Last Log Date - 04/11/05

299-E24-54 (A5911)
Historical Total Gamma Comparison

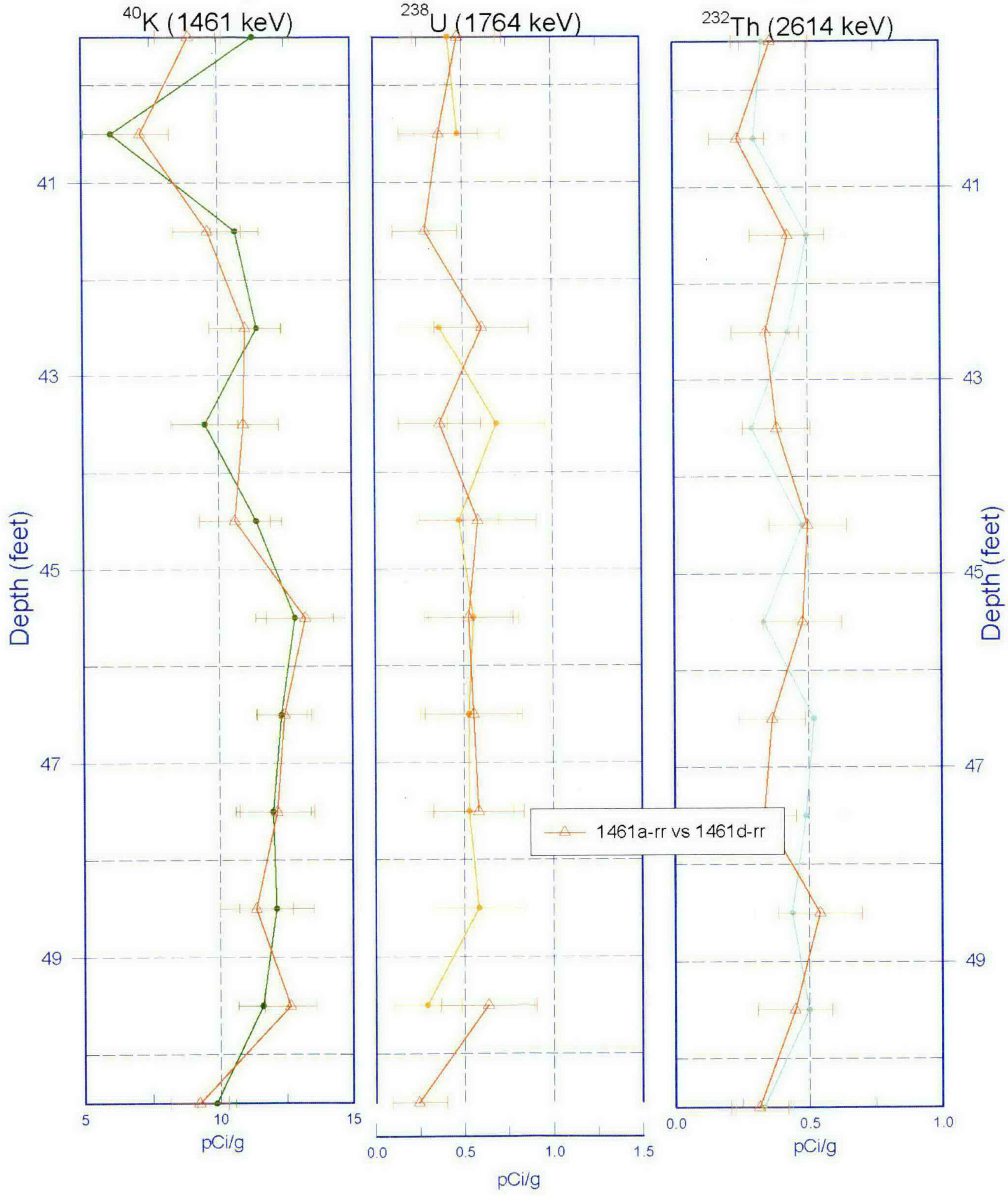


1 Reference - Top of Casing

Last Log Date - 04/11/05

299-E24-54 (A5911)

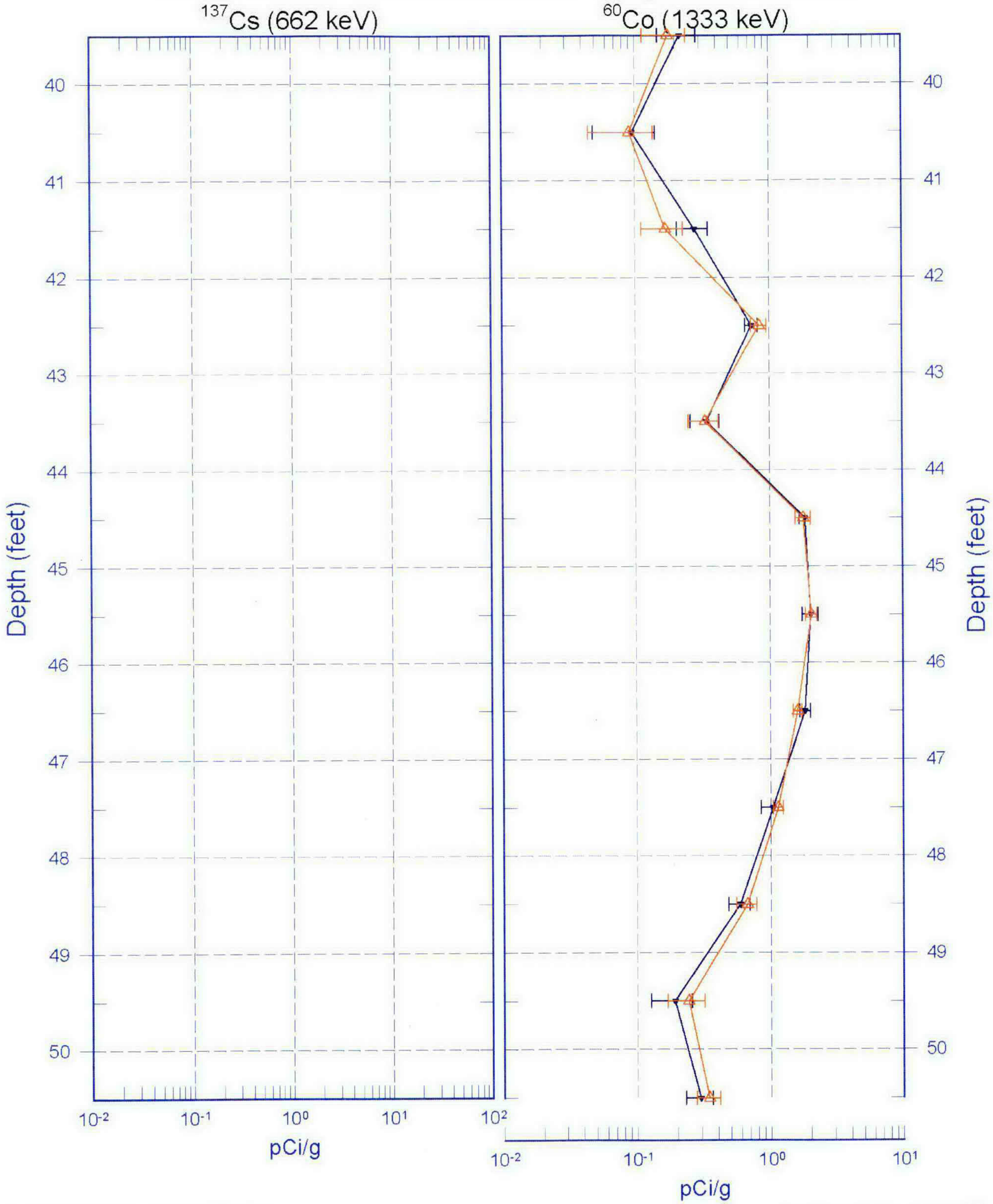
Repeat Section of Natural Gamma Logs



1 Zero Reference - Top of Casing

Last Log Date - 04/11/05

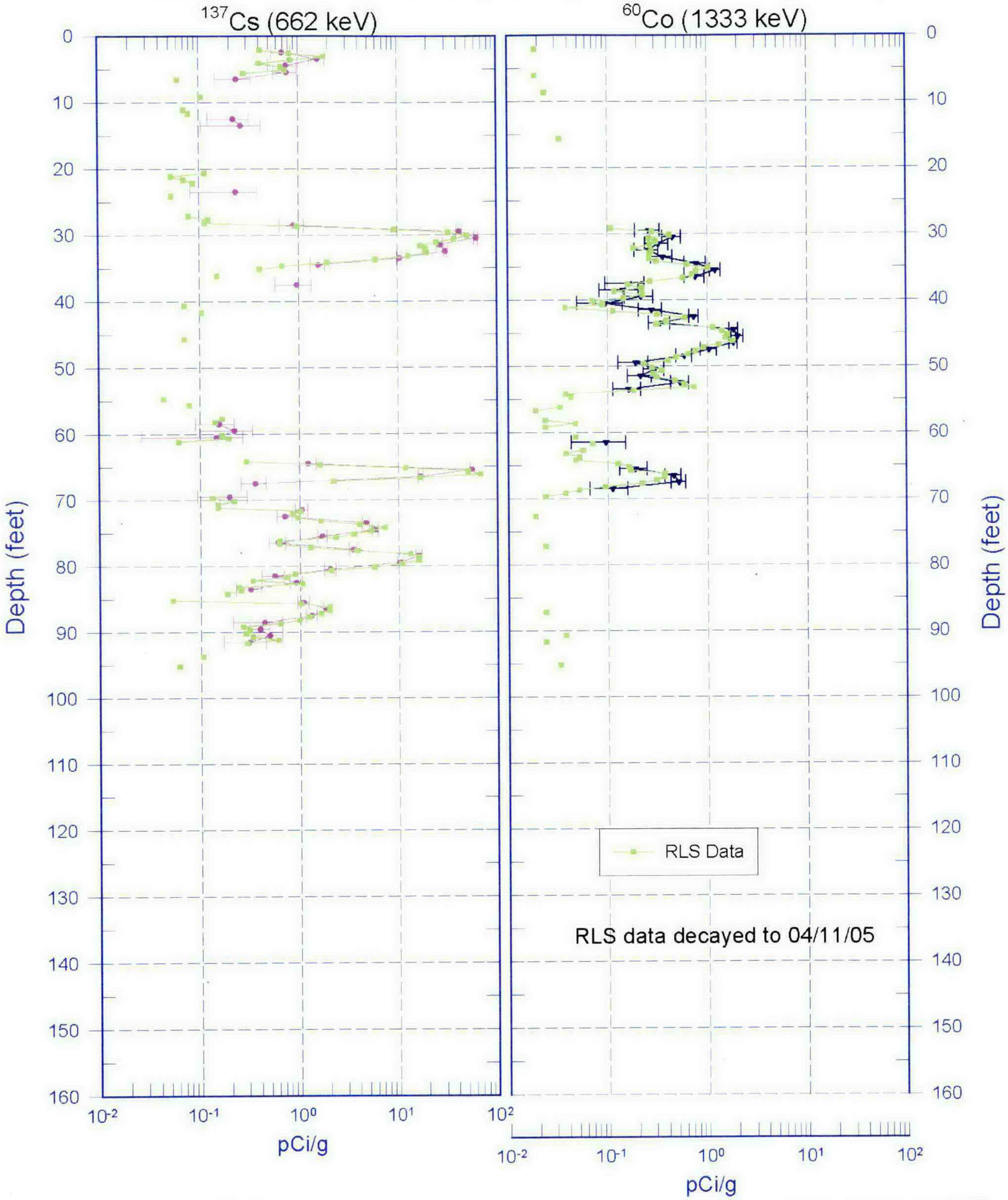
299-E24-54 (A5911)
Man-Made Radionuclide Repeat Section



1 Zero Reference - Top of Casing

Last Log Date - 04/11/05

299-E24-54 (A5911)
Comparison of RLS (1999) and SGLS (2005)



Zero Reference - Top of Casing

Last Log Date - 04/11/05

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Attachment B-7. Geophysical Log – Borehole C5571 (216-A-21 Crib)

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HGLP-LDR-086

C5571
Log Data Report

Borehole Information:

Borehole:	C5571		Site:	216-A-21	
Coordinates (WA St Plane)		GWL[1] (ft): None		GWL Date:	07/31/07
North (m)	East (m)	Drill Date	TOC Elevation	Total Depth (ft)	Type
Not available	Not available	07/07	Not available	60	Push

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Top (ft)	Bottom (ft)
Threaded Steel	1.75	6	5	1/2	1.75	60
PVC	3.9	4 1/2	4 1/4	1/8	3.9	60

Borehole Notes:

The threaded steel casing was internally contaminated. A PVC liner was introduced inside the steel casing to prevent the logging equipment from being contaminated. The PVC casing thickness was measured by the logging engineer. The steel casing dimensions were determined from the driller. Ground surface is the zero ft depth reference for data acquisition.

Logging Equipment Information:

Logging System:	Gamma 1 G		Type:	SGLS 35% HPGe SN: 34-TP10951A
Effective Calibration Date:	11/22/06	Calibration Reference:	HGLP-CC-003	
		Logging Procedure:	HGLP-MAN-002, Rev. 0	

Logging System:	Gamma 1 C		Type:	HRLS planar HPGe SN: 39A314
Effective Calibration Date:	11/22/06	Calibration Reference:	HGLP-CC-004	
		Logging Procedure:	HGLP-MAN-002, Rev. 0	

Logging System:	Gamma 4 H (with AmBe source)		Type:	NMLS SN: H310700352
Effective Calibration Date:	11/22/06	Calibration Reference:	HGLP-CC-002	
		Logging Procedure:	HGLP-MAN-002, Rev. 0	

Logging System:	Gamma 4 H (without AmBe source)		Type:	PNLS SN: H310700352
Effective Calibration Date:	11/22/06	Calibration Reference:	HGLP-CC-002	
		Logging Procedure:	HGLP-MAN-002, Rev. 0	

Spectral Gamma Logging System (SGLS) Log Run Information:

Log Run	5	6	7	8 Repeat	
Date	08/02/07	08/02/07	08/02/07	08/02/07	
Logging Engineer	McClellan	McClellan	McClellan	McClellan	
Start Depth (ft)	0.0	11.0	36.0	44.0	

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Log Run	5	6	7	8 Repeat	
Finish Depth (ft)	12.0	37.0	59.0	51.0	
Count Time (sec)	200	20	200	200	
Live/Real	R	R	R	R	
Shield (Y/N)	N	N	N	N	
MSA Interval (ft)	1.0	1.0	1.0	1.0	
ft/min	N/A	N/A	N/A	N/A	
Pre-Verification	AG131CAB	AG131CAB	AG131CAB	AG131CAB	
Start File	AG131000	AG131013	AG131040	AG131064	
Finish File	AG131012	AG131039	AG131063	AG131071	
Post-Verification	AG131CAA	AG131CAA	AG131CAA	AG131CAA	
Depth Return Error (in.)	N/A	N/A	N/A	N/A	
Comments	No fine gain adjustment	No fine gain adjustment Dead time > 40%	No fine gain adjustment	No fine gain adjustment	

High Rate Logging System (HRLS) Log Run Information:

Log Run	9	10	11	12	13 Repeat
Date	08/02/07	08/06/07	08/06/07	08/06/07	08/06/07
Logging Engineer	McClellan	McClellan	McClellan	McClellan	McClellan
Start Depth (ft)	11.0	14.0	19.0	23.0	19.0
Finish Depth (ft)	15.0	20.0	24.0	37.0	23.0
Count Time (sec)	300	300	30	300	300
Live/Real	R	R	R	R	R
Shield (Y/N)	N	N	N	N	Y (internal)
MSA Interval (ft)	1.0	1.0	1.0	1.0	1.0
ft/min	N/A	N/A	N/A	N/A	N/A
Pre-Verification	AG176CAB	AG177CAB	AG177CAB	AG177CAB	AG177CAB
Start File	AG176000	AG177000	AG177007	AG177013	AG177028
Finish File	AG176004	AG177006	AG177012	AG177027	AG177036
Post-Verification	AG176CAA	AG177CAA	AG177CAA	AG177CAA	AG177CAA
Depth Return Error (in.)	0	N/A	N/A	0	0
Comments	None	None	Dead Time > 40 %	None	Fine gain adjustment after file -028

Neutron Moisture Logging System (NMLS) Log Run Information:

Log Run	1	2 Repeat			
Date	08/01/07	08/01/07			
Logging Engineer	Spatz	Spatz			
Start Depth (ft)	0	16.0			
Finish Depth (ft)	59.25	26.0			
Count Time (sec)	15	15			
Live/Real	R	R			
Shield (Y/N)	N	N			
MSA Interval (ft)	0.25	0.25			
ft/min	N/A	N/A			
Pre-Verification	DH642CAB	DH642CAB			
Start File	DH642000	DH642238			
Finish File	DH642237	DH642278			
Post-Verification	DH642CAA	DH642CAA			
Depth Return Error (in.)	N/A	0			
Comments	None	None			

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Passive Neutron Logging System (PNLS) Log Run Information:

Log Run	3	4 Repeat			
Date	08/01/07	08/01/07			
Logging Engineer	Spatz	Spatz			
Start Depth (ft)	0	14.0			
Finish Depth (ft)	59.0	23.0			
Count Time (sec)	60	15			
Live/Real	R	R			
Shield (Y/N)	N	N			
MSA Interval (ft)	1.0	0.25			
ft/min	N/A	N/A			
Pre-Verification	DH652CAB	DH652CAB			
Start File	DH652000	DH652060			
Finish File	DH652059	DH652096			
Post-Verification	DH652CAA	DH652CAA			
Depth Return Error (in.)	N/A	0			
Comments	None	None			

Logging Operation Notes:

Logging was conducted with no centralizer on the sondes. Repeat sections were acquired to evaluate system performance.

Analysis Notes:

Analyst:	Henwood	Date:	08/15/07	Reference:	GJO-HGLP 1.6.3, Rev. 0

Pre-run and post-run verifications for the logging systems were performed before and after each day's data acquisition. The acceptance criteria were met. A combined casing correction for 0.5-in. thick steel casing and 1/8 in. thick PVC casing was applied to the spectral log data. Correction for the steel casing was derived from calibration data. A model was developed to determine the correction for the PVC casing. There is no available calibration for this casing configuration to correct moisture data to percent volumetric moisture. Therefore, the data are reported in counts per second (cps). The passive neutron data are also qualitative and are reported in cps.

SGLS and HRLS spectra were processed in batch mode using APTEC SUPERVISOR to identify individual energy peaks and determine count rates. Concentrations were calculated with EXCEL worksheet templates identified as G1GNov06.xls and G1CNov06.xls for the SGLS and HRLS, respectively, using efficiency functions and corrections for casing, water, and dead time as determined from annual calibrations. Where dead time exceeds 40 percent, HRLS data are substituted for the SGLS data. Where the HRLS dead time exceeds 40 percent, HRLS data acquired using an internal shield are substituted.

Results and Interpretations:

Cs-137 was detected throughout this borehole at concentrations ranging from 0.3 to 1.3 million pCi/g. The maximum concentration was measured at 21 ft in depth. Because there is known to be internal contamination in this borehole, concentration measured at 1 pCi/g or less is probably not valid.

Moisture data indicate very little variation. It is not known to what degree the PVC casing that contains significant hydrogen and chlorine content affects the measurement, which normally responds to the hydrogen content in formation moisture. Additionally, the instrument is sensitive to gamma rays when the Cs-137 content exceeds approximately 100,000 pCi/g so that the count rate data could be slightly over estimated between 15 and 28 ft.

The passive neutron count rate data indicate slight elevation (i.e., 2 cps) between 15 and 28 ft. In the absence of the high gamma activity caused by Cs-137, elevated readings could indicate the existence of alpha emitting radionuclides interacting with light elements, referred to as alpha - neutron reactions (α,n). These reactions create neutron activity that may reflect the existence of transuranic radionuclides such as Pu-239. However, in high gamma activity zones, it cannot be determined with certainty whether the elevated neutron count rate is caused by these reactions or is caused by the high gamma activity. Logging experience suggests, in this case, the apparent neutron activity is actually caused by the gamma activity.

The repeat sections generally indicate good agreement of the naturally occurring KUT, manmade radionuclides, and moisture and passive neutron count rates.

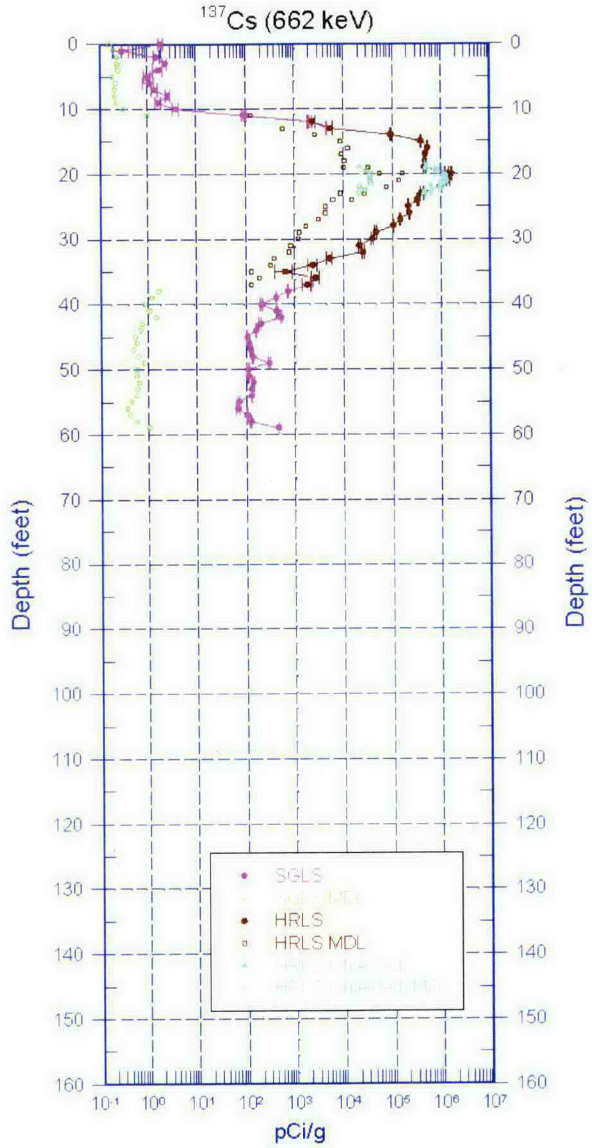
List of Log Plots:

Depth Reference is ground surface

Manmade Radionuclides
Natural Gamma Logs
Combination Plot
Total Gamma & Dead Time
Moisture & Passive Neutron
Repeat of Manmade Radionuclides
Repeat Section of Natural Gamma Logs
Repeat of Moisture & Passive Neutron

[1] GWL – groundwater level

C5571
Manmade Radionuclides



Zero Reference = Ground surface

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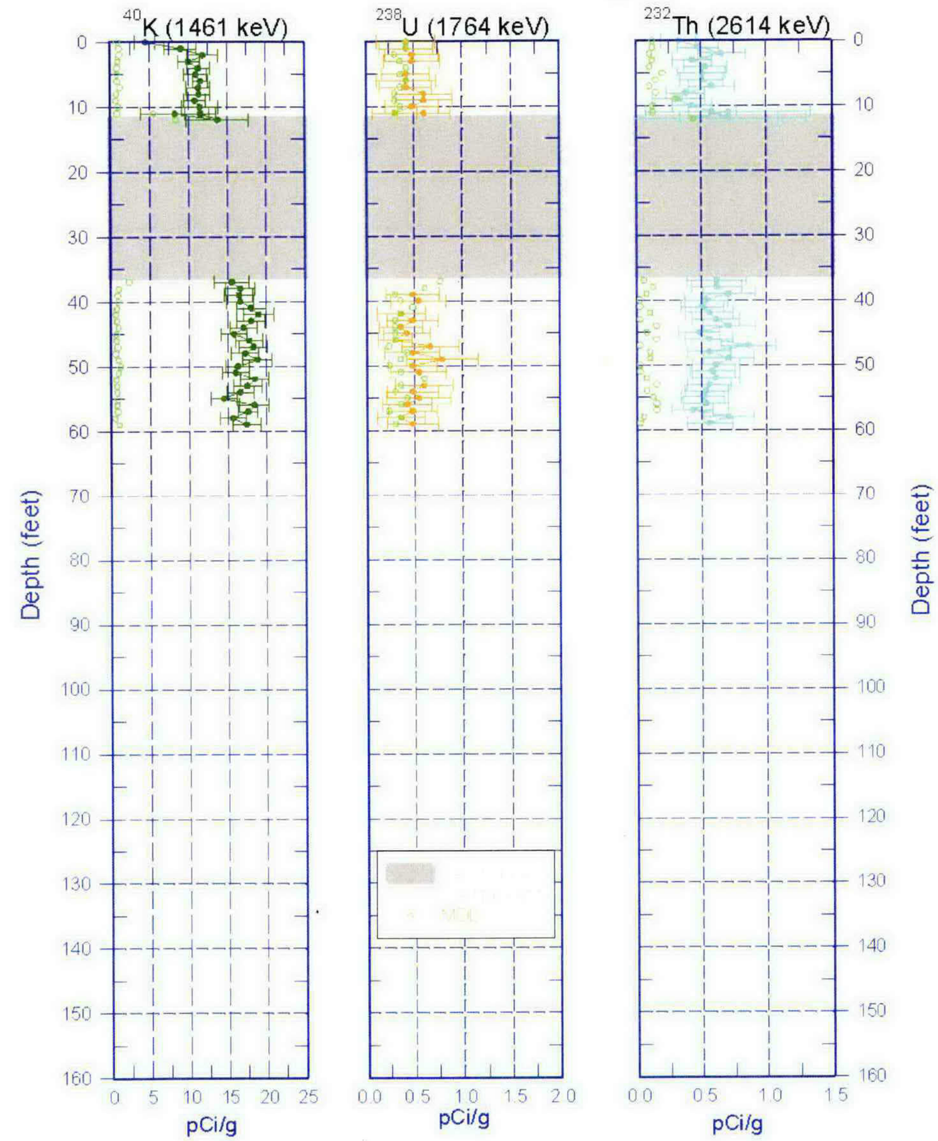
C5571
Natural Gamma Logs



Zero Reference = Ground surface

1

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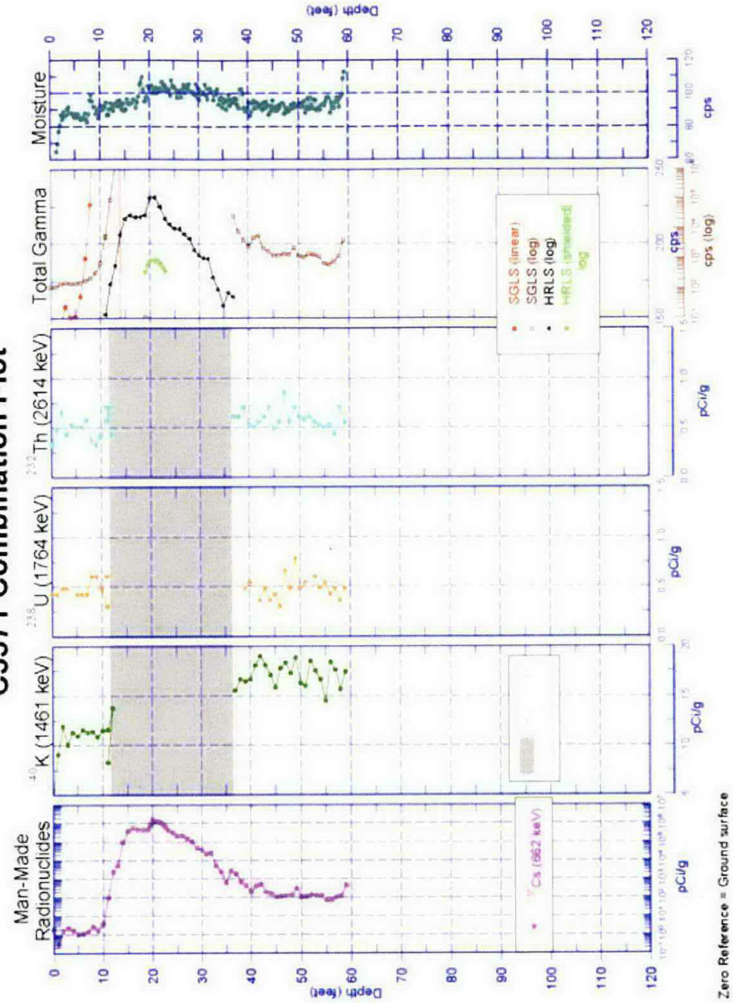
C5571 Combination Plot



Zero Reference = Ground surface

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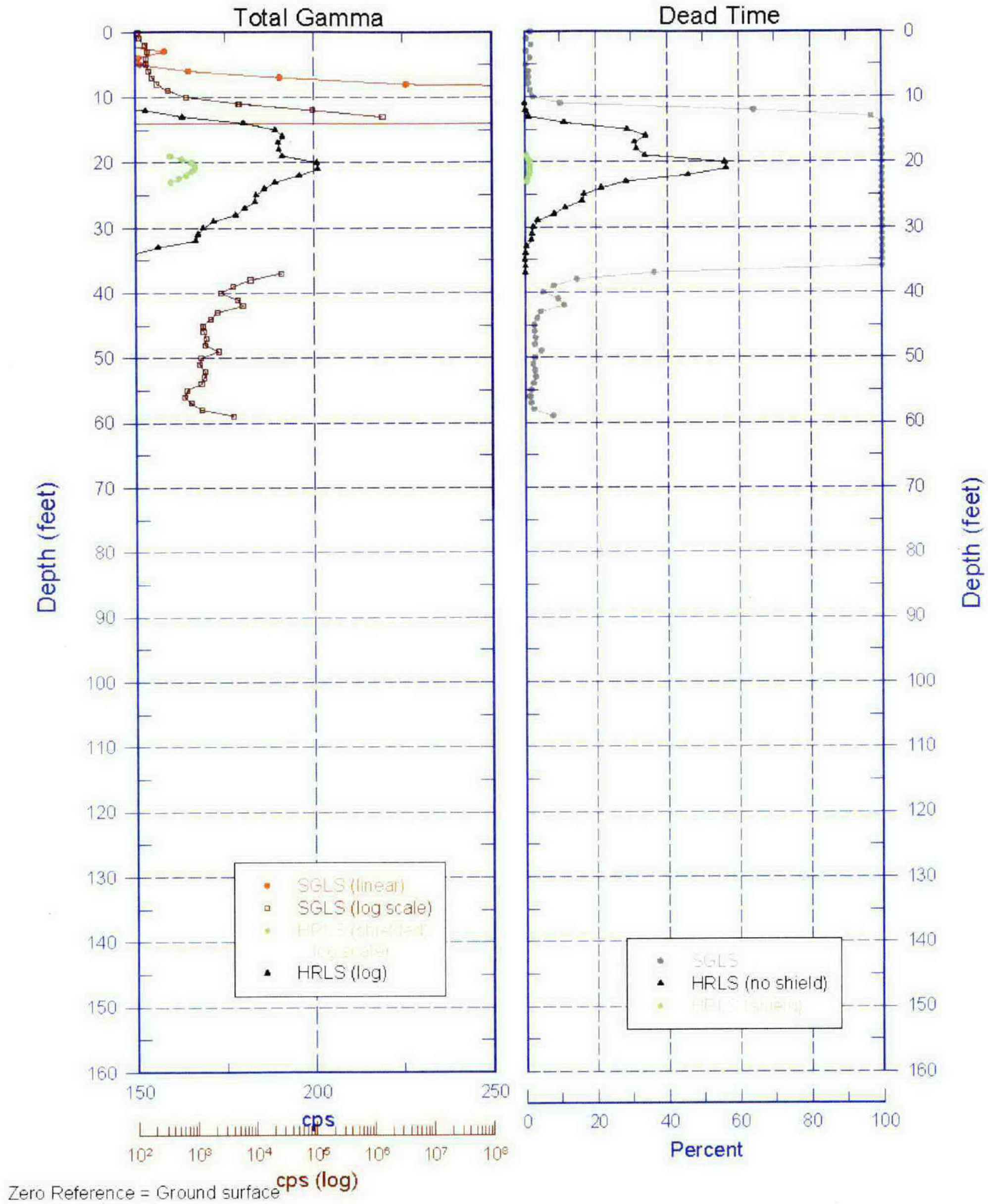
C5571
Total Gamma & Dead Time



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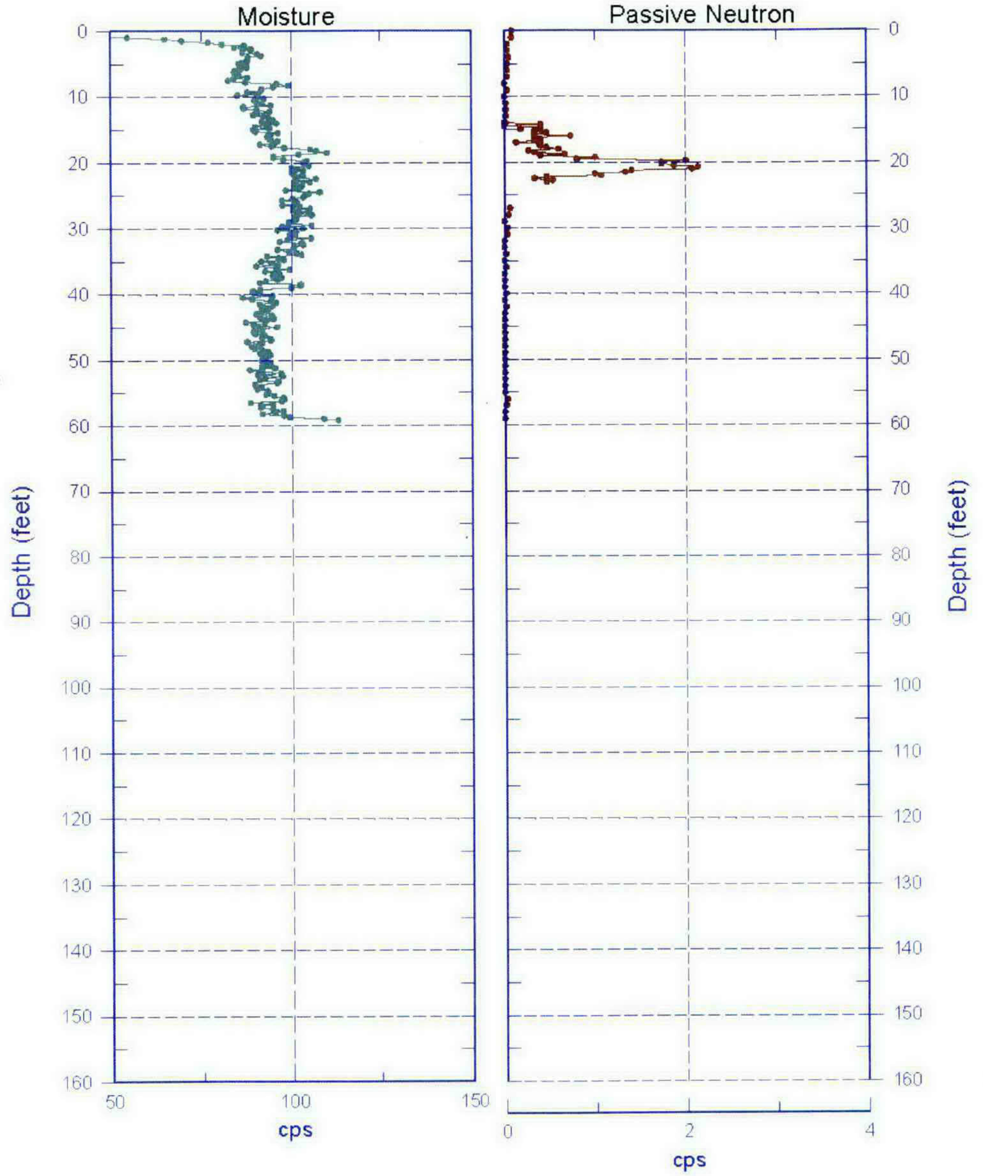
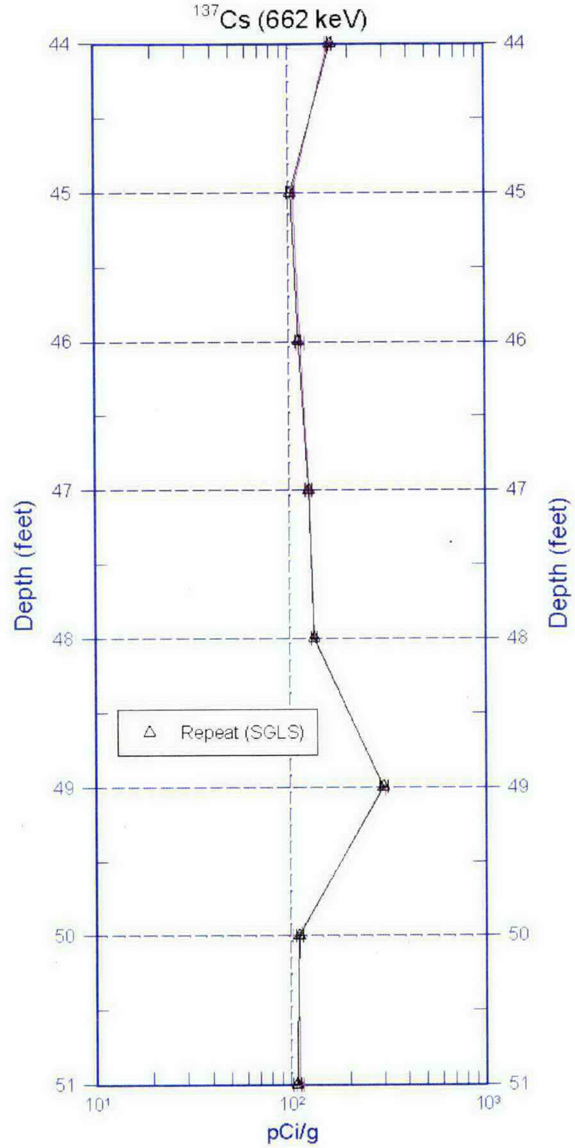
C5571
Moisture & Passive Neutron



Zero Reference = Ground surface

1

C5571
Repeat of Manmade Radionuclides



Zero Reference = Ground surface

1

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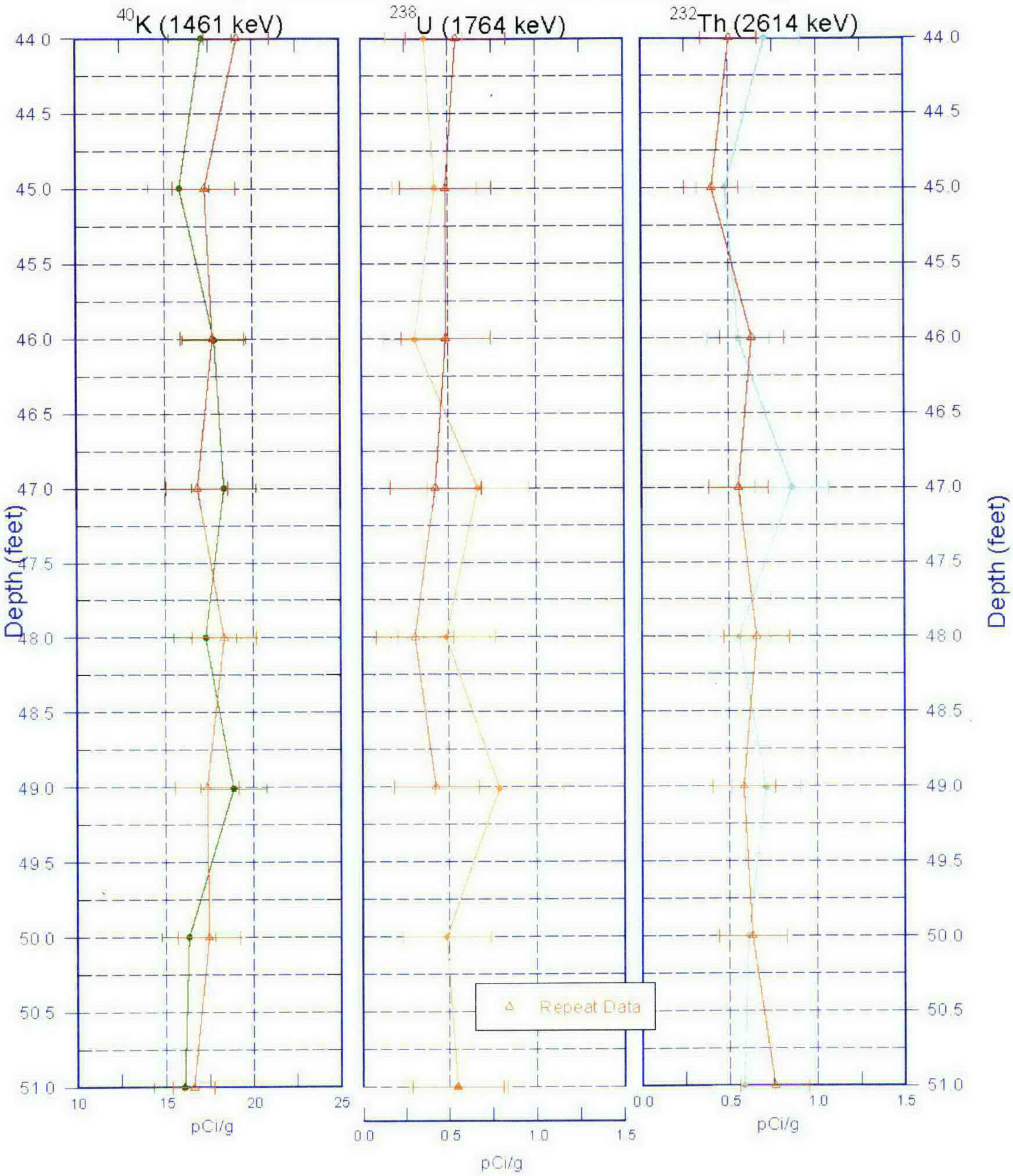
C5571

Repeat Section of Natural Gamma Logs



Zero Reference = Ground surface

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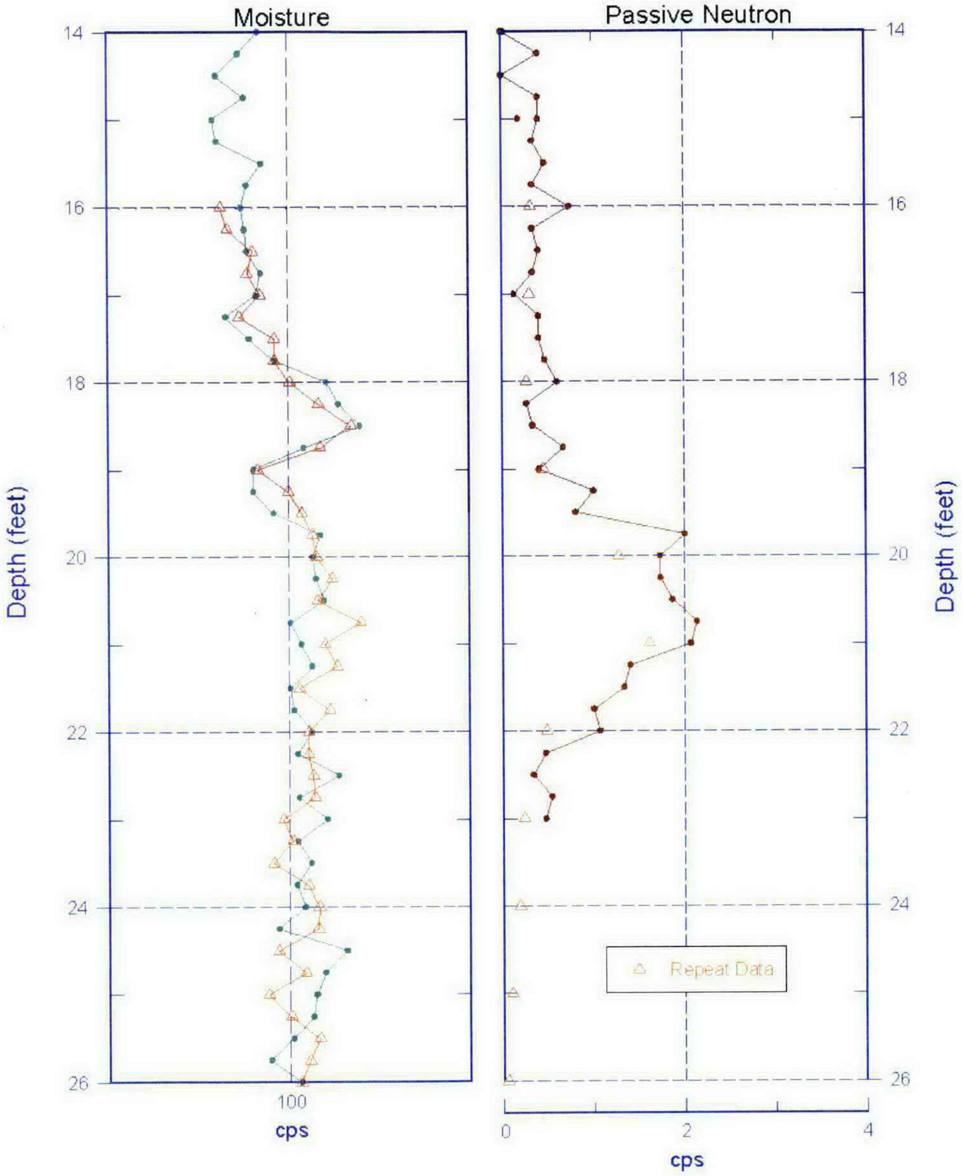
2

C5571
Repeat of Moisture & Passive Neutron



Zero Reference = Ground surface

Attachment B-8. Geophysical Log – Borehole C5302 (200-E-102 Trench)

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C5302
Log Data Report

Borehole Information:

Borehole:	C5302		Site:	200-E-102	
Coordinates (WA St Plane)		GWL[1] (ft):	none	GWL Date:	10/31/2006
North (m)	East (m)	Drill Date	TOC Elevation	Total Depth (ft)	Type
NA	NA	10/2006	NA	55	push

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Top (ft)	Bottom (ft)
Threaded steel	2.5	7	5 ¾	5/8	+2.5	55

Borehole Notes:

Zero depth reference is ground surface.

Logging Equipment Information:

Logging System:	Gamma 1E	Type:	SGLS (70%) SN: 34-TP40587A
Effective Calibration Date:	05/02/06	Calibration Reference:	DOE-EM/GJ1200-2006
		Logging Procedure:	HGLP-MAN-002, Rev 0

Logging System:	Gamma 2M	Type:	NMLS/PNLS SN: H340207279
Effective Calibration Date:	08/02/06	Calibration Reference:	DOE-EM/GJ1283-2006
		Logging Procedure:	HGLP-MAN-002, Rev 0

Logging System:	Gamma 4J	Type:	NCLS SN: 34 TN1104A
Effective Calibration Date:	08/18/06	Calibration Reference:	DOE-EM/GJ1315-2006
		Logging Procedure:	HGLP-MAN-002, Rev 0

Spectral Gamma Logging System (SGLS) Log Run Information:

Log Run	1	2-repeat	3-repeat		
Date	10/31/06	10/31/06	10/31/06		
Logging Engineer	Spatz	Spatz	Spatz		
Start Depth (ft)	0.5	35.0	51.0		
Finish Depth (ft)	54.0	45.0	53.0		
Count Time (sec)	100	400	400		
Live/Real	R	R	R		
Shield (Y/N)	N	N	N		
MSA Interval (ft)	1.0	0.5	0.5		
ft/min	N/A[2]	N/A	N/A		
Pre-Verification	AE200CAB	AE200CAB	AE200CAB		
Start File	AE200000	AE200055	AE200076		
Finish File	AE200054	AE200075	AE200080		
Post-Verification	AE200CAA	AE200CAA	AE200CAA		
Depth Return Error (in.)	N/A	N/A	0		

Log Run	1	2-repeat	3-repeat		
Comments	Adj gain after AE200020				

Neutron Moisture & Passive Neutron Logging System (NMLS/PNLS) Log Run Information:

Log Run	4 (NMLS)	5 Repeat	6 (PNLS)	7 Repeat	
Date	11/01/06	11/01/06	11/01/06	11/01/06	
Logging Engineer	Spatz	Spatz	Spatz	Spatz	
Start Depth (ft)	0.0	35.0	0.0	35.0	
Finish Depth (ft)	54.0	45.0	54.0	45.0	
Count Time (sec)	15	15	60	60	
Live/Real	R	R	R	R	
Shield (Y/N)	N	N	N	N	
Sample Interval (ft)	0.25	0.25	1.0	1.0	
ft/min	N/A	N/A	1	1	
Pre-Verification	BM015CAB	BM015CAB	BM016CAB	BM016CAB	
Start File	BM015000	BM015217	BM016000	BM016054	
Finish File	BM015216	BM015257	BM016053	BM016064	
Post-Verification	BM015CAA	BM015CAA	BM016CAA	BM016CAA	
Depth Return Error (in.)	NA	NA	NA	0	
Comments			AmBe source removed from sonde	AmBe source removed from sonde	

Neutron Capture Logging System (NCLS) Log Run Information:

Log Run	8	9 Repeat			
Date	11/02/06	11/02/06			
Logging Engineer	Spatz	Spatz			
Start Depth (ft)	53.0	53.0			
Finish Depth (ft)	34.0	50.5			
Count Time (sec)	500	500			
Live/Real	R	R			
Shield (Y/N)	N	N			
Sample Interval (ft)	1.0	1.0			
ft/min	N/A	N/A			
Pre-Verification	DJ121CAB	DJ121CAB			
Start File	DJ121000	DJ121020			
Finish File	DJ121019	DJ121025			
Post-Verification	DJ121CAA	DJ121CAA			
Depth Return Error (in.)	NA	0.0			
Comments	Fine gain adj @53 ft prior to log and at 47.0 ft.				

Logging Operation Notes:

Logging was conducted with centralizers. Measurements are referenced to ground surface. Passive neutron logging was performed by using the neutron moisture sonde with the AmBe source removed. Neutron capture logging was performed using a N-type HPGe detector (approximately 18% relative efficiency) and a 10-microgram Cf-252 neutron source. The source to detector spacing was 16 inches.

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Analysis Notes:

Analyst:	R.G. McCain	Date:	05/21/07	Reference:	GJO-HGLP 1.6.3, Rev. 0

Pre-run and post-run verifications for the logging systems were performed before and after data acquisition. Acceptance criteria were met for all systems.

A casing correction for 5/8-in.-thick casing was applied to the spectral log data (SGLS).

SGLS spectra were processed in batch mode using APTEC SUPERVISOR to identify individual energy peaks and determine count rates. Concentrations were calculated with EXCEL worksheet templates identified as G1EMay06.xls using efficiency functions and corrections for casing as determined from annual calibrations. Dead time corrections were not required.

The neutron moisture log was converted to volume percent moisture, using the calibration for a 6-inch ID borehole.

The passive neutron log showed no evidence of activity. A single neutron was counted at 8 depths. Otherwise, the count rate was zero.

The neutron capture log was run on an experimental basis and data are still under review.

Results and Interpretations

^{137}Cs is detected in this borehole from 36 ft to 42 ft, with a maximum concentration of 112 pCi/g at 38 ft. ^{137}Cs and ^{154}Eu were also detected between 48 and 54 ft. Maximum ^{154}Eu concentration of 3 pCi/g occurred at 52.5 ft. Maximum ^{137}Cs in this interval was 3 pCi/g, also at 52.5 ft.

The presence of ^{90}Sr in the interval from 40 to 47 feet is a strong possibility. Total gamma activity in this interval is slightly elevated, with no obvious contribution from either manmade or natural radionuclides. McCain and Koizumi (2002) have shown that bremsstrahlung resulting from high energy betas associated with ^{90}Sr creates an elevated Compton continuum in the lower range of the gamma energy spectrum. This results in a higher total count rate with no obvious photopeaks. The spectral shape factor SF2 is defined as total counts in the 60 to 350 keV range divided by total counts in the 350 to 650 keV range. For uncontaminated sediments, SF2 is typically about 3, increasing to about 6 to 8 where ^{90}Sr concentrations are on the order of 1000 pCi/g. A plot of SF2 shows a slight increase in the interval (40-47 ft) where total gamma activity appears to be slightly high, with no observable contamination. Maximum SF2 values are slightly above 4, so the evidence is not conclusive. However, the presence of a few hundred pCi/g of ^{90}Sr in this interval is considered highly likely.

Moisture content generally ranges between 12 and 16 volume percent. Slightly elevated moisture (3-4 volumetric percent moisture) from about 2 to 6 feet is probably related to surface infiltration. The high ^{137}Cs concentration at 36 to 42 ft does not appear to be associated with significantly elevated moisture. However, the ^{137}Cs and ^{154}Eu at 52.5 ft appears to occur in a thin bed accompanied by moisture content at about 6 volume percent.

The passive neutron log exhibited no significant activity. A total of 8 neutrons were counted over the length of the borehole, using a count time of 60 sec, and logging at 1 ft/min. The few neutron counts that were detected most likely represent statistical fluctuations, but it is worth noting that 5 of the 8 neutrons were detected in the region between 35 and 42 ft, where the highest ^{137}Cs levels were encountered.

The neutron capture data have not been fully evaluated and results of the neutron capture analysis are not included to facilitate release of the log data report.

Repeat sections for natural and manmade radionuclides and neutron moisture exhibit good repeatability. In this borehole, the repeat sections for the spectral gamma log were run at 0.5 ft intervals, while the bulk of the borehole was logged at 1.0 ft intervals. The behavior of the repeat data for ^{137}Cs at 37.5 ft indicates that the contamination is most likely present in a very thin layer. This also shows the advantage of 0.5 ft depth increments.

