1228921

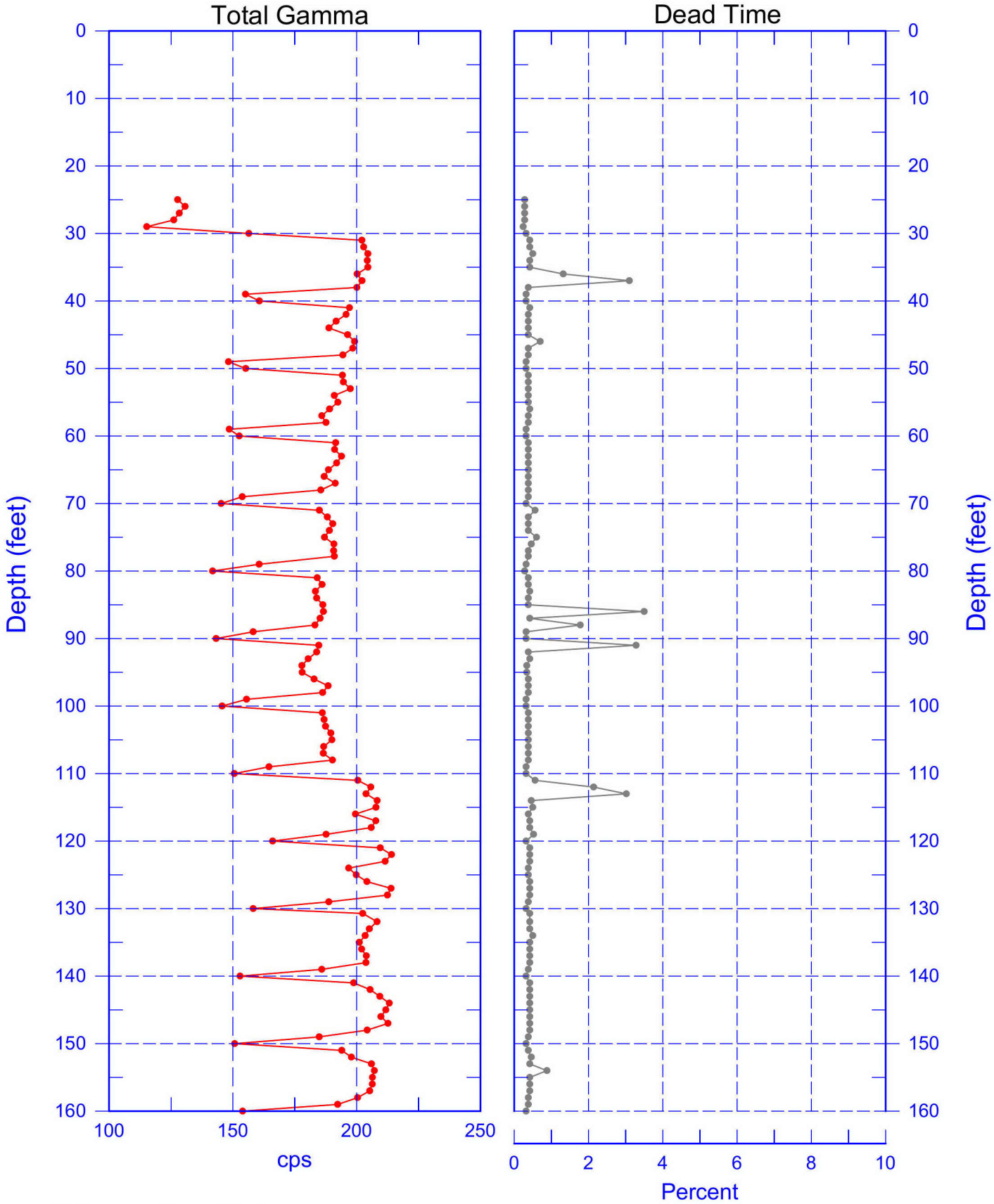
RPP-RPT-58339 DRAFT A

PHASE 2 RCRA FACILITY INVESTIGATION REPORT FOR WASTE MANAGEMENT C

SECTION 5 OF 5

C-4125

Total Gamma & Dead Time

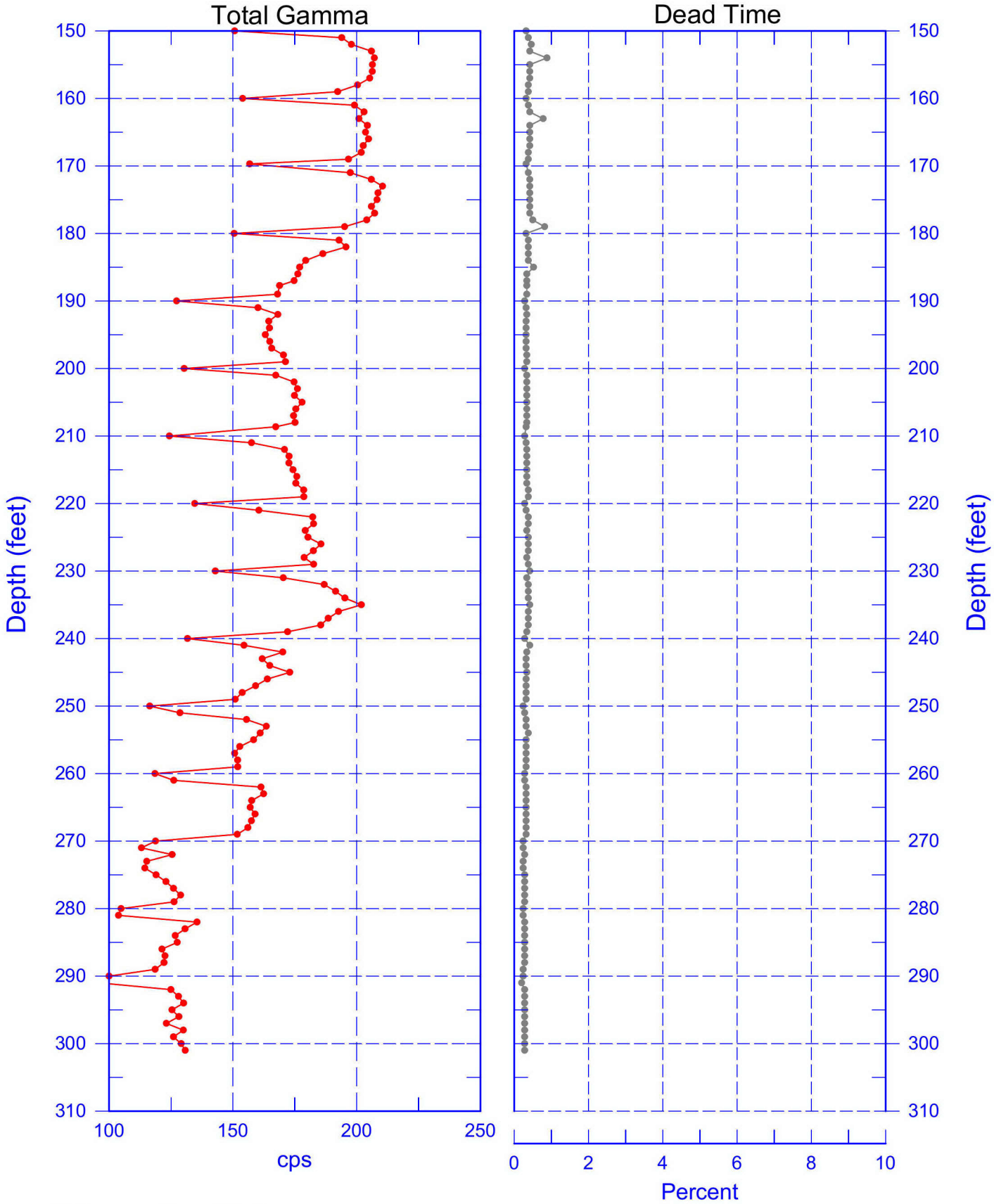


Reference - Ground Surface

Last Log Date - 08/16/03

C-4125

Total Gamma & Dead Time

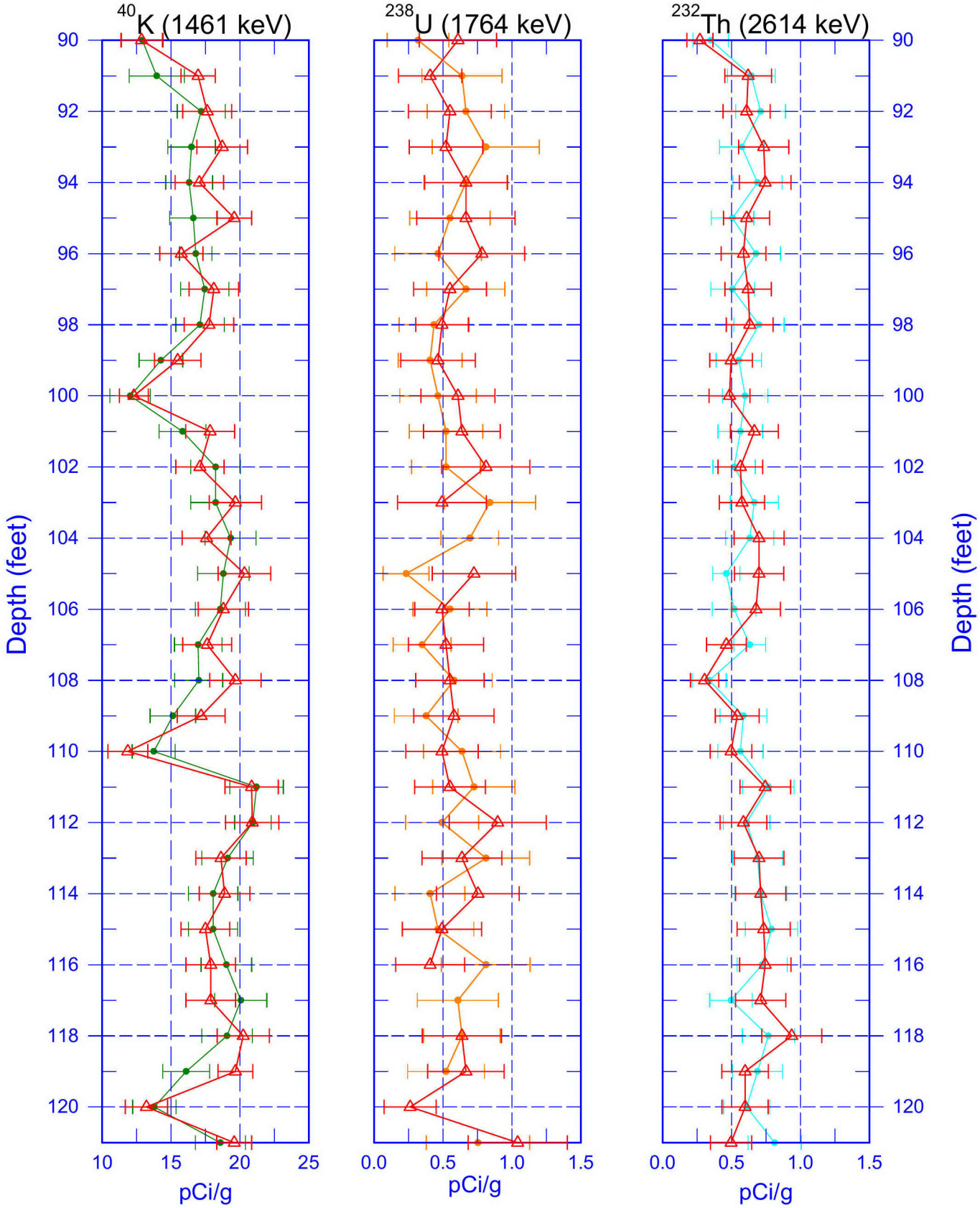


Reference - Ground Surface

Last Log Date - 08/16/03

C-4125

Repeat Section of Natural Gamma Logs



Zero Reference = Ground Surface

Last Log Date - 08/16/03

GROUNDWATER WELL LOGGING RESULTS FOR C4127

Stoller
Grand Junction Office established 1959

C-4127
Log Data Report

Borehole Information:

Borehole: C-4127			Site: South of C Tank Farm		
Coordinates (WA St Plane)		GWL[1] (ft) : 272		GWL Date: 07/21/03	
North	East	Drill Date	Ground Level Elevation	Total Depth (ft)	Type
Not available	Not available	07/03	Not available	318.0	Becker

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Top (ft)	Bottom (ft)
Steel tubing	2.7	6.24	6.0	0.125	0	318.0
Threaded Steel	2.1	9.0	8.0	0.50	0	318.0

Borehole Notes:

The casing dimensions are derived from published values for Becker drill casing. Casing thicknesses at the joints are 0.875 in. and 0.240 in. for the 8-in. and 6-in. casings, respectively. The total depth of the borehole was provided by the driller. The well site geologist provided the depth to water. Logging data acquisition is referenced to the ground surface.

Logging Equipment Information:

Logging System:	Gamma 1E		Type:	SGLS (70%) SN: 34TP40587A
Calibration Date:	07/03	Calibration Reference:	GJO-2003-468-TAR	
		Logging Procedure:	MAC-HGLP 1.6.5, Rev. 0	

Spectral Gamma Logging System (SGLS) Log Run Information:

Log Run	1	2	3 Repeat	4	
Date	07/21/03	07/22/03	07/22/03	07/22/03	
Logging Engineer	Kos	Kos	Kos	Kos	
Start Depth (ft)	30.0	316.0	142.0	109.0	
Finish Depth (ft)	0.0	110.0	110.0	29.0	
Count Time (sec)	100	100	100	100	
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[2]	N/A	N/A	N/A	
Pre-Verification	AE002CAB	AE003CAB	AE003CAB	AE003CAB	
Start File	AE002000	AE003000	AE003207	AE003240	
Finish File	AE002030	AE003206	AE003239	AE003320	
Post-Verification	AE002CAA	AE003CAA	AE003CAA	AE003CAA	

Log Run	1	2	3 Repeat	4	
Depth Return Error (in.)	0	N/A	N/A	-1.75	
Comments	No fine-gain adjustment.	No fine-gain adjustment.	No fine-gain adjustment.	Gain adjustment files -3250, -3271, and -3297	

Logging Operation Notes:

Spectral gamma logging was performed in this borehole on July 21 and 22, 2003. Logging was conducted with a centralizer on the sonde and measurements are referenced to ground surface. A repeat section was collected in this borehole to evaluate system performance.

Analysis Notes:

Analyst:	Henwood	Date:	07/28/03	Reference:	GJO-HGLP 1.6.3, Rev. 0

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

A combined casing correction for 0.675-in.-thick casing was applied throughout the borehole for both casings. The combined thickness at casing joints is 1.115 in. This thickness results in a significant reduction in gamma activity detection as the detector passes by a casing joint. However, it is not practical to correct individual data points for the effect of casing joints. The influence of the thick joints is apparent on the total gamma and ^{40}K logs where reduced count rates and concentrations are exhibited at approximately 10-ft depth intervals.

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 G1EJul03.xls using efficiency functions and corrections for casing, water, and dead time as determined from annual calibrations. Dead time corrections are applied where dead times exceed 10.5 percent; no dead times in excess of 10.5 percent were encountered. Correction for water was applied to the data below 272 ft.

Log Plot Notes:

Separate log plots are provided for the man-made radionuclide (^{137}Cs) 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 repeat log section is also included.

Results and Interpretations:

^{137}Cs was the only man-made radionuclide detected in this borehole. ^{137}Cs was detected at a few sporadic locations throughout the borehole near its MDL of approximately 0.2 pCi/g.

The repeat sections indicated good agreement of the naturally occurring KUT.

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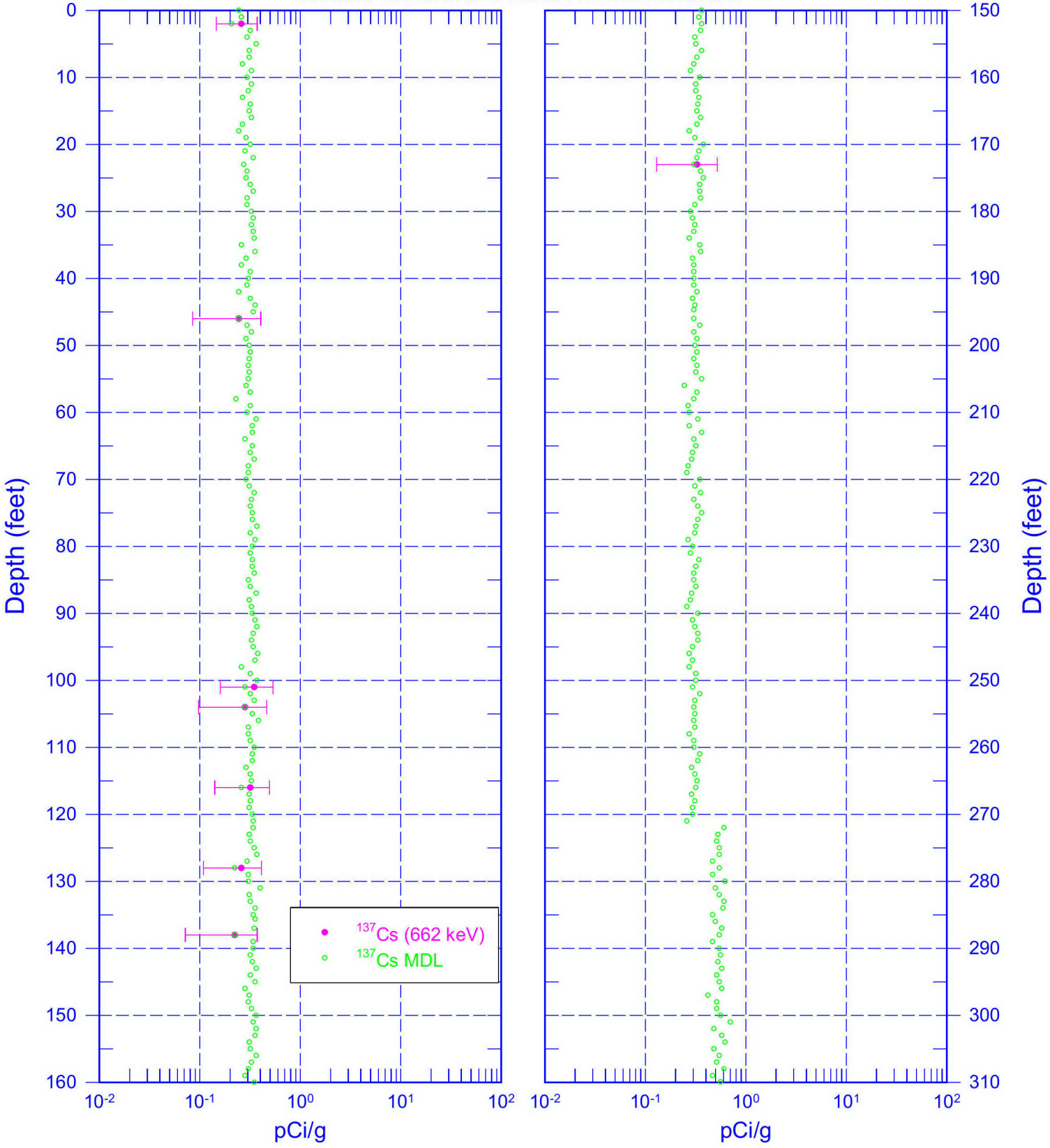
[1] GWL – groundwater level
[2] N/A – not applicable

C-4127

Man-Made Radionuclides

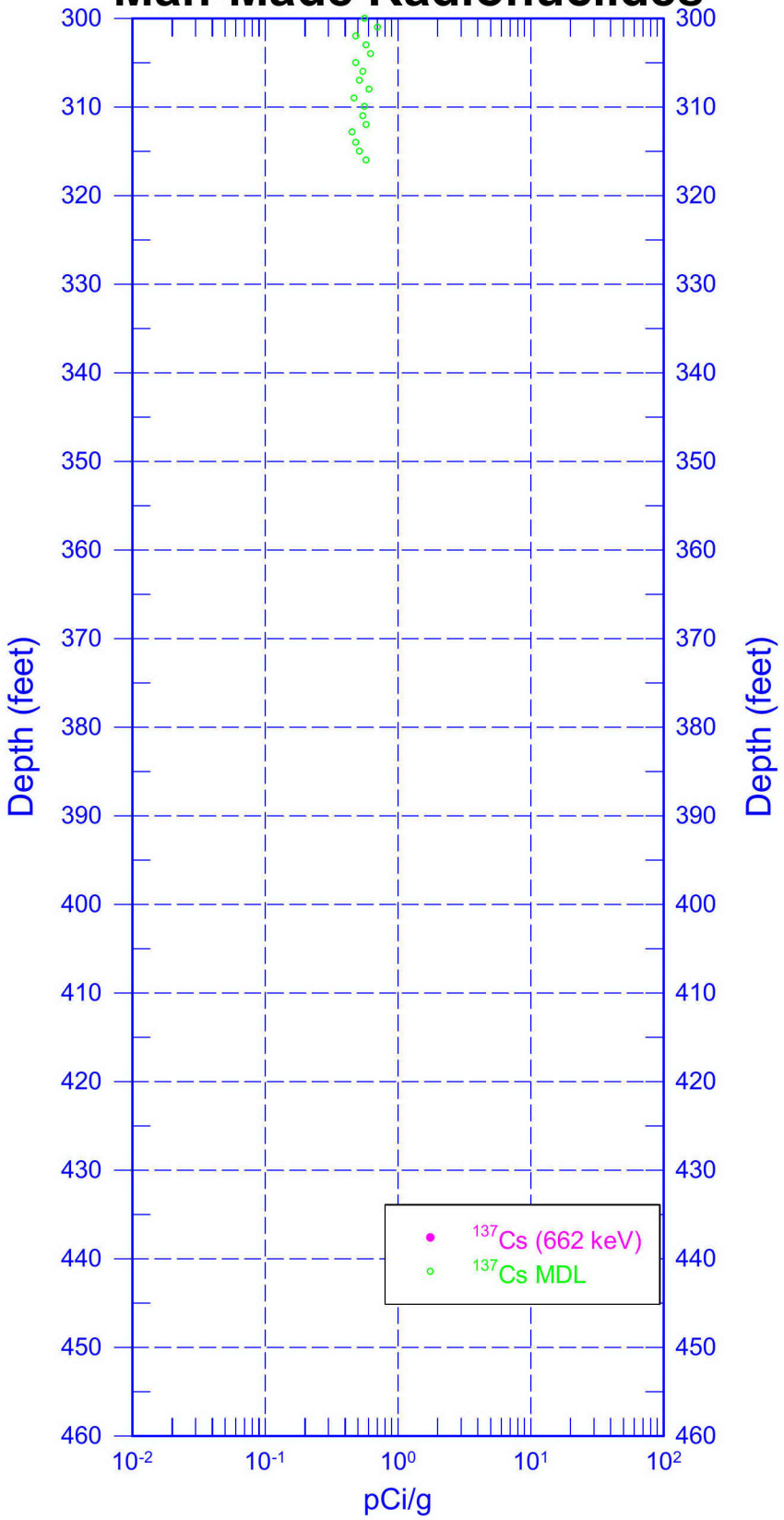


Zero Reference = Ground Surface

Last Log Date - 07/22/03

C-4127

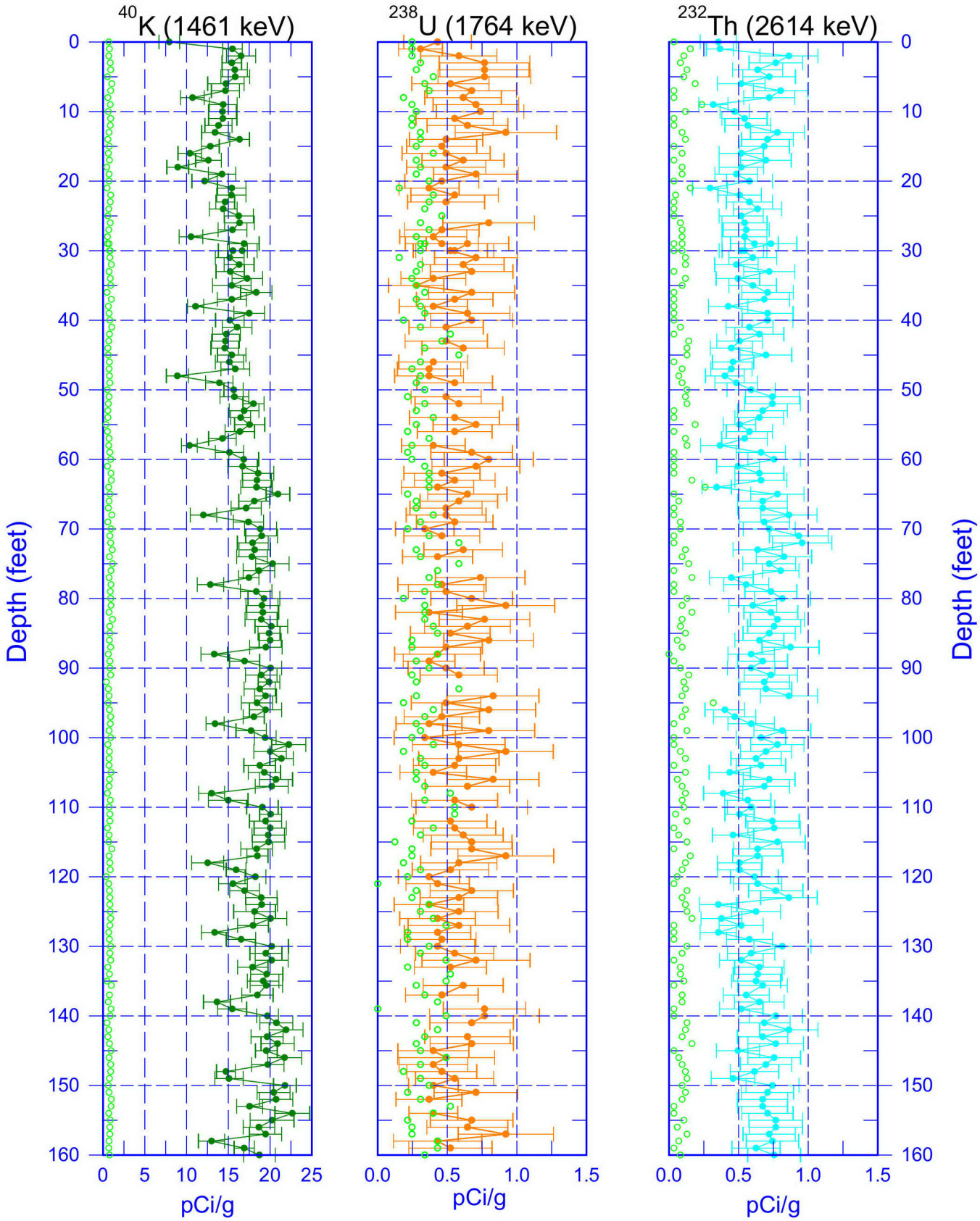
Man-Made Radionuclides



Zero Reference = Ground Surface

Last Log Date - 07/22/03

C-4127
Natural Gamma Logs



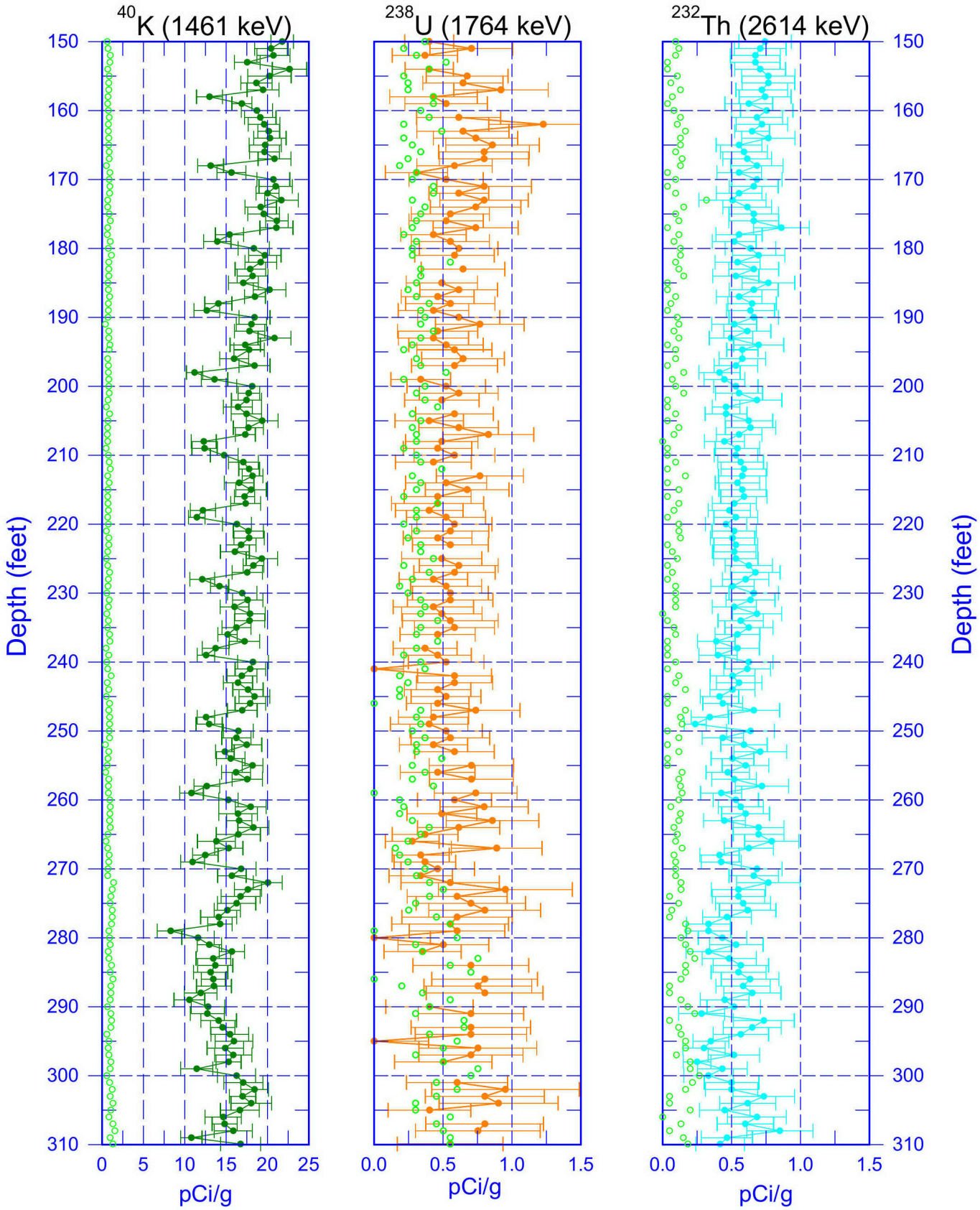
Zero Reference = Ground Surface

MDL

Last Log Date - 07/22/03

C-4127

Natural Gamma Logs



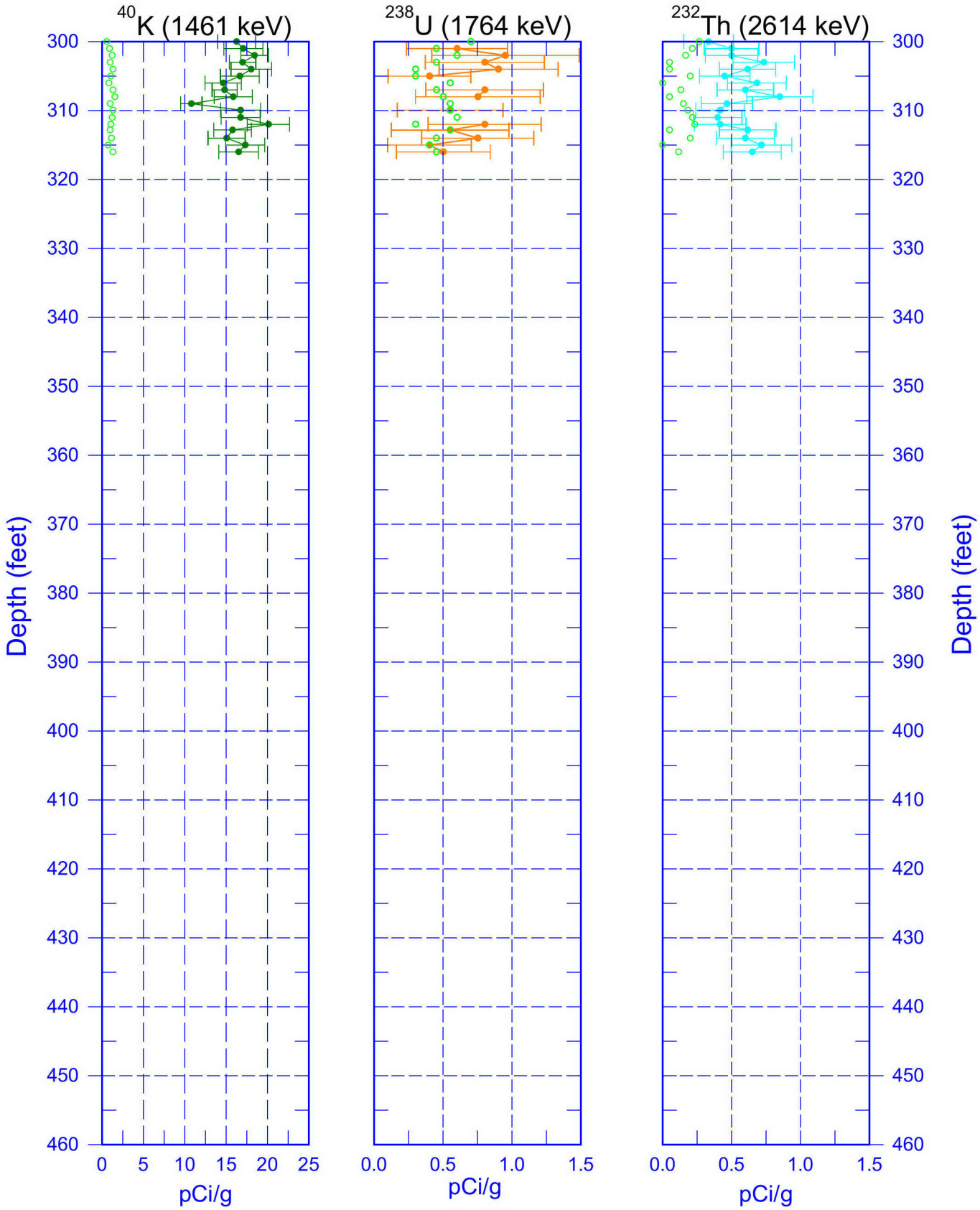
Zero Reference = Ground Surface

MDL

Last Log Date - 07/22/03

C-4127

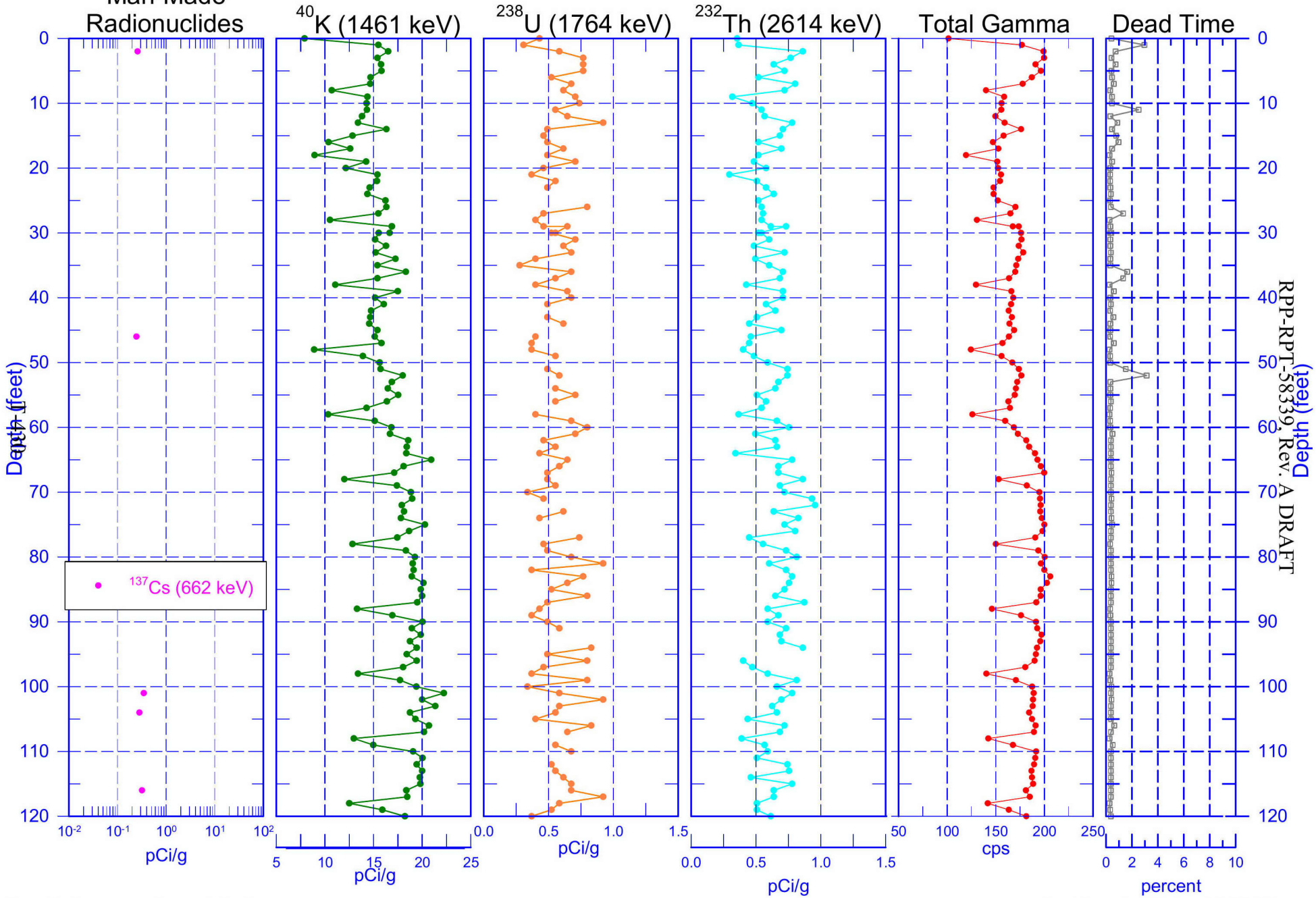
Natural Gamma Logs



Zero Reference = Ground Surface

Last Log Date - 07/22/03

C-4127 Combination Plot

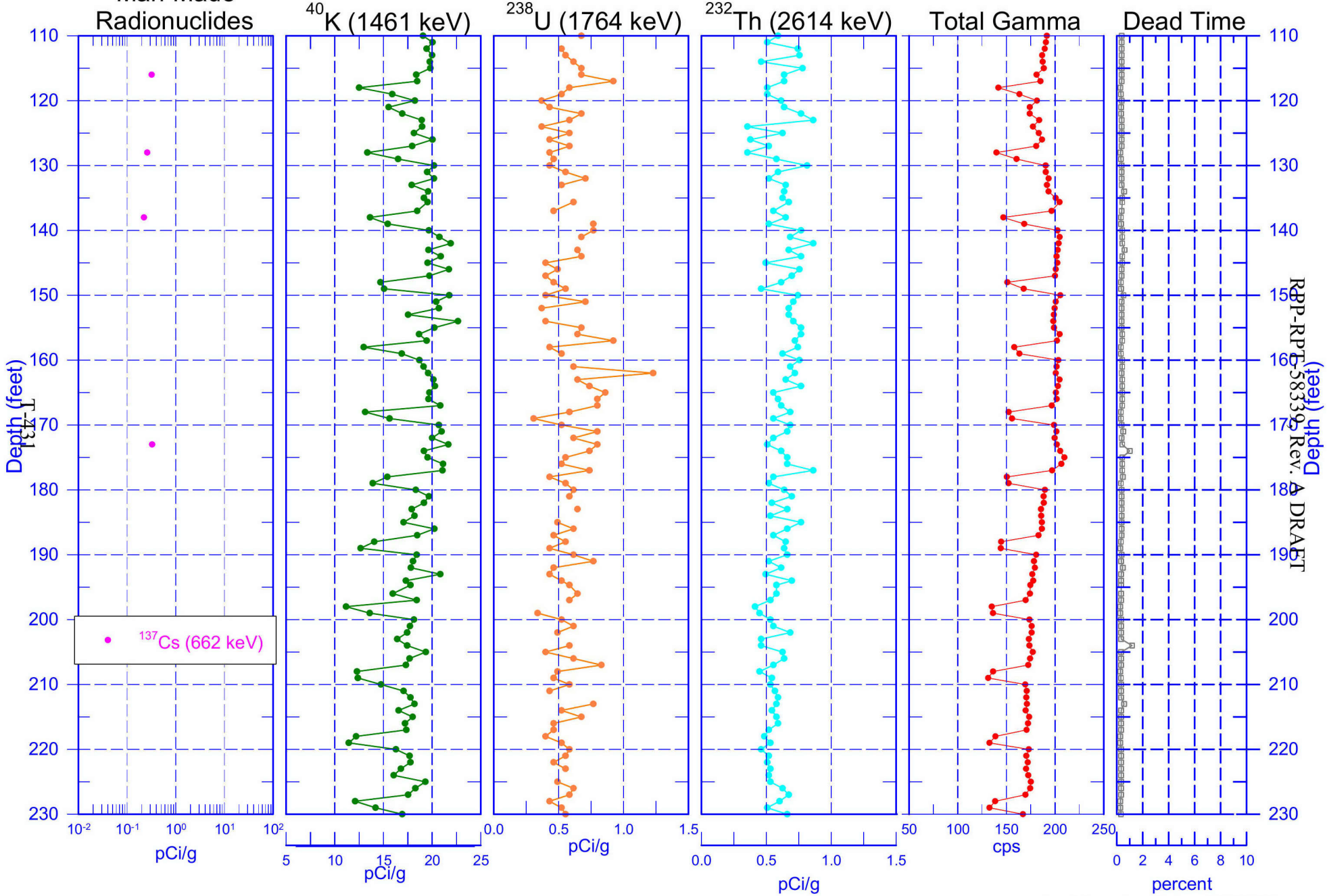


Zero Reference = Ground Surface

Last Logging Date - 07/22/03

RPP-RPT-58339, Rev. A DRAFT

C-4127 Combination Plot

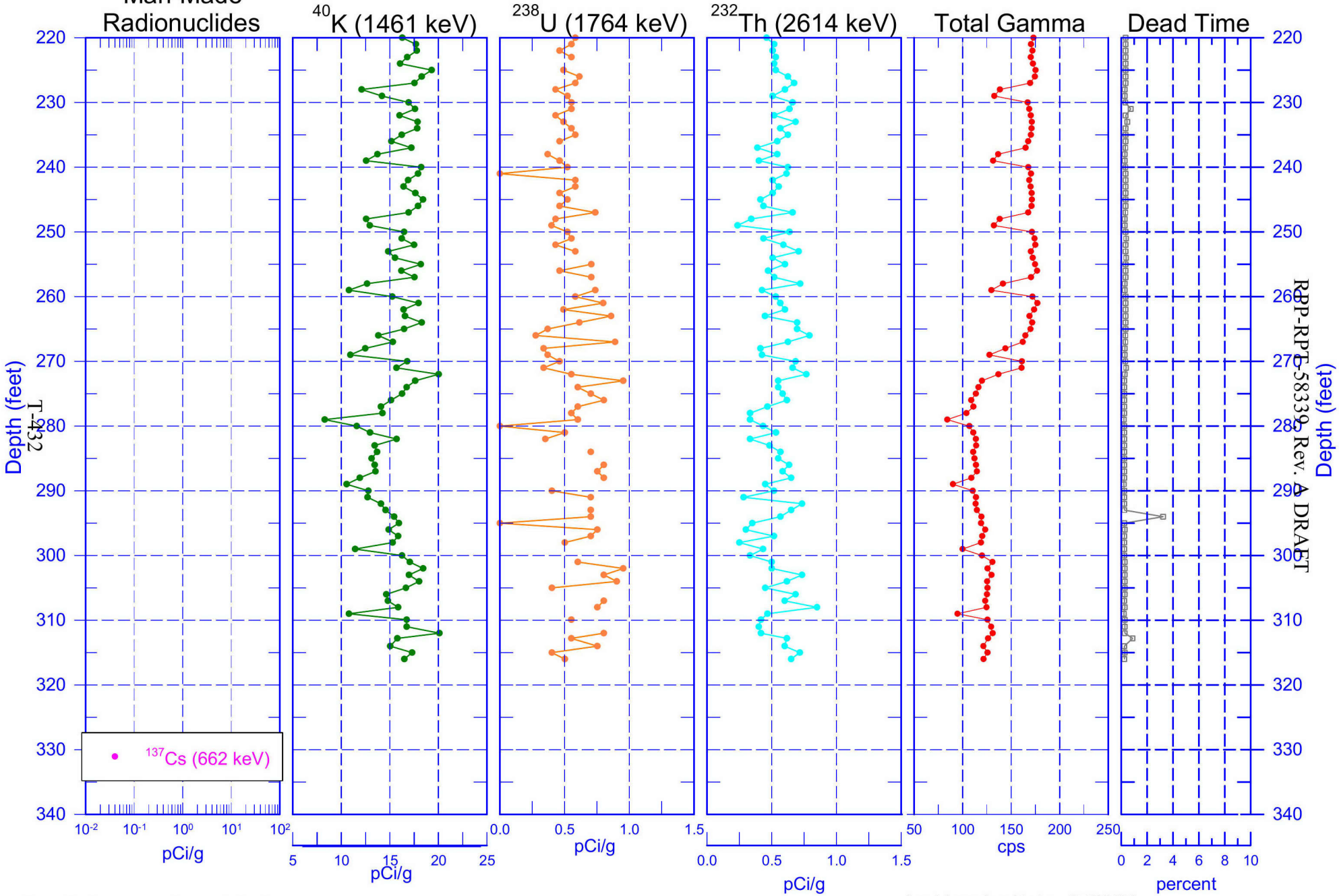


Zero Reference = Ground Surface

Last Logging Date - 07/22/03

RPP-RPT-58339, Rev. A DRAFT

C-4127 Combination Plot



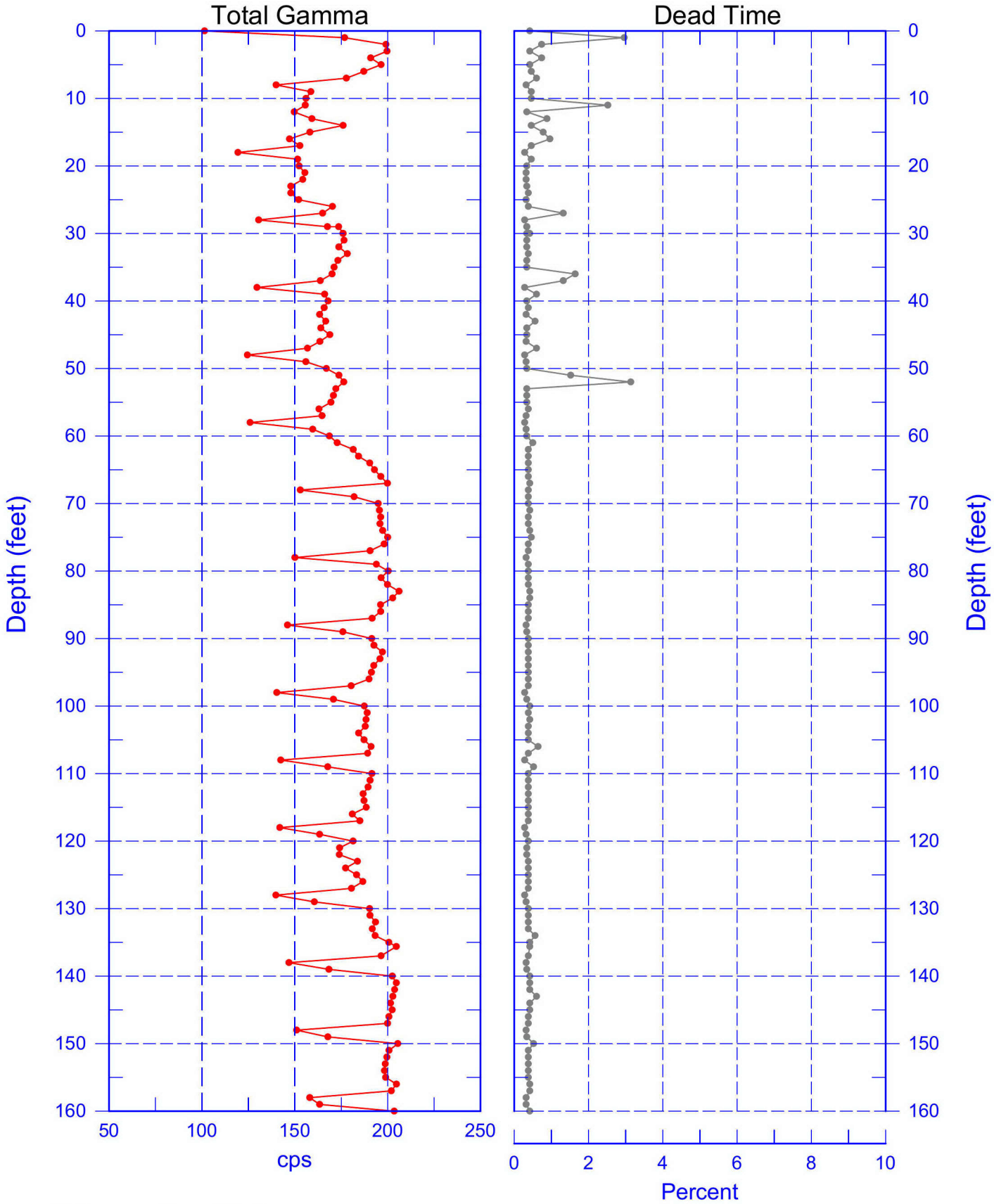
Zero Reference = Ground Surface

Last Logging Date - 07/22/03

RPP-RPT-58339, Rev. A DRAFT

C-4127

Total Gamma & Dead Time

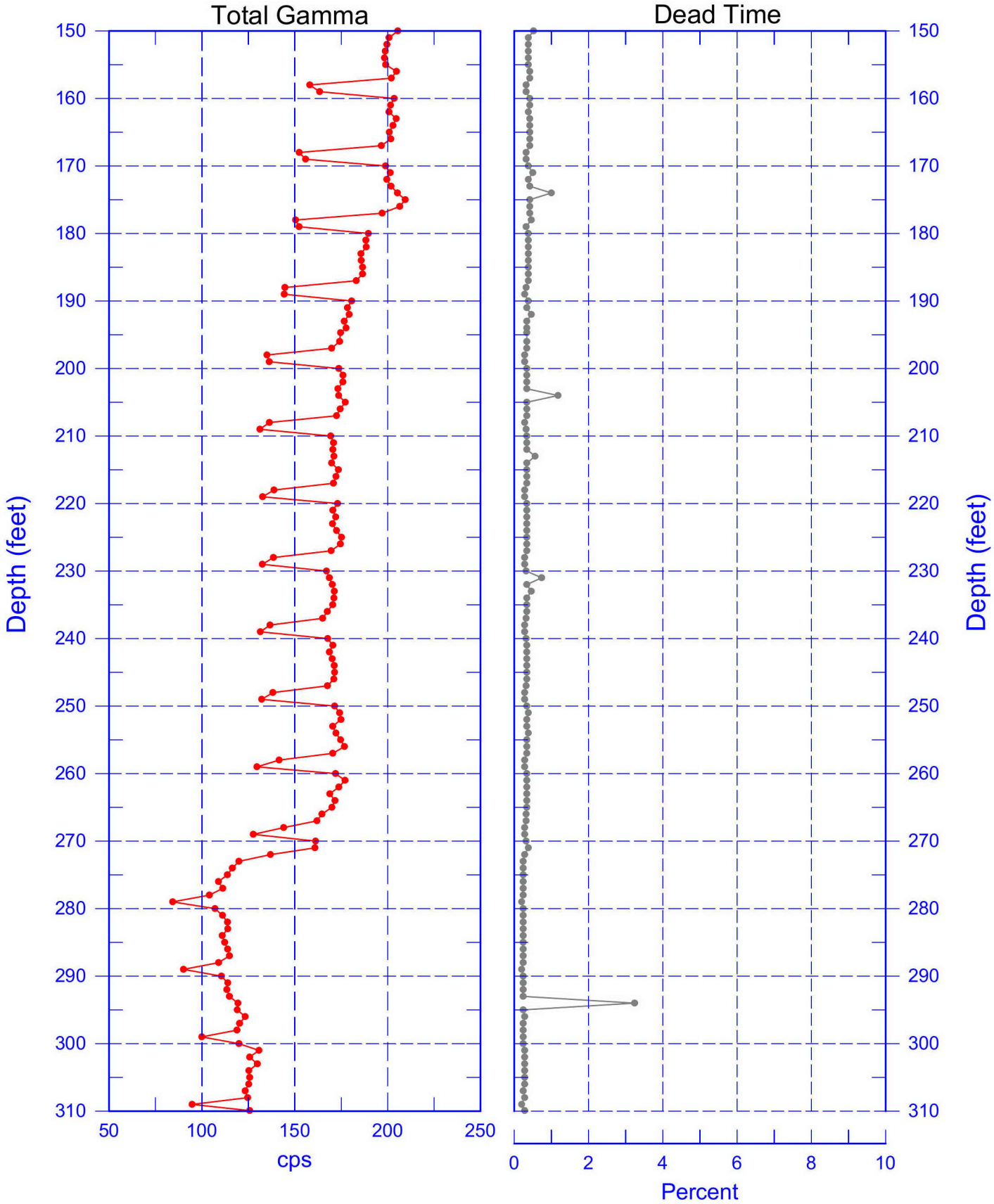


Reference - Ground Surface

Last Log Date - 07/22/03

C-4127

Total Gamma & Dead Time

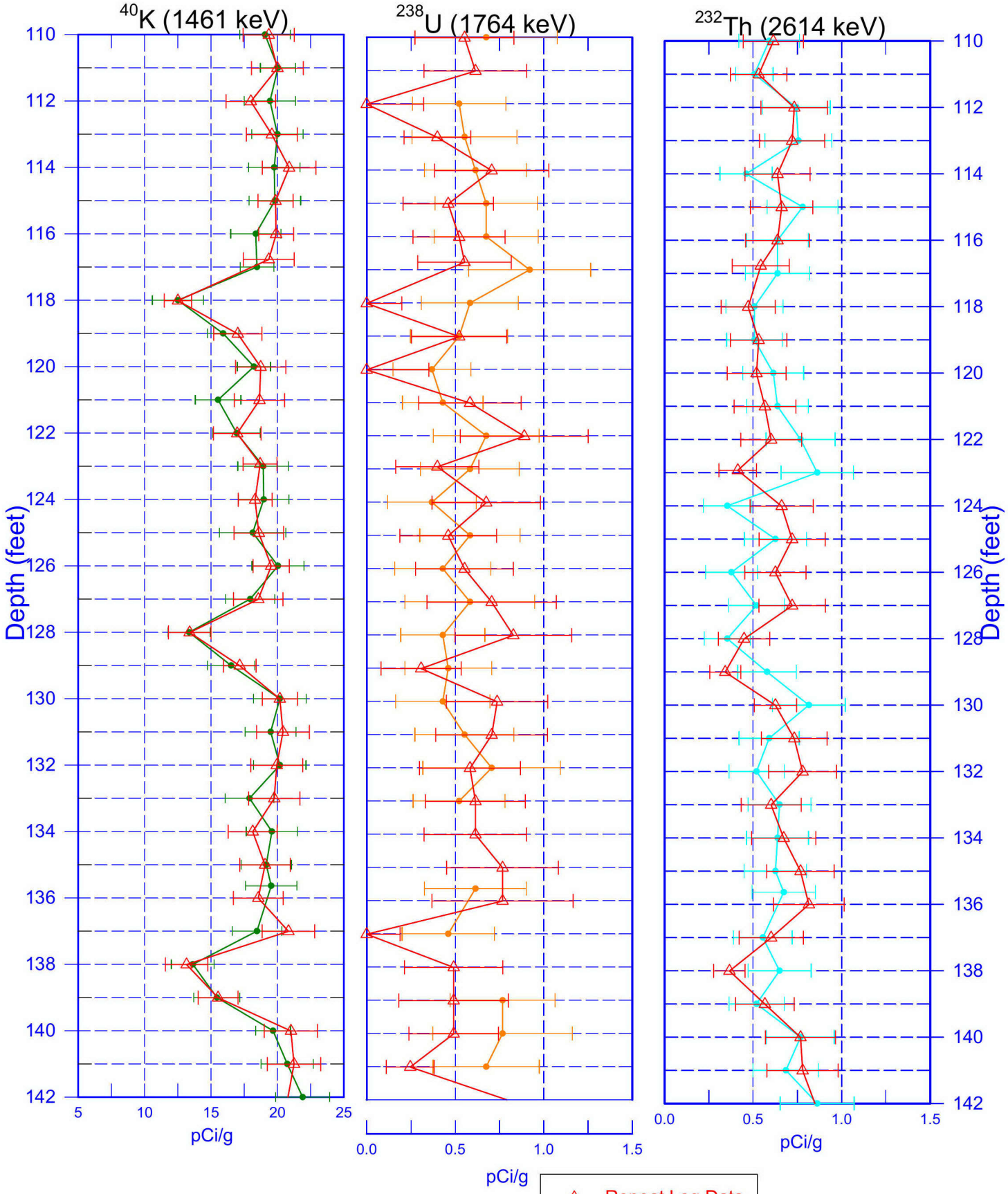


Reference - Ground Surface

Last Log Date - 07/22/03

C-4127

Repeat Section of Natural Gamma Logs



Zero Reference = Ground Surface

Last Log Date - 07/22/03

GROUNDWATER WELL LOGGING RESULTS FOR C4190

Stoller
Grand Junction Office established 1959

C4190
Log Data Report

Borehole Information:

Borehole:	C4190			Site:	Southwest of C Tank Farm
Coordinates (WA State Plane)		GWL (ft)[1]:	273	GWL Date:	8/6/2003
North	East	Drill Date	TOC[2] Elevation	Total Depth (ft)	Type
N/A[3]	N/A	August 2003	N/A	318	Becker

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Top (ft)	Bottom (ft)
Threaded steel	2.85	6 1/4	6	1/8	+2.85	318
Threaded steel	2.25	9	8	1/2	2.25	318

Casing stickup was measured using a steel tape. The logging engineer measured the outside diameters for both the 6- and 8-in. casings using a caliper. The caliper and 6-in. inside casing diameter were measured using a steel tape; measurements were rounded to the nearest 1/16 in.

Borehole Notes:

Zero reference is the ground surface. This borehole was logged through the drill pipe. The borehole is located approximately 30 ft east of UPR 200-E-86 and 20 ft north of the MO 822 change trailer. A 6-in. layer of crushed gravel is present on the ground surface surrounding the drill site.

The Becker drilling system utilizes a special dual-wall casing string. Air passes through the annular space between the inner and outer casing, and drill cuttings are brought up inside the inner casing. For this well, the casing consisted of a 6-in. ID inner casing with 0.125-in. wall thickness inside an 8-in. ID outer casing with 0.5-in. wall thickness. The inner casing is thicker at casing joints, where wall thickness is 0.406 in. Casing joints are approximately 1 ft long overall and occur at 10-ft intervals.

Logging Equipment Information:

Logging System:	Gamma 1E		Type:	70% HPGe (34-TP40587A)
Calibration Date:	07/2003	Calibration Reference:	GJO-2003-486-TAR	
		Logging Procedure:	MAC-HGLP 1.6.5, Rev. 0	

Spectral Gamma Logging System (SGLS) Log Run Information:

Log Run	1	2/Repeat	3		
Date	8/07/03	8/08/03	8/08/03		
Logging Engineer	Spatz	Spatz	Spatz		
Start Depth (ft)	319.0	147.0	114.0		
Finish Depth (ft)	115.0	115.0	0		
Count Time (sec)	100	100	100		

Log Run	1	2/Repeat	3		
Live/Real	R	R	R		
Shield (Y/N)	N	N	N		
MSA Interval (ft)	1.0	1.0	1.0		
ft/min	n/a[4]	n/a	n/a		
Pre-Verification	AE013CAB	AE014CAB	AE014CAB		
Start File	AE013000	AE014000	AE014033		
Finish File	AE013204	AE014032	AE014147		
Post-Verification	AE013CAA	AE014CAA	AE014CAA		
Depth Return Error (in.)	-2.5	n/a	-1		
Comments	No fine-gain adjustment.	No fine-gain adjustment.	Fine-gain adjustment after files -101 and -116.		

Logging Operation Notes:

Zero reference was the ground surface, and the borehole was logged through drill pipe.

SGLS data were collected using Gamma 1E. Pre- and post-survey verification measurements employed the Amersham KUT (^{40}K, ^{238}U, and ^{232}Th) verifier with serial number 118. Logging was performed with a centralizer installed on the sonde.

Analysis Notes:

Analyst:	Sobczyk	Date:	8/14/03	Reference:	GJO-HGLP 1.6.3, Rev. 0

SGLS pre-run and post-run verification spectra were collected at the beginning and end of the day and compared to the control limits. All of the verification spectra were within the control limits, except for spectrum AE013CAB. This spectrum was slightly above the upper control limit for the 609-keV peak counts per second (cps) value. The peak counts per second at the 609-keV, 1461-keV, and 2615-keV photopeaks on the post-run verification spectra as compared to the pre-run verification spectra for each day were between 0.5 percent higher and 7.0 percent lower at the end of the day. Examinations of spectra indicate that the detector functioned normally during all of the logging runs, and the spectra are accepted.

Log spectra were processed in batch mode using APTEC SUPERVISOR to identify individual energy peaks and determine count rates. The pre-run verification spectrum was used to determine the energy and resolution calibration for processing the data using APTEC SUPERVISOR. Concentrations were calculated in EXCEL (source file: G1EJul03.xls). Zero reference was the ground surface. Based on measurements supplied by the logging engineer, the casing configuration was assumed to be a string of 6-in. and 8-in. casings to 319 ft. The casing correction factor was calculated using a combined casing thickness of 5/8 in. This casing thickness is based upon the field measurements. The combined thickness at casing joints is 1.115 in. This thickness results in a significant reduction in gamma activity detection as the detector passes by a casing joint. However, it is not practical to correct individual data points for the effect of casing joints every 10.0 ft. The influence of the thick joints is apparent on the total gamma and ^{40}K logs where reduced count rates and concentrations are exhibited at approximately 10-ft depth intervals. Water corrections were applied to the data below 273 ft. SGLS dead time corrections were not applied because dead time did not exceed 10 percent.

Log Plot Notes:

Separate log plots are provided for gross gamma and dead time, naturally occurring radionuclides (^{40}K, ^{238}U, and ^{232}Th), and man-made radionuclides. Plots of the repeat logs versus the original logs are

included. 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, or casing correction. These errors are discussed in the calibration report. A combination plot is also included to facilitate correlation. The ^{214}Bi peak at 1764 keV was used to determine the naturally occurring ^{238}U concentrations on the combination plot rather than the ^{214}Bi peak at 609 keV because it exhibited higher net counts per second.

Results and Interpretations:

^{137}Cs was the only man-made radionuclide detected in this borehole. ^{137}Cs was detected near the ground surface at 2 ft and in the interval from 11 through 13 ft at concentrations ranging from the MDL (0.3 pCi/g) to 0.6 pCi/g. The maximum concentration of ^{137}Cs was measured at 12 ft. ^{137}Cs was also detected at log depths of 65, 130, and 218 ft with concentrations near the MDL.

Logging through the drill pipe used in the construction of this borehole precludes the acquisition of SGLS spectra that consistently have statistically valid photopeaks. The relatively thick casing joints effectively shield the detector from the formation over a 3.0-ft zone at 10.0-ft intervals. Energy levels below 1461 keV are severely attenuated by the drill pipe.

The plots of the repeat logs demonstrate reasonable repeatability of the SGLS. The natural radionuclides at energy levels of 609, 1461, 1764, and 2614 keV are comparable between the repeat and original SGLS log runs. ^{137}Cs encountered at 130 ft on the original log run did not repeat.

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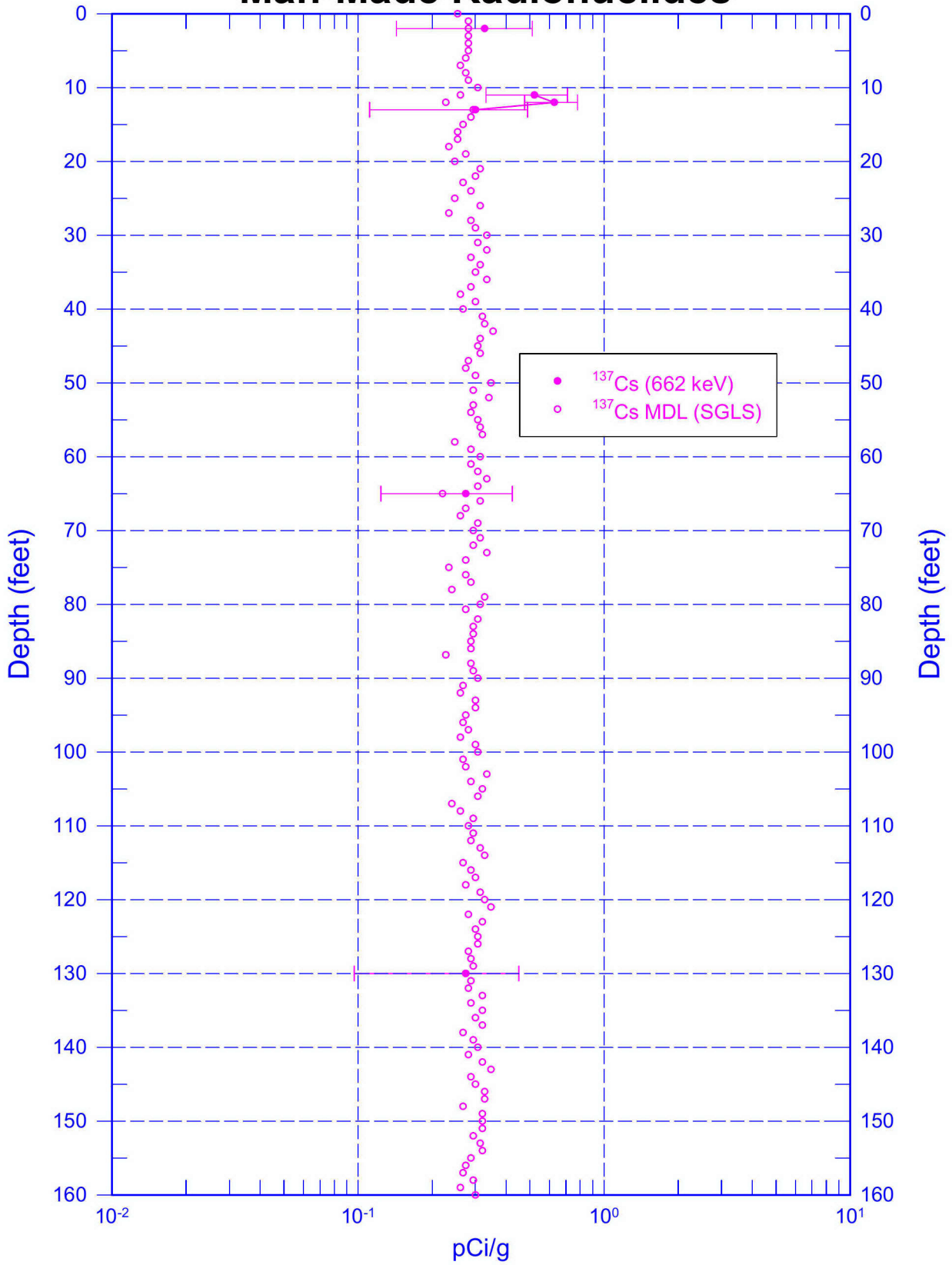
[1] GWL – groundwater level
[2] TOC – top of casing
[3] N/A – not available
[4] n/a – not applicable