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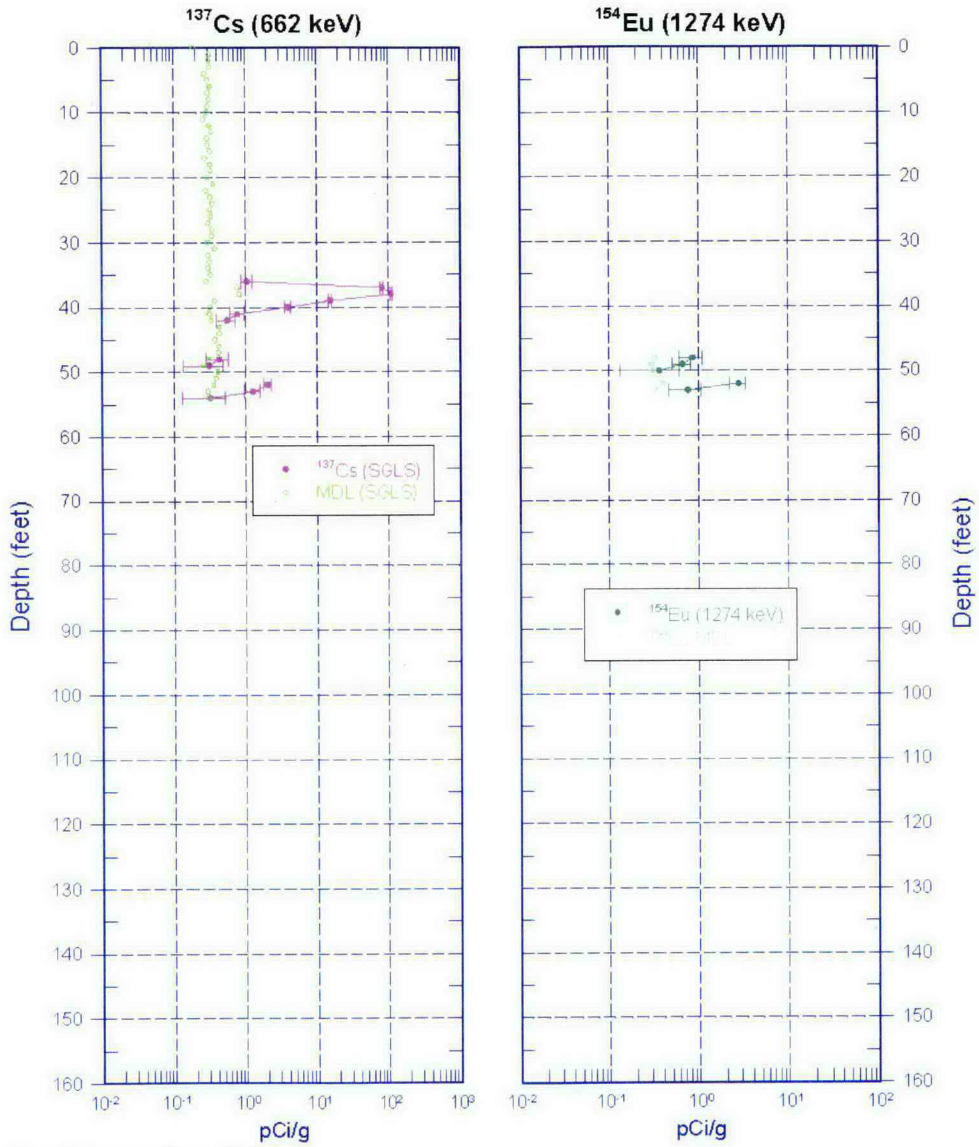
List of Log Plots

Manmade Radionuclides
Natural Gamma Logs
Combination Plot
Combination Plot (0-60 ft)
Combination Plot & SF2 (0-60 ft)
Total Gamma, Passive Neutron & Neutron Moisture
Repeat Section of Manmade Radionuclides
Repeat Section of Natural Gamma Logs
Repeat Section of Neutron Moisture

[1] GWL – groundwater level

1

C5302
Man-Made Radionuclides



Zero Reference = Ground Surface

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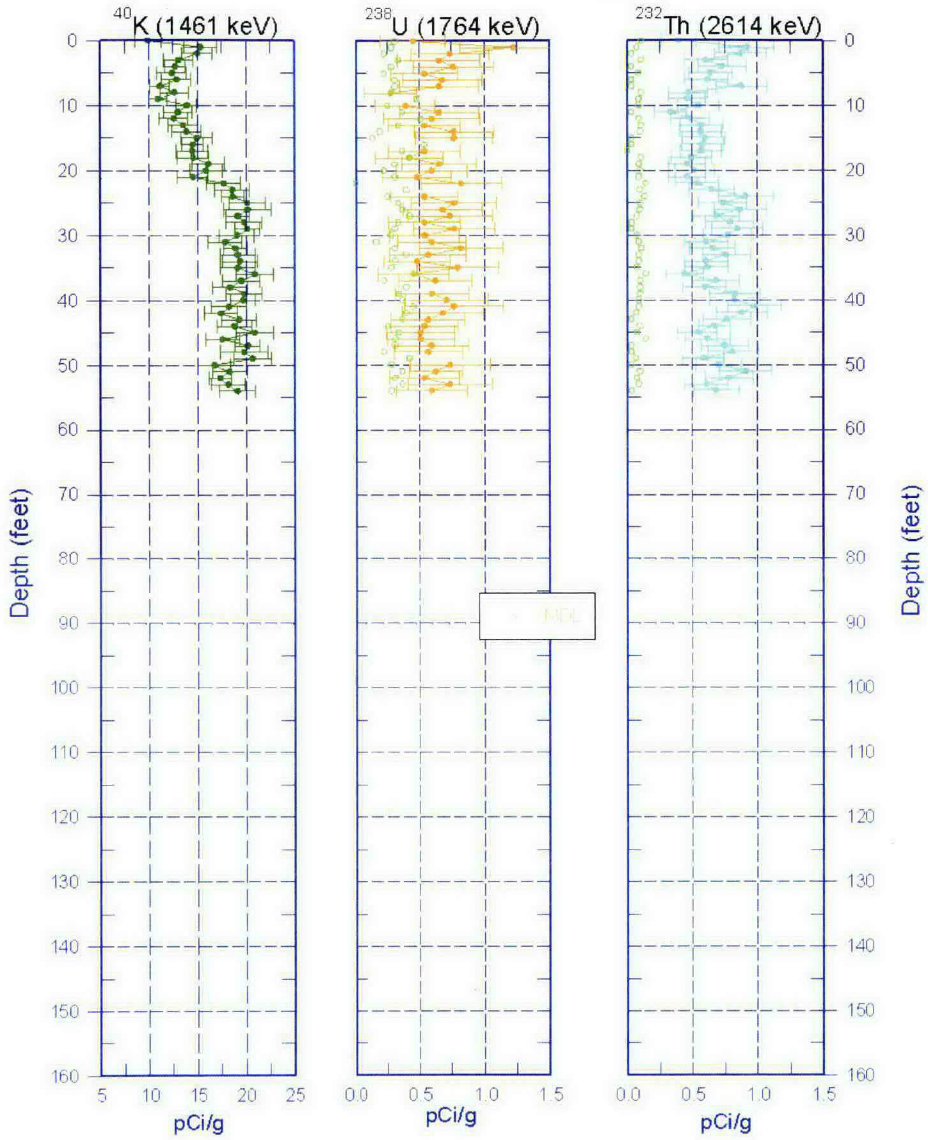
C5302
Natural Gamma Logs



Zero Reference = Ground Surface

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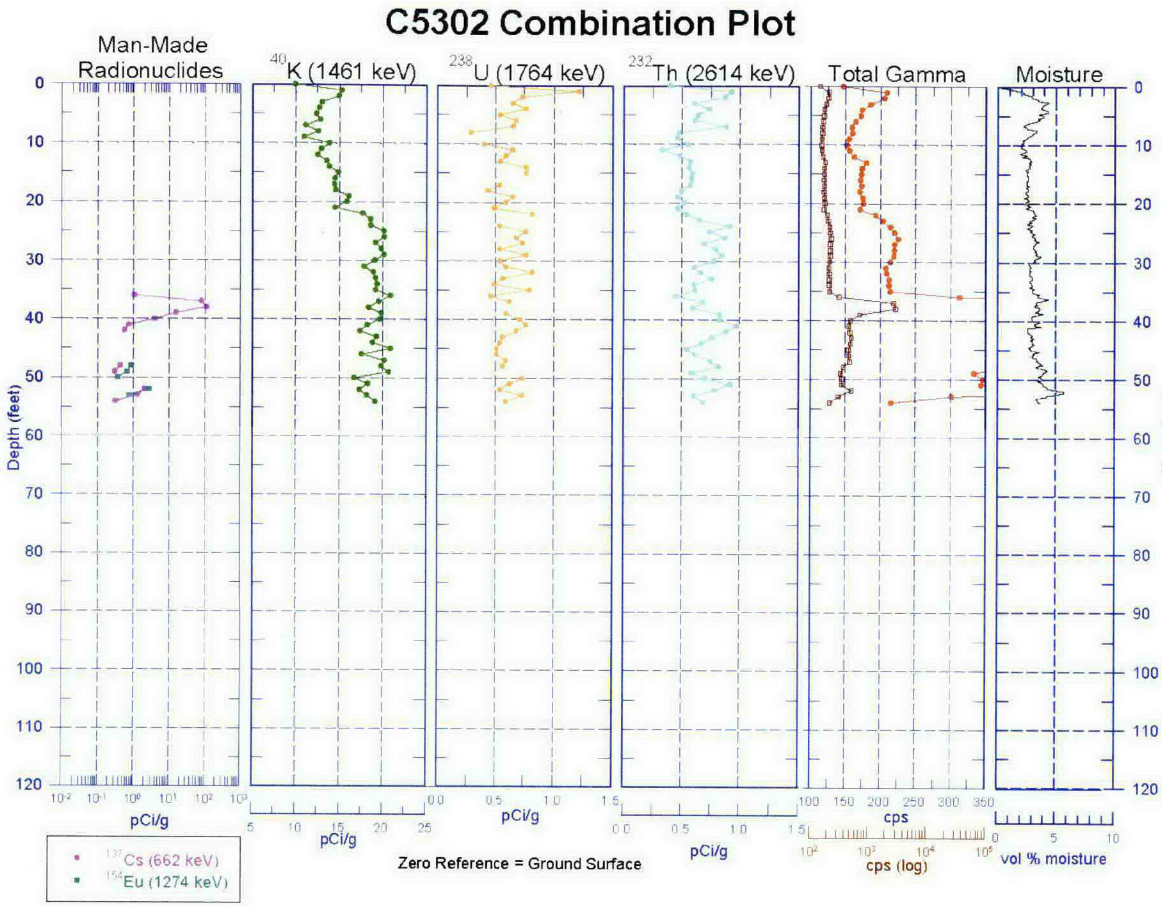

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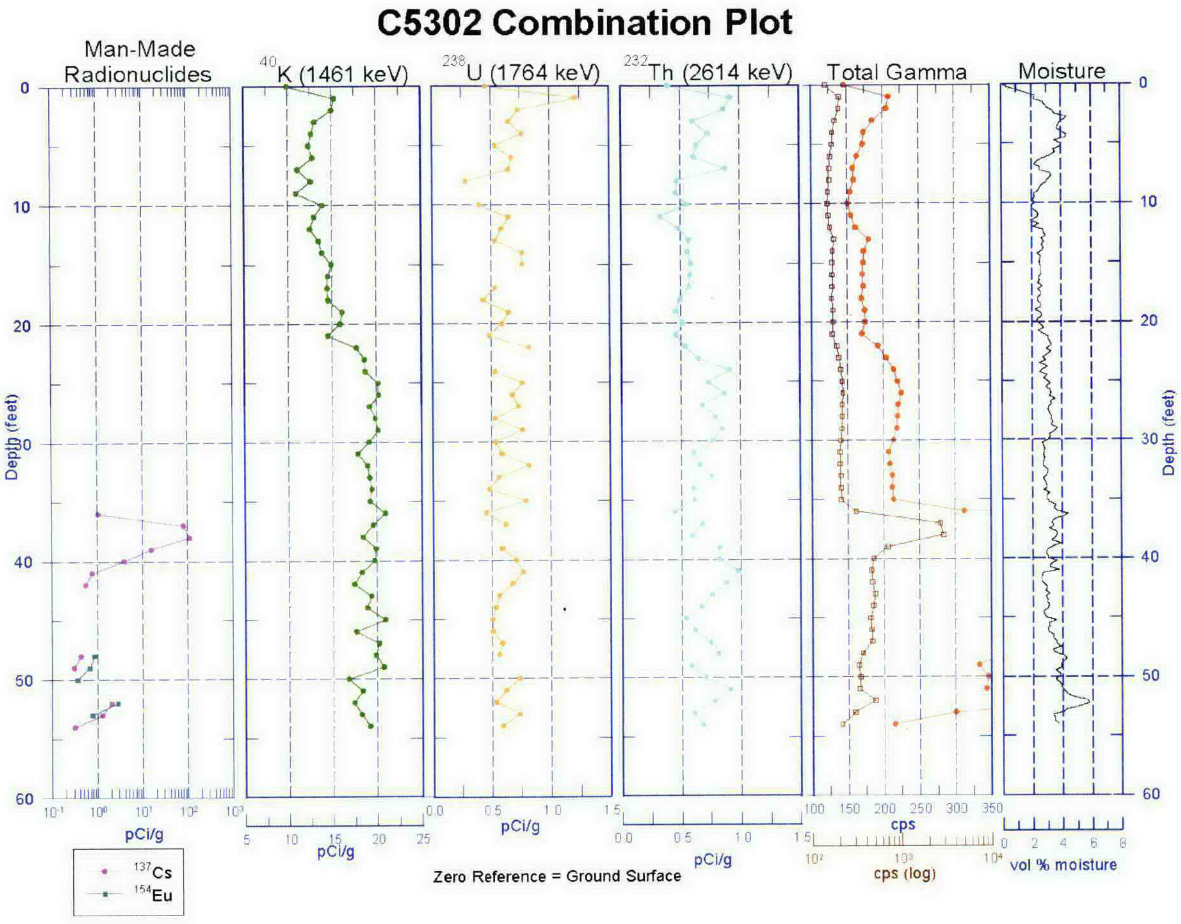

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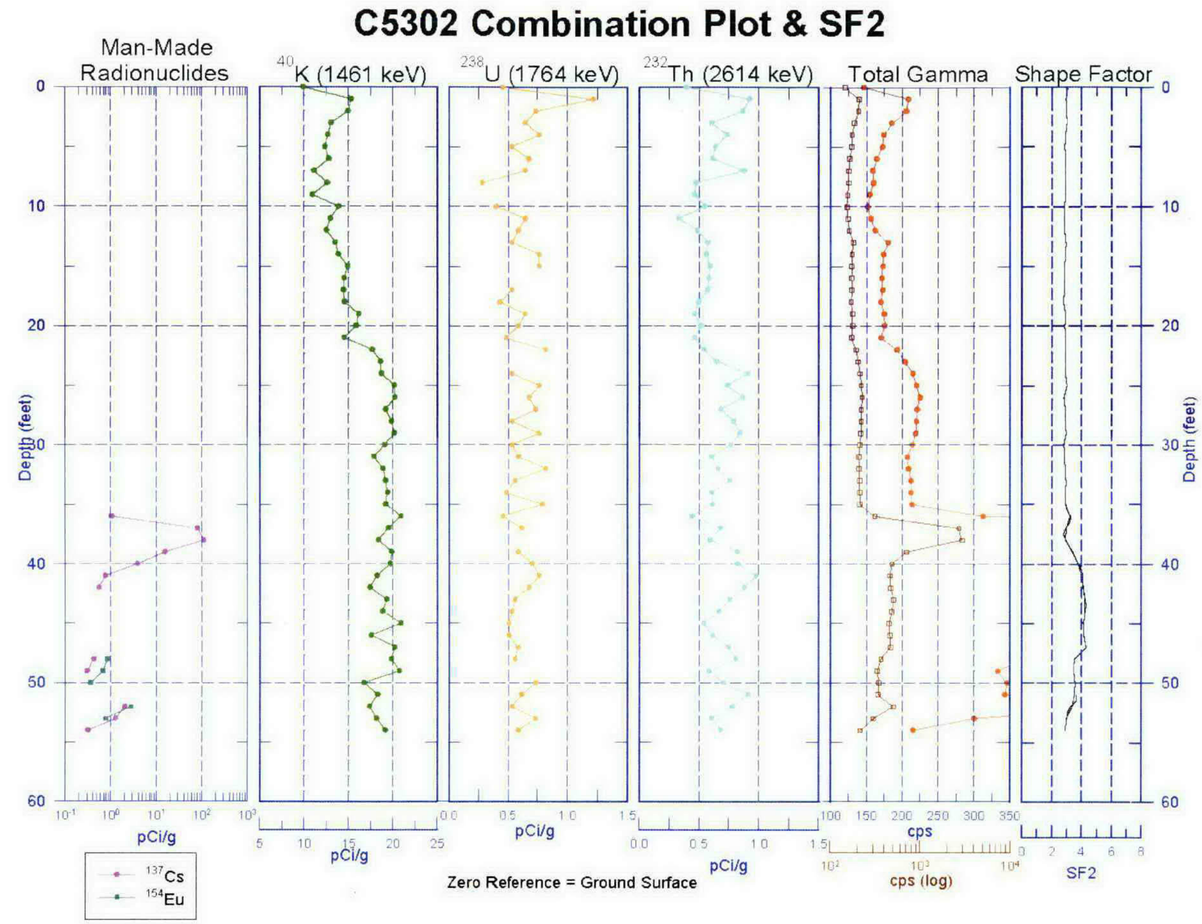

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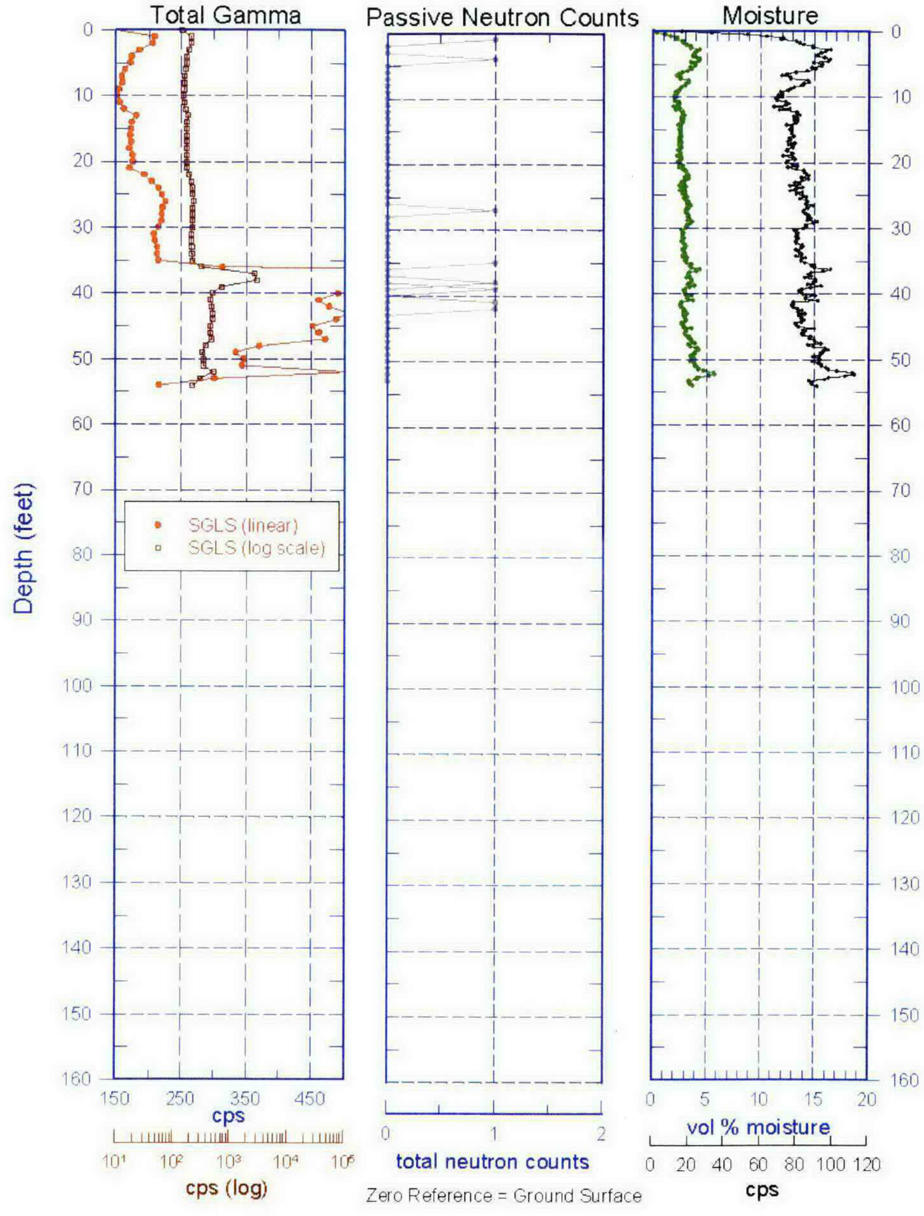
C5302
Total Gamma, Passive Neutron, & Moisture



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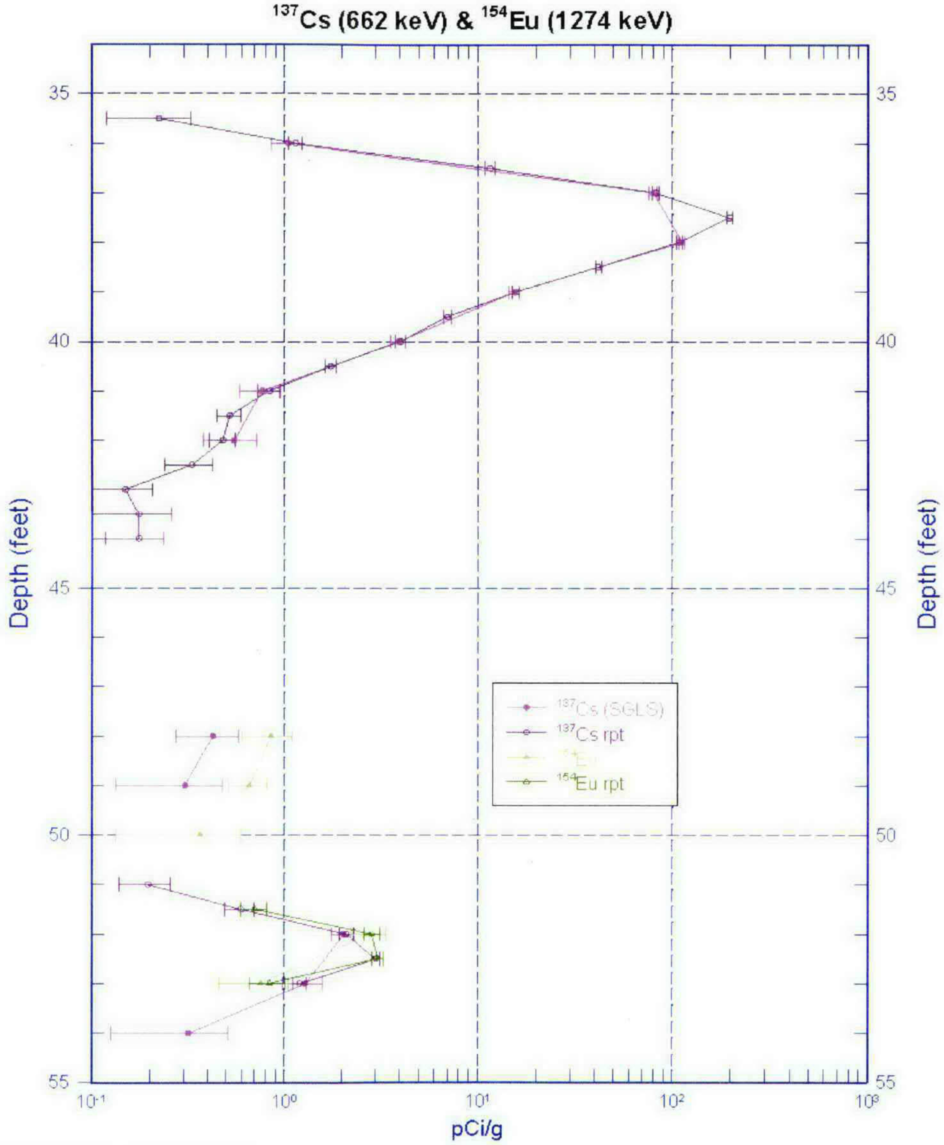
C5302
Repeat Section of Man-Made Radionuclides



Zero Reference = Ground Surface

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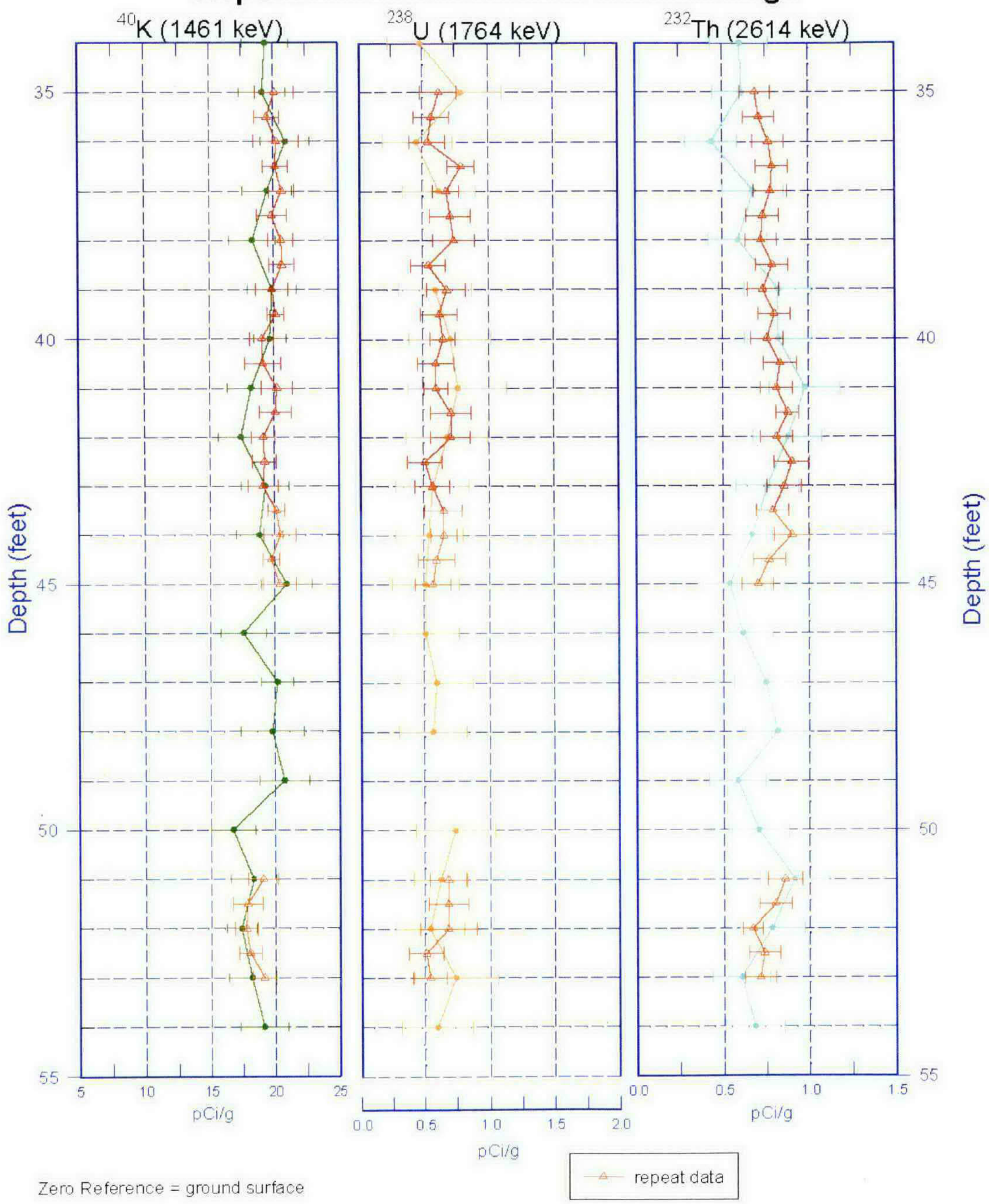
C5302

Repeat Section of Natural Gamma Logs



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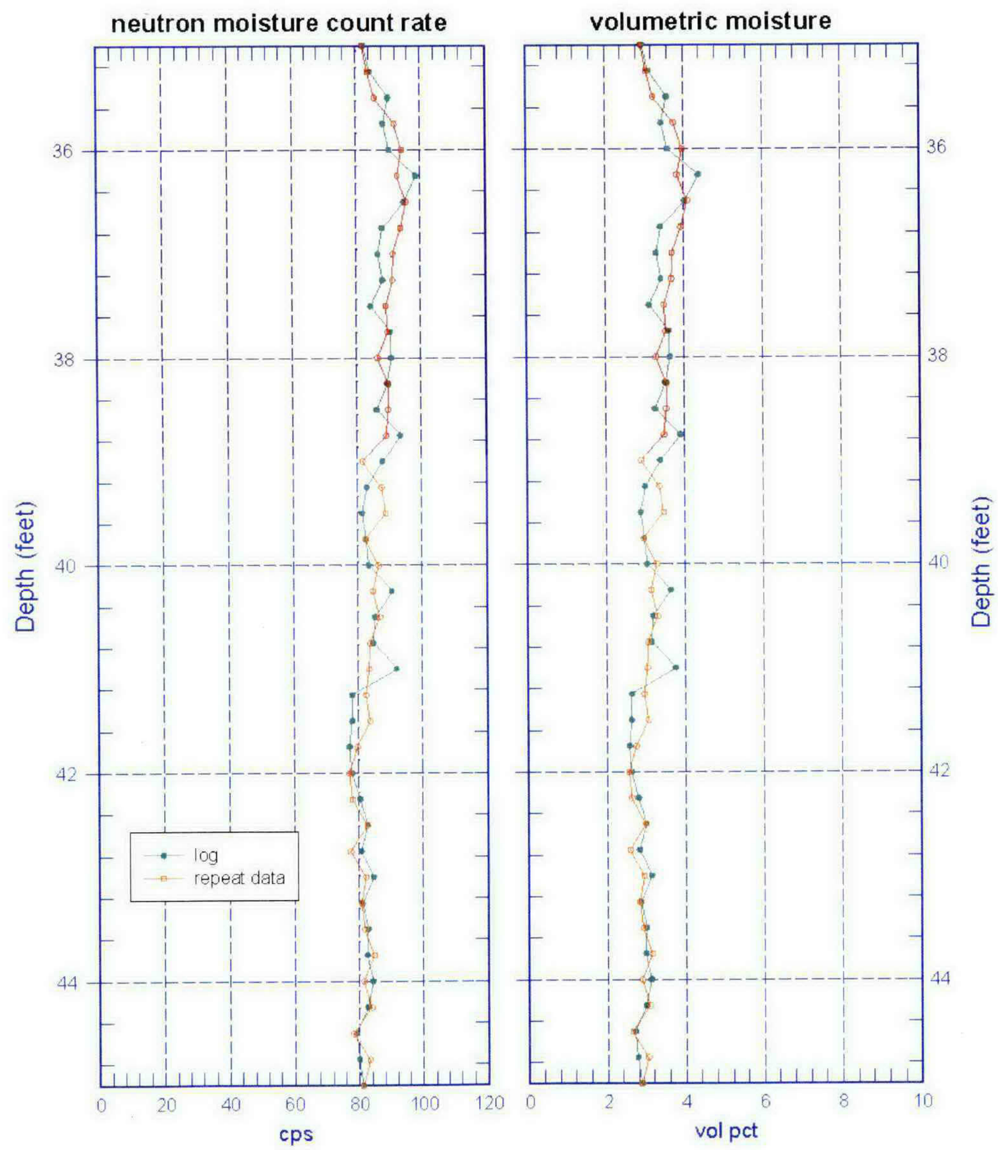
C5302
Repeat Section of Neutron Moisture



Zero Reference = Ground Surface

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Appendix C

Groundwater Impacts Evaluation

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C1 Groundwater Impact Analysis

A groundwater impacts evaluation was conducted to identify the non-radioactive and radioactive contaminants that could pose a potential future impact to groundwater using the data collected as part of the remedial investigation (RI). As part of this evaluation, a screening level comparison was conducted to assess the potential effects from leaching of non-radionuclide contaminated soil present at the 216-A-2 and 216-A-4 Cribs. In addition, modeling was conducted to assess the potential effects from leaching of radionuclide contaminated soil present at the 216-A-2 Crib and the bounding 216-A-5 Crib site. The groundwater impacts evaluation also included modeling of uranium metal contaminated soil at the 216-A-4 Crib.

The findings from these evaluations, presented in this appendix, are used in the feasibility study (FS) to determine if remedial action is necessary for groundwater quality protection.

C1.1 Non-Radionuclide Impacts Evaluation

As part of the Risk Assessment, non-radiological and radiological COPCs were identified for shallow zone soils and deep zone soils at the 216-A-2 and 216-A-4 Cribs. Soil concentrations protective of groundwater were calculated using the fixed-parameter three-phase partitioning model described in WAC 173-340-747, "Deriving Soil Concentrations for Ground Water Protection." Maximum concentrations of non-radiological COPCs at the 216-A-2 Crib at the 216-A-4 Crib were compared to their corresponding soil concentrations protective of groundwater (i.e., cleanup levels). Screening methods and results are presented in Section C1.

C1.1.1 Radionuclide Impacts Evaluation – RESRAD

RESRAD modeling is used to determine whether the radionuclides beneath the 216-A-2 Crib will reach groundwater in 1,000 years. If any of the radionuclides reach groundwater during the period of simulation, the resulting concentrations in the groundwater are compared to maximum contaminant levels (MCLs). The methodology described in WAC 173-340-747 was used as the basis for determining non-radioactive contaminant impact to groundwater. Modeling methods, assumptions, and results are presented in Section C2.

In addition, an evaluation for 216-A-5 Crib (a bounding waste site) was conducted to obtain a conservative estimate of contaminant transport through the vadose zone at the 200-MW-1 operable unit (OU) waste sites. The 216-A-5 waste site received far more liquid waste than any of the cribs in the 200-MW-1 OU; 1.6 billion liters (420 million gallons), or approximately 150 pore volumes (see Table 1-1 in Chapter 1). In addition, the waste discharged to the 216-A-5 Crib was acidic in nature. The mobility of some radionuclide contaminants, including cesium-137, strontium-90, plutonium, and americium-241, can increase under low pH conditions.

RESRAD incorporates a simplified model of contaminant transport from the contaminated zone through the unsaturated zone and the aquifer. RESRAD employs a one-dimensional simplification of advective flow in the vadose zone. The major processes affecting radionuclide transport, such as advection, sorption, and radioactive decay and ingrowths, are included. This simplified one-dimensional model leads to conservative estimates of the potential impact to the groundwater because it does not account for other processes that can reduce the contaminant concentrations in the groundwater, such as longitudinal and transverse dispersion, mineral precipitation/dissolution, and other site-specific hydrogeologic influences.

The RESRAD transport simulations for the 216-A-2 Crib were conducted using two land use scenarios; restricted, and unrestricted. A set of input parameters was developed for each land-use assumption.

The RESRAD transport simulations for the 216-A-5 Crib were conducted using unrestricted land use assumptions.

Exposure point concentrations (EPCs) used for the analysis of the 216-A-2 Crib were the maximum concentrations detected in soil between ground surface and the water table at borehole C5515. Site-specific data for the 216-A-4 Crib were not used to assess potential groundwater impacts because the deep borehole (C5301) at this location was drilled outside the crib's boundary. EPCs used for the analysis of the 216-A-5 Crib were the maximum concentrations detected at borehole C6552. This borehole was drilled to groundwater near the center of the 216-A-5 Crib.

C1.1.2 Non-Radionuclide and Radionuclide Impacts Evaluation–STOMP

A secondary evaluation of the potential for groundwater impacts of uranium and carbon-14 at the 216-A-4 and 216-A-5 Cribs, respectively, using two-dimensional fate and transport modeling results was conducted. This phase using more robust two-dimensional fate and transport modeling was undertaken to evaluate the potential risks/impacts to groundwater beyond the initial RESRAD-based screening analysis. The only COPCs assessed in this evaluation are uranium for the 216-A-4 Crib and carbon-14 for the 216-A-5 Crib. Groundwater maximum contaminant level (MCL) was used as the metric for defining unacceptable impacts according to the modeled groundwater concentrations. The methods, assumptions, key parameter values used in these evaluations, and results are described in Section C3. The results of modeling can be applied to the conceptual contaminant distributions and contaminant release models to provide an indication of the amount of remediation necessary to achieve protection of groundwater at the 216-A-4 and the 216-A-5 Cribs.

C2 216-A-2 Crib Non-Radionuclide Groundwater Impact Analysis

The non-radioactive COPCs identified for evaluation of impact to groundwater are listed in Table C2-1. Soil concentrations protective of groundwater were calculated using the fixed-parameter three-phase partitioning model described in WAC 173-340-747. Use of this model for determining soil concentrations protective of groundwater is referenced under calculation of Method B soil cleanup levels in Ecology 94-145, *Cleanup Levels and Risk Calculations under the Model Toxics Control Act Cleanup Regulation; CLARC, Version 3.1*, under WAC 173-340, "Model Toxics Control Act-Cleanup." Maximum concentrations of non-radiological COPCs at the 216-A-2 Crib at the 216-A-4 Crib are compared to their corresponding soil concentrations protective of groundwater (i.e., cleanup levels) and are shown in Table C2-1.

Because the characterization borehole inside the footprint of the 216-A-4 Crib was terminated within the crib due to the unexpected high radiation levels encountered, no deep zone data currently are available for the crib. Given the similarity in hydrogeology between the two adjacent cribs it is possible that contaminants at the 216-A-4 Crib might be present deeper in the vadose zone and thus might reach the water table.

C2.1 Results of the Non-Radionuclide Groundwater Impact Analysis

Comparisons for the 216-A-2 Crib indicate that only uranium had a maximum soil concentration (147 mg/kg) greater than the soil concentration protective of groundwater (1.32 mg/kg). Thus, for the purpose of this analysis, uranium is identified as a COC. It should be noted that uranium isotopes also are identified as COPCs and are further evaluated using RESRAD transport modeling. No other non-radiological constituents detected at the 216-A-2 Crib were greater than their soil concentration protective of groundwater as shown in Table C2-1.

Comparisons for the 216-A-4 Crib indicate that uranium metal at 1,970 mg/kg and nitrate at 185 mg/kg are present at concentrations greater than their respective soil to groundwater protective concentrations of 1.32 mg/kg and 40 mg/kg. Therefore, uranium-metal and nitrate were identified as COCs.

Table C2-1. Comparison of Non-Radionuclide Contaminants of Potential Concern to WAC 173-340-747 Soil Concentrations Protective of Groundwater

COPC	Maximum Soil Concentration (mg/kg)						Exceeds Screening Level Levels (Y=yes) (N=no)
		216-A-2 Crib		216-A-4 Crib			
	Protective of Groundwater	Borehole C5515	Depth (ft)	Borehole 4560 (C) or 5301 (P)	Depth (ft)		
Metals Analyses (mg/kg)							
Chromium (III)	2000	23.6	285-287	25-P	283-285		N, N
Chromium (Hexavalent)	18.4	0.247	132.5-135	NR	NR		N,
Copper	263	23.3	285-287	NR	NR		N,
Lead	270	10.3	285-287	NR	NR		N,
Selenium	5.20	0.786	285-287	NR	NR		N,
Uranium (metallic)	1.32 (a)	147	29-31.5	1970-C	18.5-21		Y, Y

Table C2-1. Comparison of Non-Radionuclide Contaminants of Potential Concern to WAC 173-340-747 Soil Concentrations Protective of Groundwater

COPC	Maximum Soil Concentration (mg/kg)					Exceeds Screening Level Levels (Y=yes) (N=no)
		216-A-2 Crib		216-A-4 Crib		
	Protective of Groundwater	Borehole C5515	Depth (ft)	Borehole 4560 (C) or 5301 (P)	Depth (ft)	
General Inorganic Chemistry (mg/kg)						
Cyanide	0.80	0.230	29-31.5	0.89-P	29-31.5	N, Y
Nitrate as N	40	12.9	285-287	185-P	283-285	N, Y
Nitrite as N	4	0.48	29-31.5	0.427-P	43-45.5	N, N
Phosphate	Not regulated under WAC	313	29-31.5	NR	NR	N, N
Volatile Organic Compounds (mg/kg)						
1,2,4-Trimethylbenzene	15.0h	0.00055	32-34.5	NR	NR	N
Acetone	28.9	0.0082	32-34.5	NR	NR	N
Methylene Chloride	0.0218	0.0037	32-34.5	0.011-C	18.5-21	N
Styrene	0.0328	0.009	32-34.5	0.00041-C	18.5-21	N
Toluene	4.65	0.00057	32-34.5	NR	NR	N
Semi-volatile Organic Compounds (mg/kg)						
Bis (2-ethylhexyl)phthalate	13.9	0.047	32-34.5	NR	NR	N
Di-n-butylphthalate	56.5	0.038	32-34.5	NR	NR	N
Tributyl Phosphate	0.677	0.12	29-31.5	NR	NR	N
Miscellaneous Organic Analyses (mg/kg)						
Aroclor-1254	0.0664	0.052	29-31.5	0.056-C	18.5-21	N, N

Notes:

Aroclor is an expired trademark.

WAC 173-340-747, "Deriving Soil Concentrations for Ground Water Protection."

C = borehole advanced through center of crib. P = borehole advanced at crib perimeter.

NR = not reported

WAC = Washington Administrative Code

C3 216-A-2 Crib Radionuclide Groundwater Impact Evaluation

The impact to groundwater from radionuclides was estimated using RESRAD, Version 6.4. The RESRAD code was developed by Argonne National Laboratory (*RESRAD for Windows* [ANL, 2002]) to implement DOE guidelines for allowable residual radioactive material in soil (DOE Order 5400.5, *Radiation Protection of the Public and the Environment*).

C3.1 Methods

RESRAD incorporates a simplified model of contaminant transport from the contaminated zone through the unsaturated zone and the aquifer. It is assumed that the radioactive constituents are evenly distributed within the homogeneous contaminated zone that has a specified thickness and specified physical properties. The radionuclides released from the contaminated zone are subject to transport through the vadose zone. RESRAD employs a one-dimensional simplification of advective flow in the vadose zone. However, the major processes affecting radionuclide transport, such as advection, sorption, and radioactive decay and ingrowths, are included. RESRAD allows for modeling up to five unsaturated zone layers with different hydrogeologic properties beneath the contaminated zone. The saturated zone is assumed to be homogeneous. Transport in the saturated zone includes dilution. This simplified one-dimensional model leads to conservative estimates of the potential impact to the groundwater because it does not account for other processes that can reduce the contaminant concentrations in the groundwater, such as longitudinal and transverse dispersion, mineral precipitation/dissolution, and other site-specific hydrogeologic influences.

Contaminant transport is incorporated in RESRAD as a part of the exposure analysis. The transport calculations are performed when one or more of the water-related exposure pathways are activated. To evaluate soil impact on groundwater, the drinking water pathway is activated in RESRAD. For this analysis, it is assumed that a groundwater well is installed at the down-gradient boundary of the waste site. The well is pumped during the entire 1,000-year period of interest. This implementation of RESRAD results in leaching of radionuclides from the contaminated zone and travel with the infiltrating water downward through the unsaturated zone. The radionuclides that reach groundwater during the period of interest travel down-gradient in the groundwater in the horizontal direction. The radionuclides that reach the groundwater are then captured at the well. Time-dependent contaminant concentrations at the well are calculated and compared to their respective federal MCL.

Two methods are provided in RESRAD to calculate the contaminant concentrations in groundwater from the well. The nondispersion model was used in this analysis to allow for simulating radionuclide transport in the aquifer downward from the site and to implement vertical mixing in the saturated zone. The contaminant travel time in the groundwater to the well is calculated as a function of the saturated zone hydraulic conductivity and gradient, length of the contaminant zone parallel to the hydraulic gradient, distance of the well intake below the water table, aquifer-effective porosity, depth of contamination within the saturated zone at the well location, and radionuclide-specific parameters. The contaminant concentration in the well is adjusted by the dilution in the saturated zone. Calculated concentrations are a function of the contaminated area, infiltration rate, well-pumping rate, depth of contamination within the saturated zone at the well location, and the effective pumping interval width.

Groundwater concentrations are considered for two land-use assumptions including restricted and unrestricted. For restricted land use (i.e., industrial), there is no irrigation at the site (the irrigation rate is equal to zero) but there is infiltration through precipitation, the exposure duration is 25 years, and the drinking water intake is 250 L/yr. For unrestricted land use, there is irrigation at the site (irrigation rate of 0.76 m/yr) in addition to infiltration through precipitation, the exposure duration is 30 years, and the drinking water intake is 700 L/yr.

A set of RESRAD input parameters is developed for both land-use assumptions. The input parameters are summarized in the RESRAD input parameters summary table for the groundwater exposure pathway provided in Table C3-1. This table provides the value for each input parameter, rationale for this value, and reference to the source based on which the parameter value was defined.

The contaminated area provided in the RESRAD input parameters summary table (Table C3-1) for the groundwater impact analysis is calculated based on the actual site area as recommended in PNNL-14702. The 216-A-2 Crib is 6.1 m wide and 6.1 m long, with an area equal to 37.21 m^2 (400.53ft^2). Equation 4.3 in PNNL-14702 is used to calculate the contaminated area (A_x) as follows:

$$A_x = \lambda A_0$$

$$\lambda = \frac{Q_{\max}}{k_{x\,\min} A_0}$$

where:

A_0 = actual site area (m^2)

k_{xmin} = minimum hydraulic conductivity of the unsaturated zone beneath the contaminated zone (m/s)

Q_{max} = maximum artificial liquid discharge rate (m^3/s)

This equation is used to adjust the actual site area in cases when the dimensionless parameter λ is greater than one. In the cases when the dimensionless parameter λ is equal to or smaller than one, no adjustment is needed and the contaminated area is equal to the actual site area.

The parameters in this equation are defined as follows:

- The liquid discharge rate is calculated from the total liquid discharge at the site, which is 230,000 L over 4 years of operations based on Table 3-1 in DOE/RL-2001-65, *200-MW-1 Miscellaneous Waste Group Operable Unit RI/FS Work Plan*, which translates to1.82*10^{-6} m^3/s.
- The minimum hydraulic conductivity is 17.6 m/yr (5.58*10^{-7} m/s) based on hydraulic conductivities presented in the RESRAD input parameters summary (Table C3-1).
- The dimensionless parameter λ is then 0.09, which is smaller than one. Consequently, the site area does not need to be adjusted. The resulting contaminated area used in RESRAD is 37.2 m^2 (400.5 ft^2).

Table C3-1. 216-A-2 Crib Summary of RESRAD Input Parameters for Groundwater Exposure Pathway (Restricted and Unrestricted Land-Use Scenarios) and Industrial Worker Exposure Scenario (with and without Cover)

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
Exposure Pathways	External Gamma Inhalation Plant Ingestion Meat Ingestion Milk Ingestion Aquatic Foods Drinking Water Soil Ingestion Radon	Not applicable	Suppressed Suppressed Suppressed Suppressed Suppressed Suppressed Active Suppressed Suppressed	
R011- Contaminated Zone (CZ)	Area of CZ	m^2 (ft^2)	216-A-2 Crib 37.21 (400.53)	Area based on Equation 4.3 in PNNL-14702 (Section 5.2.3).
	Thickness of CZ (baseline)	m (ft)	This will vary based on the layer of contamination that is modeled.	Uses site-specific data from the 27 to 40 ft bgs interval and the 250.5 to 315 ft bgs. Figure C3-1 and Figure C3-2.
	Length parallel to aquifer flow	m	6.1	Value selected is based on the full length of the crib. See Table 1-1 in Chapter 1.
	Radiation dose limit (industrial scenario)	mrem/ year	15	40 CFR Part 141; OSWER Directive 9200.4-31P.
	Elapsed time since waste placement	year	0	Environmental samples should be decayed to current calendar year.
Exposure Point Concentrations	Exposure point concentrations	pCi/g	chemical-specific	Maximum concentrations measured in borehole C5515. See Appendix A, Table A1-4.
R013-Cover and CZ Hydrological Data	Cover depth	m (ft)	8.23 (27) and 76.35 (250)	See Figure C3-1 and Figure C3-2.
	Cover material density	g/cm^3	1.94	Backfill sand unit (Bf) in PNNL-14702, Table 4-5.
	Cover erosion rate	m/year	0.00001	Value selected prevents appreciable erosion of the cover present over the waste site during the simulation period.
	Density of CZ	g/cm^3	1.68 and 1.73	Bulk density of each contaminated zone was calculated as an average based on available measurements. See Table C3-4 and Table C3-5.
	CZ erosion rate	m/year	0.00001	Value selected prevents appreciable erosion of the CZ over the period of simulation.
	CZ total porosity	unitless	0.349 and 0.32	The Hanford coarse sand unit (Hcs) in Table 4-5 in PNNL-14702 is used for the shallow zone and a weighted average for the hydrogeologic layers is used for the deep zone. See Table C3-4 and Table C3-5.
	CZ field capacity	unitless	0.041 and 0.1	Field capacity is calculated using parameters obtained from Table 4.5 in PNNL-14702.; field capacity equations are shown in Appendix F, Table F-3. Results are shown Table C3-4 and Table C3-5.
	CZ hydraulic conductivity	m/year	716 and 83.86	The Hanford coarse sand unit (Hcs) in Table 4-5 in PNNL-14702 is used for the shallow zone and a weighted average for the hydrogeologic layers is used for the deep zone. See Table C3-4 and Table C3-5.

Table C3-1. 216-A-2 Crib Summary of RESRAD Input Parameters for Groundwater Exposure Pathway (Restricted and Unrestricted Land-Use Scenarios) and Industrial Worker Exposure Scenario (with and without Cover)

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	CZ b parameter	unitless	4.05	Determined from soil textures listed in Table C3-1 in RESRAD Version 6 manual (ANL/EAD-4). This hydrogeologic unit has little of the finer material (silt and clay) listed in Table C3-1. Hence, the "b" parameter is assigned the value of 4.05 for sand.
	Humidity in air	g/cm^3	Not applicable	Not applicable.
	Evapotranspiration coefficient	unitless	0.977	Value assigned results in an annual recharge rate of 0.4 cm/y (PNNL-14702)
	Wind speed	m/s	3.4	Value obtained from in PNNL-15160, Table 5-1.
	Precipitation	m/year	0.177	Value obtained from PNNL-15160, Table 4-1.
	Irrigation rate	m/year	0.76 (Unrestricted) 0 (Restricted)	DOE/RL-96-17, Table B-1.
	Irrigation mode	Not applicable	Overhead	RESRAD default.
	Runoff coefficient	unitless	0	Runoff coefficient of zero indicates all precipitation soaks into the ground.
	Watershed area for nearby stream or pond	m^2	1.00E+06	RESRAD default.
	Accuracy for water/soil computations	unitless	0.001	RESRAD default.
R014 - Saturated Zone (SZ) hydrological data	Density of SZ	g/cm^3	1.93	Hanford gravel unit (Hg) in Table 4-5 of PNNL-14702.
	SZ total porosity	unitless	0.167	Hanford gravel unit (Hg) in Table 4-5 of PNNL-14702.
	SZ effective porosity	unitless	0.167	Hanford gravel unit (Hg) in Table 4-5 of PNNL-14702.
	SZ field capacity	unitless	0.062	Field capacity calculated using parameters obtained from Table 4-5 in PNNL-14702 for the Hanford gravel unit (Hg). See Table C3-4 Layer 1.
	SZ hydraulic conductivity	m/year	104	Hanford gravel unit (Hg) in Table 4-5 of PNNL-14702.
	SZ hydraulic gradient	unitless	2.00E-05	Value obtained from DOE/RL-2008-01, Appendix H, Table H2-2.
	SZ b parameter	unitless	4.05	Determined from soil textures listed in Table C3-1 in RESRAD Version 6 Manual (ANL/EAD-4). This hydrogeologic unit has little of the finer material (silt and clay) listed in Table C3-1. Hence the "b" parameter is assigned the value of 4.05 for sand.
	Water table drop rate	m/year	0.0001	Value selected results in little change in the depth of the groundwater during the simulation period.
	Well pump intake depth below water table	m	10	Located mid-aquifer for 75-ft-thick aquifer for both groundwater exposure pathway land-use scenarios.
	Nondispersion or mass-balance	Not applicable	Nondispersion	RESRAD default.
	Well pumping rate	m^3/year	250	RESRAD default.
R015 - Uncontaminated and Unsaturated Strata Hydrological Data	Number of unsaturated strata	Not applicable	5 layers used for shallow zone and 1 layer used for deep zone.	Sediment stratigraphy based on data from borehole C5515. See Figure C3-1 and Figure C3-2.

Table C3-1. 216-A-2 Crib Summary of RESRAD Input Parameters for Groundwater Exposure Pathway (Restricted and Unrestricted Land-Use Scenarios) and Industrial Worker Exposure Scenario (with and without Cover)

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	Thickness	m	This will vary based on the layer of contamination that is modeled	Hanford coarse sand (Hcs), Hanford fine sand unit (Hfs); Hanford formation sandy gravel (Hg); Hanford formation silt (PPlz); Hanford formation sandy gravel (Hg). See Figure C3-1 and Figure C3-2.
	Soil density	g/cm^3	This will vary based on the layer of contamination that is modeled	Values from each unit were obtained from PNNL-14702, Table 4-5. See Table C3-4 and Table C3-5.
	Total porosity	unitless	This will vary based on the layer of contamination that is modeled	Values from each unit were obtained from PNNL-14702, Table 4-5. See Table C3-4 and Table C3-5.
	Effective porosity	unitless	This will vary based on the layer of contamination that is modeled	Values from each unit were obtained from PNNL-14702, Table 4-5. See Table C3-4 and Table C3-5.
	Field Capacity	unitless	This will vary based on the layer of contamination that is modeled	Field capacity calculated using parameters obtained from PNNL-14702, Table 4-5. See Table C3-4 and Table C3-5.
	Soil-specific b parameter	unitless	This will vary based on the layer of contamination that is modeled	Determined from soil textures listed in Table C3-1 in RESRAD Version 6 Manual (ANL/EAD-4). Except for Hanford formation silt, each of the hydrogeologic units has little of the finer material (silt and clay) listed in Table C3-1. Hence, the "b" parameters are all near 4.05 for sand. The soil class Hg was assigned the silty clay value of 10.4. See Table C3-4 and Table C3-5.
	Hydraulic conductivity	m/year	This will vary based on the layer of contamination that is modeled	Values from each unit were obtained from PNNL-14702, Table 4-5. See Table C3-4 and Table C3-5.
R016 - Distribution Coefficients and Leach Rates for Individual Radionuclides	Distribution coefficients for contaminated zone, uncontaminated zone and saturated zone	cm^3/g	Contaminant-specific	Best estimate values obtained from Table 4-11 of PNNL-14702. Distribution coefficient values for Co-60 and Am-241 were obtained from the "no impact" category from in PNNL-17154, Table A1-1.
	Saturated leach rate	yr^{-1}	Contaminant-specific	RESRAD default.
	Solubility limit	mol/L	0	RESRAD default.
R017 - Inhalation and External Gamma	Inhalation rate	m^3/year	Not applicable	Not applicable.
	Mass loading for inhalation	g/m^3	Not applicable	Not applicable.
	Exposure duration	year	30 (Unrestricted) 25 (Restricted)	EPA, 1991.
	Indoor Dust Filtration factor	unitless	Not applicable	Not applicable.
	External gamma shielding factor	unitless	Not applicable	Not applicable.
	Indoor time fraction	unitless	Not applicable	Not applicable.
	Outdoor time fraction	unitless	Not applicable	Not applicable.
	Shape factor	Not applicable	Not applicable	Not applicable.
R018 - Ingestion Pathway Data, Dietary Parameters	Soil Ingestion Intake	g/yr	Not applicable	Not applicable.
	Drinking Water Intake	L/yr	700 (Unrestricted) 250 (Restricted)	Groundwater exposure pathway (unrestricted) based on 2 L/day (350 days/yr), Luftig and Weinstock, 1997. Groundwater exposure pathway (restricted) based on 1 L/day (250 days/yr), Luftig and Weinstock, 1997.

Table C3-1. 216-A-2 Crib Summary of RESRAD Input Parameters for Groundwater Exposure Pathway (Restricted and Unrestricted Land-Use Scenarios) and Industrial Worker Exposure Scenario (with and without Cover)

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	Leafy Vegetable Consumption	kg/yr	Not applicable	The food consumption pathway is considered incomplete for this exposure scenario.
	Fruits, Vegetables, and Grain Consumption	kg/yr	Not applicable	The food consumption pathway is considered incomplete for this exposure scenario.
	Milk Consumption	L/yr	Not applicable	The food consumption pathway is considered incomplete for this exposure scenario.
	Meat and Poultry Consumption	kg/yr	Not applicable	The food consumption pathway is considered incomplete for this exposure scenario.
	Fish Consumption	kg/yr	Not applicable	The consumption of fish is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Other Seafood Consumption	kg/yr	Not applicable	The consumption of seafood is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Drinking Water Contamination Fraction	Unitless	1	RESRAD default.
	Household Water Contamination Fraction	Unitless	Not applicable	Not applicable.
	Livestock Water Contamination Fraction	Unitless	Not applicable	Not applicable.
	Irrigation Water Contamination Fraction	Unitless	Not applicable	Not applicable.
	Aquatic Food Contamination Fraction	Unitless	Not applicable	Not applicable.
	Plant Food Contamination Fraction	Unitless	Not applicable	Not applicable.
	Meat Contamination Fraction	Unitless	Not applicable	Not applicable.
	Milk Contamination Fraction	Unitless	Not applicable	Not applicable.
R019- Ingestion Pathway Data, Nondietary	Livestock Fodder Intake for Meat	kg/d	Not applicable	Not applicable.
	Livestock Fodder Intake for Milk	kg/d	Not applicable	Not applicable.
	Livestock Water Intake for Meat	L/d	Not applicable	Not applicable.
	Livestock Water Intake for Milk	L/d	Not applicable	Not applicable.
	Livestock Intake of Soil	kg/d	Not applicable	Not applicable.
	Mass Loading for Foliar Deposition	g/m^3	Not applicable	Not applicable.
	Depth of Soil Mixing Layer	m	0.15	RESRAD default.
	Depth of Roots	m	Not applicable	Not applicable.
Plant Factors	Wet Weight Crop Yield, Non-Leafy	kg/m^2	Not applicable	Not applicable.
	Wet Weight Crop Yield, Leafy	kg/m^2	Not applicable	Not applicable.
	Wet Weight Crop Yield, Fodder	kg/m^2	Not applicable	Not applicable.
	Length of Growing Season, Non-Leafy	yr	Not applicable	Not applicable.
	Length of Growing Season, Leafy	yr	Not applicable	Not applicable.

Table C3-1. 216-A-2 Crib Summary of RESRAD Input Parameters for Groundwater Exposure Pathway (Restricted and Unrestricted Land-Use Scenarios) and Industrial Worker Exposure Scenario (with and without Cover)

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	Length of Growing Season, Fodder	yr	Not applicable	Not applicable
	Translocation Factor, Non-Leafy	unitless	Not applicable	Not applicable
	Translocation Factor, Leafy	unitless	Not applicable	Not applicable
	Translocation Factor, Fodder	unitless	Not applicable	Not applicable
	Weathering Removal Constant	yr^{-1}	Not applicable	Not applicable
	Wet Foliar Interception Factor, Non-Leafy	unitless	Not applicable	Not applicable
	Wet Foliar Interception Factor, Leafy	unitless	Not applicable	Not applicable
	Wet Foliar Interception Factor, Fodder	unitless	Not applicable	Not applicable
	Dry Foliar Interception Factor, Non-Leafy	unitless	Not applicable	Not applicable
	Dry Foliar Interception Factor, Leafy	unitless	Not applicable	Not applicable
	Dry Foliar Interception Factor, Fodder	unitless	Not applicable	Not applicable
R020–Groundwater Usage	Groundwater Fractional Usage – Drinking Water	unitless	1	RESRAD default
	Groundwater Fractional Usage – Household Usage	unitless	Not applicable	Not applicable
	Groundwater Fractional Usage – Livestock Water	unitless	Not applicable	Not applicable
	Groundwater Usage –Irrigation	unitless	Not applicable	Not applicable
R021-Radon	Not used	Not applicable	Not applicable	Not applicable
Storage Times	Fruit, Non-Leafy Vegetables, and Grain	day	Not applicable	Not applicable
	Leafy Vegetables	day	Not applicable	Not applicable
	Milk	day	Not applicable	Not applicable
	Meat	day	Not applicable	Not applicable
	Fish	day	Not applicable	Not applicable
	Crustacea and Mollusks	day	Not applicable	Not applicable
	Well Water	day	Not applicable	Not applicable
	Surface Water	day	Not applicable	Not applicable
	Livestock Fodder	day	Not applicable	Not applicable
C-14	Not used	Not applicable	Not applicable	Not applicable

Table C3-1. 216-A-2 Crib Summary of RESRAD Input Parameters for Groundwater Exposure Pathway (Restricted and Unrestricted Land-Use Scenarios) and Industrial Worker Exposure Scenario (with and without Cover)

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation

Notes:

40 CFR 141, "National Primary Drinking Water Regulations."

ANL/EAD-4, 2001, *User's Manual for RESRAD, Version 6.*

DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area.*

EPA/540/R-99/006, *Radiation Risk Assessment At CERCLA Sites: Q&A*, OSWER Directive 9200.4-31P.

PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments.*

PNNL-15160, *Hanford Site Climatological Summary 2004 with Historical Data.*

PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.*

bgs = below ground surface
CZ = Contaminated Zone
RESRAD = RESidual RADioactivity
SZ = Saturated Zone

The soil density for the shallow contaminated zone (RESRAD input parameter) was calculated based on the dry bulk density values provided in this appendix. Four dry bulk density values reported in kg/m^3 are 1740, 1700, 1550, and 1717. The average dry bulk density is 1680 kg/m^3 (1.68 g/cm^3). This is in good agreement with the bulk density of the Hanford formation coarse sand (1.67 g/cm^3) in which the shallow contaminated zone is located. The value of 1.68 g/cm^3 was used in the RESRAD calculations. The soil density for the deep contaminated zone was calculated as a weighted average of the densities for the four hydrogeologic units included in this zone. Four dry bulk density values reported in kg/m^3 are 1600, 1930, 1680, and 1930. The weighted average dry bulk density is 1730 kg/m^3 (1.73 g/cm^3).

The unitless evapotranspiration coefficient (C_e) is used in RESRAD to calculate the infiltration rate (I) through the unsaturated zone. The infiltration rate cannot be explicitly specified in RESRAD. It is calculated implicitly by RESRAD as (Equation E.4 in ANL/EAD-4):

$$I = (1 - C_e)[(1 - C_r)P_r + I_{rr})],$$

where:

C_r = run-off coefficient (unitless)

P_r = precipitation (m/yr)

I_{rr} = irrigation rate (m/yr)

The run-off coefficient, precipitation, and irrigation rate are defined in Table C3-1.
The evapotranspiration coefficient is calculated as:

$$C_e = 1 - \frac{I}{(1 - C_r)P_r + I_{rr}}$$

The infiltration rate used in this equation is 0.004 m/yr. This corresponds to the estimated long-term recharge rate (when the site stabilized and returns to the natural conditions) for Hanford sand (PNNL-14702, Table 4-15). The resulting evapotranspiration coefficient is 0.977.

The only parameters that are not provided in the RESRAD input summary table are the contaminant-specific paramcters such as EPCs and distribution coefficients (K_ds). For the purpose of this analysis, EPCs for COPCs are defined as the maximum concentrations encountered between ground surface and the water table (approximately 0 to 96 m [0 to 314 ft] below ground surface [bgs]). The maximum concentrations and the depth interval are summarized in Appendix A, Table A1-5. The parameters defined in Table C3-1 and the radionuclide-specific parameters described below were used to set up the RESRAD input files. There are two contaminated zones: (1) a shallow zone from 8.2 to 12.2 m (27 to 40 ft bgs), and (2) a deep zone from 76 to 96 m (250.5 to 315 ft) bgs.

C3.1.1 Radionuclide-Specific Parameters

As previously described, the EPCs for this analysis are the maximum concentrations from borehole C5515 based on the commercial laboratory and 222-S Laboratory analytical data (Appendix A, Table A1-4). Maximum radionuclide COPC concentrations are encountered within the depth interval 8.2 to 12.2 m (27 ft to 40 ft) bgs except tritium where it is encountered within the depth interval from 76 to 96 m (250.5 ft to 315 ft) bgs. This first depth interval where maximum contaminant concentrations are encountered is referred to as the shallow contaminated zone. This second depth interval where the maximum tritium concentration is encountered is referred to as the deep contaminated zone. Because RESRAD cannot simultaneously model multiple contaminated zones, each contaminated zone was modeled separately. The COPC EPCs for the shallow and deep contaminated zones are provided in Table C3-2 and Table C3-3, respectively. These shallow and deep zone EPCs are used in both restricted and unrestricted land-use scenarios.

Table C3-2. Radionuclide-Specific Exposure Point Concentrations and Distribution Coefficients for the Groundwater Impact Analysis, Shallow Contaminated Zone

Number	Radionuclide	EPC (pCi/g)	K_d (cm^3/g)
1	Am-241	94,000	300
2	Cs-137	31,000	2,000
3	Co-60	0.382	10
4	Eu-154	1.28	200
5	Ni-63	10.6	300
6	Pu-238	120	600
7	Pu-239	426,000	600
8	Sr-90	125,000	22
9	Tc	6.27	0
10	U-234	49.8	0.8
11	U-235	4.28	0.8
12	U-236	1.03	0.8
13	U-238	56.6	0.8
14	Ac-227	0	20
15	Np-237	0	10
16	Pa-231	0	50
17	Pb-210	0	100
18	Ra-226	0	20
19	Ra-228	0	20
20	Th-228	0	60,000
21	Th-229	0	60,000
22	Th-230	0	60,000
23	Th-232	0	60,000
24	U-233	0	0.8

Note:

Radionuclides with 0 pCi/g are daughter products and are not part of the initial EPC inventory.

EPC = exposure point concentration

K_d = distribution coefficient

Table C3-3. Radionuclide-Specific Exposure Point Concentrations and Distribution Coefficients for the Groundwater Impact Analysis, Deep Contaminated Zone.