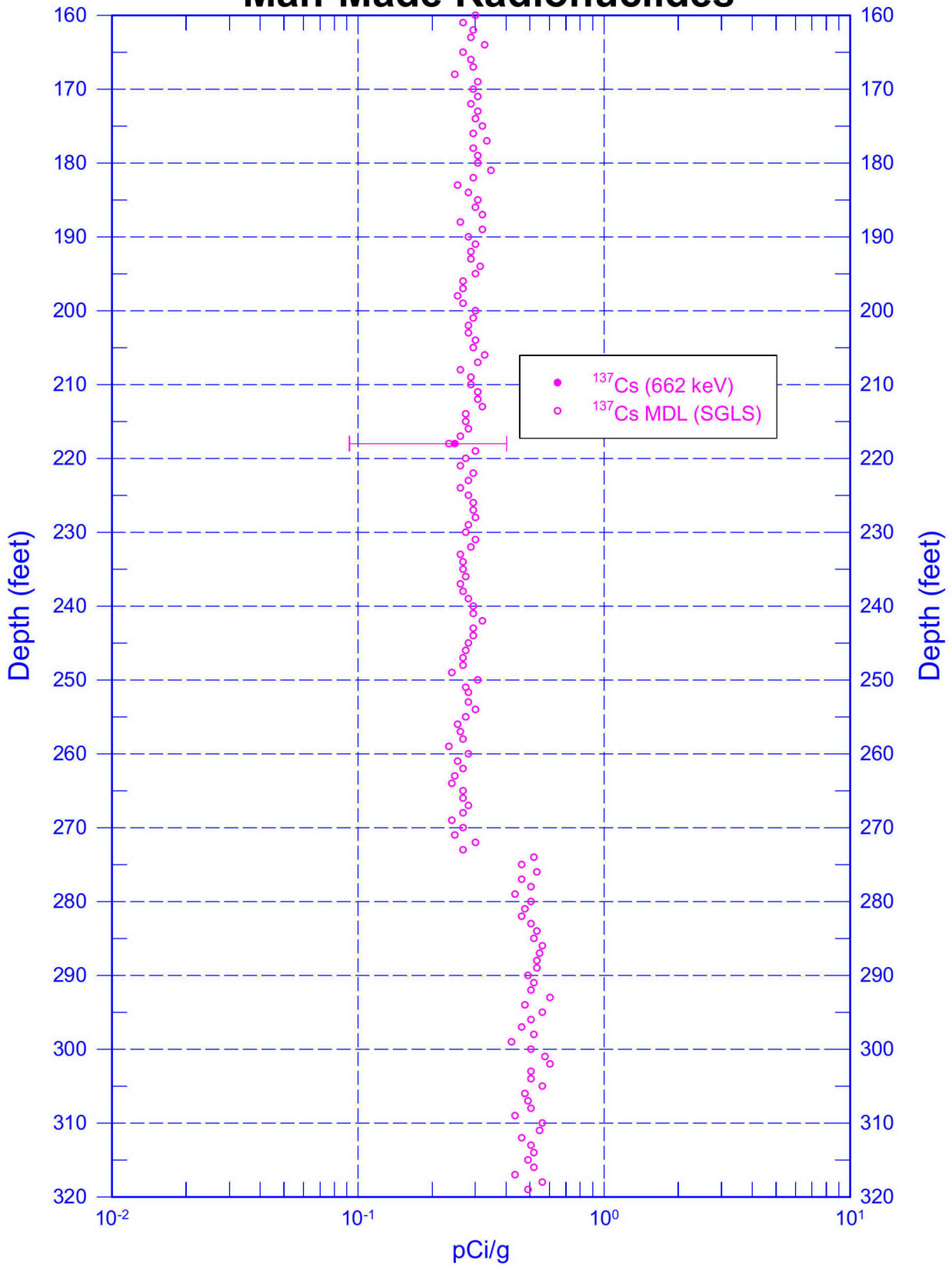
C4190
Man-Made Radionuclides



Zero Reference = Ground Surface

Date of Last Logging Run
8/08/2003

C4190
Man-Made Radionuclides

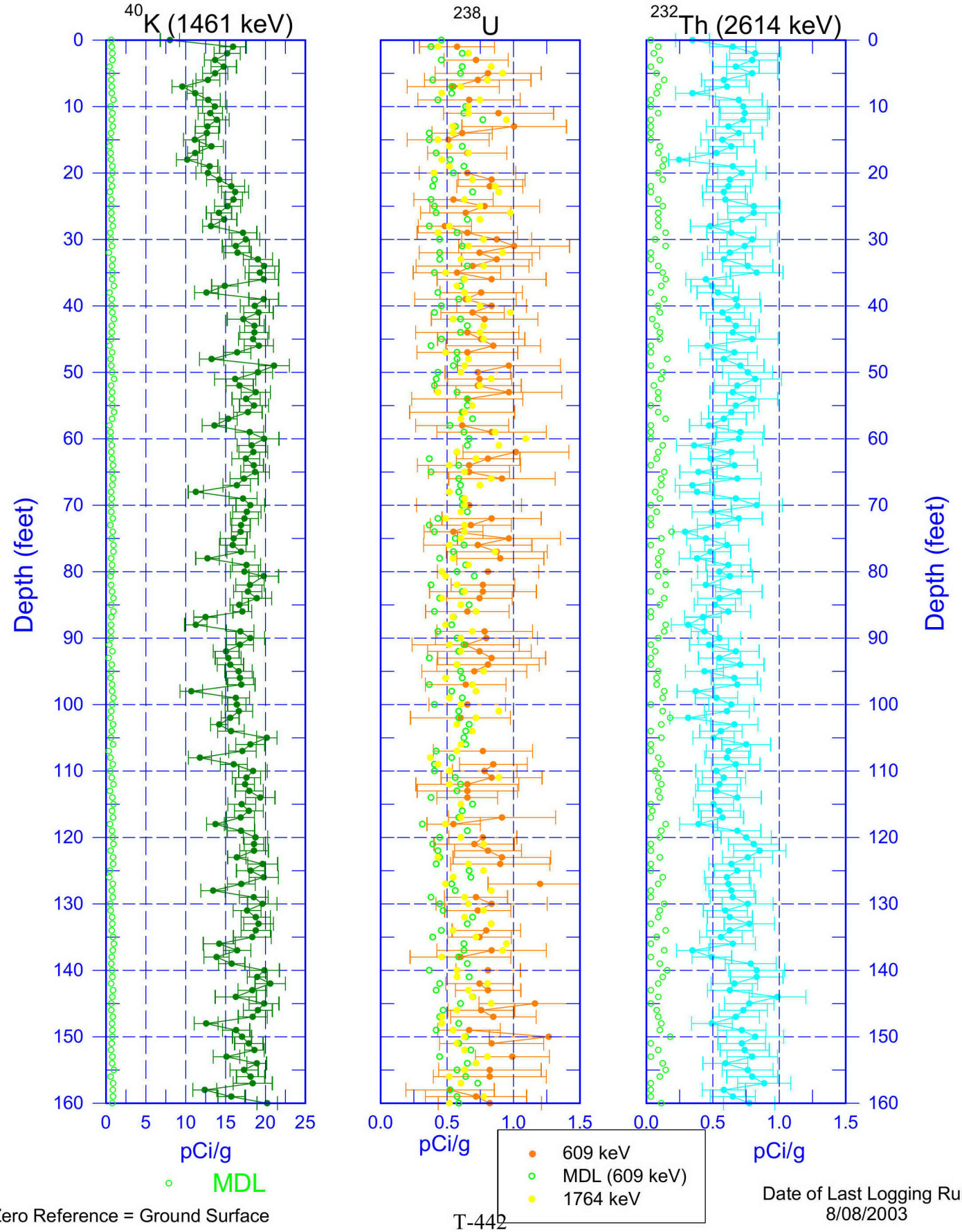


Zero Reference = Ground Surface

Date of Last Logging Run
8/08/2003

C4190

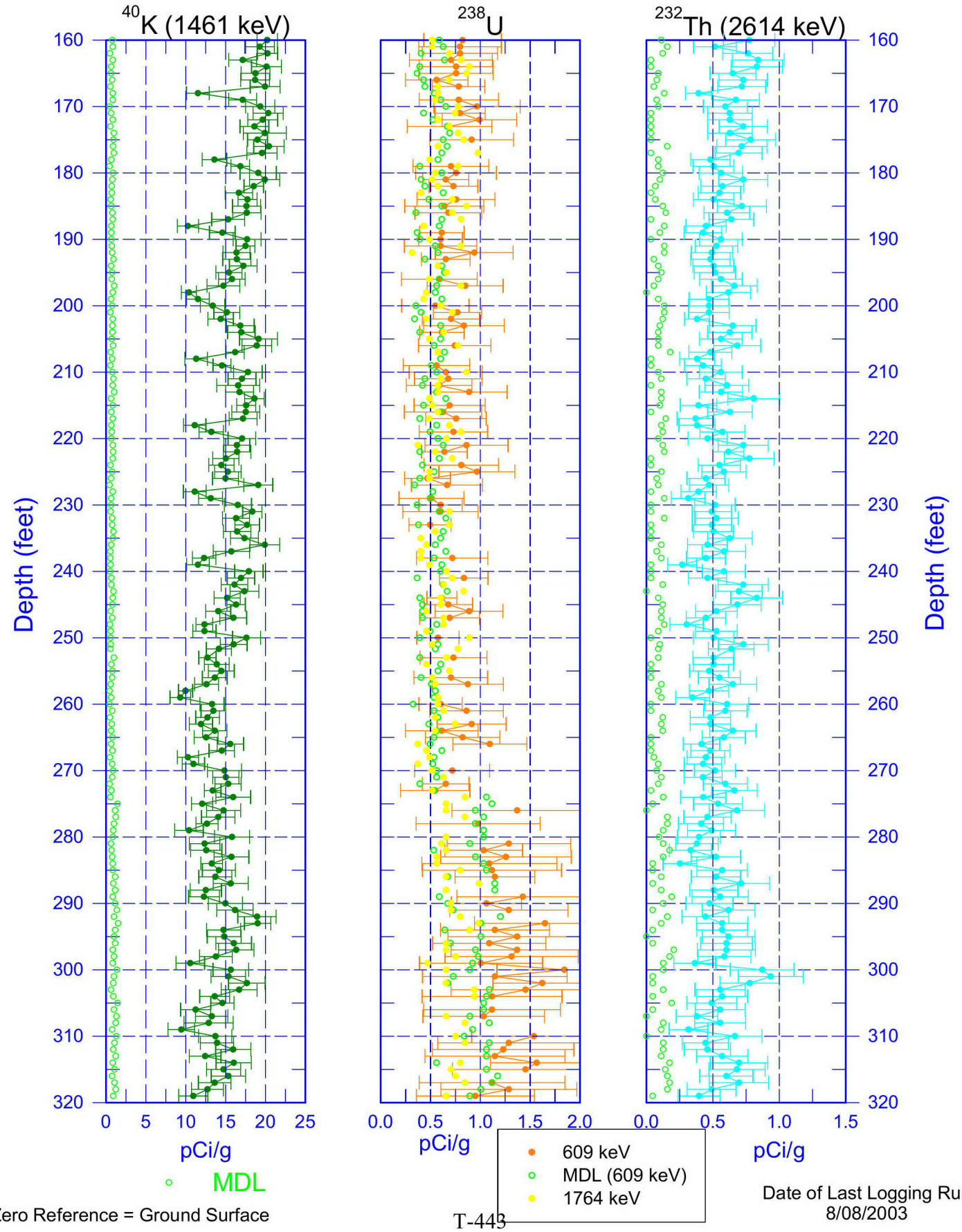
Natural Gamma Logs



Zero Reference = Ground Surface

Date of Last Logging Run
8/08/2003

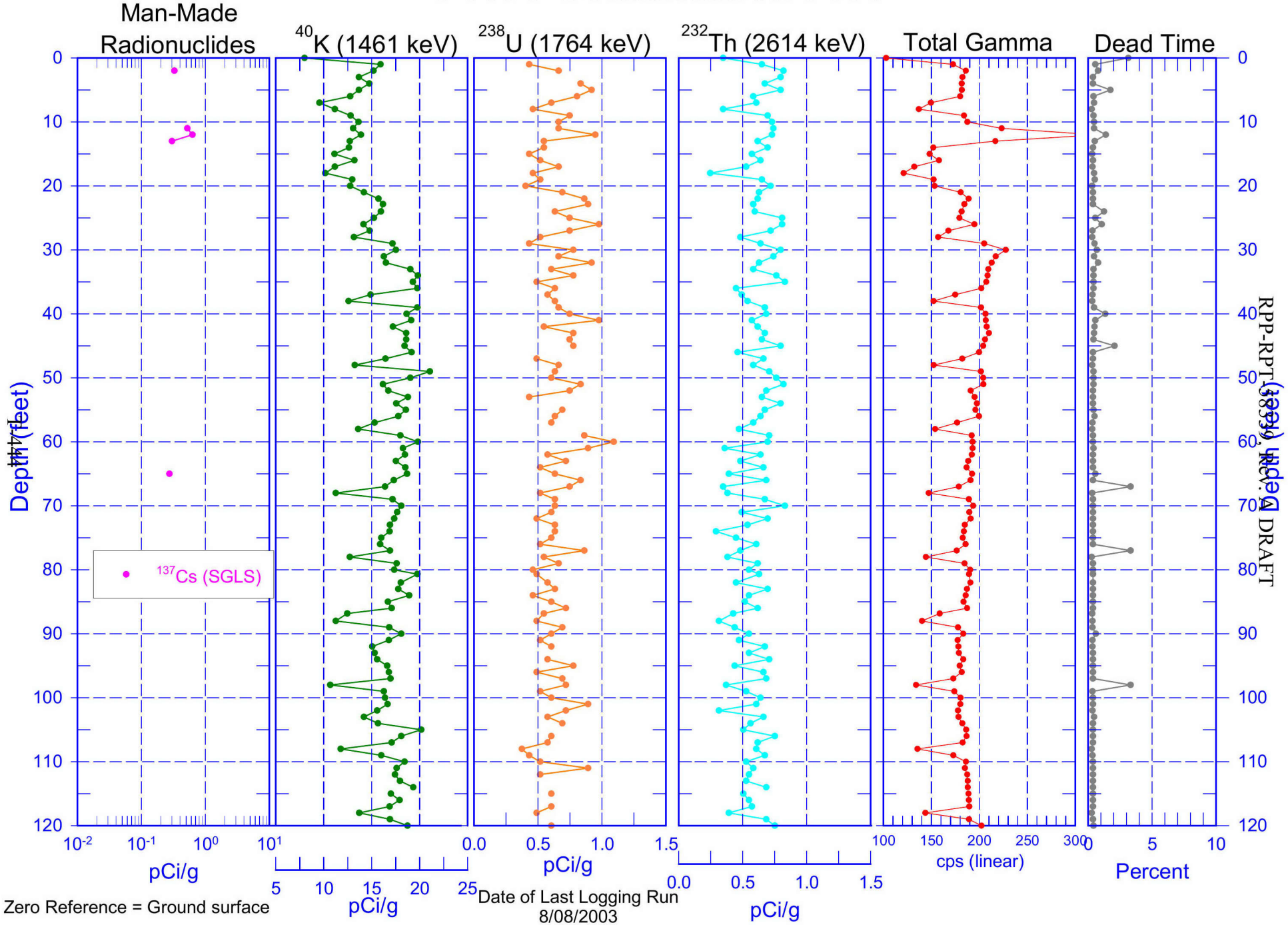
C4190
Natural Gamma Logs



Zero Reference = Ground Surface

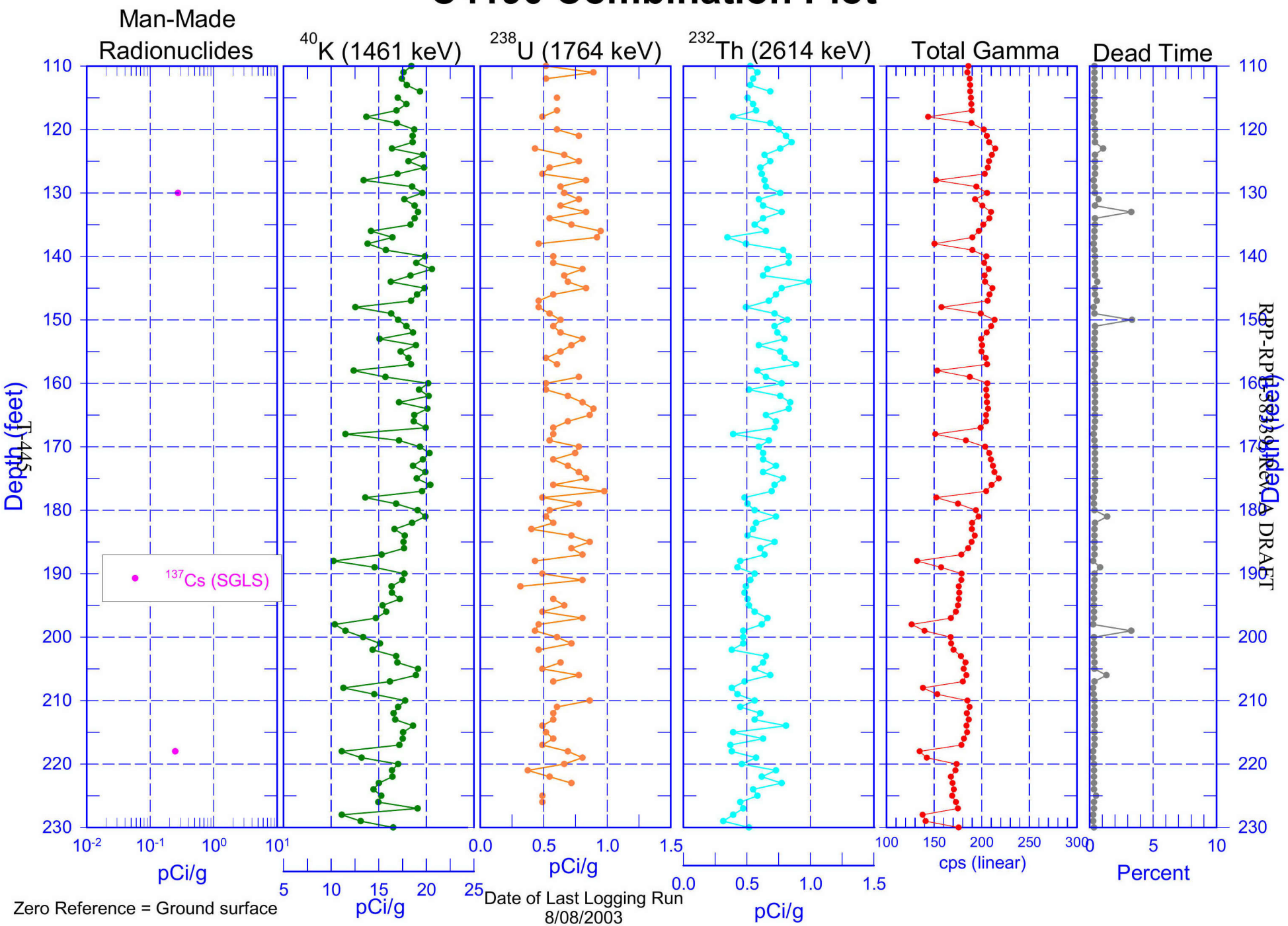
Date of Last Logging Run
8/08/2003

C4190 Combination Plot



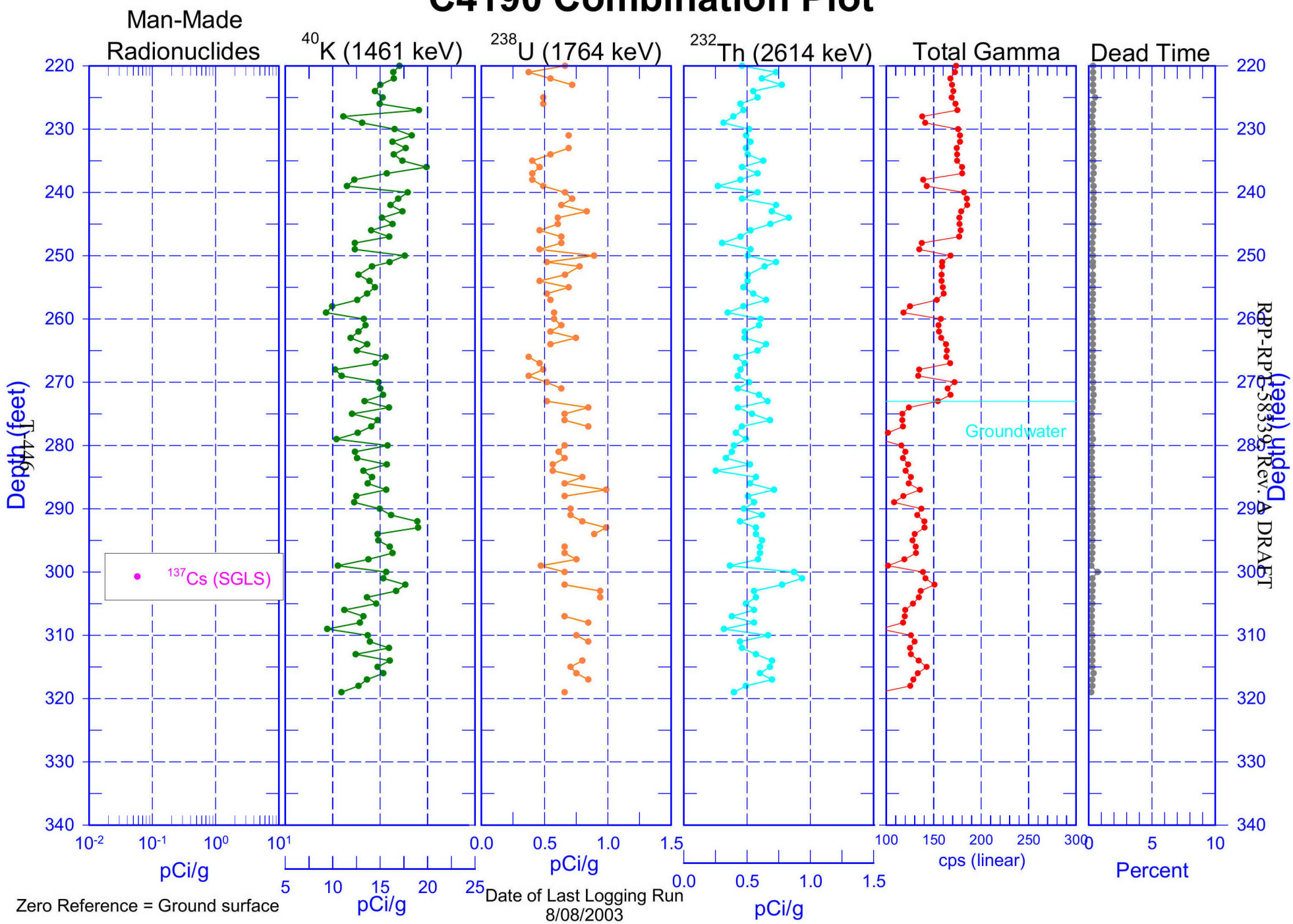
RPP-RPT-38339, Rev. 0, Draft

C4190 Combination Plot



RPP-RPT-15833, Rev. A DRAFT

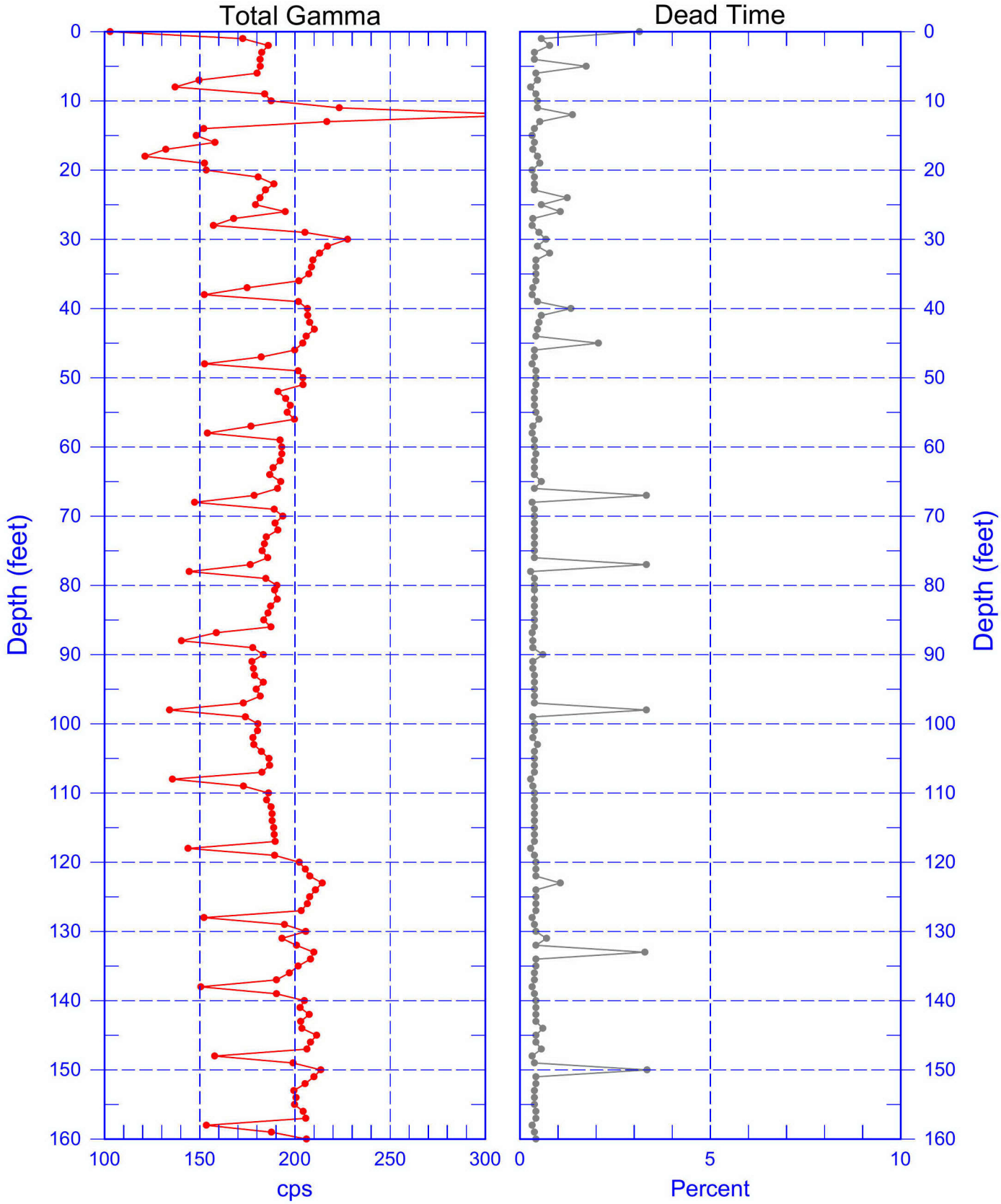
C4190 Combination Plot



RPP-RPT-58339, Rev. A DRAFT

C4190

Total Gamma & Dead Time

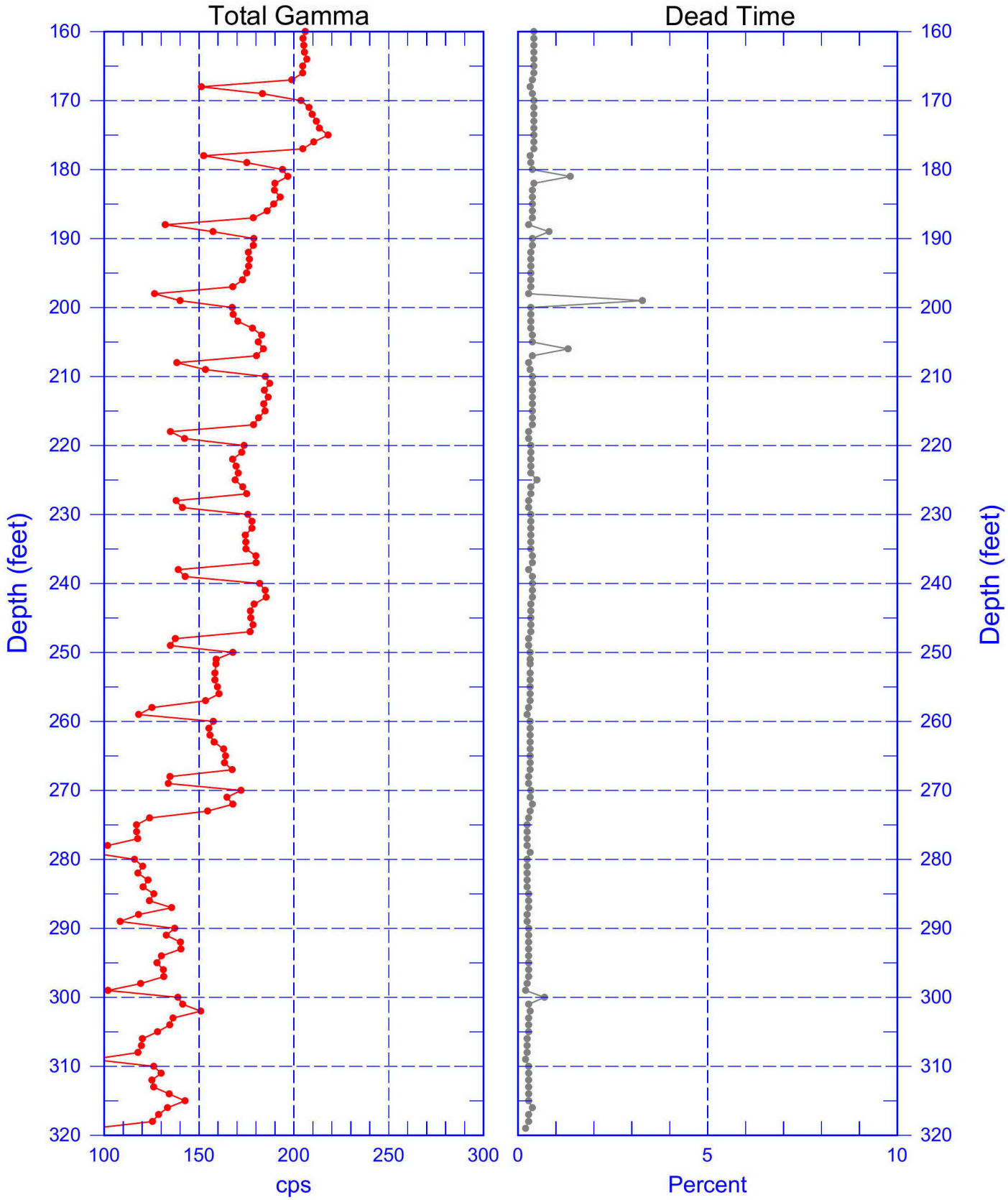


Zero Reference = Ground Surface

Date of Last Logging Run
8/08/2003

C4190

Total Gamma & Dead Time

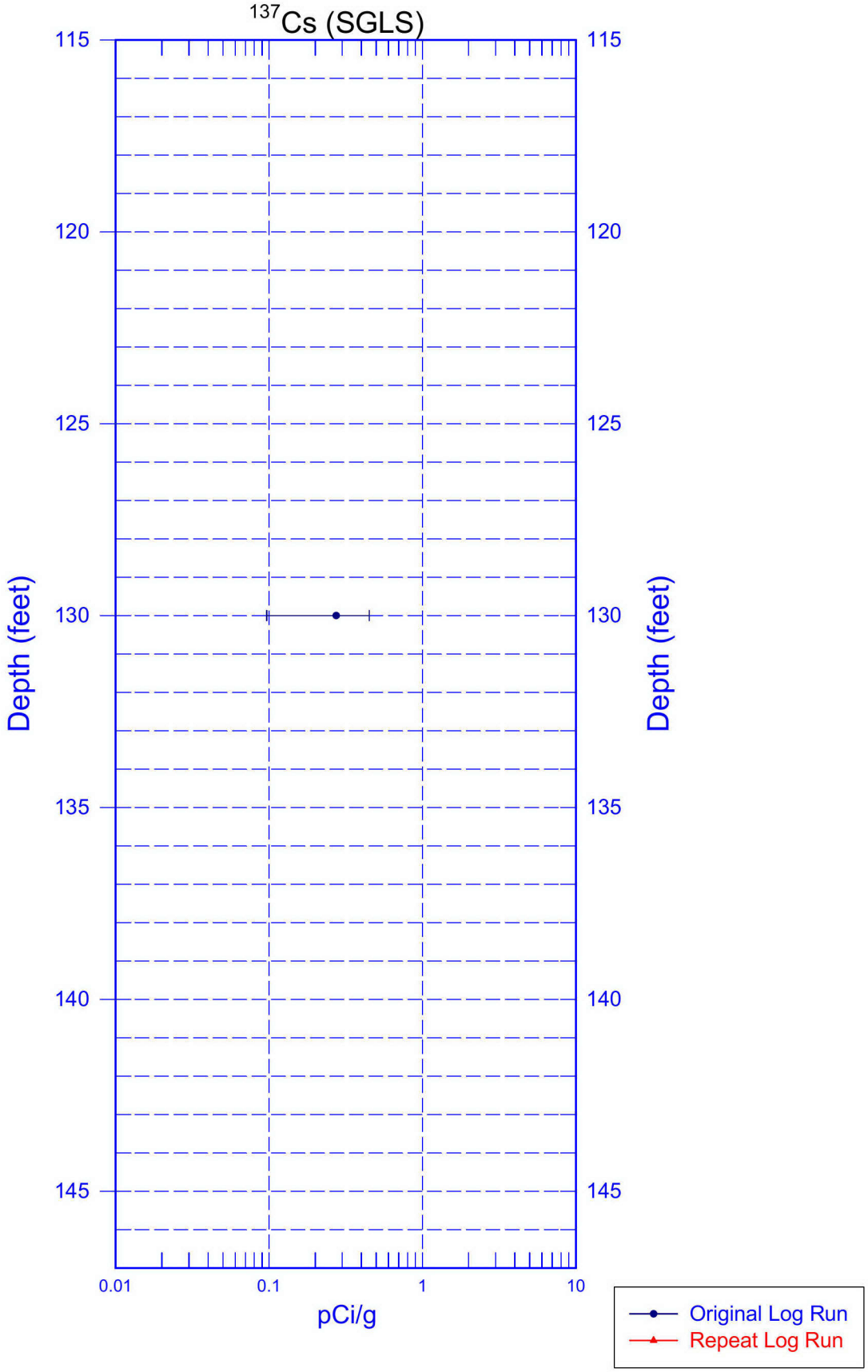


Zero Reference = Ground Surface

Date of Last Logging Run
8/08/2003

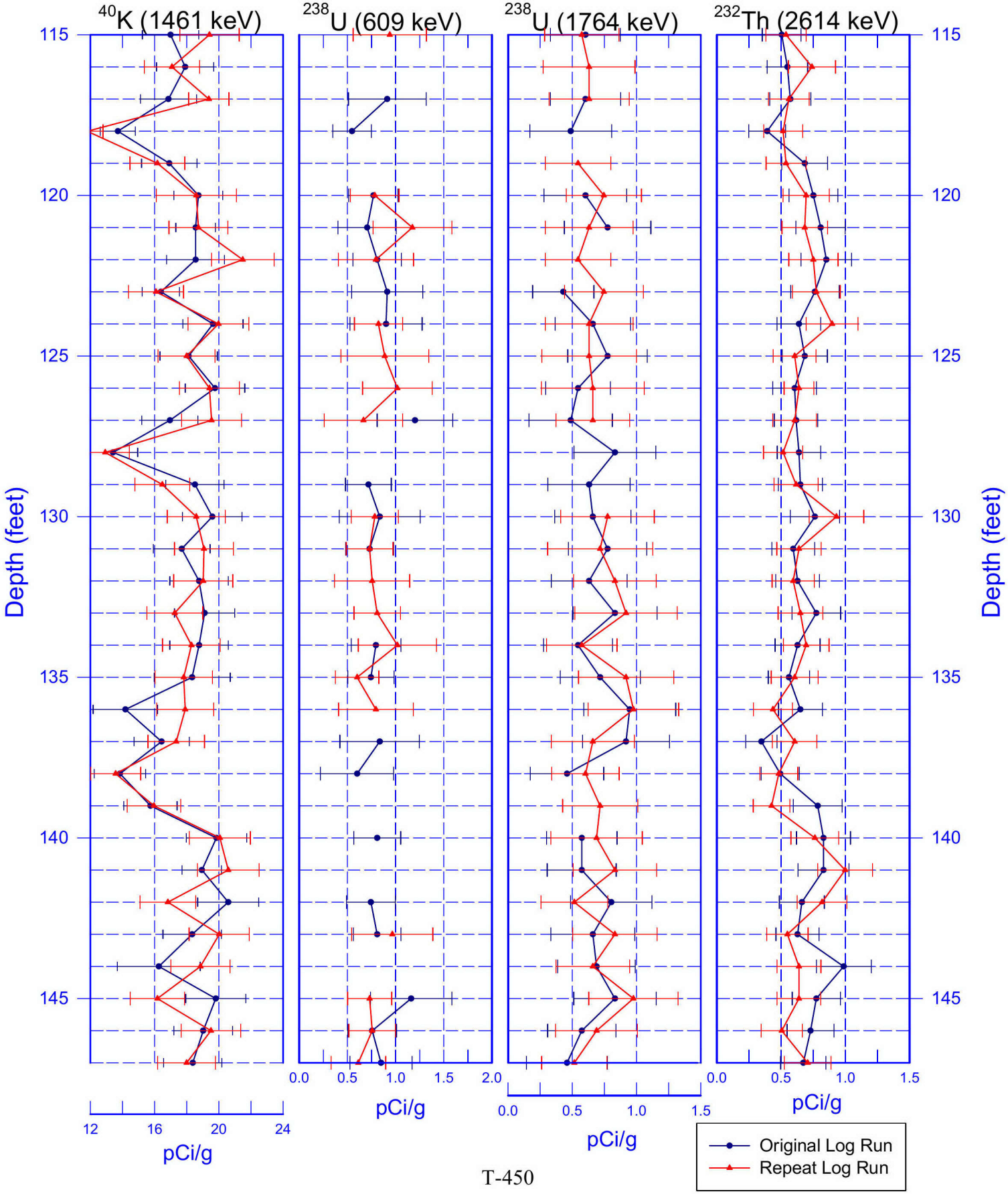
C4190

Rerun of ^{137}Cs (147.0 to 115 ft)



C4190

Rerun of Natural Gamma Logs (147.0 to 115.0 ft)



GROUNDWATER WELL LOGGING RESULTS FOR 299-E27-155 (C5852)

299-E27-155 (C5852)
Log Data Report

Borehole Information:

Borehole:	299-E27-155 (C5852)			Site:	Southwest of C Farm
Coordinates (WA St Plane)		GWL[1] (ft) :	280.8	GWL Date:	10/29/07
North (m)	East (m)	Drill Date	TOC Elevation	Total Depth (ft)	Type
Not available	Not available	10/07	Not available	340	Cable

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Top (ft)	Bottom (ft)
Threaded Steel	0.9	11 3/4	10 1/4	3/4	0.9	130
Threaded Steel	3.4	8 5/8	7 1/8	3/4	3.4	335

Borehole Notes:

The logging engineer measured the casing diameters using a caliper and steel tape. Drill depth and the bottom of casing information were reported by the Fluor Hanford on site representative. This borehole was logged through a single casing from 0 to 130 ft on October 3 and from 129 to 337 ft on October 30. The zero depth reference is ground surface for both logging events.

Logging Equipment Information:

Logging System:	Gamma 1E		Type: Serial No.:	SGLS (70%) 34TP40587A
Effective Calibration Date:	05/22/07	Calibration Reference:	HGLP-CC-016	
		Logging Procedure:	HGLP-MAN-002 Rev. 0	

Logging System:	Gamma 4E		Type: Serial No.:	SGLS (70%) 34TP40587A
Effective Calibration Date:	05/17/07	Calibration Reference:	HGLP-CC-015	
		Logging Procedure:	HGLP-MAN-002 Rev. 0	

Logging System:	Gamma 4H		Type: Serial No.:	NMLS 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	1	2	3 Repeat	4	5
Date	10/02/07	10/03/07	10/03/07	10/29/07	10/30/07
Logging Engineer	Spatz	Spatz	Spatz	Spatz	Spatz
Start Depth (ft)	130.0	51.0	28.0	337.0	194.0
Finish Depth (ft)	50.0	0.0	13.0	193.0	129.0
Count Time (sec)	100	100	100	100	100
Live/Real	R	R	R	R	R
Shield (Y/N)	N	N	N	N	N
MSA Interval (ft)	1.0	1.0	1.0	1.0	1.0
ft/min	N/A[2]	N/A	N/A	N/A	N/A

Log Run	1	2	3 Repeat	4	5
Pre-Verification	AE232CAB	AE233CAB	AE233CAB	DEH41CAB	DEH51CAB
Start File	AE232000	AE233000	AE233052	DEH41000	DEH51000
Finish File	AE232080	AE233051	AE233067	DEH41144	DEH51065
Post-Verification	AE232CAA	AE233CAA	AE233CAA	DEH41CAA	DEH51CAA
Depth Return Error (in.)	0	- 0.5	0	- 2	N/A
Comments	No fine-gain adjustment	No fine-gain adjustment	No fine-gain adjustment	No fine-gain adjustment	No fine-gain adjustment

Log Run	6 Repeat				
Date	10/30/07				
Logging Engineer	Spatz				
Start Depth (ft)	160.0				
Finish Depth (ft)	140.0				
Count Time (sec)	100				
Live/Real	R				
Shield (Y/N)	N				
MSA Interval (ft)	1.0				
ft/min	N/A				
Pre-Verification	DEH51CAB				
Start File	DEH51066				
Finish File	DEH51086				
Post-Verification	DEH51CAA				
Depth Return Error (in.)	- 1				
Comments	No fine-gain adjustment				

Neutron Moisture Logging System (NMLS) Log Run Information:

Log Run	7	8 Repeat	9	10 Repeat	
Date	10/03/07	10/03/07	10/30/07	10/30/07	
Logging Engineer	Spatz	Spatz	Spatz	Spatz	
Start Depth (ft)	129.75	100.00	129.0	265.0	
Finish Depth (ft)	0.0	85.0	280.5	250.0	
Count Time (sec)	15	15	15	15	
Live/Real	R	R	R	R	
Shield (Y/N)	NA	NA	NA	NA	
Sample Interval (ft)	0.25	0.25	0.25	0.25	
ft/min	NA	NA	NA	NA	
Pre-Verification	DH732CAB	DH732CAB	DH772CAB	DH772CAB	
Start File	DH732000	DH732520	DH772000	DH772608	
Finish File	DH732519	DH732580	DH772607	DH772668	
Post-Verification	DH732CAA	DH732CAA	DH772CAA	DH772CAA	
Depth Return Error (in.)	- 0.5	- 1	N/A	- 1.5	
Comments	None	None	Stopped at top of water	None	

Logging Operation Notes:

Logging was conducted with a centralizer on each sonde and measurements are referenced to ground surface.

Analysis Notes:

Analyst:	P.D. Henwood	Date:	12/05/2007	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 casing correction for a 3/4-in. thick casing was applied to the SGLS data. There is no calibration available to convert NMLS data to volume percent moisture in the 7- and 10-in. casings. These data are reported in counts per second.

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 G1EMay07.xls and G4EMay07.xls for logging systems gamma 1E and gamma 4E, respectively, using efficiency functions and corrections for casing and dead time as determined from annual calibrations. A correction for water was applied to the data below 280.8 ft.

Results and Interpretations:

No manmade radionuclides were detected in this borehole. Cs-137 was encountered at or near the MDL at two isolated points. These are simply statistical fluctuations.

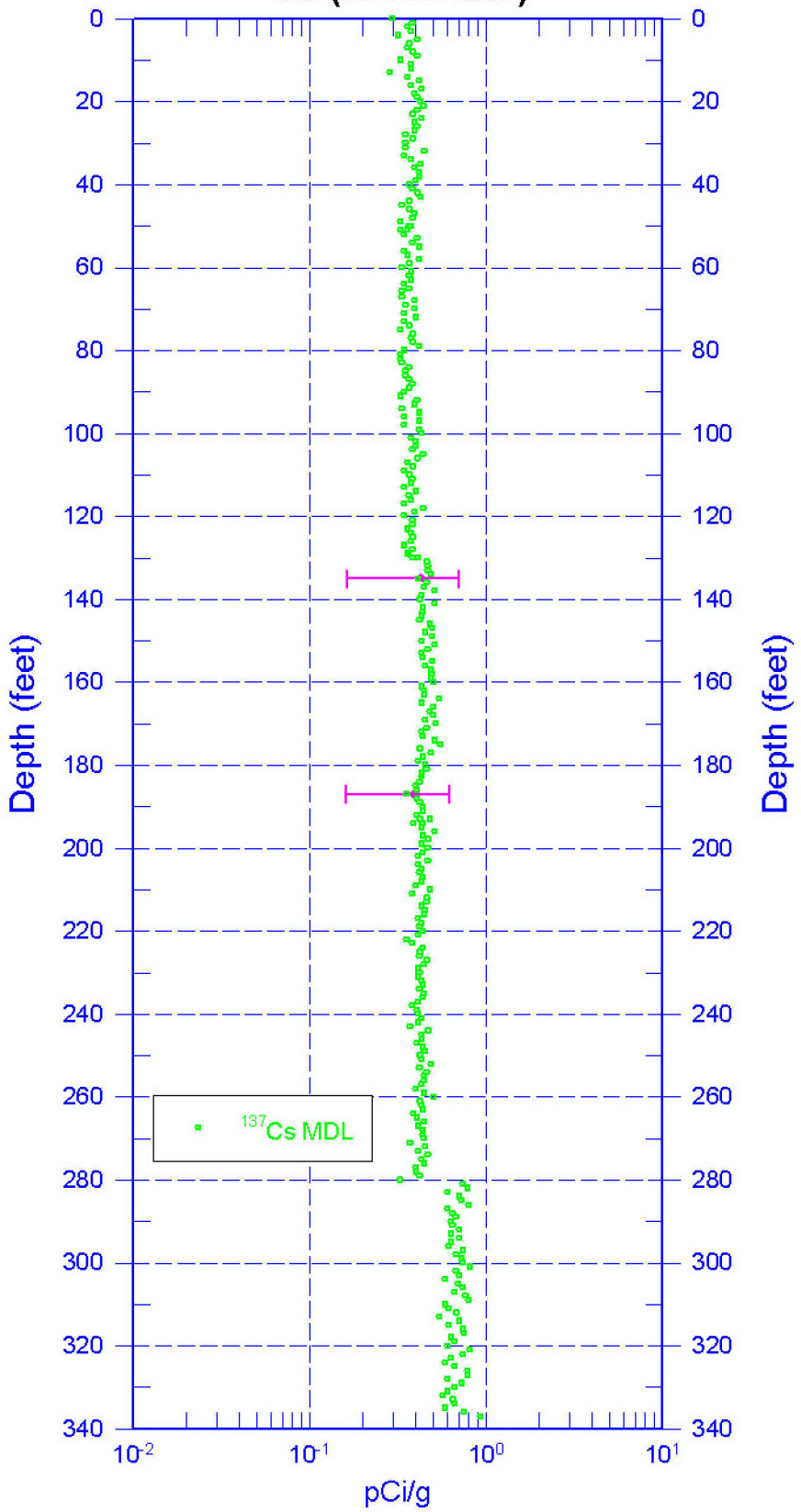
The SGLS and NMLS repeat logs show good repeatability.

List of Log Plots:

Manmade Radionuclides
Natural Gamma Logs
Combination Plot
Total Gamma, Dead Time & Moisture
Repeat of Natural Gamma Logs (13 to 28 ft)
Repeat of Natural Gamma Logs (140 to 160 ft)
Repeat of Moisture (85 to 100 ft)
Repeat of Moisture (250 to 265 ft)

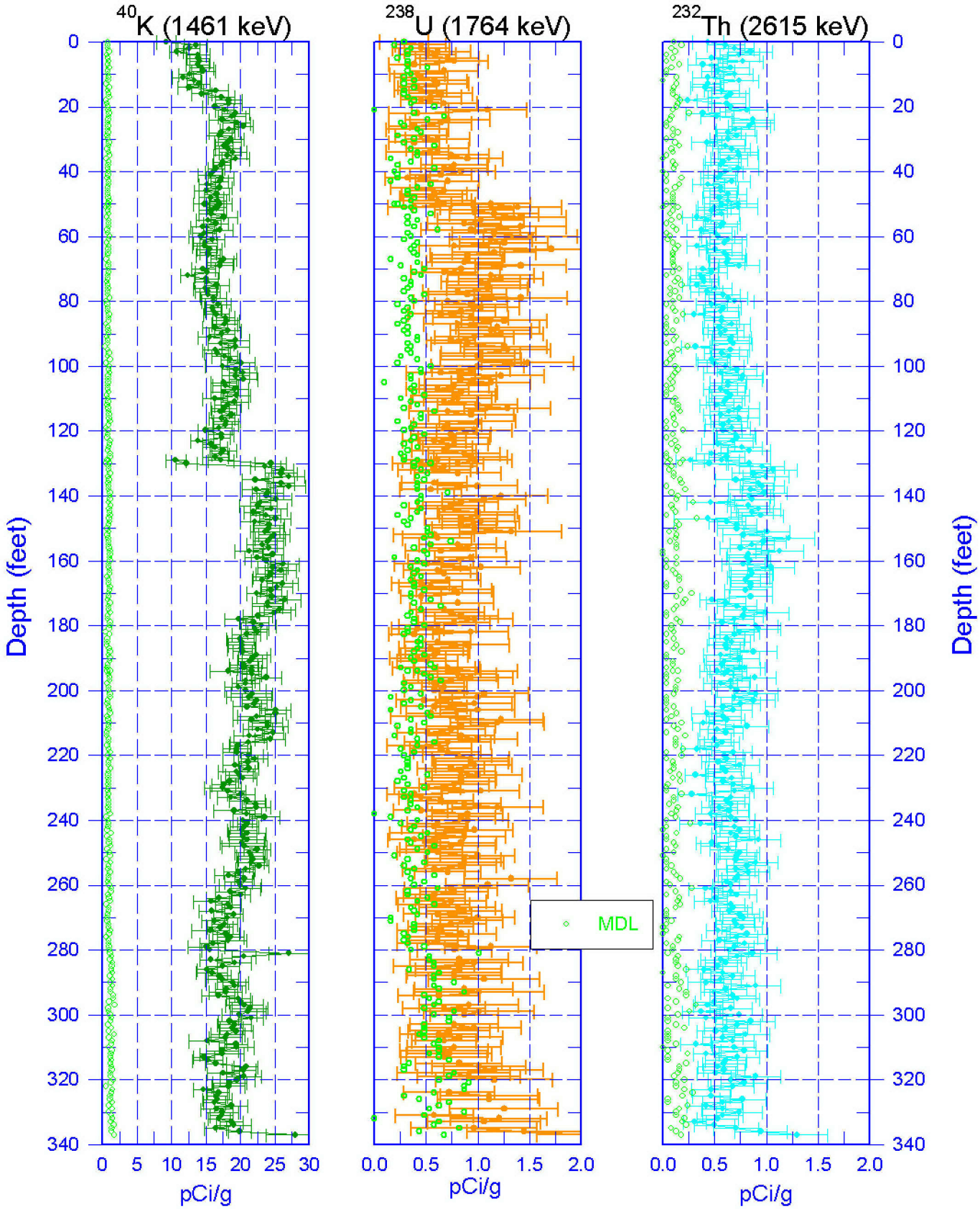
[1] GWL – groundwater level
[2] N/A - not applicable

299-E27-155 (C5852)
Manmade Radionuclides
^{137}Cs (661.66 keV)



Zero Reference - Ground Surface

299-E27-155 (C5852)
Natural Gamma Logs



Zero Reference - Ground Surface

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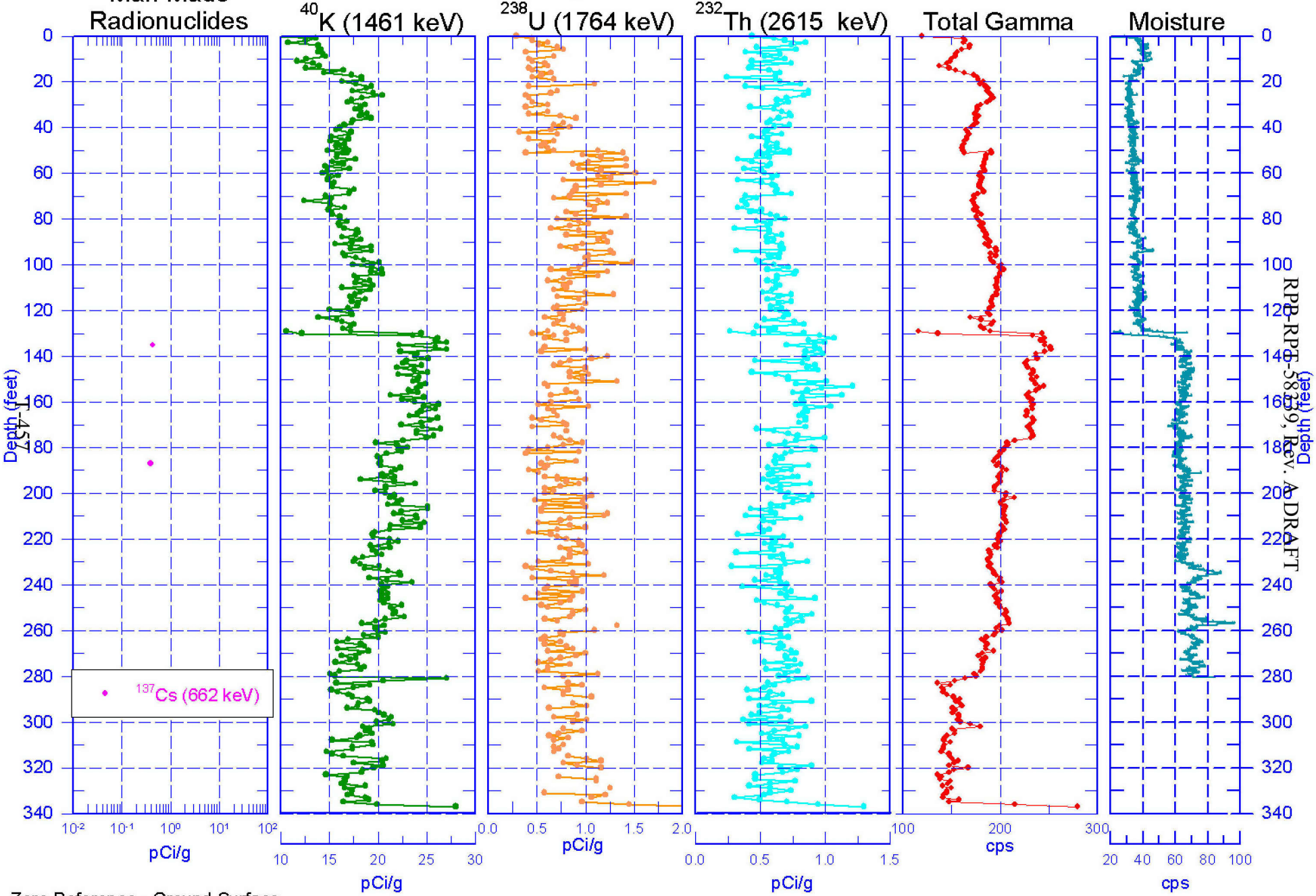
Hanford Office

299-E27-155 (C5852) Combination Plot

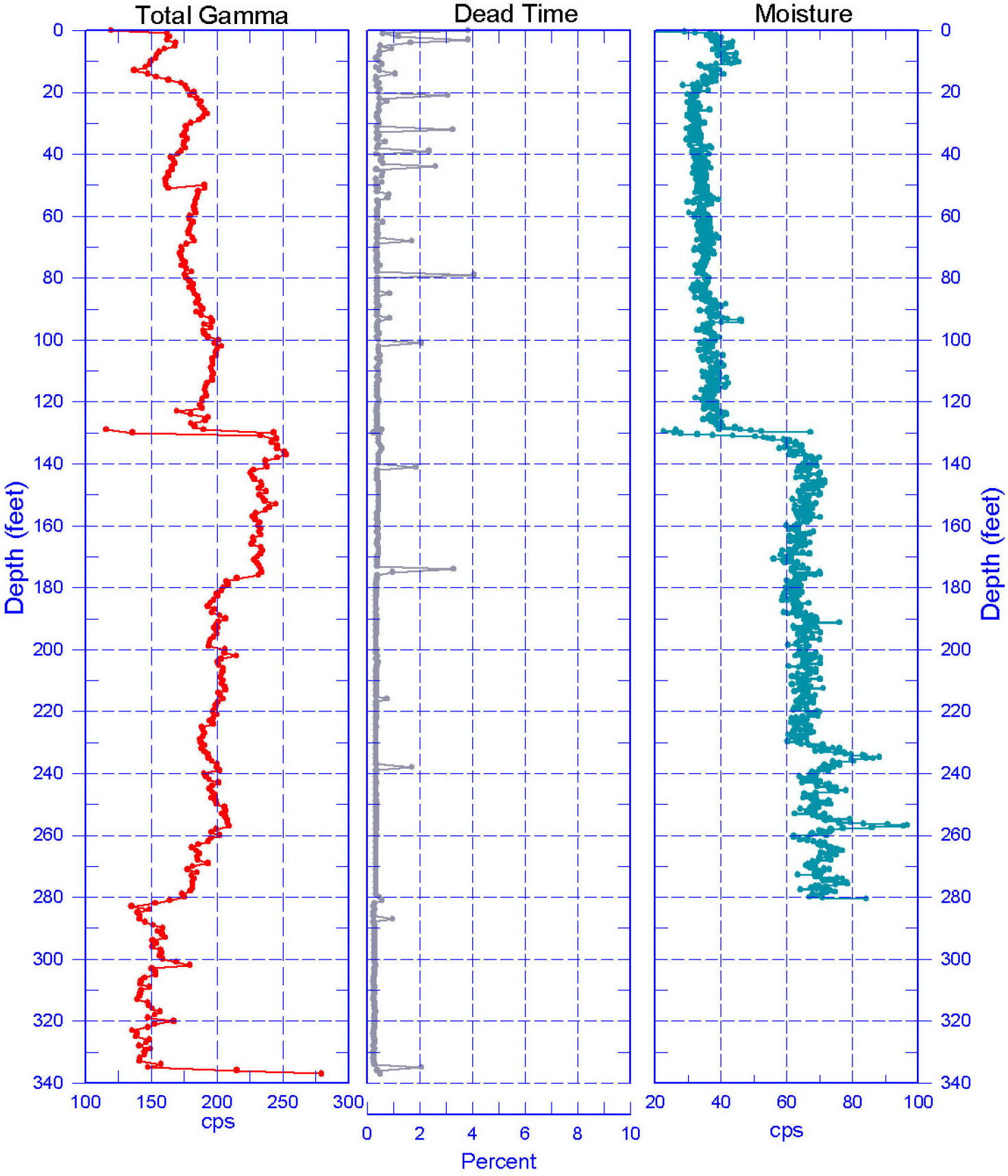


Zero Reference - Ground Surface

RPP-RPT-58259, Rev. A DRAFT

299-E27-155 (C5852)

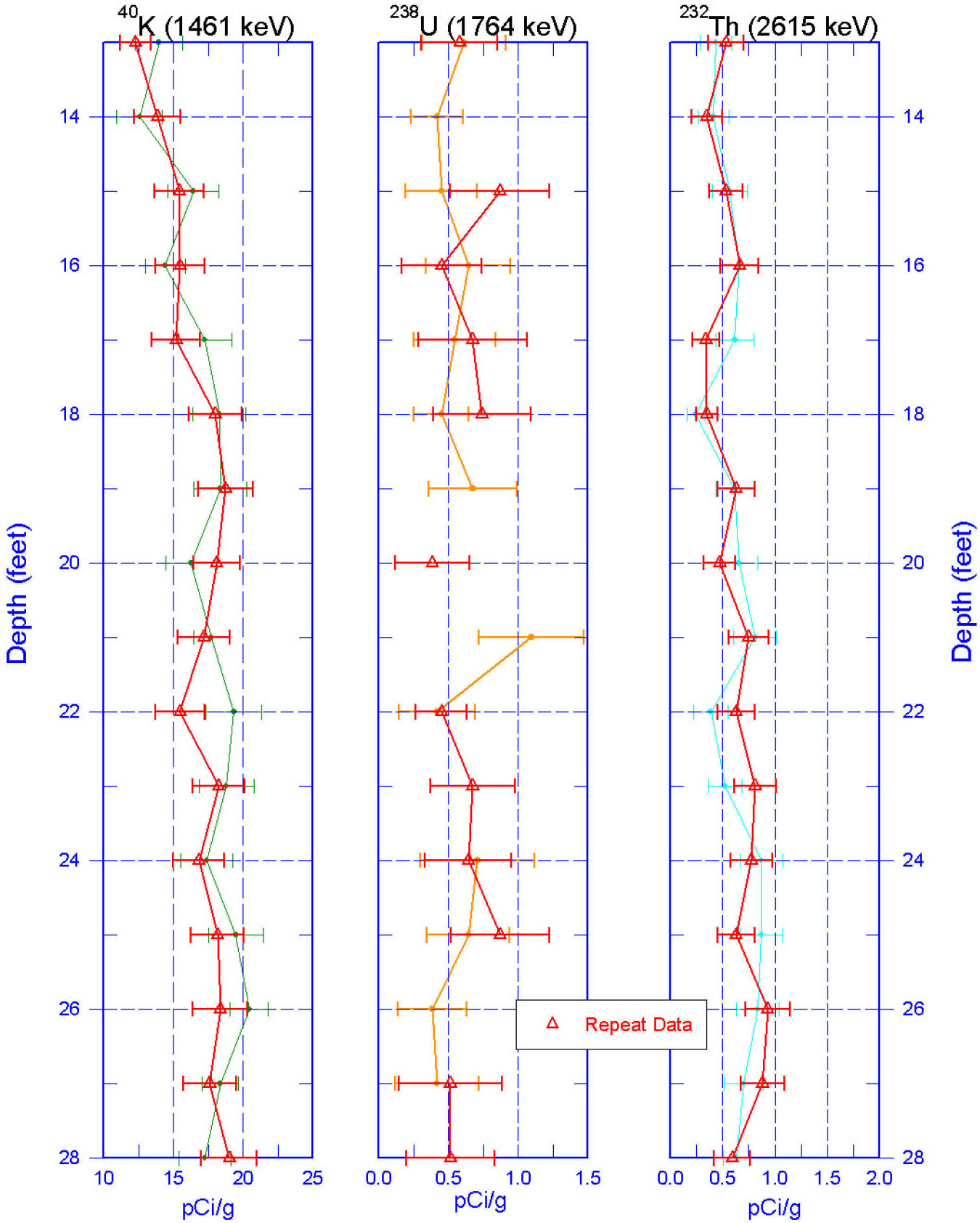
Total Gamma, Dead Time & Moisture



Reference - Ground Surface

299-E27-155 (C5852)

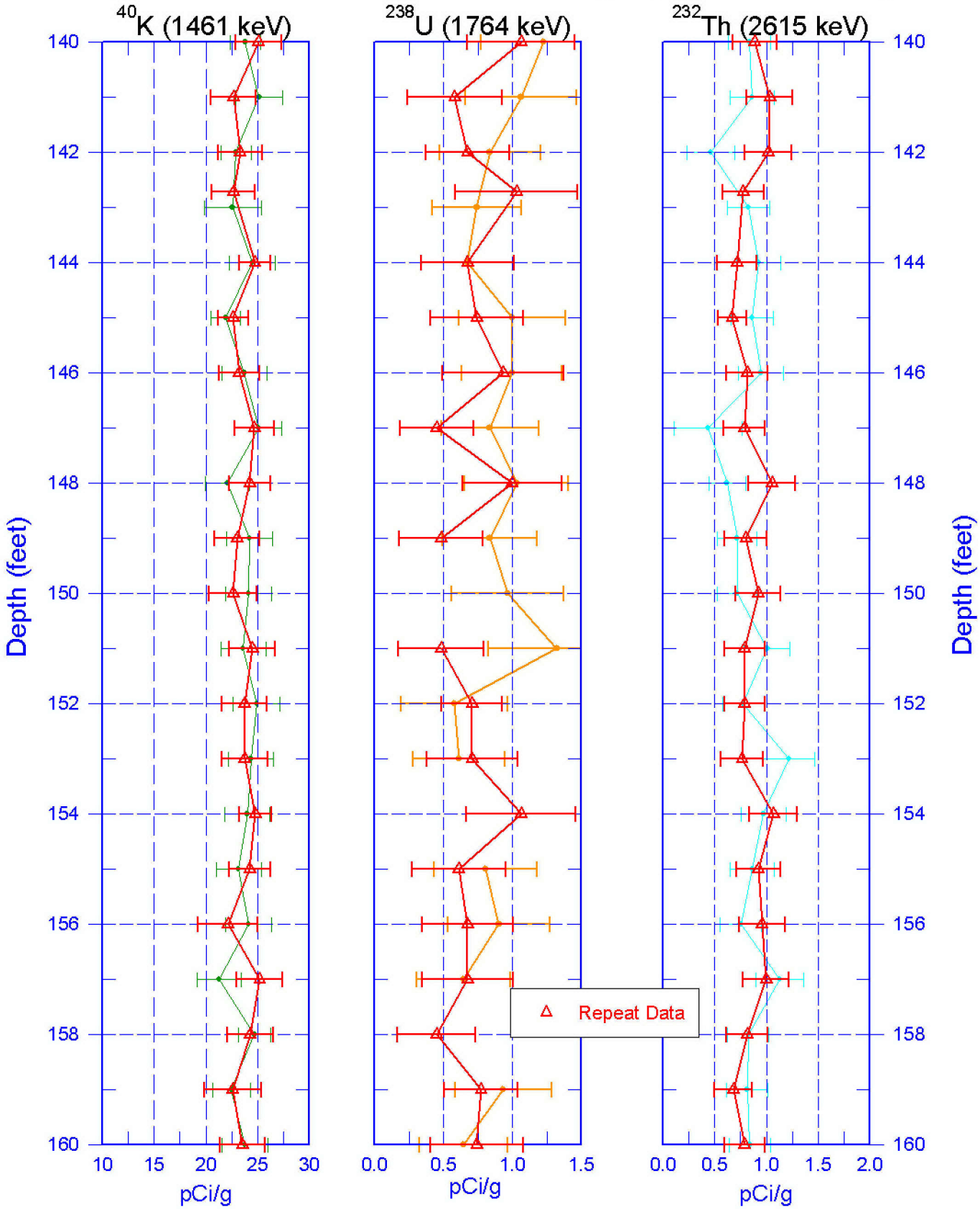
Repeat of Natural Gamma Logs (13 to 28 ft)



Zero Reference - Ground Surface

299-E27-155 (C5852)

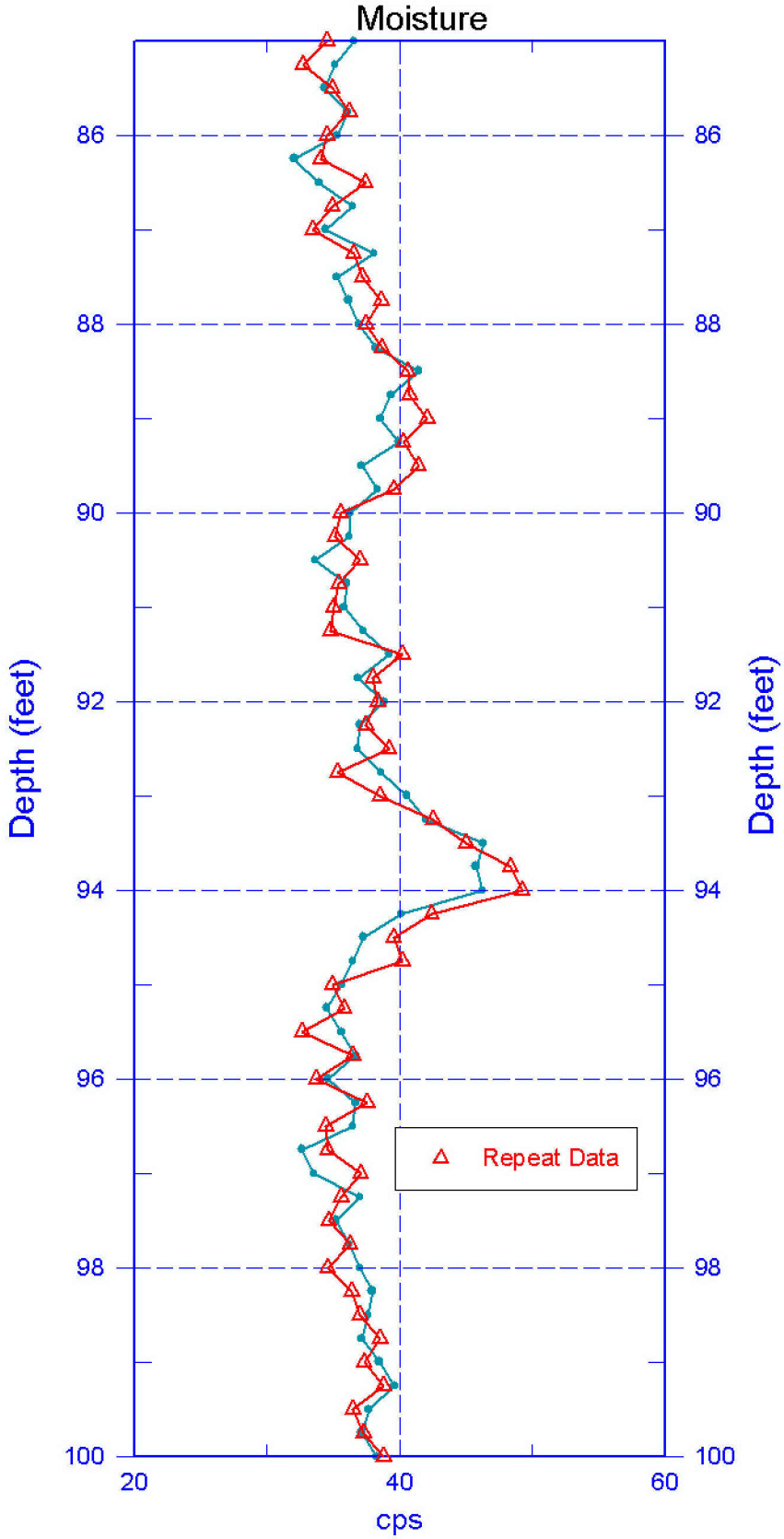
Repeat of Natural Gamma Logs (140 to 160 ft)



Zero Reference - Ground Surface

299-E27-155 (C5852)

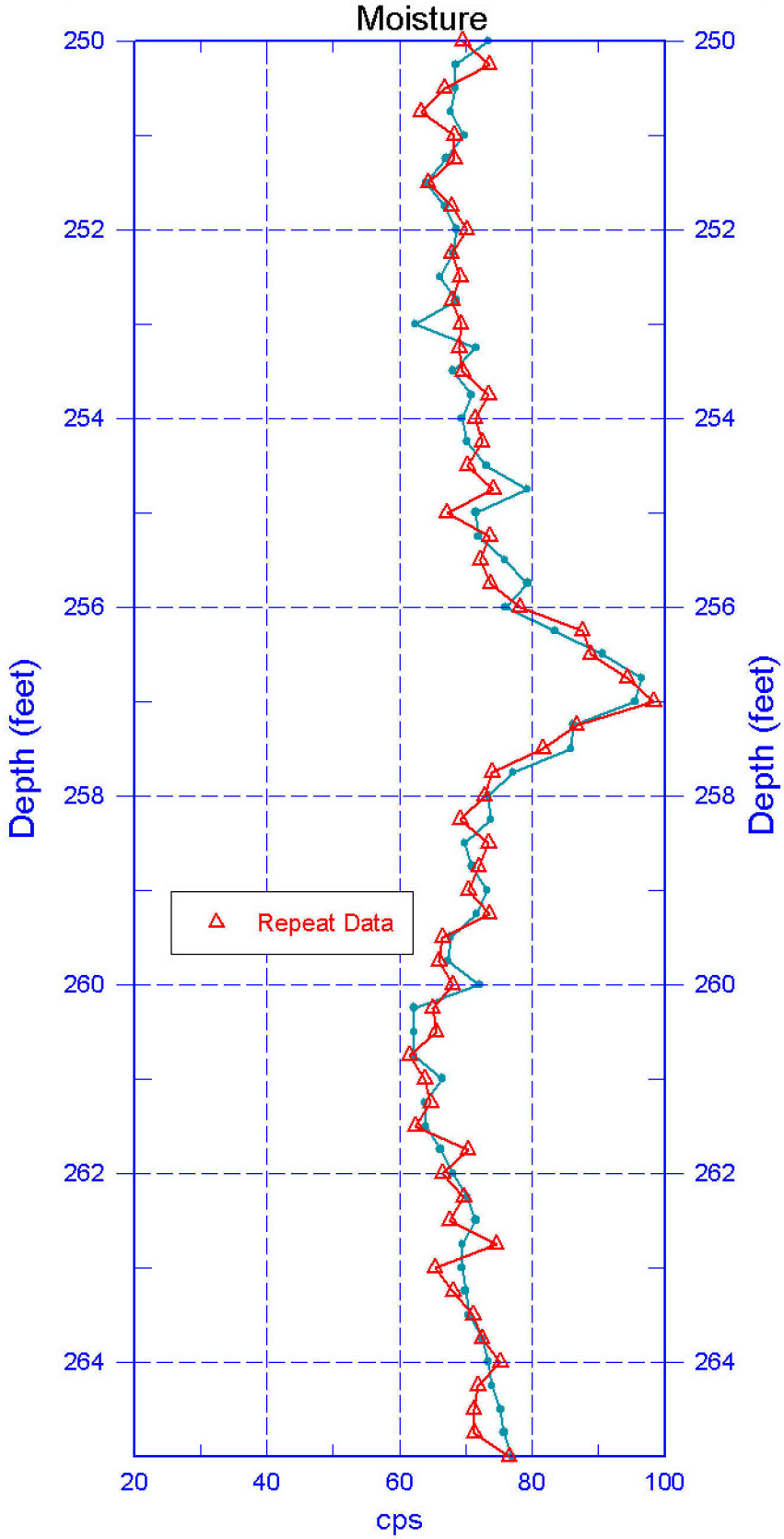
Repeat of Moisture (85 to 100 ft)



Reference - Ground Surface

299-E27-155 (C5852)

Repeat of Moisture (250 to 265 ft)



Reference - Ground Surface

GROUNDWATER WELL LOGGING RESULTS FOR 299-E27-245 (C7570)

299-E27-24 (C7570)
Log Data Report

Borehole Information:

Borehole:	299-E27-24 (C7570)		Site:	200-BP-5, South of C Farm	
Coordinates (WA St Plane)		GWL[1] (ft) :	265.8	GWL Date:	5/15/10
North (m)	East (m)	Drill Date	TOC[2] Elevation	Total Depth (ft)	Type
Unknown	Unknown	5/14/10	Unknown	317.9	Becker

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in)	Inside Diameter (in)	Thickness (in)	Top (ft)	Bottom (ft)
Becker Dual Wall Casing	5.2	6 ¾ & 9	6 & 8	0.620	5.2	317

Borehole Notes:

The driller reported total depth and casing depth. The logging engineer measured depth to water.