Number	Radionuclide	EPC (pCi/g)	K_d (cm^3/g)
1	H-3	2,860	0

EPC = exposure point concentration
K_d = distribution coefficient

Analytical results for the isotopes of Pu-239/240 and U-233/U234 are not differentiated. Because in most cases Pu-239 is the dominant isotope, it is reasonable to assume that Pu-239/240 is all Pu-239. Similarly, it is commonly accepted that U-234 is the dominant isotope, so it is reasonable to assume that U-233/234 is all U-234. This is reflected in the values of the EPCs provided in Table C3-2.

The radionuclides listed in Table C3-2 with zero concentrations represent the daughter products of the parent radionuclides selected for analysis. The K_ds required for each radionuclide are provided in Table C3-2 and Table C3-3. Except for Co-60 and Am-241, the K_ds used in RESRAD are based on the best estimate values obtained from PNNL-14702 (Table 4-11). The K_d values for Co-60 and Am-241 are obtained from the "no impact" category from Table A1-1 in PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*.

For assessing impacts to groundwater from contaminants in the shallow zone, the cover depth is 8.23 m (27 ft) and the contaminated zone thickness is 4 m (13 ft), as shown in Figure C3-1. There are five unsaturated zone layers beneath the contaminated zone (Figure C3-1). The parameters of the contaminated zone and the unsaturated zone layers were defined based on the properties of the different hydrogeologic units and are summarized in Table C3-4.

For assessing impacts to groundwater from contaminants in the deep zone, the cover depth is 76.35 m (250.5 ft) and the contaminated zone thickness is 19.7 m (64.6 ft) as shown in Figure C3-2. Although the deep contaminated zone extends to the water table, the RESRAD model requires an unsaturated zone beneath the contaminated zone. To minimize the impacts of this requirement, a very thin (0.01 m) unsaturated layer was included in the model (Figure C3-2). The contaminated zone in this case consists of four hydrogeologic units. RESRAD assumes that the contaminated zone is homogeneous; the parameters of this homogeneous contaminated zone were calculated as the weighted averages of the corresponding parameters of the four hydrogeologic units. For example, the contaminated zone total porosity (ε_{cz}) is calculated as:

$$\varepsilon_{cz} = (\varepsilon_1 d_1 + \varepsilon_2 d_2 + \varepsilon_3 d_3 + \varepsilon_4 d_4)/(d_1 + d_2 + d_3 + d_4)$$

where:

ε_1, ε_2, ε_3, and ε_4 are the total porosity of the corresponding hydrogeologic unit and d_1, d_2, d_3, and d_4 are the unit thicknesses. The only exception was soil parameter *b*. This parameter was set equal to 4.05 to represent the properties of the three major units. The parameters for the deep contaminated zone case are summarized in Table C3-5.

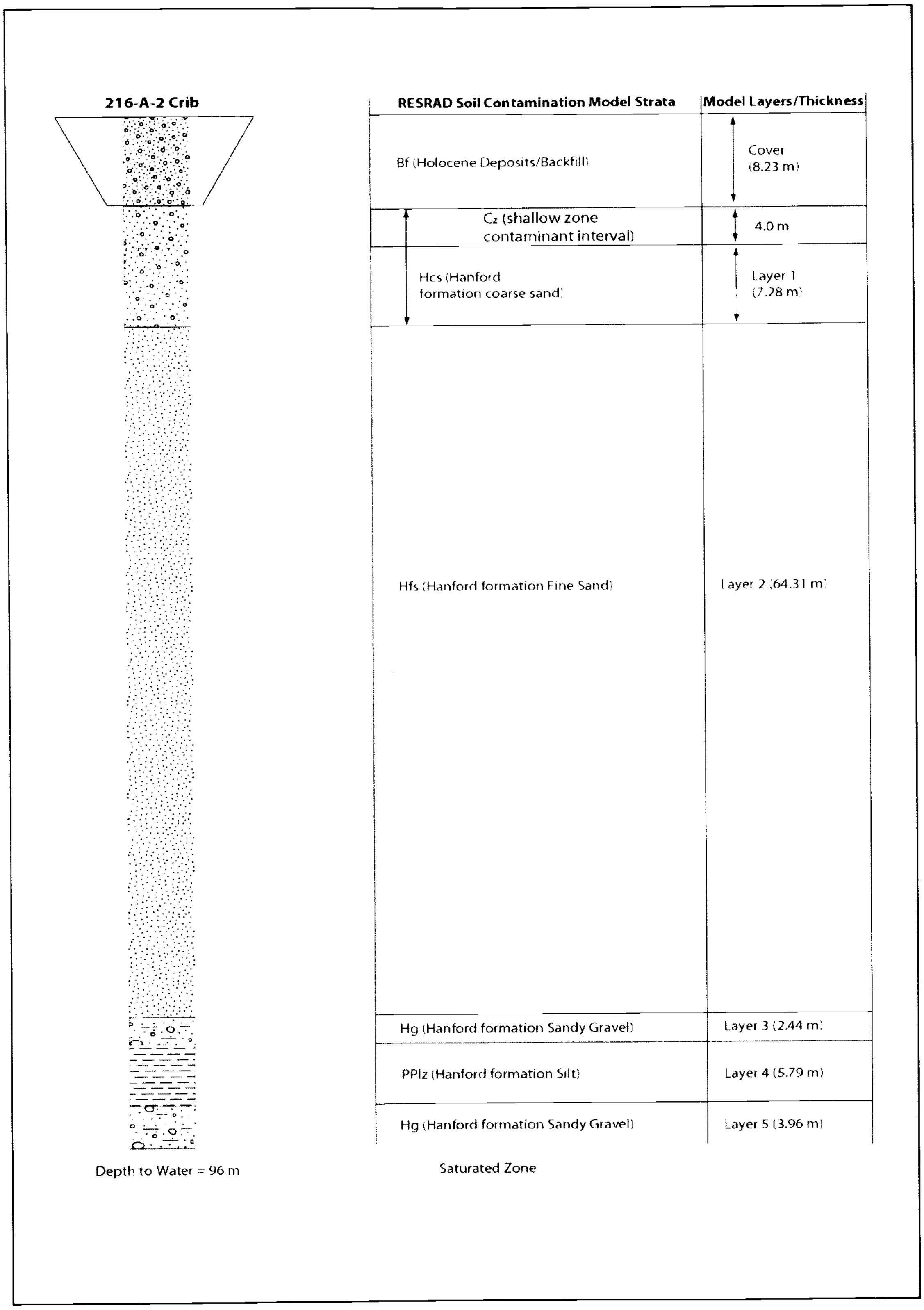


Figure C3-1. Shallow Contaminated Zone RESRAD Model Layering

Table C3-4. Hydrogeologic Parameters of the Shallow Contaminated Zone

Modeling Layer	Thickness (m)	Bulk Density (g/cm^3)	Total Porosity	Effective Porosity	Field Capacity	Hydraulic Conductivity (m/yr)	Soil Parameter *b*
Cover	8.23	--	--	--	--	--	--
Contaminated Zone	4	1.68	0.349	--	0.041	716	4.05
UZ Layer 1	7.28	1.67	0.349	0.349	0.041	716	4.05
UZ Layer 2	64.3	1.60	0.379	0.379	0.058	118	4.05
UZ Layer 3	2.44	1.93	0.167	0.167	0.062	104	4.05
UZ Layer 4	5.88	1.68	0.419	0.419	0.210	17.6	10.4
UZ Layer 5	4	1.93	0.167	0.167	0.062	104	4.05

UZ = unsaturated zone

C3.2 Results of Radionuclide Groundwater Impact Analysis

The results of the radionuclide groundwater impact analysis are presented below for the restricted and unrestricted land use. The radionuclide groundwater impact analyses include calculations for both the shallow contaminated zone and deep contaminated zone.

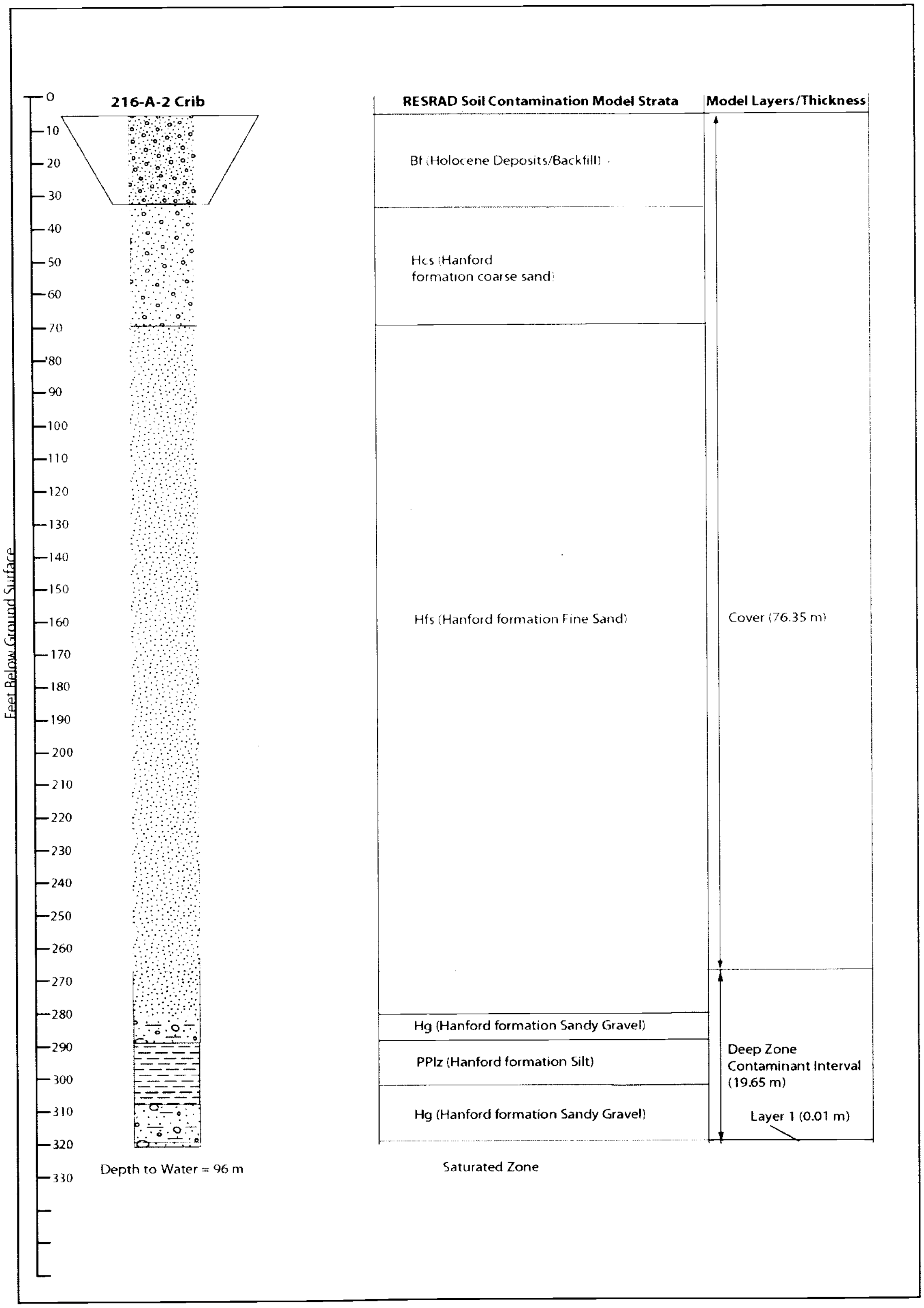


Figure C3-2. Deep Contaminated Zone RESRAD Model Layering

Table C3-5. Hydrogeologic Parameters of the Deep Contaminated Zone

Modeling Layer	Thickness (m)	Bulk Density (g/cm^3)	Total Porosity	Effective Porosity	Field Capacity	Hydraulic Conductivity (m/yr)	Soil Parameter *b*
Cover	76.35	--	--	--	--	--	--
Contaminated Zone	4	1.73	0.32	--	0.1	83.86	4.05
UZ Layer 1	0.01	1.93	0.167	0.167	0.062	104	4.05

UZ = unsaturated zone

C3.2.1 Restricted Land Use

None of the radionuclide COPCs from the shallow zone contaminant layer reaches groundwater during the 1,000-year period of interest. The radionuclide-specific time of travel through the unsaturated zone is summarized in Table C3-6. Technetium-99 has the shortest time of travel through the unsaturated zone because it does not sorb (K_d of 0 cm^3/g), reaching the groundwater in 3,114 years. The peak Tc-99 concentration in groundwater is 12 pCi/L, which arrives at year 3,524. This concentration is substantially below the MCL of 900 pCi/L. The remaining radionuclide COPCs all sorb to some degree, as indicated by their non-zero K_d, and will reach groundwater at times greater than 31,000 years. If the K_d of the parent radionuclide is less than that of the daughter product, then travel time for the daughter product is calculated by RESRAD to be the same as for the parent. For instance, consider Ac-227, which is a daughter of one of the uranium isotopes. Table C3-6 indicates uranium (all isotopes) and Ac-227 have a K_d of 0.8 and 20 cm^3/g, respectively, but have the same RESRAD-calculated time of travel to the water table of 31,310 years. For situation where the K_d of the parent is greater than that of the daughter, RESRAD calculates travel times of the individual COPC. Consider in Table C3-6 Am-241, which is the parent of Np-237. Americium-241 and Np-237 have a K_ds of 300 and 10 cm^3/g, respectively. RESRAD calculates the travel time to the water table to be "infinite" for Am-241 and 648,900 years for Np-237 (Table C3-6).

Tritium is the only radionuclide present in the deep contaminated zone. Tritium reaches the groundwater during the first year of simulation with the maximum groundwater concentration of 298 pCi/L arriving 19 years in the future (Figure C3-3). The peak tritium concentration of 298 pCi/L is well below the MCL of 20,000 pCi/L and quickly diminishes by radioactive decay.

C3.2.2 Unrestricted Land Use

Among the radionuclide COPCs present in the shallow contaminated zone, only Tc-99 reaches the groundwater table during the 1,000 year period of interest. The maximum Tc-99 concentration in groundwater is 12.0 pCi/L at 750 years in the future (Figure C3-4). The peak Tc-99 concentration of 12.0 pCi/L is substantially less than the MCL of 900 pCi/L and diminishes to less than 1 pCi/L within 100 years of the peak concentration. Technetium-99 did not reach the groundwater table in the restricted land-use scenario because the infiltration rate used (0.004 m/yr) is about five times smaller than the infiltration rate used in the unrestricted land use scenario (0.02 m/yr).

Table C3-6. Travel Times of Contaminants of Potential Concern in Shallow Zone to Groundwater for Restricted Land Use

Radionuclide	K_d (cm^3/g)	Time of Travel to the Water Table (Years)*
Ac-227	20	31310
Am-241	300	Infinite
Co-60	10	648900
Cs-137	2000	Infinite
Eu-154	200	Infinite
Ni-63	300	Infinite
Np-237	10	648900
Pa-231	50	31310
Pb-210	100	31310
Pu-238	600	Infinite
Pu-239	600	Infinite
Ra-226	20	31310
Ra-228	20	31310
Sr-90	22	Infinite
Tc-99	0	3114
Th-228	60,000	31310
Th-229	60,000	31310
Th-230	60,000	31310
Th-232	60,000	31310
U-233	0.8	31310
U-234	0.8	31310
U-235	0.8	31310
U-236	0.8	31310
U-238	0.8	31310

* When the contaminant of potential concern travel time through the vadose zone is very large, RESRAD outputs the word "infinite" instead of a numerical value.

K_d = distribution coefficient

RESRAD = RESidual RADioactivity

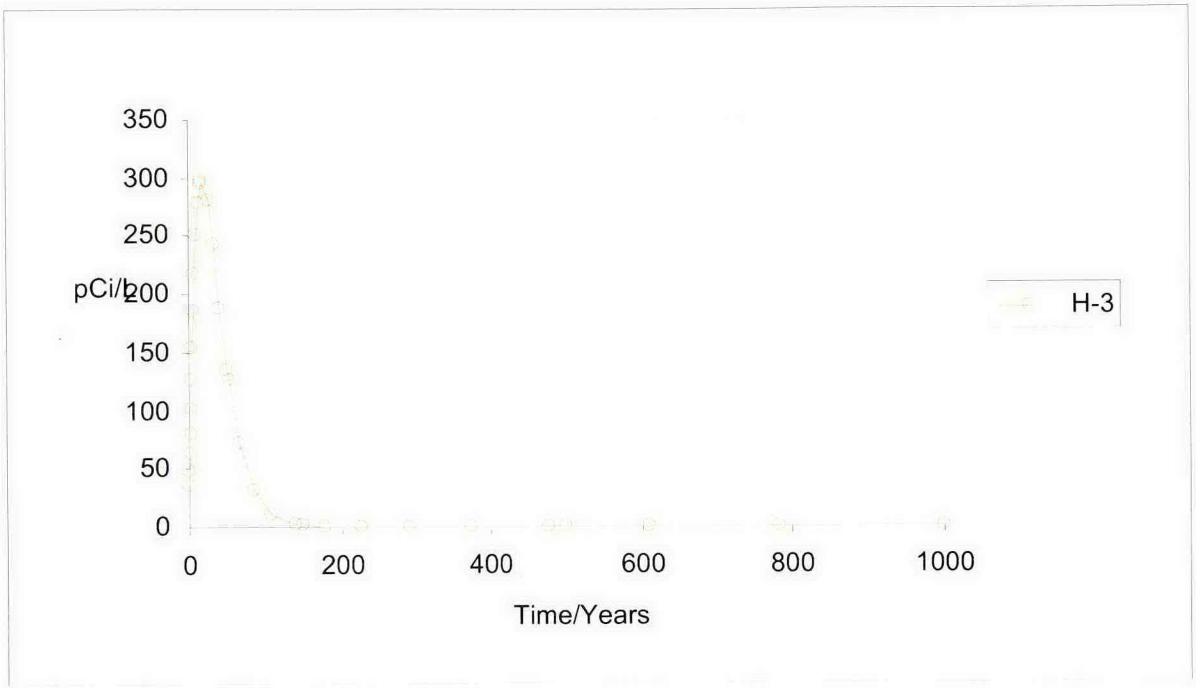


Figure C3-3. Groundwater Concentrations of Tritium for Restricted Land Use

Tritium is the only radionuclide present in the deep contaminated zone. Tritium reaches the groundwater during the first year of simulation with the maximum groundwater concentration of 1,304 pCi/L at 15 years in the future (Figure C3-5). The peak tritium concentration of 1,304 pCi/L is substantially below the MCL of 20,000 pCi/L and quickly diminishes by radioactive decay.

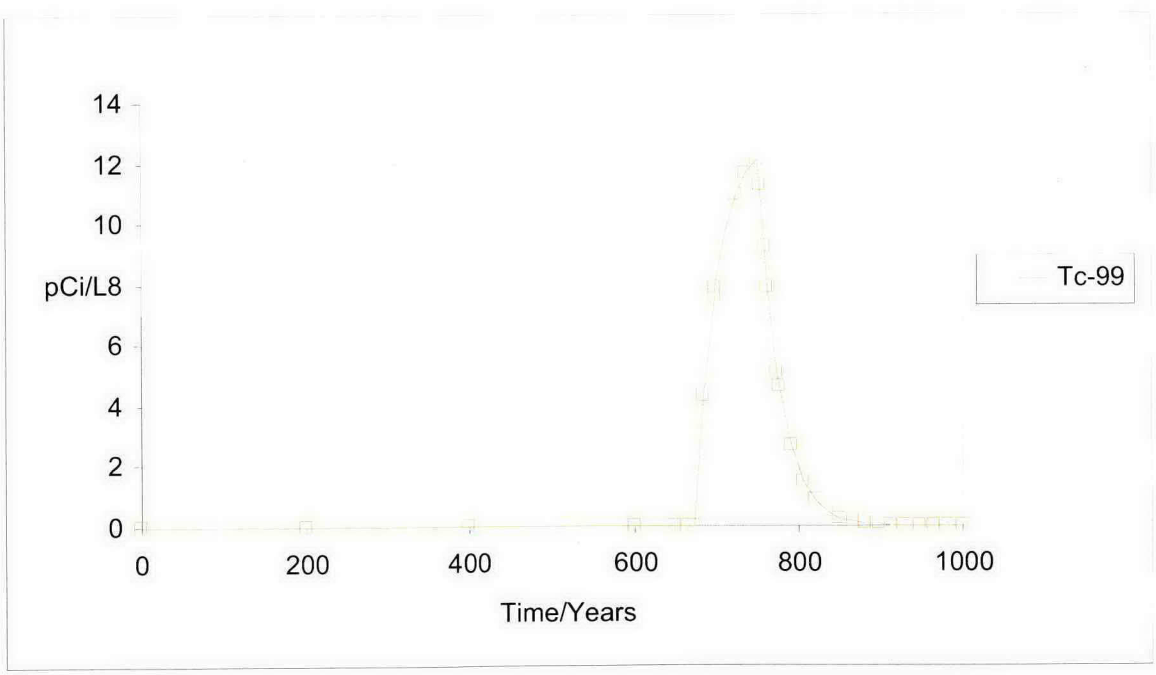


Figure C3-4. Groundwater Concentrations of Technetium-99 for Unrestricted Land Use

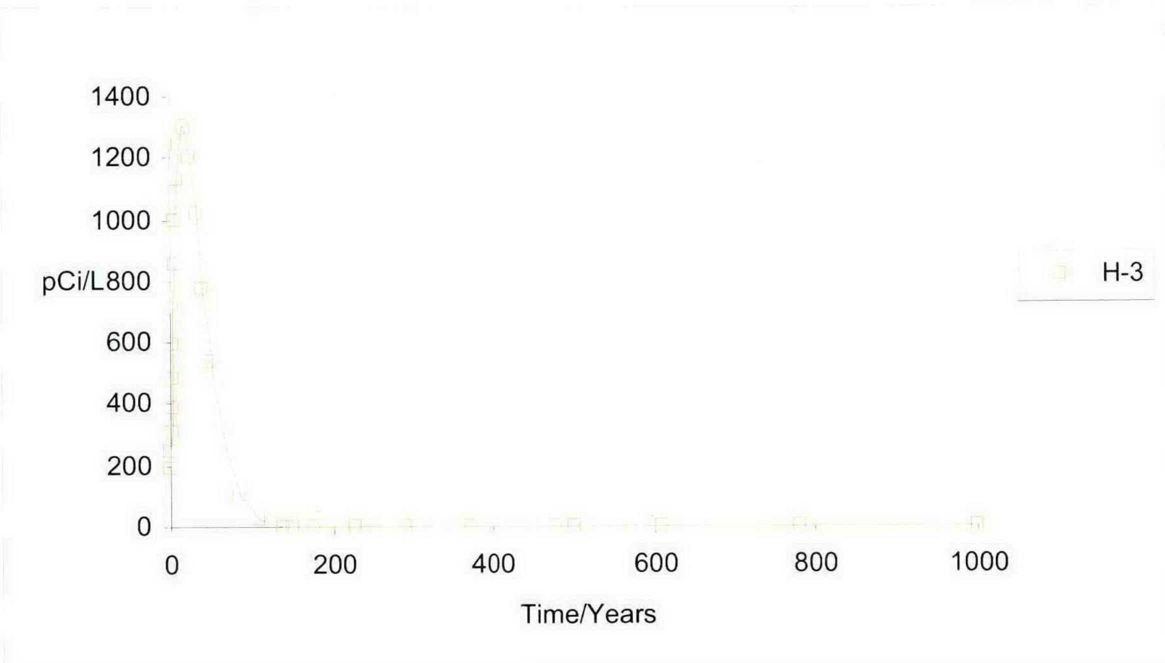


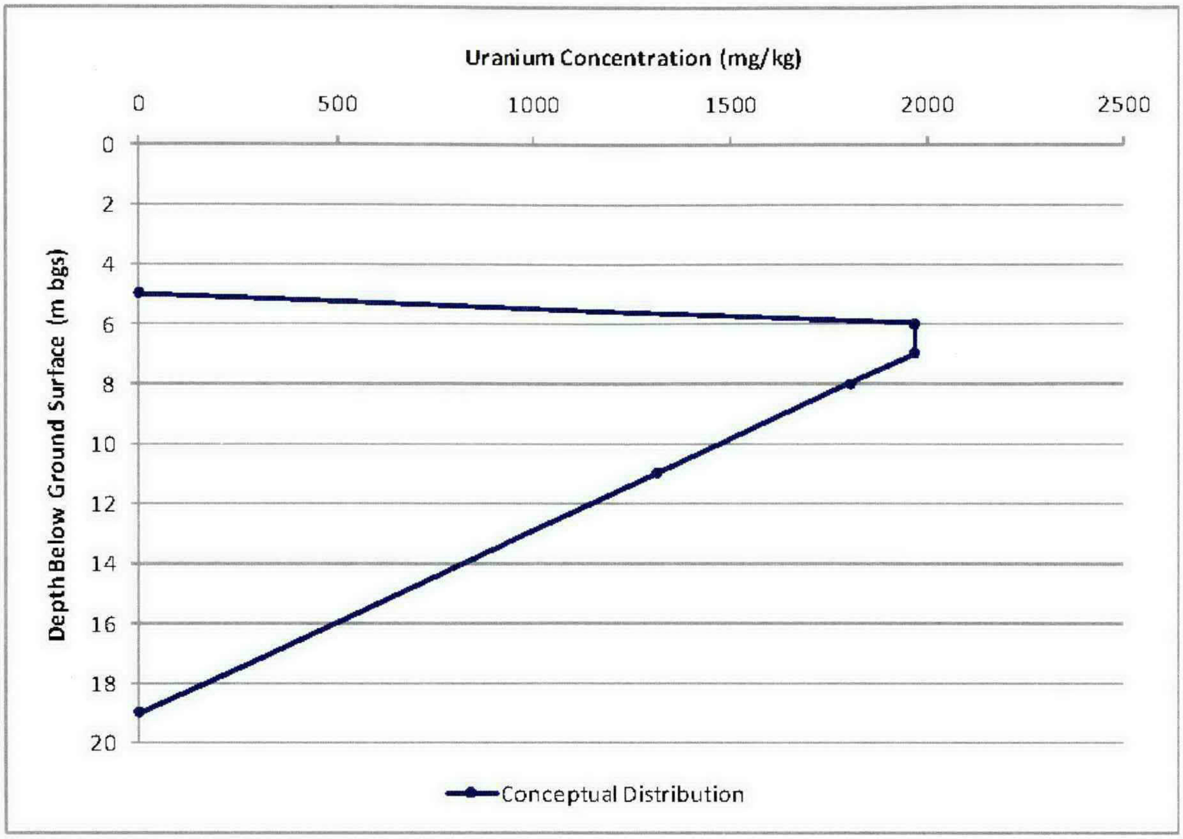
Figure C3-5. Groundwater Concentrations of Tritium for Unrestricted Land Use

C4 216-A-4 and 216-A-5 Cribs Uranium Evaluation with Two-Dimensional Fate and Transport Modeling

A secondary evaluation of the potential for groundwater impacts of uranium and carbon-14 at the 216-A-4 and 216-A-5 Cribs, respectively, using two-dimensional fate and transport modeling results was conducted. This phase, using more robust two-dimensional fate and transport modeling, was undertaken to evaluate the potential risks/impacts to groundwater beyond the initial RESRAD-based screening analysis. This phased approach is consistent with the graded approach of model evaluation and with EPA guidance on soil screening (EPA/540/F-95/041, *Soil Screening Guidance: Fact Sheet*). The secondary evaluation was also motivated in part from the results of an evaluation of modeling methods in DOE/RL-2007-34, *Regulatory Criteria for the Selection of Vadose Zone Modeling in Support of the 200-UW-1 Operable Unit,* which identified "complex" models of "fate, flow, and transport" as being necessary to incorporate the principal features, events, and processes associated with contaminant transport occurring in the Hanford Site 200 Areas vadose zone. As indicated in DOE/RL-2007-34, RESRAD one-dimensional model results would be expected to yield vadose zone leachate and groundwater concentrations as much as an order of magnitude larger than two-dimensional model results for comparable run conditions and input parameters. Thus, the corresponding soil contamination levels that are protective of groundwater predicted from RESRAD results may be as much as 10 to 15 times lower (more conservative) than those determined using more robust and applicable two-dimensional model results. Based on the federal guidelines for the selection and use of model types and codes specifically for risk characterization, it is indicated that two-dimensional fate and transport modeling is an appropriate model type for the Central Plateau of the Hanford Site as a subsequent screening and/or risk characterization method for evaluation groundwater protection (DOE/RL-2007-34).

The only COPCs assessed in this evaluation are uranium for the 216-A-4 Crib and carbon-14 for the 216-A-5 Crib. Groundwater MCLs for uranium (30 µg/L) and carbon-14 (2,000 pCi/L) were used as the metric for defining unacceptable impacts. The point of calculation (POCal) of the groundwater concentration coincided with the location in the model of the highest modeled groundwater concentrations. The assumptions and key parameter values used in these evaluations are described in Section C3.3.

The soil concentration data used in this evaluation are from characterization data documented in the Remedial Investigation Report (DOE/RL-2008-37, *Remedial Investigation Report for the 200 MW I Miscellaneous Waste Group Operable Unit Supplemental Investigations*). The soil concentration profiles evaluated for uranium and carbon-14 are discussed in Section C3.2 and are shown in Table C4-1 and Figure C4-1.



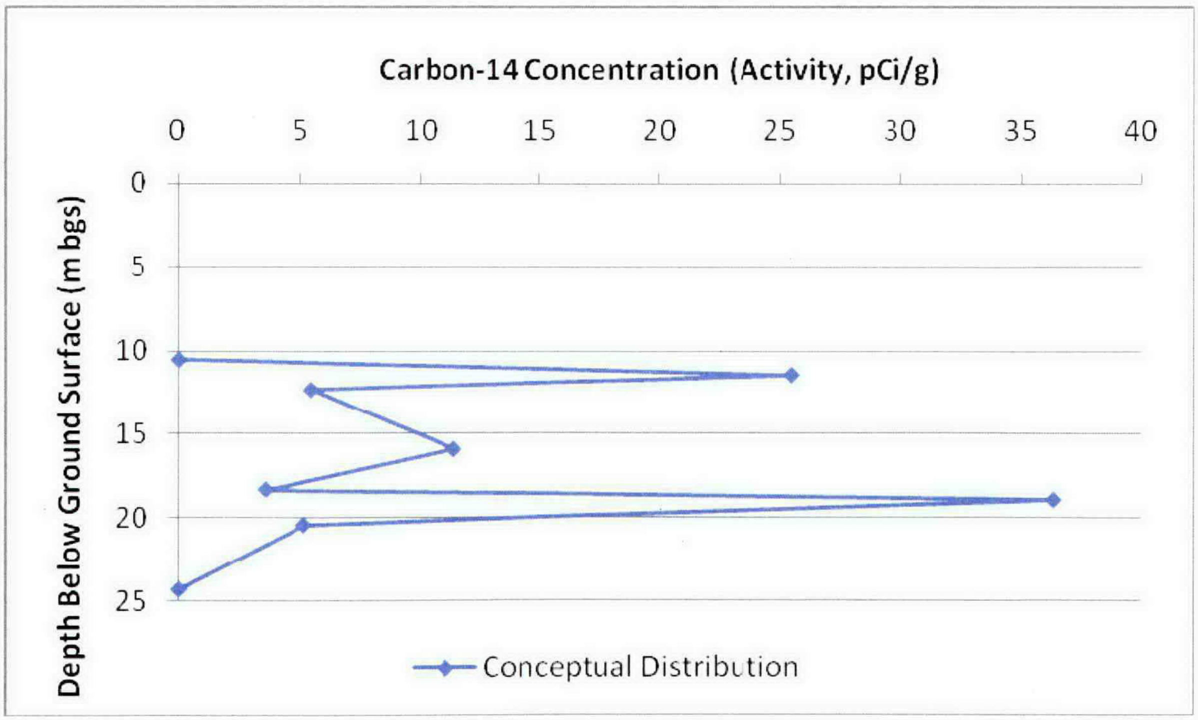


Figure C4-1. Vadose Zone Soil Concentration Conceptual Distribution Profiles (with Assumed Linear Interpolation)

Table C4-1. Conceptual Distributions of the Uranium Contamination Profile at the 216-A-4 Crib and Carbon-14 at 216-A-5 Crib

Uranium Concentration (mg/kg)	Depth (ft bgs)	Depth (m bgs)
	Distribution	
0	15	4.6
1970	18.4	5.6
1970	20.7	6.3
0	33	18.3
Carbon-14 Concentration (pCi/g)	**Depth (ft bgs)**	**Depth (m bgs)**
	Distribution	
0	32.8	10
25.5	37.3	11.4
5.43	40	12.2
11.4	52.1	15.9
3.5	60	18.3
36.4	62	18.9
5.12	67	20.4
0	82	25

Two contaminant release conceptual models were considered for the uranium at 216-A-4 Crib, but only one was considered for carbon-14 at the 216-A-5 Crib. For the purpose of this evaluation, transport and retardation of uranium through the vadose zone are considered separately from the release of uranium from the source area. The first conceptual model considers the release of uranium and carbon-14 to be unlimited by any mechanisms that would restrain the release, such as solubility limits, metal precipitation, or contaminant sequestration from the advective flow path. All of the uranium and carbon-14 in the source area is available for advective transport. The second conceptual model includes a solubility limit for the release of uranium from the source area of contamination that maintains a specified limit on the aqueous concentration.

Sensitivity analyses performed in conjunction with the two-dimensional modeling includes a range of key input parameters. The key input parameters varied in the sensitivity analysis include the post-remediation recharge rate, the initial contaminant distribution in the vadose zone, and the contaminant release mechanism (uranium only). For the purpose of this evaluation, maximum estimates of contaminant inventory developed on the basis of the sampling data were used for the inventory. The recharge rates represent the two most probable end states after remediation, reclamation of the shrub-steppe surface and vegetation (8 mm/yr for 30 years and 4 mm/yr thereafter), and an evapotranspiration (ET) surface barrier (0.5 for 500 years and 1.0 mm/yr thereafter). The reclamated shrub-steppe and vegetation surface was considered to be the base case because it represents the minimum remediation expected to occur at the waste sites.

C4.1 216-A-4 and 216-A-5 Crib Contaminant Profile and Distribution Conceptual Model

Appendix C and Appendix D present the best estimate and likely ranges of the uranium and carbon-14 distribution directly beneath the 216-A-4 Crib and 216-A-5 Crib, respectively. The cribs were constructed similarly. The 216-A-4 Crib's piping is ~18 ft bgs, and the crib bottom is at ~25 ft bgs with gravel placed between the pipes and crib bottom. The 216-A-4 Crib received liquid waste categorized as Concentrated Miscellaneous Uranium Nitrate Hexahydrate from 1955 to 1958, although a low probability exists that it received small volumes of Plutonium-Uranium Extraction (PUREX) waste. Total volume disposed to the 216-A-4 Crib was 6.21 mega liters (6,210,000 L). According to Rev. 1 of the soil inventory model (SIM), the 216-A-4 Crib received 5,388 kg of uranium (best estimate value). The 216-A-5 Crib's piping is ~24 ft bgs, and the crib bottom is at ~29 ft bgs with gravel placed between the pipes and crib bottom. Total volume disposed to 216-A-5 Crib was 1.63 billion liters (1,630,000,000 L) between 1955 and 1961 and during 1966, containing 0.01 Ci of carbon-14 according to the best estimate value in the SIM.

C4.1.1 216-A-4 Crib Uranium Profile and Distribution

There are insufficient soil measurements of uranium at the 216-A-4 Crib to develop a vadose zone contaminant distribution on the basis of the uranium measurements alone. However, the available data indicate that the distribution of uranium within the crib footprint appears to be similar to the distribution of Cs-137. High concentrations of uranium occur right below the crib bottom, and much lower concentrations were found at comparable depths right outside the crib footprint. A large quantity of uranium at both the 216-A-2 and 216-A-4 Cribs appears to be adsorbed on sediments close to the facilities, although slightly more uranium than Cs-137 appears to have migrated into the sediments below the crib bottoms. Uranium is expected to migrate more readily than Cs-137 because of the difference in sorption tendencies. However, uranium exhibits pH-dependent solubility and adsorption properties and binds more strongly to sediments when the pH conditions are slightly caustic, such as those at the 216-A-2 and 216-A-4 Cribs.

The vertical extent of the Cs-137 plume has not been determined, but it does not appear to extend below 58 ft. The center of mass of Cs-137 disposed to the crib remains near the crib bottom within the gravel between 20 and 25 ft bgs. Very large concentrations of Cs-137 occur between the depth of the crib piping inlet and 5 ft above the bottom of the crib, or approximately 20 ft bgs. The very high concentrations observed at 20 ft bgs appear to be approximately 1 ft thick, and the bulk of the contamination appears to drop off in concentration below approximately 35 ft bgs at this location. Lateral migration of Cs-137 from the crib footprint is quite limited even around the zone of very concentrated Cs-137 near the bottom of the 216-A-4 Crib.

Measurements of mobile constituents such as nitrate and tritium in the deeper sediments from the borehole adjacent to the crib indicate that fluids disposed to the 216-A-4 Crib have percolated down to ~300 ft bgs and have spread at least 2.5 m southwest of the crib's footprint. A 20 to 22 ft thick zone of elevated moisture at the depths of ~280 to 305 ft bgs and approximately 15 ft above the current water table was observed in the boreholes adjacent to both cribs. This deeper moist zone correlates exactly with a very fine-grained sand to silt interval. It is most likely an efficient perching horizon or horizontal spreading plane for fluids that were disposed to the cribs. This deep and relatively thick zone of fine-grained sediment contains elevated concentrations of several mobile contaminants, but there is no indication that the silt zone below either crib contains mobile uranium. However, groundwater samples obtained from the boreholes located adjacent to the 216-A-2 and 216-A-4 Cribs did contain 11 μg/L and 79.5 μg/L dissolved uranium, respectively. The absence of the uranium in the silty interval suggests that the uranium in groundwater came from a different source; however, the cribs cannot be ruled out as the source.

Because of the uncertainty associated with the depth of the uranium contamination at the 216-A-4 Crib, three conceptual distributions of the contamination profile are considered in the groundwater impact evaluation. All three distributions include the assumption that the high concentrations, 1970 mg/kg, are contained in the interval between 6.0 and 7.0 m bgs (20 and 23 ft bgs), and that the concentration increases or decreases linearly between the high concentration zone and the top and bottom endpoints of contamination. In the distribution used in this evaluation, the contamination extends to a depth of 19 m bgs (62 ft) (see Table C4-2). The evaluation used this conceptual model because it represents the maximum amount of contamination in the vadose zone.

The contaminated area appears to be contained within the surface dimensions of the crib, between Well 299-E24-54 (installed in 1955 at the northeast corner of the crib) and Well 299-E24-23 (C5301), (located at the southwest corner of the crib). The drilling of the C5301 borehole, installed 2.5 meters from the edge of the crib (at ground surface), did not encounter high contaminant concentrations compared to the levels encountered during the drilling of borehole C4560 through the base of the crib. Similarly, the logging of Well 299-E24-54 detected manmade radionuclides Cs-137 and Co-60, but not at the concentration observed during the drilling of borehole C4560. If these wells represent the extent of horizontal contamination and the contaminated area is approximated by a square, then the diagonal dimension of contamination measures approximately 26.6 m (87 ft), and the side length measures 18.8 m (62 ft). Using these dimensions and the profile distribution, the mass of contamination can be estimated. The total mass of uranium in the soil calculated for the three profile distributions is 9042 kg, which is almost twice the value of the SIM inventory best estimate value of 5,388 kg.

Table C4-2. Modeled Distributions of the Uranium Contamination Profile at the 216-A-4 Crib

Depth (m bgs)	Uranium Concentration Vertical Distribution (mg/kg)
4.5	0
5.5	985
6.5	1970
7.5	1888
8.5	1724
9.5	1560
10.5	1395
11.5	1231
12.5	1067
13.5	903
14.5	739
15.5	575
16.5	410
17.5	246

Table C4-2. Modeled Distributions of the Uranium Contamination Profile at the 216-A-4 Crib

Depth (m bgs)	Uranium Concentration Vertical Distribution (mg/kg)
18.5	82
19.5	0

Table C4-3. Modeled Distributions of the Carbon-14 Contamination Profile at the 216-A-5 Crib

Bottom of Depth Interval (m bgs)	Carbon-14 Concentration (Activity) Vertical Distribution (pCi/g)
9.5	0.0
10.5	12.8
11.5	25.5
12.5	5.4
13.5	7.4
14.5	9.4
15.5	11.4
16.5	8.8
17.5	6.1
18.5	3.5
19.5	36.4
20.5	5.1
21.5	3.8
22.5	2.6
23.5	1.3
24.5	0.0

C4.1.2 216-A-5 Crib Carbon-14 Profile and Distribution

As discussed in Appendix D, the contaminated zones are defined based on the COPC distribution pattern in borehole C6552 sample data. The vertical extent of the carbon-14 plume appears to be contained in the upper contaminated zone from 10.5 to 24.3 m (34.5 to 79.8 ft) bgs, which is below the crib bottom and the gravel (Table C4-3). The contaminant distribution through the depth appears bimodal, with elevated concentrations measured 11.4 and 18.9 m (37 and 67 ft) bgs. The relatively high concentrations observed at 11.4 m (37 ft) and 18.9 m (67 ft) bgs appear to be limited in thickness to less than one meter. Lateral migration of carbon-14 from the crib footprint is uncertain. The contaminated area, assumed to be square, estimated using the method described in Section C5.3.1 is 15,194 m^2 (163,547 ft^2). The contaminated length parallel to groundwater flow is then 123.3 m (404 ft).

Combining the contaminant concentration profile data and the estimated contaminated area results in an estimate of 3.08 Ci of carbon-14 being contained in the vadose zone. This value is over 300 times the carbon-14 inventory best estimate value (0.010 Ci), and over 170 times the 99.5 percentile value (0.018 Ci) from the SIM. The discrepancy between the estimated inventory of carbon-14 discharged to the crib and the total mass (activity) determined from the contaminant profile and contaminated area indicates that the uncertainty in the contaminant mass (activity) contained in the vadose zone is high.

C4.1.3 216-A-4 and 216-A-5 Cribs Vadose Zone Fate and Transport Conceptual Model Components and Parameter Selection

The general vadose zone conceptual models, model conditions, and parameters for the reference model that served as the basis for the evaluation of the 216-A-4 and 216-A-5 Cribs vadose zone contamination are described in DOE/RL-2007-34. The generalized models, conditions, and parameters were refined and augmented for the 216-A-4 and 216-A-5 Cribs evaluation. The site-specific conceptual model components for the 216-A-4 and 216-A-5 Cribs evaluation are listed below. Although the model domain and boundary conditions are not generally regarded as conceptual model elements, they are included in the list to emphasize the fundamental nature of boundary conditions in the modeling:

- Model domain and boundary conditions
- Geologic setting
- Source term
- Groundwater domain and characteristics
- Vadose zone hydrogeology and fluid transport
- Recharge
- Geochemistry

Pursuant to CERCLA and pertinent ARAR driven Washington State requirements for the purpose of determining soil cleanup levels for the uppermost part of the vadose zone soils, the evaluation used modeling assumptions and parameter estimates appropriate for the 216-A-4 and 216-A-5 Cribs site-specific conditions. Table C4-4 provides a summary of key elements and parameters for the conceptual model components. These parameters represent the values selected for use in the model from the ranges of plausible parameter values. The individual conceptual model components, described in the subsequent subsections, provide the basis, rationale, and references for the values. These values may differ from parameter estimates for other Hanford Site modeling performed for different purposes or areas of the Hanford Site, or at different scales.

Table C4-4. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-A-4 and 216-A-5 Cribs

Model Domain and Boundary Conditions	216-A-4 Crib, 450 m (1476 ft) x 1 m x 111 m (364 ft) 216-A-5 Crib, 650 m (2133 ft) x 1 m x 111 m (364 ft) Prescribed flux across the top (Recharge); no-flow along vertical side boundaries in the vadose zone; prescribed head at the along vertical side boundaries in the aquifer, including the capillary fringe; no-flow along the bottom of the model (aquifer).
Geologic Setting	Seven stratigraphic units from surface to groundwater consisting of the following: • Crib Backfill • Hanford H1 Coarse Sand • Hanford H2 Sand • Hanford H3 Sandy Gravel • Plio-Pleistocene • Hanford Sandy Gravel-Vadose • Hanford Sandy Gravel-Aquifer
Source Term	Specified, homogeneous and uniform (generic) contaminant source term **(1 kg)** Specified source term dimensions (base cases): • Length Parallel to Groundwater Flow: – 216-A-4 Crib, 26.6 m (87 ft) rounded to 27 m (89 ft) – 216-A-5 Crib, 123.3 m (405 ft) rounded to nearest even number: 124 m (407 ft) – Source-term depths (m or ft-bgs, inclusive): – 216-A-4 Crib, **5-19 m (16-62 ft)** – 216-A-5 Crib, **10-24 m (33-79 ft)** Two Release Models Evaluated: • Unlimited advective release, K_d control only (Uranium and Carbon-14) • Solubility limited release in source area (Uranium only)
Groundwater Domain and Characteristics	Average water table elevation **approximately 119 m NAVD88** Groundwater thickness **approximately 15 m;** Groundwater concentrations evaluated for upper **5 m** Hydraulic gradient **approximately 0.00001 m/m** Average hydraulic conductivity **1,000 m/day**
Vadose Zone Hydrogeology and Fluid Transport	K_d-controlled release source term (mass) Hydrogeologic properties from *Vadose Zone Hydrogeology Data Package for Hanford Assessments* (PNNL-14702, Rev. 1) Hydraulic Conductivity and Dispersion Anisotropy **(10:1)**
Recharge	Recharge (Pre-Operational; undisturbed ground) **(4 mm/yr)** Recharge (Operational through Pre-Remediation) **(63 mm/yr [12/1955 through 2010])** Recharge (Post-Remediation; vegetated disturbed soil) **(8 mm/yr for 30 years, 4mm/yr long-term)**
Geochemistry	Uranium **K_d = 0.6** in all stratigraphic units Carbon-14 **K_d = 0** in all stratigraphic units

Notes:

NAVD88 is the *North American Vertical Datum of 1988*, National Geodetic Survey, U.S. Department of Commerce.

bgs = below ground surface

C4.1.4 Model Domain and Boundary Conditions

The model domain and boundary conditions establish both a framework and limiting conditions for the numerical model. The model domain for flow and transport in the vadose zone is represented numerically as a two-dimensional, vertical cross-section aligned in the general direction of groundwater flow. Aligning the vertical cross-sections with the general direction of groundwater flow allows concentrations to be calculated downgradient of the waste sites. The numerical model adapts the physical elements of the conceptual model to a Cartesian grid and also assigns numerical values to the parameters used in algorithms to represent the physical and geochemical systems and processes. Modeling of the 216-A-4 and 216-A-5 Cribs involved model domains of 450 m (1,476 ft) and 650 m (2,133 ft), respectively, by approximately 96 m (315 ft), by 1 m (3.3 ft), and extended about 15 m (49 ft) below the water table. The grid for the 216-A-5 Crib required a larger domain to minimize boundary effects during the high volume discharge period. A horizontal-to-vertical node spacing of 1 m:1 m was used across 50 m (164 ft) in the center of the grid in the vicinity of the cribs, and a spacing of 2 m:1 m was used outside the center to the boundaries. The total number of nodes equaled 27,750 and 38,850, respectively. Two-dimensionally, the 216-A-4 Crib extended 32 m (105 ft) at the surface, tapering to 6 m (20 ft) at the base at a depth of 8 m (26 ft) (see Figure 4-13). The 216-A-5 Crib extended 45 m (148 ft) at the surface, tapering to 11 m (36 ft) at the base at a depth of 11 m (36 ft).

A specified-flux boundary condition was applied at the surface to simulate recharge. Recharge rates varied spatially and temporally along the upper boundary depending on site conditions, the location and physical dimensions of the waste site, and the time of waste site operations and surface remedy. Boundary conditions at the sides of the model domain, located far enough away to avoid interfering with the solution in the area of interest, were assumed to be no flow in the vadose zone and constant head in the aquifer. The bottom boundary of the unsaturated (vadose) zone is the water table, and the bottom of the model (aquifer) was defined as a vertical no flow boundary condition. The model domain and boundary conditions used in this modeling and the conceptual model components are summarized as follows:

- Model domain: 450 m (1,476 ft) and 650 m (2,133 ft), for 216-A-4 Crib and 216-A-5 Crib models, respectively, by approximately 96 m (315 ft) in the vadose zone and an additional 15 m (49 ft) extended below the water table by 1 m (3.3 ft).

- A horizontal-to-vertical node spacing of 1 m:1 m was used across 50 m (164 ft) in the center of the grid in the vicinity of the cribs, and a spacing of 2 m:1 m was used outside the center to the boundaries. The total number of nodes equaled 27,750 and 38,850, respectively for the 216-A-4 Crib and 216-A-5 Crib models.

- Waste site dimensions: Two-dimensionally, the 216-A-4 Crib extended 32 m (105 ft) at the surface, tapering to 6 m (20 ft) at the base at a depth of 8 m (26 ft). The 216-A-5 Crib extended 45 m (148 ft) at the surface, tapering to 11 m (36 ft) at the base at a depth of 11 m (36 ft).

- Grid size: A horizontal-to-vertical node spacing of 1 m:1 m was used across 50 m (164 ft) in the center of the grid in the vicinity of the cribs, and a spacing of 2 m:1 m was used outside the center to the boundaries. The total number of nodes equaled 27,750 and 38,850 for the 216-A-4 and 216-A-5 Cribs, respectively.

Boundary conditions:

- Surface: Specified-flux boundary condition to simulate recharge

- Sides: No flow in the vadose zone and prescribed head in the aquifer

- Bottom: Boundary of the unsaturated (vadose) zone is the water table; the bottom of the model (aquifer) was defined as a vertical no-flow boundary condition

C4.1.5 Geologic Setting

The stratigraphy shown in Figure C3-1 of DOE/RL-2008-38 was adapted for use in the two-dimensional analysis of the waste sites. The vadose near the eastern boundary of 200 East Area is approximately 96 meters (315 ft) thick. The stratigraphy has been divided into the following hydrostratigraphic units with corresponding approximate unit thicknesses:

- 216-A-4 Crib 8 m (representing 7.9 m or 26 ft)
- 216-A-5 Crib 11 m (representing 10.7 m or 35 ft)
- Hanford H1 Coarse Sand 11 m (representing 11.28 m or 37 ft)
- Hanford H2 Sand 73 m (representing 72.54 m or 238 ft)
- Hanford H3 Sandy Gravel 2 m (representing 2.44 m or 8 ft)
- Plio-Pleistocene 6 m (representing 5.79 m or 19 ft)
- Hanford Sandy Gravel–Vadose 4 m (representing 3.96 m or 13 ft)
- Hanford Sandy Gravel–Aquifer 15 m (representing 5 m or 15 ft)

Where crib backfill exists, it is contained within the depth of the Hanford H1 coarse sand. The two-dimensional model included one change from the stratigraphy shown in Figure C3-1. The stratigraphy shown in that figure indicates that the Hanford H1 coarse sand extends in depth to approximately 19.5 m bgs (64 ft bgs). However, that depth is greater than the depth indicated for this unit in Section 3.1.1 and Appendix A of SGW-33959 (approximately 5.8 m [19 ft]), the depth indicated in Figure C5-1 (the stratigraphy of the 216-A-5 Crib), and other generalized depictions of the geology in the PUREX area (e.g. approximately 9.1 m [30 ft] in PNNL-14702). For this two-dimensional model evaluation, which included both the 216-A-4 and 216-A-5 Cribs, the Hanford H2 sand extended from the bottom of the deeper crib (216-A-5) through a depth of 73 meters (240 ft). The Hanford Sandy Gravel aquifer unit adds approximately 2 m (6.6 ft) of capillary fringe from the Hanford Sandy Gravel vadose unit, which is directly above the water table. This model is proposed as an acceptable representation of the geologic setting for both the 216-A-4 and 216-A-5 Cribs.

C4.1.6 Contaminant Source Term

The contaminant sources were assumed to be rectangular shaped, 27 m (89 ft) in length, 1 m (3.3 ft) wide, and 15 m (49 ft) thick at 216-A-4, and 124 m (407 ft) in length, 1 m (3.3 ft) wide, and 25 m (82 ft) thick at 216-A-5. The length of contamination at the 216-A-4 Crib was estimated on the basis of the distance between wells 299-E24-54 and 299-E24-23. The length of contamination at the 216-A-5 Crib was estimated by calculating the square root (123 m [404 ft]) of the contaminated zone area (15,194 m2 [163,547 ft2]) determined in Section C5.3.1. Because of the 216-A-5 model grid spacing, the contaminated length had to be rounded up to 124 m (407 ft). The depths represent the maximum depth of the uranium and carbon-14 contamination believed to exist at the cribs according to the uranium contamination distribution conceptual model described in Section 4.2.2 and Appendix B, and the carbon-14 sampling data, respectively. The uranium and carbon-14 concentrations in the contaminant profile were assumed to be constant within the 1 m (3.3 ft) thick model row layers at the source depths identified in Table C4-3 and Table C4-4.

There are two contaminant release conceptual models considered for the 216-A-4 Crib. For the purpose of this evaluation, transport and retardation of uranium through the vadose zone is considered separately from the release of uranium from the source area. The first conceptual model considers only advective release of uranium from the sediments. The release of uranium is unlimited by any mechanisms that would restrain the release, such as solubility limits, metal precipitation, or contaminant sequestration from the advective flow path. All of the uranium in the source area is available for advective transport, and the release occurs according to the equilibrium K_d, which is equal to 0.6 ml/g. The second conceptual model includes an estimate for the solubility limit for uranium in the source area of approximately 100 mg/L. Only the uranium in the source area at concentrations at or below 100 mg/L is available for advective transport. The release of the remaining mass of contaminant is controlled by solubility limits, or other kinetically controlled processes as represented by the solubility. Kinetically controlled releases occur at a much slower rate than advection-controlled releases, and generally result in lower peak concentration values in groundwater than unlimited advection-controlled releases. Elsewhere in the model domain, the K_d is equal to 0.6 ml/g.

Incorporating the solubility limit into the uranium release conceptual model required a change to the numerical model construction pertaining to the contaminant source term. In the STOMP model code calculations, the solubility limit is only applied to the release term concentration. The release calculations do not factor in the existing aqueous concentration of the water entering the source area. Thus, the aqueous concentration leaving the source area could exceed the prescribed solubility limit if the sources interacted. To prevent this from occurring, the source term was compressed into one model row layer, approximately 10 m deep.

One contaminant release conceptual models is considered for the carbon-14 at the 216-A-5 Crib. This conceptual model considers only advective release of carbon-14 from the sediments. The release of carbon-14 is unlimited by any mechanisms that would restrain the release, such as solubility limits or contaminant sequestration from the advective flow path. All of the carbon-14 in the source area is available for advective transport, and the release occurs according to the equilibrium K_d, which is equal to 0 ml/g.

C4.1.7 Groundwater Domain and Characteristics

The direction of groundwater flow is generally northwest to southeast in the area around the 216-A-4 and 216-A-5 Cribs. The groundwater table is expected to drop over the next 300 years due to the cessation of large operational liquid discharges to the ground. It is estimated that in the eastern boundary of 200 East Area, the water table will drop in elevation to about 119 m (390 ft) over the next 100 years (NAVD88), based on Appendix E of PNNL-11800, *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site*. Steady-state conditions are expected to occur by the year 2350. For this modeling activity, a long-term average groundwater hydraulic gradient of 0.00001 (estimated from Figure 2-8 in *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds* [WHC-EP-0645]) is assumed, with a groundwater table elevation of 119 m (390 ft) (NAVD88).

The aquifer, identified as Hanford Sandy Gravel–Aquifer, is separated from that portion of the Hanford H3 Sandy Gravel above the water table (Hanford Sandy Gravel–Vadose), reflecting the distinctly different saturation conditions. Within the model domain, the aquifer extends to a depth of approximately 15 m (49 ft). The horizontal saturated hydraulic conductivity for the aquifer is estimated to be 1,000 m/day (3,280 ft/day) on the basis of PNNL-14753, *Groundwater Data Package for Hanford Assessments*. Table C4-5 presents a summary of the aquifer hydraulic parameters.

C4.1.8 Vadose Zone Hydrogeology and Transport

The flow and transport pathway process used for 216-A-4 and 216-A-5 Cribs vadose zone modeling is porous media continuum flow. The vadose zone sediments at the Hanford Site are composed of sediments ranging in particle size associated with gravels to silts or clays. Thus, in the model selection process, where the features, events, and processes are evaluated for simulation of fate and transport behavior in the vadose zone at the Hanford Site (DOE/RL-2007-34), porous media continuum transport in unsaturated media is regarded as the fundamental process and feature for modeling.

The hydraulic properties describing the water flow and retention characteristics associated with each of the 216-A-4 and 216-A-5 Cribs area geologic layers are approximated by average values, with each unit having different flow and transport parameter values (Table C4-6). PNNL-14702 includes statistical summaries of measurements of the hydraulic properties for Hanford Site vadose zone sediments. The summary statistics include minimum, maximum, mean, standard deviation, and for hydraulic conductivity, mean and standard deviation of the natural log transforms of the data

Table C4-5. Soil Hydraulic Properties for Aquifer Soil Type at 216-A-4 Crib

Aquifer Soil Type	Bulk Density (g/cm^c)	Total Porosity	Saturated Moisture Content	Horizontal Saturated Hydraulic Conductivity[a,b] (m/day)	Longitudinal Dispersivity[c] (m)	Aquifer Hydraulic Gradient[a] (m/m)
Ringold Gravel (aquifer)	1.93	0.280	0.167	1000	1.9	1.0E-05

Notes:

Aquifer soil hydraulic properties adopted from PNNL-14702, with the following exceptions:

a. Horizontal Saturated Hydraulic Conductivity and Aquifer Hydraulic Gradient estimated from PNNL-14753, Rev. 1 and 1944 hindcast water table map, respectively.

b. Vertical Saturated Hydraulic Conductivity equal to 1/10 of the Horizontal Saturated Hydraulic Conductivity (i.e., 100 m/day, assuming an anisotropy ratio of 10:1).

c. Longitudinal dispersivity calculated using Gelhar and Axness (1983) equation; transverse dispersivity equal to 1/10 of the longitudinal dispersivity.

Estimates of longitudinal dispersivity for each of the hydrostratigraphic units were estimated using the Gelhar and Axness (1983) "Three-Dimensional Stochastic Analysis of Macrodispersion in Aquifers"stochastic solution:

$$A_L = \sigma^2_{LnKs} \lambda$$

where:

A_L = longitudinal dispersivity (m or cm)

σ^2_{LnKs} = the variance of the log of the saturated hydraulic conductivity measurements (dimensionless)

λ = vertical correlation scale (i.e., average distance over which conductivities are correlated) for log of the saturated hydraulic conductivity measurements (m or cm)

This stochastic model relates macrodispersive spreading to the spatial variability of saturated hydraulic conductivity in saturated porous media. PNNL-14702 includes the standard deviation of the natural log transform for the saturated hydraulic conductivity measurements of the Hanford soils. The estimate of the correlation length, λ, is based on saturated hydraulic conductivity estimates collected at approximate 30-cm intervals for a depth of 18 m within the Hanford formation (RPP-17209, *Modeling Data Package for an Initial Assessment of Closure of the S and SX Tank Farms*). The fitted spherical variogram of the data suggests a correlation length of about 50 cm Figure D-1 in RPP-17209). However, as indicated by Russo (1993), the correlation scale is expected to decrease as the moisture content decreases; hence, a smaller value (30 cm) is used to determine the dispersivities.