The Becker drilling system uses a dual-wall casing. Air flows down the annulus and cuttings are returned inside the inner casing. Total wall thickness is 0.620 inch, increasing to 1.115 inches at the casing joints that occur at 10-foot intervals. The casing dimensions are derived from published values for Becker dill casing.

The zero reference is the ground surface.

Logging Equipment Information:

Logging System:	Gamma 4 L		Type: Serial No.:	60% HPGe SGLS 47-TP32211A
Effective Calibration Date:	1/20/2010	Calibration Reference:	HGLP-CC-054, Rev. 0	
		Logging Procedure:	HGLP-MAN-002, Rev. 0	

Logging System:	Gamma 4 M		Type: Serial No.:	NMLS H340207279, Rev. 0
Effective Calibration Date:	1/18/2010	Calibration Reference:	HGLP-CC-CC-052, Rev. 0	
		Logging Procedure:	HGLP-MAN-002, Rev. 0	

Spectral Gamma Logging System (SGLS) Log Run Information:

Log Run	5	6 Repeat			
HEIS Number	1016119	1016120			
Date	5/17/10	5/17/10			
Logging Engineer	Pearson	Pearson			
Start Depth (ft)	317.0	51.0			
Finish Depth (ft)	0.0	20.0			
Count Time (sec)	100	100			
Live/Real	R	R			
Shield (Y/N)	N	N			
MSA Interval (ft)	1.0	1.0			
Log Speed (ft/min)	N/A	N/A			
Pre-Verification	DLD41CAB	DLD41CAB			
Start File	DLD41000	DLD41318			

Log Run	5	6 Repeat			
Finish File	DLD41317	DLD41349			
Post-Verification	DLD41CAA	DLD411CAA			
Depth Return Error (in)	2 Low	2 low			
Comments	No fine gain adjustments made.	No fine gain adjustments made.			

Neutron Moisture Logging System (NMLS) Log Run Information:

Log Run	1	2	3	4 Repeat	
HEIS Number	1016121	1016122	1016123	1016124	
Date	05/15/10	05/15/10	05/15/10	05/15/10	
Logging Engineer	Pearson	Pearson	Pearson	Pearson	
Start Depth (ft)	0.0	100.25	200.25	230.0	
Finish Depth (ft)	100.0	200.0	265.75	257.0	
Count Time (sec)	15	15	15	15	
Live/Real	R	R	R	R	
Shield (Y/N)	N	N	N	N	
MSA Interval (ft)	0.25	0.25	0.25	0.25	
Log Speed (ft/min)	N/A	N/A	N/A	N/A	
Pre-Verification	DMP82CAB	DMP82CAB	DMP82CAB	DMP82CAB	
Start File	DMP82000	DMP82401	DMP92000	DMP92263	
Finish File	DMP82400	DMP82800	DMP92262	DMP92371	
Post-Verification	DMP92CAA	DMP92CAA	DMP92CAA	DMP92CAA	
Depth Return Error (in)	N/A	N/A	N/A	1 low	
Comments	None	None	None	None	

Logging Operation Notes:

SGLS data were collected using Gamma 4, HO 68B-3573. Pre- and post-survey verification measurements were acquired in the KUTh-115 field verifier. A centralizer was installed on the sonde.

NMLS data were collected using Gamma 4, HO 68B-3573. Pre- and post-survey verification measurements were acquired in the AmBe standard field verifier. A centralizer was installed on the sonde.

Analysis Notes:

Analyst:	LEGLER	Date:	5/20/2010	Reference:	GJO-HGLP 1.6.3, Rev. 0

The SGLS and NMLS pre- and post-survey verification measurements met the acceptance criteria for the established systems.

A combined casing correction for a 0.620-inch thick (0.120 + 0.500 for the 6- and 9-inch. Becker dual wall casings respectively) was applied during analysis. The combined thickness at casing joints is 1.115 inch. This thickness results in a significant reduction in gamma activity detection as the detector passes by a casing joint. However, it is not practical to correct individual data points for the effect of casing joints. The influence of the thick joints is apparent on the total gamma where reduced count rates are exhibited at approximately 10-foot depth intervals.

A water correction (for a 6-inch casing) was also applied to depths below 265.8 feet.

The SGLS spectra were processed in batch mode using APTEC SUPERVISOR to identify individual peaks and count rates. Concentrations were calculated using an EXCEL template identified as DL20100120.xlsx using an efficiency function and corrections for casing, dead time and water as determined by annual calculations.

During routine processing of gamma spectra, regions of interest are forced at specific energy levels associated with natural and manmade radionuclides that are anticipated to be present. This processing approach sometimes results in an isolated "detection" near the minimum detection level (MDL) resulting in a false positive. Where these detections occur, the individual spectrum is scrutinized and a determination is made regarding the validity of the detection. If the detection is deemed not representative of a full energy peak, or if confirming peaks are not detected, it is removed from the data set. The integrity of the raw data files and the processed files are maintained should questions arise in the future regarding these determinations.

NMLS data are presented in counts per second (cps) because there is no calibration for a Becker casing configuration.

Results and Interpretations:

Cs-137 was detected at the surface of the borehole and at 10 feet, with a maximum concentration of 0.8 pCi/g at the surface of the borehole.

A decrease in gamma activity and apparent moisture occurs at each casing joint, where the increase in wall thickness results in greater attenuation.

The neutron moisture log primarily responds to moisture present in the surrounding formation. In general, an increase in count rate reflects an increase in moisture content. Moisture content may increase in sediments of relatively high silt or clay. The moisture profile was highly variable.

The KUT and moisture repeat plots indicate that the respective systems were working properly.

List of Log Plots:

Depth Reference is ground surface

Manmade Radionuclides
Natural Gamma Logs (3 pages)
Combination Plot (3 pages)
Combination Plot (0-320 ft)
Total Gamma & Dead Time (3 Pages)
Total Gamma & Moisture (3 Pages)
Repeat Section of Natural Gamma Logs
Moisture Repeat Section

[1] GWL – groundwater level
[2] TOC – top of casing

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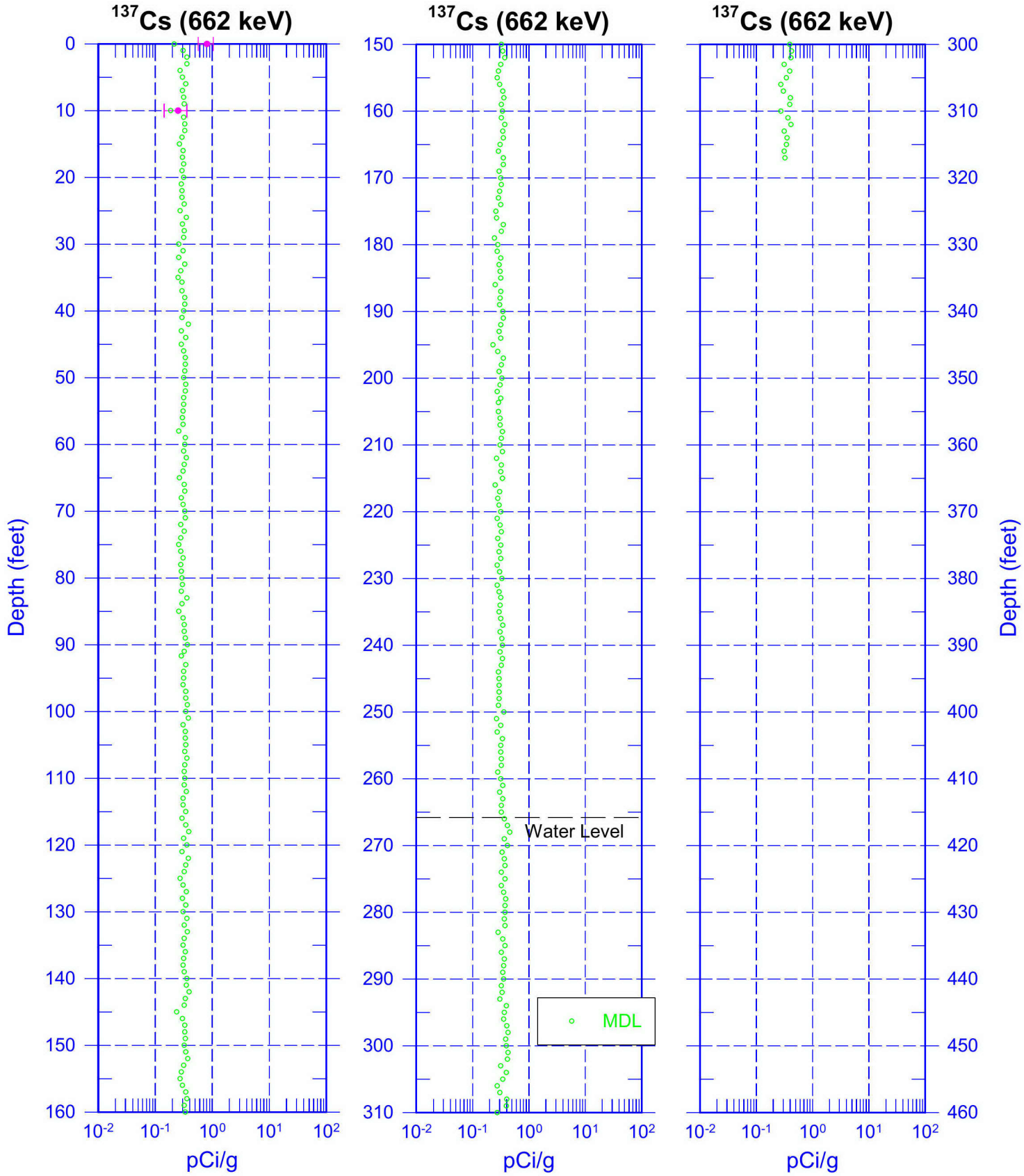
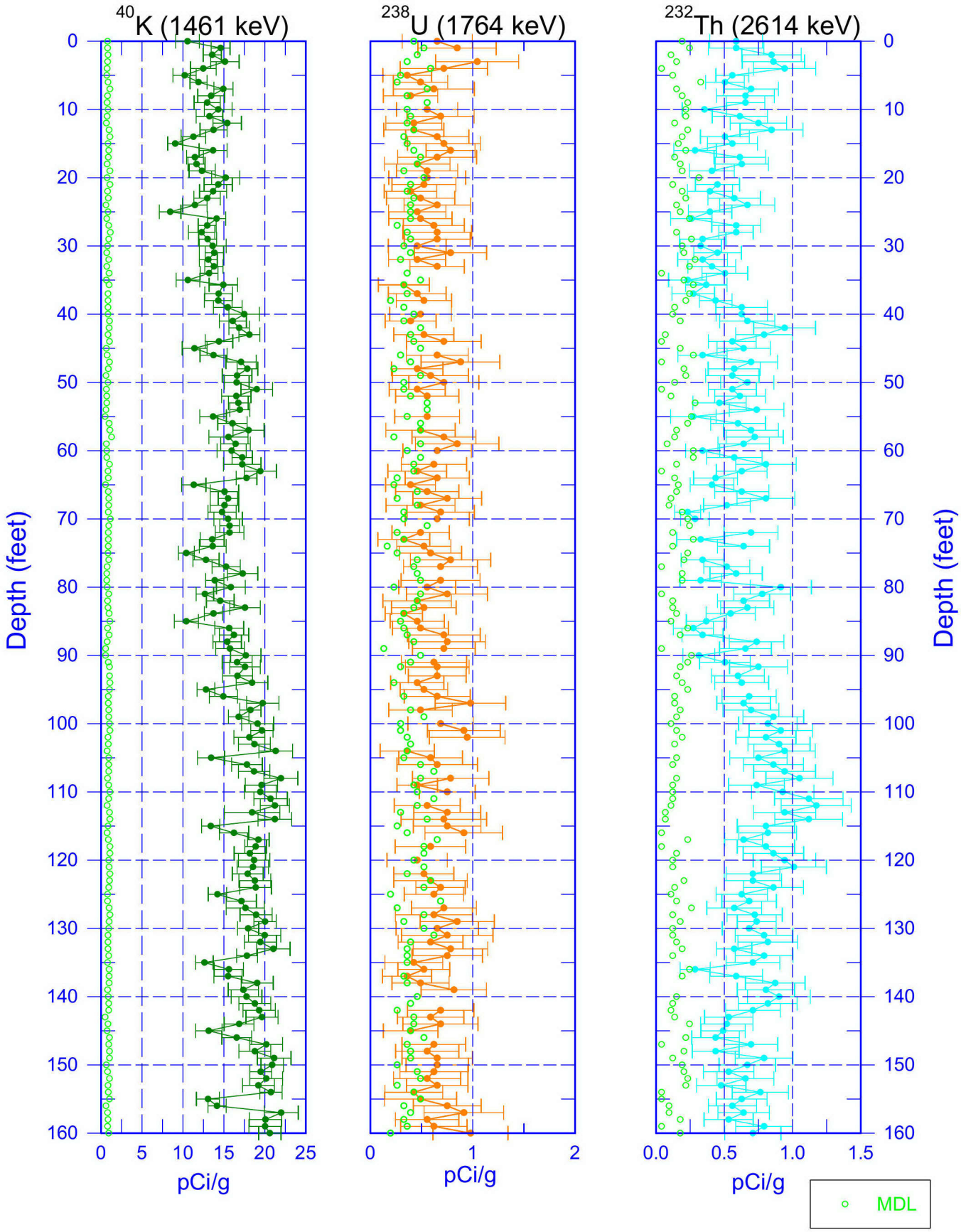
299-E27-24 (C7570)
Manmade Radionuclides



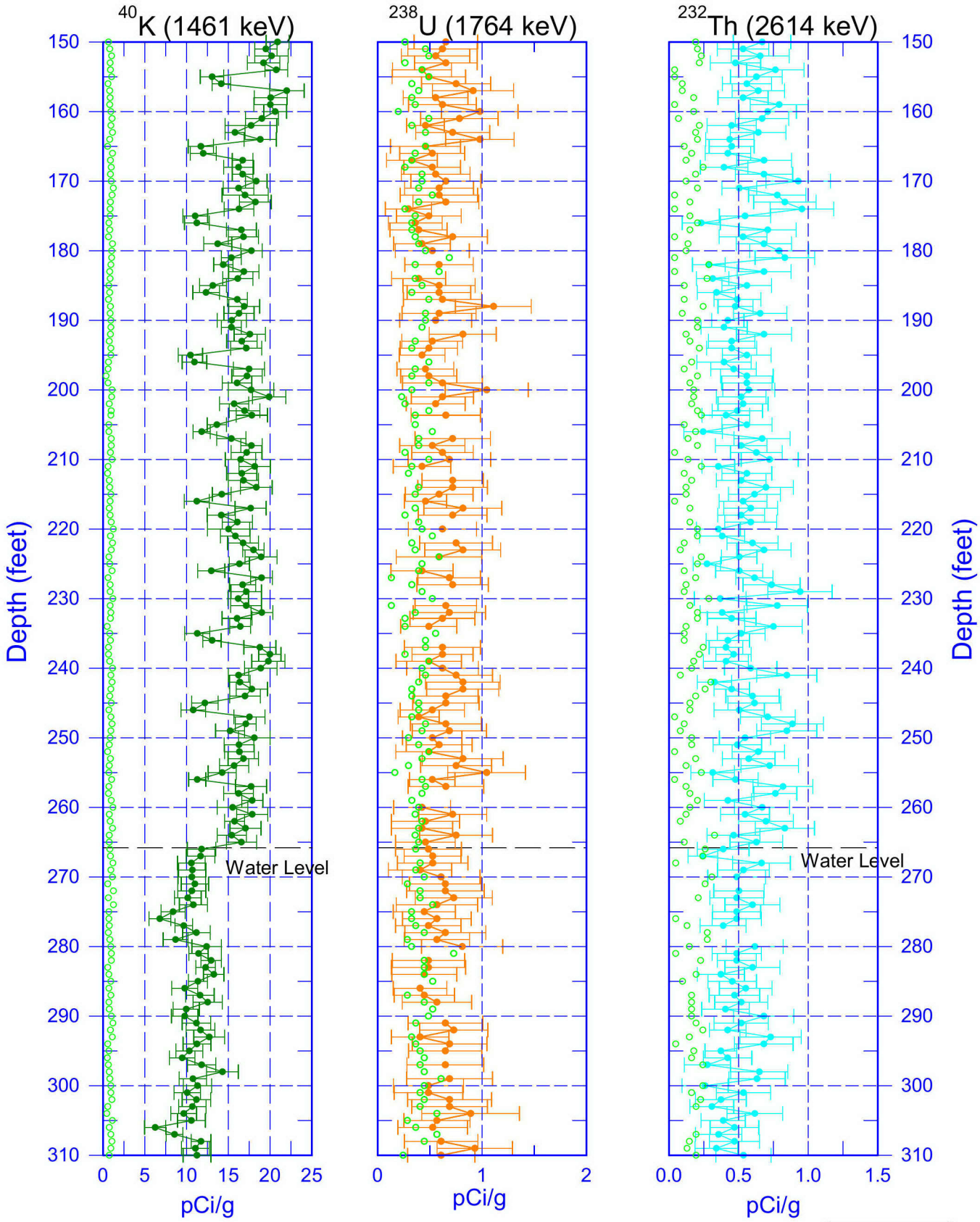
Zero Reference - Ground Surface

299-E27-24 (C7570)
Natural Gamma Logs



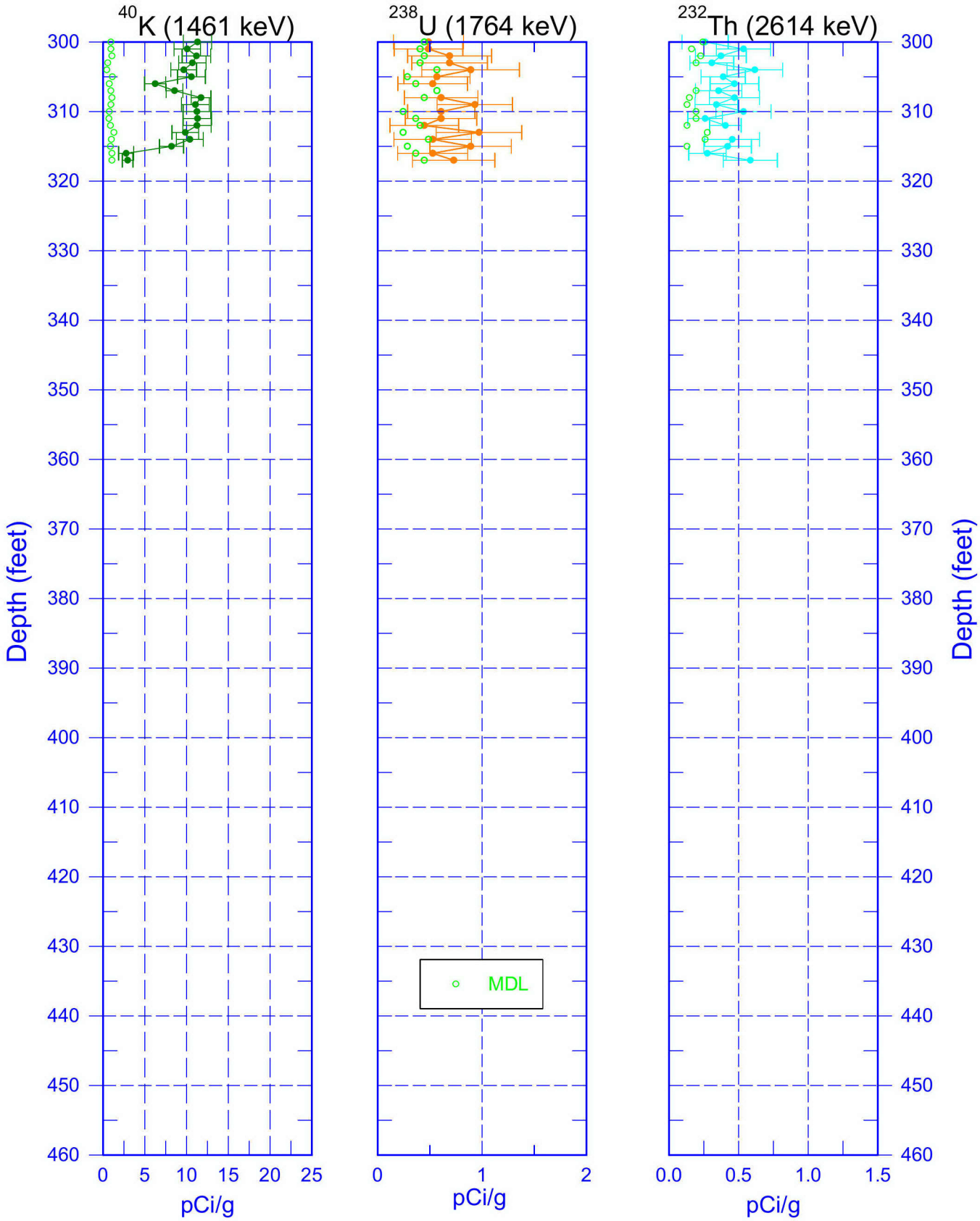
Zero Reference - Ground Surface

299-E27-24 (C7570)
Natural Gamma Logs



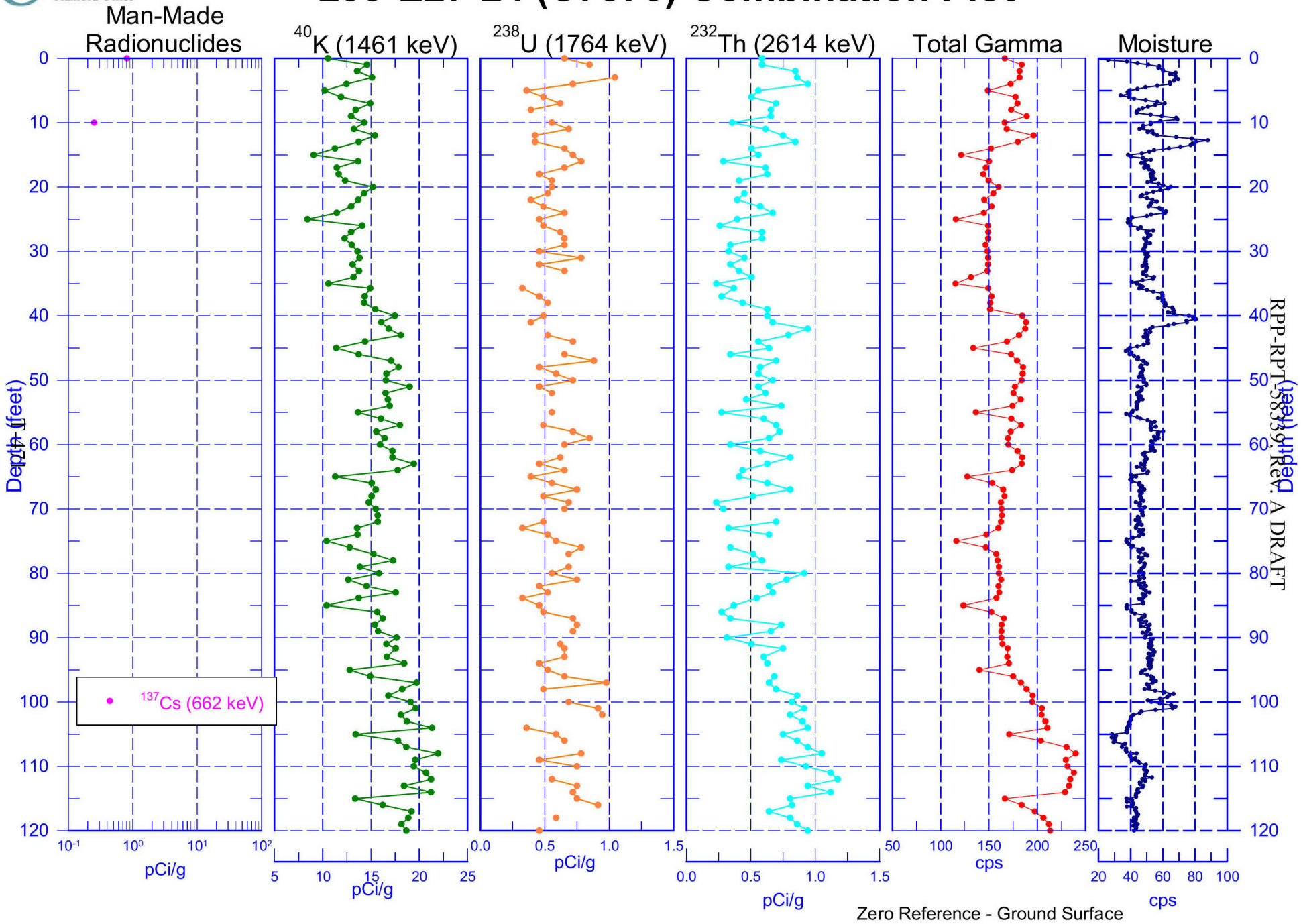
Zero Reference - Ground Surface

299-E27-24 (C7570)
Natural Gamma Logs



Zero Reference - Ground Surface

299-E27-24 (C7570) Combination Plot



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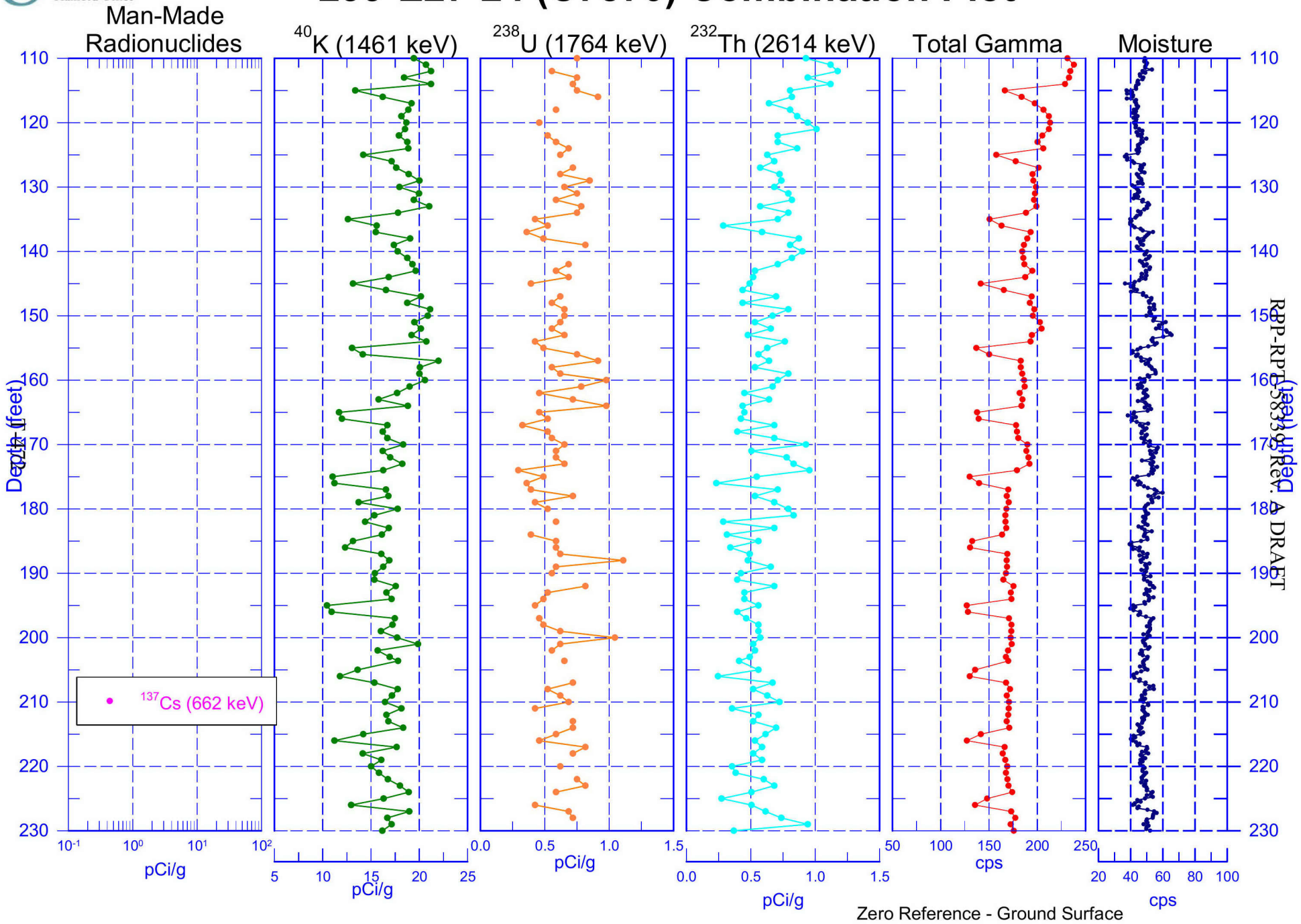
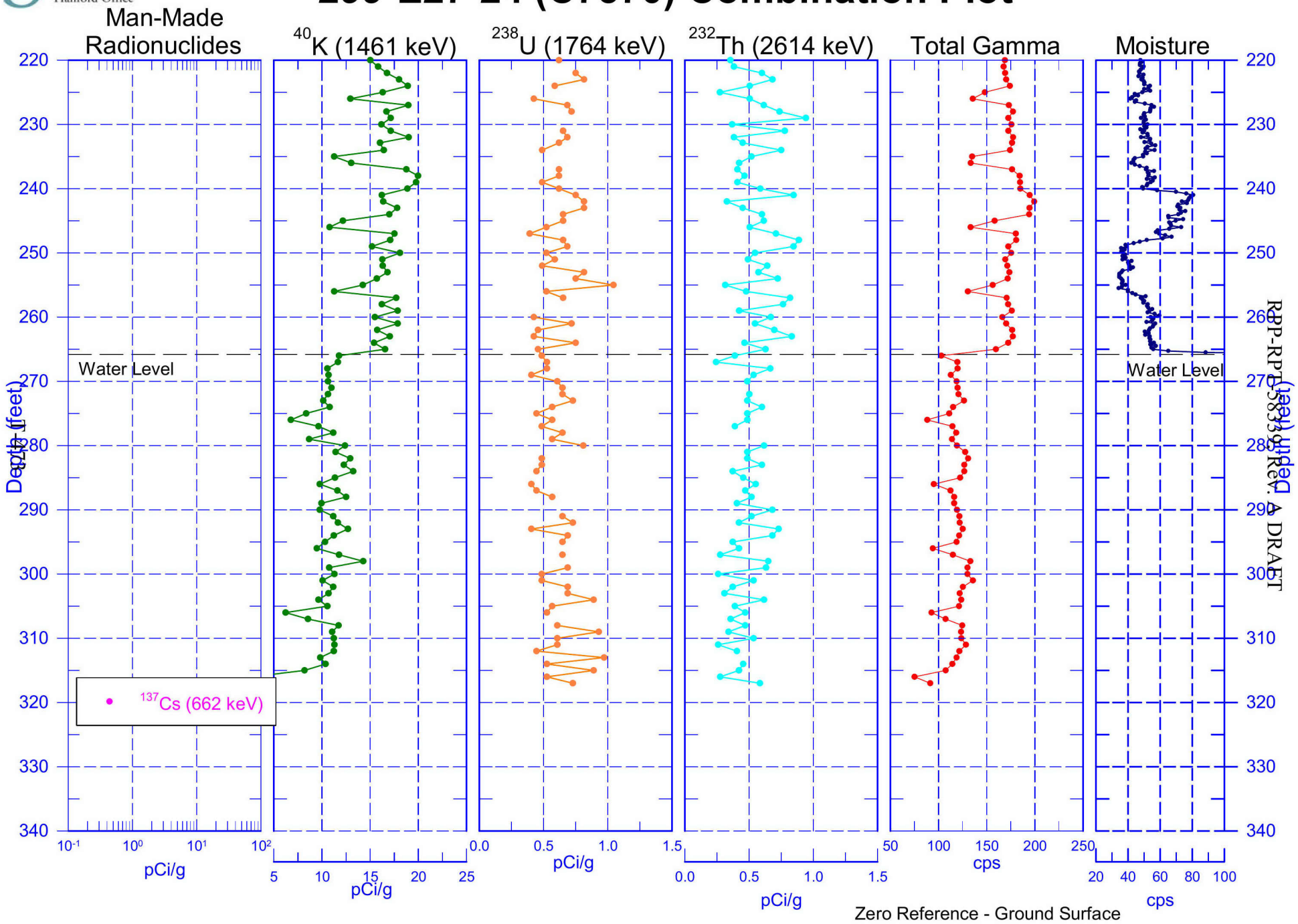
299-E27-24 (C7570) Combination Plot



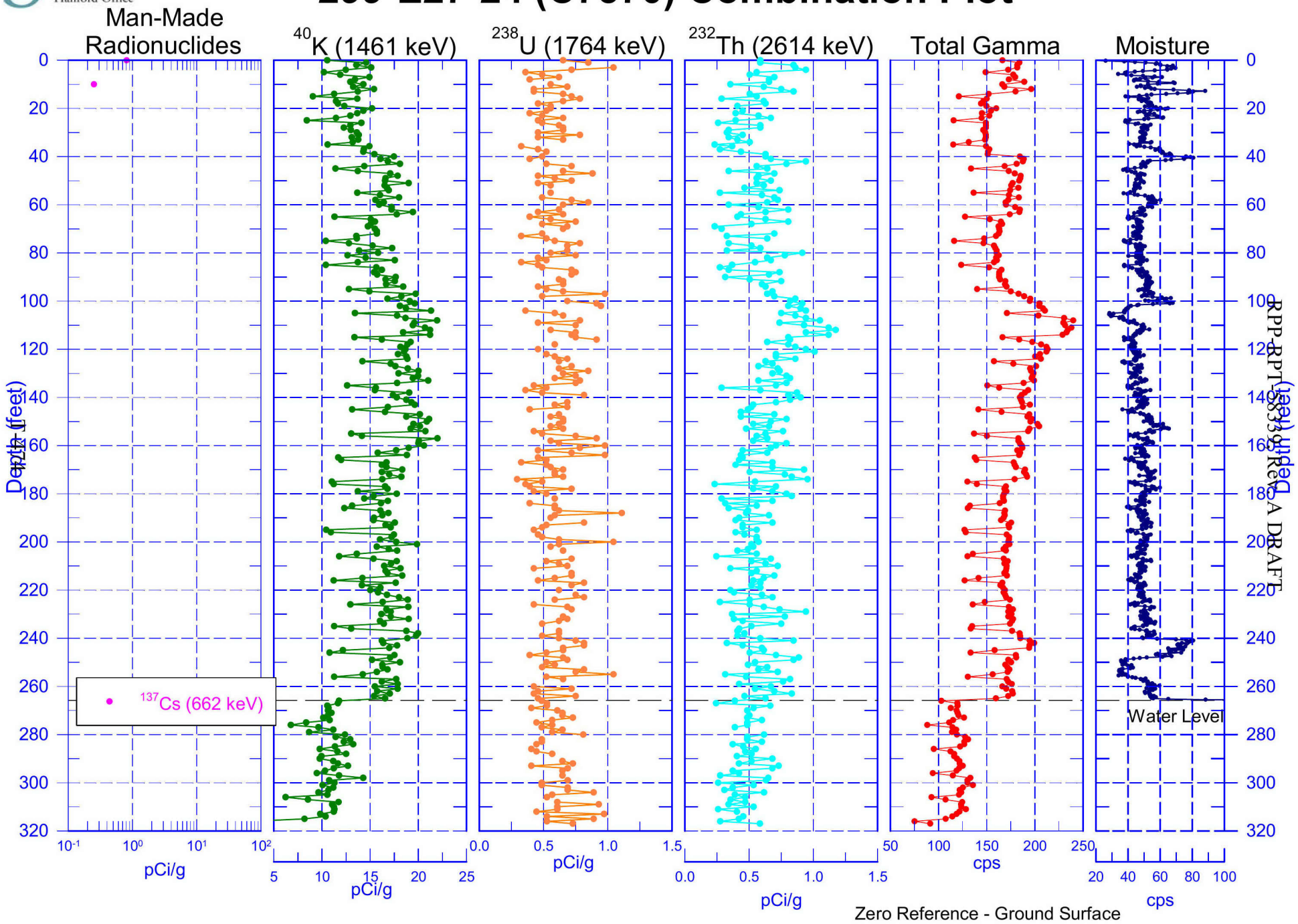
RPP-RPT-58339, Rev. A DRAFT

299-E27-24 (C7570) Combination Plot



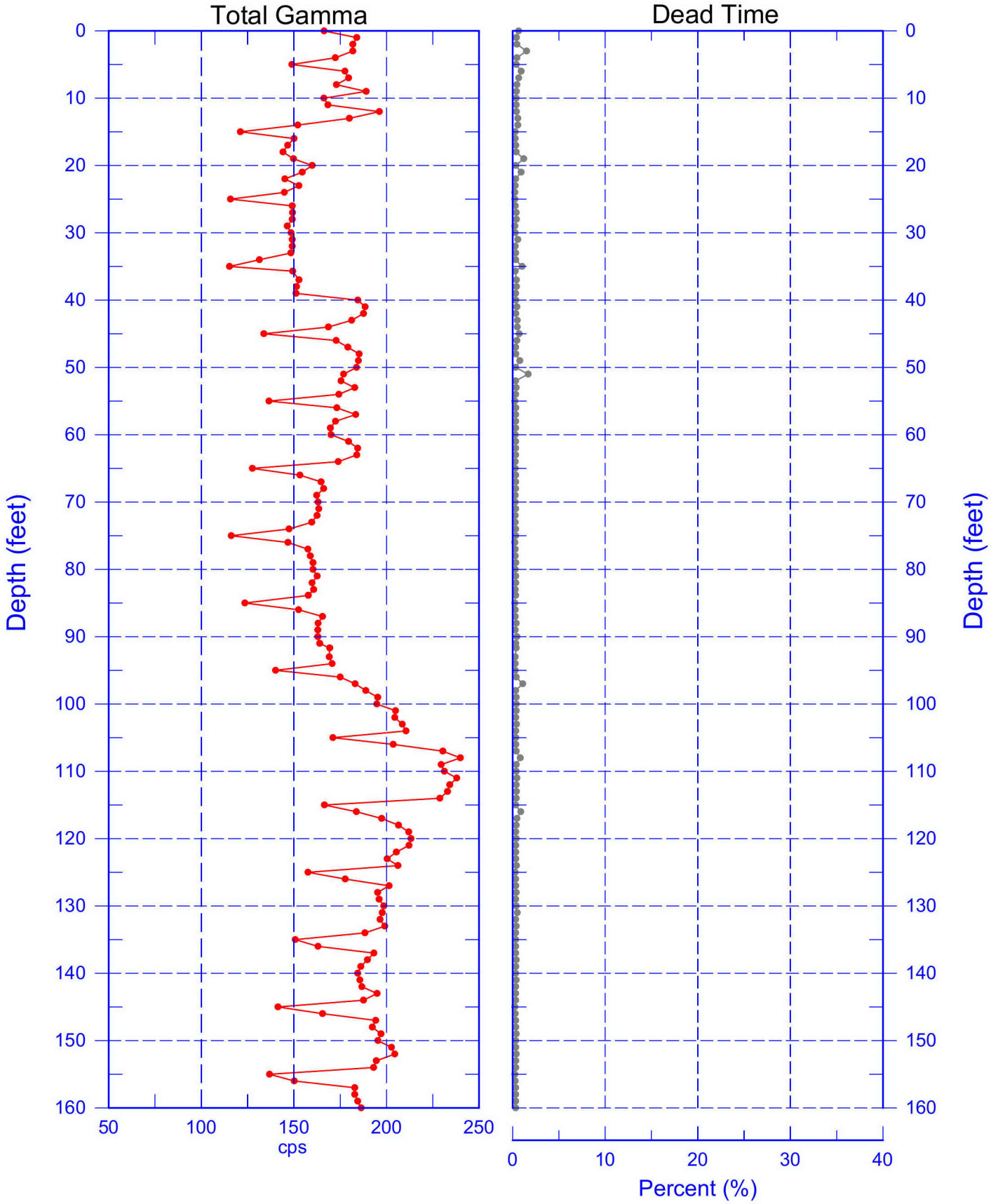
RPP-RPT-58330, Rev. A DRAFT

299-E27-24 (C7570) Combination Plot



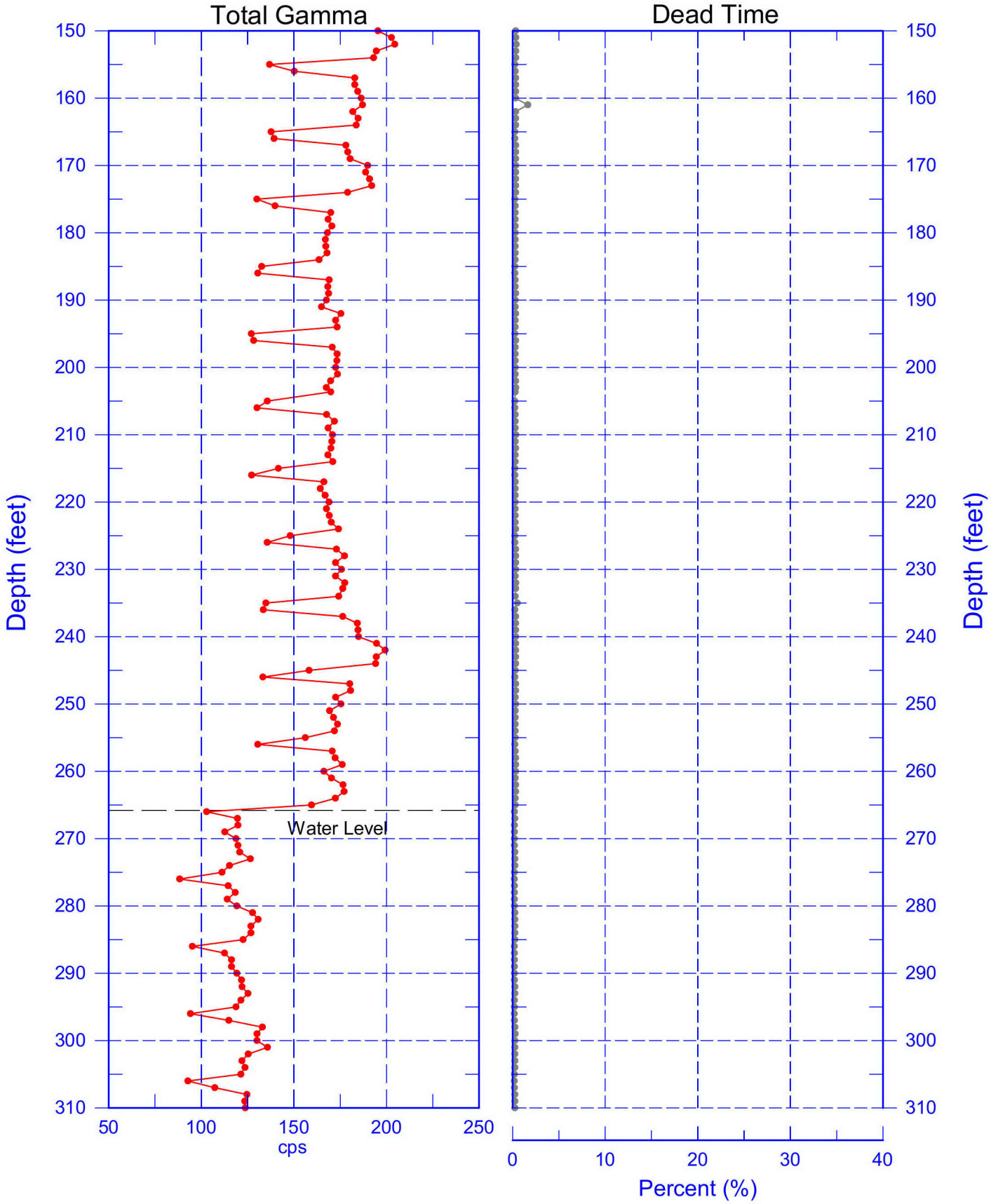
RPP-RPT-58330, Rev. A DRAFT

299-E27-24 (C7570)
Total Gamma & Dead Time



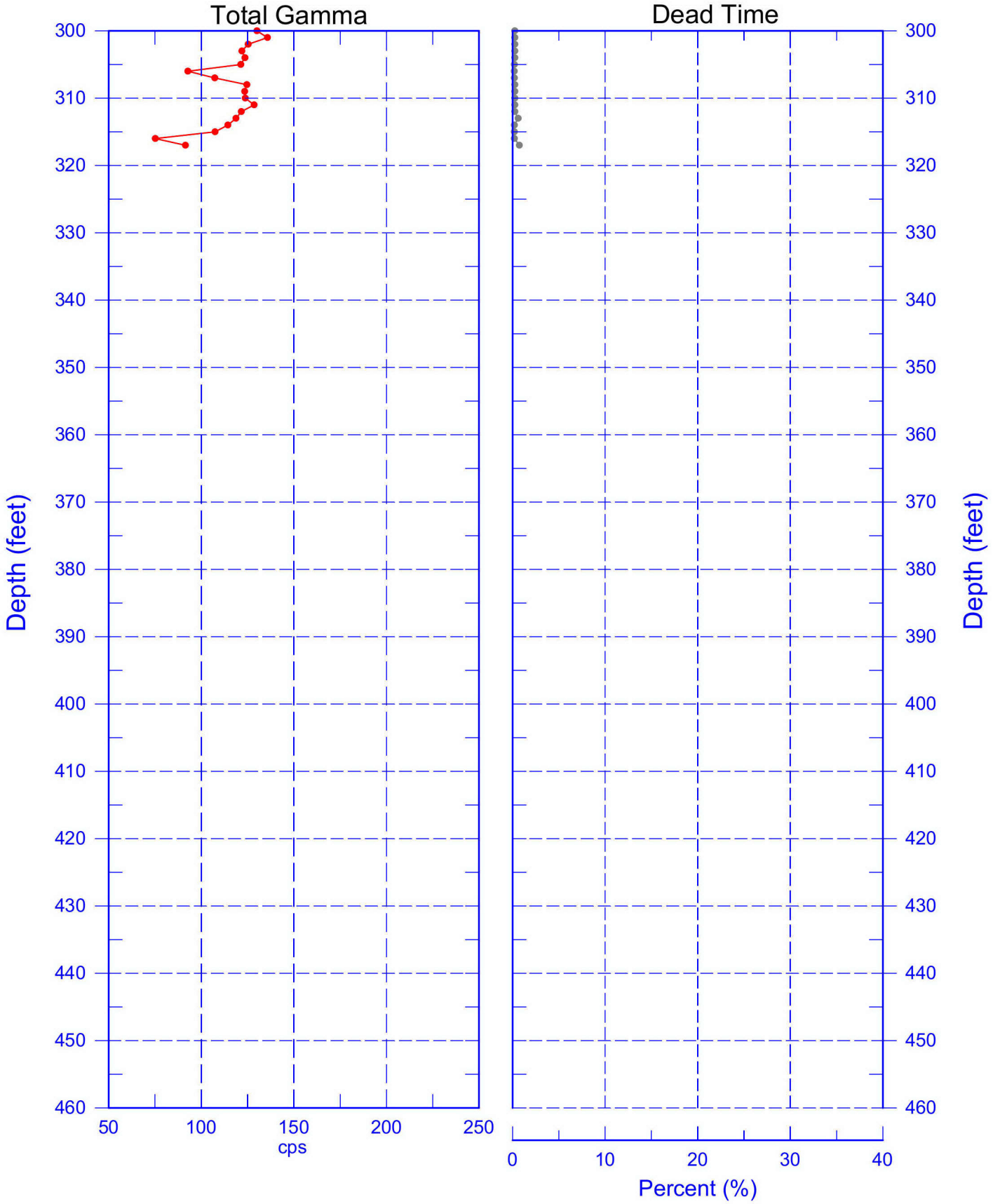
Zero Reference - Ground Surface

299-E27-24 (C7570)
Total Gamma & Dead Time



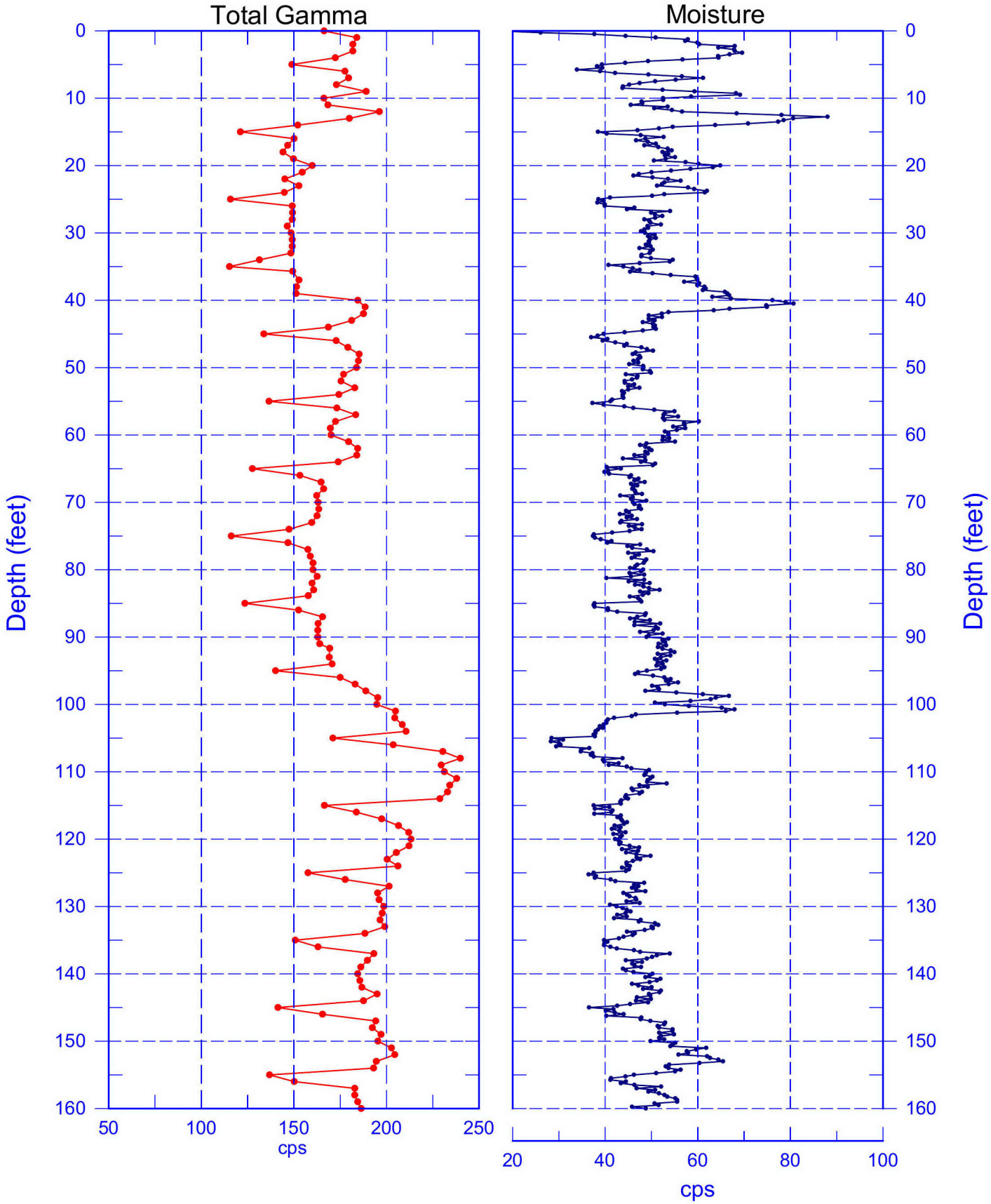
Zero Reference - Ground Surface

299-E27-24 (C7570)
Total Gamma & Dead Time



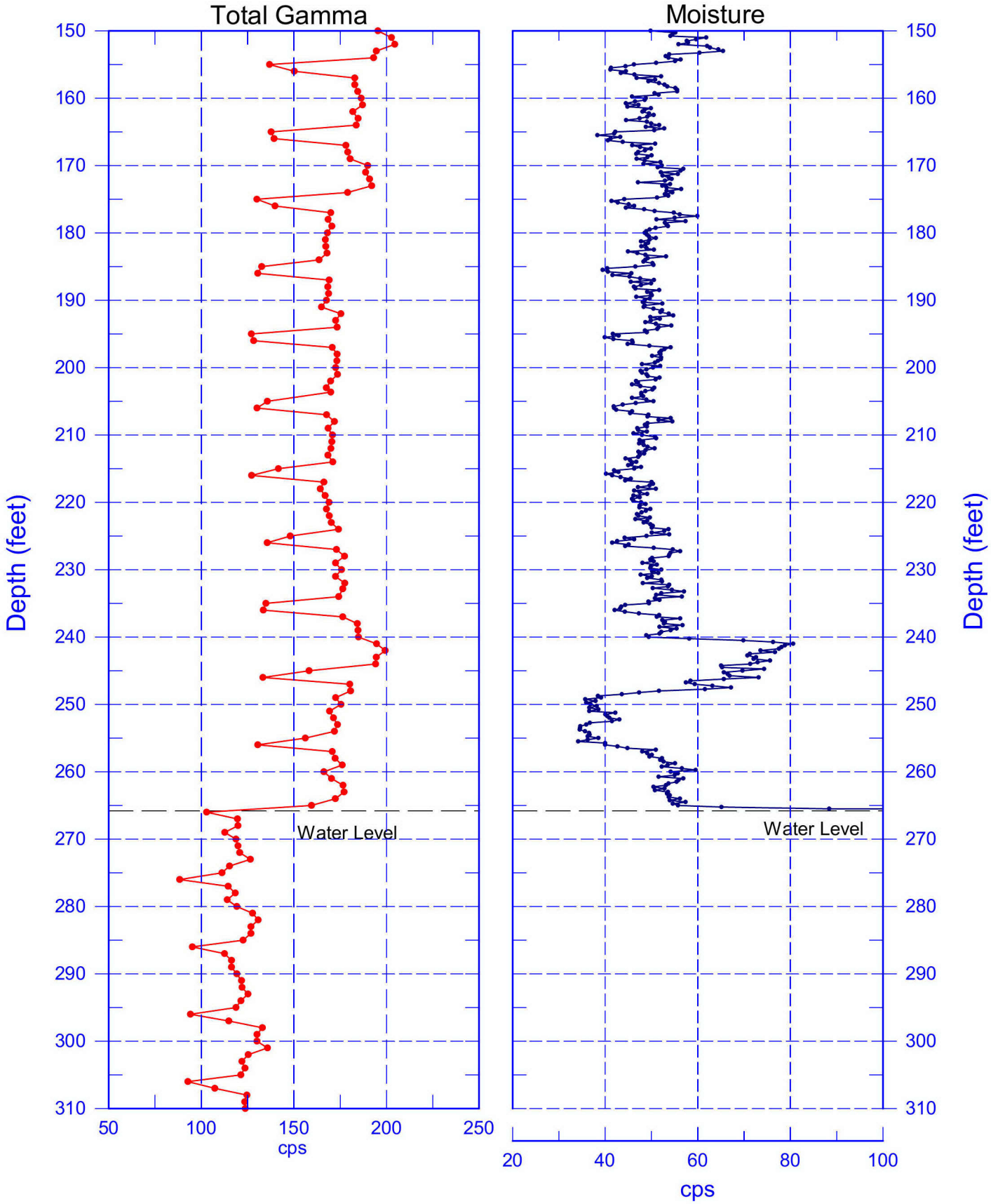
Zero Reference - Ground Surface

299-E27-24 (C7570)
Total Gamma & Moisture



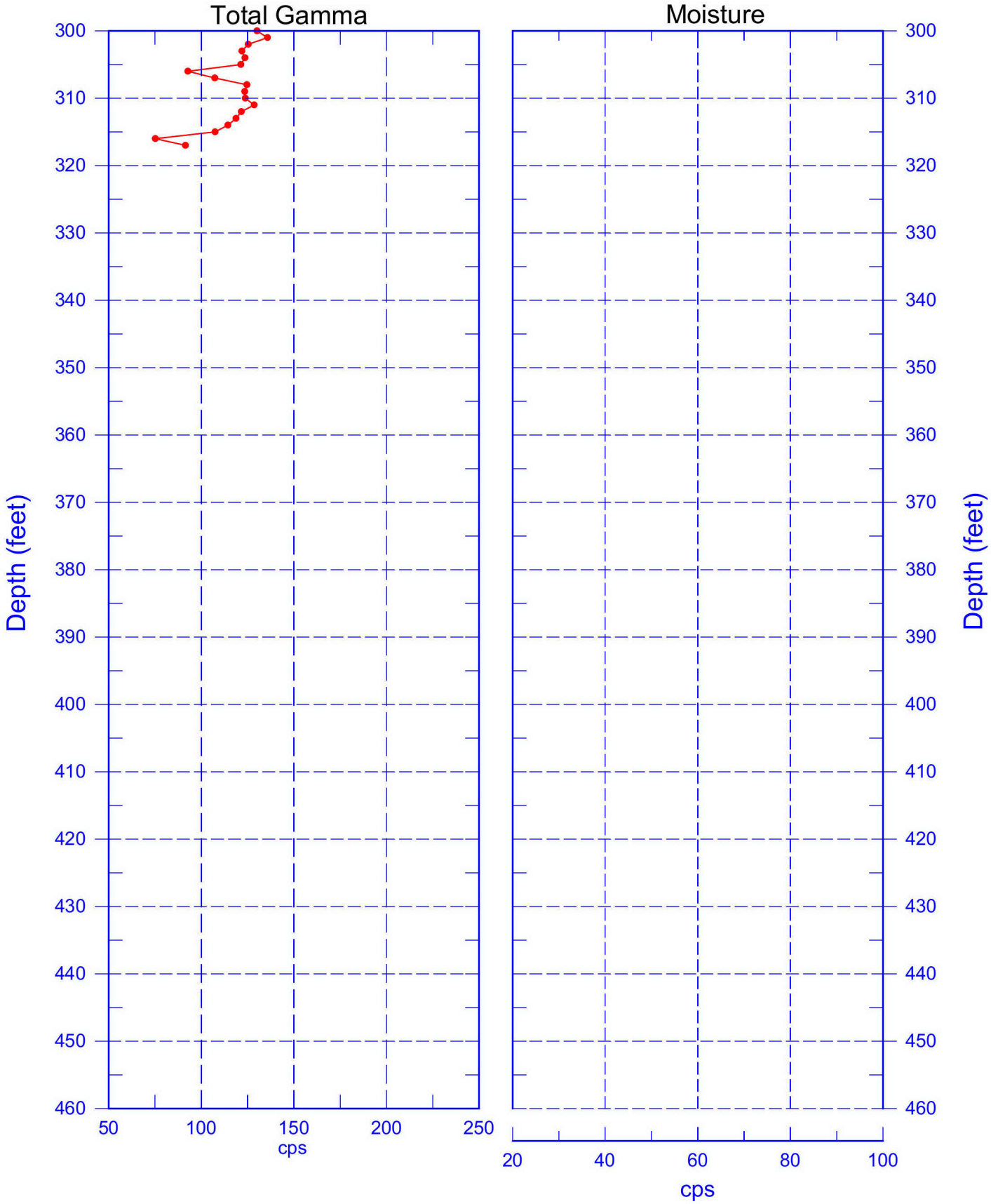
Zero Reference - Ground Surface

299-E27-24 (C7570)
Total Gamma & Moisture



Zero Reference - Ground Surface

299-E27-24 (C7570)
Total Gamma & Moisture



Zero Reference - Ground Surface

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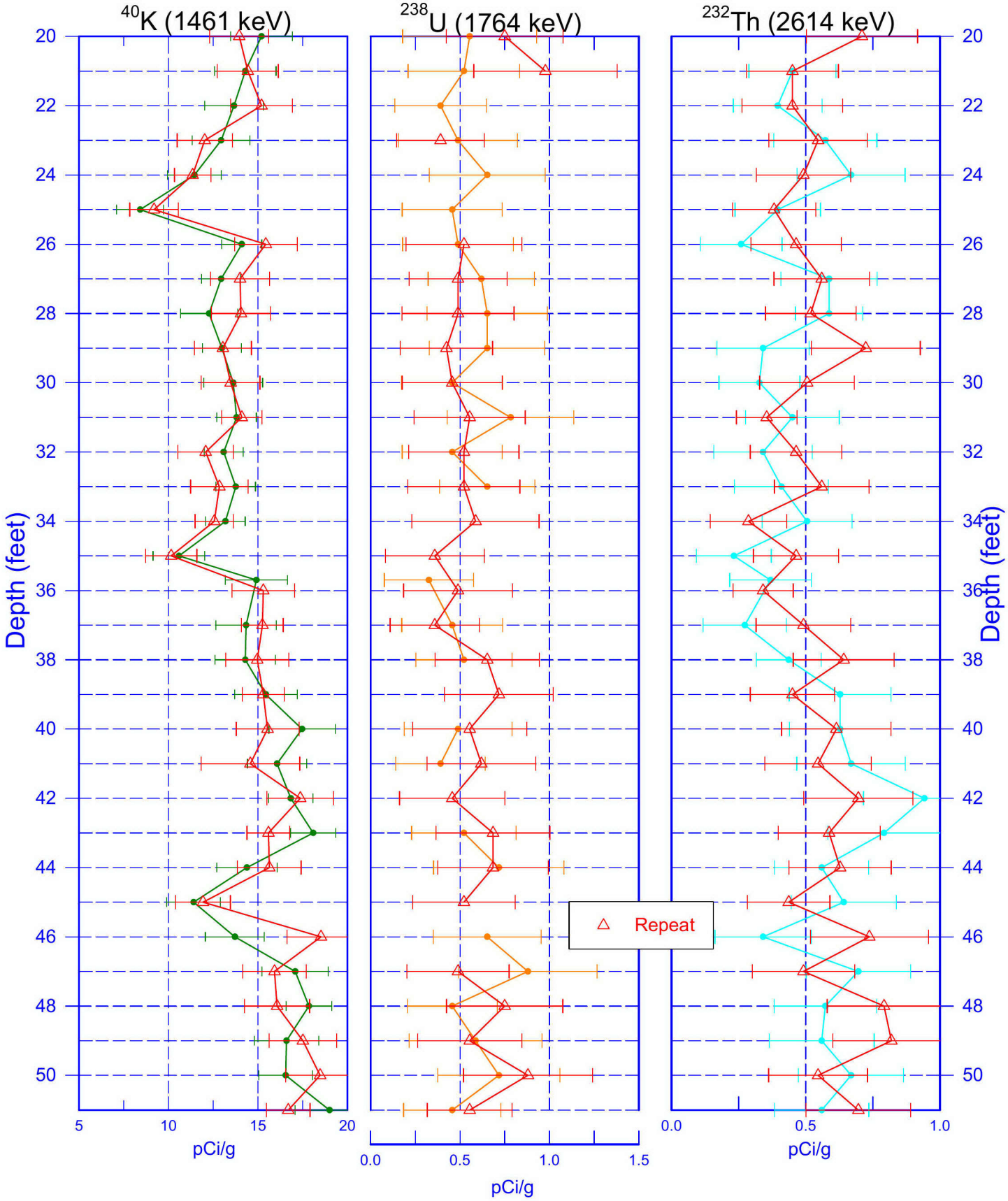
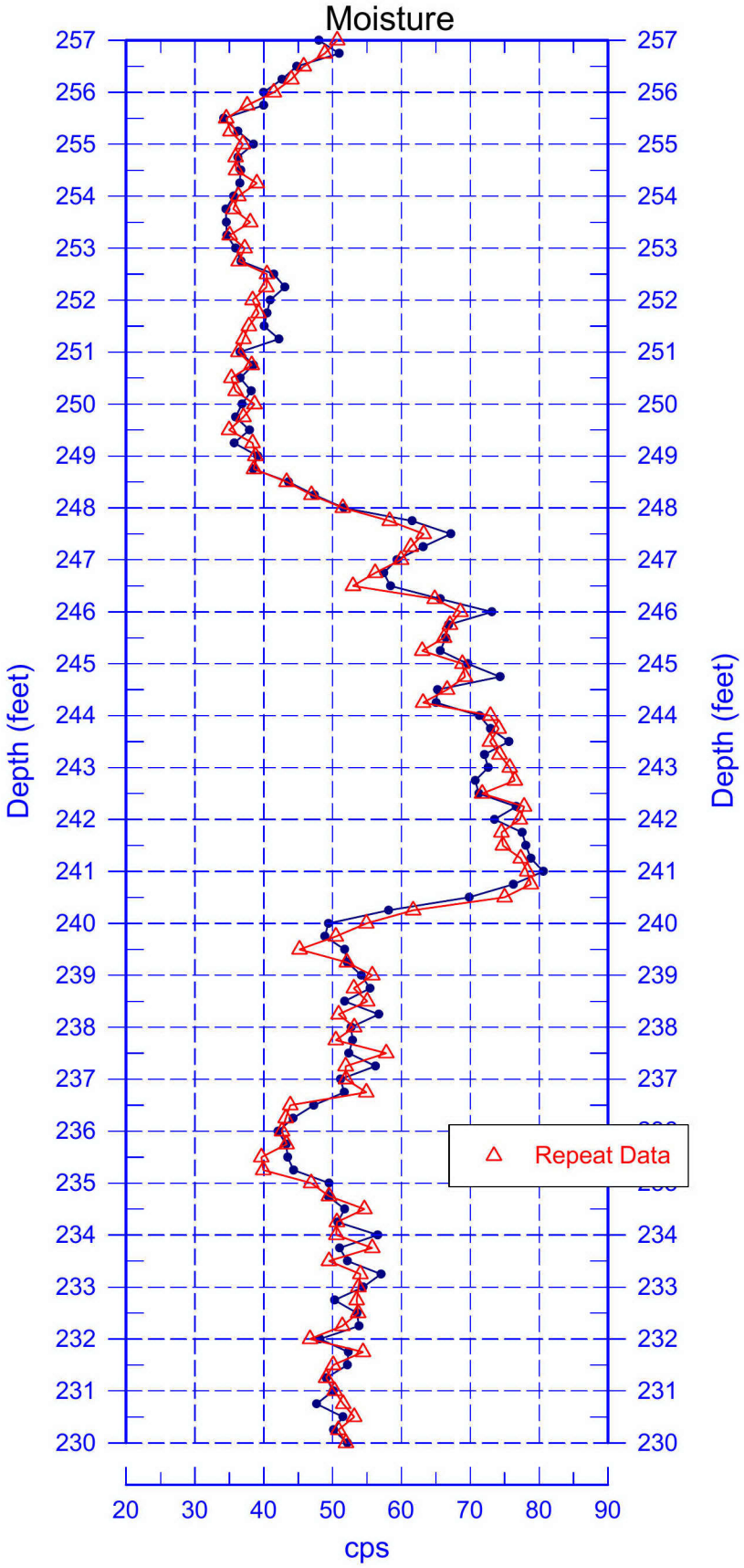
299-E27-24 (C7570)

Repeat Section of Natural Gamma Logs



Zero Reference - Ground Surface

299-E27-24 (C7570)
Moisture Repeat Section



Zero Reference - Ground Surface

GROUNDWATER WELL LOGGING RESULTS FOR 299-E27-25 (C7571)

299-E27-25 (C7571)
Log Data Report

Borehole Information:

Borehole:	299-E27-25 (C7571)		Site:	200-BP-5, near C- farm	
Coordinates (WA St Plane)		GWL[1] (ft) :	213.7	GWL Date:	03/26/10
North (m)	East (m)	Drill Date	TOC[2] Elevation	Total Depth (ft)	Type
Unknown	Unknown	4/08/10	Unknown	248.0	Becker

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in)	Inside Diameter (in)	Thickness (in)	Top (ft)	Bottom (ft)
Threaded Steel	0.7					

Borehole Notes:

The site geologist reported total depth and casing depth. The logging engineer measured depth to water.