Table C4-6. Soil Hydraulic Properties for Vadose Zone Soil Types at 216-A-4 Crib

Soil Type	Bulk Density (g/cm^c)	Total Porosity[a]	Saturated Moisture Content	van Genuchten α (1/cm)	van Genuchten n	Residual Saturation	Residual Moisture Content[b]	Vertical Saturated Hydraulic Conductivity[c] (cm/s)	Longitudinal Dispersivity (m)[d]
Backfill (B) 216-A-4 216-A-5	1.94	0.276	0.262	0.019	1.4	0.162	0.042	5.98E-04 cm/s	0.8 1.1
Hanford H1 Coarse Sand (Hcs)	1.93	0.377	0.349	0.061	2.031	0.134	0.047	2.27E-03 cm/s	1.0
Hanford H2 Sand (Hfs)	1.49	0.403	0.379	0.027	2.168	0.162	0.061	3.74E-04 cm/s	0.2
Hanford H3 Sandy Gravel (Hg)	1.93	0.280	0.167	0.017	1.725	0.134	0.022	3.30E-04 cm/s	0.6
Plio-Pleistocen ce (PPlz)	1.60	0.419	0.419	0.005	2.249	0.086	0.036	5.57E-05 cm/s	1.9
Ringold Gravel - (vadose) (Hg)	1.93	0.280	0.167	0.017	1.725	0.134	0.022	3.30E-04 cm/s	1.9

Notes:

Vadose zone soil hydraulic properties adopted from PNNL-14702, with the following exceptions:

a. Total porosity calculated from 1 – (bulk density/2.68 cm/g^3).

b. Residual Moisture Content calculated from Saturated Moisture Content * Residual Saturation.

c. Horizontal Saturated Hydraulic Conductivity is equal to 10 times the vertical saturated hydraulic conductivity (assuming an anisotropy ratio of 10:1), except for backfill soil types, for which the vertical and horizontal saturated hydraulic conductivities are equal.

d. Longitudinal Dispersivity calculated using Gelhar and Axness (1983) equation; transverse dispersivity equal to 1/10 of the longitudinal dispersivity.

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Longitudinal dispersivity also appears to be correlated with the model domain scale. The correlation between the dispersivity and the model domain scale appears to be approximately 1:10. Therefore, the dispersivity of any single unit was not allowed to exceed 1/10th of the units' thickness in the model. For the purpose of this calculation, the artificial division of Hanford Sandy Gravel – Vadose and–Aquifer was considered to be a single unit. Longitudinal dispersivity (i.e., in the direction of flow) is assumed to be 10 times larger than dispersivity in the transverse direction, which is consistent with the 10:1 anisotropy ratio of the hydraulic conductivity. A molecular diffusion coefficient of 2.50 x10^{-9} m^2/sec is used, consistent with WHC-SD-WM-EE-004, *Performance Assessment of Ground Double-Shell Tank Waste Disposal at Hanford*[Volumes 1 and 2].

While mechanisms producing preferential pathways exist in the vadose zone, preferential pathways are not the most common or probable transport-related mechanism in the Hanford vadose zone under normal water flux conditions (e.g., see Wang and Narasimhan, 1985, "Hydrologic Mechanisms Governing Fluid Flow in Saturated, Fractured Porous Media"; "PNNL-14224, *Influence of Clastic Dikes on Vertical Migration of Contaminants in the Vadose Zone at Hanford*; and DOE/RL-2007-34). Precipitation at arid sites is usually too low (in relation to saturated hydraulic conductivity) to invoke preferential flow. Much of the water in the dry soils is simply retained on grain surfaces by capillary forces and does not accelerate along preferential pathways. Preferential pathways are of particular interest because of their perceived potential for bypassing normal vadose zone fate and transport processes, and introducing more extensive impacts to groundwater than otherwise possible. DOE/ORP-2005-01, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site Washington* presents a thorough discussion and explanation on the effects of these preferential pathway features on unsaturated flow. Further information on the hydrogeology and transport is found in Appendix A of DOE/RL-2007-34.

C4.1.9 Recharge

The magnitude of recharge for soils at the Hanford Site varies as a function of the soil type, condition of the vegetation cover, and soil integrity (e.g., disturbed versus undisturbed) (PNNL-13033, *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment*; PNNL-14744, *Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment*; PNNL-14702; PNNL-14725,;and PNNL-14725, *Geographic and Operational Site Parameters List (GOSPL) for Hanford Assessments*). The range of recharge values reported in these documents represent distinct populations of data based on lysimetry and isotopic measurements, and interpretation, and in some instances extrapolation, by Hanford site subject matter experts. The natural background recharge rates represent a population for natural vegetated conditions. The range of values for operational, pre-remediation conditions represents a population of recharge rates for vegetation-free disturbed soil (sand).

The most appropriate soil type for estimates of recharge rates in the 200 East Area of the Hanford Central Plateau is the variety of Rupert sand appropriate for that area (PNNL-14702; PNNL-14725). The recharge rates representing the pre-operational natural soil conditions and the 55-year operational period prior to remedy implementation (1955 though 2010) were 4 mm/yr and 63 mm/yr, respectively. The most appropriate surface condition for waste sites that undergo backfilling and post-remediation re-vegetation is young shrub-steppe plant community that develops and matures (PNNL 14725; DOE/RL-2007-34). The recharge rates were selected from the range of values reported as appropriate for the various soil types and conditions at the Hanford Site (e.g., PNNL-14702; PNNL-14725). The long-term post-remediation recharge rate estimate of 4 mm/yr is based on estimated values of long-term recharge rates (LTRRs) for all Hanford soil types (PNNL-14702, PNNL-16688, *Recharge Data Package for Hanford Single-Shell Tanks Waste Management Areas*). These estimates indicate that for post-remedy LTRR, a post-remediation value of 8 mm/yr should be used for the first 30-years after site closure, followed by the value of 4 mm/yr thereafter. The applicability of these recharge rates include the inherent assumption that the natural shrub-steppe vegetation cover reclaims the ground surface.The sensitivity analyses included scenarios representative of worst case no action, where only shallow rooted plant species such as cheatgrass dominate the surface vegetation, and the installation of a surface barrier that limits percolation of precipitated water by storage and evapotranspiration processes. These are considered to be the upper and lower bounding cases for post-remediation long term recharge rates. An additional sensitivity analysis, representative of the cribs being actively maintained free of vegetation indefinitely into the future, was also included solely for the purpose of comparison. The recharge rates were selected from the range of values reported as appropriate for the various soil types and conditions at the Hanford Site (PNNL-14702; PNNL-14725). The recharge rates for the sensitivity analysis included 63 mm/yr, 22 mm/yr, and 0.5 mm/yr for 500 years followed by 1.0 mm/yr thereafter. LTRRs for each of the pre-operational, operational, post-operational, and classes for the Rupert sand soil type used in the modeling and evaluation are presented in Table C4-7.

Table C4-7. Summary and Comparison of Recharge Rate Values for Rupert Sand and Disturbed Soil in the Modeling Evaluation of the 216-A-4 and 216-A-5 Cribs

	Pre-Operational Period	Operational Period (1944 through 2010)	Post-Remediation Period	Long-Term Post-Remediation Period
Waste Site Condition	Undisturbed Rupert sand with shrub-steppe plant community (natural condition)	Rupert sand-disturbed, with no vegetation	ET Barrier (500 years) or Rupert sand-with young shrub-steppe plant community (30 years)	ET Barrier or Rupert sand-with mature shrub-steppe plant community
ET Barrier	4 mm/yr	63 mm/yr	0.5 mm/yr	1 mm/yr
RTD Revegetation-Best Estimate	4 mm/yr	63 mm/yr	8 mm/yr	4 mm/yr
RTD Revegetation-Worst Case No Action	4 mm/yr	63 mm/yr	22 mm/yr	22 mm/yr

The modeling assumptions and parameter estimates used are based on the 216-A-4 and 216-A-5 Cribs site-specific conditions, which may differ from those used for other Hanford Site modeling performed for different purposes, areas, or scales. Estimates of recharge rates on the scale of the entire Hanford Site, for example, 3.5 mm/yr for Pre-Hanford conditions and barrier post design life (DOE/RL EIS-TGD, *Technical Guidance Document for Tank Closure Environmental Impact Statement Vadose Zone and Groundwater Revised Analyses*), differ somewhat from those used here. The EIS modeling concerns Hanford Site post-closure conditions on the scale of the Hanford Site, and involves parameter estimates for site-wide conditions that involve a variety of soil types and vegetation conditions, including barrier and non-barrier conditions and degraded barrier conditions. The recharge rate estimates selected for the 216-A-4 and 216-A-5 Cribs site-specific conditions, therefore, differ from those used for the EIS modeling because the most representative values appropriate for these modeling efforts involve different population(s) of recharge rate.

C4.1.10 Geochemistry

The geochemistry conceptual model component for the modeling involves the technical basis and rationale for the following two primary elements:

- Hanford Site-specific contaminant partitioning behavior regarding release and retardation/attenuation mechanisms, and simplifying assumptions.

The selection of site-specific and contaminant-specific parameter values (e.g., K_d partitioning coefficient values):

- K_d=0.6 mL/g for uranium throughout the vadose zone excluding the source area.
- K_d=0 mL/g for carbon-14 throughout the vadose zone excluding the source area.

The following key aspects of this geochemistry conceptual model are discussed in detail in DOE/RL-2007-34:

- The rationale for the simplifying assumption that the use of a linear k_d isotherm is a reasonable conservative description for the release and attenuation of contaminants in the context of providing an upper-bounding condition.
- The rationale and source(s) of the data used in the selection of contaminant K_d values.
- The rationale for the use of a single K_d for all vadose zone units.

The geochemistry conceptual models for the Hanford Site are based on extensive laboratory studies, testing, and measurements involving Hanford Site-specific sediments, contaminants, and conditions performed using batch and column tests in measurements of adsorption and desorption coefficients under saturated and unsaturated conditions (e.g., PNNL-13895, *Hanford Contaminant Distribution Coefficient Database and Users Guide*; PNNL-11966, *Radionuclide Distribution Coefficients for Sediments Collected from Borehole 299-E17-21*; PNNL-13037, *Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment*; PNNL-15502, *Characterization of UP-1 Aquifer Sediments and Results of Sorption-Desorption Tests Using Spike Uncontaminated Groundwater*; PNNL-15121, *Uranium Geochemistry in Vadose Zone and Aquifer Sediments from the 300 Area Uranium Plume*). The K_d value for carbon-14 is 0 ml/g, which is a very conservative estimate according to PNNL-13037. The use of a single K_d value of 0.6 ml/g for uranium was based on the fact that the best-estimate K_d values for each of the lithologic units were the same value (0.8 mL/g) in the hydrogeologic template (PNNL-14702) that describes the shallow disposal waste sites around PUREX. The uranium (VI) K_d value of 0.6 mL/g is regarded as a reasonable, conservatively representative estimate of the uranium K_d values for these units for the following reasons:

- This value is 25 percent lower than the best-estimate values for the PUREX Cribs template derived from the Hanford K_d database (PNNL-14702).
- Over 90 percent of the uranium (VI) adsorption K_d values (low impact) in the Hanford K_d database are between 0.6 and 4 mL/g (PNNL-11966, PNL-13037).

The value 0.6 mL/g (±0.1 mL/g) from batch experiments was also recommended for Hanford sediments dominated by sand-sized particles (PNNL-11800). This value was also the median value of 13 Hanford sorption values for uranium (PNL-10379, *Geochemical Factors Affecting Radionuclide Transport Through Near and Far Fields at a Low-Level Waste Disposal Site.*). This value is significantly lower than most experimentally determined desorption values, which range to values greater than 50 mL/g. Mass transfer rates for uranium (VI) for kinetically dominated release are significantly less than those for equilibrium partitioning and have apparent K_d values that range to greater than 50 mL/g.

C4.1.11 Point of Calculation, Protectiveness Metric, and Timeframe Considerations

In accordance with risk assessment guidelines, the determination of the levels of soil contamination that will be protective of groundwater also requires the definition and rationale for the following:

- The place/point in the groundwater domain where modeled groundwater concentrations are to be assessed for potential impacts and protectiveness, referred to here as the POCal.
- Rationale for the metric(s) to be used in the assessment of protectiveness at the POCa.l.
- Timeframe considerations for the calculation of RAG values and assessing compliance.

C4.1.12 Point of Calculation

The PoCal for the protection of groundwater is related to the "Exposure Point" in the context of conventional human health risk assessments (EPA/540/1-89/002, *Risk Assessment Guidance for Superfund Volume I, Human Health Evaluation Manual [Part A]*) and to "Point of Compliance" in federal and state regulations and guidelines (EPA/540/1-89/002, Section 6.3.3; 40 CFR 264.95; 40 CFR 270.14(c)(3)(7); 40 CFR 192.02(c)(4); 40 CFR 192.32(a)(2)(iv); 10 CFR 40, Appendix A; WAC 173-200-020(21); WAC 173-340-720(8); WAC 173-340-740(6)(b)). The POCal is intended to serve as the point where exposure point groundwater concentrations are evaluated in the model for protectiveness.

The POCal used for the modeling results was the location according to the model results where maximum concentrations in groundwater occurred. As calculated in the model, lateral flow caused by the geologic stratigraphy and the contrast between the vertical and horizontal transport in the capillary fringe results in the maximum concentrations occurring downgradient from the waste site. For this evaluation, output groundwater concentrations were calculated at the edge of the waste site, 4 or 5 meters downgradient from the waste site (depending on whether the grid size resolution was 1 or 2 meters at the edge of the waste site), 10, 20, 30, 40, 60, and 100 meters downgradient from the waste site.

The aquifer mixing zone extended over the upper five meters of the aquifer. The 5-meter vertical interval corresponds to a conceptual groundwater monitoring well with the 15-ft well screen length (and mixing zone dimension) associated with state monitoring well descriptions (WAC 173-340-747). To account for any possible anomalous conditions associated with transport occurring in the capillary fringe, the evaluation included the upper five meters of the aquifer and the upper five meters of the aquifer with one additional meter of the capillary fringe included. Whichever result produced the highest concentration was used in the evaluation.

C4.1.13 Protectiveness Metric for the Protection of Groundwater Pathway

Defining the protection of groundwater in the context of vadose zone fate and transport requires consideration of the soil and groundwater media as a hybrid or coupled pathway. This pathway involves the determination of future concentrations in the groundwater medium that result from the transport of contamination currently existing in the soil medium. Among the various metrics that can be used for demonstrating groundwater protectiveness, the metrics determined to be most appropriate for the derivation of RAG values were the MCLs (DOE/RL-2007-34). The reasons for the selection of the MCLs included the following:

- They are metrics appropriate for a RME scenario in groundwater (i.e., potential future drinking water source).

- Their use is consistent with federal RAGs (EPA/540/R-92/003, *Risk Assessment Guidance for Superfund Volume 1, Human Health Evaluation Manual [Part B, Development of Risk-Based Preliminary Remediation Goals*), and federal regulatory requirements and guidelines for the establishment of media-specific cleanup levels (40 CFR 300; CERCLA; OSWER Directive 9481.00-6C).
- Their use is consistent with the goals stated in DOE/RL-2002-59, *Hanford Site Groundwater Strategy, Protection, Monitoring, and Remediation.*
- They are appropriate metrics for identifying waste site scale impacts to groundwater.

The working definition of protectiveness for the protection of groundwater pathway at the 216-A-4 and 216-A-5 Cribs was, therefore, considered achieved if the contaminant levels in the vadose zone soil do not cause groundwater concentrations to exceed MCLs at the POCal within the specified timeframe.

Use of the MCLs as a protectiveness metric for groundwater is also consistent with the intent of an effective "no growth" policy for groundwater contamination. In this context, the MCLs represent the “allowable concentrations” and/or “acceptable limits” of a contaminant for minimizing further degradation of groundwater in accordance with the conditions identified in state and federal anti-degradation goals (e.g., EPA/540/R-92/003; OSWER Directive 9481.00-6C; DOE/RL-2002-59).

C4.1.14 Uncertainties, Assumptions, and Conservatisms

Potential sources of uncertainty in risk assessments are primarily in the following categories:

- model uncertainties
- scenario uncertainties
- parameter uncertainties

Model uncertainty pertaining to the equations used as numerical representations of the natural processes is expected to be relatively small. DOE/RL-2007-34 provides a summary evaluation of the comparisons of field data and field test results to corresponding model results obtained using the Subsurface Transport Over Multiple Phases (STOMP) code (PNNL-11216, *STOMP Subsurface Transport Over Multiple Phases: Application Guide*), and the evaluation indicates that the equations used in STOMP adequately simulate the natural processes. The technical basis regarding scenario and parameter selection and the evaluation of uncertainty and variability is also documented in DOE/RL-2007-34, and in the conceptual model sections. Documentation is provided in Section 4.0 and Section 5.0 of DOE/RL-2007-34 on:

- dominant model factors
- model parameter values and plausible ranges of parameter values
- model assumptions and effects on model results
- model limitations

The results of the sensitivity analyses are intended to address parameter uncertainty. The main categories of factors that dominate model results are the same as those identified in the evaluation of model assumptions, sensitivity analyses, and model limitations. The uncertainty analysis indicates that the conservatism in the model assumptions, together with conservatism in parameter values, contribute to a conservative bias in the model results overall.

An evaluation of the primary and largely common assumptions associated with this vadose zone modeling approach at the Hanford Site is summarized in Table 5-4 in DOE/RL-2007-34. The evaluation of these assumptions indicates the following:

- Most of the assumptions involve hydrogeologic and geochemical factors
- Most of the assumptions are either conservative or neutral
- Source-term uncertainty is potentially non-conservative
- The majority of conservative assumptions range from moderate to high magnitudes in terms of their potential effect on risk and vadose zone model results

The evaluation of these assumptions indicates that, with the exception of the source-term uncertainty, the assumptions associated with model parameterization are largely conservative. Based on the assumptions evaluation, results of vadose zone modeling for the 216-A-4 and 216-A-5 Cribs should provide conservative estimates of risk in terms of impacts to groundwater from soil contaminants.

There are some differences that can affect the magnitude of the concentration values for the 216-A-4 and 216-A-5 Cribs that are not addressed in the sensitivity analysis. One consideration possible for 216-A-4 and 216-A-5 Cribs is the length of the screened interval in the aquifer. The 216-A-4 and 216-A-5 Cribs model and the 200-UW-1 RAG values were developed on the basis of a 5-m well screen, per WAC 173-340-747. This length of screen represents the common length for a monitoring well. The potential risk associated with the groundwater results from pathways involving its use as a source of drinking water. In this case, a well screen length of 35 feet (10 m) appears more appropriate on the basis of experience pumping the groundwater for the 200-ZP-1 OU pump-and-treat system.

C4.1.15 Results

The results of modeling provide an indication to the amount of remediation necessary to achieve protection of groundwater at 216-A-4 and 216-A-5 Cribs. The recharge rates shown in Table C4-3 represent the two probable end states after remediation, reclamation of the shrub-steppe surface and vegetation (4 mm/yr), either naturally or artificially enhanced, or a surface barrier that reduces or eliminates percolation of water through the contamination (0.5 mm/yr for 500 years and 1.0 mm/yr thereafter). The results for the 216-A-4 Crib (Table C4-8) indicate that with natural vegetation reestablished on the surface, uranium does not reach the water table within 1,000 years. Even if no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the surface, (long-term recharge remains 22 mm/yr indefinitely), the maximum groundwater concentration does not exceed the MCL during the first 1,000 years. The concentration at the end of the 1,000 year period is essentially zero (3.40E-11 μg/L), and the concentration does not exceed the MCL until 3,700 years into the future.

The results of the modeling indicate that carbon-14 at 216-A-5 Crib may not require any specific remedial action to achieve the protection of groundwater (Table C4-9). Even if no efforts to reestablish natural vegetation are made, and shallow rooted invasive species such as cheatgrass were to dominate the surface (long-term recharge remains 22 mm/yr indefinitely), the maximum groundwater concentration does not exceed the MCL. The maximum concentration during the 1,000 year evaluation period is 1,224 pCi/L, which is less than 1/2 of the MCL. With natural vegetation reestablished on the surface, the results indicate that carbon-14 concentration remains less than 980 pCi/L.

C4.1.16 Implications for Barrier Effectiveness

The main implications of these results for the 216-A-4 Crib are the recharge reduction to levels of about 4 mm/yr produce efficiencies in decreasing peak contaminant concentrations in groundwater and reduction in peak groundwater arrival times, only slightly less than those obtained with an ET barrier/cover. Thus, it is indicated that the primary risk mitigation objectives of the "ET-barrier/cover" remedy may be achieved by the restoration of the site to natural vegetation conditions, which is estimated to occur in a period of less than 30 years (PNNL-14725, DOE/RL-2007-34). The cost benefit of an ET barrier for the mitigation of groundwater impacts of vadose zone contamination remaining at the 216-A-4 and 216-A-5 Cribs may, therefore, be minimal compared to restoration of the site(s) to natural conditions, in conjunction with an ongoing remedy such as monitored natural attenuation (MNA).

Table C4-8. Results of Uranium Evaluation at the 126-A-4 Crib

5-Meter Well Screen							
K_d	Post-Remediation Recharge Rate	Solubility Limit (mg/L)	Concentration at Year 3010 (mg/m^3)	Year of First Non-Zero Concentration Arrival	Year of First Arrival of MCL	Maximum Concentration (mg/m^3)	Year of Maximum Concentration (mg/m^3)
0.6	8 mm/yr and 4 mm/yr	N/A	0.00E+00	4856	12001	2132	20861
0.6	0.5 mm/yr and 1.0 mm/yr	N/A	0.00E+00	6773	19452	1312	32010
0.6	22 mm/yr	N/A	3.40E-11	2848	4782	5767	7679
0.6	63 mm/yr	N/A	2.81E+01	2327	3014	14921	4147
0.6	8 mm/yr and 4 mm/yr	100	0.00E+00	5540	15474	612	32010
0.3	8 mm/yr and 4 mm/yr	N/A	0.00E+00	3413	7105	3986	12093

Table C4-9. Results of Carbon-14 Evaluation at the 126-A-5 Crib

5-Meter Well Screen		
Post-Remediation Recharge Rate	Maximum Concentration (mg/m^3)	Year of Maximum Concentration (mg/m^3)
8 mm/yr and 4 mm/yr	980	3392
0.5 mm/yr and 1.0 mm/yr	687	3735
22 mm/yr	1,224	2415
63 mm/yr	2,727	2184

C4.1.17 STOMP Software Quality Assurance

The vadose zone fate and transport calculations were performed using the STOMP Version 3.2 code, Hanford Information Systems Inventory identification number 2471. STOMP executes on the RANSAC Linux Cluster (ransac-0.pnl.gov) that is managed by Pacific Northwest National Laboratory (PNNL). The computer property tag identifier is WD56054 (PNNL Property System). The STOMP simulations were conducted in accordance with CHPRC-00176, *STOMP Software Management Plan.*

STOMP meets the criteria developed in HNF-5294, Computer Code Selection Criteria for Flow and Transport,Code(s) to be Used in Vadose Zone Calculations for Environmental Analyses in the Hanford Site Central Plateau (see RPP-18227, Appendix A for the evaluation of STOMP against the criteria), and has been used extensively at the Hanford Site for similar fate and transport studies (e.g. DOE/RL-2004-23). The use of STOMP for fate and transport modeling meets the requirements of WAC-173-340-747(8)(B) (see DOE/RL-2007-34). PNNL-12030, *STOMP Subsurface Transport Over Multiple Phases Version 2.0, Theory Guide*, and PNNL-14478, *STOMP Subsurface Transport Over Multiple Phases Version 3.1, User's Guide*, present the theoretical basis and describe the numerical transcription and implementation of that theory, and PNNL-11216, present several test cases that compare STOMP output to both field and laboratory data and other comparable computer codes.

C5 RESRAD Groundwater Impact Analysis for the 216-A-5 Crib

This appendix evaluates potential radiological impacts to groundwater at the 216-A-5 Crib. The purpose of this analysis is to identify the radioactive contaminants that could pose a potential future impact to groundwater using the data collected as part of the remedial investigation. Modeling with the RESRAD code (ANL, 2007) is used to determine whether the radionuclides beneath the 216-A-5 Crib will reach groundwater in 1,000 years. If any of the radionuclides reach groundwater during the period of simulation, the resulting concentrations in the groundwater are compared to MCLs.

C5.1 Selection of Contaminants of Potential Concern

The radionuclides included in the analysis are radionuclides identified as contaminants of potential concern (COPCs) at the 216-A-5 Crib. COPCs are defined as potentially site-related radioactive substances that are detected in the environment at levels that may place exposed humans at risk for adverse health effects. The COPC identification process is performed using borehole sample data from borehole C6552. This borehole was drilled to groundwater near the center of the 216-A-5 crib in 2008 and sampled throughout much of the interval from 3.8 to 100.4 m (12.5 to 329.5 ft) bgs.

The following step-wise data evaluation process is used to identify COPCs:

1. Identification of detected radionuclides
2. Comparison of shallow zone and deep zone soils to Hanford Site background levels
3. Availability of toxicity values for human health evaluation

COPCs are identified separately for shallow-and deep zone soils. Shallow zone soils are defined as soils from the ground surface to a depth of 4.6 m (15 ft) bgs. Deep zone soils are defined as soils from the ground surface to the groundwater table. The analysis of groundwater impacts is performed using deep zone COPCs; data evaluation for shallow zone COPC identification is included for information purposes.

C5.1.1 Identification of Detected Radionuclides

Radionuclides must be detected in at least one soil sample from borehole C6552 to be carried through to the next step of the COPC screening process. To identify detected radionuclides, sample data with concentrations less than or equal to zero are first eliminated from further consideration and then sample data flagged with a "U" qualifier (indicating non-detect) are eliminated from further consideration. Results of the detected radionuclide screening process are presented in Table C5-1.

C5.1.2 Comparison to Hanford Site Background Values

The next step in the COPC screening process is to identify detected radionuclides that are present at concentrations exceeding naturally occurring levels. Hanford Site radionuclide background values are identified in *Hanford Site Background: Part 2, Soil Background for Radionuclides* (DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, Table 5-1). The maximum detected concentration of each detected radionuclide is compared to the lognormal 90th percentile background value. If the maximum detected concentration is less than the background value, the radionuclide is eliminated from further consideration. If the maximum detected concentration is greater than the background value, the radionuclide is carried through to the next step of the screening process. Detected radionuclides that do not have a background value reported in DOE/RL-96-12 are also carried through to the next step of the screening process.

Table C5-1. Identification of 216-A-5 Crib Detected Radionuclides (Borehole C6552)

Radionuclides Detected in Shallow Zone Soil	Radionuclides Detected in Deep Zone Soil	
Potassium-40	Americium-241	Potassium-40
Radium-226	Carbon-14	Radium-226
Radium-228	Cesium-137	Radium-228
Thorium-228	Europium-154	Thorium-228
Thorium-230	Europium-155	Thorium-230
Thorium-232	Gross alpha	Thorium-232
Uranium-233/234	Gross beta	Total beta radiostrontium
Uranium-238	Iodine-129	Tritium
	Neptunium-237	Uranium-233/234
	Plutonium-238	Uranium-235
	Plutonium-239	Uranium-238
	Plutonium-239/240	

Results of the background screening process are presented in Table C5-2 and Table C5-3. Of the eight detected radionuclides in shallow zone soils, none have maximum soil concentrations above their respective background values. Of the 23 detected radionuclides in deep zone soils, 17 have maximum soil concentrations above their respective background values and are carried through to the next step of the screening process.

Table C5-2. Comparison of 216-A-5 Crib Maximum Soil Concentrations from Zero to 4.6 m (15 ft) bgs to Hanford Site Background (Borehole C6552)

Constituent Name	Maximum Detected Concentration from 0 to 4.6 m (15 ft) bgs (pCi/g)	Start Depth of Maximum Detect (ft bgs)	End Depth of Maximum Detect (ft bgs)	90th Percentile Background Concentration	Does Maximum Detect from 0 to 4.6 m (15 ft) Exceed Background?
Potassium-40	16.7	3.81	4.572	16.6	Yes*
Radium-226	0.523	3.81	4.572	0.815	No
Radium-228	0.803	3.81	4.572	1.32	No
Thorium-228	0.887	3.81	4.572	1.32	No
Thorium-230	0.443	3.81	4.572	1.1	No
Thorium-232	1.01	3.81	4.572	1.32	No
Uranium-233/234	0.736	3.81	4.572	1.1	No
Uranium-238	0.631	3.81	4.572	1.06	No

Table C5-2. Comparison of 216-A-5 Crib Maximum Soil Concentrations from Zero to 4.6 m (15 ft) bgs to Hanford Site Background (Borehole C6552)

Constituent Name	Maximum Detected Concentration from 0 to 4.6 m (15 ft) bgs (pCi/g)	Start Depth of Maximum Detect (ft bgs)	End Depth of Maximum Detect (ft bgs)	90th Percentile Background Concentration	Does Maximum Detect from 0 to 4.6 m (15 ft) Exceed Background?

* Potassium-40 maximum detected concentration is within range of natural background observations, and this constituent is therefore eliminated from further consideration.

bgs = below ground surface

Table C5-3. Comparison of 216-A-5 Crib Maximum Soil Concentrations from Zero to Groundwater Table to Hanford Site Background (Borehole C6552)

Constituent Name	Maximum Detected Concentration from 0 to Groundwater Table (pCi/g)	Start Depth of Maximum Detect (ft bgs)	End Depth of Maximum Detect (ft bgs)	90th Percentile Background Concentration	Does Maximum Detect from 0 to Groundwater Table Exceed Background?
Americium-241	422	10.58	11.37	No Background	Not Available
Carbon-14	36.4	18.17	18.9	No Background	Not Available
Cesium-137	2860	10.58	11.37	1.05	Yes
Europium-154	0.34	17.65	18.29	0.0334	Yes
Europium-155	0.134	17.65	18.29	0.0539	Yes
Gross Alpha	7360	10.52	10.67	No Background	Not Available
Gross Beta	4000	10.52	10.67	22.96	Yes
Iodine-129	10.8	10.58	11.37	No Background	Not Available
Neptunium-237	0.393	10.58	11.37	No Background	Not Available
Plutonium-238	13.6	10.58	11.37	0.00378	Yes
Plutonium-239	8870	10.52	10.67	0.0248	Yes
Plutonium-239/ 240	936	10.58	11.37	0.0248	Yes
Potassium-40	18.3	18.17	18.9	16.6	Yes*
Radium-226	0.563	18.17	18.9	0.815	No
Radium-228	0.96	19.66	20.42	1.32	No
Thorium-228	1.1	15.12	15.88	1.32	No
Thorium-230	0.978	NA	30.602	1.1	No

Table C5-3. Comparison of 216-A-5 Crib Maximum Soil Concentrations from Zero to Groundwater Table to Hanford Site Background (Borehole C6552)

Constituent Name	Maximum Detected Concentration from 0 to Groundwater Table (pCi/g)	Start Depth of Maximum Detect (ft bgs)	End Depth of Maximum Detect (ft bgs)	90th Percentile Background Concentration	Does Maximum Detect from 0 to Groundwater Table Exceed Background?
Thorium-232	1.01	3.81	4.572	1.32	No
Total Beta Radiostrontium	68.6	19.66	20.42	0.178	Yes
Tritium	1560	86.685	87.447	No Background	Not Available
Uranium-233/234	4.21	11.43	12.19	1.1	Yes
Uranium-235	0.338	11.43	12.19	0.109	Yes
Uranium-238	4.39	11.43	12.19	1.06	Yes

* Potassium-40 maximum detected concentration is within range of natural background observations, and this constituent is therefore eliminated from further consideration.

bgs = below ground surface

C5.1.3 Availability of Toxicity Values

The final step in the COPC screening process is to identify whether a toxicity value is available for the 17 detected radionuclides with maximum soil concentrations above their respective background values. Gross alpha and gross beta measurements are considered indicators of general radiological quality but do not have radiotoxicity values and are not available in the RESRAD dose conversion libraries. Based on the lack of radiotoxicity information, gross alpha and gross beta are eliminated from further consideration.

C5.1.4 Results of the COPC Selection Process

Results of the COPC selection process for radionuclides detected in shallow zone soils (zero to 4.6 m [15 ft] bgs) indicate there are no COPCs in shallow zone soils. Results of the COPC selection process for radionuclides detected in deep zone soils (zero to the groundwater table) are summarized in Table C5-4. Fifteen COPCs are identified in deep zone soils. These 15 radionuclides are carried forward to the groundwater impact analysis.

C5.2 RESRAD Groundwater Impact Analysis Methodology

The impact to groundwater from radionuclides is estimated using RESRAD, Version 6.4. The RESRAD code was developed by Argonne National Laboratory (*RESRAD for Windows* [ANL, 2007]) to implement DOE guidelines for allowable residual radioactive material in soil (DOE Order 5400.5).

Table C5-4. Radionuclide Contaminants of Potential Concern for the 216-A-5 Crib RESRAD Groundwater Impact Analysis

Constituent Name	Maximum Detected Concentration from 0 to Groundwater Table (pCi/g)	Start Depth of Maximum Detect (ft bgs)	End Depth of Maximum Detect (ft bgs)	Does Maximum Detect from 0 to Groundwater Table Exceed Background?
Americium-241	422	10.58	11.37	Not Available
Carbon-14	36.4	18.17	18.9	Not Available
Cesium-137	2860	10.58	11.37	Yes
Europium-154	0.34	17.65	18.29	Yes
Europium-155	0.134	17.65	18.29	Yes
Iodine-129	10.8	10.58	11.37	Not Available
Neptunium-237	0.393	10.58	11.37	Not Available
Plutonium-238	13.6	10.58	11.37	Yes
Plutonium-239	8870	10.52	10.67	Yes
Plutonium-239/240	936	10.58	11.37	Yes
Total Beta Radiostrontium	68.6	19.66	20.42	Yes
Tritium	1560	86.685	87.447	Not Available
Uranium-233/234	4.21	11.43	12.19	Yes
Uranium-235	0.338	11.43	12.19	Yes
Uranium-238	4.39	11.43	12.19	Yes

RESRAD incorporates a simplified model of contaminant transport from the contaminated zone through the unsaturated zone and the aquifer. It is assumed that the radioactive constituents are evenly distributed within the homogeneous contaminated zone that has a specified thickness and specified physical properties. The radionuclides released from the contaminated zone are subject to transport through the vadose zone. RESRAD employs a one-dimensional simplification of advective flow in the vadose zone. However, the major processes affecting radionuclide transport, such as advection, sorption, and radioactive decay and ingrowths, are included. RESRAD allows for modeling up to five unsaturated zone layers with different hydrogeologic properties beneath the contaminated zone. The saturated zone is assumed to be homogeneous. Transport in the saturated zone includes dilution. This simplified one-dimensional model leads to conservative estimates of the potential impact to the groundwater because it does not account for other processes that can reduce the contaminant concentrations in the groundwater, such as longitudinal and transverse dispersion, mineral precipitation/dissolution, and other site-specific hydrogeologic influences.

Contaminant transport is incorporated in RESRAD as a part of the exposure analysis. The transport calculations are performed when one or more of the water-related exposure pathways are activated. To evaluate soil impact on groundwater, the drinking water pathway is activated in RESRAD. For this analysis, it is assumed that a groundwater well is installed at the down-gradient boundary of the waste site. The well is pumped during the entire 1,000-year period of interest. This implementation of RESRAD results in leaching of radionuclides from the contaminated zone and travel with the infiltrating water downward through the unsaturated zone. The radionuclides that reach groundwater during the period of interest travel down-gradient in the groundwater in the horizontal direction. The radionuclides that reach the groundwater are then captured at the well. Time-dependent contaminant concentrations at the well are calculated and compared to their respective Federal MCL.

Two methods are provided in RESRAD to calculate the contaminant concentrations in groundwater from the well. The nondispersion model was used in this analysis to allow for simulating radionuclide transport in the aquifer downward from the site and to implement vertical mixing in the saturated zone. The contaminant travel time in the groundwater to the well is calculated as a function of the saturated zone hydraulic conductivity and gradient, length of the contaminant zone parallel to the hydraulic gradient, distance of the well intake below the water table, aquifer-effective porosity, depth of contamination within the saturated zone at the well location, and radionuclide-specific parameters. The contaminant concentration in the well is adjusted by the dilution in the saturated zone. Calculated concentrations are a function of the contaminated area, infiltration rate, well-pumping rate, depth of contamination within the saturated zone at the well location, and the effective pumping interval width.

C5.2.1 RESRAD Input Parameters

A complete set of analysis-specific input parameters is required to implement the RESRAD calculations. Groundwater concentrations are calculated in this analysis based on an unrestricted land-use assumption in which the site receives irrigation water (irrigation rate = 0.76 m/yr) in addition to water that infiltrates through precipitation. The input parameters developed for this analysis are summarized Table C5-5. This table provides the value for each input parameter, the rationale for its use, and a reference to the source for the value.

A graphical representation showing the geologic units and modeling layers identified for use in the RESRAD model calculations is provided in Figure C5-1. Three contaminated zones are defined based on the COPC distribution pattern in borehole C6552 sample data:

1. An upper contaminated zone from 10.5 to 24.3 m (34.5 to 79.8 ft) bgs

2. A middle contaminated zone from 17.6 to 39.7 m (57.9 to 130.1) ft bgs

3. A lower contaminated zone from 30.6 to 100.4 m (100.4 to 329.47 ft) bgs

Because RESRAD cannot simultaneously model multiple contaminated zones, each contaminated zone is modeled separately. A separate input file is required for each contaminated zone. The input files are set up using the parameters defined in Table C5-5. Supporting information not provided in Table C5-5, such as the derivation of input values for certain physical and hydrogeologic parameters and the radionuclide-specific EPCs and K_ds, are discussed in the remaining subsections of Section C5.

Table C5-5. Summary of RESRAD Input Parameters for the 216-A-5 Crib Groundwater Impact Analysis

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
Exposure Pathways	External gamma Inhalation Plant ingestion Meat ingestion Milk ingestion Aquatic foods Drinking water Soil ingestion Radon	NA	Suppressed Suppressed Suppressed Suppressed Suppressed Suppressed Active Suppressed Suppressed	
R011- Contaminated Zone (CZ)	Area of CZ	m^2	15,194	Wetted footprint area calculated based on Equation 4.3 in PNNL-14702.
	Thickness of CZ1	m	13.81	Site-specific data from the 34.5 to 79.8 ft bgs depth interval (borehole C6552).
	Thickness of CZ2	m	22.01	Site-specific data from the 57.9 to 130.1 ft bgs depth interval (borehole C6552).
	Thickness of CZ3	m	69.82	Site-specific data from the 100.4 to 329.47 ft bgs depth interval (borehole C6552).
	Length parallel to aquifer flow	m	123.3	Assumes contaminated zone is a square oriented perpendicular to aquifer flow (calculated as square root of CZ area).
	Radiation dose limit	mrem/year	15	40 CFR 141; EPA 540/R-99/006.
	Elapsed time since waste placement	year	0	RESRAD default.
Exposure Point Concentrations (EPCs)	EPCs	pCi/g	Radionuclide-specific	See Table C5-6. Maximum concentrations measured in borehole C6552 soil samples.
R013-Cover and CZ Hydrological Data	Cover depth (CZ1)	m	10.52	Site-specific data (see Figure C5-1).
	Cover depth (CZ2)	m	17.65	Site-specific data (see Figure C5-1).
	Cover depth (CZ3)	m	30.6	Site-specific data (see Figure C5-1).
	Cover material density (CZ1)	g/cm^3	1.94	Value for Bf (PNNL-14702, Table 4-5).
	Cover material density (CZ2)	g/cm^3	1.81	Thickness weighted average of values for Bf and Hfs (PNNL-14702, Table 4-5).
	Cover material density (CZ3)	g/cm^3	1.72	Thickness weighted average of values for Bf and Hfs (PNNL-14702, Table 4-5).
	Cover erosion rate	m/year	0.00001	Value selected prevents appreciable erosion of the cover over the simulation period.
	Density of CZ1	g/cm^3	1.61	Thickness weighted average of values for Bf and Hfs (PNNL-14702, Table 4-5).

Table C5-5. Summary of RESRAD Input Parameters for the 216-A-5 Crib Groundwater Impact Analysis

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	Density of CZ2	g/cm^3	1.60	Value for Hfs (PNNL-14702, Table 4-5).
	Density of CZ3	g/cm^3	1.71	Thickness weighted average of values for Hfs, PPlz, and Hg (PNNL-14702, Table 4-5).
	CZ erosion rate	m/year	0.00001	Value selected prevents appreciable erosion of the contaminated zones over the simulation period (used only if cover depth becomes zero through erosion).
	CZ total porosity (CZ1)	unitless	0.393	Thickness weighted average of values for Bf and Hfs (PNNL-14702, Table 4-5).
	CZ total porosity (CZ2)	unitless	0.397	Value for Hfs (PNNL-14702, Table 4-5).
	CZ total porosity (CZ3)	unitless	0.326	Thickness weighted average of values for Hfs, PPlz, and Hg (PNNL-14702, Table 4-5).
	CZ field capacity (CZ1)	unitless	0.061	Thickness weighted average of values for Bf and Hfs (PNNL-14702, Table 4-5).
	CZ field capacity (CZ2)	unitless	0.058	Value for Hfs (PNNL-14702, Table 4-5).
	CZ field capacity (CZ3)	unitless	0.067	Thickness weighted average of values for Hfs, PPlz, and Hg (PNNL-14702, Table 4-5).
	CZ hydraulic conductivity (CZ1)	m/year	120.3	Thickness weighted average of values for Bf and Hfs (PNNL-14702, Table 4-5).
	CZ hydraulic conductivity (CZ2)	m/year	118	Value for Hfs (PNNL-14702, Table 4-5).
	CZ hydraulic conductivity (CZ3)	m/year	109	Thickness weighted average of values for Hfs, PPlz, and Hg (PNNL-14702, Table 4-5).
	CZ b parameter (CZ1)	unitless	4.05	Determined from soil textures listed in ANL/EAD-4 (Table C3-1). Thickness weighted average of values assigned to CZ1 units (Bf = 4.05 for sand, Hfs = 4.05 for sand).
	CZ b parameter (CZ2)	unitless	4.05	Determined from soil textures listed in ANL/EAD-4 (Table C3-2). Value assigned to CZ2 unit (Hfs = 4.05 for sand).
	CZ b parameter (CZ3)	unitless	4.35	Determined from soil textures listed in ANL/EAD-4 (Table C3-1). Thickness weighted average of values assigned to CZ3 units (Hfs = 4.05 for sand, PPlz = 10.4 for silty clay, Hg = 4.05 for sand).
	Evapotranspiration coefficient	unitless	0.977	Value assigned results in an annual recharge rate of 0.4 cm/yr.

Table C5-5. Summary of RESRAD Input Parameters for the 216-A-5 Crib Groundwater Impact Analysis

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	Wind speed	m/s	3.4	Based on annual average prevailing wind speed of 7.6 mph (3.4 m/s) measured at Hanford Meteorology Station (PNNL-15160, Table 5-1).
	Precipitation	m/year	0.177	Based on normal annual precipitation of 6.98 in. (0.177 mm) measured at Hanford Meteorology Station (PNNL-15160, Table 4-1)
	Irrigation rate	m/year	0.76	WDOH/320-015 (Appendix B).
	Irrigation mode	Overhead or ditch	Overhead	RESRAD default.
	Runoff coefficient	unitless	0	Value selected conservatively assumes all precipitation penetrates the topsoil.
	Watershed area for nearby stream or pond	m^2	1.00E+06	RESRAD default.
	Accuracy for water/soil computations	unitless	0.001	RESRAD default.
R014 - Saturated Zone (SZ) Hydrological Data	Density of SZ	g/cm^3	1.93	Value for Hg (PNNL-14702, Table 4-5).
	SZ total porosity	unitless	0.167	Value for Hg (PNNL-14702, Table 4-5).
	SZ effective porosity	unitless	0.167	Value for Hg (PNNL-14702, Table 4-5).
	SZ field capacity	unitless	0.062	Calculated using parameters for Hg from PNNL-14702 (Table 4-5).
	SZ hydraulic conductivity	m/year	104	Value for Hg (PNNL-14702, Table 4-5).
	SZ hydraulic gradient	unitless	2.00E-05	DOE/RL-2008-01 (Table H2-2).
	SZ b parameter	unitless	4.05	Determined from soil textures listed in ANL/EAD-4 (Table C3-1). Saturated zone unit (Hg) has little of the finer material (silt and clay) listed in Table C3-1 and hence is assigned value of 4.05 for sand.
	Water table drop rate	m/year	0.0001	Value selected results in little change in the depth of groundwater over the simulation period.
	Well pump intake depth below water table	m	10	RESRAD default.
	Model for water transport	Nondispersion (ND) or mass balance	ND	RESRAD default.
	Well pumping rate	m^3/year	250	RESRAD default.
R015-Uncontaminated and Unsaturated Strata Hydrological Data	Number of unsaturated strata (CZ1)	Not applicable	5	Sediment stratigrahpy based on borehole data from borehole C6552 driller through the 216-A-5 crib. See Figure C5-1.

Table C5-5. Summary of RESRAD Input Parameters for the 216-A-5 Crib Groundwater Impact Analysis

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	Number of unsaturated strata (CZ2)	Not applicable	5	Sediment stratigrahpy based on borehole data from borehole C6552 driller through the 216-A-5 crib. See Figure C5-1.
	Number of unsaturated strata (CZ3)	Not applicable	1	Sediment stratigrahpy based on borehole data from borehole C6552 driller through the 216-A-5 crib. See Figure C5-1.
	Thickness (CZ1)	m	50.96, 2.74, 8.53, 0.61, 13.26	Site-specific data (Hfs, PPlz, Hg, PPlz, and Hg).
	Thickness (CZ2)	m	35.63, 2.74, 8.53, 0.61, 13.26	Site-specific data (Hfs, PPlz, Hg, PPlz, and Hg).
	Thickness (CZ3)	m	0.01	Site-specific data (Hg).
	Soil density (CZ1)	g/cm^3	1.60, 1.68, 1.93, 1.68, 1.93	PNNL-14702 (Table 4-5).
	Soil density (CZ2)	g/cm^3	1.60, 1.68, 1.93, 1.68, 1.93	PNNL-14702 (Table 4-5).
	Soil density (CZ3)	g/cm^3	1.93	PNNL-14702 (Table 4-5).
	Total porosity/effective porosity (CZ1)	unitless	0.397, 0.419, 0.167, 0.419, 0.167	PNNL-14702 (Table 4-5).
	Total porosity/effective porosity (CZ2)	unitless	0.397, 0.419, 0.167, 0.419, 0.167	PNNL-14702 (Table 4-5).
	Total porosity/effective porosity (CZ3)	unitless	0.167	PNNL-14702 (Table 4-5).
	Field capacity (CZ1)	unitless	0.058, 0.210, 0.062, 0.210, 0.062	Calculated using parameters from PNNL-14702 (Table 4-5).
	Field capacity (CZ2)	unitless	0.058, 0.210, 0.062, 0.210, 0.062	Calculated using parameters from PNNL-14702 (Table 4-5).
	Field capacity (CZ3)	unitless	0.062	Calculated using parameters from PNNL-14702 (Table 4-5).
	Hydraulic conductivity (CZ1)	m/year	118, 17.6, 104, 17.6, 104	PNNL-14702 (Table 4-5).
	Hydraulic conductivity (CZ2)	m/year	118, 17.6, 104, 17.6, 104	PNNL-14702 (Table 4-5).
	Hydraulic conductivity (CZ3)	m/year	104	PNNL-14702 (Table 4-5).
	Soil-specific *b* parameter (CZ1)	unitless	4.05, 10.4, 4.05, 10.4, 4.05	Determined from soil textures listed in ANL/EAD-4 (Table C3-1). Except for PPlz, the units have little of the finer material (silt and clay) listed in Table C3-1 and hence are assigned the sand value of 4.05. PPlz is assigned the silty clay value 10.5.
	Soil-specific *b* parameter (CZ2)	unitless	4.05, 10.4, 4.05, 10.4, 4.05	Determined from soil textures listed in ANL/EAD-4 (Table C3-1). Except for PPlz, the units have little of the finer material (silt and clay) listed in Table C3-1 and hence are assigned the sand value of 4.05. PPlz is assigned the silty clay value 10.5.

Table C5-5. Summary of RESRAD Input Parameters for the 216-A-5 Crib Groundwater Impact Analysis

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	Soil-specific b parameter (CZ3)	unitless	4.05	Determined from soil textures listed in ANL/EAD-4 (Table C3-1). Hg unit has little of the finer material (silt and clay) listed in Table C3-1 and hence is assigned the sand value of 4.05.
R016-Distribution Coefficients and Leach Rates for Individual Radionuclides	Distribution coefficients (K_ds) for contaminated zone, uncontaminated zone, and saturated zone	cm^3/g	Radionuclide-specific	See Table C5-7 and and C5-8. K_ds assigned to CZ1 are best estimate values from PNNL-14702, Table 4.11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H). K_ds assigned to all other RESRAD layers (CZ2, CZ3, all uncontaminated unsaturated zone layers, and saturated zone) are best estimate values from PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1). K_ds assigned to radionuclides not addressed in PNNL-14702 (Am-241, Pb-210, Ra-226) are best estimate values from PNNL-17154, Table A1-1., Sand-Size Sediments - No Impact Zone. K_ds for radionuclides not addressed in either PNNL-14702 or PNNL-17154 (Ac-227, Pa-231, Th-229, Th-230) are RESRAD default values.
	Leach rate	yr^{-1}	0	RESRAD default.
	Solubility limit	mol/L	0	RESRAD default.
R017 - Inhalation and External Gamma	Inhalation rate	m^3/year	NA	Not applicable.
	Mass loading for inhalation	g/m^3	NA	Not applicable.
	Exposure duration	year	30	EPA (1991).
	Indoor dust filtration factor	unitless	NA	Not applicable.
	External gamma shielding factor	unitless	NA	Not applicable.
	Indoor time fraction	unitless	NA	Not applicable.
	Outdoor time fraction	unitless	NA	Not applicable.
	Shape factor	Not applicable	NA	Not applicable.
R018 - Ingestion Pathway Data, Dietary Parameters	Fruit, vegetable, and grain consumption	kg/yr	NA	Not applicable.
	Leafy vegetable consumption	kg/yr	NA	Not applicable.
	Milk consumption	L/yr	NA	Not applicable.
	Meat and poultry consumption	kg/yr	NA	Not applicable.
	Fish consumption	kg/yr	NA	Not applicable.

Table C5-5. Summary of RESRAD Input Parameters for the 216-A-5 Crib Groundwater Impact Analysis

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation
	Other seafood consumption	kg/yr	NA	Not applicable.
	Soil ingestion intake	g/yr	NA	Not applicable.
	Drinking water intake	L/yr	700	Based on a drinking water ingestion rate of 2 L/day (350 days/yr) (EPA, 1991).
	Drinking water contamination fraction	unitless	1	RESRAD default.
	Household water contamination fraction	unitless	NA	Not applicable.
	Livestock water contamination fraction	unitless	NA	Not applicable.
	Irrigation water contamination fraction	unitless	NA	Not applicable.
	Aquatic food contamination fraction	unitless	NA	Not applicable.
	Plant food contamination fraction	unitless	NA	Not applicable.
	Meat contamination fraction	unitless	NA	Not applicable.
	Milk contamination fraction	unitless	NA	Not applicable.
R019- Ingestion Pathway Data, Nondietary	Livestock fodder intake for meat	kg/d	NA	Not applicable.
	Livestock fodder intake for milk	kg/d	NA	Not applicable.
	Livestock water intake for meat	L/d	NA	Not applicable.
	Livestock water intake for milk	L/d	NA	Not applicable.
	Livestock intake of soil	kg/d	NA	Not applicable.
	Mass loading for foliar deposition	g/m^3	NA	Not applicable.
	Depth of soil mixing layer	m	NA	Not applicable.
	Depth of roots	m	NA	Not applicable.
R020 – Groundwater Usage	Groundwater fractional usage – drinking water	unitless	1	Not applicable.
	Groundwater fractional usage – household usage	unitless	NA	Not applicable.
	Groundwater fractional usage – livestock water	unitless	NA	Not applicable.
	Groundwater fractional usage –irrigation	unitless	NA	Not applicable.
R021 – Radon	Not used	NA	NA	Not applicable.

Table C5-5. Summary of RESRAD Input Parameters for the 216-A-5 Crib Groundwater Impact Analysis

Description	Parameter	Units	Groundwater Exposure Pathway	Rationale and Citation

Notes:

40 CFR 141, "National Primary Drinking Water Regulations."

ANL/EAD-4, 2001, *User's Manual for RESRAD, Version 6.*

ANL, 2007, *RESRAD*, Version 6.4

DOE/RL-2008-01, *Hanford Site Groundwater Monitoring for Fiscal Year 2007.*

EPA, 1991, *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final.*

EPA/540/R-99/006, *Radiation Risk Assessment At CERCLA Sites: Q&A*, OSWER Directive 9200.4-31P.

PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments.*

PNNL-15160, *Hanford Site Climatological Summary 2004 with Historical Data.*

PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.*

WDOH/320-015, *Hanford Guidance for Radiological Cleanup.*

bgs = below ground surface
CZ = contaminated zone
RESRAD = RESidual RADioactivity (ANL, 2007)
SZ = saturated zone

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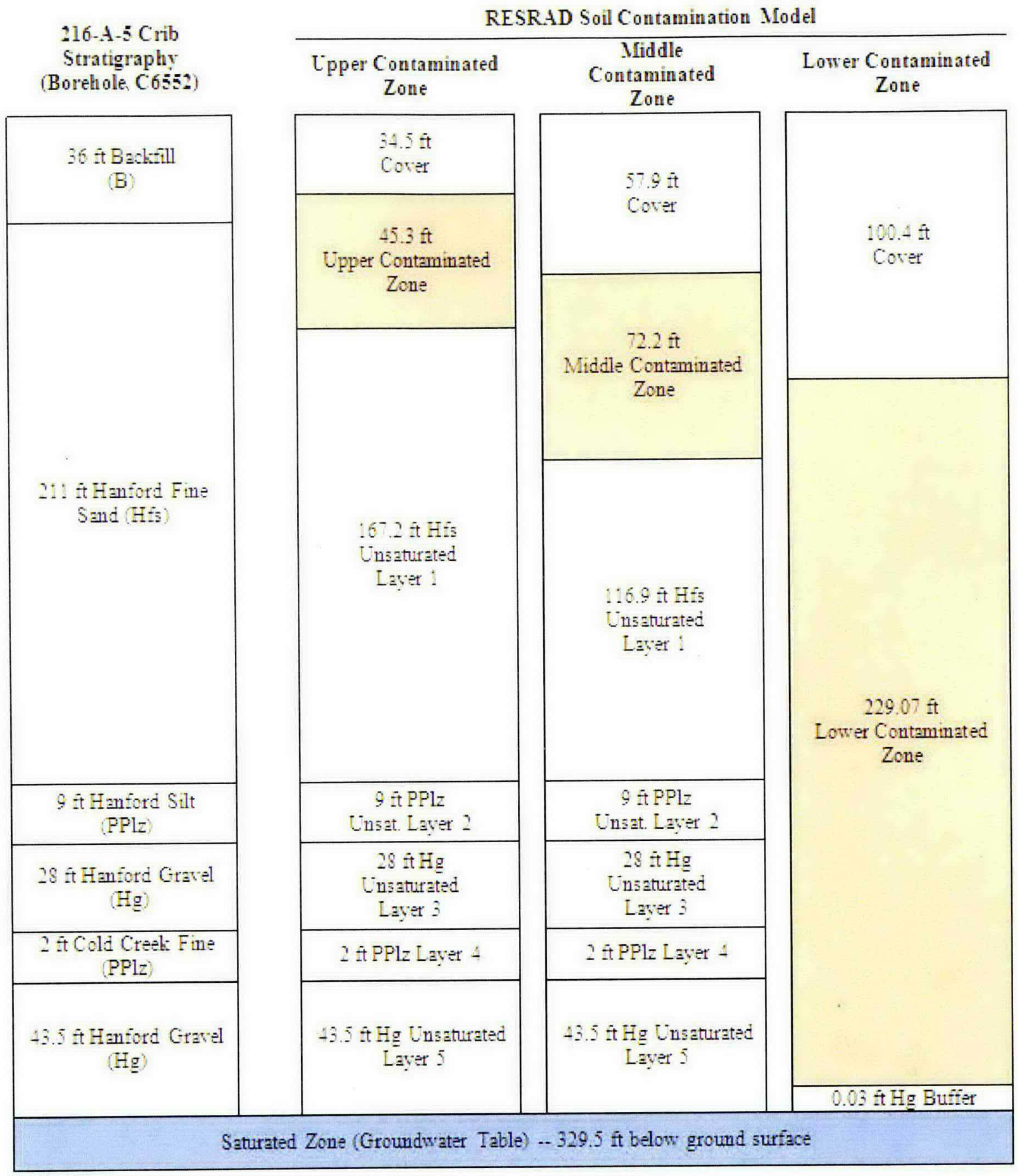

Notes:

For input to RESRAD the following mixtures are used:

Upper contaminated zone is 1.5 ft Bf + 43.8 ft Hfs.

Cover above middle contaminated zone is 36 ft Bf + 21.9 ft Hfs.

Cover above lower contaminated zone is 36 ft Bf + 64.4 ft Hfs

Lower contaminated zone is 146.6 ft Hfs + 9ft PPlz + 28 ft PPlz + 43.47 ft Hg.

Figure C5-1. Modeling Layers for the 216-A-5 Crib RESRAD Groundwater Impact Analysis Contaminated Zone Area

The RESRAD contaminated zone area parameter is calculated based on the actual site area as recommended in PNNL-14702. The calculation considers the lateral spreading of liquids discharged to the crib and uses a dimensionless scaling factor λ to relate the wetted vadose zone footprint to the actual facility footprint. The 216-A-5 crib base area is 10.7 m (35 ft) wide and 10.7 m (35 ft) long, with an area equal to 114.5 m^2 (1,232 ft^2) (Drawing H-2-56050). Equation 4.3 in PNNL-14702 is used to calculate the contaminated area (A_x) as follows:

$$A_x = \lambda A_0$$

$$\lambda = \frac{Q_{\max}}{k_{s\,\min} A_0}$$

where:

A_0 = actual site area (m^2)

k_{smin} = minimum hydraulic conductivity of the unsaturated zone beneath the contaminated zone (m/s)

Q_{max} = maximum artificial liquid discharge rate (m^3/s)

This equation is used to adjust the actual site area in cases when the dimensionless parameter λ is greater than one. In the cases when the dimensionless parameter λ is equal to or smaller than one, no adjustment is needed and the contaminated area is equal to the actual site area.

The parameters in this equation are defined as follows.

- The liquid discharge rate is calculated from the total liquid discharge at the site, which is 1.6 billion L over 6 years of operations. This translates to 8.46×10^{-3} m^3/s.
- The minimum hydraulic conductivity is 17.6 m/yr (5.58×10^{-7} m/s) based on the hydraulic conductivity of the Hanford Silt/Cold Creek Fine (PPlz) unit (PNNL-14702, Table 4-5).

The dimensionless parameter λ is then 132.7, which is greater than one. Consequently, the site area needs to be adjusted. The resulting contaminated zone area used in RESRAD is 15,194 m^2 (163,547 ft^2).

C5.2.1.1 Evapotranspiration Coefficient

The unitless evapotranspiration coefficient (C_e) is used in RESRAD to calculate the infiltration rate (I) through the unsaturated zone. The infiltration rate cannot be explicitly specified in RESRAD. It is calculated implicitly by RESRAD as (Equation E.4 in ANL/EAD-4):

$$I = (1 - C_e)[(1 - C_r)P_r + I_{rr})]$$

where:

C_r = run-off coefficient (unitless)

P_r = precipitation (m/yr)

I_{rr} = irrigation rate (m/yr)

The run-off coefficient, precipitation, and irrigation rate are defined in Table C5-5.

The evapotranspiration coefficient is calculated as:

$$C_e = 1 - \frac{I}{(1 - C_r)P_r + I_{rr}}$$

The infiltration rate used in this equation is 0.004 m/yr. This corresponds to the estimated long-term recharge rate (when the site stabilized and returns to the natural conditions) for Hanford sand (PNNL-14702, Table 4-15). The resulting evapotranspiration coefficient is 0.977.

C5.2.1.2 Exposure Point Concentrations

As previously discussed, three contaminated zones are defined to facilitate RERAD modeling of the radionuclide soil distribution pattern at the 216-A-5 Crib. Each contaminated zone is modeled with a separate RESRAD run. Top and bottom depths for each contaminated zone are defined based on intervals of continuously elevated COPC detections between the ground surface and the groundwater table in borehole C6552 soil samples (Figure C5-1). The EPCs in each contaminated zone are conservatively defined based on the maximum detected COPC concentrations within each zone. Radionuclide-specific EPCs for each contaminated zone are provided in Table C5-6.