The Becker drilling system uses a dual-wall casing. Air flows down the annulus and cuttings are returned inside the inner casing. Total wall thickness is 0.620 inch, increasing to 1.115 inch at the casing joints that occur at 10-foot intervals. The casing dimensions are derived from published values for Becker dill casing.

The zero reference is the ground surface.

Logging Equipment Information:

Logging System:	Gamma 4 N		Type: Serial No.:	60% HPGe SGLS 47TP22010A
Effective Calibration Date:	01/25/2010	Calibration Reference:	HGLP-CC-051, Rev. 0	
		Logging Procedure:	HGLP-MAN-002, Rev. 0	

Logging System:	Gamma 1 M		Type: Serial No.:	NMLS H340207279
Effective Calibration Date:	01/18/2010	Calibration Reference:	HGLP-CC-052, Rev. 0	
		Logging Procedure:	HGLP-MAN-002, Rev. 0	

Spectral Gamma Logging System (SGLS) Log Run Information:

Log Run	4	5	6 Repeat		
HEIS Number	1016095	1016096	1016097		
Date	04/09/10	04/09/10	04/09/10		
Logging Engineer	Spatz/ McClellan	Spatz/ McClellan	Spatz/ McClellan		
Start Depth (ft)	0.0	233.0	30.0		
Finish Depth (ft)	234.0	248.0	55.0		
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		
Log Speed (ft/min)	N/A	N/A	N/A		
Pre-Verification	DNE31CAB	DNE31CAB	DNE31CAB		
Start File	DNE31000	DNE31235	DNE31251		
Finish File	DNE31234	DNE31250	DNE31276		

Log Run	4	5	6 Repeat		
Post-Verification	DNE31CAA	DNE31CAA	DNE31CAA		
Depth Return Error (in)	Low 3	N/A	Low 3		
Comments	No fine gain adjustments made.	No fine gain adjustments made.	No fine gain adjustments made.		

Neutron Moisture Logging System (NMLS) Log Run Information:

Log Run	1	2	3 Repeat		
HEIS Number	1016098	1016099	1016100		
Date	03/26/10	03/26/10	03/26/10		
Logging Engineer	Spatz	Spatz	Spatz		
Start Depth (ft)	0.0	114.0	127.0		
Finish Depth (ft)	115.0	213.5	148.0		
Count Time (sec)	15	15	15		
Live/Real	R	R	R		
Shield (Y/N)	N	N	N		
MSA Interval (ft)	0.25	0.25	0.25		
Log Speed (ft/min)	N/A	N/A	N/A		
Pre-Verification	AM079CAB	AM079CAB	AM079CAB		
Start File	AM079000	AM079461	AM079860		
Finish File	AM079460	AM079859	AM079944		
Post-Verification	AM079CAA	AM079CAA	AM079CAA		
Depth Return Error (in)	N/A	N/A	Low ½		
Comments	None	None	None		

Logging Operation Notes:

SGLS data were collected using Gamma 4, HO 68B-3573. Pre- and post-survey verification measurements were acquired in the KUTh-115 field verifier. A centralizer was installed on the sonde.

NMLS data were collected using Gamma 1, HO 68B-3574. Pre- and post-survey verification measurements were acquired in the standard field verifier. A centralizer was installed on the sonde.

Analysis Notes:

Analyst:	LEGLER	Date:	05/07/2010	Reference:	GJO-HGLP 1.6.3, Rev. 0

The SGLS and NMLS pre- and post-survey verification measurements met the acceptance criteria for the established systems.

A combined casing correction for a 0.620-inch thick (0.120 + 0.500 for the 6- and 9-inch Becker dual wall casings respectively) was applied during analysis. Casing thickness (additive for the 6- and 9-inch casings) is approximately 0.620 inch. The combined thickness at casing joints is 1.115 inch. The thickness results in a significant reduction in gamma activity detection as the detector passes by a casing joint. However, it is not practical to correct individual data points for the effect of casing joints. The influence of the thick joints is apparent on the total gamma where reduced count rates are exhibited at approximately 10-foot depth intervals.

A water correction (for a 6-inch casing) was also applied to depths below 213.7 feet.

The SGLS spectra were processed in batch mode using APTEC SUPERVISOR to identify individual peaks and count rates. Concentrations were calculated using an EXCEL template identified as DN20100125.xls using an efficiency function and corrections for casing, dead time and water as determined by annual calculations.

During routine processing of gamma spectra, regions of interest are forced at specific energy levels associated with natural and manmade radionuclides that are anticipated to be present. This processing approach sometimes results in an isolated "detection" near the minimum detection level (MDL) resulting in a false positive. Where these detections occur, the individual spectrum is scrutinized and a determination is made regarding the validity of the detection. If the detection is deemed not representative of a full energy peak, or if confirming peaks are not detected, it is removed from the data set. The integrity of the raw data files and the processed files are maintained should questions arise in the future regarding these determinations.

NMLS data are presented in counts per second (cps) because there is no calibration for a Becker casing configuration.

Results and Interpretations:

Cs-137 was detected at 1 foot with an approximate concentration of 0.24 pCi/g.

A decrease in gamma activity and apparent moisture occurs at each casing joint, where the increase in wall thickness results in greater attenuation.

The neutron moisture log primarily responds to moisture present in the surrounding formation. In general, an increase in count rate reflects an increase in moisture content. Moisture content may increase in sediments of relatively high silt or clay. The moisture profile is highly variable.

The repeat plots indicate that the respective systems were working properly.

List of Log Plots:

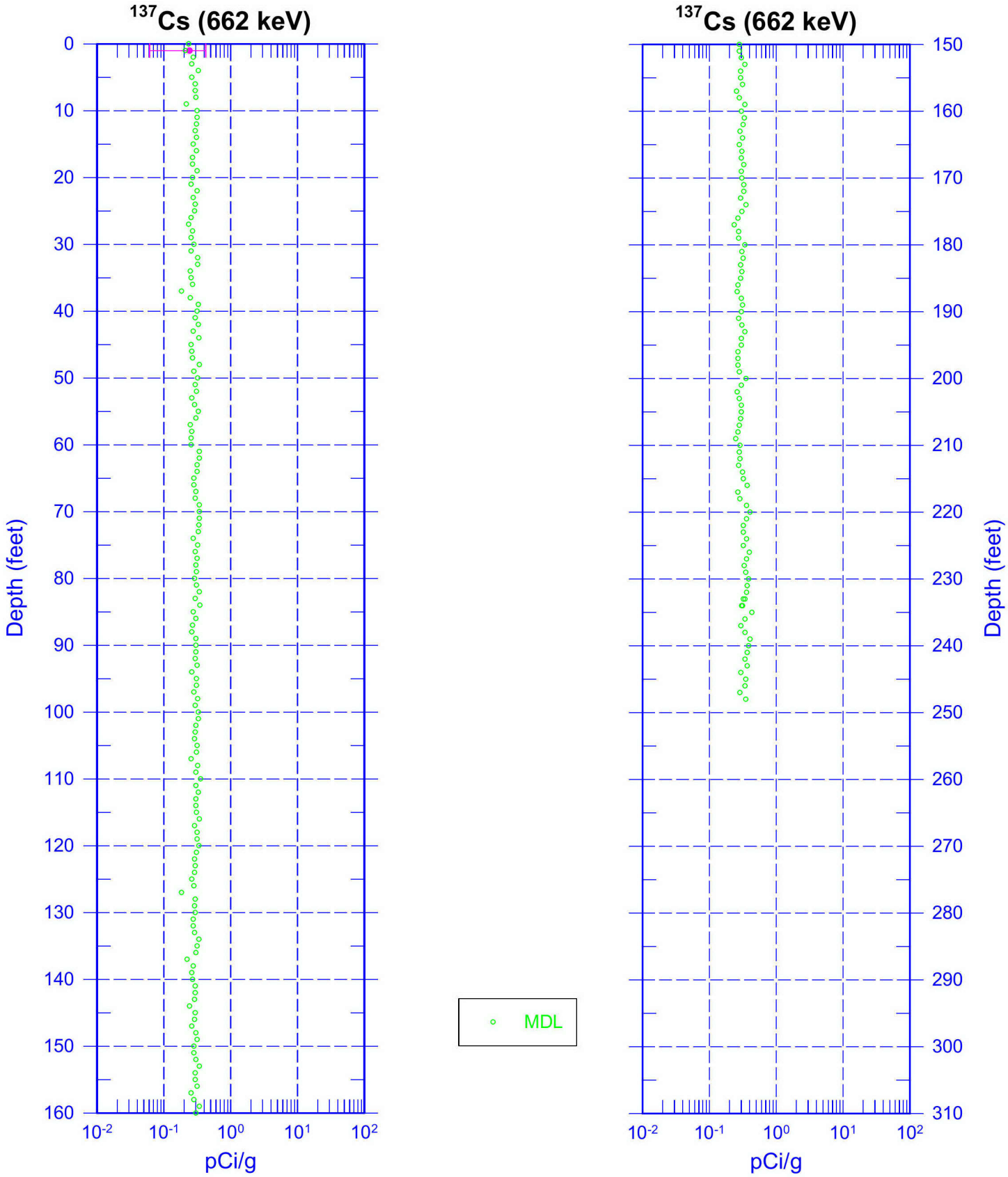
Depth Reference is ground surface

Manmade Radionuclides
Natural Gamma Logs (2 pages)
Combination Plot (3 pages)
Combination Plot (0-260 ft)
Total Gamma & Dead Time (2 pages)
Total Gamma & Moisture (2pages)
Repeat Section of Natural Gamma Logs
Moisture Repeat Section