Radionuclides shown in Table C5-6 with zero concentrations are daughter products included automatically by RESRAD when the parent radionuclide (COPC) is selected. For purposes of this analysis, analytical results reported as undifferentiated plutonium-239/240 are assumed to be all plutonium-239. This is considered reasonable because in most cases plutonium-239 is the dominant isotope. Similarly, analytical results reported as undifferentiated uranium-233/234 are assumed to be all uranium-234 because it is commonly accepted that uranium-234 is the dominant isotope.

The base of the 216-A-5 Crib is at a depth of 10.7 m (35 ft) bgs. Maximum concentrations for all COPCs except strontium-90 and tritium are encountered within the depth interval from 10.5 to 24.3 m (34.5 to 79.8 ft) bgs. This interval is defined as the upper contaminated zone. Maximum strontium-90 concentrations are encountered within the depth interval from 17.6 to 39.7 m (57.9 to 130.1) ft bgs. This interval is defined as the middle contaminated zone. Maximum tritium concentrations are encountered within the depth interval from 30.6 to 100.4 m (100.4 to 329.47 ft) bgs. This interval is defined as the lower contaminated zone. Although elevated tritium detections extend to the water table, the RESRAD model requires an unsaturated layer beneath the contaminated zone. To minimize the impacts of this requirement, a very thin (0.01 m) unsaturated layer is included in the model (Figure C3-1).

C5.2.1.3 Distribution Coefficients

RESRAD accepts user-specified radionuclide-specific K_ds for each modeling layer from the release point to the groundwater withdrawal well (i.e., contaminated zone, unsaturated zone layers, and saturated zone). The waste released to the 216-A-5 Crib was acidic. For the upper contaminated zone, the acidic fluids are assumed to have affected K_d values. The K_d values used to represent the upper contaminated zone in RESRAD are the best estimate values for the "very acidic waste category, high-impact zone" provided in PNNL-14702, Table 4-11. The upper contaminated zone K_d values are listed in Table C5-7.

Table C5-6. Radionuclide-Specific Exposure Point Concentrations for the 216-A-5 Crib RESRAD Groundwater Impact Analysis

Radionuclide	EPC (pCi/g)
Upper Contaminated Zone	
Americium-241	422
Carbon-14	36.4
Cesium-137	2860
Europium-154	0.34
Europium-155	0.134
Iodine-129	10.8
Neptunium-237	0.393
Plutonium-238	13.6
Plutonium-239, - 239/240	8870
Uranium-233/234	4.21
Uranium-235	0.338
Uranium-238	4.39
Actinium-227	0
Protactinium-231	0
Lead-210	0
Radium-226	0
Thorium-229	0
Thorium-230	0
Uranium-233	0
Middle Contaminated Zone	
Strontium-90	68.6
Lower Contaminated Zone	
Tritium	1560

EPC = exposure point concentration

For all other RESRAD modeling layers (contaminated zones 2 and 3, all unsaturated zone layers, and the saturated zone), the acidic fluids are assumed to have been neutralized by the natural soil. The K_d values used to represent the other modeling layers in RESRAD are the best estimate values for the "very acidic waste category, intermediate impact zone" provided in PNNL-14702, Table 4-11. The K_d values for the other modeling layers are listed in Table C5-8.

K_d values used for radionuclides not addressed in PNNL-14702 are best estimate values for the "no impact" category provided in PNNL-17154, Table A1-1. K_d values used for radionuclides not addressed in either PNNL-14702 or PNNL-17154 are RESRAD default values.

Table C5-7. Radionuclide-Specific Distribution Coefficients for the 216-A-5 Crib RESRAD Upper Contaminated Zone

Radionuclide	K_d (cm^3/g)	Reference
Americium-241	300	PNNL-17154, Table A1-1
Carbon-14	0	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Cesium-137	1000	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Europium-154	20	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Europium-155	20	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Iodine-129	4	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Neptunium-237	0	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Plutonium-238	0.4	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Plutonium-239, - 239/240	0.4	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Uranium-233/234	0.2	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Uranium-235	0.2	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Uranium-238	0.2	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)
Actinium-227	20	RESRAD Default
Protactinium-231	50	RESRAD Default
Lead-210	50	PNNL-17154, Table A1-1
Radium-226	20	PNNL-17154, Table A1-1
Thorium-229	60,000	RESRAD Default
Thorium-230	60,000	RESRAD Default
Uranium-233	0.2	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, High Impact (1H)

Notes:

PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments.*

PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.*

Table C5-8. Radionuclide-Specific Distribution Coefficients for the 216-A-5 Crib RESRAD Middle and Lower Contaminated Zones, Unsaturated Zone Layers, and Saturated Zone

Radionuclide	$K_d(cm^3/g)$	Reference
Americium-241	300	PNNL-17154, Table A1-1
Carbon-14	0	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Cesium-137	2000	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Europium-154	200	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Europium-155	200	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Iodine-129	0.2	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Neptunium-237	10	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Plutonium-238	600	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Plutonium-239, - 239/240	600	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Strontium-90	22	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Tritium	0	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Uranium-233/234	0.8	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Uranium-235	0.8	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Uranium-238	0.8	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)
Actinium-227	20	RESRAD Default
Protactinium-231	50	RESRAD Default
Lead-210	50	PNNL-17154, Table A-1
Radium-226	20	PNNL-17154, Table A-1
Thorium-229	60,000	RESRAD Default
Thorium-230	60,000	RESRAD Default
Uranium-233	0.8	PNNL-14702, Table 4-11, Waste Chemistry/Source Category 1: Very Acidic, Intermediate Impact - Sand (1I1)

Table C5-8. Radionuclide-Specific Distribution Coefficients for the 216-A-5 Crib RESRAD Middle and Lower Contaminated Zones, Unsaturated Zone Layers, and Saturated Zone

Radionuclide	K_d(cm^3/g)	Reference

Notes:

PNNL-14702, Vadose Zone Hydrogeology Data Package for Hanford Assessments.

PNNL-17154, Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.

C5.2.1.4 Hydrogeologic Parameters

Hydrogeologic parameters for each modeling layer in each of the three RESRAD model runs are defined based on the properties of the different hydrogeologic units in each layer and are obtained from PNNL-14702, Table 4-5.

For assessing impacts to groundwater from contaminants in the upper contaminated zone, the cover depth is 10.5 m (34.5 ft) and the contaminated zone thickness is 13.8 m (45.3 ft). There are five unsaturated zone layers between the contaminated zone and the saturated zone (Figure C5-1). The contaminated zone in this case consists of two hydrogeologic units. RESRAD assumes that the contaminated zone is homogeneous. The parameters of the homogeneous contaminated zone are calculated as the weighted averages of the corresponding parameters of the two hydrogeologic units. For example, the contaminated zone total porosity (ε_{cz}) is calculated as:

$$\varepsilon_{cz} = (\varepsilon_1 d_1 + \varepsilon_2 d_2)/(d_1 + d_2)$$

where:

ε_1 and ε_2 are the total porosity of the corresponding hydrogeologic unit and d_1 and d_2 are the unit thicknesses. The hydrogeologic parameters for the upper contaminated zone RESRAD model run are summarized in Table C5-9.

Table C5-9. Hydrogeologic Parameters of the 216-A-5 Crib Upper Contaminated Zone RESRAD Model Run

Modeling Layer	Thickness (m)	Bulk Density (g/cm3)	Total Porosity	Effective Porosity	Field Capacity	Hydraulic Conductivity (m/yr)	Soil Parameter *b*
Cover	10.52	--	--	--	--	--	--
Contaminated Zone	13.81	1.61	0.393	0.393	0.061	120.3	4.05
UZ Layer 1	50.96	1.60	0.397	0.397	0.058	118	4.05
UZ Layer 2	2.74	1.68	0.419	0.419	0.210	17.6	10.4
UZ Layer 3	8.53	1.93	0.167	0.167	0.062	104	4.05
UZ Layer 4	0.61	1.68	0.419	0.419	0.210	17.6	10.4
UZ Layer 5	13.26	1.93	0.167	0.167	0.062	104	4.05
Saturated Zone	--	1.93	0.167	0.167	0.062	104	4.05

UZ = unsaturated zone

For assessing impacts to groundwater from contaminants in the middle contaminated zone, the cover depth is 17.65 m (57.9 ft) and the contaminated zone thickness is 22.01 m (72.2 ft). As for the upper contaminated zone, there are five unsaturated zone layers between the contaminated zone and the saturated zone (Figure C5-1). The hydrogeologic parameters for the middle contaminated zone RESRAD model run are summarized in Table C5-10.

Table C5-10. Hydrogeologic Parameters of the 216-A-5 Crib Middle Contaminated Zone RESRAD Model Run

Modeling Layer	Thickness (m)	Bulk Density (g/cm3)	Total Porosity	Effective Porosity	Field Capacity	Hydraulic Conductivity (m/yr)	Soil Parameter *b*
Cover	17.65	--	--	--	--	--	--
Contaminated Zone	22.01	1.60	0.397	0.397	0.058	118	4.05
UZ Layer 1	35.63	1.60	0.397	0.397	0.058	118	4.05
UZ Layer 2	2.74	1.68	0.419	0.419	0.210	17.6	10.4
UZ Layer 3	8.53	1.93	0.167	0.167	0.062	104	4.05
UZ Layer 4	0.61	1.68	0.419	0.419	0.210	17.6	10.4
UZ Layer 5	13.26	1.93	0.167	0.167	0.062	104	4.05
Saturated Zone	--	1.93	0.167	0.167	0.062	104	4.05

UZ = unsaturated zone

For assessing impacts to groundwater from contaminants in the lower contaminated zone, the cover depth is 30.6 m (100.4 ft) and the contaminated zone thickness is 69.82 m (229.07 ft). As previously discussed, tritium detections in the deep contaminated zone extend to the water table; however, the RESRAD model requires an unsaturated zone beneath the contaminated zone. To minimize the impacts of this requirement, a very thin (0.01 m) unsaturated layer was included in the model (Figure C5-1). The contaminated zone in this case consists of five hydrogeologic units. As discussed above, the parameters of the contaminated zone are calculated as weighted averages of the corresponding parameters of the five units. The hydrogeologic parameters for the lower contaminated zone RESRAD model run are summarized in Table C5-11.

Table C5-11. Hydrogeologic Parameters of the 216-A-5 Crib Lower Contaminated Zone RESRAD Model Run

Modeling Layer	Thicknes s (m)	Bulk Density (g/cm3)	Total Porosity	Effective Porosity	Field Capacity	Hydraulic Conductivity (m/yr)	Soil Parameter *b*
Cover	30.6	--	-	-	-	-	-
Contaminated Zone	69.82	1.71	0.326	0.326	0.067	109	4.35
UZ Layer 1	0.01	1.93	0.167	0.167	0.062	104	4.05
Saturated Zone	--	1.93	0.167	0.167	0.062	104	4.05

UZ = unsaturated zone

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C6 Results of RESRAD Groundwater Impact Analysis

Among the radionuclide COPCs present in the upper contaminated zone, only carbon-14 reaches the groundwater table during the 1,000 year period of interest. Carbon-14 has the shortest time of travel through the unsaturated zone because it does not sorb (K_d = 0 cm^3/g), reaching the groundwater in 560 years. The maximum carbon-14 concentration in groundwater is 2,240 pCi/L at 638 years in the future (Figure C6-1). The peak carbon-14 concentration slightly exceeds the MCL of 2,000 pCi/L but occurs as a sharp spike that diminishes to less than 2,000 pCi/L within 50 years of the peak concentration. At 1,000 years in the future, the carbon-14 concentration in groundwater has fallen to less than 100 pCi/L.

Strontium-90 is the only radionuclide present in the middle contaminated zone. Strontium-90 is moderately immobile in the environment (K_d = 22 cm^3/g) and travels slowly through the unsaturated zone. Analysis results indicate that strontium -90 will not reach groundwater during the 1,000-year period of interest. The RESRAD calculated time of travel to the groundwater table is 134,000 years.

Tritium is the only radionuclide present in the deep contaminated zone. Tritium is non-sorbing (K_d=0 cm^3/g) and reaches the groundwater during the first year of the simulation. The maximum groundwater concentration is 14,422 pCi/L at 18 years in the future (Figure C6-2). The peak tritium concentration is below the MCL of 20,000 pCi/L and quickly diminishes by radioactive decay.

These results are calculated for an unrestricted land-use assumption in which the site receives irrigation water (irrigation rate = 0.76 m/yr) in addition to water that infiltrates through precipitation. For a restricted land-use assumption in which there is no irrigation at the site (irrigation rate = 0 m/yr), groundwater impacts are reduced compared to the unrestricted land-use case. Carbon-14 reaches the groundwater table from the upper contaminated zone in 2,575 years with the maximum groundwater concentration of 1,868 pCi/L arriving 2,984 years in the future. Tritium still reaches the groundwater table from the lower contaminated zone in the first year of the simulation but the maximum groundwater concentration is 3,157 pCi/L at 18 years in the future.

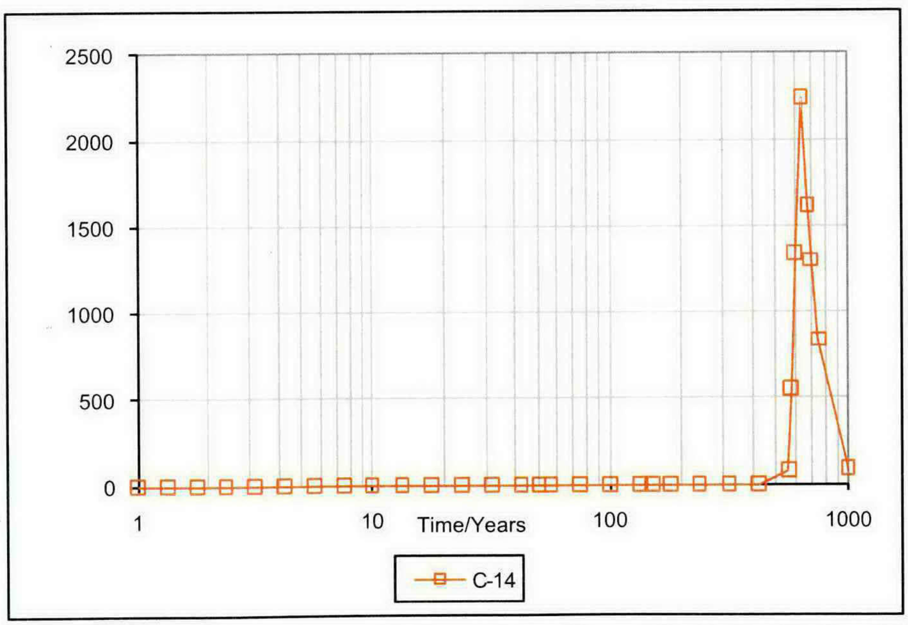

Figure C6-1. 216-A-5 Crib RESRAD Groundwater Impact Analysis – Carbon-14 Concentration in Groundwater over Time

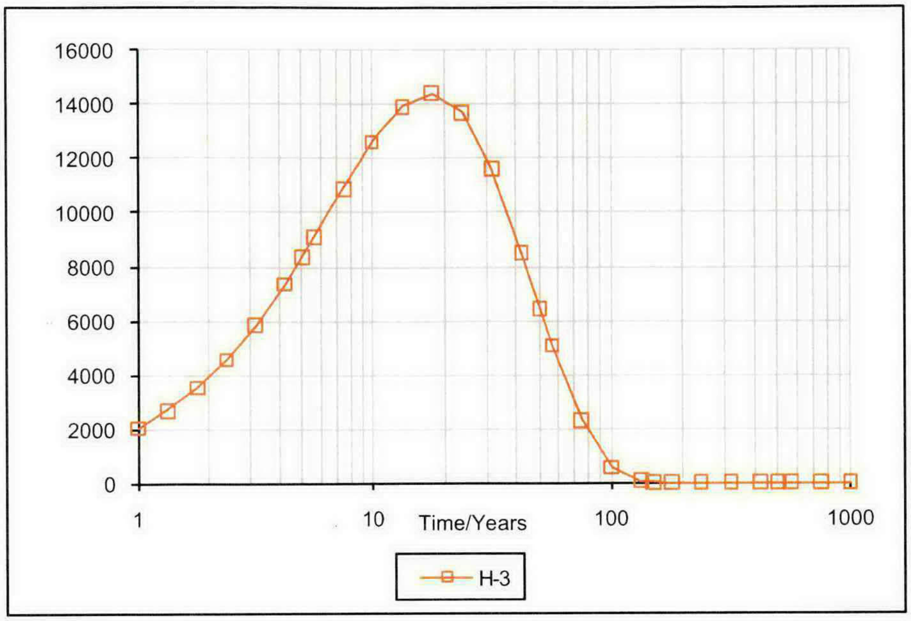

Figure C6-2. 216-A-5 Crib RESRAD Groundwater Impact Analysis – Tritium Concentration in Groundwater over Time

C7 References

10 CFR 40, "Nuclear Regulatory Commission," *Code of Federal Regulations* [26 FR 284, dated January 14, 1961, as amended; 35 FR 11460, July 17, 1970; 48 FR 32328, July 15, 1983]; Appendix A to Part 40, "Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content."

40 CFR 141, "National Primary Drinking Water Regulations," Title 40, *Code of Federal Regulations*, Part 141. *Code of Federal Regulations*. Available at: http://www.access.gpo.gov/nara/cfr/waisidx_09/40cfr141_09.html.

40 CFR 192.02(c)(4), "Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings," Subpart A – "Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites," *Code of Federal Regulations* [60 FR 2865, dated January 11, 1995].

40 CFR 192.32(a)(2)(iv), "Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings," Subpart D – "Standards for Management of Uranium Byproduct Materials Pursuant to Section 84 of the Atomic Energy Act of 1954, as amended," *Code of Federal Regulations* [48 FR 45946, dated October 7, 1983, as amended at 58 FR 60355–60356, dated November 15, 1993].

40 CFR 264.95, "Protection of the Environment, Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," Subpart F- "Releases from Solid Waste Management Units, Point of Compliance," *Code of Federal Regulations*.

40 CFR 270.14(c)(3)(7); "Protection of the Environment," Part 270 – "EPA Administered Permit Program," Subpart B – "Permit Application, General Requirements; Additional Information Requirements," *Code of Federal Regulations*.

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Appendix D

Human Health Risk Assessment

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D1 Human Health Risk Assessment (216-A-2 Crib)

This appendix describes the human health risk assessment performed for the radiological contaminants of potential concern (COPCs) identified at the 216-A-2 Crib. The 216-A-2 Crib waste site assessment includes the following direct contact exposure scenarios:

- Hypothetical Rural Resident Exposure Scenario
- Industrial Worker Scenario

To provide a consistent basis for determining whether remedial action is necessary at core zone waste sites, the U.S. Department of Energy (DOE) has begun including a hypothetical rural resident exposure scenario in baseline risk assessments (BRAs) for these sites which represents the true baseline risk to evaluate the "no action" alternative, essentially leaving the site available for completely unrestricted use. Inclusion of a hypothetical rural resident exposure scenario in a BRA is consistent with *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), U.S. Environmental Protection Agency (EPA), and DOE guidance provided in EH-231-014/1292, *Use of Institutional Controls in a CERCLA Baseline Risk Assessment*, and is intended to provide a conservative yet defensible estimate of the reasonable maximum exposure (RME), or true baseline risk, associated with a waste site in the absence of any remedial action or control (institutional or otherwise).

In estimating a baseline RME, the only pre-existing controls or actions that can be considered are those actions that have already been taken to reduce or eliminate contaminants as opposed to controlling or precluding exposure (EH-231-014/1292). No credit is taken for actions that simply control access to a site or limit exposure to existing contamination in developing the hypothetical rural resident exposure scenario. Therefore, although the existing institutional controls at the 216-A-2 Crib limit current and future exposures, they do not reduce or eliminate contaminants from the site and are not considered in the exposure assessment for this analysis.

The hypothetical rural resident exposure scenario is evaluated based on exposure to a hypothetical rural resident assuming unrestricted use. This scenario does not represent one of the future land uses envisioned for the Central Plateau and generally is not the basis for developing final remediation goals. Use of this scenario is only intended to define the true baseline to evaluate the no action alternative within the feasibility study (FS). The results of this analysis can be used as a basis for taking remedial action and it can be used in evaluation of remedial alternatives to identify areas where institutional controls or other remedial actions may need to be implemented.

The industrial worker scenario is used for the BRA to represent potential exposure under reasonably anticipated current and future land use. Industrial land use within the core zone is considered more consistent with future land use plans than the hypothetical rural resident exposure scenario. The application of an industrial land use assumption allows for the use of institutional controls such as deed restrictions. As a result, this limits the number of complete exposure pathways and reduces exposure frequency and duration as compared to unrestricted use. It should be noted that the industrial worker scenario is also the basis for developing preliminary remediation goals (PRGs).

D1.1 Exposure Scenario Description

Hypothetical Rural Resident Exposure Scenario. This scenario represents an individual exposed to radiological contaminants from direct contact with soil and through the food chain pathway. The fundamental assumption associated with this exposure scenario is that a receptor unknowingly establishes a residence on or near the waste site and installs a nearby well that is used for drinking water and irrigation purposes. The mass of contamination at the 216-A-2 Crib resides at depths greater than

4.6 meters (m) (15 feet [ft]) below ground surface (bgs), which precludes the direct contact exposure pathway in its current configuration. Therefore, it is assumed that drill cuttings from the well are brought to the surface, creating the mechanism for which exposure to contamination can occur. It is assumed that the contamination exhumed during well drilling has been incorporated into the surface soil over an area of 100 square meters (m^2) (1,076 square feet [ft^2]) to a depth of 0.15 m (0.5 ft).

Exposure estimates are based on an exposure frequency of 350 days/yr over a 30-year exposure duration. The direct contact pathway includes exposure through external radiation, incidental soil ingestion, and inhalation of dust particulates. An external gamma-shielding factor of 0.4, an incidental soil ingestion rate of 100 mg/day, and an inhalation rate of 20 cubic meters (m^3)/day (706 cubic feet [ft^3]/day) are assumed.

The food chain pathway includes exposure from ingestion of fruits and vegetables grown in a backyard garden and consumption of meat and milk from livestock that graze on and are penned on a rural pasture. Consumption rates of 2.7 kilograms per year (kg/yr) (5.9 pounds [lb]/yr) of leafy vegetables; 110 kg/yr (243 lb/yr) of fruits, vegetables, and grains; 100 liters per year (L/yr) (26 gallons [gal]/yr) of milk; and 36 kg/yr (79 lb/yr) of meat and poultry are assumed. The exposure assumptions and RESidual RADioactivity (RESRAD) modeling input parameters used for the analysis are provided in Table D2-1. The table lists the value used for each parameter, the rationale for its use, and a reference to the source for the value.

Industrial Worker Scenario. This scenario represents an individual exposed to radiological contaminants from direct contact with soil. The fundamental assumption associated with this exposure scenario is that exposure to the receptor occurs while the waste site is in its current configuration and with institutional controls in place. As described in the hypothetical rural resident exposure scenario, the mass of contamination at the 216-A-2 Crib is below the direct contact point of compliance of 4.6 m (15 ft) bgs.

Exposure estimates are based on an exposure frequency of 250 days/yr over a 25-year exposure duration. The direct contact pathway includes exposure through external radiation, incidental soil ingestion, and inhalation of dust particulates. An external gamma-shielding factor of 0.4, an incidental soil ingestion rate of 50 mg/day, and an inhalation rate of 20 m^3/day (706 ft^3/day) are assumed. The exposure assumptions and RESRAD modeling input parameters used for the analysis are provided in Table D2-2. The table lists the value used for each parameter, the rationale for its use, and a reference to the source for the value.

Time dependent total radioactive excess lifetime cancer risk (ELCR) was calculated for each exposure scenario using the RESidual RADioactivity dose model (*RESRAD*, Version 6.4 [ANL 2007]). The model was implemented following guidance given in ANL/EAD-4, *User's Manual for RESRAD Version 6*. The RESRAD code was developed by Argonne National Laboratory to implement DOE guidelines for allowable residual radioactive material in soil (DOE Order 5400.5, *Radiation Protection of the Public and the Environment*).

D2 RESRAD Analysis

A set of RESRAD input parameters was developed for each exposure scenario. The input parameters corresponding to each exposure scenario are summarized in Table D2-1 for the hypothetical rural resident exposure scenario and Table D2-2 for the industrial worker scenario. These tables list the value used for each input parameter, rationale for use of this value, and reference to the source for the value. Supporting information not provided in these tables, such as certain values associated with the unsaturated zone strata hydrogeologic units and the contaminant-specific exposure point concentrations (EPCs) and distribution coefficients (K_ds), are presented in Table D2-3 through Table D2-5. Graphic representations showing the geologic strata and layers identified for use in the RESRAD model calculations, and a conceptual site model for the industrial worker and hypothetical rural resident exposure scenario are presented in Figure D2-1 and Figure D2-2, respectively.

Certain parameters, such as the contaminated area, identified in Table D2-1 and Table D2-2 vary by exposure scenario. Derivation of the values used for the industrial worker and hypothetical rural resident exposure scenarios is discussed in the subsections below. The parameters defined in Table D2-1 and Table D2-2 and radionuclide-specific information presented in the following sections were used to set up the RESRAD input files. A simulation time of 1,000 years was used in all the RESRAD runs. The maximum ELCR over the 1,000-year period was calculated for each exposure scenario. For comparative purposes, ELCR estimates are discussed relative to the following exposure times:

- 0 year represents current waste site conditions.
- 50 years is the estimated time that DOE will have an onsite presence.
- 150 years is the estimated time that institutional controls are assumed to be effective.
- 500 years is the estimated time that passive institutional controls are assumed to be effective.
- 1,000 years is the estimated time frame that peak radiation dose and risk estimates should fall within.
- The year in which the ELCR regulatory threshold of 10^{-4} is achieved.

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Table D2-1. 216-A-2 Crib Summary of RESRAD Input Parameters for the Hypothetical Rural Residential Exposure Scenario

Description	Parameter	Units	Unrestricted Land Use Scenario	Rationale and Citation
Exposure Pathways	External gamma: Inhalation: Plant ingestion: Meat ingestion: Milk ingestion: Aquatic foods: Drinking water: Soil ingestion: Radon:	Not applicable.	Active Active Active Active Active Suppressed Active Active Suppressed	Assumes a rural resident uses land contaminated by drill cuttings that have been incorporated into the surface soil.
R011 – Contaminated Zone (CZ)	Area of CZ	m^2 (ft^2)	100	Area is consistent with current Hanford Site performance assessments (HNF-SD-WM-TI-707; ORNL/TM-13401). See Figure D2-2.
	Thickness of CZ (baseline)	m (ft^2)	0.15	Assumes contamination has been incorporated into the top 0.15 m (6 in.) of soil.
	Length parallel to aquifer flow	m (ft^2)	10^2	Assumes CZ is a square oriented perpendicular to aquifer flow.
	Radiation dose limit	mrem/year	15	40 CFR 141; EPA 540/R/99/006.
	Elapsed time since waste placement	year	0	RESRAD default.
Exposure Point Concentrations	EPCs	pCi/g	Chemical-specific	See Table D2-5.
R013 – Cover and CZ Hydrological Data	Cover depth	m	0	Assumes contamination is exposed at the ground surface
	Cover material density	g/cm^3	Not applicable.	Not applicable.
	Cover erosion rate	m/yr	Not applicable.	Not applicable.
	Density of CZ	g/cm^3	1.68	Assumed equivalent to sand dominated Hanford formation, coarse sand unit (Hcs). Bulk density of this unit was calculated as an average of four measurements available for borehole C5301.
	CZ erosion rate	m/yr	0.00001	Value selected prevents appreciable erosion of the contaminated zone during the simulation period.
	CZ total porosity	unitless	0.349	Assumed equivalent to Hcs in Table 4.5 in PNNL-14702.
	CZ field capacity	unitless	0.041	CZ field capacity calculated for the Hcs using parameters from Table 4.5 in PNNL-14702.
	CZ hydraulic conductivity	m/yr	716	Assumed equivalent to Hanford Hcs in Table 4.5 in PNNL-14702.
	CZ b parameter	unitless	4.05	Determined from soil textures listed in ANL/EAD-4, Table E.2. This hydrogeologic unit has little of the finer material (silt and clay) listed in Table E.2. Hence, the "b" parameter is assigned the value of 4.05 for sand.
	Humidity in air	g/cm^3	Not applicable.	Not applicable. .
	Evapotranspiration coefficient	unitless	0.977	Value assigned results in an annual infiltration rate of 0.4 cm/yr.
	Wind speed	m/s	3.4	Value obtained from Table 5.1 in PNNL-15160.
	Precipitation	m/yr	0.177	Value obtained from Table 4.1 in PNNL-15160.
	Irrigation rate	m/yr	0.76	Based on Table B-1 in DOE/RL-96-17.

Table D2-1. 216-A-2 Crib Summary of RESRAD Input Parameters for the Hypothetical Rural Residential Exposure Scenario

Description	Parameter	Units	Unrestricted Land Use Scenario	Rationale and Citation
	Irrigation mode	Not applicable.	Overhead	RESRAD default.
	Run-off coefficient	Unitless	0	Run-off coefficient of 0 indicates all precipitation soaks into the ground.
	Watershed area for nearby stream or pond	m^2	1.00E+06	RESRAD default.
	Accuracy for water/soil computations	unitless	0.001	RESRAD default.
R014 – Saturated Zone (SZ) hydrological data	Density of SZ	g/cm^3	1.93	Hanford gravel unit (Hg) in Table 4.5 of PNNL-14702.
	SZ total porosity	unitless	0.167	Hg in Table 4.5 of PNNL-14702.
	SZ effective porosity	unitless	0.167	Hg in Table 4.5 of PNNL-14702.
	SZ field capacity	unitless	0.062	Saturated zone field capacity calculated for the Hg using parameters from PNNL-14702, Table 4.5.
	SZ hydraulic conductivity	m/yr	104	Hg in Table 4.5 of PNNL-14702.
	SZ hydraulic gradient	unitless	2.00E-05	Value obtained from Table H2-2 in DOE/RL-2008-01.
	SZ b parameter	unitless	4.05	Determined from soil textures listed in ANL/EAD-4, Table E.2. This hydrogeologic unit has little of the finer material (silt and clay) listed in Table E.2. Hence, the "b" parameter is assigned the value of 4.05 for sand.
	Water table drop rate	m/yr	0.0001	Value selected results in little change in the depth of the groundwater during the time simulation period.
	Well pump intake depth below water table	M	10	Located mid-aquifer for 22.9 m (75 ft) thick aquifer.
	Nondispersion (ND) or mass-balance	Not applicable.	ND	RESRAD default.
	Well pumping rate	m^3/yr	250	RESRAD default.
R015 –Uncontaminated and Unsaturated Strata Hydrological Data	Number of unsaturated strata	Not applicable.	5	Sediment stratigraphy based on borehole data from borehole C5515 drilled through the 216-A-2 Crib.
	Thickness	m	19.36, 64.3, 2.44, 5.8, 4.0	Hcs, Hanford fine sand unit (Hfs), Hg, Hanford formation silt (PPlz).
	Soil density	g/cm^3	1.67, 1.60, 1.93, 1.68, 1.93	Values from each unit were obtained from PNNL-14702, Table 4.5.
	Total porosity	unitless	0.349, 0.379, 0.167, 0.419, 0.167	Values from each unit were obtained from PNNL-14702, Table 4.5.
	Effective porosity	unitless	0.349, 0.379, 0.167, 0.419, 0.167	Values from each unit were obtained from PNNL-14702, Table 4.5.
	Field capacity	unitless	0.041, 0.058, 0.062, 0.210, 0.062	Field capacity calculated using parameters obtained from PNNL-14702, Table 4.5. See Table D-3.
	Soil-specific *b* parameter	unitless	4.05, 4.05, 4.05, 10.4, 4.05	Determined from soil textures listed in ANL/EAD-4, Table E.2. Except for Pplz, each of the hydrogeologic units has little of the finer material (silt and clay) listed in Table E.2. Hence, the "b" parameters are all near 4.05 for sand. The soil class Hg was assigned the silty clay value of 10.4.
	Hydraulic conductivity	m/yr	716, 118, 104, 17.6, 104	Values from each unit were obtained from Table 4.5 in PNNL-14702.
R016 – Distribution Coefficients and Leach Rates for Individual Radionuclides	Distribution coefficients (K_d) for contaminated zone, uncontaminated zone and saturated zone	cm^3/g	Chemical-specific	Best estimate values obtained from Table 4.11 of PNNL-14702. K_d values for Co-60 and Am-241 were obtained from the "no impact" category from Table A.1 in PNNL-17154.
	Saturated leach rate	yr^{-1}	0	RESRAD default.

Table D2-1. 216-A-2 Crib Summary of RESRAD Input Parameters for the Hypothetical Rural Residential Exposure Scenario

Description	Parameter	Units	Unrestricted Land Use Scenario	Rationale and Citation
	Saturated solubility	mol/L	0	RESRAD default.
R017 – Inhalation and External Gamma	Inhalation rate	m^3/yr	7,300	Assumes an inhalation rate of 20 m^3/day (365 d/yr) (EPA/600/P-95/002Fa).
	Mass loading for inhalation	g/m^3	0.0001	WDOH/320-015.
	Exposure duration	year	30	EPA, 1991 (OSWER Directive 9285.6-03).
	Indoor dust filtration factor	unitless	0.4	RESRAD default.
	External gamma shielding factor	unitless	0.4	EPA/540/R-00/007 (Equation 4).
	Indoor time fraction	unitless	0.6	Assumes that 15 hr/d spent indoors, 350 d/yr (5,250 hours divided by 8,760 hours).
	Outdoor time fraction	unitless	0.12	Assumes 3 h/d is spent outdoors, 350 d/yr (1,050 hours divided by 8,760 hours).
	Shape factor	Not applicable.	Circular	RESRAD default.
R018 – Ingestion Pathway Data, Dietary Parameters	Soil ingestion intake	g/yr	35	Based on 100 mg/d (350 d/yr).
	Drinking water intake	L/yr	700	Based on 2 L/d (350 d/yr) (EPA/600/P-95/002Fa).
	Leafy vegetable consumption	kg/yr	2.7	WDOH/320-015 (Appendix B).
	Fruits, vegetables, and grain consumption	kg/yr	110	WDOH/320-015 (Appendix B).
	Milk consumption	L/yr	100	WDOH/320-015 (Appendix B).
	Meat and poultry consumption	kg/yr	36	WDOH/320-015 (Appendix B).
	Fish consumption	kg/yr	Not applicable.	The consumption of fish is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Other seafood consumption	kg/yr	Not applicable.	The consumption of seafood is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Drinking water contamination fraction	unitless	1	RESRAD default.
	Household water contamination fraction	unitless	1	RESRAD default.
	Livestock water contamination fraction	unitless	1	RESRAD default.
	Irrigation water contamination fraction	unitless	1	RESRAD default.
	Aquatic food contamination fraction	unitless	Not applicable.	Not applicable.
	Plant food contamination fraction	unitless	-1	RESRAD default.
	Meat contamination fraction	unitless	-1	RESRAD default.
	Milk contamination fraction	unitless	-1	RESRAD default.
R019 – Ingestion Pathway Data, Nondietary	Livestock fodder intake for meat	kg/d	68	RESRAD default.
	Livestock fodder intake for milk	kg/d	55	RESRAD default.
	Livestock water intake for meat	L/d	50	RESRAD default.
	Livestock water intake for milk	L/d	160	RESRAD default.

Table D2-1. 216-A-2 Crib Summary of RESRAD Input Parameters for the Hypothetical Rural Residential Exposure Scenario

Description	Parameter	Units	Unrestricted Land Use Scenario	Rationale and Citation
	Livestock intake of soil	kg/d	0.5	RESRAD default.
	Mass loading for foliar deposition	g/m^3	0.0001	RESRAD default.
	Depth of soil mixing layer	m	0.15	RESRAD default.
	Depth of roots	m	0.9	RESRAD default.
Plant Factors	Wet weight crop yield, non-leafy	kg/m^2	0.7	RESRAD default.
	Wet weight crop yield, leafy	kg/m^2	1.5	RESRAD default.
	Wet weight crop yield, fodder	kg/m^2	1.1	RESRAD default.
	Length of growing season, non-leafy	yr	0.17	RESRAD default.
	Length of growing season, leafy	yr	0.25	RESRAD default.
	Length of growing season, fodder	yr	0.08	RESRAD default.
	Translocation factor, non-leafy	unitless	0.1	RESRAD default.
	Translocation factor, leafy	unitless	1	RESRAD default.
	Translocation factor, fodder	unitless	1	RESRAD default.
	Weathering removal constant	yr^{-1}	20	RESRAD default.
	Wet foliar interception factor, non-leafy	unitless	0.25	RESRAD default.
	Wet foliar interception factor, leafy	unitless	0.25	RESRAD default.
	Wet foliar interception factor, fodder	unitless	0.25	RESRAD default.
	Dry foliar interception factor, non-leafy	unitless	0.25	RESRAD default.
	Dry foliar interception factor, leafy	unitless	0.25	RESRAD default.
	Dry foliar interception factor, fodder	unitless	0.25	RESRAD default.
R020 – Groundwater Usage	Groundwater fractional usage – drinking water	unitless	1	RESRAD default.
	Groundwater Fractional usage – household usage	unitless	1	RESRAD default.
	Groundwater Fractional usage – livestock water	unitless	1	RESRAD default.
	Groundwater usage –irrigation	unitless	1	RESRAD default.
R021 – Radon	Not used	Not applicable.	Not applicable.	Not applicable.
Storage Times	Fruit, non-leafy vegetables, and grain	day	14	RESRAD default.
	Leafy vegetables	day	1	RESRAD default.
	Milk	day	1	RESRAD default.
	Meat	day	20	RESRAD default.
	Fish	day	Not applicable.	RESRAD default.
	Crustacea and mollusks	day	Not applicable.	RESRAD default.
	Well water	day	1	RESRAD default.

Table D2-1. 216-A-2 Crib Summary of RESRAD Input Parameters for the Hypothetical Rural Residential Exposure Scenario

Description	Parameter	Units	Unrestricted Land Use Scenario	Rationale and Citation
	Surface water	day	1	RESRAD default.
	Livestock fodder	day	45	RESRAD default.
C-14	Not used	Not applicable.	Not applicable.	Not applicable.

Notes:

40 CFR Part 141, "National Primary Drinking Water Regulations."

ANL, 2007, *RESRAD*, Version 6.4.

DOE M 435.1-1, *Radioactive Waste Management Manual.*

DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area.*

DOE/RL-2007-35, *Hanford Facility Dangerous Waste Permit Application: Encapsulation and Storage Facility.*

DOE/RL-2008-01, *Hanford Site Groundwater Monitoring for Fiscal Year 2007.*

EPA, 1991, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final*, OSWER Directive 9285.6-03.

OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites.*

EPA/540/R-00/007, *Soil Screening Guidance for Radionuclides: User's Guide*, OSWER 9355.4-16A.

EPA 540/R/99/006, *Radiation Risk Assessment at CERCLA Sites: Q & A*, OSWER Directive 9200.4-31P.

EPA/600/8-89/043, *Exposure Factors Handbook.*

EPA/600/P-95/002Fa, *Exposure Factors Handbook Volume 1: General Factors.*

HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment.*

ORNL/TM-13401, *Performance Assessment for the Class L-II Disposal Facility.*

PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments.*

PNNL-15160, *Hanford Site Climatological Summary 2004 with Historical Data.*

PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.*

WDOH/320-015, *Hanford Guidance for Radiological Cleanup.*

Table D2-2. 216-A-2 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Industrial Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation
Exposure Pathways	External gamma: Inhalation: Plant ingestion: Meat ingestion: Milk ingestion: Aquatic foods: Drinking water: Soil ingestion: Radon:	Not applicable.	Active Active Suppressed Suppressed Suppressed Suppressed Suppressed Active Suppressed	
R011 – Contaminated Zone (CZ)	Area of CZ	m2 (ft2)	37.21 (400.53)	Area based on Equation 4.3 in PNNL-14702.
	Thickness of CZ (baseline)	m (ft)	4.0 (13)	Direct contact (with cover) using site-specific data from 27 to 40 ft bgs interval.
	Length parallel to aquifer flow	m	Not applicable.	Not applicable. . Water dependent pathways not activated.
	Radiation dose limit (industrial scenario)	mrem/yr	15	40 CFR 141; EPA/540/R/99/006.
	Elapsed time since waste placement	year	0	Environmental samples are decayed to current calendar year.
Exposure Point Concentrations	EPCs	pCi/g	Chemical-specific	Maximum concentrations measured in borehole C5515. See Table D2-4.
R013-Cover and CZ Hydrological Data	Cover depth	m (ft)	8.23 (27)	See Figure D2-1.
	Cover material density	g/cm3	1.94	Backfill sand unit (Bf) in Table 4.5 in PNNL-14702.
	Cover erosion rate	m/yr	0.00001	Value selected prevents appreciable erosion of the cover currently present over the waste site during the simulation period.
	Density of CZ	g/cm3	1.68	Sand dominated Hanford formation, coarse sand unit (Hcs). Bulk density of this unit was calculated as an average of four measurements available for borehole C5301.
	CZ erosion rate	m/yr	0.00001	Value selected prevents appreciable erosion of the contaminated zone when the cover depth is assumed equal to 0.
	CZ total porosity	unitless	0.349	Hcs Unit in Table 4.5 in PNNL-14702.
	CZ field capacity	unitless	0.041	CZ field capacity calculated for the Hcs using parameters from PNNL-14702, Table 4.5.
	CZ hydraulic conductivity	m/yr	716	Hcs in Table 4.5 in PNNL-14702.
	CZ b parameter	unitless	4.05	Determined from soil textures listed in ANL/EAD-4, Table E.2. This hydrogeologic unit has little of the finer material (silt and clay) listed in Table E.2. Hence, the "b" parameter is assigned the value of 4.05 for sand.
	Humidity in air	g/cm3	Not applicable.	Not applicable.
	Evapotranspiration coefficient	unitless	0.977	Value assigned results in an annual recharge rate of 0.4 cm/yr.
	Wind speed	m/s	3.4	Value obtained from Table 5.1 in PNNL-15160.
	Precipitation	m/yr	0.177	Value obtained from Table 4.1 in PNNL-15160.
	Irrigation rate	m/yr	0	Based on Table B-1 in DOE/RL-96-17.
	Irrigation mode	Not applicable.	Overhead	RESRAD default.

Table D2-2. 216-A-2 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Industrial Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation
	Run-off coefficient	unitless	0	Run-off coefficient of 0 indicates all precipitation soaks into the ground.
	Watershed area for nearby stream or pond	m2	Not applicable.	Not applicable.
	Accuracy for water/soil computations	unitless	Not applicable.	Not applicable.
R014 – Saturated Zone (SZ) hydrological data	Density of SZ	g/cm3	Not applicable.	Not applicable.
	SZ total porosity	unitless	Not applicable.	Not applicable.
	SZ effective porosity	unitless	Not applicable.	Not applicable.
	SZ field capacity	unitless	Not applicable.	Not applicable.
	SZ hydraulic conductivity	m/yr	Not applicable.	Not applicable.
	SZ hydraulic gradient	unitless	Not applicable.	Not applicable.
	SZ b parameter	unitless	Not applicable.	Not applicable.
	Water table drop rate	m/yr	Not applicable.	Not applicable.
	Well pump intake depth below water table	m	Not applicable.	Not applicable.
	Nondispersion or mass-balance	Not applicable.	Not applicable.	Not applicable.
	Well pumping rate	m3/yr	Not applicable.	Not applicable.
R015 – Uncontaminated and Unsaturated Strata Hydrological Data	Number of unsaturated strata	Not applicable.	Not applicable.	Not applicable.
	Thickness	m	Not applicable.	Not applicable.
	Soil density	g/cm3	Not applicable.	Not applicable.
	Total porosity	unitless	Not applicable.	Not applicable.
	Effective porosity	unitless	Not applicable.	Not applicable.
	Field capacity	unitless	Not applicable.	Not applicable.
	Soil-specific parameter	unitless	Not applicable.	Not applicable.
	Hydraulic conductivity	m/yr	Not applicable.	Not applicable.
R016 – Distribution Coefficients and Leach Rates for Individual Radionuclides	Distribution coefficients (K_d) for contaminated zone, uncontaminated zone and saturated zone	cm3/g	Contaminant-specific	Best estimate values obtained from Table 4.11 of PNNL-14702. Kd values for Co-60 and Am-241 were obtained from the "no impact" category from Table A.1 in PNNL-17154.
	Saturated leach rate	yr-1	0	RESRAD default.
	Solubility limit	mol/L	0	RESRAD default.
R017 – Inhalation and External Gamma	Inhalation rate	m3/yr	7,300	Assumes an inhalation rate of 20 m3/d for 365 d/yr (EPA/600/P-95/002Fa).
	Mass loading for inhalation	g/m3	0.0001	WDOH/320-015.
	Exposure duration	year	25	EPA, 1991 (OSWER Directive 9285.6-03).
	Indoor dust filtration factor	unitless	0.4	RESRAD default.
	External gamma shielding factor	unitless	0.4	EPA/540/R-00/007 (Equation 4)

Table D2-2. 216-A-2 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Industrial Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation
	Indoor time fraction	unitless	0.171	Assumes that 6 h/d spent indoors, 250 d/yr (1,500 hours divided by 8,760 hours).
	Outdoor time fraction	unitless	0.057	Assumes that 2 h/d spent outdoors, 250 d/yr (500 hours divided by 8,760 hours).
	Shape factor	Not applicable.	Circular	RESRAD default.
R018 – Ingestion Pathway Data, Dietary Parameters	Soil ingestion intake	g/yr	12.5	Based on 50 mg/d (250 d/yr)
	Drinking water intake	L/yr	Not applicable.	Drinking water ingestion is an incomplete exposure pathway for the industrial worker exposure scenario.
	Leafy vegetable consumption	kg/yr	Not applicable.	The food consumption pathway is considered incomplete for this exposure scenario.
	Fruits, vegetables, and grain consumption	kg/yr	Not applicable.	The food consumption pathway is considered incomplete for this exposure scenario.
	Milk consumption	L/yr	Not applicable.	The food consumption pathway is considered incomplete for this exposure scenario.
	Meat and poultry consumption	kg/yr	Not applicable.	The food consumption pathway is considered incomplete for this exposure scenario.
	Fish consumption	kg/yr	Not applicable.	The consumption of fish is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Other seafood consumption	kg/yr	Not applicable.	The consumption of seafood is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Drinking water contamination fraction	unitless	Not applicable.	Drinking water ingestion is an incomplete exposure pathway for the industrial worker exposure scenario.
	Household water contamination fraction	unitless	Not applicable.	Not applicable.
	Livestock water contamination fraction	unitless	Not applicable.	Not applicable.
	Irrigation water contamination fraction	unitless	Not applicable.	Not applicable.
	Aquatic food contamination fraction	unitless	Not applicable.	Not applicable.
	Plant food contamination fraction	unitless	Not applicable.	Not applicable.
	Meat contamination fraction	unitless	Not applicable.	Not applicable.
	Milk contamination fraction	unitless	Not applicable.	Not applicable.
R019–Ingestion Pathway Data, Nondietary	Livestock fodder intake for meat	kg/d	Not applicable.	Not applicable.
	Livestock fodder intake for milk	kg/d	Not applicable.	Not applicable.
	Livestock water intake for meat	L/d	Not applicable.	Not applicable.
	Livestock water intake for milk	L/d	Not applicable.	Not applicable.
	Livestock intake of soil	kg/d	Not applicable.	Not applicable.
	Mass loading for foliar deposition	g/m3	Not applicable.	Not applicable.
	Depth of soil mixing layer	m	0.15	RESRAD default.
	Depth of roots	m	Not applicable.	Not applicable.

Table D2-2. 216-A-2 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Industrial Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation
Plant Factors	Wet weight crop yield, non-leafy	kg/m2	Not applicable.	Not applicable.
	Wet weight crop yield, leafy	kg/m2	Not applicable.	Not applicable.
	Wet weight crop yield, fodder	kg/m2	Not applicable.	Not applicable.
	Length of growing season, non-leafy	yr	Not applicable.	Not applicable.
	Length of growing season, leafy	yr	Not applicable.	Not applicable.
	Length of growing season, fodder	yr	Not applicable.	Not applicable.
	Translocation factor, non-leafy	unitless	Not applicable.	Not applicable.
	Translocation factor, leafy	unitless	Not applicable.	Not applicable.
	Translocation factor, fodder	unitless	Not applicable.	Not applicable.
	Weathering removal constant	yr-1	Not applicable.	Not applicable.
	Wet foliar interception factor, non-leafy	unitless	Not applicable.	Not applicable.
	Wet foliar interception factor, leafy	unitless	Not applicable.	Not applicable.
	Wet foliar interception factor, fodder	unitless	Not applicable.	Not applicable.
	Dry foliar interception factor, non-leafy	unitless	Not applicable.	Not applicable.
	Dry foliar interception factor, leafy	unitless	Not applicable.	Not applicable.
	Dry foliar interception factor, fodder	unitless	Not applicable.	Not applicable.
R020 – Groundwater Usage	Groundwater fractional usage – drinking water	unitless	Not applicable.	Not applicable.
	Groundwater fractional usage – household usage	unitless	Not applicable.	Not applicable.
	Groundwater fractional usage – livestock water	unitless	Not applicable.	Not applicable.
	Groundwater usage –irrigation	unitless	Not applicable.	Not applicable.
R021 – Radon	Not used	Not applicable.	Not applicable.	Not applicable.
Storage Times	Fruit, non-leafy vegetables, and grain	day	Not applicable.	Not applicable.
	Leafy vegetables	day	Not applicable.	Not applicable.
	Milk	day	Not applicable.	Not applicable.
	Meat	day	Not applicable.	Not applicable.
	Fish	day	Not applicable.	Not applicable.
	Crustacea and mollusks	day	Not applicable.	Not applicable.
	Well water	day	Not applicable.	Not applicable.
	Surface water	day	Not applicable.	Not applicable.
	Livestock fodder	day	Not applicable.	Not applicable.
C-14	Not used	Not applicable.	Not applicable.	Not applicable.

Table D2-2. 216-A-2 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Industrial Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation

Notes:

40 CFR 141, "National Primary Drinking Water Regulations".

ANL, 2007, *RESRAD*, Version 6.4.

DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area.*

EPA, 1991, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final*, OSWER Directive 9285.6-03.

EPA/540/R/99/006, *Radiation Risk Assessment At CERCLA Sites: Q&A*, OSWER Directive 9200.4-31P.

EPA/540/R-00/007, *Soil Screening Guidance for Radionuclides: User's Guide*, OSWER 9355.4-16A.

EPA/600/P-95/002Fa, *Exposure Factors Handbook Volume 1: General Factors.*

PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments.*

PNNL-15160, *Hanford Site Climatological Summary 2004 with Historical Data.*

PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.*

WDOH/320-015, *Hanford Guidance for Radiological Cleanup.*

bgs = below ground surface

Table D2-3. Unsaturated Zone Strata RESRAD Modeling Input Values for the 216-A-2 Crib (Based on Geologic Data from Borehole C5515)

Geologic Unit Name	Unit Symbol	Top (ft bgs)	Bottom (ft bgs)	Thickness (ft)	Thickness (m)	m [a]	n	S [b]	a	f_f [c]	f_r	f_s
Holocene Deposits/Backfill	Bf	0	27	27	8.23	0.286	1.4	0.466	0.019	0.138	0.03	0.262
Hanford Formation Coarse Sand	Hcs	27	64	37	11.28	0.508	2.031	0.044	0.061	0.041	0.027	0.349
Hanford Formation Fine Sand	Hfs	64	275	211	64.31	0.539	2.168	0.075	0.027	0.058	0.032	0.379
Hanford Formation Sandy Gravel	Hg	275	283	8	2.44	0.420	1.725	0.276	0.017	0.062	0.022	0.167
Hanford Formation Silt	PPlz	283	302	19	5.79	0.555	2.249	0.447	0.005	0.210	0.04	0.419
Hanford Formation Sandy Gravel	Hg	302	315	13	3.96	0.420	1.725	0.276	0.017	0.062	0.022	0.167

Notes:

Values of a, n, f_r, f_s are from PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, Table 4.5.

The parameters selected for the Hanford formation silt interval used the PPlz (from PNNL-14702, Table 4.5) to more closely match the silt content of the Hanford formation silt unit.

a. m = 1-1/n

b. S = $[1+(ah)^n]^{-m}$, h = pressure corresponding to field capacity (-1/3 bar is commonly used)

c. Field Capacity = $S(f_s-f_r)+f_r$

bgs = below ground surface

Table D2-4. 216-A-2 Crib Radionuclide-Specific Exposure Point Concentrations and Distribution Coefficients for the Industrial Worker Exposure Scenario

Radionuclide	EPC (pCi/g)	K_d (cm^3/g)
Am-241	94,000	300
Cs-137	31,000	2,000
Co-60	0.382	10
Eu-154	1.28	200
Ni-63	10.6	300
Pu-238	120	600
Pu-239	426,000	600
Sr-90	125,000	22
Tc-99	6.27	0
U-234	49.8	0.8
U-235	4.28	0.8
U-236	1.03	0.8
U-238	56.6	0.8
Ac-227	0	20
Np-237	0	10
Pa-231	0	50
Pb-210	0	100
Ra-226	0	20
Ra-228	0	20
Th-228	0	60,000
Th-229	0	60,000
Th-230	0	60,000
Th-232	0	60,000
U-233	0	0.8

EPC = exposure point concentration

K_d = distribution coefficient

Table D2-5. 216-A-2 Crib Radionuclide-Specific Exposure Point Concentrations and Distribution Coefficients for the Hypothetical Rural Resident Exposure Scenario

Radionuclide	EPC (pCi/g)	Maximum Concentration (pCi/g)	K_d (cm^3/g)
Dilution Factor 1.885x10^{-2} (based on 100 m^2 exposure area)			
Am-241	1.77×10^{3}	94,000	300
Cs-137	5.84×10^{2}	31,000	2,000
Co-60	7.20×10^{-3}	0.382	10
Eu-154	2.41×10^{-2}	1.28	200
Ni-63	2.00×10^{-1}	10.6	300
Pu-238	2.26×10^{0}	120	600
Pu-239	8.03×10^{3}	426,000	600
Sr-90	2.36×10^{3}	125,000	22
Tc	1.18×10^{-1}	6.27	0
U-234	9.39×10^{-1}	49.8	0.8
U-235	8.07×10^{-2}	4.28	0.8
U-236	1.94×10^{-2}	1.03	0.8
U-238	1.07×10^{0}	56.6	0.8
Dilution Factor 9.264x10^{-2} (based on 100 m^2 exposure area)			
H-3	2.65×10^{2}	2,860	0
Daughter Radionuclides			
Ac-227	0	0	20
Np-237	0	0	10
Pa-231	0	0	50
Pb-210	0	0	100
Ra-226	0	0	20
Ra-228	0	0	20
Th-228	0	0	60,000
Th-229	0	0	60,000
Th-230	0	0	60,000
Th-232	0	0	60,000
U-233	0	0	0.8

EPC = exposure point concentration
K_d = distribution coefficient

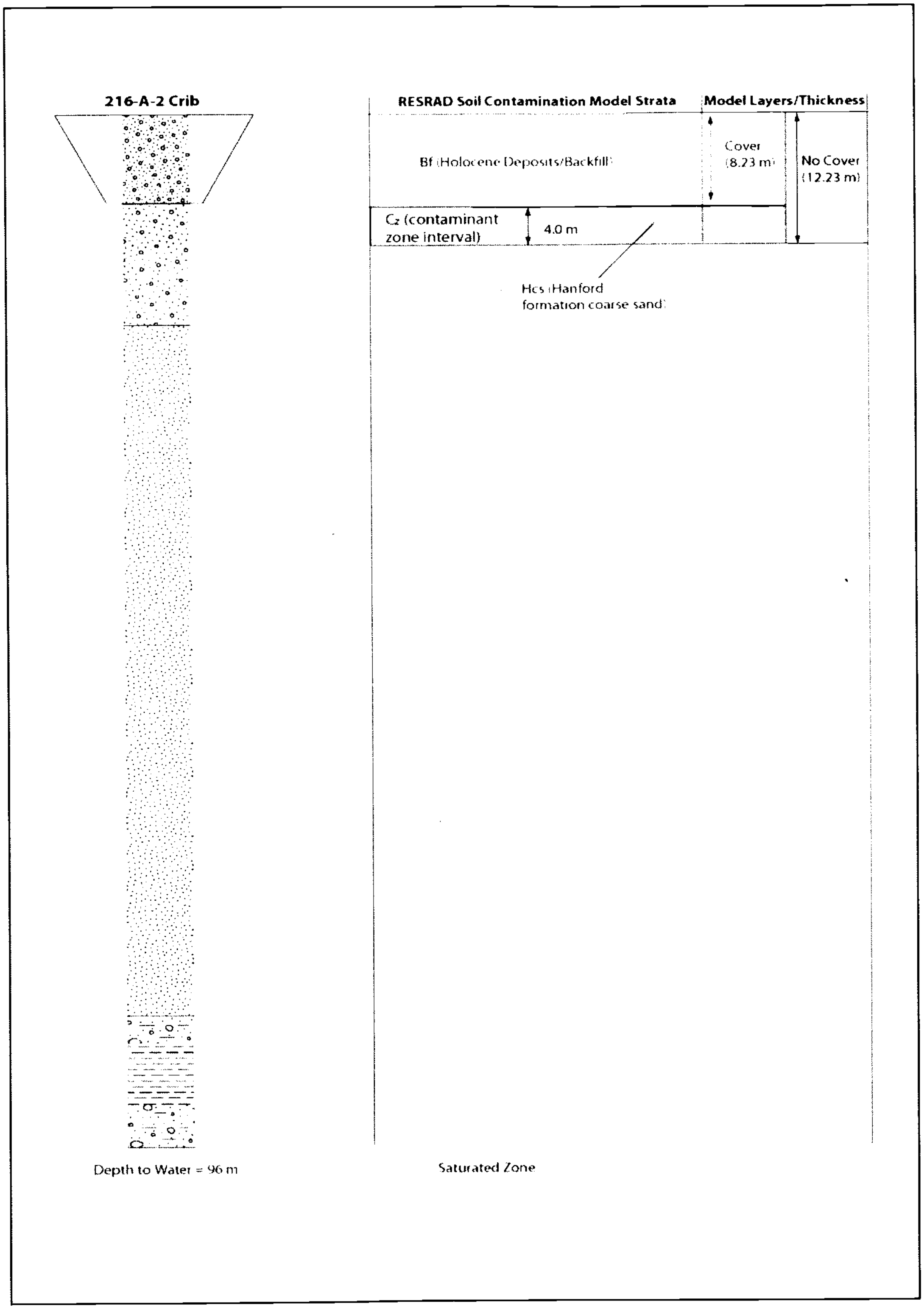


Figure D2-1. Identification of Model Layers Used for the 216-A-2 Crib Industrial Worker Exposure Scenario

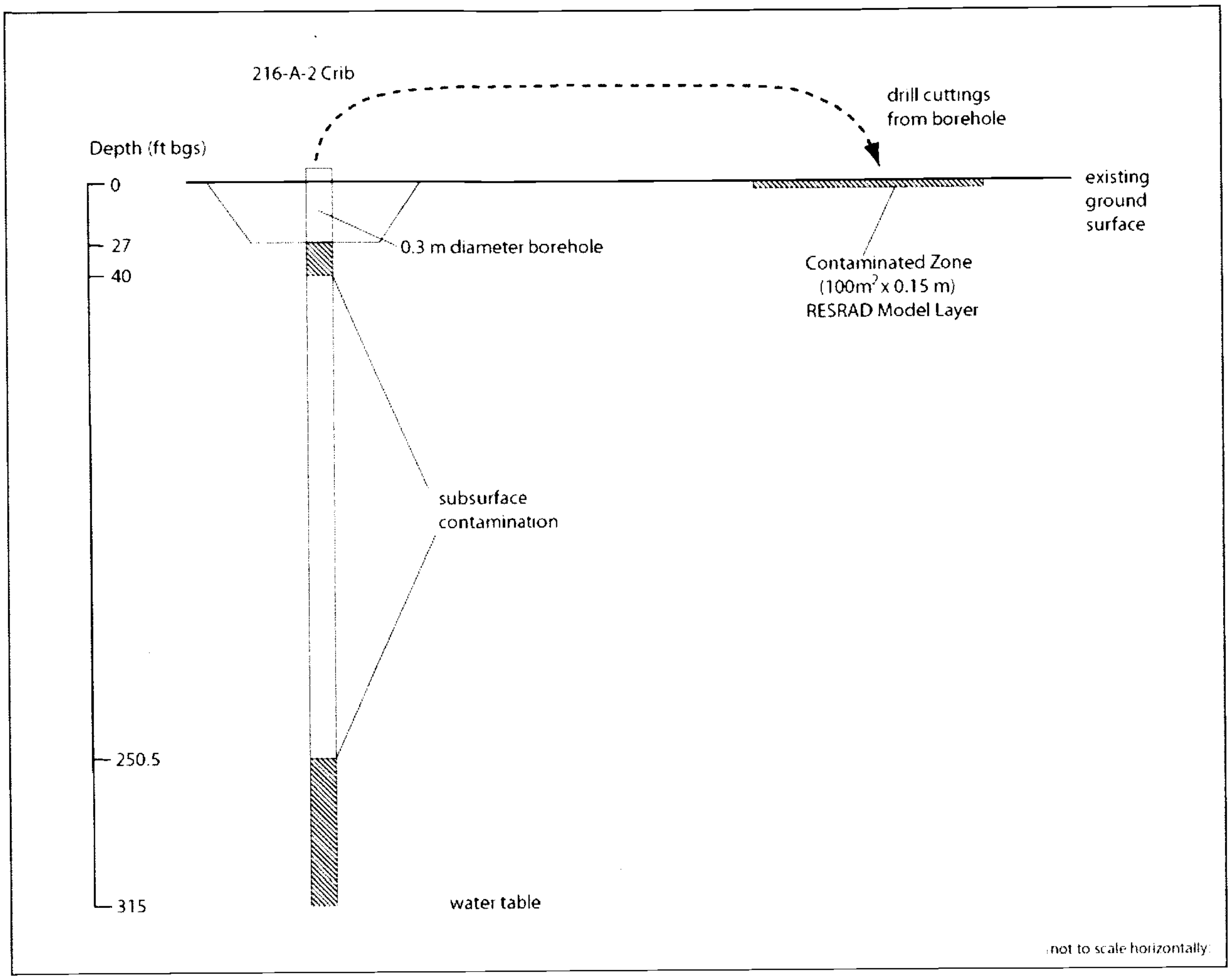


Figure D2-2. Conceptual Site Model for the 216-A-2 Crib Hypothetical Rural Resident Exposure Scenario

D2.1 Industrial Worker Scenario Input Values and Results

This section discusses the derivation of input values for key RESRAD parameters and provides analysis results for the industrial worker scenario.

D2.1.1 Exposure Point Concentrations and Distribution Coefficients

The EPCs for the industrial worker scenario are the maximum concentrations detected in borehole C5515 within the 8.2 to 12 m (27 ft to 40 ft) bgs depth interval. Only radionuclides identified as COPCs in Chapter 4 of this report were evaluated.

In most cases, Pu-239 is the dominant isotope; for RESRAD input, it was assumed that the Pu-239/240 analytical value was entirely Pu-239. Similarly, the commonly accepted assumption is that the dominant isotope represented by the U-233/234 analytical result is U-234. Therefore, it was assumed that the U-233/234 analytical value was entirely U-234. The input values for all the radionuclide EPCs used for the industrial worker scenario are shown in Table D2-4. Those radionuclides in Table D2-4 with zero concentrations represent the daughter products of the parent radionuclides selected for this analysis.

Additional data required for RESRAD input of these radionuclides are the associated K_ds. The radionuclide K_ds are based on the best estimate values obtained from PNNL-14702, *Vadose Zone*

Hydrogeology Data Package for Hanford Assessments, Table 4-11. K_d values for Co-60 and Am-241 were obtained from the "no impact" category from PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*, Table A.1.

D2.1.1 Contaminated Area

The contaminated area shown in the RESRAD input parameters summary for the industrial worker scenario (Table D2-2) is calculated based on the actual site area as recommended in PNNL-14702. The 216-A-2 Crib is 6.1 m (20 ft) wide and 6.1 m (20 ft) long, with an area of 37.21 m^2 (400.53 ft^2). Equation 4.3 in PNNL-14702 was used to calculate the contaminated area (A_x) as follows:

$$A_x = \lambda A_0$$

$$\lambda = \frac{Q_{\max}}{k_{s\,\min} A_0}$$

Where:

A_0	=	actual site area (m^2)
k_{smin}	=	minimum hydraulic conductivity of the unsaturated zone beneath the contaminated zone (m/s)
Q_{max}	=	maximum artificial liquid discharge rate (m^3/s)

This equation is used to adjust the actual site area in cases when the dimensionless parameter λ is greater than 1. In cases when the dimensionless parameter λ is equal to or smaller than 1, no adjustment is needed and the contaminated area is equal to the actual site area.

The parameters in this equation were defined as follows:

- The liquid discharge rate was calculated from the total liquid discharge at the site, which is 230,000 L (60,720 gal) over 4 years of operations based on Table 2-1 in DOE/RL-2001-65, *200-MW-1 Miscellaneous Waste Group Operable Unit RI/FS Work Plan*, which translates to 1.82×10^{-6} m^3/s.
- The minimum hydraulic conductivity is 17.6 m/yr (57.7 ft/yr) (5.58×10^{-7} meters per second [m/s]) (18 ft/s) based on hydraulic conductivities presented in Table D2-2.

The dimensionless parameter λ is then 0.09, which is smaller than 1. Consequently, the site area does not need to be adjusted. The contaminated area used in RESRAD was 37.2 m^2 (400.5 ft^2).

D2.1.2 Contaminated Zone Soil Density

The soil density of the contaminated zone (RESRAD input parameter) was calculated based on the dry bulk density values provided in Appendix A. Four dry bulk density values are 1,740, 1,700, 1,550, and 1,717 kg/m^3 (3,837, 3,749, 3,418. and 3,786 lb/ft^3). The average dry bulk density is 1,680 kg/m^3 (3,704 lb/ft^3) (1.68 g/cm^3) (0.06 ounces per inch [oz/in.]). This is in good agreement with the bulk density of the Hanford formation coarse sand (1.67 g/cm^3) (0.058 oz/in.) in which the contaminated zone is located. The value of 1.68 g/cm^3 (0.06 oz/in.) was used in the RESRAD calculations.

D2.1.3 Evapotranspiration Coefficient

The unitless evapotranspiration coefficient (C_e) is used in RESRAD to calculate the infiltration rate (I) through the unsaturated zone. The infiltration rate cannot be explicitly specified in RESRAD. It is calculated implicitly by RESRAD as (Equation E.4 in ANL/EAD-4):

$$I = (1 - C_e)[(1 - C_r)P_r + I_{rr}]$$

Where:

C_r	=	run-off coefficient (unitless)
P_r	=	precipitation (m/yr)
I_{rr}	=	irrigation rate (m/yr).

The run-off coefficient, precipitation, and irrigation rate are defined in Table D2-2. The evapotranspiration coefficient was calculated as:

$$C_e = 1 - \frac{I}{(1 - C_r)P_r + I_{rr}}$$

The infiltration rate used in this equation was 0.004 m/yr (0.013 ft/yr). This corresponds to the estimated long-term recharge rate (when the site is stabilized and returns to natural conditions) for Hanford sand (PNNL-14702, Table 4.15). The resulting evapotranspiration coefficient is 0.977.

D2.1.4 Analysis Results

Results of the RESRAD analysis indicate that under the current site configuration the 216-A-2 Crib poses no radiological cancer risk for the industrial worker scenario. The calculated ELCR value is zero at the present time (analysis time zero) and is projected to remain at zero over the entire 1,000-year simulation period.

Three exposure routes are evaluated in this scenario: external gamma radiation, incidental soil ingestion, and inhalation of dust particulates. As a result of the shielding effects of the cover material, there is no exposure from the external gamma radiation exposure route. Additionally, there is no exposure from the inhalation and incidental ingestion exposure routes because deposition of contaminants on top of the cover soil has not occurred. The inhalation and incidental ingestion exposure routes would be complete if the contaminated zone were exposed at the surface. The contaminated zone would become exposed at the surface only when the clean cover erodes to a depth greater than 8.23 m (27 ft). The RESRAD model assumed an erosion rate of 1×10^{-5} m/yr. As a result, the contaminated zone will not be exposed to the surface during the 1,000-year simulation period, and therefore is not an exposure risk to an industrial worker.

D2.2 Hypothetical Rural Residential Exposure Scenario Inputs

Analytical data from borehole C5515 soil samples indicate that the uppermost contamination beneath the 216-A-2 Crib occurs within the interval from 8.3 to 12.2 m (27 to 40 ft) bgs. Because the onset of contamination occurs at a depth greater than 4.6 m (15 ft) bgs, the direct contact pathway for soil is incomplete and by definition, no risk exists via this pathway. However, a fundamental assumption associated with having a residence on the Central Plateau is the presence of a nearby well that is used for drinking water and irrigation purposes. For purposes of this scenario, it is assumed that such a well has been drilled to groundwater within the footprint of the 216-A-2 Crib and that the drill cuttings from the well have been disposed of by spreading them over the surface of a nearby land parcel. Well drilling is conservatively assumed to occur with the waste site in its current configuration, prior to any migration of radioactive contamination away from the site.

The hypothetical rural resident is assumed to unknowingly establish a residence on the land parcel immediately after the well is drilled and to receive exposure to radioactive contamination in the drill cuttings by direct contact with the soil and through the food chain. The direct contact pathway includes exposure through external radiation, incidental soil ingestion, and inhalation of dust particulates. The food chain pathway includes exposure from ingestion of fruits and vegetables grown in a backyard garden and consumption of meat and milk from livestock raised in the contaminated area. The contribution of radioactive contamination in the redistributed drill cuttings to drinking water and water used for irrigation purposes is also included in the evaluation. Radioactive soil contamination represents a potential future source of exposure via the groundwater pathway through leaching and transport of the soil contamination to groundwater by infiltrating moisture.

This section discusses the derivation of input values for key RESRAD parameters and provides analysis results for the hypothetical rural residential exposure scenario.

D2.2.1 Well Characteristics

The hypothetical well in this scenario is assumed to extend from the ground surface to the water table. Based on drilling data from borehole C5515, the depth to the water table is assumed to be 96 m (315 ft). The diameter of the well is assumed to be 0.3 m (12 in.). Although this is consistent with well diameters used in previous Hanford Site performance assessments (BHI-00169, *Environmental Restoration Disposal Facility Performance Assessment*; DOE/ORP-2000-24, *Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version*), it is larger than typical for domestic wells drilled near the Hanford Site. As discussed in HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment*, the typical diameter for domestic wells in the area is 0.15 m (6 in). A diameter of 0.3 m (10 in.) is typical of wells drilled for small-scale irrigation, which require a larger pump than used for domestic service. The larger the well diameter the greater the volume of contaminated sediment brought to the surface. Thus, use of a 0.3-m (12-in.) diameter well in this analysis is considered conservative (that is, tends to overestimate the expected exposure).

D2.2.2 Contaminated Zone and Cover Characteristics

It is assumed that the contamination exhumed during well drilling has been incorporated into the surface soil over an area of 100 m^2 (328 ft^2) to a depth of 0.15 m (0.5 ft) (Figure D1-2). As discussed in HNF-SD-WM-TI-707, a garden size of 100 m^2 (328 ft^2) is generally sufficient to supply an average person's garden produce needs and is consistent with the garden size used in other Hanford Site performance assessments (DOE/ORP-2000-24, and DOE/ORP-2005-01, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site*). Use of a 100 m^2 (328 ft^2) garden area is considered conservative in that use of a larger area would lower (or dilute) the soil concentrations and resulting exposures.

Tilling to prepare the surface soil for planting is assumed to affect only the top 15 cm (5.9 in.) of soil, consistent with previous Hanford Site performance assessments. A default value of 15 cm (5.9 in.) is also used in RESRAD for the depth of soil mixing (ANL/EAD-4). This is considered a conservative assumption in that the deeper the soil is tilled, the more dilute the radionuclide concentrations in the contaminated zone become. Although some garden plants have root systems that penetrate deeper than 15 cm, a depth of 15 cm (5.9 in.) is typical of the root systems for most garden vegetables (HNF-SD-WM-TI-707).

Values of 100 m^2 (328 ft^2) and 0.15 m (0.5 ft) are input into RESRAD for the contaminated zone area and thickness, respectively, and an input value of zero is entered for cover thickness to represent the contaminated zone being exposed at the ground surface.

D2.2.3 Exposure Point Concentrations and Distribution Coefficients

The EPCs used for the hypothetical rural resident exposure scenario are calculated as:

$$EPC_i = C_{i,\max} f$$

Where:

$C_{i,max}$	=	maximum concentration of radionuclide *i* (pCi/g) in borehole C5515 within the depth interval 8.2 to 12 m (27 to 40 ft) bgs
f	=	scenario-based dilution factor (unitless)

The $C_{i,max}$ values used for the hypothetical rural resident exposure scenario are shown in Table D2-1. These values are the same as the EPCs shown in Table D2-4 for the industrial worker scenario. The only exception is tritium. The maximum concentration of tritium was detected in borehole C5515 within the depth interval 76 to 96 m (250.5 to 315 ft) bgs. The maximum concentration detected within this interval was used. Tritium was not included in the industrial worker scenario because it was not detected within the 8.2 to 12 m (27 to 40 ft) bgs depth interval.

The dilution factor is calculated as:

$$f = \frac{V_w}{V_{cz}}$$

$$V_w = \pi r^2 d_w$$

$$V_{cz} = A_{cz} d_s$$

Where:

r	=	well radius (m)
dw	=	thickness of the contamination within the well drilled through the contaminated zone (m)
Acz	=	scenario based contaminated area (m2) as defined above
ds	=	thickness of the contaminated zone as defined above

The thickness of the contamination (d_w) intercepted by the well for all radionuclides, except tritium, is 4 m (13 ft). Assuming A_{cz} = 100 m^2 (328 ft^2) and r = 0.15 m (0.5 ft), the dilution factor f for these radionuclides is 1.885 x 10^{-2}. The thickness of the contamination for tritium is 19.66 m (64.5 ft). The corresponding dilution factor f then equals 9.264 x 10^{-2}. The resulting EPCs for all the radionuclides considered in this scenario are presented in Table D2-5.

As discussed previously for the industrial worker scenario, the radionuclide K_ds are based on the best estimate values obtained from PNNL-14702 and PNNL-17154.

D2.2.4 Analysis Results

Results of the RESRAD analysis for the hypothetical rural resident exposure scenario at the 216-A-2 Crib are provided in Table D2-6 and Table D2-7. Table D2-6 provides a summary of the results while Table D2-7 provides the radionuclide- and pathway-specific ELCR contributions. Analysis results indicate that contributions from four radionuclides (Cs-137, Sr-90, Am-241 and Pu-239) account for nearly 100 percent of the total ELCR over the entire 1,000-year simulation period. Contributions from the other radionuclides included in the analysis (see Table D2-6) never exceed 0.01 percent of the total ELCR. To simplify the presentation, ELCR contributions from radionuclides other than Cs-137, Sr-90, Am-241 and Pu-239 have been omitted from Table D2-7.

Time dependent changes in the total and pathway-specific ELCR values over the 1,000-year simulation period are displayed in Figure D2-3. Analysis results indicate that the total ELCR is dominated by contributions from external radiation exposure, inhalation, plant consumption, and soil ingestion. Contributions from meat and milk consumption do not exceed 1 percent of the total ELCR at any time during the simulation period. Meat and milk contributions are included in Table D2-7.

Analysis results indicate that over the 1,000-year simulation period there are no exposure contributions from water dependent pathways (that is, use of groundwater for drinking water, crop irrigation, and livestock water). The RESRAD calculations indicate that leaching would not cause radionuclides in the redistributed drill cuttings to reach the water table during the 1,000-year simulation period.

The maximum ELCR occurs at the beginning of the simulation period (that is, analysis time zero) at a value slightly greater than 1×10^{-2}. The ELCR remains above EPA's target risk threshold of 1×10^{-4} through the end of the simulation period, and the ELCR is projected to remain above the risk threshold until approximately 5,740 years from the present. The primary contributors to the ELCR at time zero are Cs-137 from external radiation exposure (77 percent) and Sr-90 from plant consumption (12 percent). The total ELCR falls sharply for the first 150 years in response to radioactive decay of Cs-137 and Sr-90 and thereafter falls more gradually as the long-lived isotopes Am-241 and Pu-239 become the primary ELCR contributors.

After 500 years, Cs-137 and Sr-90 have decayed completely and the primary contributors to total ELCR are Pu-239 from inhalation (42 percent) and soil ingestion (16 percent) and Am-241 from external radiation exposure (29 percent). At the end of the 1,000-year simulation period, the primary contributors to total ELCR continue to be Pu-239 from inhalation (51 percent) and soil ingestion (20 percent) and Am-241 from external radiation exposure (16 percent).

Table D2-6. 216-A-2 Crib Radiological Cancer Risk Summary for the Hypothetical Rural Resident Exposure Scenario

Total ELCR	Time (years)	Primary Radionuclides	Percentage of Total ELCR	Pathway
1.01E-01	0	Cs-137	77%	External
		Am-141	4%	
		Pu-239	2%	Inhalation
		Sr-90	12%	Plant
3.93E-03	50	Cs-137	67%	External
		Am241	10%	
		Pu-239	7%	Inhalation
		Sr-90	8%	Plant
		Pu-239	3%	Soil Ingestion

Table D2-6. 216-A-2 Crib Radiological Cancer Risk Summary for the Hypothetical Rural Resident Exposure Scenario

Total ELCR	Time (years)	Primary Radionuclides	Percentage of Total ELCR	Pathway
1.07E-03	150	Am-241	30%	External
		Cs-137	24%	
		Pu-239	24%	Inhalation
		Pu-239	4%	Plant
		Pu-239	10%	Soil Ingestion
5.70E-04	500	Am-241	29%	External
		Pu-239	42%	Inhalation
		Pu-239	6%	Plant
		Pu-239	16%	Soil Ingestion
4.10E-04	1000	Am-241	16%	External
		Pu-239	51%	Inhalation
		Pu-239	8%	Plant
		Pu-239	20%	Soil Ingestion

Table D2-7. 216-A-2 Crib Pathway-Specific Radiological Cancer Risk for the Hypothetical Rural Resident Exposure Scenario

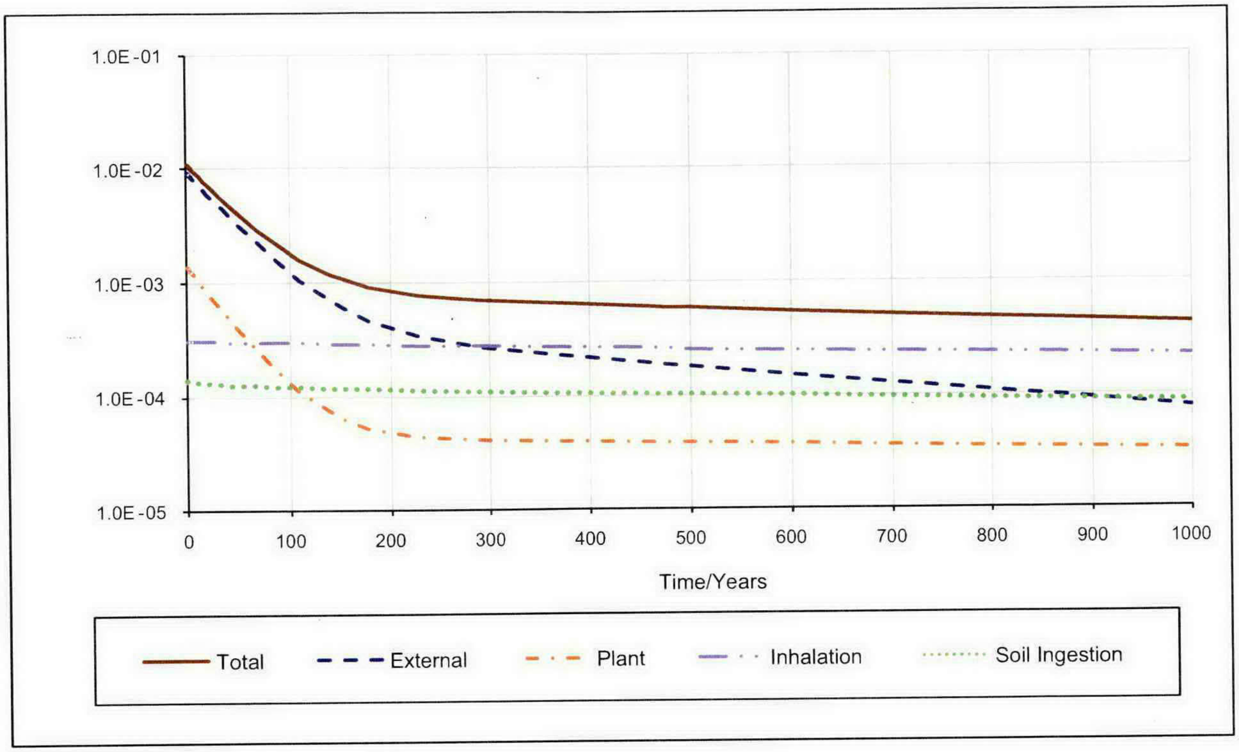
		Contribution to Total All Pathways ELCR													
		External		Inhalation		Plant		Meat		Milk		Soil Ingestion		All Pathways	
Time (year)	Radionuclide	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total
0	Am-241	4.27E-04	4%	3.95E-05	<1%	6.51E-06	<1%	--	<1%	--	<1%	1.74E-05	<1%	4.91E-04	4%
	Cs-137	8.44E-03	77%	--	<1%	1.77E-05	<1%	2.43E-06	<1%	1.64E-06	<1%	1.19E-06	<1%	8.46E-03	77%
	Pu-239	1.40E-05	<1%	2.69E-04	2%	3.93E-05	<1%	--	<1%	--	<1%	1.05E-04	<1%	4.28E-04	4%
	Sr-90	2.58E-04	2%	--	<1%	1.29E-03	12%	2.57E-05	<1%	1.49E-05	<1%	1.15E-05	<1%	1.60E-03	15%
	Total	9.14E-03	83%	3.09E-04	3%	1.35E-03	12%	2.86E-05	<1%	1.65E-05	<1%	1.35E-04	1%	1.10E-02	100%
50	Am-241	3.89E-04	10%	3.58E-05	<1%	5.90E-06	<1%	--	<1%	--	<1%	1.58E-05	<1%	4.46E-04	11%
	Cs-137	2.65E-03	67%	--	<1%	5.56E-06	<1%	--	<1%	--	<1%	--	<1%	2.66E-03	68%
	Pu-239	1.39E-05	<1%	2.65E-04	7%	3.89E-05	<1%	--	<1%	--	<1%	1.04E-04	3%	4.23E-04	11%
	Sr-90	6.46E-05	2%	--	<1%	3.22E-04	8%	6.43E-06	<1%	3.72E-06	<1%	2.88E-06	<1%	4.00E-04	10%
	Total	3.12E-03	79%	3.01E-04	8%	3.73E-04	10%	7.60E-06	<1%	4.25E-06	<1%	1.23E-04	3%	**3.93E-03**	100%
150	Am-241	3.22E-04	30%	2.94E-05	3%	4.86E-06	<1%	--	<1%	--	<1%	1.30E-05	1%	3.69E-04	35%
	Cs-137	2.61E-04	24%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	2.62E-04	24%
	Pu-239	1.36E-05	1%	2.59E-04	24%	3.80E-05	4%	--	<1%	--	<1%	1.02E-04	10%	4.13E-04	39%
	Sr-90	4.05E-06	<1%	--	<1%	2.01E-05	2%	--	<1%	--	<1%	--	<1%	2.50E-05	2%
	Total	6.01E-04	56%	2.89E-04	27%	6.35E-05	6%	--	<1%	--	<1%	1.15E-04	11%	**1.07E-03**	100%
500	Am-241	1.66E-04	29%	1.48E-05	3%	2.45E-06	<1%	--	<1%	--	<1%	6.55E-06	1%	1.90E-04	33%
	Cs-137	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%
	Pu-239	1.28E-05	2%	2.38E-04	42%	3.49E-05	6%	--	<1%	--	<1%	9.34E-05	16%	3.80E-04	67%
	Sr-90	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%
	Total	1.79E-04	31%	2.53E-04	44%	3.74E-05	7%	--	<1%	--	<1%	9.99E-05	18%	**5.70E-04**	100%

Table D2-7. 216-A-2 Crib Pathway-Specific Radiological Cancer Risk for the Hypothetical Rural Resident Exposure Scenario

		Contribution to Total All Pathways ELCR													
		External		Inhalation		Plant		Meat		Milk		Soil Ingestion		All Pathways	
Time (year)	Radionuclide	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total	ELCR	Percent of Total
1,000	Am-241	6.47E-05	16%	5.57E-06	1%	--	<1%	--	<1%	--	<1%	2.46E-06	<1%	7.36E-05	18%
	Cs-137	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%
	Pu-239	1.16E-05	3%	2.11E-04	51%	3.09E-05	8%	--	<1%	--	<1%	8.28E-05	20%	3.37E-04	82%
	Sr-90	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%	--	<1%
	Total	7.63E-05	19%	2.17E-04	53%	3.19E-05	8%	--	<1%	--	<1%	8.52E-05	21%	**4.10E-04**	100%

-- indicates an ELCR contribution of less than 1.00E-06

ELCR = excess lifetime cancer risk



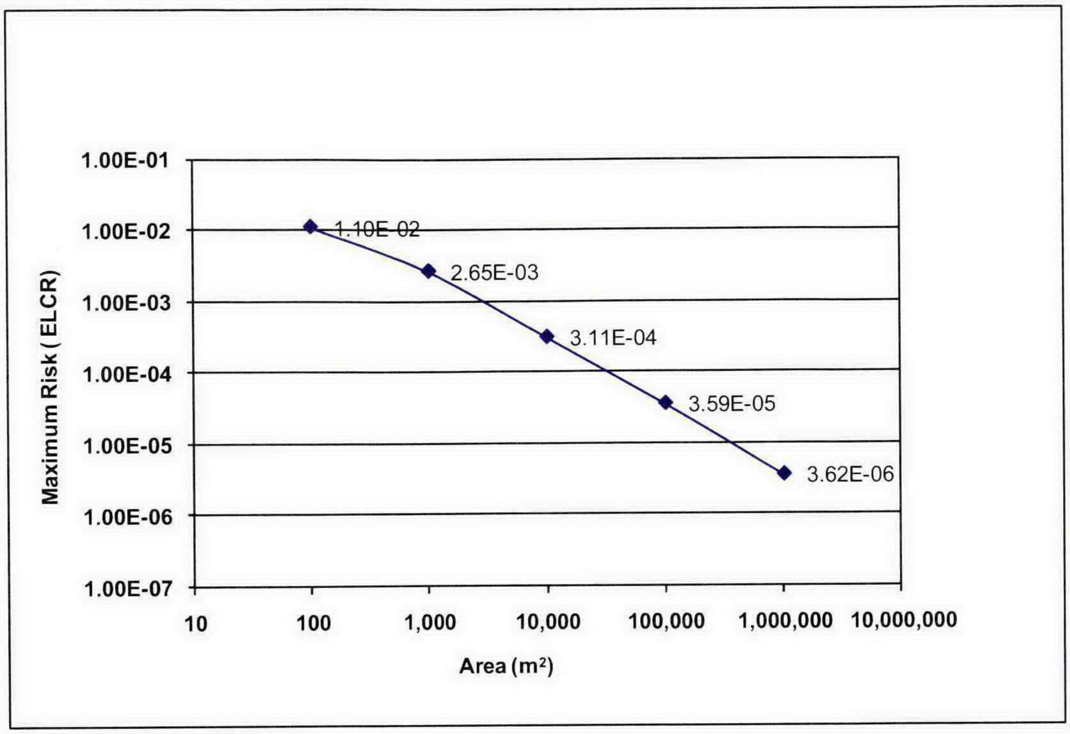
ELCR = excess lifetime cancer risk

Figure D2-3. 216-A-2 Crib Total and Pathway-Specific Radiological Cancer Risks for the Hypothetical Rural Resident Exposure Scenario

D2.2.5 Uncertainty Analysis

An important uncertainty associated with the hypothetical rural resident exposure scenario is the area over which the drill cuttings are assumed to be distributed (that is, the value assigned to the RESRAD input parameter for contaminated zone area). Use of a smaller area decreases soil dilution, increases radionuclide EPCs, and generates higher calculated ELCR values compared to the use of a larger area. An area of 100 m^2 (328 ft^2) was selected for the present analysis for consistency with previous assessments and to provide a measure of conservatism (that is, to bias the results toward overestimation rather than underestimation of exposure). The area of 100 m^2 (328 ft^2) is assumed to support both a backyard garden and support livestock that graze on and are penned on a rural pasture.

To test the sensitivity of the RESRAD results to the assumed contaminated zone area, a series of additional RESRAD runs were made using the same input file used for the present analysis but with progressively larger contaminated zone areas and a set of corresponding EPCs. A plot showing the variation in maximum ELCR with contaminated zone area is provided in Figure D2- 4. Results of the sensitivity test indicate that for the 216-A-2 Crib a roughly linear relationship exists between exposure area and the maximum ELCR for the hypothetical rural resident exposure scenario. This suggests that, in general, an order of magnitude increase in the assumed exposure area causes roughly an order of magnitude decrease in the maximum ELCR for this scenario.



ECLR = excess lifetime cancer risk

Figure D2-4: Variation in Radiological Cancer Risk with Contaminated Zone Area for the Hypothetical Rural Resident Exposure Scenario at the 216-A-2 Crib

D3 Summary

A summary of the RESRAD results for the exposure scenarios evaluated for the 216-A-2 Crib is presented in Table D3-1. Results for the industrial worker scenario for the BRA indicate that there is no radiological cancer risk for this scenario with the waste site in its current configuration. The total ELCR for the hypothetical rural resident exposure scenario exceeds EPA's target risk threshold limit of 10^{-4} over the entire 1,000-year simulation period and is projected to remain above the risk threshold until approximately 5,740 years from the present.

Table D3-1. Summary of RESRAD Risk Analysis for the 216-A-2 Crib

Scenario	Maximum Total Risk	Time of Maximum Total Risk (year)
Industrial Worker	0	Not applicable.
Hypothetical Rural Resident	1.1E-02	0

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D4 Human Health Risk Assessment (216-A-4 Crib)

This section describes the human health risk assessment performed for the radiological contaminants of potential concern (COPC) identified at the 216-A-4 Crib. The 216-A-4 Crib waste site assessment includes the following direct contact exposure scenarios:

- Industrial worker
- Confederated Tribes of the Umatilla Indian Reservation (CTUIR)
- Yakama Nation

The industrial worker scenario is used for the BRA to represent potential exposure under reasonably anticipated current and future land use. Industrial land use within the core zone is considered more consistent with future land use plans than the hypothetical rural resident exposure scenario. The application of an industrial land use assumption allows for the use of institutional controls such as deed restrictions. As a result, this limits the number of complete exposure pathways and reduces exposure frequency and duration as compared to unrestricted use. It should be noted, the industrial worker scenario is also the basis for developing PRGs.

Two available Native American exposure scenarios (CTUIR and Yakama Nation) are used for the BRA for the purpose of evaluating the modifying criteria in the detailed remedial alternatives analysis. These scenarios reflect exposure conditions if the land use within the industrial exclusive zone of the Central Plateau were released for traditional lifeway activities assuming the current waste site configuration of the 216-A-4 Crib. Traditional lifeway activities do not include drilling a well to use groundwater for domestic or ceremonial purposes.

D4.1 Exposure Scenario Description

Industrial Worker Scenario. The industrial worker scenario represents an individual exposed to radiological contaminants from direct contact with soil. The fundamental assumption associated with this exposure scenario is that exposure to the receptor occurs while the waste site is in its current configuration and with institutional controls in place. The contaminated zone for the 216-A-4 Crib is located between 5.64 to 6.4 m (18.5 to 21 ft) below ground surface (bgs), which is below the direct contact point of compliance of 4.6 m (15 ft) bgs.

Exposure estimates are based on an exposure frequency of 250 days/yr over a 25-year exposure duration. The direct contact pathway includes exposure through external radiation, incidental soil ingestion, and inhalation of dust particulates. An external gamma-shielding factor of 0.4, an incidental soil ingestion rate of 50 mg/day, and an inhalation rate of 20 m^3/day (706 ft^3/day) are assumed. The exposure assumptions and RESRAD modeling input parameters used for the analysis are provided in Table D4-1. The table lists the value used for each parameter, the rationale for its use, and a reference to the source for the value.

Native American Scenarios. Several local and regional tribes have ancestral ties to the Hanford Reach of the Columbia River. The U.S. Department of Energy (DOE) has requested that each Tribe provide an exposure scenario that reflects their traditional activities. At this time, the CTUIR (*Application of the CTUIR Traditional Lifeways Exposure Scenario in Hanford Risk Assessments* [Harris, 2008], *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* [Harris and Harper, 2004]) and Yakama Nation (*Yakama Nation Exposure Scenario for Hanford Site Risk Assessment* [Ridolfi, 2007]) have provided scenarios.

Evaluation of both scenarios is performed using the current 216-A-4 Crib waste site configuration in which there is a clean soil cover above the contamination. Each scenario is evaluated assuming that radionuclides residing in soil from the ground surface to the groundwater table are the source of contamination for all exposure pathways.

Both the CTUIR and Yakama Nation exposure scenarios represent an individual exposed to radiological contaminants from direct contact with soil and through the food chain. The direct contact pathway includes exposure through external radiation, incidental soil ingestion, and inhalation of dust particulates. The food chain pathway includes exposure from ingestion of fruits and vegetables grown in a backyard garden, and consumption of beef and poultry that graze on and are penned on a rural pasture. Milk consumption is included in the Yakama Nation scenario (Ridolfi 2007) but not the CTUIR scenario (Harris 2008; Harris and Harper 2004). Both exposure scenarios include exposure assumptions to represent consumption of wild game hunted and foods gathered on the Central Plateau. However, exposure from consumption of wild game is not included in this evaluation because the area of the 216-A-4 Crib is considered too small to support foraging wild game.

Exposure through the food chain pathway is contributed from uptake of radionuclides that are currently in the soil and includes use of groundwater potentially contaminated by migration of contamination through the vadose zone. It does not consider groundwater that is currently contaminated beneath the 200-MW-1 OU. Drinking water ingestion and irrigation water use are activated in the RESRAD exposure analysis and it is assumed that 100 percent of drinking water, irrigation water, and livestock water is obtained from an onsite well that is suitable for domestic use.

Both the CTUIR and Yakama Nation exposure scenarios also include exposure assumptions for estimating potential exposure from the consumption of fish, and sweat lodge use. For purposes of this risk assessment, both exposure pathways are considered incomplete and are not evaluated. The fish consumption exposure pathway is being included by the 100 Areas and 300 Area River Corridor Baseline Risk Assessment. The sweat lodge exposure pathway is not included because only contamination associated with the source area is addressed in this risk assessment. The exposure assumptions and RESRAD modeling input parameters used for the CTUIR and Yakama Nation scenarios are provided in Section D5 (Table D5-2). The table lists the value for each parameter, the rationale for its use, and a reference to the source for the value.

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D5 RESRAD Analysis Methodology

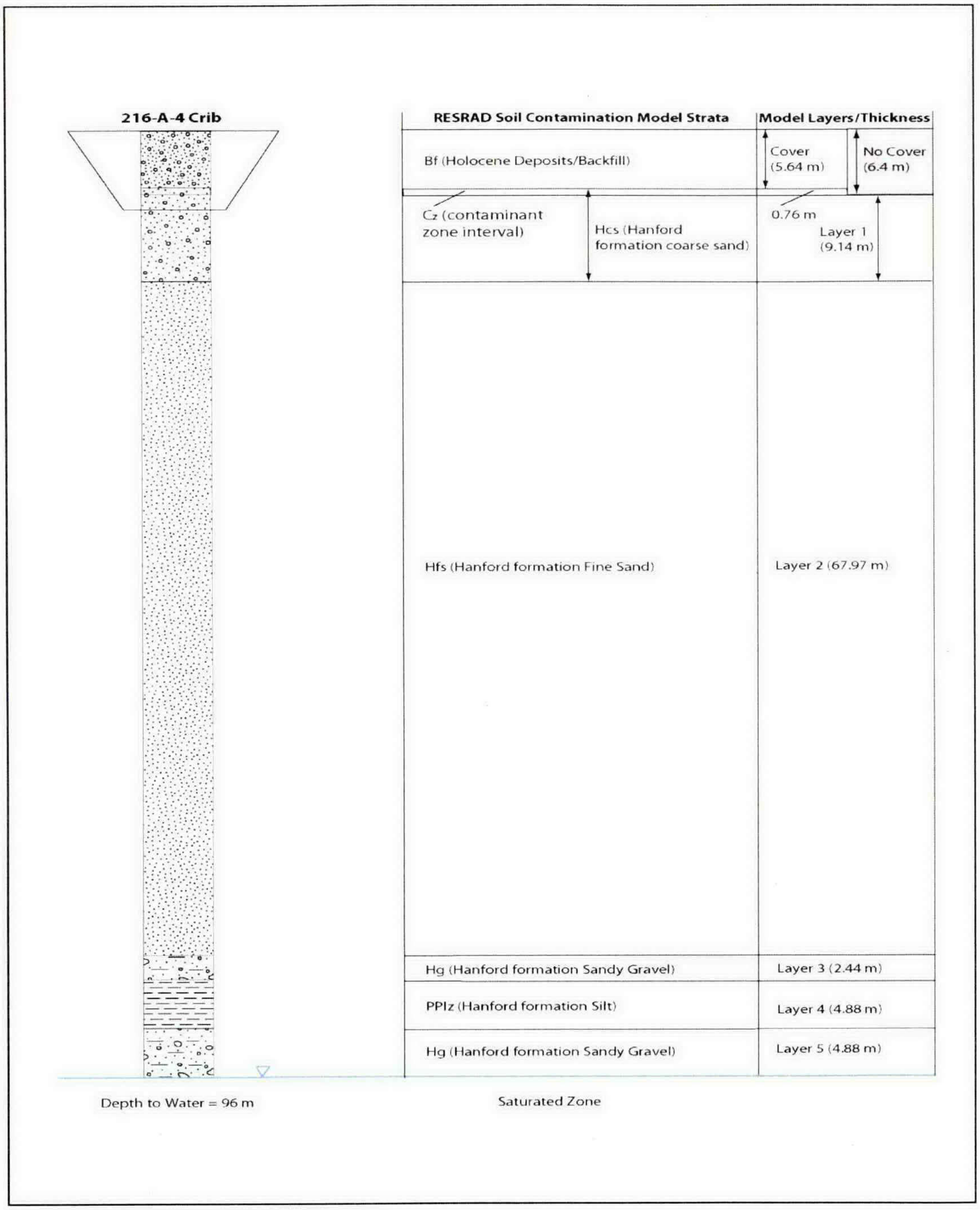
RESRAD requires a complete set of site- and scenario-specific input parameters for each exposure scenario. The input parameters corresponding to each exposure scenario are summarized in Table D5-1 for the industrial worker scenario and Table D5-2 for the CTUIR and Yakama Nation exposure scenarios. These tables list the value used for each input parameter, the rationale for use of the value, and a reference source for the value. Supporting information not provided in these tables, such as certain values associated with the unsaturated zone strata hydrogeologic units and the contaminant-specific EPCs and K_ds, are presented in Table D5-3 and Table D5-4. Graphic representations showing the geologic strata and layers identified for use in the RESRAD model calculations, and a conceptual site model for the industrial worker in presented in Figure D5-1.

Time dependent total radioactive excess lifetime cancer risk (ELCR) was calculated for each exposure scenario using *RESRAD*, Version 6.4 (ANL 2007). The model was implemented following guidance given in ANL/EAD-4, *User's Manual for RESRAD Version* 6. The RESRAD code was developed by Argonne National Laboratory to implement DOE guidelines for allowable residual radioactive material in soil (DOE Order 5400.5).

The parameters defined in Table D5-1 through Table D5-4 were used for RESRAD input. A simulation time of 1,000 years was used in all of the RESRAD runs.

The maximum ELCR over the 1,000-year period was calculated for each exposure scenario and, for comparative purposes, ELCR estimates are discussed relative to the following exposure times:

- Zero year represents current waste site conditions.
- 50 years is the estimated time that DOE will have an onsite presence.
- 150 years is the estimated time that institutional controls are assumed to be effective.
- 500 years is the estimated time that passive institutional controls are assumed to be effective.
- 1,000 years is the estimated time frame that peak radiation dose and risk estimates should fall within.
- The year in which the ELCR regulatory threshold of 10^{-4} is achieved.



* Layers depicted below contaminant zone (Layers 1 through 5) are used for rural residential, CTUIR, and Yakama Nation exposure scenarios but not for industrial worker exposure scenario.

Figure D5-1. Identification of Model Layers Used For the 216-A-4 Crib *

Table D5-1. 216-A-4 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Restricted Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation
Exposure Pathways	External gamma Inhalation Plant ingestion Meat ingestion Milk ingestion Aquatic foods Drinking water Soil ingestion Radon	Not applicable.	Active Active Suppressed Suppressed Suppressed Suppressed Suppressed Active Suppressed	
R011 – Contaminated Zone (CZ)	Area of CZ	m^2 (ft^2)	88.19 (949.27)	Area based on Equation 4.3 in PNNL-14702. See Figure D2-1.
	Thickness of CZ (baseline)	m (ft)	0.76 (2.5)	Direct contact (with cover) using site-specific data from 5.64 to 6.4 m (18.5 to 21 ft) bgs depth interval.
	Length parallel to aquifer flow	m	Not applicable.	Not applicable. Water dependent pathways not activated.
	Radiation dose limit (industrial scenario)	mrem/ year	15	40 CFR 141; EPA/540/R/99/006.
	Elapsed time since waste placement	year	0	Environmental samples are decayed to the current calendar year.
Exposure Point Concentrations	EPCs	pCi/g	Chemical-specific	Maximum concentration measured in borehole C4560.
R013 – Cover and CZ Hydrological Data	Cover depth	m (ft)	5.64 (18.5)	
	Cover material density	g/cm^3	1.94	Backfill sand unit (Bf) in PNNL-14702, Table 4.5.
	Cover erosion rate	m/yr	0.00001	Value selected prevents appreciable erosion of the cover currently present over the waste site during the simulation period.
	Density of CZ	g/cm^3	1.68	Sand dominated Hanford formation, coarse sand unit (Hcs). Bulk density of this unit was calculated as an average of four measurements available for borehole C5301.
	CZ erosion rate	m/yr	0.00001	Value selected prevents appreciable erosion of the CZ.
	CZ total porosity	Unitless	0.349	Hcs in PNNL-14702, Table 4.5.
	CZ field capacity	Unitless	0.041	CZ field capacity calculated for the Hcs using parameters from in PNNL-14702, Table 4.5. See Table G-3.
	CZ hydraulic conductivity	m/yr	716	Hcs in PNNL-14702, Table 4.5
	CZ b parameter	Unitless	4.05	Determined from soil textures listed in ANL/EAD-4, Table E.2. This hydrogeologic unit has little of the finer material (silt and clay) listed in Table E.2. Hence, the "b" parameter is assigned the value of 4.05 for sand.
	Humidity in air	g/cm^3	Not applicable.	Not applicable.
	Evapotranspiration coefficient	Unitless	0.977	Value assigned results in an annual recharge rate of 0.4 cm/yr.
	Wind speed	m/s	3.4	Value obtained from PNNL-15160, Table 5.1.
	Precipitation	m/yr	0.177	Value obtained from PNNL-15160, Table 4.1.
	Irrigation rate	m/yr	0	Based on Table B-1 in DOE/RL-96-17.

Table D5-1. 216-A-4 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Restricted Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation
	Irrigation mode	Not applicable.	Overhead	RESRAD default.
	Run-off coefficient	Unitless	0	Run-off coefficient of 0 indicates all precipitation soaks into the ground.
	Watershed area for nearby stream or pond	m^2	Not applicable.	Not applicable.
	Accuracy for water/soil computations	Unitless	Not applicable.	Not applicable.
R014 – Saturated Zone (SZ) hydrological data	Density of SZ	g/cm^3	Not applicable.	Not applicable.
	SZ total porosity	Unitless	Not applicable.	Not applicable.
	SZ effective porosity	Unitless	Not applicable.	Not applicable.
	SZ field capacity	Unitless	Not applicable.	Not applicable.
	SZ hydraulic conductivity	m/yr	Not applicable.	Not applicable.
	SZ hydraulic gradient	Unitless	Not applicable.	Not applicable.
	SZ b parameter	Unitless	Not applicable.	Not applicable.
	Water table drop rate	m/yr	Not applicable.	Not applicable.
	Well pump intake depth below water table	m (ft)	Not applicable.	Not applicable.
	Nondispersion (ND) or mass-balance	Not applicable.	Not applicable.	Not applicable.
	Well pumping rate	m^3/yr	Not applicable.	Not applicable.
R015 – Uncontaminated and Unsaturated Strata Hydrological Data	Number of unsaturated strata	Not applicable.	Not applicable.	Not applicable.
	Thickness	m	Not applicable.	Not applicable.
	Soil density	g/cm^3	Not applicable.	Not applicable.
	Total porosity	Unitless	Not applicable.	Not applicable.
	Effective porosity	Unitless	Not applicable.	Not applicable.
	Field Capacity	Unitless	Not applicable.	Not applicable.
	Soil-specific *b* parameter	Unitless	Not applicable.	Not applicable.
	Hydraulic conductivity	m/yr	Not applicable.	Not applicable.
R016 – Distribution Coefficients and Leach Rates for Individual Radionuclides	Distribution coefficients (K_d) for CZ, uncontaminated zone and saturated zone	cm^3/g	Contaminant-specific	Best estimate values obtained from PNNL-14702, Table 4.11. K_d values for Co-60 and Am-241 were obtained from the "no impact" category from PNNL-17154, Table A.1.
	Saturated leach rate	yr^{-1}	0	RESRAD default.
	Saturated solubility	mol/L	0	RESRAD default.
R017 – Inhalation and External Gamma	Inhalation rate	m^3/yr	7,300	Assumes an inhalation rate of 20 m^3/d (365 d/yr) (EPA/600/P-95/002Fa).
	Mass loading for inhalation	g/m^3	0.0001	WDOH/320-015.
	Exposure duration	year	25	EPA, 1991 (OSWER Directive 9285.6-03).
	Indoor Dust Filtration factor	Unitless	0.4	RESRAD default.

Table D5-1. 216-A-4 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Restricted Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation
	External gamma shielding factor	Unitless	0.4	EPA/540/R-00/007 (Equation 4).
	Indoor time fraction	Unitless	0.171	Assumes that 6 h/d spent indoors, 250 d/yr (1,500 hours divided by 8,760 hours).
	Outdoor time fraction	Unitless	0.057	Assumes that 2 h/d spent outdoors, 250 d/yr (500 hours divided by 8,760 hours).
	Shape factor	Not applicable.	Circular	RESRAD default.
R018 – Ingestion Pathway Data, Dietary Parameters	Soil ingestion intake	g/yr	12.5	Based on 50 mg/d (250 d/yr).
	Drinking water intake	L/yr	Not applicable.	Drinking water ingestion is an incomplete exposure pathway for the industrial worker exposure scenario.
	Leafy vegetable consumption	kg/yr	Not applicable.	The food consumption pathway is considered incomplete for this exposure scenario.
	Fruits, vegetables, and grain consumption	kg/yr	Not applicable.	The food consumption pathway is considered incomplete for this exposure scenario.
	Milk consumption	L/yr	Not applicable.	The food consumption pathway is considered incomplete for this exposure scenario.
	Meat and poultry consumption	kg/yr	Not applicable.	The food consumption pathway is considered incomplete for this exposure scenario.
	Fish consumption	kg/yr	Not applicable.	The consumption of fish is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Other seafood consumption	kg/yr	Not applicable.	The consumption of seafood is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Drinking water contamination fraction	Unitless	Not applicable.	Not applicable.
	Household water contamination fraction	Unitless	Not applicable.	Not applicable.
	Livestock water contamination fraction	Unitless	Not applicable.	Not applicable.
	Irrigation water contamination fraction	Unitless	Not applicable.	Not applicable.
	Aquatic food contamination fraction	Unitless	Not applicable.	Not applicable.
	Plant food contamination fraction	Unitless	Not applicable.	Not applicable.
	Meat contamination fraction	Unitless	Not applicable.	Not applicable.
	Milk contamination fraction	Unitless	Not applicable.	Not applicable.
R019 – Ingestion Pathway Data, Nondietary	Livestock fodder intake for meat	kg/d	Not applicable.	Not applicable.
	Livestock fodder intake for milk	kg/d	Not applicable.	Not applicable.
	Livestock water intake for meat	L/d	Not applicable.	Not applicable.
	Livestock water intake for milk	L/d	Not applicable.	Not applicable.
	Livestock intake of soil	kg/d	Not applicable.	Not applicable.
	Mass loading for foliar deposition	g/m^3	Not applicable.	Not applicable.
	Depth of soil mixing layer	m	0.15	RESRAD default.
	Depth of roots	m	Not applicable.	Not applicable.
Plant Factors	Wet weight crop yield, non-leafy	kg/m^2	Not applicable.	Not applicable.
	Wet weight crop yield, leafy	kg/m^2	Not applicable.	Not applicable.

Table D5-1. 216-A-4 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Restricted Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation
	Wet weight crop yield, fodder	kg/m^2	Not applicable.	Not applicable.
	Length of growing season, non-leafy	yr	Not applicable.	Not applicable.
	Length of growing season, leafy	yr	Not applicable.	Not applicable.
	Length of growing season, fodder	yr	Not applicable.	Not applicable.
	Translocation factor, non-leafy	Unitless	Not applicable.	Not applicable.
	Translocation factor, leafy	Unitless	Not applicable.	Not applicable.
	Translocation factor, fodder	Unitless	Not applicable.	Not applicable.
	Weathering removal constant	yr^{-1}	Not applicable.	Not applicable.
	Wet foliar interception factor, non-leafy	Unitless	Not applicable.	Not applicable.
	Wet foliar interception factor, leafy	Unitless	Not applicable.	Not applicable.
	Wet foliar interception factor, fodder	Unitless	Not applicable.	Not applicable.
	Dry foliar interception factor, non-leafy	Unitless	Not applicable.	Not applicable.
	Dry foliar interception factor, leafy	Unitless	Not applicable.	Not applicable.
	Dry foliar interception factor, fodder	Unitless	Not applicable.	Not applicable.
R020 – Groundwater Usage	Groundwater fractional usage – drinking water	Unitless	Not applicable.	Not applicable.
	Groundwater fractional usage – household usage	Unitless	Not applicable.	Not applicable.
	Groundwater fractional usage – livestock water	Unitless	Not applicable.	Not applicable.
	Groundwater usage –irrigation	Unitless	Not applicable.	Not applicable.
R021 – Radon	Not used	Not applicable.	Not applicable.	Not applicable.
Storage Times	Fruit, non-leafy vegetables, and grain	day	Not applicable.	Not applicable.
	Leafy vegetables	day	Not applicable.	Not applicable.
	Milk	day	Not applicable.	Not applicable.
	Meat	day	Not applicable.	Not applicable.
	Fish	day	Not applicable.	Not applicable.
	Crustacea and mollusks	day	Not applicable.	Not applicable.
	Well water	day	Not applicable.	Not applicable.
	Surface water	day	Not applicable.	Not applicable.
	Livestock fodder	day	Not applicable.	Not applicable.
C-14	Not used	Not applicable.	Not applicable.	Not applicable.

Table D5-1. 216-A-4 Crib Summary of RESRAD Input Parameters for the Industrial Worker (Restricted Land Use) Exposure Scenario

Description	Parameter	Units	Industrial Worker Scenario	Rationale and Citation

Notes:

40 CFR 141, "National Primary Drinking Water Regulations"

ANL/EAD-4, *User's Manual for RESRAD, Version 6*

DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*

DOE/RL-2008-01, *Hanford Site Groundwater Monitoring for Fiscal Year 2007*

EPA, 1991, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final*, OSWER Directive 9285.6-03

EPA/540/R/99/006, *Radiation Risk Assessment At CERCLA Sites: Q&A*, OSWER Directive 9200.4-31P

EPA/540/R-00/007, *Soil Screening Guidance for Radionuclides: User's Guide*, OSWER 9355.4-16A

EPA/600/P-95/002Fa, *Exposure Factors Handbook Volume 1: General Factors*

PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*

PNNL-15160, *Hanford Site Climatological Summary 2004 with Historical Data*

PNNL-17154, *Geochemical Characterization data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*

WDOH/320-015, *Hanford Guidance for Radiological Cleanup*

bgs = below ground surface

RESRAD = RESidual RADioactivity (ANL/EAD-4)

Table D5-2. 216-A-4 Crib Summary of RESRAD Input Parameters for the Native American Exposure Scenarios (Unrestricted Land Use)

Description	Parameter	Units	CTUIR Scenario	Yakama Nation Scenario	Rationale and Citation
Exposure Pathways	External Gamma Inhalation Plant Ingestion Meat Ingestion Milk Ingestion Aquatic Foods Drinking Water Soil Ingestion Radon	Not applicable.	Active Active Active Active Suppressed Suppressed Active Active Suppressed	Active Active Active Active Active Suppressed Active Active Suppressed	
R011 – Contaminated Zone (CZ)	Area of CZ	m^2 (ft^2)	88.19 (949.27)	88.19 (949.27)	Area based on Equation 4.3 in PNNL-14702.
	Thickness of CZ (baseline)	m (ft)	0.76 (2.5)	0.76 (2.5)	Direct contact (with cover) using site-specific data from 5.64 to 6.4 m (18.5 to 21 ft) bgs depth interval.
	Length parallel to aquifer flow	m	9.4	9.4	Value selected is based on the full length of the crib. See Chapter 1, Figure 1-8 for crib construction dimensions.
	Radiation dose limit (industrial scenario)	mrem/ year	15	15	40 CFR Part 141; EPA/540/R/99/006.
	Elapsed time since waste placement	year	0	0	Environmental samples should be decayed to current calendar year.
Exposure Point Concentrations	EPCs	pCi/g	Chemical-specific	Chemical-specific	Maximum concentration measured in borehole C4560.
R013 – Cover and CZ Hydrological Data	Cover depth	m (ft)	5.64 (18.5)	5.64 (18.5)	See Figure D5-1.
	Cover material density	g/cm^3	1.94	1.94	Backfill sand unit (Bf) in PNNL-14702, Table 4.5.
	Cover erosion rate	m/yr	0.00001	0.00001	Value selected prevents appreciable erosion of the cover currently present over the waste site during the simulation period.
	Density of CZ	g/cm^3	1.68	1.68	Sand-dominated Hanford formation, coarse sand unit (Hcs). Bulk density of this unit was calculated as an average of four measurements available for borehole C5301.
	CZ erosion rate	m/yr	0.00001	0.00001	Value selected prevents appreciable erosion of the CZ.
	CZ total porosity	Unitless	0.349	0.349	Hcs in PNNL-14702, Table 4.5.
	CZ field capacity	Unitless	0.041	0.041	CZ field capacity calculated for the Hcs using parameters from PNNL-14702, Table 4.5.
	CZ hydraulic conductivity	m/yr	716	716	Hcs in PNNL-14702, Table 4.5.
	CZ b parameter	Unitless	4.05	4.05	This hydrogeologic unit has little of the finer material (silt and clay) listed in Table E.2. Hence, the "b" parameter is assigned the value of 4.05 for sand.
	Humidity in air	g/cm^3	Not applicable.	Not applicable.	Not applicable.
	Evapotranspiration coefficient	Unitless	0.977	0.977	Value assigned results in an annual recharge rate of 0.4 cm/yr.
	Wind speed	m/s	3.4	3.4	Value obtained from PNNL-15160, Table 5.1.

Table D5-2. 216-A-4 Crib Summary of RESRAD Input Parameters for the Native American Exposure Scenarios (Unrestricted Land Use)

Description	Parameter	Units	CTUIR Scenario	Yakama Nation Scenario	Rationale and Citation
	Precipitation	m/yr	0.177	0.177	Value obtained from PNNL-15160, Table 4.1.
	Irrigation rate	m/yr	0.76	0.76	Based on DOE/RL-96-17, Table B-1.
	Irrigation mode	Not applicable.	Overhead	Overhead	RESRAD default.
	Run-off coefficient	Unitless	0	0	Run-off coefficient of 0 indicates all precipitation soaks into the ground.
	Watershed area for nearby stream or pond	m^2	1.00E+06	1.00E+06	RESRAD default.
	Accuracy for water/soil computations	Unitless	0.001	0.001	RESRAD default.
R014 – Saturated Zone (SZ) hydrological data	Density of SZ	g/cm^3	1.93	1.93	Hanford Gravel unit (Hg) in PNNL-14702, Table 4.5.
	SZ total porosity	Unitless	0.167	0.167	Hanford Gravel unit (Hg) in PNNL-14702, Table 4.5.
	SZ effective porosity	Unitless	0.167	0.167	Hanford Gravel unit (Hg) in PNNL-14702, Table 4.5.
	SZ field capacity	Unitless	0.062	0.062	Saturated zone field capacity calculated for the Hanford Gravel unit (Hg) using parameters from PNNL-14702, Table 4.5.
	SZ hydraulic conductivity	m/yr	104	104	Hanford Gravel unit (Hg) in PNNL-14702, Table 4.5.
	SZ hydraulic gradient	Unitless	2.00E-05	2.00E-05	Value obtained from Table H2-2 in DOE/RL-2008-01.
	SZ b parameter	Unitless	4.05	4.05	This hydrogeologic unit has little of the finer material (silt and clay) listed in Table E.2. Hence, the "b" parameter is assigned the value of 4.05 for sand.
	Water table drop rate	m/yr	0.0001	0.0001	Value selected results in little change in the depth of the groundwater during the simulation period.
	Well pump intake depth below water table	m	10	10	Located mid-aquifer for 75 ft thick aquifer.
	Nondispersion (ND) or mass-balance	Not applicable.	ND	ND	RESRAD default.
	Well pumping rate	m^3/yr	250	250	RESRAD default.
R015 – Uncontaminated and Unsaturated Strata Hydrological Data	Number of unsaturated strata	Not applicable.	5	5	See Figure D5-1.
	Thickness	m	9.14, 68, 2.4, 4.88, 4.88	9.14, 68, 2.4, 4.88, 4.88	Hcs, Hanford Fine Sand unit (Hfs), Hg, Hanford formation silt (PPlz).
	Soil density	g/cm^3	1.67, 1.60, 1.93, 1.68, 1.93	1.67, 1.60, 1.93,1.68, 1.93	Values from each unit were obtained from PNNL-14702, Table 4.5.
	Total porosity	Unitless	0.349, 0.379, 0.167, 0.419, 0.167	0.349, 0.379, 0.167, 0.419, 0.167	Values from each unit were obtained from PNNL-14702, Table 4.5.
	Effective porosity	Unitless	0.349, 0.379, 0.167, 0.419, 0.167	0.349, 0.379, 0.167, 0.419,0.167	Values from each unit were obtained from PNNL-14702, Table 4.5.
	Field Capacity	Unitless	0.041,0.058, 0.062, 0.210, 0.062	0.041,0.058, 0.062, 0.210, 0.062	Unsaturated strata field capacity calculated using parameters from PNNL-14702, Table 4.5.

Table D5-2. 216-A-4 Crib Summary of RESRAD Input Parameters for the Native American Exposure Scenarios (Unrestricted Land Use)

Description	Parameter	Units	CTUIR Scenario	Yakama Nation Scenario	Rationale and Citation
	Soil-specific *b* parameter	Unitless	4.05, 4.05, 4.05, 10.4,4.05	4.05, 4.05, 4.05, 10.4, 4.05	This hydrogeologic unit has little of the finer material (silt and clay) listed in Table E.2. Except for Hanford formation Silt, each of the hydrogeologic units has little of the finer material (silt and clay) listed in Table E.2. Hence, the "b" parameters are all near 4.05 for sand. The soil class Hg was assigned the silty clay value of 10.4.
	Hydraulic conductivity	m/yr	716, 118,104,17.6, 104	716, 118,104,17.6, 104	Values from each unit were obtained from PNNL-14702, Table 4.5.
R016 – Distribution Coefficients and Leach Rates for Individual Radionuclides	Distribution coefficients (K_d) for CZ, uncontaminated zone and saturated zone	cm^3/g	Contaminant-specific	Contaminant-specific	Best estimate values obtained from PNNL-14702, Table 4.11. K_d values for Co-60 and Am-241 were obtained from the "no impact" category from PNNL-17154, Table A.1.
	Saturated leach rate	yr^{-1}	0	0	RESRAD default.
	Solubility limit	mol/L	0	0	RESRAD default.
R017 – Inhalation and External Gamma	Inhalation rate	m^3/yr	9,125	9,490	CTUIR scenario assumes a rate of 25 m^3/day (365 days/yr) (Harris 2008). Yakama Nation scenario assumes a rate of 26 m^3/day (365 days/yr) (Ridolfi, 2007).
	Mass loading for inhalation	g/m^3	0.0001	0.0001	WDOH/320-015 (Appendix B).
	Exposure duration	year	70	70	Ridolfi, 2007; Harris and Harper, 2004.
	Indoor dust filtration factor	Unitless	0.4	0.4	RESRAD default.
	External gamma shielding factor	Unitless	0.4	0.4	EPA/540/R-00/007 (Equation 4).
	Indoor time fraction	Unitless	0.5	0.5	Fraction of the year spent onsite indoors. Both CTUIR and Yakama Nation scenarios assume 12 hr/day indoors, 365 days/yr (4380 hr/8,760 hr).
	Outdoor time fraction	Unitless	0.25	0.25	Fraction of the year spent onsite outdoors. Both CTUIR and Yakama Nation scenarios assume 6 hr/day outdoors, 365 days/yr (2,190 hr/8,760 hr).
	Shape factor	Not applicable.	Circular	Circular	RESRAD default.
R018 – Ingestion Pathway Data, Dietary Parameters	Soil ingestion intake	g/yr	146	73	CTUIR scenario is based on 400 mg/day (365 days/yr) (Harris 2008, Harris and Harper 2004). Yakama Nation scenario is based on 200 mg/day (365 days/yr) (Ridolfi 2007).
	Drinking water intake	L/yr	1,460	1,460	Both CTUIR and Yakama Nation scenarios are based on 4 L/day (365 days/yr) (Harris, 2008; Harris and Harper, 2004; Ridolfi, 2007).
	Leafy vegetable consumption	kg/yr	100	100	For the CTUIR scenario, Harris (2008, Figure 1) provides a value of 613 g/day (224 kg/yr) summed across categories of bulbs, other vegetation, greens, tea, medicines, spices, roots, and tubers. For the Yakama Nation scenario, Ridolfi (2007, Table 7) provides a value of 1,118 g/day (408 kg/yr) summed across categories of wild roots, stalks/leaves, and vegetables. A maximum value of 100 kg/yr can be input into the RESRAD code; the remaining portion (124 or 308 kg/yr, respectively) is assigned to "fruit, vegetable, and grain consumption."

Table D5-2. 216-A-4 Crib Summary of RESRAD Input Parameters for the Native American Exposure Scenarios (Unrestricted Land Use)

Description	Parameter	Units	CTUIR Scenario	Yakama Nation Scenario	Rationale and Citation
	Fruits, vegetables, and grain consumption	kg/yr	184	417	For the CTUIR scenario, Harris (2008, Figure 1) provides a value of 164 g/day (60 kg/yr) summed across categories of berries, fruits, honey, sweeteners, seeds, nuts, and grain. Also includes 124 kg/yr from "leafy vegetable consumption". For the Yakama Nation scenario, Ridolfi (2007, Table 7) provides a value of 299 g/day (109 kg/yr) summed across categories of fruits and wild berries. Also includes 308 kg/yr from "leafy vegetable consumption".
	Milk consumption	L/yr	Not applicable.	438	No value for CTUIR scenario given in Harris (2008) or Harper and Harris (2004). For Yakama Nation scenario, Ridolfi (2007, Table 7) provides a rate of 1.2 L/day (365day/yr).
	Meat and poultry consumption	kg/yr	68.3	154	CTUIR scenario assumes game, fowl, and egg consumption (187 g/day) is from penned livestock rather than game. Yakama Nation scenario assumes 60 percent of combined rate for game and meat (704 g/day) is from penned livestock.
	Game consumption	kg/yr	Not applicable.	Not applicable.	Contaminated area considered too small to support foraging wild game.
	Fish consumption	kg/yr	Not applicable.	Not applicable.	The consumption of fish is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Other seafood consumption	kg/yr	Not applicable.	Not applicable.	The consumption of seafood is considered an incomplete exposure pathway for waste site operable units within the Central Plateau.
	Drinking water contamination fraction	Unitless	1	1	RESRAD default.
	Household water contamination fraction	Unitless	Not applicable.	Not applicable.	Used in RESRAD only for computation of radon exposure.
	Livestock water contamination fraction	Unitless	1	1	RESRAD default.
	Irrigation water contamination fraction	Unitless	1	1	RESRAD default.
	Aquatic food contamination fraction	Unitless	Not applicable.	Not applicable.	Not applicable.
	Plant food contamination fraction	Unitless	-1	-1	RESRAD default.
	Meat contamination fraction	Unitless	-1	-1	Considers all of the meat from penned livestock is contaminated.
	Milk contamination fraction	Unitless	Not applicable.	-1	RESRAD default.

Table D5-2. 216-A-4 Crib Summary of RESRAD Input Parameters for the Native American Exposure Scenarios (Unrestricted Land Use)

Description	Parameter	Units	CTUIR Scenario	Yakama Nation Scenario	Rationale and Citation
R019 – Ingestion Pathway Data, Nondietary	Livestock fodder intake for meat	kg/d	68	68	RESRAD default.
	Livestock fodder intake for milk	kg/d	Not applicable	55	RESRAD default.
	Livestock water intake for meat	L/d	50	50	RESRAD default.
	Livestock water intake for milk	L/d	Not applicable.	160	RESRAD default.
	Livestock intake of soil	kg/d	0.5	0.5	RESRAD default.
	Mass loading for foliar deposition	g/m^3	0.0001	0.0001	RESRAD default.
	Depth of soil mixing layer	m	0.15	0.15	RESRAD default.
	Depth of roots	m	0.9	0.9	RESRAD default.

Table D5-3. Unsaturated Zone Strata RESRAD Modeling Input Values for the 216-A-4 Crib (Based on Geologic Data from Borehole C5301)

Geologic Unit Name	Unit Symbol	Top (ft bgs)	Bottom (ft bgs)	Thick (ft)	Thick (m)	m[a]	n	S[b]	a	f_f[c]	f_r	f_s
Holocene Deposits/Backfill	Bf	0	25	25	7.62	0.286	1.4	0.466	0.019	0.138	0.03	0.262
Hanford formation Coarse Sand	Hcs	25	51	26	7.92	0.508	2.031	0.044	0.061	0.041	0.027	0.349
Hanford formation Fine Sand	Hfs	51	274	223	67.97	0.539	2.168	0.075	0.027	0.058	0.032	0.379
Hanford formation Sandy Gravel	Hg	274	282	8	2.44	0.420	1.725	0.276	0.017	0.062	0.022	0.167
Hanford formation Silt	PPlz	282	298	16	4.88	0.555	2.249	0.447	0.005	0.210	0.04	0.419
Hanford formation Sandy Gravel	Hg	298	314	16	4.88	0.420	1.725	0.276	0.017	0.062	0.022	0.167

Notes:

Values of a, n, f_r, f_s are from PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, Table 4.5.

The parameters selected for the Hanford formation silt interval used the PPlz (from PNNL-14702, Table 4.5) to more closely match the silt content of the Hanford formation silt unit.

a. m 1-1/n

b. $S=[1+(ah)^n]^{-m}$, h = pressure corresponding to field capacity (-1/3 bar is commonly used)

c. Field Capacity=$S(f_s-f_r)+f_r$

bgs = below ground surface

Table D5-4. 216-A-4 Crib Radionuclide-Specific Exposure Point Concentrations and Distribution Coefficients

Radionuclide	EPC (pCi/g)	K_d (cm^3/g)
Am-241	3,810	300
Cs-137	63,600	2,000
Co-60	14.3	10
Eu-154	179	200
Pu-238	209	600
Pu-239	21,400	600
Sr-90	3,860,000	22
U-234	478	0.8
U-238	683	0.8
Ac-227	0	20
Np-237	0	10
Pa-231	0	50
Pb-210	0	100
Ra-226	0	20
Th-228	0	60,000
Th-229	0	60,000
Th-230	0	60,000
Th-232	0	60,000
U-233	0	0.8
U-235	0	0.8
U-236	0	0.8

EPC = exposure point concentration
K_d = distribution coefficient

D5.1 Exposure Scenario Input Values and Results

This section discusses the derivation of input values for key RESRAD parameters and provides analysis results for each of the exposure scenarios evaluated.

D5.1.1 Exposure Point Concentrations and Distribution Coefficients

The EPCs used in all three direct contact exposure scenarios are the maximum values of the radionuclides detected within the 5.6 to 6.4 m (18.5 to 21 ft) depth interval of borehole C4560.

In most cases, Pu-239 is the dominant isotope; for RESRAD input, it was assumed that the Pu-239/240 analytical value was entirely Pu-239. Similarly, the commonly accepted assumption is that the dominant isotope represented by the U-233/234 analytical result is U-234. Therefore, it was assumed that the U-233/234 analytical value was entirely U-234. The input values for all the radionuclide EPCs are shown in Table D2-4. Those radionuclides in Table D2-4 with zero concentrations represent the daughter products of the parent radionuclides selected for this analysis.

Additional data required for RESRAD input of these radionuclides are the associated K_ds. The radionuclide K_ds are based on the best estimate values obtained from PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, Table 4.11. K_d values for Co-60 and Am-241 were obtained from the "no impact" category from PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*, Table A.1.

D5.1.2 Contaminated Area

The contaminated area shown in the RESRAD input parameters summary (Table D2-1 and Table D2-2) was calculated based on the actual site area as recommended in PNNL-14702. The 216-A-4 Crib is 6.1 m (20 ft) wide and 6.1 m (20 ft) long with an area of 37.21 m^2 (400.53 ft^2). Equation 4.3 in PNNL-14702 was used to calculate the contaminated area (A_x) as follows:

$$A_x = \lambda A_0$$

$$\lambda = \frac{Q_{\max}}{k_{s\,\min} A_0}$$

Where:

A_0 = actual site area (m^2)
k_{smin} = minimum hydraulic conductivity of the unsaturated zone beneath the contaminated zone
Q_{max} = maximum artificial liquid discharge rate (m^3/s)

This equation is used to adjust the actual site area in the case when the dimensionless parameter λ is greater than 1. In the case when the dimensionless parameter λ is equal to or smaller than 1, no adjustment is needed and the contaminated area is equal to the actual site area.

The parameters in this equation were defined as follows.

- The liquid discharge rate was calculated from the total liquid discharge at the site, which is 6,210,000 liters (L) (1,639,440 gallons [gal]) over 4 years of operations based on DOE/RL-2001-65, *200-MW-1 Miscellaneous Waste Group Operable Unit RI/FS Work Plan*, Table 2-1, which is equivalent to 4.92×10^{-5} m^3/s. [does this need to be converted?].
- The minimum hydraulic conductivity is 17.6 m/yr (5.58×10^{-7} m/s) based on hydraulic conductivities presented in the RESRAD input parameters summary (Table D2-1 and Table D2-2).
- The dimensionless parameter λ is then 2.37, which is greater than 1. Consequently, the site area has to be adjusted. The resulting contaminated area used in all RESRAD analyses is 88.2 m^2 (949.5 ft^2).

D5.1.3 Contaminated Zone Soil Density

The soil density of the contaminated zone (RESRAD input parameter) was calculated based on the dry bulk density values provided in Appendix B. Four dry bulk density values reported are 1,740, 1,700, 1,550, and 1717 kg/m^3. The average dry bulk density is 1680 kg/m^3 (1.68 g/cm^3). This is in good agreement with the bulk density of the Hanford formation coarse sand (1.67 g/cm^3) in which the contaminated zone is located. The value of 1.68 g/cm^3 was used in the RESRAD calculations.

D5.1.4 Evapotranspiration Coefficient

The unitless evapotranspiration coefficient (C_e) is used in RESRAD to calculate the infiltration rate (I) through the unsaturated zone. The infiltration rate cannot be explicitly specified in RESRAD. It is calculated implicitly by RESRAD as (Equation E.4 in ANL/EAD-4):

$$I = (1 - C_e)[(1 - C_r)P_r + I_{rr})],$$

Where:

C_r	=	*run-off coefficient (unitless)*
P_r	=	*precipitation (m/yr)*
I_{rr}	=	*irrigation rate (m/yr)*

The run-off coefficient, precipitation, and irrigation rate are defined in Table D2-1 and Table D2-2 for the different scenarios considered for this analysis. The evapotranspiration coefficient was calculated as:

$$C_e = 1 - \frac{I}{(1-C_r)P_r + I_{rr}}$$

The infiltration rate used in this equation was 0.004 m/yr. This corresponds to the estimated long-term recharge rate (when the site stabilized and returns to the natural conditions) for Hanford sand (PNNL-14702, Table 4.15). The resulting evapotranspiration coefficient is 0.977.

D5.1.5 Analysis Results for the Industrial Worker Scenario

Results of the RESRAD analysis indicate that under the current site configuration the 216-A-4 Crib poses no radiological cancer risk for the industrial worker scenario. The calculated ELCR value is zero at the present time (analysis time zero) and is projected to remain at zero over the entire 1,000-year simulation period.

Three exposure routes are evaluated in this exposure scenario: external gamma radiation, incidental soil ingestion, and inhalation of dust particulates. The current site configuration indicates that a 5.6 m (18.5 ft) clean cover is placed over the 0.76 m (2.5 ft) contaminated zone. As a result of the shielding effects of the cover material, there is no exposure from the external gamma radiation exposure route. Additionally, there is no exposure from the inhalation and incidental ingestion exposure routes because deposition of contaminants on top of the cover soil has not occurred. The inhalation and incidental ingestion exposure routes would be complete if the contaminated zone were exposed at the surface. The contaminated zone would become exposed at the surface only when the clean cover erodes to a depth greater than 5.6 m (18.5 ft). The RESRAD model assumed an erosion rate of 1×10^{-5} m/yr; as a result, the contaminated zone will not be exposed at the surface during the 1,000 years of the simulation period, and therefore is not an exposure risk to an industrial worker.

D5.1.6 Analysis Results for the CTUIR Scenario

Results of the RESRAD analysis indicate that under the current site configuration there is no radiological cancer risk for the future CTUIR exposure scenario. The calculated ELCR value is zero at the present time (analysis time zero) and is projected to remain at zero over the entire 1,000-year simulation period. The CTUIR exposure scenario includes exposure from the direct contact pathway (that is, external gamma radiation, incidental soil ingestion, and inhalation of dust particulates) and the food chain pathway (that is, consumption of fruits and vegetables grown in a backyard garden and beef and poultry that graze and are penned on a rural pasture).

Exposure from the food chain pathway is contributed from uptake of contaminants that are currently in the soil and includes use of groundwater potentially contaminated by migration of radionuclides currently in the vadose zone beneath the 216-A-4 Crib. Drinking water ingestion and irrigation water use are activated in the RESRAD exposure analysis to evaluate potential future exposures resulting from migration to groundwater of contaminants currently located within the 5.6 to 6.4 m (18.5 to 21 ft) bgs depth interval. The groundwater pathway exposure modeling only addresses migration of contaminants currently measured in the vadose zone beneath the waste site. It does not address existing groundwater contamination underlying the 200-MW-1 Operable Unit.

Based on the current site configuration, there is no radiological risk for the CTUIR exposure scenario because the direct contact exposure pathway is incomplete (that is, the receptor cannot come into direct contact with contamination) and exposure through the food chain pathway cannot occur because the depth of contamination is greater than the rooting depth of typical homegrown fruit, produce, and livestock fodder.

The ground surface is currently shielded from the contaminated zone by 5.6 m (18.5 ft) of cover. Cover erosion over the 1,000-year evaluation time period is estimated to be approximately 1 cm (0.394 inches [in.]) (0.00001 m/yr × 1000 yr = 0.01 m). A loss of 1 cm (0.394 in.) is not sufficient to cause exposures from either the external gamma radiation exposure route or the food chain pathway through uptake of contamination into crops and livestock.

The groundwater pathway analysis indicates that none of the existing vadose zone contaminants would reach groundwater during the 1,000-year analysis period; therefore, there is no exposure contribution from either drinking water ingestion or the water dependent (irrigation) food chain pathways.

D5.1.7 Analysis Results for the Yakama Nation Scenario

Based on the current site configuration, there is no radiological cancer risk for the future Yakama Nation exposure scenario. The reasons for this are the same as those previously discussed for the CTUIR exposure scenario: the direct contact exposure pathway is incomplete, exposure through the food chain pathway cannot occur, and migration of existing vadose zone contamination would not result in exposure from groundwater use during the period of simulation.

D6 Summary

A summary of the RESRAD results for the scenarios evaluated for the 216-A-4 Crib is presented in Table D6-1. With the waste site in its current configuration, the radiological risk is zero for all scenarios over the entire 1,000-year simulation period.

Table D6-1. Summary of 216-A-4 Crib RESRAD Scenario Analyses

Scenario	Maximum Total Risk	Time of Maximum Total Risk (year)
Industrial with Cover—Baseline Risk Assessment	0	Not applicable.
Native American, Yakama Nation—Balancing and Modifying Criteria Evaluation	0	Not applicable.
Native American, CTUIR—Balancing and Modifying Criteria Evaluation	0	Not applicable.

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D7 216-A-2 and 216-A-4 Cribs Comparison Tables

Table D7-1 and Table D7-2 are provided for comparison of maximum soil concentrations for 216-A-2 and 216-A-4 Cribs to WAC 173-340-740, "Model Toxics Control Act—Cleanup," "Unrestricted Land Use Soil Cleanup Standards," levels.

Table D7-1. 216-A-2 Crib Comparison of Maximum Soil Concentrations from 0 to 12.2 m (0 to 40 ft) bgs to WAC 173-340-740 Cleanup Levels

Constituent Name	Maximum Detected Concentration from 0 to 12.2 m	Depth of Maximum Detected from 0 to 12.2 m	WAC 173-340-740 Cleanup Level	Does Maximum Concentration Exceed WAC 173-340-740 CUL?	Excess Lifetime Cancer Risk	Hazard Quotient
Metals Analyses (mg/kg)						
Chromium (VI)	0.22	29-31.5	240	No	NA	0.00092
General Inorganic Chemistry (mg/kg)						
Cyanide	0.23	29-31.5	1,600	No	NA	1.44E-04
Nitrite as N	0.78	29-31.5	8,000	No	NA	9.75E-05
Volatile Organic Compounds (mg/kg)						
1,2,4-Trimethylbenzene	5.50E-04	32-34.5	Not Available	No	NA	NA
Acetone	0.0082	32-34.5	72,000	No	NA	1.14E-07
Methylene Chloride	0.0037	32-34.5	133	No	2.78E-11	NA
Styrene	0.0090	32-34.5	33	No	2.70E-10	NA
Toluene	5.70E-04	32-34.5	6,400	No	NA	8.91E-08
Semi-volatile Organic Compounds (mg/kg)						
Bis (2-ethylhexyl)phthalate	0.047	32-34.5	71	No	6.58E-10	NA
Di-n-butylphthalate	0.038	32-34.5	8,000	No	NA	4.75E-06
Tributyl Phosphate	0.12	29-31.5	185	No	6.49E-10	NA
Miscellaneous Organic Analyses (mg/kg)						
Aroclor-1254	0.052	29-31.5	0.50	No	1.04E-07	NA

Notes:

Total Excess Lifetime Cancer Risk: 1.06E-07

Hazard Index: 0.00116

WAC 173-340-740, "Unrestricted Land Use Soil Cleanup Standards"

CUL = cleanup level

NA = Not applicable.

Table D7-1. 216-A-2 Crib Comparison of Maximum Soil Concentrations from 0 to 12.2 m (0 to 40 ft) bgs to WAC 173-340-740 Cleanup Levels

Constituent Name	Maximum Detected Concentration from 0 to 12.2 m	Depth of Maximum Detected from 0 to 12.2 m	WAC 173-340-740 Cleanup Level	Does Maximum Concentration Exceed WAC 173-340-740 CUL?	Excess Lifetime Cancer Risk	Hazard Quotient

Table D7-2. 216-A-4 Comparison of Maximum Soil Concentrations from 0 to 6.4 m (0 to 21 ft) Bgs to WAC 173-340-740 Cleanup Levels

Constituent Name	Maximum Detected Concentration from 0. 4.6 m	Depth of Maximum Detected from 0 to 6.4 m	WAC 173-340-740 Cleanup Level	Does Maximum Concentration Exceed WAC 173-340-740 CUL?	Excess Lifetime Cancer Risk	Hazard Quotient
Metals Analyses (mg/kg)						
Boron	144	18.5 - 21	16,000	No	NA	0.009
Uranium (metallic)	1,970	18.5 - 21	240	Yes	NA	8.2
Volatile Organic Compounds (mg/kg)						
Acetone	0.022	18.5 - 21	72,000	No	NA	3.13E-07
Methylene Chloride	0.011	18.5 - 21	133	No	8.25E-11	NA
Styrene	0.000	18.5 - 21	0,033	No	1.23E-11	NA
Miscellaneous Organic Analyses (mg/kg)						
Aroclor-1254	0.056	18.5 - 21	0.50	No	1.12E-07	NA
Aroclor-1260	0.047	18.5 - 21	0.50	No	9.40E-08	NA

Notes:

Total Excess Lifetime Cancer Risk: 2.1E-07

Hazard Index: 8.2

WAC 173-340-740, "Unrestricted Land Use Soil Cleanup Standards"

CUL = cleanup level

NA = not applicable

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Appendix E

Potential Applicable or Relevant and Appropriate Requirements

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E1 Potential Applicable or Relevant and Appropriate Requirements for the 200-MW-1 Operable Unit Waste Sites

This appendix identifies and evaluates potential applicable or relevant and appropriate requirements (ARARs) for remediation of the 200-MW-1 operable unit (OU) waste sites. The potential ARARs identified in this document provide the framework for determining or developing the levels to which contaminants must be remediated, and the manner in which the remedial action(s) shall be conducted to protect human health and the environment (HHE). Final ARARs will be established in the Record of Decision (ROD).

E1.1 ARARs Definition

Section 121 of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), as amended, requires, in part, that any applicable or relevant and appropriate standard, requirement, criterion or limitation promulgated under any federal environmental law, or any more stringent state requirement promulgated pursuant to a state environmental statute, be met (or a waiver justified) for any hazardous substance, pollutant, or contaminant that will remain on site after **completion** of the remedial action. The ARARs identification process is based on CERCLA guidance (EPA/540/G-89/006, *CERCLA Compliance with Other Laws Manual: Interim Final*; EPA/540/G-89/004, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA,* Interim Final).

The waste sites in the 200-MW-1 OU will be remediated under a CERCLA decision document; therefore, remedial action(s) at the individual waste sites will be required to meet ARARs. In many cases, the ARARs form the basis for the preliminary remediation goals (PRGs) to which contaminants must be remediated to protect HHE. ARARs also define or restrict how specific elements of a remedial alternative can be implemented based on the nature of the activity or the site's location.

An "applicable" requirement is an environmental requirement that a private party would have to comply with by law if the same action was being undertaken apart from CERCLA authority. All jurisdictional prerequisites of the requirement must be met in order for the requirement to be applicable.

"Relevant and appropriate" requirements are environmental requirements, such as cleanup standards, that address problems or situations sufficiently similar to those encountered at the CERCLA site so that their use is well-suited to the particular site (40 CFR 300.400(g)(2), "Identification of Applicable or Relevant and Appropriate Requirements"). A requirement that is relevant and appropriate may not meet one or more jurisdictional prerequisites for applicability but still makes sense at the site, given the circumstances of the site and the release. In evaluating the relevance and appropriateness of a requirement, the eight comparison factors in 40 CFR 300.400(g)(2) are considered:

1. The purpose of the requirement and the purpose of the CERCLA action
2. The medium regulated or affected by the requirement and the medium contaminated or affected at the CERCLA site
3. The substances regulated by the requirement and the substances found at the CERCLA site
4. The actions or activities regulated by the requirement and the remedial action contemplated at the CERCLA site
5. Any variances, waivers, or exemptions of the requirement and their availability for the circumstances at the CERCLA site

6. The type of place regulated and affected by the release or CERCLA action

7. The type and size of structure or facility regulated and the type and size of structure or facility affected by the release or contemplated by the CERCLA action

8. Any consideration of use or potential use of affected resources in the requirement and the use or potential use of the affected resource at the CERCLA site

In addition, potential ARARs were evaluated to determine if they fall into one of three categories: chemical-specific, location-specific, or action-specific. These categories are defined as follows:

- Chemical-specific requirements are usually health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, result in the establishment of public and worker safety levels and site cleanup levels.

- Location-specific requirements are restrictions placed on the concentration of dangerous substances or the conduct of activities solely because they occur in special geographic areas.

- Action-specific requirements are usually technology- or activity-based requirements or limitations triggered by the remedial actions performed at the site.

In summary, an environmental requirement is applicable if the specific terms or jurisdictional prerequisites of the law or regulations directly address the circumstances at the site. If not applicable, an environmental requirement may nevertheless be relevant and appropriate if 1) circumstances at the site are, based on best professional judgment, sufficiently similar to the problems or situations regulated by the requirement and 2) the requirement's use is well-suited to the site. Only the substantive requirements (for example, use of control/containment equipment, compliance with numerical standards) associated with ARARs apply to CERCLA onsite activities. ARARs associated with administrative requirements, such as permitting, are not applicable to CERCLA onsite activities (CERCLA, Section 121[e][1]). In general, this CERCLA permitting exemption will be extended to all remedial activities conducted at the 200-MW-1 OU.

CERCLA also provides for the identification of to-be-considered (TBC) information. TBC information is defined as non-promulgated advisories or guidance issued by federal or state governments that are not legally binding and do not have the status of potential ARARs. In some circumstances, TBCs will be considered along with ARARs in determining the remedial action necessary for protection of HHE. TBC information generally complements ARARs in determining protectiveness at a site or implementation of certain actions. For example, because soil cleanup standards do not exist for all contaminants, screening levels, which would be TBCs, may be helpful in defining appropriate remedial action goals.

Independent of the TBC and ARARs identification process at the Hanford Site, the requirements of U.S. Department of Energy (DOE) Orders must also be met.

E1.2 Waivers from Applicable or Relevant and Appropriate Requirements

The U.S. Environmental Protection Agency (EPA) may waive ARARs and select a remedial action that does not attain the same level of site cleanup as that identified by the ARARs. Section 121 of the *Superfund Amendments and Reauthorization Act of 1986* identifies six circumstances in which the EPA may waive ARARs for onsite remedial actions. The six circumstances are as follows:

- The remedial action selected is only a part of a total remedial action (such as an interim action), and the final remedy will attain the ARAR upon its completion.

- Compliance with the ARAR will result in a greater risk to HHE than alternative options.
- Compliance with the ARAR is technically impracticable from an engineering perspective.
- An alternative remedial action will attain an equivalent standard of performance through the use of another method or approach.
- The ARAR is a state requirement that the state has not consistently applied (or demonstrated the intent to apply consistently) in similar circumstances.
- In the case of Section 104 (Superfund-financed remedial actions), compliance with the ARAR will not provide a balance between protecting HHE and the availability of Superfund money for response at other facilities.

E1.2.1 Potential ARARS Identified for the 200-MW-1 Operable Unit

Potential federal and state ARARs are presented in Table E-1.

E1.2.2 Chemical-Specific ARARs

The chemical-specific ARARs that may affect remediation of the 200-MW-1 OU waste sites are the elements of the *Washington Administrative Code* (WAC) regulations that implement WAC 173-340, "Model Toxics Control Act – Cleanup." Within this branch of the WAC, there are detailed regulations associated with developing standards for remedial actions involving soil cleanup (WAC 173-340-745, "Soil Cleanup Standards for Industrial Properties" and WAC 173-340-747, "Deriving Soil Concentrations for Ground Water Protection"). These standards are in the form of risk-based concentrations that help establish soil cleanup standards for nonradioactive and radioactive contaminants.

Elsewhere with federal and state air regulations, there are emission standards that are likely to be important in identifying limits and control requirements for any remedial action that has the potential to produce hazardous air pollutants and radionuclides. WAC 173-303, "Dangerous Waste Regulations," also contains important standards applicable to the designation, management, and disposal of hazardous wastes and debris generated during remedial actions including Land Disposal Restrictions (LDRs) for wastes that will be land disposed.

E1.2.3 Location-Specific ARARs

Potential location-specific ARARs that have been identified for the 200 MW-01 OU include those that protect cultural, historical, and Native American sites and artifacts; migratory birds; and critical habitats of federally endangered and threatened species. However, these resources are not expected to be encountered during 200 MW-01 OU remediation.

E1.2.4 Action-Specific ARARs

Action-specific ARARs that could be pertinent to possible remediation activities relate to the state solid and dangerous waste regulations (for management of characterization and remediation wastes and performance standards for waste left in place) and the *Atomic Energy Act of 1954* regulations (for performance standards for radioactive waste sites).

In regard to waste management activities during remediation, a variety of waste streams may be generated under the proposed remedial action alternatives. It is anticipated that most of the waste will be designated as low-level radioactive waste (LLW). At the 216-A-2 Crib, there is contaminated soil that may meet the definition of transuranic (TRU) waste. The potential for encountering chemically hazardous (dangerous) waste or mixed dangerous and radioactive (mixed) waste, polychlorinated biphenyl (PCB) contaminated waste, and asbestos and asbestos-containing material (ACM) from buried pipelines and structures may also occur during remediation activities. Based on existing site information, the potential for encountering PCB-contaminated soil at concentrations above regulatory thresholds, mixed waste, and ACM is expected to be low.

The identification, treatment, storage, and disposal of hazardous wastes and debris, and the hazardous component of mixed waste, are governed by the *Resource Conservation and Recovery Act of 1976* (RCRA). The State of Washington is fully authorized to implement RCRA requirements under WAC 173-303. The WAC 173-303 standards for generation and storage would apply to the management of any dangerous or mixed waste generated, and its subsequent storage prior to final disposition, during this remedial action. Treatment standards for dangerous or mixed waste and hazardous debris, subject to RCRA LDRs as set forth by EPA in 40 CFR Part 268, are incorporated by reference into WAC 173-303-140, "Land Disposal Restrictions," which will also apply.

The *Toxic Substances Control Act of 1976* (TSCA), and regulations of 40 CFR Part 761 govern the management and disposal of PCB wastes. The TSCA regulations contain specific provisions for PCB waste, including PCB waste that contains a radioactive component. PCBs are also considered to be underlying hazardous constituents under RCRA, and thus could be subject to WAC 173-303 and 40 CFR 268, "Land Disposal Restrictions," requirements.

Removal and disposal of asbestos and ACM are regulated under 40 CFR Part 61, "National Emission Standards for Hazardous Air Pollutants," Subpart M, "National Emission Standard for Asbestos." This regulation provides for special precautions to prevent environmental releases or exposure to personnel of airborne emissions of asbestos fibers during remedial actions. 40 CFR 61.52, "National Emission Standards for Hazardous Air Pollutants," "Emission Standard," identifies packaging requirements. Asbestos and ACM would be removed, packaged as appropriate, and disposed in the Environmental Restoration Disposal Facility (ERDF).

Waste from the 200-MW-01 OU that is designated as LLW and that meets ERDF acceptance criteria is assumed to be disposed of at ERDF, which is engineered to meet appropriate performance standards under 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste". In addition, waste designated as dangerous or mixed waste would be treated, as appropriate to meet LDRs and ERDF acceptance criteria, and disposed of at ERDF. ERDF is engineered to meet minimum technical requirements for landfills under WAC 173-303-665, "Landfills." Applicable packaging and pre-transportation requirements for dangerous or mixed waste generated at the 200-MW-01 OU would be identified and implemented before movement of any waste. Alternate disposal locations may be considered when the remedial action occurs if a suitable and cost-effective location is identified. Any potential alternate disposal location will be evaluated for appropriate performance standards to ensure that it is adequately protective of HHE.

Waste designated as PCB remediation waste likely would be disposed at ERDF, depending on whether it is LLW and meets the waste acceptance criteria. PCB waste that does not meet ERDF waste acceptance criteria would be retained at a PCB storage area, meeting the requirements for TSCA storage, and would be transported for future treatment and disposal at an appropriate disposal facility. CERCLA Section 104(d)(4) states that where two or more noncontiguous facilities are reasonably related on the basis of geography, or on the basis of the threat or potential threat to the public health or welfare or the environment, the facilities can be treated as one for purposes of CERCLA response actions. Consistent with this, the 200-MW-1 OU and ERDF would be considered to be onsite for purposes of Section 104 of CERCLA, and waste may be transferred between the facilities without requiring a permit.

All remedial action alternatives will be performed in compliance with the waste management ARARs. Waste streams will be evaluated, designated, and managed in compliance with the ARAR requirements. Before disposal, waste will be managed in a protective manner to prevent releases to the environment or unnecessary exposure to personnel.

Table E-1. Identification of Potential Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) for the 200-MW-1 OU Waste Sites Remediation

Regulatory Citation	Type	Regulatory Requirements	Relevancy	Possible Actions
		Groundwater		
		***Safe Drinking Water Act of 1974* (SDWA) (42 USC 300(f) et seq.), "National Primary Drinking Water Standards" (40 CFR 141)**		
"Maximum Contaminant Levels/ Maximum Contaminant Level Goals for Organic Contaminants," 40 CFR 141.61/141.50	Federal Chemical	Establishes maximum contaminant levels (MCLs) and nonzero maximum contaminant levels goals (MCLGs) as criteria for groundwater and surface water that is or may be used for drinking water. The standards/goals are designed to protect human health from adverse effects of organic contaminants in the drinking water.	ARAR	Chemical groundwater monitoring for wastes contained or treated on site and monitored natural attenuation.
"Maximum Contaminant Levels / Maximum Contaminant Level Goals for Inorganic Contaminants," 40 CFR 141.62/141.51	Federal Chemical	Establishes maximum contaminant levels (MCLs) and nonzero maximum contaminant levels goals (MCLGs) as criteria for groundwater and surface water that is or may be used for drinking water. The standards/goals are designed to protect human health from adverse effects of inorganic contaminants in the drinking water.	ARAR	Chemical groundwater monitoring for wastes contained or treated on site and monitored natural attenuation.
"Maximum Contaminant Levels / Maximum Contaminant Level Goals for Radionuclides," 40 CFR 141.66/141.55	Federal Chemical	Establishes maximum contaminant levels (MCLs) and nonzero maximum contaminant levels goals (MCLGs) as criteria for groundwater and surface water that is or may be used for drinking water. The standards/goals are designed to protect human health from adverse effects of radionuclides in the drinking water.	ARAR	Chemical groundwater monitoring for wastes contained or treated on site and monitored natural attenuation.
		Vadose Zone Soil		
		"Public Health and Safety," "Hazardous Waste Cleanup – Model Toxics Control Act" (RCW 70.105D)		
"Model Toxics Control Act -- Cleanup," "Soil Cleanup Standards for Industrial Properties," WAC 173-340-745(1) and WAC 173-340-745(5)(b)	State Chemical	Establishes soil cleanup levels where industrial land use represents the reasonable maximum exposure under both current and future site use conditions. The Hanford Comprehensive land Use Plan Environmental Impact Statement (HCP EIS) and associated ROD issued in 1999 designated the 200-MW-1 OU waste sites as an 'Industrial-Exclusive' land use area.	ARAR	Verification sampling of partial and completed remedial actions that involve filling, excavation, etc. to demonstrate that the concentration of hazardous substances in soil remaining on site following meet MTCA Method C cleanup levels
"Soil Cleanup Standards for Industrial Properties," WAC 173-340-745(1) and WAC 173-340-745(5)(b)	State Chemical	Establishes soil cleanup levels where industrial land use represents the reasonable maximum exposure under both current and future site use conditions. The Hanford Comprehensive land Use Plan Environmental Impact Statement (HCP EIS) and associated ROD issued in 1999 designated the 200-MW-1 OU waste sites as an 'Industrial-Exclusive' land use area.	ARAR	Verification sampling of partial and completed remedial actions that involve filling, excavation, etc. to demonstrate that the concentration of hazardous substances in soil remaining on site following meet MTCA Method C cleanup levels
"Deriving Soil Concentrations for Groundwater Protection, WAC 173-340-747	State Chemical	Establishes soil cleanup levels that will not cause contamination of groundwater at levels that exceed groundwater cleanup levels established under WAC 173-340-720.	ARAR	Future soil cleanup actions where concentration of hazardous substances in the soil exceeds soil concentrations for groundwater protection at the relevant point of compliance.
"Terrestrial Ecological Evaluation Procedures," WAC 173-340-7490 through "Priority Contaminants of Ecological Concern," WAC 173-340-7494	State Chemical	Defines goals and procedures for determining whether a release of hazardous substances to soil may pose a threat to the terrestrial environment; characterizes existing or potential threats to terrestrial plants or animals exposed to hazardous substances in soil; and establishes site-specific cleanup standards for the protection of terrestrial plants and animals.	ARAR	Potential future soil remediation activities may include excavation and use of overburden soil. The soil may contain contaminants that require evaluation to determine if ecological exposures have the potential to cause significant adverse effects.
		Guidance		
"Regional Screening Levels (RSL) for Chemical Contaminants at Superfund Sites" (EPA, 2009)	Federal Chemical Guidance	Provides a set of risk-based screening levels to help determine whether levels of contamination found at CERCLA Hazardous Waste sites may warrant further investigation or site cleanup, or whether no further investigation or action may be required. The RSLs provides tables of human health risk-based screening levels calculated using the latest toxicity values, default exposure assumptions and physical and chemical properties.	TBC	Delineation of areas, contaminants, and conditions during remedial investigations and site cleanup.
Guidance for Developing Ecological Soil Screening Levels, OSWER Directive 9285.7-55 (EPA, 2003)	Federal Chemical Guidance	Provides a set of ecological risk-based soil screening levels (Eco-SSLs) for several soil contaminants that are of ecological concern for terrestrial plants and animals at hazardous waste sites. Also describes the process used to derive these levels and provides guidance for their use.	TBC	Identification of areas, contaminants, and conditions that require further remedial investigation.

Table E-1. Identification of Potential Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) for the 200-MW-1 OU Waste Sites Remediation

Regulatory Citation	Type	Regulatory Requirements	Relevancy	Possible Actions
, "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination," OSWER No. 9200.4-18(Luftig and Weinstock, 1997) and "Distribution of OSWER Radiation Risk Assessment Q & A's Final Guidance" (Luftig and Page, 1999)	Federal Chemical Guidance !	This memorandum presents clarification for establishing protective cleanup levels in media including soil for radioactive contamination at CERCLA sites. EPA has determined that the dose limits established in 62 FR 39058, "Radiological Criteria for License Termination Final Rule" (25 mrem/yr which is equivalent to 5 x 10 –4 increase lifetime risk) will not provide a protective basis for establishing preliminary remediation goals (PRGs) under CERCLA. A dose of 15 mrem/yr effective dose equivalent (approximately equivalent to 3 x 10 –4 increase lifetime risk) is preferred as the maximum dose limit for humans. In the Final Guidance, EPA further clarifies that 15 milli-rem per year is not a presumptive cleanup level under CERCLA. Rather, site decision makers should continue to use the CERCLA risk range when ARARs are not used to set cleanup levels. This is because for several reasons, using dose-based guidance would result in unnecessary inconsistency regarding how radiological and non-radiological (chemical) contaminants are addressed at CERCLA sites.	TBC	Development of soil cleanup levels for remediation and associated verification.
		Air		
		***Clean Air Act of 1977* (42 USC 7401 et seq.), "Standards of Performance for New Stationary Sources" (40 CFR 60)**		
"Standards of Performance For New Stationary Sources," 40 CFR 60	Federal Action	Applies to specific stationary sources that emit toxic air pollutants where construction or modification of the facility commences after the effective date of any standard promulgated in this regulation.	ARAR	Soil remedial activities (e.g., full and/or partial RTD, E/T cover installation activities decontamination, demolition, and other site preparation and/or excavation activities) that have the potential to emit visible, particulate, fugitive, and hazardous air emissions and odors.
		***Clean Air Act of 1977* (42 USC 7401 et seq.), "National Primary and Secondary Ambient Air Quality Standards" (40 CFR 50)**		
"National Primary and Secondary Ambient Air Quality Standards for Particulate Matter," 40 CFR 50.7	Federal Action	Establishes primary and secondary air quality standards for particulate matter, which are 15 µg/m^3 annually or 65 µg/m^3 per 24-hour average concentration.	ARAR	Particulates and dust can be generated during RI/FS actions. Remediation activities (e.g., excavation, RTD, containment) that have the potential to emit particulate matter above maximum acceptable levels. May be applicable in evaluating whether or not there are air impacts at the site during remediation activities.
		"Washington Clean Air Act" (RCW 70.94), "General Regulations for Air Pollution Sources" (WAC 173-400)		
"General Standards for Maximum Emissions," WAC 173-400-040	State Action	Requires all sources of air contaminants to meet emission standards for visible, particulate, fugitive, odors, and hazardous air emissions. Requires use of reasonably available control technology.	ARAR	If remedial actions result in visible, particulate, fugitive, and hazardous air emissions and odors, applicable control technology is required.
"General Standards for Maximum Emissions," WAC 173-400-040	State Action	All sources and emissions units are required to meet the general emission standards unless a specific source standard is available. General standards apply to visible emissions, particulate fallout, fugitive emissions, odors, emission detrimental to health and property, sulfur dioxide, and fugitive dust.	ARAR	For actions performed at the 200-MW-1 OU that have the potential to release hazardous air emissions.
"Emission Standards for General Process Units," WAC 173-400-060	State Action	General process units are required to meet all applicable provisions of WAC 173-400-040 and, no person shall cause or allow the emission of particulate material from any general process operation in excess of 0.23 grams per dry cubic meter at standard conditions (0.1 grain/dscf) of exhaust gas. EPA test methods (in effect on February 20, 2001) from 40 CFR Parts 51, 60, 61, and 63 and any other approved test procedures which are contained in Ecology's *Source Test Manual - Procedures for Compliance Testing* as of July 12, 1990, will be used to determine compliance.	ARAR	For actions performed at the 200-MW-1 OU that have the potential to release hazardous air emissions.

Table E-1. Identification of Potential Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) for the 200-MW-1 OU Waste Sites Remediation

Regulatory Citation	Type	Regulatory Requirements	Relevancy	Possible Actions
"Emission Standards for Sources Emitting Hazardous Air Pollutants," WAC 173-400-075	State Action	Establishes national emission standards for hazardous air pollutants. Adopts, by reference, 40 CFR 61 and Appendices.	ARAR	For actions performed at the 200-MW-1 OU that could result in the emission of hazardous air pollutants including decontamination, demolition, and excavation activities implemented during remediation tat have the potential to emit visible, particulate, fugitive, and hazardous air emissions and odors.
"Requirements for New Sources in Attainment or Unclassifiable Areas," WAC 173-400-113	State Action	Defines methods of control to be employed to minimize the release of air contaminants associated with fugitive emissions resulting from materials handling, construction, demolition, or other operations. Emissions are to be minimized through application of best available control technology.	ARAR	For actions performed at the 200-MW-1 OU that could result in the emission of hazardous air pollutants including decontamination, demolition, and excavation activities implemented during the RI/FS that have the potential to emit visible, particulate, fugitive, and hazardous air emissions and odors.
"Washington Clean Air Act" (RCW 70.94), "Controls for New Sources of Toxic Air Pollutants" (WAC 173-460)				
"Control Technology Requirements," WAC 173-460-060(1)	State Action	Requires that person shall not establish, operate, or cause to be established or operated any new or modified toxic air pollutant source which is likely to increase TAP emissions without installing and operating best available control technology (BACT).	ARAR	For actions performed at the 200-MW-1 OU that have the potential to increase TAP emissions subject to BACT.
"Ambient Impact Requirement," WAC 173-460-070	State Action	Must demonstrate that the increase in emissions of toxic air pollutants from the new or modified emission units at the source are sufficiently low to protect human health and safety from potential carcinogenic and/or other toxic effects. Compliance must be demonstrated in any area to which the applicant does not restrict or control access by using procedures established in this chapter.	ARAR	For actions performed at the 200-MW-1 OU that have the potential to increase TAP emissions.
"First Tier Review," WAC 173-460-080	State Action	Must include an acceptable source impact level analysis for each TAP emitted by the new or modified emission units with an emission increase greater than the de minimis emission level specified in WAC 173-460-150. The acceptable source impact analysis requirement of WAC 173-460-070 can be satisfied for any TAP using either dispersion modeling or the small quantity emission rate.	ARAR	For actions performed at the 200-MW-1 OU that have the potential to increase TAP emissions.
"Table of ASIL, SQER and De Minimis Emission Values," WAC 173-460-150	State Action	Provides the common name of toxic air pollutants, the chemical abstract service (CAS) number; the averaging period; the acceptable source impact level (ASIL); the small quantity emission rate (SQER); and de minimis emission values.	ARAR	For actions performed at the 200-MW-1 OU that have the potential to increase TAP emissions.
"Washington Clean Air Act" (RCW 70.94), "Ambient Air Quality Standards for Particulate Matter" (WAC 173-470)				
"Ambient Air Quality Standards," WAC 173-470-100	State Action	Sets maximum acceptable levels for particulate matter in the ambient air at 150 $\mu g/m^3$ over a 24-hour period, or 60 $\mu g/m^3$ annual geometric mean. It also sets the 24-hour ambient air concentration standard for particles less than 10 µm in diameter (PM10), which is set at 105 $\mu g/m^3$ and 50 $\mu g/m^3$ geometric mean.	ARAR	For remediation activities (e.g., excavation, RTD, containment) that have the potential to emit particulate matter above maximum acceptable levels. May be applicable in evaluating whether or not there are air impacts at the site during remediation activities
"Particle Fallout Standards," WAC 173-470-110	State Action	Establishes the standard for particle fallout not to exceed 10 g/m^2 per month in an industrial area or 5 g/m^2 per month in residential or commercial areas. Alternative levels for areas where natural dust levels exceed 3.5 g/m^2 per month are set at 6.5g/m2 per month, plus background levels for industrial areas and 1.5 g/m^2 per month plus background in residential and commercial areas	ARAR	For remediation activities (e.g., excavation, RTD, containment) that have the potential to emit particulate matter above maximum acceptable levels.
"Washington Clean Air Act" (RCW 70.94), "Ambient Air Quality Standards and Emission Limits for Radionuclides" (WAC 173-480)				
"Ambient Standard," WAC 173-480-040	State Action	Sets the ambient air standard under 40 CFR 61, Subpart H and I are not to exceed amounts that result in an effective dose equivalent of 10 mrem/yr to any member of the public. For workers, the maximum allowable level for radionuclides in the ambient air shall not cause a maximum accumulated dose equivalent of 25 mrem/yr to the whole body or 75 mrem/yr to any critical organ.	ARAR	For remediation activities (e.g., excavation, RTD, demolition, ventilation, vacuuming/exhaust) that have the potential to emit radionuclides above maximum acceptable levels.

Table E-1. Identification of Potential Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) for the 200-MW-1 OU Waste Sites Remediation

Regulatory Citation	Type	Regulatory Requirements	Relevancy	Possible Actions
"General Standards for Maximum Permissible Emissions," WAC 173-480-050(1)	State Action	All radionuclide emission units are required to meet the emission standards in this chapter. At a minimum all emission units shall meet chapter 246-247 or 246-248 WAC (as applicable) requiring every reasonable effort to maintain radioactive materials in effluents to unrestricted areas, as low as reasonably achievable (ALARA). For the purposes of this chapter, control equipment of facilities operating under ALARA shall be defined as best available radionuclide control technology (BARCT).	ARAR	For remediation units, control equipment, etc. utilized at the 200-MW-1 OU that have the potential to increase radionuclide emissions subject maximum permissible emission limits.
"Emission Standards for New and Modified Emission Units," WAC 173-480-060(1) and (2)	State Action	Construction, installation, or establishment of a new emission unit subject to this chapter shall utilize best available radionuclide control technology (BARCT). Additions to, enlargement, modification, replacement, alteration of any process or emission unit or replacement of air pollution control equipment which will significantly change potential radionuclide emissions or significantly change the dose equivalent will require the proposed project to utilize best available radionuclide control technology (BARCT) for emission control.	ARAR	For remediation equipment with emission units (new and/or modifications thereof) that will significantly change potential radionuclide emissions or significantly change the dose equivalent.
"Emission Monitoring and Compliance Procedures," WAC 173-480-070(2)	State Action	Requires that radionuclide emissions shall be determined by calculating the dose to members of the public using department of health approved sampling procedures at the point of maximum annual air concentration in an unrestricted area where any member of the public may be.	ARAR	If remedial actions result in radioactive air emissions, the dose to members of the public at the point of maximum annual air concentration in an unrestricted area where any member of the public may be need to be calculated.
		"Nuclear Energy and Radiation" (RCW 70.98), "Radiation Protection-Air Emissions" (WAC 246-247)		
"National Standards Adopted by Reference for Sources of Radionuclide Emissions," WAC 246-247-035(1)(a)(ii)	State Action	This regulation incorporates requirements of 40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities," by reference. Radionuclide airborne emissions from the facility shall be controlled so as not to exceed amounts that would cause an exposure to any member of the public of greater than 10 mrem/yr effective dose equivalent.	ARAR	If remedial actions result in visible, particulate, fugitive, and radioactive air emissions, applicable control technology is required. Substantive requirements of this standard are pertinent because this remedial action may provide airborne emissions of radioactive particulates to unrestricted areas. As a result, requirements limiting emissions apply.
"General Standards," WAC 246-247-040(3) and (4)	State Action	Emissions shall be controlled to ensure that emission standards are not exceeded. Actions creating new sources or significantly modified sources shall apply best available controls. All other actions shall apply reasonably achievable controls.	ARAR	If remedial actions in the 200 OA-1 Operable Units result in visible, particulate, fugitive, and radioactive air emissions, applicable control technology is required.
"Monitoring, Testing, and Quality Assurance," WAC 246-247-075(1), (2), (3), and (4)	State Action	1) All radioactive air emissions monitoring, testing, and quality assurance requirements of 40 CFR 61, subparts H and I (as effective on October 9, 2002), are adopted by reference, as applicable as specified by the referenced subparts. 2) Equipment and procedures used for the continuous monitoring of radioactive air emissions shall conform, as applicable, to the guidance contained in ANSI N13.1, ANSI N42.18, ANSI N323, ANSI N317, reference methods 1, 1A, 2, 2A, 2C, 2D, 4, 5, and 17 of 40 CFR Part 60, Appendix A, 40 CFR Part 52, Appendix E, and any other methods approved by the department. 3) The operator of an emission unit with a potential-to-emit of less than 0.1 mrem/yr TEDE to the MEI may estimate those radionuclide emissions, in lieu of monitoring, in accordance with 40 CFR 61 Appendix D, or other procedure approved by the department. The department may require periodic confirmatory measurements (e.g., grab samples) during routine operations to verify the low emissions. Methods to implement periodic confirmatory monitoring shall be approved by the department. 4) The department may allow a facility to use alternative monitoring procedures or methods if continuous monitoring is not a feasible or reasonable requirement.	ARAR	Substantive requirements of this standard are pertinent when fugitive and non-point source emissions of radionuclides to the ambient air may result from activities, such as operation of exhauster and vacuums, performed during a remedial action. This standard exists to ensure compliance with emission standards.
"Monitoring, Testing and Quality Assurance," WAC 246-247-075(8)	State Action	Facility (site) emissions resulting from non-point and fugitive sources of airborne radioactive material shall be measured. Measurement techniques may include ambient air measurements, or in-line radiation detector or withdrawal of representative samples from the effluent stream, or other methods as determined by the lead agency.	ARAR	Substantive requirements are pertinent when fugitive and diffuse emissions of airborne radioactive material due to excavation and related activities occur and will require measurement.

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Regulatory Citation	Type	Regulatory Requirements	Relevancy	Possible Actions
		Guidance		
		Radionuclide ARAR Dose Compliance Concentrations (DCCs) for Superfund		
Luftig and Weinstock, 1997 Luftig and Page, 1999	Federal Chemical and Action Guidance	This memorandum presents clarification for establishing protective cleanup levels in media for radioactive contamination at *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) sites. EPA has determined that the dose limits established in 62 FR 39058 (25 mrem/yr which is equivalent to 5 x 10 –4 increase lifetime risk) will not provide a protective basis for establishing preliminary remediation goals (PRGs) under CERCLA. A dose of 15 mrem/yr effective dose equivalent (approximately equivalent to 3 x 10 –4 increase lifetime risk) is preferred as the maximum dose limit for humans. In the Final Guidance, EPA further clarifies that 15 millirem per year is not a presumptive cleanup level under CERCLA. Rather, site decision makers should continue to use the CERCLA risk range when ARARs are not used to set cleanup levels. This is because for several reasons, using dose-based guidance would result in unnecessary inconsistency regarding how radiological and non-radiological (chemical) contaminants are addressed at CERCLA sites.	TBC	Development of media cleanup levels for remediation and associated verification.
		Polychlorinated Biphenyls (PCBs)		
		***Toxic Substances Control Act of 1976* (TSCA) (15 USC 2601 et seq.), "Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions" (40 CFR 761)**		
"Applicability," (for PCB Disposal) 40 CFR 761.50(b)1, 2, 3, .4 and 7 40 CFR 761.50(c)	Federal Action	Establishes general PCB disposal requirements for the storage and disposal of PCB wastes including liquid PCB wastes, PCB Items, PCB Remediation Waste, PCB Bulk Product Wastes and PCB/Radioactive Wastes at concentrations greater than 50 ppm.	ARAR"	Applies to soil excavation and remediation, equipment and debris handling and disposal, and Investigation-Derived Waste (IDW) management and disposal if PCB contamination is encountered.
"Disposal Requirements," 40 CFR 761.60(a), (b), and (c)	Federal Action	Establishes requirements applicable to the handling and disposal of PCB Liquids and PCB Articles and PCB Containers.	ARAR	Applies to equipment and debris handling, storage, and disposal, IDW management and disposal if PCB articles and/or containers are encountered
"PCB Remediation Waste," 40 CFR 761.61	Federal Action	Provides cleanup and disposal options for PCB remediation waste based on the concentration at which the PCBs are found.	ARAR	Applies to soil remediation (e.g., Retrieve, Treat, and Dispose (RTD) remedies), Debris, and IDW management and disposal if PCB wastes are encountered.
		Hazardous and Solid Waste		
		"Solid Waste Management – Reduction and Recycling" (RCW 70.105, as amended)		
"Owner Responsibilities for Solid Waste," WAC 173-350-025 "Performance Standards," WAC 173-350-040 "Onsite Storage, Collection and Transportation Standards," WAC 173-350-300	State Action	Establishes minimum functional performance standards for the proper handling and disposal of solid waste. Establishes requirements for the proper handling of solid waste materials originating from residences, commercial, agricultural, and industrial operations and other sources and identifies those functions necessary to ensure effective solid waste handling programs at both the state and local levels.	ARAR	Solid, non-dangerous waste may be generated during the implementation of the RI/FS.
		***Washington State Hazardous Waste Management Act of 1976*" (RCW 70.105, as amended), "Dangerous Waste Regulations" (WAC 173-303)**		
"Identifying Solid Waste and Recycling Processes Involving Solid Waste," WAC 173-303-016	State Action	Identifies those materials that are and are not solid wastes.	ARAR	Potential investigative and/or remedial actions that may result in solid waste being generated and managed. Substantive requirements of this regulation are pertinent because they define which materials are subject to the designation regulations.
"Recycling Processes Involving Solid Waste," WAC 173-303-017	State Action	Identifies materials that are and are not solid wastes when recycled.	ARAR	For identifying wastes that are not solid wastes when recycled from investigative and remediation activities (i.e., disposal,

Table E-1. Identification of Potential Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) for the 200-MW-1 OU Waste Sites Remediation

Regulatory Citation	Type	Regulatory Requirements	Relevancy	Possible Actions
				storage, recycling, and on-site treatment).
"Designation of Dangerous Waste," WAC 173-303-070(3)	State Action	Establishes whether a solid waste is, or is not, a dangerous waste or an extremely hazardous waste.	ARAR	For identifying if wastes generated from investigative and remediation activities (i.e., disposal, storage, recycling, and on-site treatment) are dangerous or extremely hazardous wastes.
"Excluded Categories of Waste," WAC 173-303-071	State Action	Describes those categories of wastes that are excluded from the requirements of WAC 173-303 (excluding "Department of Ecology Cleanup Authority," WAC 173-303-050).	ARAR	For Investigative and remediation activities (i.e., disposal, storage, recycling, and on-site treatment) that may be excluded from the requirements of this standard.
"Conditional Exclusion of Special Wastes," WAC 173-303-073	State Action	Establishes the conditional exclusion and the management requirements of special wastes, as defined in "Definitions," WAC 173-303-040.	ARAR	Substantive requirements of these regulations apply to special wastes if generated during investigative and/or remedial actions.
"Requirements for Universal Waste," WAC 173-303-077	State Action	Identifies those wastes exempted from regulation under WAC 173-303-140 and WAC 173-303-170 through "Special Waste Bill of Lading," WAC 173-303-9906 (excluding "Special Powers and Authorities of the Department," WAC 173-303-960). These wastes are subject to regulation under "Standards for Universal Waster Management," WAC 173-303-573.	ARAR	Substantive requirements are pertinent to investigative and/or remedial actions if Universal Wastes are generated.
"Recycled, Reclaimed, and Recovered Wastes," WAC 173-303-120 WAC 173-303-120(3) WAC 173-303-120(5)	State Action	These regulations define the requirements for recycling materials that are solid and dangerous waste. Specifically, WAC 173-303-120(3) provides for the management of certain recyclable materials, including spent refrigerants, antifreeze, and lead acid batteries. WAC 173-303-120(5) provides for the recycling of used oil.	ARAR	Remediation recycling activities consistent with the requirements of this WAC and are not otherwise subject to CERCLA requirements as hazardous substances.
"Land Disposal Restrictions," WAC 173-303-140 WAC 173-303-140(2)(a)	State Action	Establishes treatment requirements and disposal prohibitions for land disposal of dangerous waste and incorporates by reference Federal land disposal restrictions (LDRs) of 40 CFR 268, that are applicable to solid waste that is designated as dangerous or mixed waste in accordance with WAC 173-303-070(3). Incorporates by reference Part 268.45 requiring hazardous debris to be treated prior to land disposal, using specific technologies from one or more of approved of debris treatment technologies.	ARAR	For remediation wastes that are dangerous wastes destined for land waste disposal, including excavated soil, debris, and treatment residuals. Waste profiles and designations must be developed and approved for each waste source in accordance with the requirements specified in approved Disposal Sites' waste acceptance criteria which includes compliance with land disposal requirements
"Requirements for Generators of Dangerous Waste," WAC 173-303-170	State Action	Establishes the requirements for dangerous waste generators. WAC 173-303-170(3) includes the substantive provisions of WAC 173-303-200 by reference. WAC 173-303-200 further includes certain substantive standards from "Use and Management of Containers," WAC 173-303-630, and "Tank Systems," WAC 173-303-640 by reference. Specifically, the substantive standards for management of dangerous/ mixed waste are relevant and appropriate to the management of dangerous waste that will be generated during the remedial action.	ARAR	Potential investigative and/or remedial actions may generate dangerous waste (i.e. investigation derived wastes [IDW] and treatment chemicals, contaminated soil and groundwater, etc.).
"Accumulating Dangerous Waste On-Site," WAC 173-303-200	"State Action	Establishes the requirements for accumulating wastes on-site. WAC 173-303-200 further includes certain substantive standards from WAC 173-303-630, Container Management, and -640 by reference.	ARAR	For management of dangerous waste during remedial and investigative actions
"Purpose and Applicability," WAC 173-303-64610 "Requirements," WAC 173-303-64620	State Action	Establishes requirements for corrective action for releases of dangerous wastes and dangerous constituents including releases from solid waste management units and spill sites requiring cleanup.	ARAR	The *Hanford Federal Facility Agreement and Consent Order* (Ecology et al., 1989) requires that CERCLA remedial actions also meet the technical requirements of RCRA corrective action. Substantive portions of this regulation are pertinent to establish minimum requirements for *Washington State Hazardous Waste Management Act of 1976* corrective action.
"Landfills," WAC 173-303-665	State Action	Specifies design and operating and closure/post-closure requirements for landfills including the liner system (WAC 173-303-665(2)(i)).	ARAR	For containment remedies that may use a monofill evapotranspiration barrier or cover

Table E-1. Identification of Potential Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) for the 200-MW-1 OU Waste Sites Remediation

Regulatory Citation	Type	Regulatory Requirements	Relevancy	Possible Actions
		Historical or Ecological Resources		
		***American Indian Religious Freedom Act* (42 USC 1996 et seq.)**		
American Indian Religious Freedom Act	Federal Location	Protects religious, ceremonial, and burial sites and the free practice of religions by Native American groups.	ARAR	Burial sites may exist within the 200 OA 1 Operable Units. The substantive requirements of this act apply to activities that could cause the loss of religious or burial data.
		***Archeological and Historic Preservation Act* (1960) (16 USC 469-469c et seq.)**		
Archeological and Historic Preservation Act (1960)	Federal Location	Requires that remedial actions do not cause the loss of any archaeological or historic data. This act mandates preservation of the data but does not require protection of the actual historical sites.	ARAR	Archaeological or historic sites may exist within the 200 OA-1 Operable Units a. The substantive requirements of this act apply to activities that could cause the loss of archaeological or historic data.
		***National Historic Preservation Act of 1966* (16 USC 470, Section 106, et seq.)**		
National Historic Preservation Act of 1966	Federal Location	Requires federal agencies to consider the impacts of their undertaking on cultural properties through identification, evaluation, and mitigation processes.	ARAR	Cultural and historic sites may exist within the 200 OA-1 Operable Units. The substantive requirements of this act are applicable to actions that disturb these sites.
		***Native American Graves Protection and Repatriation Act of 1990* (25 USC 3001, et seq.)**		
Native American Graves Protection and Repatriation Act	Federal Location	Establishes federal agency responsibility for discovery of human remains, associated and unassociated funerary objects, sacred objects, and items of cultural patrimony.	ARAR	The substantive requirements of this act apply to remedial activities and areas where Native American graves and related objects may occur.
		***Migratory Bird Treaty Act* (1918) (MBTA) (16 USC 703 et seq.)**		
Migratory Bird Treaty Act (1918)	Federal Location	Implements various treaties and conventions for the protection of migratory birds. Under this Act, taking, killing or possessing migratory birds is unlawful.	ARAR	Remediation activities that have the potential to kill migratory birds and/or destroy their eggs or nests.
		"Fish and Wildlife," Powers and Duties," "Habitat Buffer Zone for Bald Eagle—Rules" (RCW 77.12.655), "Permanent Regulations" (WAC 232-12)		
"Bald Eagle Protection Rules," WAC 232-12-292	State Location	Protects eagle habitat to maintain eagle populations so that the species are not classified as threatened, endangered, or sensitive in Washington State.	ARAR	Remediation activities that may occur on or can impact Bald Eagle critical habitats and/or designated buffer zones. (Bald Eagles are found along the Columbia River and adjoining land.)
		Guidance		
66 FR 3853, "Responsibilities of Federal Agencies to Protect Migratory Birds"	Federal Location and Action Guidance	Encourages federal agencies to integrate migratory bird conservation principles into plans and actions.	TBC	Potential remedial actions that may affect migratory bird species.
		Well Construction		
		***Water Well Construction Act of 1971* (RCW 18.104), "Minimum Standards for Construction and Maintenance of Wells" (WAC 173-160)**		
WAC 173-160	State Action	Identifies well planning and construction requirements.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Requirements for the Location of the Well Site and Access to the Well?" WAC 173-160-171	State Action	Identifies the requirements for locating a well.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Requirements for Preserving the Natural Barriers to Ground Water Movement Between Aquifers?" WAC 173-160-181	State Action	Identifies the requirements for preserving natural barriers to groundwater movement between aquifers.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.

Table E-1. Identification of Potential Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) for the 200-MW-1 OU Waste Sites Remediation

Regulatory Citation	Type	Regulatory Requirements	Relevancy	Possible Actions
"What Are the Minimum Standards for Resource Protection Wells and Geotechnical Soil Borings?" WAC 173-160-400	State Action	Identifies the minimum standards for resource protection wells and geotechnical soil borings.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the General Construction Requirements for Resource Protection Wells?" WAC 173-160-420	State Action	Identifies the general construction requirements for resource protection wells.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Minimum Casing Standards?" WAC 173-160-430	State Action	Identifies the minimum casing standards.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Equipment Cleaning Standards?" WAC 173-160-440	State Action	Identifies the equipment cleaning standards.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Well Sealing Requirements?" WAC 173-160-450	State Action	Identifies the well sealing requirements.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Is the Decommissioning Process for Resource Protection Wells?" WAC 173-160-460	State Action	Identifies the decommissioning process for resource protection wells.	ARAR	Remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.

Notes:

ARAR = applicable or relevant and appropriate requirement
CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR = *Code of Federal Regulations*
MCL = maximum contaminant level
OSWER = Office of Solid Waste and Emergency Response
OU = operable unit
RCRA = *Resource Conservation and Recovery Act of 1976*
USC = United States Code
WAC = *Washington Administrative Code*

The proposed remedial action alternatives have the potential to generate airborne emissions of radioactive and hazardous air pollutants. The federal *Clean Air Act of 1990*, and Amendments, and the "Washington Clean Air Act" (RCW 70.94) require regulation of air pollutants. Under federal implementing regulations,Title 40 CFR Part 61, "National Emission Standards for Hazardous Air Pollutants," Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities," requires that radionuclide airborne emissions from the facility shall be controlled so as not to exceed amounts that would cause an exposure to any member of the public of greater than 10 millirem per year effective dose equivalent. The same regulation addresses point sources (i.e., stacks or vents) emitting radioactive airborne emissions, requiring monitoring of such sources with a major potential for radioactive airborne emissions, and requiring periodic confirmatory measurement sufficient to verify low emissions from such sources with a minor potential for emissions. The State of Washington is fully delegated to implement the 40 CFR Part 61 federal air regulations. WAC 246-247, "Radiation Protection—Air Emissions," requires the use of applicable control technologies to address radioactive airborne emissions from new and existing units. In order to address the substantive aspect of these requirements, best or reasonably achieved control technology will be addressed by ensuring that applicable emission control technologies (those successfully operated in similar applications) will be used when economically and technologically feasible (i.e., based on cost/benefit). If it is determined that there are substantive aspects of the requirement for monitoring of fugitive or non-point sources emitting radioactive airborne emissions (WAC 246-247-075(8)), then these will be addressed by sampling the effluent streams and/or ambient air as appropriate using reasonable and effective methods.

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Appendix F

Development of Radionuclide Preliminary Remediation Goals for the 216-A-2 and 216-A-4 Cribs

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F1 Introduction

This appendix describes the development of preliminary remediation goals (PRGs) for radionuclide contaminants in soil at the 216-A-2 and 216-A-4 Cribs in the 200-MW-1 operable unit (OU). Although the PRG development focuses on the 216-A-2 and 216-A-4 Cribs, the PRGs are also applicable to the other waste sites in the 200-MW-1 OU.

PRGs are risk-based radionuclide concentrations in soil that would attain a designated level of protectiveness for a human receptor based on anticipated future land use. PRGs are used to support the evaluation of remedial alternatives for the 200-MW-1 OU. The PRGs correspond to an industrial worker direct contact exposure, excess lifetime cancer risk (ELCR) of 10^{-4}. The industrial worker scenario represents the current and anticipated future land use at the sites, and a level of protectiveness equal to 10^{-4} ELCR is used for consistency with the U.S. Environmental Protection Agency's (EPA) target risk threshold value. The calculations used to develop the PRGs were performed using the RESidual RADioactivity (RESRAD) computer code, Version 6.4 (ANL, 2007).

F1.1 RESRAD Analysis Methodology

The RESRAD code is implemented following guidance provided in ANL/EAD-4, *User's Manual for RESRAD Version 6*. The overall methodology is identical to that used to conduct the radiological risk assessment for DOE/RL-2008-37, *200-MW-1 Remedial Investigation Report*. A simulation period of 1,000 years is used for all of the RESRAD runs. A summary of the 200-MW-1 OU radiological risk assessment is provided in Section 6.1 of this remedial investigation/feasibility study (RI/FS) report. Detailed descriptions of the RESRAD evaluations for the 216-A-2 and 216-A-4 Cribs are provided in Appendix D of this RI/FS report. The RESRAD input files generated and used for the baseline risk assessment (BRA) served as the starting point for this analysis. The only modifications made to the files for use in this analysis are to the inputs for radionuclide soil concentrations and the cover and contaminated zone thicknesses. All other input parameters, including those used to represent the hydrostratigraphic conceptual model at each crib and the human receptor usage and occupancy factors, remain the same as described in Appendix D.

F1.2 Contaminants of Potential Concern

PRGs were developed in this analysis for the individual radionuclide contaminants of potential concern (COPCs) identified at the 216-A-2 and 216-A-4 Cribs. The COPC identification process is described in Section 6.1 of the RI/FS. Table F-1 lists the radionuclide COPCs identified during the RI at each crib and the exposure point concentrations (EPCs) for each COPC. The EPCs represent the maximum measured radionuclide soil concentrations encountered within the identified depth intervals during RI characterization activities at each crib. The EPCs are the soil concentration values used in the RESRAD analysis of the BRA presented in Chapter 6 of the RI/FS report.

Maximum COPC concentrations were encountered from 8 to 12 m (27 to 40 ft) below ground surface (bgs) at the 216-A-2 Crib and from 5.6 to 6.5 m (18.5 to 21 ft) bgs at the 216-A-4 Crib. At the 216-A-2 Crib, a second depth interval from 76 to 96 m (250.5 to 315 ft) bgs was also identified based on maximum detected tritium concentrations, as shown in Table F-2.

Table F-1. Radionuclide Exposure Point Concentrations for Shallow Zone Soil at the 216-A-2 and 216-A-4 Cribs

COPC	216-A-2 Crib EPC[a] (Depth Interval = 27 to 40 ft bgs) (pCi/g)	216-A-4 Crib EPC[b] (Depth Interval = 18.5 to 21 ft bgs) (pCi/g)
Americium-241	94,000	3,810
Cesium-137	31,000	63,600
Cobalt-60	0.382	14.3
Europium-154	1.28	179
Nickel-63	10.6	NA
Plutonium-238	120	209
Plutonium-239	426,000	21,400
Technetium-99	6.27	NA
Strontium-90	125,000	3,860,000
Uranium-234	49.8	478
Uranium-235	4.28	NA
Uranium-236	1.03	NA
Uranium-238	56.6	683

Notes:

a. Source: DOE/RL-2008-37, Appendix F, Table F-4

b. Source: DOE/RL-2008-37, Appendix G, Table G-4

bgs = below ground surface

EPC = exposure point concentration

COPC = contaminant of potential concern

NA = not applicable (not a COPC)

Table F-2. Radionuclide Exposure Point Concentrations for Deep Zone Soil at the 216-A-2 Crib

COPC	216-A-2 Crib EPC* (Depth Interval = 250.5 to 315 ft bgs) (pCi/g)
Tritium	2,860

Notes:

* Source: DOE/RL-2008-37, Chapter 5, Table 5-4

bgs = below ground surface

EPC = exposure point concentration

COPC = contaminant of potential concern

F1.3 Exposure Scenario Description

Exposures are assessed for this analysis using an industrial worker direct contact exposure scenario. The industrial worker exposure scenario is used to reflect the current and reasonably anticipated future land use within the industrial (exclusive) zone of the Central Plateau. The direct contact exposure routes evaluated for the industrial worker scenario are external gamma radiation, incidental soil ingestion, and inhalation of dust particulates. Results of the RI risk assessment indicate that under current site configurations, there is no radiological risk to an industrial worker at either crib because the direct contact pathway is incomplete (i.e., the receptor cannot come into direct contact with contamination). This is because the uncontaminated soil cover layer at each crib (8 m [27 ft] at the 216-A-2 Crib; 5.6 m [18.5 ft] at the 216-A-4 Crib) shields the ground surface and prevents exposure from the external gamma radiation exposure route. Additionally, the direct contact inhalation and incidental ingestion exposure routes are incomplete as long as the soil covers remain in place.

Although the cribs in their current configurations are protective for industrial direct contact soil exposure, the need to take remedial action was defined in the BRA based on analysis of a reasonable maximum exposure (RME). The RME scenario is based on the assumption that direct contact exposure pathways to the industrial worker are complete. Therefore, for purposes of providing information on levels of protectiveness supporting future (post-remediation) industrial land use, RESRAD calculations are made assuming that the existing soil cover has been removed and the radiological contaminants are exposed at the ground surface. This is accomplished in RESRAD by extending the contaminated zone thickness to the ground surface and setting the cover thickness to zero. Under these assumptions, the direct contact pathway is complete, and PRGs representing residual soil concentrations protective of industrial direct contact exposure at a 10^{-4} ELCR level can be calculated. In addition, these assumptions provide a conceptual exposure model that is identical for both the 216-A-2 and 216-A-4 Cribs. Therefore, the PRGs described in the following section are applicable to both the 216-A-2 and 216-A-4 Cribs. The PRGs are also applicable to the other 200-MW-1 OU waste sites including the 216-A-21 and 216-A-27 Cribs, the 200-E-102 Trench, and the 216-B-4 and 216-C-2 Reverse Wells.

F1.4 Preliminary Remediation Goals

Table F-3 provides the individual industrial direct contact PRGs calculated for each radionuclide COPC identified at the 216-A-2 Crib. This table provides PRG numerical values (i.e., soil concentrations in units of pico Curies per gram [pCi/g]) corresponding to an ELCR value of 10^{-4}. The COPCs at the 216-A-4 Crib are a subset of those identified at the 216-A-2 Crib; therefore, Table F-3 includes all COPCs identified at the two cribs.

The PRGs shown in Table F-3 are radionuclide-specific (i.e., calculated assuming each COPC is the only one present). The PRGs are calculated one radionuclide at a time with RESRAD using the following steps. First, a value of 15 millirems per year (mrem/yr) is entered for the basic radiation dose limit, and an initial run is made. The soil concentration input for this initial run is not important and can be any non-zero value (e.g., 10 pCi/g). The reason the soil concentration input is not important is because, regardless of the value entered, RESRAD automatically calculates and reports a soil concentration corresponding to the specified dose limit (summary report, single radionuclide soil guidelines). A value of 15 mrem/yr is specified for the dose limit because for some radionuclides, this value roughly equates to an ELCR of 10^{-4}. In the next step, the arbitrarily assigned soil concentration from the initial run is replaced with the reported soil concentration for the 15 mrem/yr dose limit, and the code is re-run. The ELCR output from this run is then compared to the 10^{-4} target value, and the code is re-run with the soil concentration input adjusted up or down accordingly. The PRGs are calculated by iteratively changing the soil concentration and rerunning the code until the 10^{-4} ELCR target goal is exactly achieved.

Table F-3. 216-A-2 Crib Radionuclide Soil Preliminary Remediation Goals for Industrial Direct Contact Exposure (No Cover)

COPC	Background Concentration[a] (pCi/g)	10^{-4} ELCR[b] (pCi/g)
Americium-241	NA	1,487
Cesium-137	1.05	24.6
Cobalt-60	0.00842	13.1[e]
Europium-154	0.0334	18.7[e]
Nickel-63	NA	32,000,000[e]
Plutonium-238	0.00378	12,350[e,f]
Plutonium-239/240 [c]	0.0248	10,360
Technetium-99	NA	522,400[e]
Strontium-90	0.178	3,198
Tritium	NA	243,000[e]
Uranium-233/234 [d]	1.1	3,061[e,f]
Uranium-234	1.1	3,061[e,f]
Uranium-235	0.109	83.3[e]
Uranium-236	NA	21,650[e]
Uranium-238	1.06	408.5[e]

Notes:

a. DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides.*

b. PRG numerical values corresponding to industrial worker direct contact soil exposures of 10^{-4} ELCR were calculated with RESRAD Version 6.4 (ANL, 2007). Calculations are based on the 216-A-2 Crib waste site configuration assuming shallow zone radiological contaminants currently located within the 8- to 12-m (27- to 40-ft) depth interval are exposed at the ground surface without a clean soil cover. For purposes of this analysis, deep zone tritium contamination currently located within the 76 to 96 m (250.5 to 315 ft) depth interval is analyzed as a shallow zone contaminant.

c. PRG numerical values are calculated for Pu-239.

d. PRG numerical values are calculated for U-234.

e. PRG numerical value exceeds the BRA EPC at the 216-A-2 Crib.

f. PRG numerical value exceeds the BRA EPC at the 216-A-4 Crib.

ELCR = excess lifetime cancer risk

NA = no reference source available

PRG = preliminary remediation goal

COPC = contaminant of potential concern

F2 References

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Appendix G

200-MW-1 Operable Unit Feasibility Study Cost Estimate Backup

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G1 Introduction

The cost estimates for the 200-MW-1 Operable Unit (OU) feasibility study (FS) were developed in accordance with EPA/540/R-00/002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, OSWER 9355.0-75. The cost estimate is one of the five balancing criteria evaluated in the FS that provides input into the selection of a remedial alternative. The MAESTRO Cost Estimator software was used in conjunction with the remedial alternative descriptions presented in Chapter 5 of the FS report to develop cost estimates for each of the remedial alternatives.

The cost estimates are based on actual pricing information derived from historical experience. The unit costs associated with each one of the quantity estimates may have been factored/adjusted by the estimator and/or task lead, as appropriate, to reflect influences by the contract, work site, or other identified special conditions. Historical information from similar Hanford Site planning and reverse well decommissioning efforts was applied to this estimate.

The costs are presented as net present worth values. The net present worth method establishes a common baseline for evaluating costs that occur during different time periods, thus allowing for direct cost comparisons between different alternatives. The net present worth value represents the dollars that would need to be set aside today, at the defined interest rate, to ensure that funds would be available in the future as they are needed to perform the remedial alternative.

Net present worth costs were estimated using the real discount rate published in Appendix C of Office of Management and Budget (OMB) Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, effective through January 2008. Programs with durations longer than 30 years use the 30-year interest rate of 2.7 percent. Net present worth costs are discussed for each alternative in the following subsections. The period of analysis for the net present worth cost is 1,000 years.

EPA/540/R-00/002 recommends including the non-discounted costs in the FS. The non-discounted cost estimates demonstrate the impact of the discount rate on the total present worth cost. The non-discounted costs were also calculated based on 1,000-year duration (as applicable to each alternative) and are provided for comparison purposes only.

This FS does not account for economies associated with implementing similar remedial alternatives across multiple sites or OUs. This approach was used to provide greater flexibility in selecting a remedial alternative for each of the 200-MW-1 OU waste sites. These aspects will be considered in the future as part of long-range planning and through post Record of Decision activities such as remedial design. Potential areas of cost sharing to reduce overall remediation costs include the following:

- Remediating all waste sites with a common remedial alternative at the same time
- Sharing mobilization and demobilization costs
- Sharing surveillance and maintenance costs
- Sharing barrier performance monitoring costs

Section G2 of this appendix provides a general description for each remedial alternative. Major costing assumptions are discussed in Section G3.

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G2 Remedial Alternative Summary Descriptions

Four alternatives were developed for the 200-MW-1 OU waste sites. However, due to different site characteristics, the four alternatives are not applicable to all of the waste sites. Additionally, many of the alternatives share common activities such as institutional controls (ICs), vadose zone monitoring, and other operation and maintenance (O&M) activities. Where ICs, site-specific monitoring, and O&M are included as a component of an individual alternative, the duration of these activities may extend for periods up to 1,000 years.

The following four alternatives were developed for the 200-MW-1 OU waste sites:

Alternative 0 – No Action. This alternative applies to all seven waste sites and has an assumed cost of $0 because it contains no remedial construction or O&M activities.

Alternative 1 – Institutional Controls (ICs) and Monitored Natural Attenuation (MNA). This alternative applies to all of the waste sites and generally consists of maintaining each waste site in its present condition. Many of the ICs already implemented under DOE/RL-2001-41, *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions*, Rev. 4, would be continued for 1,000-years. Periodic inspection, soil cover maintenance, radiological surveys, and vadose zone monitoring would be performed to confirm that remedial action objectives are being met. For the two reverse wells, this alternative also includes decommissioning of the wells in accordance with Washington State Department of Ecology (Ecology) regulations.

Alternative 2 – Evapotranspiration (ET) Barrier. This alternative applies to the cribs and trench sites and consists of constructing a monofill ET barrier over the contaminated soil footprint with a 6.1 m (20 ft) extension on each side. The site would then be revegetated per the ET barrier provisions, and ICs would be prepared and implemented as described for Alternative 1. Periodic inspection, maintenance, and vadose zone monitoring would be conducted to confirm that the cap is performing in accordance with design criteria. Long-term maintenance of the ET cap and ICs are continued for 1,000 years.

Alternative 3 – Removal, Treatment, and Disposal (RTD). This alternative applies to the trench only and consists of removing contaminated soil from the shallow zone (0 to 3 m [0-10 ft]) direct-contact exposure horizon. Long-term maintenance of the ICs, as described for Alternative 2, will not be required.

Table G-1 and Table G-2 provide an overview of the site information used for preparing the cost estimates of each alternative. This includes the area and volume that need to be capped, excavated, and backfilled, and details of any barrier construction that may be occurring are provided. Table G-3, Table G-4, and Table G-5 present each alternative capital cost breakdown. Table G-6, Table G-7, and Table G-8 present each alternative cost breakdown by capital cost, periodic cost, non-discounted cost, and total present worth cost.

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Table G-1. 200-MW-1 Operable Unit Feasibility Study Site Information OU 200-MW-1, Hanford Site, Richland, Washington

				ICs, MESC, MNA Site Dimensions (ft)				Capping Dimensions (ft)			ET Monofill Barrier			
Waste Site	Site Description	Length (Top) (ft)	Width (Top) (ft)	Clean Soil Depth (bgs)	Side Slope (assumed)	End Slope (assumed)	Surface Area (Ac)	Length (ft)	Width (ft)	Overlap (ft)	Acres of Capping (Ac)	Pre-Leveling Fill (yd^3)	Duration (days)	Cap Type
216-A-2	Crib	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216-A-4	Crib	106	106	0	1.5	1.5	0.258	194	194	20	0.87	0	19	ET Monofill
216-A-21	Crib	100	58	0	1.5	1.5	0.133	183	141	20	0.60	0	18	ET Monofill
216-A-27	Crib	200	55	0	1.5	1.5	0.253	283	138	20	0.90	0	19	ET Monofill
200-E-102	Trench	70	15	1.5	1.5	1.5	0.024	150	95	20	0.33	0	17	ET Monofill
216-B-4	Reverse Well	1	1	0.5	1.5	1.5	0.00002	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216-C-2	Reverse Well	1	1	0.5	1.5	1.5	0.00002	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table G-2. 200-MW-1 Operable Unit Feasibility Study Site Information OU 200-MW-1, Hanford Site, Richland, Washington

		RTD Dimensions (ft)				RTD Excavation Dimensions (ft)							
Waste Site	Site Description	Length (ft)	Width (ft)	Side Slope (assumed)	Length (Top) (ft)	Width (Top) (ft)	Excavation Depth (ft)	Clean Overburden Depth (ft)	Contam. Soil Volume (yd^3)	Excav. Vol. (yd^3)	Overburden Soil Volume (yd^3)	Backfill (yd^3)	Duration (days)
216-A-2	Crib	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216-A-4	Crib	106	106	benched	136	136	10	0	4162	5423	1261	4162	27
216-A-21	Crib	100	58	benched	130	88	10	0	2149	3110	961	2149	20
216-A-27	Crib	150	55	benched	180	85	10	0	3056	4278	1222	3056	24
200-E-102 *	Trench	70	15	1.5	85	30	5	2	137	323	186	137	11
216-B-4	Reverse Well	1	1	casing	70	70	110	1	263	291	28	291	46
216-C-2	Reverse Well	1	1	casing	40	40	40	1	30	165	135	165	40

**Table G-3. IC/MESC/MNA Site Summary Sheet, Capital Cost
200-MW-1, 200 Area Waste Sites – Cost Estimate Breakdown***

Site	Description	Opt	Alternative	Institutional Controls	Other site Stabilization Work	Construction Staff	Project Management	Sub Total	Remedial Design	Total Project
216-A-2	Crib	N/A	IC/MESC/MNA	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216-A-4	Crib	N/A	IC/MESC/MNA	$20,000	$0	$1,200	$2,400	$23,600	$4,720	$28,320
216-A-21	Crib	N/A	IC/MESC/MNA	$20,000	$0	$1,200	$2,400	$23,600	$4,720	$28,320
216-A-27	Crib	N/A	IC/MESC/MNA	$20,000	$0	$1,200	$2,400	$23,600	$4,720	$28,320
200-E-102	Trench	N/A	IC/MESC/MNA	$20,000	$0	$1,200	$2,400	$23,600	$4,720	$28,320
216-B-4**	Reverse Well	N/A	IC/MESC/MNA	$20,000	$250,000	$1,200	$2,400	$273,600	$4,720	$278,320
216-C-2**	Reverse Well	N/A	IC/MESC/MNA	$20,000	$225,000	$1,200	$2,400	$248,600	$4,720	$252,140

**. Institutional controls is well decommissioning.

**Table G-4. ET Monofill Barrier Site Summary Sheet, Capital Cost
200-MW-1, 200 Area Waste Sites – Cost Estimate Breakdown**

Site	Description	Opt	Alternative	Mobilization/ Demobilization	Monitoring & Sampling	Site Work	Soil Excavation	Cap	Construction Staff	Project Management	Sub Total	Remedial Design	Total Project
216-A-2	Crib	N/A	ET Monofill Barrier	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216-A-4	Crib	N/A	ET Monofill Barrier	$83,925	$3,939	$58,259	$0	$251,753	$79,237	$61,685	$538,798	$64,656	$603,454
216-A-21	Crib	N/A	ET Monofill Barrier	$83,063	$3,939	$57,527	$0	$180,318	$75,674	$59,111	$459,632	$68,945	$528,577
216-A-27	Crib	N/A	ET Monofill Barrier	$84,394	$3,939	$58,657	$0	$248,377	$79,237	$61,685	$536,289	$64,355	$600,644
200-E-102	Trench	N/A	ET Monofill Barrier	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216-B-4	Reverse Well	N/A	ET Monofill Barrier	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216-C-2	Reverse Well	N/A	ET Monofill Barrier	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table G-5. RTD (Unrestricted Land Use) Site Summary Sheet, Capital Cost 200-MW-1, 200 Area Waste Sites – Cost Estimate Breakdown

Site	Description	Opt	Alternative	Mobilization/ Demobilization	Monitoring & Sampling	Site Work	Soil Excavation	Cap	Construction Staff	Project Management	Sub Total	Remedial Design	Total Project
216-A-2	Crib	N/A	RTD	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216-A-4	Crib	N/A	RTD	$174,343	$255,836	$115,351	$937,467	$0	$125,927	$82,278	$1,691,202	$202,944	$1,894,146
216-A-21	Crib	N/A	RTD	$158,827	$253,713	$68,562	$506,456	$0	$96,457	$64,259	$1,148,274	$137,793	$1,286,067
216-A-27	Crib	N/A	RTD	$174,246	$254,775	$84,290	$703,151	$0	$113,297	$74,556	$1,404,315	$168,518	$1,572,833
200-E-102	Trench	N/A	RTD	$157,407	$251,589	$31,025	$52,349	$0	$58,567	$41,093	$592,030	$71,044	$663,074
216-B-4	Reverse Well	N/A	RTD	$425,518	$251,589	$124,397	$2,118,116	$0	$205,916	$131,184	$3,256,720	$260,538	$3,517,258
216-C-2	Reverse Well	N/A	RTD	$406,913	$251,589	$81,099	$1,240,297	$0	$180,656	$115,740	$2,276,294	$182,104	$2,458,398

Table G-6. IC/MESC/MNA Capital Costs, Periodic Costs, Non-Discounted Costs, and Present Worth Costs 200-MW-1 Feasibility Cost Study

Site	Site Description	Alternative	Total Capital Cost	Non-Discounted Annual & Periodic Cost	Non-Discounted Cost	Total Present Worth Cost
216-A-2	Crib	Alt 1 - IC/MESC/MNA	N/A	N/A	N/A	N/A
216-A-4	Crib	Alt 1 - IC/MESC/MNA	$28,320	$34,655,962	$34,684,282	$1,285,117
216-A-21	Crib	Alt 1 - IC/MESC/MNA	$28,320	$34,655,962	$34,684,282	$1,285,117
216-A-27	Crib	Alt 1 - IC/MESC/MNA	$28,320	$34,655,962	$34,684,282	$1,285,117
200-E-102	Trench	Alt 1 - IC/MESC/MNA	$28,320	$34,655,962	$34,684,282	$1,285,117
216-B-4	Reverse Well	Alt 1 - IC/MESC/MNA	$278,320	$34,655,962	$34,934,282	$1,535,117
216-C-2	Reverse Well	Alt 1 - IC/MESC/MNA	$252,140	$34,655,962	$34,908,102	$1,508,937

**Table G-7. ET Monofill Barrier Capital Costs, Periodic Costs, Non-Discounted Costs, and Present Worth Costs
200-MW-1 Feasibility Cost Study**

Site	Site Description	Alternative	Total Capital Cost	Non-Discounted Annual & Periodic Cost	Non-Discounted Cost	Total Present Worth Cost
216-A-2	Crib	Alt 2 - Barrier	N/A	N/A	N/A	N/A
216-A-4	Crib	Alt 2 - Barrier	$603,454	$34,655,962	$35,259,416	$1,860,251
216-A-21	Crib	Alt 2 - Barrier	$528,577	$34,655,962	$35,184,539	$1,785,374
216-A-27	Crib	Alt 2 - Barrier	$600,644	$34,655,962	$35,256,606	$1,857,441
200-E-102	Trench	Alt 2 - Barrier	N/A	N/A	N/A	N/A
216-B-4	Reverse Well	Alt 2 - Barrier	N/A	N/A	N/A	N/A
216-C-2	Reverse Well	Alt 2 - Barrier	N/A	N/A	N/A	N/A

Table G-8. Full Depth RTD Capital Costs, Periodic Costs, Non-Discounted Costs, and Present Worth Costs

200-MW-1 Feasibility Cost Study

Site	Site Description	Alternative	Total Capital Cost	Non-Discounted Annual & Periodic Cost	Non-Discounted Cost	Total Present Worth Cost
216-A-2	Crib	Alt 3-RTD	N/A	N/A	N/A	N/A
216-A-4	Crib	Alt 3-RTD	$1,894,146	$0	$1,894,146	$1,869,248
216-A-21	Crib	Alt 3-RTD	$1,286,067	$0	$1,286,067	$1,286,067
216-A-27	Crib	Alt 3-RTD	$1,572,833	$0	$1,572,833	$1,552,158
200-E-102	Trench	Alt 3-RTD	$663,074	$0	$663,074	$663,074
216-B-4	Reverse Well	Alt 3-RTD	$3,517,258	$0	$3,517,258	$3,517,258
216-C-2	Reverse Well	Alt 3-RTD	$2,458,398	$0	$2,458,398	$2,458,398

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G3 Basis of Estimates

This section provides backup information and assumptions used in developing the cost estimates for each remedial alternative.

G3.1 Global Assumptions

G3.1.1 Labor

Fixed-price (FP) construction craft labor rates are those listed in Appendix A of the *Site Stabilization Agreement for All Construction Work for the U.S. Department of Energy at the Hanford Site* (commonly known as the Hanford Site Stabilization Agreement [HSSA]). The HSSA rates include base wage, fringe benefits, and other compensation as negotiated between Fluor Hanford (FH) and the National Building and Construction Trades Department American Federation of Labor-Congress of Industrial Organizations (AFL-CIO). Other factors that account for additional costs (e.g., Workman's Compensation and the *Social Security Act of 1935* [*Federal Insurance Contributions Act* or FICA]), and state and federal unemployment insurance) to develop a fully burdened rate by craft have been incorporated. The labor rates used are for 2009.

CH2M HILL Plateau Remediation Company (CHPRC) contract labor rates for management, engineering, safety oversight, and technical support are based on the CHPRC-approved planning rates for fiscal year 2009.

G3.1.2 Markups

The following section describes the direct costs, indirect costs, and general assumptions that were used for developing this cost estimate.

G3.1.2.1 Direct Cost Factors

The following direct cost factors are included in the cost estimates:

Washington State sales tax has been applied to all materials and equipment purchases at 8.3 percent.

Construction consumables are estimated at 3.5 percent of FP direct craft labor costs to provide an allowance for small tools, tape, plastics, gloves, etc.

A general supervisor factor of 3 percent has been applied to FP craft labor hours.

A general requirements factor of 5 percent has been applied to cover incidental labor for transporting personnel and materials and to cover other miscellaneous labor.

G3.1.2.2 Indirect Cost Factors

The following indirect cost factors are included in the cost estimates:

Contractor overhead, profit, bond, and insurance costs have been applied at a rate of 26.5 percent on FP labor, materials, and equipment.

CHPRC general and administrative (G&A) cost has been applied at a rate of 16.2 percent to all CHPRC labor, material, and equipment. G&A is also applied to the FP contractor costs.

G3.1.3 General Assumptions

The following general pricing assumptions were included in the cost estimates:

CHPRC cost estimating templates for site remediation are used as the basis for each waste site cost estimate.

Construction labor, material, and equipment units were estimated based on standard commercial estimating resources and databases (Means, 2001, *ECHOS Environmental Remediation Cost Data – Unit Price*; Means 2009, *Building Construction Cost Data*; Means, 2009, *Heavy Construction Cost Data*; Richardson, 2001, *Process Plant Construction Estimating Standards*; and the Equipment Watch *Rental Rate Blue Book for Construction Equipment*. The units may have been factored or adjusted by the estimator, as appropriate, to reflect influences by contract, work site, or other identified project or special conditions.

Quotes from local commercial sources are used for materials that need to be acquired for the construction of barriers or temporary improvements.

Equipment rates are based on 21 working days per month.

Equipment operation is based on one shift of 8 hours per day.

One workweek equals 5 days.

Work stoppages or shutdowns caused by inclement weather are factored into the estimates or planning schedules. It is assumed that there will be 20 days of delays per calendar year. For projects that are less or greater than one year, the delay time is prorated.

Work delays or stoppages caused by waiting for laboratory results or approval for backfilling waste site excavations are included in the estimates. For the RTD alternatives, one year of site monitoring and maintenance work is included in the estimate.

The cost estimates include costs for design, work plan preparation, and any other preparation costs normally associated with activities occurring before field mobilization.

Remedial design capital costs are based on EPA/540/R-00/002, Exhibit 5-8. The following guidelines are used for this study:

For projects with construction costs less than $100,000 – remedial design is planned at 20 percent of the construction cost.

For projects with construction costs from $100,000 to $500,000 – remedial design is planned at 15 percent of the construction cost.

For projects with construction costs from $500,000 to $2 million – remedial design is planned at 12 percent of the construction cost.

For projects with construction costs from $2 million to $10 million – remedial design is planned at 8 percent of the construction cost.

For projects with construction costs greater than $10 million – remedial design is planned at 6 percent of the construction cost.

Escalation has not been included in the calculations. All costs are present day (fiscal year 2009).

Contingency has been applied to the capital costs, and the following rates are based on EPA/540/R-00/002, Section 5.4:

Soil Excavation: covers all excavation at the waste site, disposal, related monitoring/sampling; scope contingency, 35 percent; bid contingency, 10 percent; total contingency is 45 percent.

Capping: covers work at borrow sites, backfilling, spreading, compaction, material hauling, and related monitoring/sampling; scope contingency, 10 percent; bid contingency 10 percent; total contingency is 20 percent.

Surface Grading: covers work at borrow sites, backfilling, spreading, compaction, and material hauling; scope contingency, 10 percent; bid contingency, 10 percent; total contingency is 20 percent.

Revegetation: covers sites preparation, planting, and irrigation; scope contingency, 5 percent; bid contingency, 10 percent; total contingency is 15 percent.

Project Management and Construction Management: scope contingency, 5 percent; bid contingency, 10 percent; total contingency is 15 percent.

Mobilization/Demobilization: scope contingency, 5 percent; bid contingency, 10 percent; total contingency is 15 percent.

All fill or soil from a borrow site is assumed to come from an onsite location. During the remedial design, the actual borrow source location will be identified and will comply with all *National Environmental Policy Act of 1969* requirements. All gravel or fractured rock products will come from an offsite commercial source.

G3.2 No Action Alternative

The No Action Alternative represents a situation where no legal restrictions, access controls, or active remedial measures are applied to the waste site. Taking no action implies "walking away from the waste site" and allowing the waste to remain in its current configuration, affected only by natural processes. No maintenance or ICs are included in this alternative.

Because the No Action Alternative assumes no further actions will be taken at the waste site, costs are assumed to be zero.

G3.3 Alternative 1 – Institutional Controls and Monitored Natural Attenuation

This alternative, which can have one-time or recurring costs (capital, annual operations and maintenance, or periodic), includes non-engineering or legal/administrative measures designed to prevent or minimize the potential for exposure to site contamination or hazards by controlling access to a waste site. For Alternative 1, this is the only type of work being performed at the 200-MW-1 OU waste sites. ICs and MNA are also used for the ET barrier (Alternative 2).

IC measures typically include written plans (i.e., DOE/RL-2001-41), restrictive covenants, easements, zoning, deed notices, advisories, land and groundwater use restrictions, and site information databases. The ICs plan describes the controls for a site and how they would be implemented. A site information database (i.e., the Waste Information Data System [WIDS]) would provide a system for managing and retrieving data on each of the waste sites. ICs incur project-specific costs that can be an important component of a remedial alternative and, as such, generally should be estimated separately from other costs, usually on a sub-element basis. ICs may need to be updated or maintained, either annually or periodically.

The ICs cost model used for this alternative was developed by the CHPRC Project Controls and Estimating department. The duration for ICs development assumes a one year period, whereas the annual/periodic activities associated with ICs implementation and monitoring is based on a 1,000-year duration.

The primary annual/periodic costs associated with this alternative are for surveillance and cover maintenance and MNA. The costs for these annual/periodic activities were estimated based on the area of the individual waste sites or groups.

The unit cost for surveillance and maintenance was assumed to be the same as the current unit cost for surveillance and maintenance activities conducted annually on the waste sites. The unit cost accounts for activities, such as site radiation surveys and repair of the existing soil cover, on the sites where it is present. Because the existing soil cover is maintained annually, costs for replacing all or large portions of the existing cover at specified intervals (i.e., every 20 years) are considered unnecessary.

The costs associated with MNA are divided into three components: radiological surveys of surface soils, spectral gamma logging of vadose-zone boreholes, and groundwater monitoring. The costs to perform radiological surveys of surface soils at waste sites are assumed to be similar to those for current survey practices at the sites and are included in the surveillance and maintenance costs.

Vadose zone monitoring costs assume spectral gamma logging of one borehole per waste site to a 15 m (50 ft) depth once every five years for a 1,000-year duration. This monitoring is considered for sites with high concentrations of contaminants in the shallow zone or near the bottom of crib and well structures. It also assumes that the service life of vadose zone boreholes is 30 years. Costs are included for logging and periodic replacement of these boreholes for a 1,000-year duration.

Groundwater monitoring costs are not included for this OU.

G3.3.1 General Assumptions

The general assumptions for ICs are as follows:

Costs were calculated for each of the sites based on the specific area of each site. These calculated costs are presented in Table G-1 and Table G-2.

Site areas are less than 0.4 hectares (1 acre); therefore, the same construction crews will be used for all sites. The minimum size used for ICs is one acre.

Fencing, monuments, and signs for ICs and fencing maintenance are included.

The proposed ICs consist of seven general activities: implementation, site inspection and surveillance, existing cover maintenance, natural attenuation monitoring, reporting, site reviews, and vadose zone monitoring.

The prices that make up the cost estimate were obtained from the following sources:

Means, 2001, ECHOS Environmental Remediation Cost Data – Unit Price
Means, 2009, Building Construction Cost Data; and Heavy Construction Cost Data
Experience on similar projects

G3.3.2 Special Conditions

The following subsections identify issues that apply only to specific sites.

Alternative 1 – Site 216-B-4 and 216-C-2 Reverse Wells Decommissioning

Under the implementation phase of this alternative, the two reverse wells will be decommissioned. The process involves geophysical logging, perforating the casing, grouting or plugging the well to state and local requirements, waste removal, and site cleanup. Verification documentation will be prepared and sent to the state as part of the closeout process. The wells would be considered high-risk work due to the nature of the waste material discharged to the well casing. This may require that certain tools used for the decommissioning cannot be reused at other locations.

G3.4 Alternative 2 – Evapotranspiration Barrier

There is one type of barrier used for the 200-MW-1 OU waste sites: the monofill ET barrier. The ET barrier is the primary design used for Alternative 2. The side overlap of barriers will be 6.1 m (20 ft) for all exterior sides.

Figure G-1 shows details of the assumed design for the ET barrier.

G3.4.1 General Assumptions

The general assumptions for this alternative are as follows:

All fill or soil from a borrow site is assumed to come from an onsite source. During the remedial design, the actual borrow source location will be identified and will comply with all *National Environmental Policy Act of 1969* requirements.

Fieldwork, such as mobilization and demobilization, borrow site excavation, barrier fill, revegetation, and some of the post-construction work, will be contracted to a FP contractor. Project management, radiological control technician (RCT) support, sampling, and safety oversight will be performed by CHPRC.

Mobilization and startup activities include site training, mobilization of equipment and personnel, installation of temporary construction fences, construction of access roads, and setting up offices and storage trailers with utilities. It is assumed that four barriers will be built under one FP contract. The cost of mobilization and demobilization activities will be shared equally among the four sites.

Revegetation of the waste site barrier includes planting native dry land grass using tractors with seed drills and hand broadcasting, and two irrigation events in the spring or early summer. All disturbed areas, such as around the barrier, stockpile, staging areas, and access roads, will be replanted.

The CHPRC Project Management team consists of a part-time project manager, with a full-time field supervisor and part-time engineering support. Quality assurance (QA), radiological control, and safety also provide oversight along with other support for contract management and project controls. Total hours for this staff are planned at 22.5 hours per day. The duration of this work is based on total project duration.

The FP contractor field supervisory team consists of a full-time construction manager and field supervisor, along with part-time QA, construction safety, and clerical support. Two pickup trucks are included in the cost. Total hours for this staff are planned at 21 hours per day. The duration of this work is based on total project duration.

Demobilization includes demobilizing equipment and personnel and removing temporary construction fences, access roads, and office/storage trailers.

At the completion of the construction work, the CHPRC team performs a final site survey, prepares as-built drawings, and completes a Cleanup Verification Package. The FP contractor performs a final construction records turnover as part of this process.

There are two onsite sources for the fill materials used to construct the three soil/fill layers. The source for engineered fill is located at Pit 30, approximately halfway between the 200 East and 200 West Areas. This pit is assumed to have a sufficient quantity of material for this project. The source for the silt required for Layers 1 and 2 is located at Area C about two miles south of the 200 West Area.

The crushed base course and pea gravel will be supplied by offsite vendors or from commercial gravel pits. The materials will be delivered to the waste site by the vendor's trucks.

All barrier sites are considered to have settled and are compacted enough to support construction of a barrier without further site preparation. Dynamic compaction or other compaction methods are not required to compact the site.

The barrier sites are considered level and will not require additional pre-leveling before the start of construction.

The ET barrier will consist of four different layers described as follows (see Figure G-1):

At waste sites where the top of the contamination layer is less than 5m (17 ft) from the ground surface, a bio intrusion barrier will be constructed. This layer is constructed of 12 inches of crushed road ballast topped with 4 inches of 1½ crushed surfacing base course rock for a total depth of 16 inches. The production rate for this work is 208 yd^3/hr.

Construct Biobarrier Stockpile Crushed Surfacing Rock from Commercial Source – The rock is from a commercial source and is delivered to a stockpile site by the supplier's trucks.

Construct Biobarrier Stockpile Ballast Rock from Commercial Source – The rock is from a commercial source and is delivered to a stockpile site by the supplier's trucks.

Construct Biobarrier Spread Crushed Surfacing and Ballast Rock – The spreading and compaction equipment used at the biobarrier is a 5 yd^3 loader to haul and place the rock, a 300-hp dozer with a U-blade to spread the rock, and one 12-ton vibratory roller. Dust is controlled with a 4,000-gal water truck. One laborer supports the placement work.

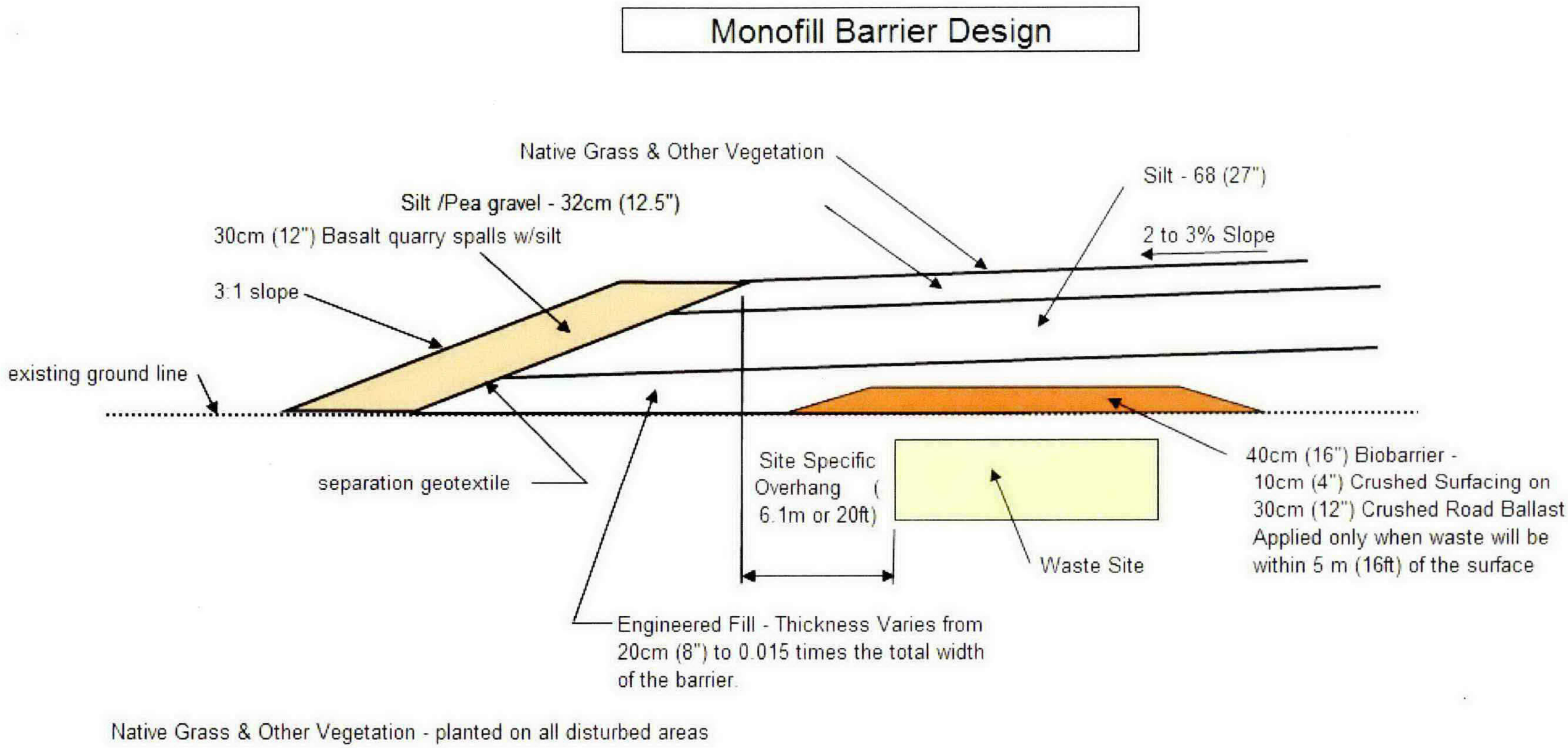

Figure G-1. Monofill ET Barrier Cross Section

The second layer is constructed of engineered or screened fill material which have a minimum thickness of 8 inches. The construction of the engineered fill layer requires the excavation of suitable borrow from an onsite source pit. The estimated time to complete the fill is based on the production rate of a 5-yd^3 loader excavating at the pit. All material is screened with a grizzly mounted on a surge bin to remove 4 inch or larger rocks. Five 16-yd^3 end dump trucks with 16-yd^3 trailers are used to keep up with the loader. One 4,000-gallon water truck provides dust control at the pit. The production rate for this work is 185 yd^3/hr. The spreading and compaction equipment used at the barrier includes a 250- to 300-hp dozer with a U-blade to spread fill, and two 12-ton vibratory tandem rollers. A 4,000-gallon water truck provides dust control. To produce a smooth surface to prevent low areas, the surface of the engineered fill is fine graded.

Work involves a 5-yd^3 loader, 12-ton vibratory single drum roller, a laser-leveling equipped dozer, and a water truck. The production rate is 2,500 yd^2/hr to fine grade the fill surface area. One laborer supports the dozer operator and the water truck driver. Two engineer technicians set up the grade and elevation control.

The third layer is constructed of 0.7 m (2.25 ft) of silt. The construction of this layer involves excavating and hauling the silt from the onsite pit to the barrier. The estimated time to complete the fill is based on the production rate of a 5-yd^3 loader excavating at the pit. Five 16-yd^3 end dump trucks with 16-yd^3 trailers are used to keep up with the loader. One 4,000-gal water truck provides dust control at the pit. The production rate for this work is 185 yd^3/hr. At the barrier, the silt is spread with two 90- to 120-hp low ground pressure dozers. The silt is scarified to prevent over compaction. A 4,000-gallon water truck provides dust control at the barrier.

The top layer is constructed of 0.3 m (1 ft) of silt/pea gravel fill. This layer requires fill consisting of silt with 15 percent pea gravel added by weight. The silt is excavated with a 5-yd^3 loader and hauled from the site silt source by two dump trucks to a process area near the pit. Pea gravel is provided from a commercial source. The supplier will haul and stockpile the gravel at the silt process area. A 5-yd^3 loader and a pug mill with belt loader are used to mix the silt and gravel. The hauling from the process area is the same as described for the second layer. Spreading also is the same as the second layer.

The side slopes of the barrier will be fine graded before placing fractured basalt. The work involves a 100-to 150-hp dozer with laser controls, a 5-yd^3 loader, one 12-ton vibratory single drum roller, and a water tanker. The production rate is 2,500 yd^2/hr for the engineered fill surface area. One laborer supports the dozer operator and the water truck driver. Two engineer technicians set up the grade and elevation control.

A geotextile is placed on the side slopes. This item of work covers the placement of needle punched 120 millimeter polypropylene geotextile on the side slopes. The production rate is 300 yd^2/hr. Three laborers place and splice the fabric. One operator with a 2.5-yd^3 loader and a teamster with a flatbed truck support the work.

The top layer of the side slopes is covered with a 0.3 m (1 ft) deep fractured basalt with silt. The fractured basalt is from a commercial source and is delivered to the site by the supplier. The silt is from the onsite pit and is hauled to the barrier site. The equipment used to spread the basalt is a 5-yd^3 loader, 300-hp dozer with a U-blade, and 1/4-time 4,000-gallon water truck. Two equipment operators and 1/4-time truck driver operate the equipment. One laborer supports the operators as a grade checker and helps place fractured basalt. The placement of the silt involves excavating at the pit, hauling to the barrier, and spreading the fractured basalt. This work occurs at the same time as the placement of the fractured basalt to ensure that the silt is worked into the basalt. The excavation and hauling from the pit uses one 5-yd^3 loader and three 16-yd^3 end dump trucks with 16-yd^3 trailers. The placement and mixing with the basalt use one 5-yd^3 loader. A 4,000-gallon water truck is used for dust control. Two operators, four truck drivers, and one laborer operate the equipment and support the work. The production rate for this work is 70 yd^3/hr.

Monitoring instrumentation is not included for this series of barriers.

After completion of the barrier construction work, a 1.2 m (4 ft) high steel post and chain fence will be built around the site. The fence location is at the toe of the barrier slope.

Operation and maintenance costs under this alternative include barrier performance monitoring and repair costs. For the purposes of this FS, it is assumed annual repairs to the cap will include replacement of 0.2 m (0.5 ft) of topsoil layer and revegetation over 10 percent of the barrier area. This is considered a conservative estimate because the barrier has been designed to require minimal maintenance, particularly after vegetation has been established.

During the construction of the barrier, compaction testing will be performed on the different layers. The engineered fill layer will require that a minimum level of compaction has been reached. The top two layers will be tested to ensure that the fill does not become over compacted.

G3.4.2 Special Conditions

There are no special conditions that apply to this alternative.

G3.5 Alternative 3 – Removal, Treatment, and Disposal

The four cribs, trench, and reverse well sites will be excavated to the depth requirements associated with alternatives. All excavated material exceeding unrestricted use/unrestricted exposure PRGs will be transported to Environmental Restoration Disposal Facility (ERDF) for disposal. Table G-1 lists the excavation depths for these alternatives.

G3.5.1 General Assumptions

The general assumptions for these alternatives include:

Fieldwork such as mobilization/demobilization, excavation, backfill, revegetation, and some of the post-construction work will be contracted to a FP contractor. Project management, radiological control technician (RCT) support, sampling, and safety oversight will be performed by CHPRC. The waste disposal work involved with hauling from the site to ERDF and ERDF dumping cost/fees are included in the ERDF disposal cost.

Mobilization and startup include site training; mobilization of equipment and personnel; installation of temporary construction fences; construction of staging/container storage areas and access roads; and setting up office, change, and storage trailers with utilities, temporary survey buildings, and decontamination areas. The cost of mob and demob activities will be shared equally between four sites.

The excavation sites will have contaminated waste removed. The sides of the excavation will be sloped at 1.5:1 to the bottom of the excavation for sites with a depth of 6.1 m (20 ft) or less.

For excavation sites, uncontaminated overburden will be removed with a 2- to 3-yd^3 excavator and two haul trucks. The soil will be stockpiled near the waste site. A 4,000-gallon water truck is used to control dust during this activity. The production rate for one crew is 146 yd^3/hr.

Contaminated waste will be excavated using a 2- to 3-yd^3 hydraulic crawler excavator. The contaminated soil will be placed directly into lined ERDF containers and hauled from the excavation site. A 4,000-gallon water truck is used to control dust during this activity. Crew labor consists of one operator, one laborer, and one truck driver. The production rate for one crew is 60 yd^3/hr.

During the excavation activity, RCTs will monitor the work. For uncontaminated soil removal, a crew of two RCTs will be present to monitor the excavator and survey the stockpile area. For contaminated waste removal, a crew of five RCTs is assumed. One RCT will monitor the excavator, three will monitor and survey the waste containers and haul trucks, and one RCT will monitor the work area. For demolition of concrete and small structures/pipelines two RCTs will monitor the demolition area.

Air sampling will be performed at the start of the remediation, once per quarter for a one year period during the remedial action, and at the conclusion of the remedial action. A minimum of two samples will be taken per each sampling period. The planning cost per sample is $544. The sampling crew consists of one sample collection technician and one RCT.

Soil samples will be taken of the overburden, from ERDF containers, and for pre-verification and final verification following excavation. The following soil sampling costs are based on the contaminants expected to be found at the sites:

Uncontaminated soil sampling (overburden material lying above the contaminated soil footprint)

There will be a maximum of six samples or one sample per cubic yard, whichever is less.
QA samples required: 1.
Planning cost per sample: $1,319.

Sampling required for waste going to ERDF (waste acceptance)

There will be one sample for every 70 containers.

There will be a minimum of six samples per site.

QA samples required: a minimum of 1 sample or 5 percent of total ERDF samples, whichever is greater.

Planning cost per sample: $473.

Pre-verification sampling (preliminary samples needed to determine if all of the required waste has been removed from a site being excavated)

There will be one sample per 2,500 m^2 (50 × 50 m) (26,899 ft^2).

There will be a minimum of six samples per site.

QA samples required: a minimum of 2 samples or 5 percent of total the samples, whichever is greater.

Planning cost per sample: $2,329.

Pre-verification sampling is expected to happen twice during the excavation process.

If the samples show that the site has met the requirement, then verification sampling will start.

Verification sampling (these samples are the final samples needed to see if all of the required waste has been removed from a site being excavated)

There will be one sample per 25m x 25m or 625 m^2 (6,724 ft^2).

There will be a minimum of six samples per site.

QA samples required: a minimum of 2 samples or 5 percent of total the samples, whichever is greater.

Planning cost per sample: $9,784.

Verification sampling occurs once during the excavation process.

Sampling crews

Pre-verification and verification sampling – one hour for each sample taken by a crew consisting of one RCT and one sample technician.

Other sampling (air, ERDF, uncontaminated soil) – two hours for each sample taken by a crew consisting of one RCT and one sample technician.

The ERDF container handling and loading process starts with a site haul truck picking up an empty container at the staging area. The container is moved to a preparation area where laborers install a bed liner. The haul truck and container proceed to the loading area. After loading, the liner is sealed and the container is secured by laborers. The container is moved to the survey building where RCTs inspect and survey the container and truck for contamination. From there, the haul truck and container are driven to the storage area. The container is unloaded from the truck at the storage area. Three trucks are required to support each contaminated excavation crew.

The ERDF disposal fee, transportation, and handling costs are estimated at $55 per ton. An environmental restoration subcontractor driver and truck/trailer will move a loaded container to ERDF and place an empty container in the staging area. The estimated costs include the rental of the containers used. For planning purposes, the capacity of an ERDF container is 13 yd^3 of contaminated waste.

Backfilling consists of the following operations:

Moving stockpiled overburden back to the excavation site will require one crew. The equipment used by a crew is one 5-yd^3 loader and two haul trucks. Labor is one operator and two truck drivers. The production rate for one crew is 185 yd^3/hr.

Moving of borrow material to the excavation site is performed by one crew hauling from an onsite pit source. The equipment used by the crew consists of one 5-yd^3 loader, five 16-yd^3 end dump trucks with 16-yd^3 trailers, and one 4,000-gal water truck. Labor includes one loader operator and six truck drivers. The production rate for one crew is 185 yd^3/hr.

Spreading and compaction of the backfill at the site is performed by one crew. The equipment used per crew is one 300-hp dozer and one 4,000-gallon water truck. Labor consists of one operator, one truck driver, and one laborer. The production rate for one crew is 185 yd^3/hr.

Revegetation of the waste site includes planting native dry land grass using tractors with seed drills and hand broadcasting, and two irrigation events in the spring or early summer. All disturbed areas, such as around the waste site, stockpile, staging areas, and access roads, will be replanted.

The CHPRC project management team consists of a part-time project manager with a full-time field supervisor and part-time engineering support. QA, radiological control, and safety personnel also provide oversight along with other support for contract management and project controls. Total hours for this staff are planned at 22.5 hours per day. The duration of this work is based on total project duration.

The FP contractor field supervisory team consists of a full-time construction manager and field supervisor, along with part-time QA, construction safety, and clerical support. Two pickup trucks are included in the cost. Total hours for this staff are planned at 21 hours per day. The duration of this work is based on total project duration.

G3.5.2 Special Conditions

RTD of Site 216-B-4 and the 216-C-2 Reverse Wells uses an oscillating casing.

Alternative 3 work at Reverse Wells B-4 and C-2 will be excavated in a similar fashion. A 10-ft diameter steel casing will be sunk around each reverse well site to the required depth using a hydraulic oscillator. The inside of the casing will be excavated using a hammer grab attachment on a heavy duty crane. The planned excavation depths are 120 ft for the 216-B-4 Reverse Well and 50 ft for the 216-C-2 Reverse Well. The uncontaminated waste will be sent to ERDF using a standard waste container. The casing will be left in place except for the top 20 ft. The inside of the casing will be backfilled with controlled density fill (CDF) to within 20 ft. The top 20 ft will be cut up into 8 ft by 20 ft sections and removed. The steel sections will be taken to ERDF for disposal. After the steel has been removed, the remaining hole will be backfilled with CDF to the ground surface.

G4 References

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