[1] GWL – groundwater level
[2] TOC – top of casing

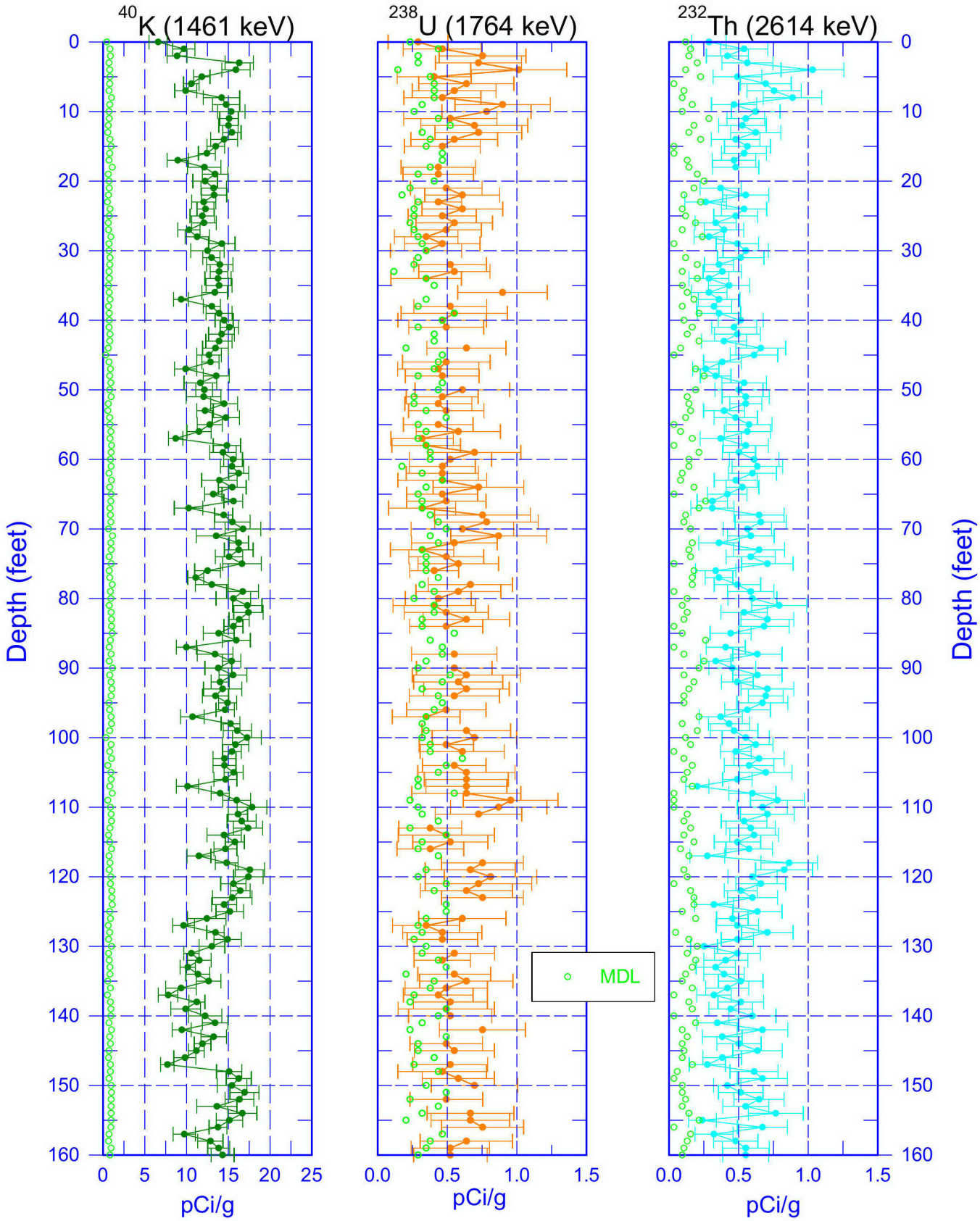
Stoller Hanford Office

299-E27-25 (C7571)
Manmade Radionuclides



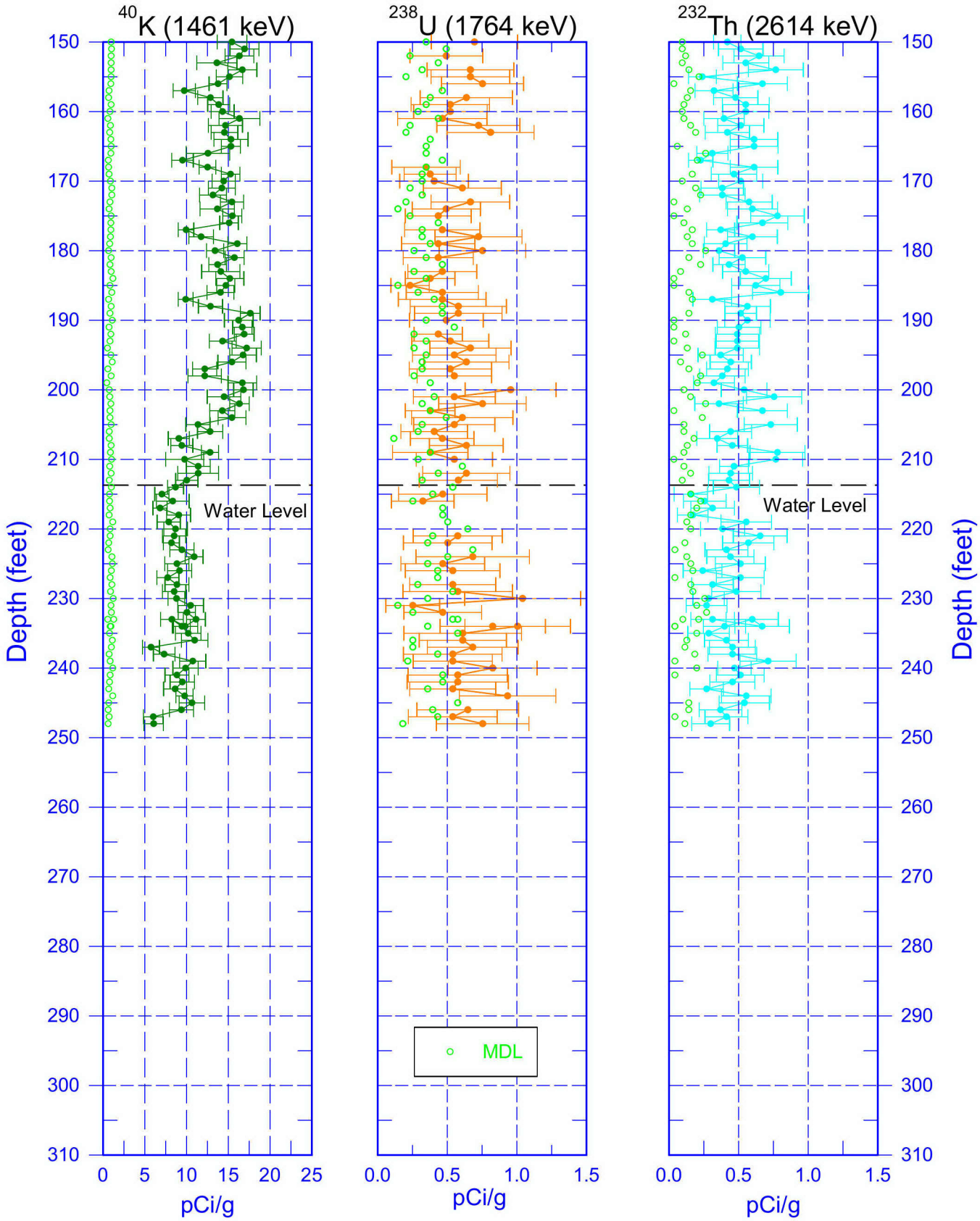
Zero Reference - Ground Surface

299-E27-25 (C7571)
Natural Gamma Logs



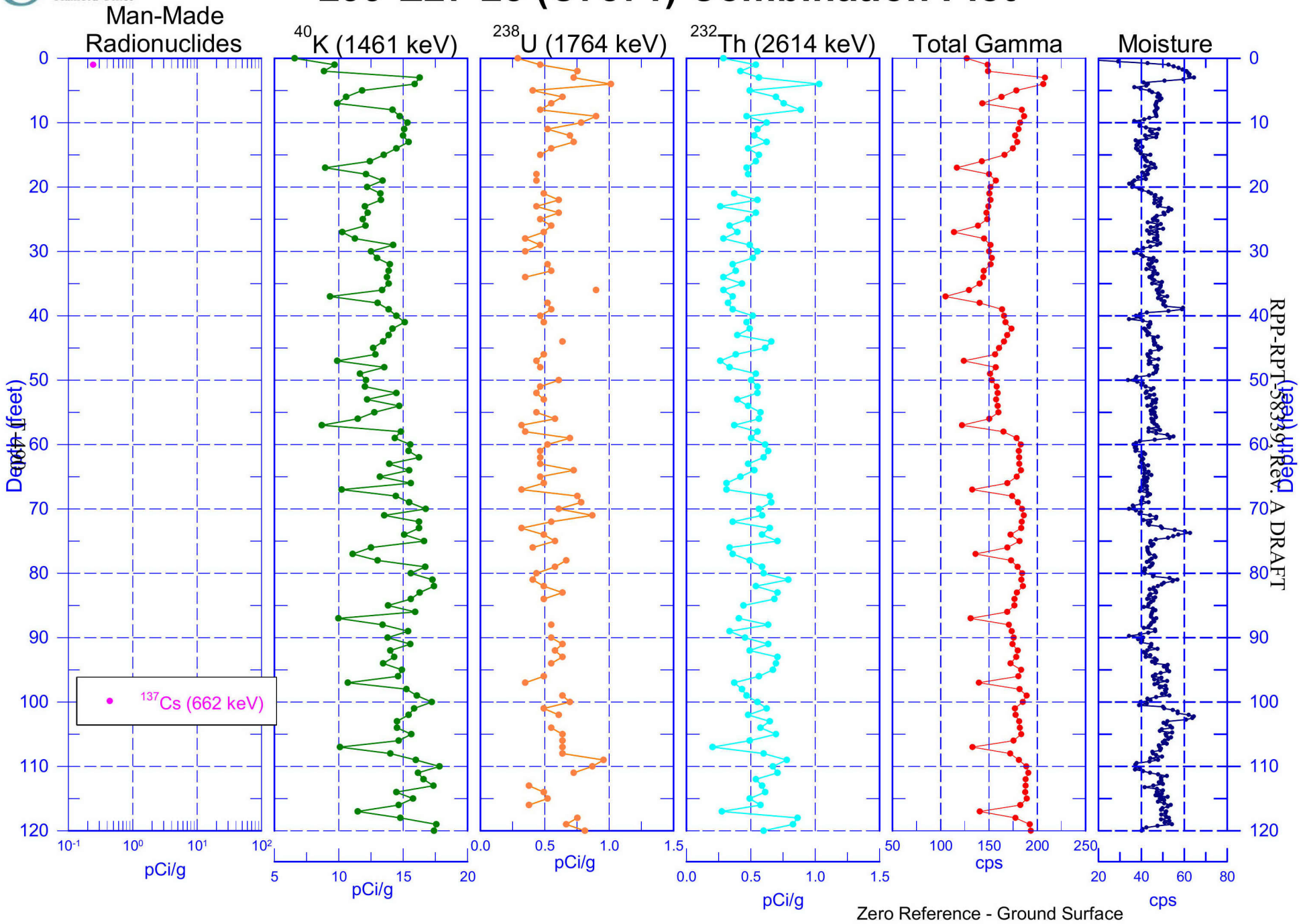
Zero Reference - Ground Surface

299-E27-25 (C7571)
Natural Gamma Logs



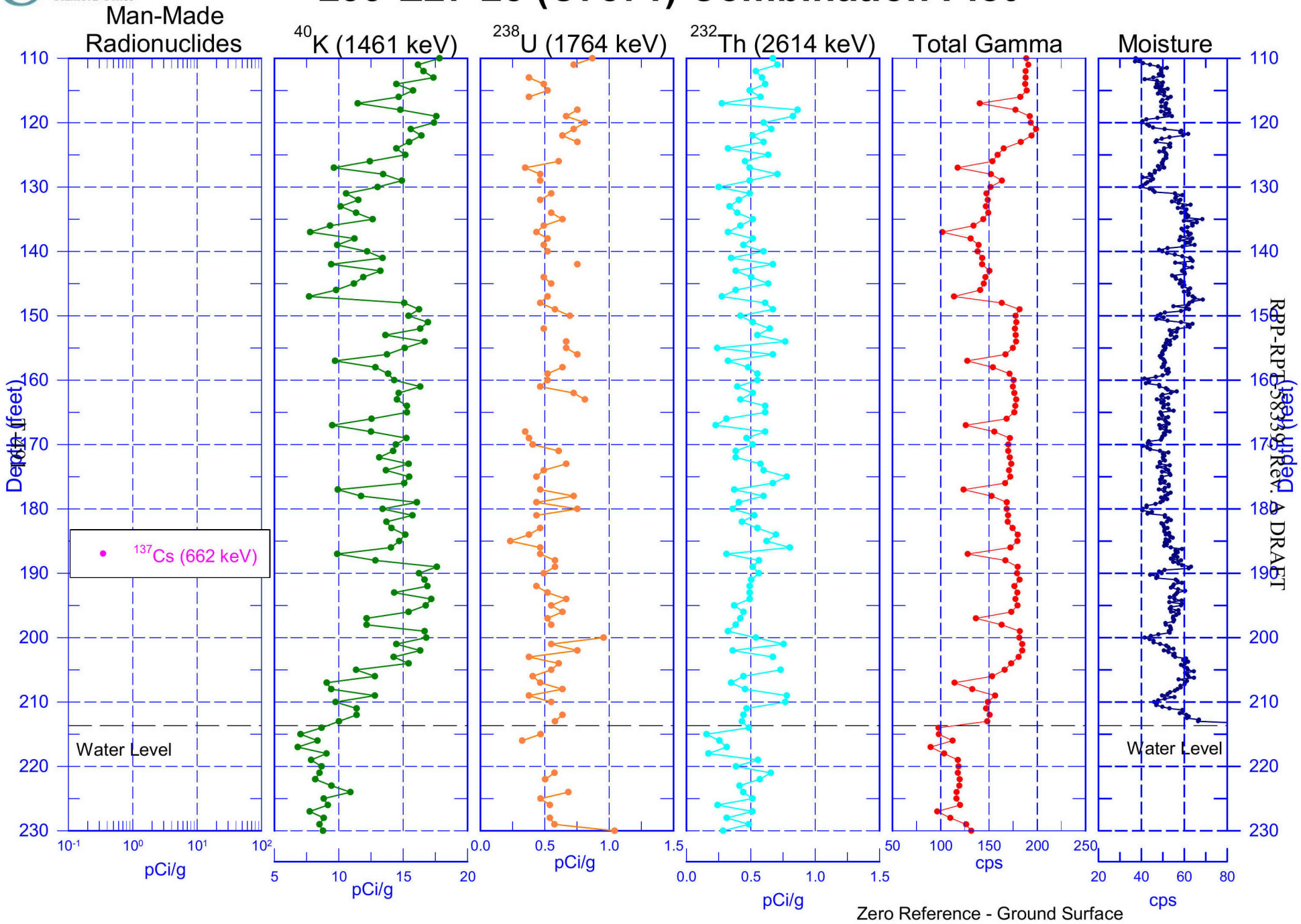
Zero Reference - Ground Surface

299-E27-25 (C7571) Combination Plot



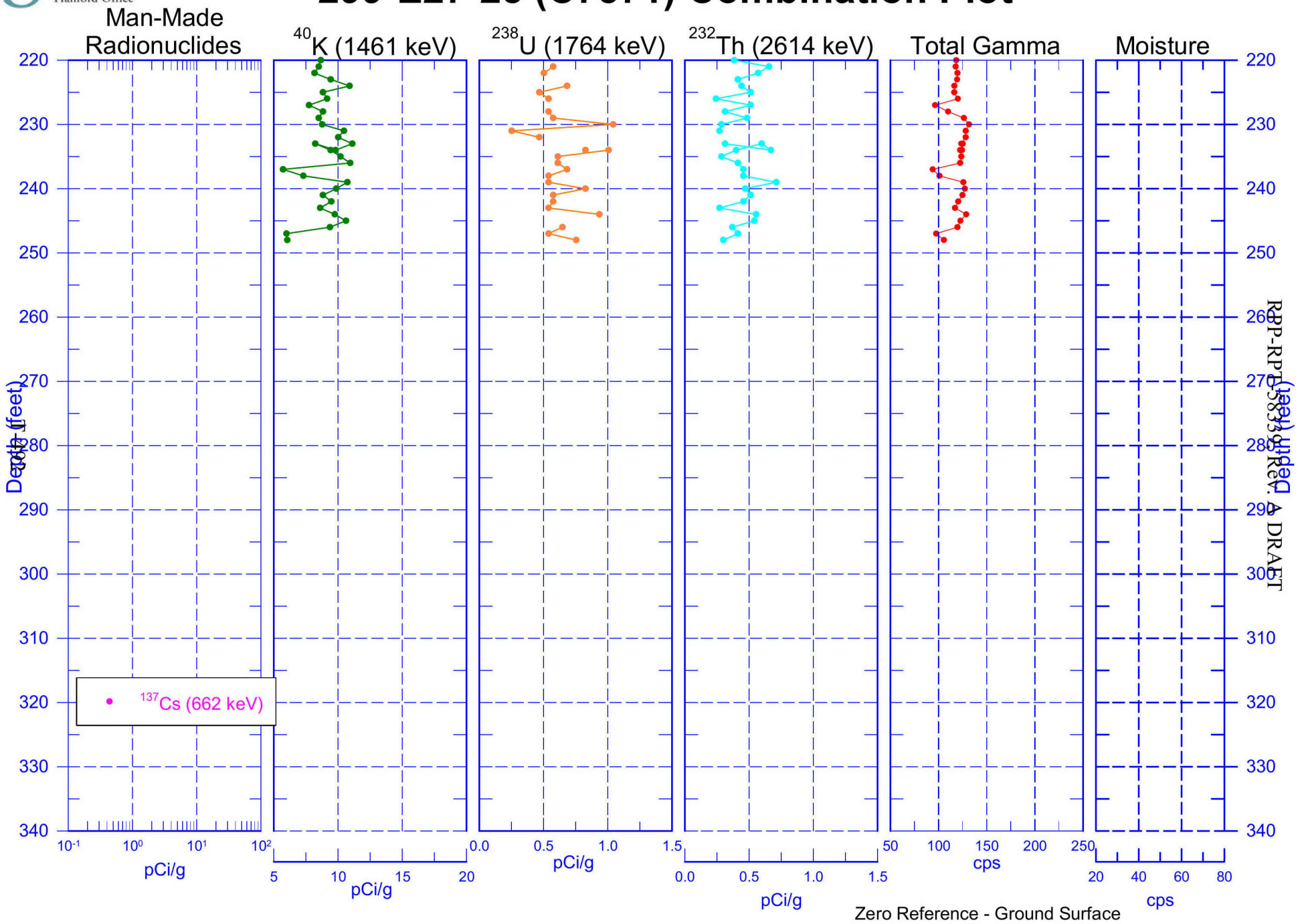
RPP-RPT-58339, Rev. A DRAFT

299-E27-25 (C7571) Combination Plot



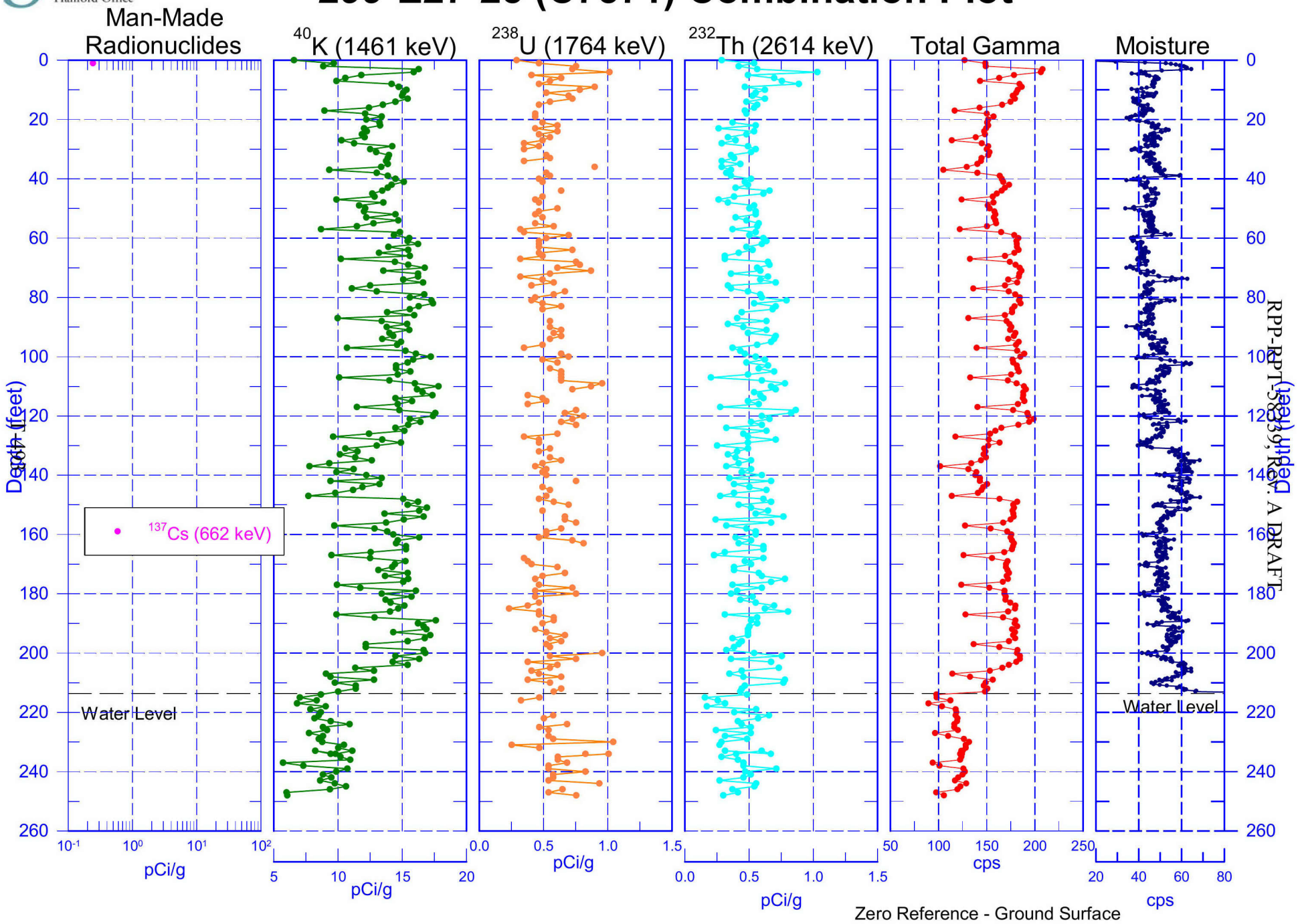
RPP-RPT-58339, Rev. A DRAFT

299-E27-25 (C7571) Combination Plot



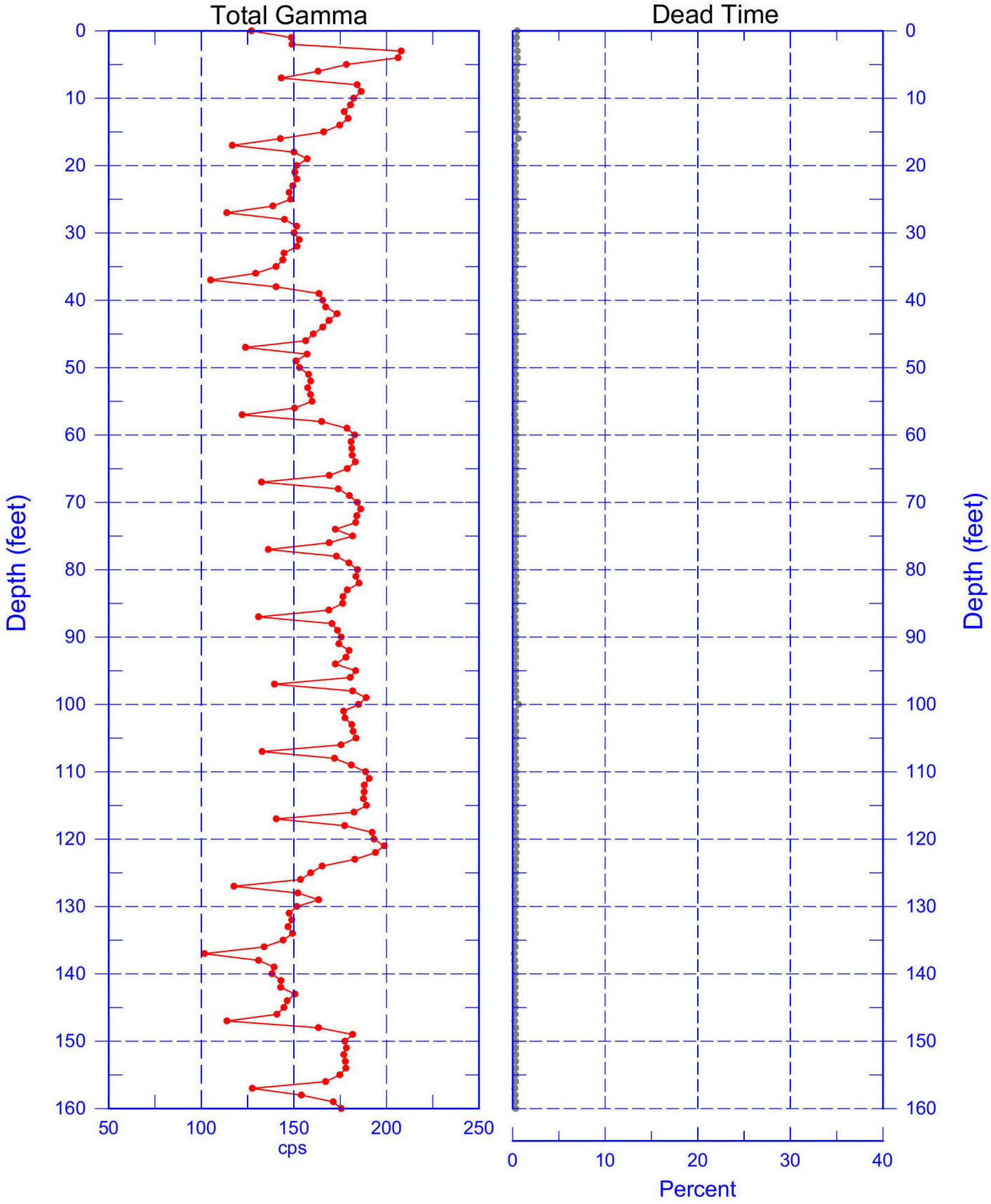
RPP-RPT-58330, Rev. A DRAFT

299-E27-25 (C7571) Combination Plot



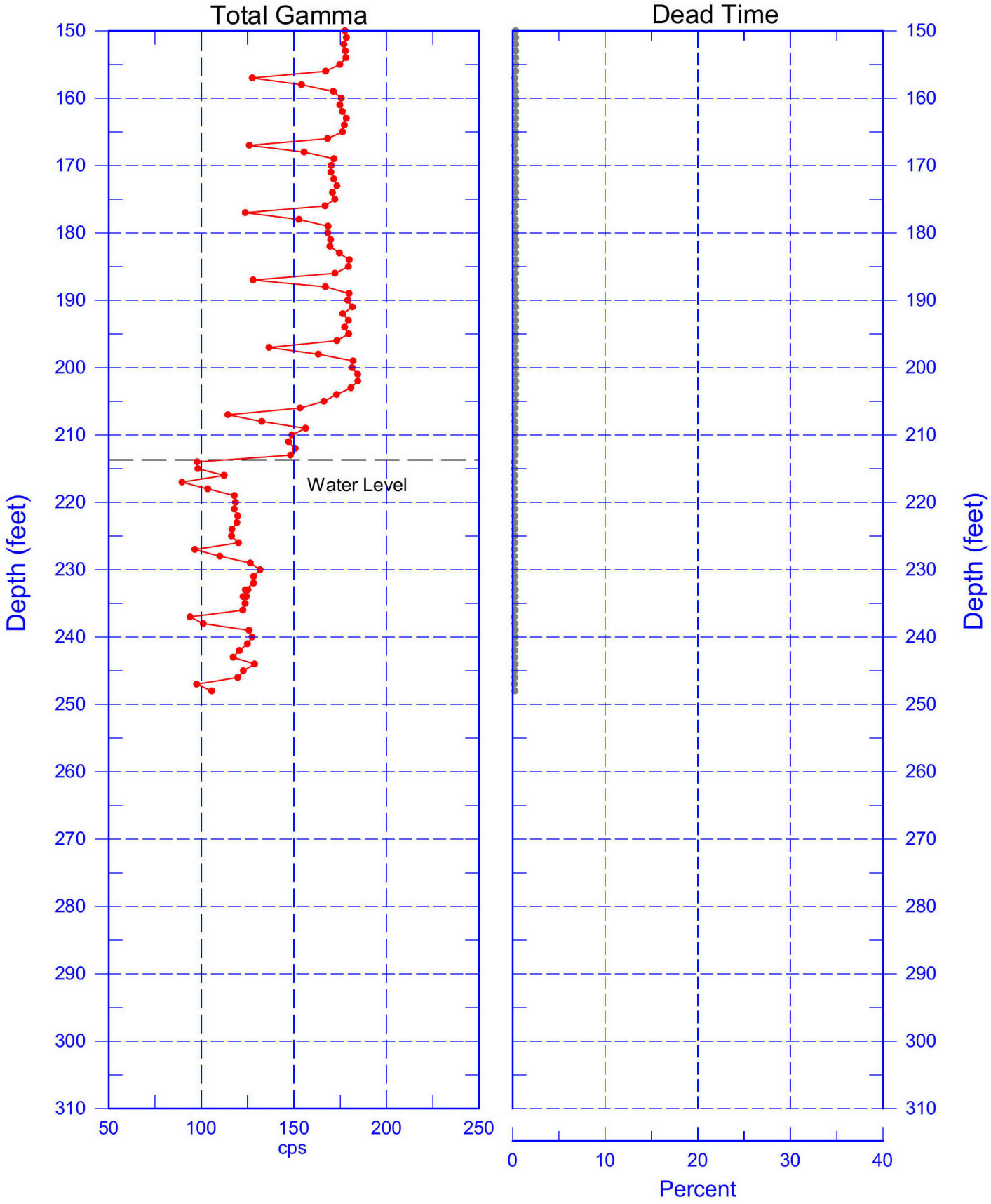
RPP-RPT-58339, Rev. A DRAFT
Deep Vadose Zone Characterization Project

299-E27-25 (C7571)
Total Gamma & Dead Time



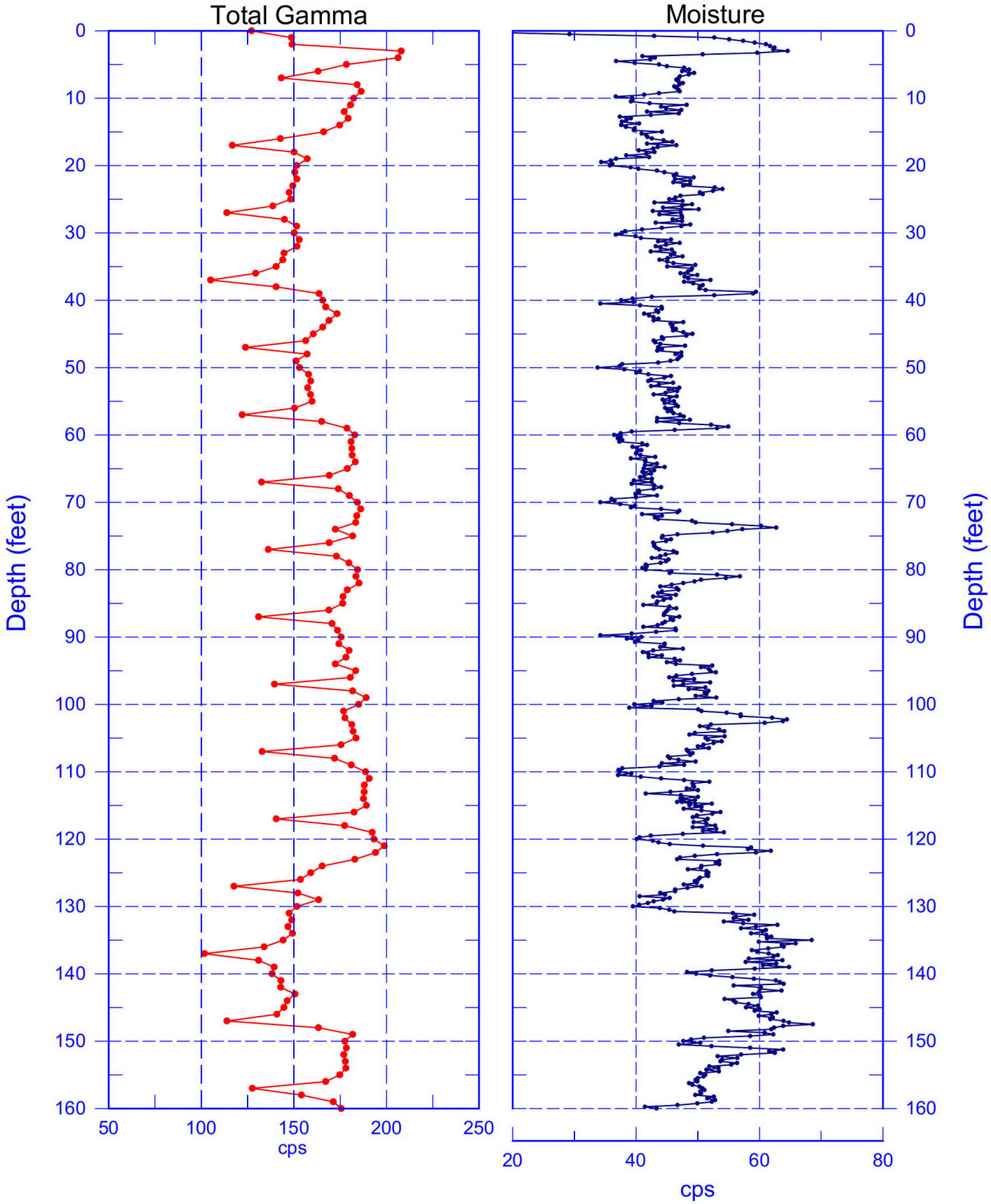
Reference - Ground Surface

299-E27-25 (C7571)
Total Gamma & Dead Time



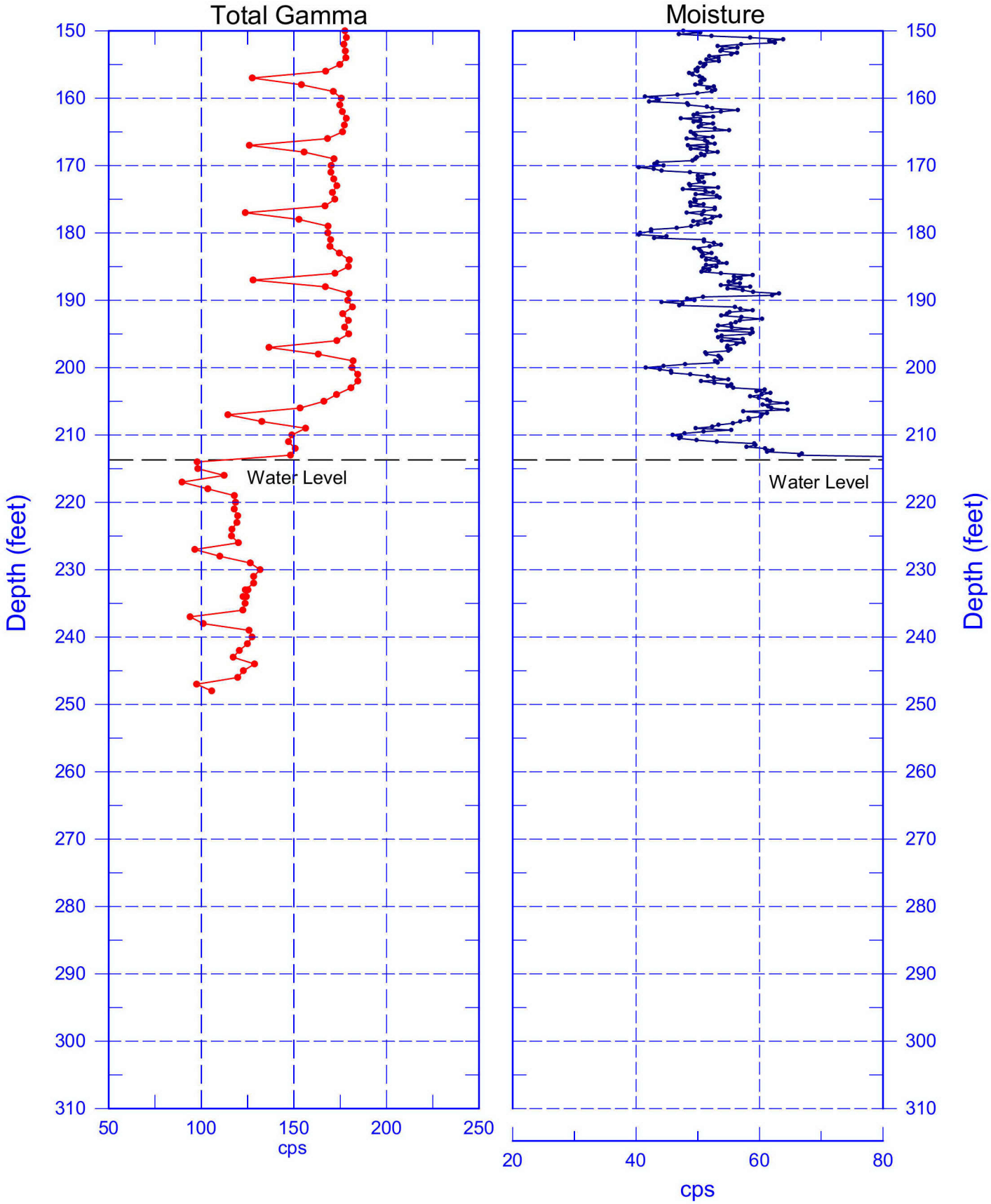
Reference - Ground Surface

299-E27-25 (C7571)
Total Gamma & Moisture



Reference - Ground Surface

299-E27-25 (C7571)
Total Gamma & Moisture

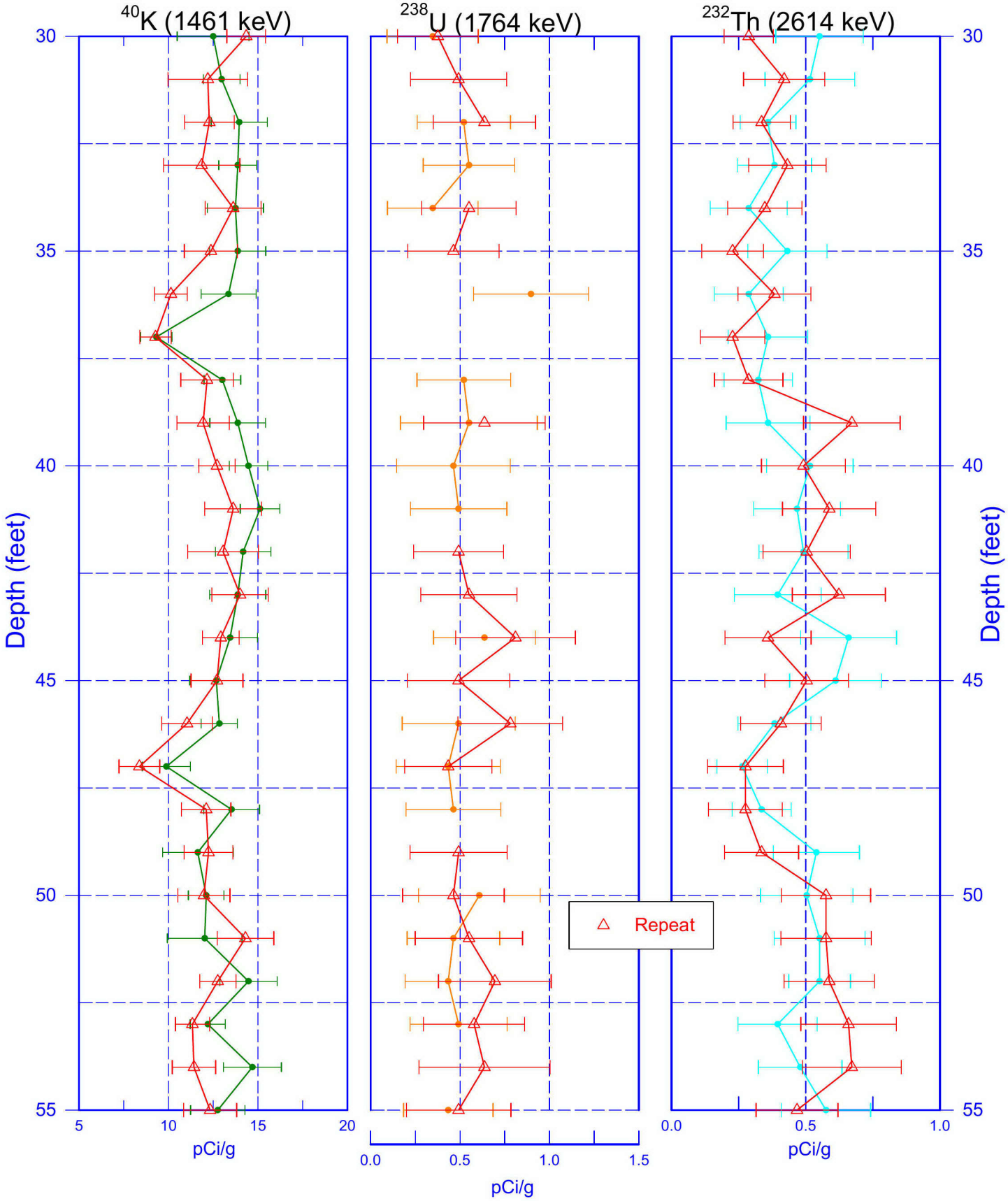


Reference - Ground Surface

Stoller Hanford Office

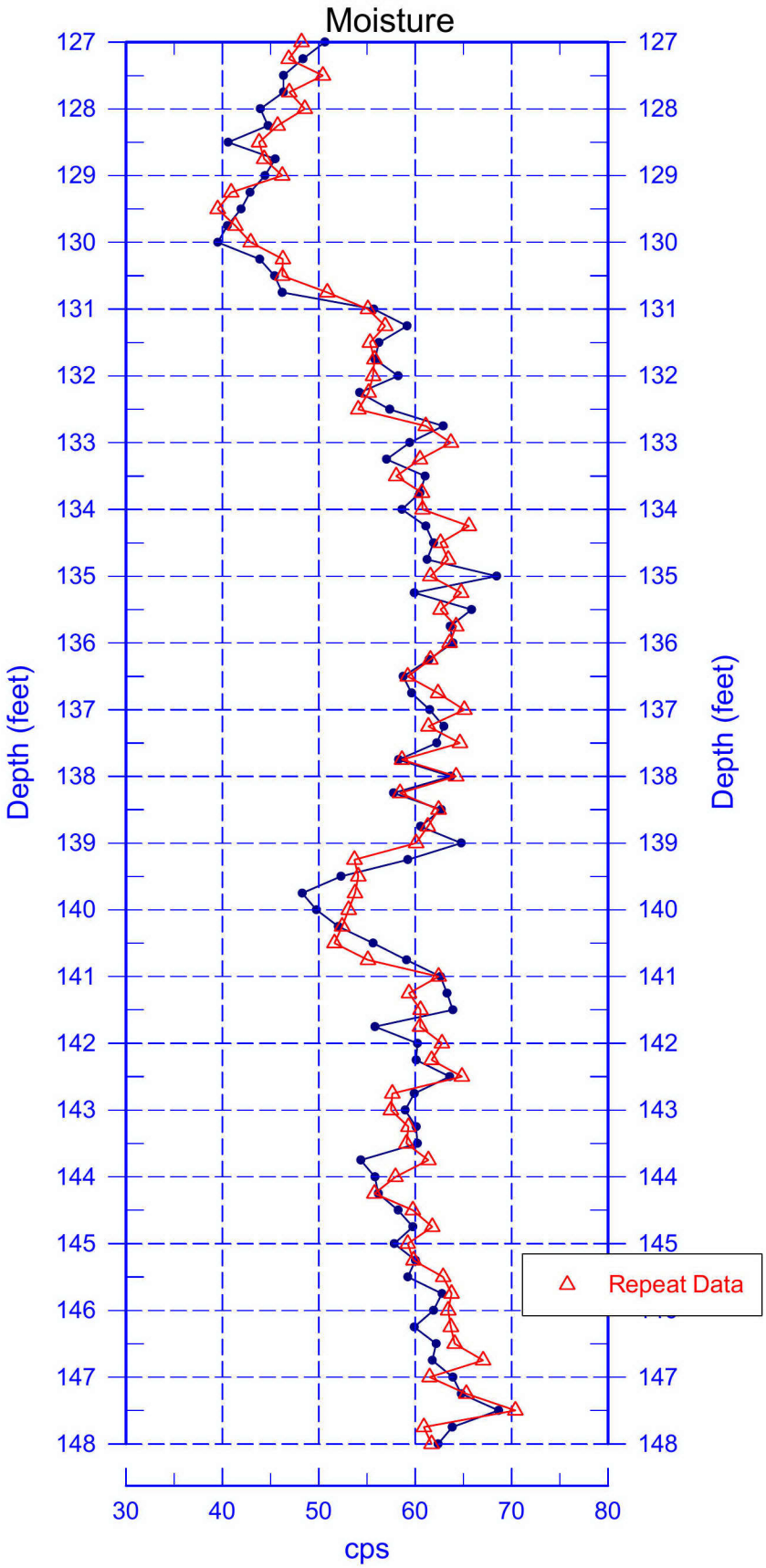
299-E27-25 (C7571)

Repeat Section of Natural Gamma Logs



Zero Reference - Ground Surface

299-E27-25 (C7571)
Moisture Repeat Section



Reference - Ground Surface

DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-RPT-43823, COMPLETION REPORT FOR LEAK DETECTION CHARACTERIZATION NEAR SINGLE-SHELL TANK 241-C-105

APPENDIX D

SMALL DIAMETER GEOPHYSICAL LOGGING FOR C TANK FARM LEAK ASSESSMENT OF TANK 241-C-105

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SMALL DIAMETER GEOPHYSICAL LOGGING FOR C TANK FARM LEAK ASSESMENT OF TANK 241-C-105

by

Russel Randall, PhD and Randall Price

to

EnergySolutions Federal Services, Inc.
2345 Stevens Drive
Richland, Washington 99354

November 2009

Pacific Northwest Geophysics
4200 West 19th Avenue
Kennewick, Washington 99338

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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TERMS

GM	Geiger Mueller
KUT	potassium, uranium and thorium
NaI	sodium-iodide
PNG	Pacific Northwest Geophysics

SMALL DIAMETER GEOPHYSICAL LOGGING FOR C TANK FARM LEAK ASSESMENT OF TANK 241-C-105

1.0 PROBEHOLE SURVEYS

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in a probehole installed near the cascade overflow pipe line of single-shell tank 241-C-105, in C Tank Farm.

Logging surveys were conducted with the sodium-iodide (NaI) scintillation gross gamma detector and the moderate sensitivity Geiger Mueller (GM) gross gamma detector. The logs were collected according to approved procedures (PNG 2009). Detector calibration certificates for the NaI and Green-GM detectors are presented in Section 2.0, "Gamma Detector Calibrations."

Nonstandard logging conditions were provided because radioactive contamination was encountered inside the probehole. The survey was acquired (as requested) from the top of the probehole (ground surface) down to the bottom. Logging was halted before the probe touched the bottom of the casing, which was at 11 m (36 ft). The probehole was surveyed twice. The first survey was conducted with the Green GM detector positioned above the NaI detector. The second survey was conducted with the Green GM detector positioned at the bottom of the tool string, so that the gamma activity at the bottom of the probehole could be measured.

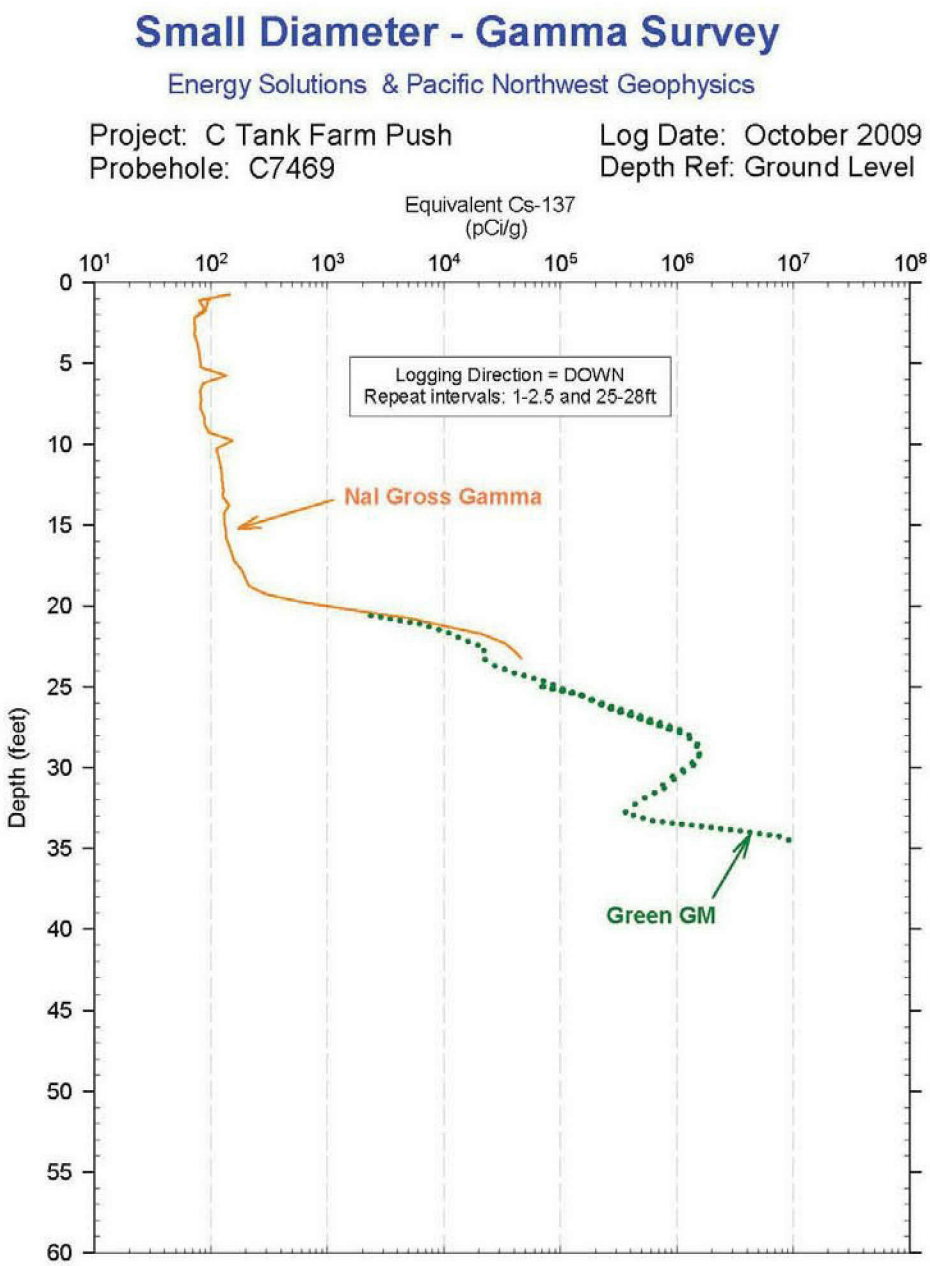
Due to concerns about contamination control, the log repeat measurement could only be acquired at the beginning of the survey. The computed results of the main and repeat intervals were reviewed and the results agree within the uncertainty of the measurement counting statistics. The repeat log data are presented with the main log plot.

The gross gamma survey data were deadtime corrected and the results were converted to the eCs-137 calibration units. Zero depth reference is at the ground surface. The survey results for the probehole are presented as a depth-versus-concentration plot.

The survey results for the NaI detector are shown as an orange solid line (_____) and the results for the Green GM detector are shown as a green dotted line (.....). The plot scale for eCs-137 is logarithmic from 10 to 100,000,000 pCi/g (i.e., 10^1 to 10^8 or seven orders of magnitude).

The radiation levels within subsurface exceeded the NaI detection range of 68,000 pCi/g (eCs-137) at 7.16 m (23.5 ft) below ground surface. The radiation levels in the probehole continued to increase toward the bottom of the probehole, and activity exceeded the Green GM detection range of 43,000,000 pCi/g of eCs-137 at 10.7 m (35 ft) below ground surface. The deadtime limit for measuring gamma radiation activity is 80% for both the NaI and Green GM detectors.

The log survey results for probehole C7469 are shown in the following plot.


Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: C Tank Farm Push
Probehole: C7469
Log Date: October 2009
Depth Ref: Ground Level
Equivalent Cs-137
(pCi/g)
Depth (feet)
Logging Direction = DOWN
Repeat intervals: 1-2.5 and 25-28ft
NaI Gross Gamma
Green GM

2.0 GAMMA DETECTOR CALIBRATIONS

The gross gamma detectors were calibrated for both eRa-226 and eCs-137. In the geophysical logging industry, eRa-226 is a measurement standard used in gross gamma detectors to establish the activity levels of the naturally occurring radionuclides (potassium, uranium and thorium [KUT]). The calibration for eCs-137 assumes that all of the gammas are due to the presence of Cs-137. The gamma activity encountered in this probehole exceeded the levels of the naturally occurring radionuclides; consequently, the plot shows only eCs-137.

The calibration for the NaI detector is discussed first, followed by the Green GM calibration.

The gross gamma scintillation detector uses a NaI crystal. The NaI crystal (2.54 cm [1 in.] long) is hydroscopic and is enclosed in a hermetically sealed can (2.54 cm [1 in.] diameter) to maintain its integrity.

The NaI gamma surveys were logged at 0.30 m (2 ft) per minute. A spectrum of 256 channels was collected each 0.15 m (0.5 ft) from the top of the probehole to the bottom. Detector count rates were deadtime corrected and the gamma survey data was processed as gross gamma response to determine the concentration of eRa-226 in pCi/g.

The deadtime correction is a nonparalysable relationship (Knoll 1979) and is described by the following equation:

$$C_t = \frac{C_{obs}}{1 - \varepsilon \cdot C_{obs}}$$

where C_t is the true or deadtime corrected count rate in c/s, C_{obs} is the observed count rate in c/s, and ε is the deadtime factor of 8.92 μs. The deadtime factor was determined when the detector was calibrated for eCs-137 in the Hanford vadose well 299-W10-72.

The NaI gross gamma detector was also calibrated for eCs-137 (pCi/g). Calibration for eCs-137 was performed in Hanford vadose well 299-W10-72 (Cs-137 calibration standard). The Cs-137 in the well is stable, except for the 30 year half-life decay of the radioisotope. Also, distribution of Cs-137 ranges from less than 1 pCi/g to 40,000 pCi/g along the well path (depth). The concentrations of Cs-137 were established by two high-purity germanium detectors (70% and high rate tools, operated by Stoller Corporation). Casing in the well is 0.732 cm (0.288 in.) thick. In order to duplicate the 0.97 cm (0.38-in.) casing of the small diameter probeholes, a section of steel tubing 0.241 cm (0.095 in.) thick was installed over the detector for calibration. The conversion factor from detector count rate (counts per second) to eCs-137 is 0.384 pCi/g per counts per second for casing thickness of 0.97 cm (0.38 in.) See Figure 1 for the NaI calibration certificate.

The Green GM detector has lower sensitivity than the NaI detector and is designed to measure high gamma ray flux. The Green GM detector count rates were deadtime corrected (as described above for the NaI detector).and the gamma survey data was processed to determine the concentration of eCs-137 in pCi/g. The deadtime factor for the Green GM detector is 160 μs. The Green GM calibration certificate is shown in Figure 2.

Figure 1. NaI Calibration Certificate.

Certificate of Calibration

SD.NaI.1

March 17, 2009

Data were taken at the Hanford KUT models on March 17, 2009. SD.NaI.1 is the designated Scintillator tool. Two models were used for the gross gamma calibration (SBU and SBL). Ten spectra were recorded for each model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation. Refer to the files compressed: StatisticsNaI.xls for this analysis.

The instrument was covered with 0.97 cm (0.38-in.) wall-thickness probe tubing.

The coefficient analysis is determined by the algorithm described in WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, Rev. 0 (Randall and Stromswold 1995). The gross gamma calibration for equivalent Ra-226 in pCi/g is a regression function and is generally defined by:

$$Ra = a*GR + b$$

where Ra is the eRa-226 in pCi/g, and GR is the observed gross gamma count rate (c/s), deadtime corrected. The coefficients of a & b are the fit coefficients. A more physical relationship constrains the intercept (b) to a zero value. This computation yields improved response extrapolated to low concentrations of K, U, and Th (clean zones). The coefficients were determined to be:

$$a = .1078 \quad Eq.^{226}Ra\ pCi/g\ /\ (c/s)$$
$$b \equiv 0$$

The calibration for eCs-137 in pCi/g for the SD.NaI.1 instrument is described in RPP-RPT-27605, *Gamma Surveys of Single Shell Tank Laterals for A and SX Tank Farm* (Randall and Price 2006). The gross gamma calibration for equivalent Cs-137 in pCi/g is a regression function and is generally defined by:

$$Cs = \alpha*GR$$

where Cs is the eCs-137 in pCi/g, and GR is the observed gross gamma count rate (c/s), deadtime corrected. The coefficient α is the fit coefficient.

There is a ratio of eRa-226 calibration coefficient to the eCs-137 calibration coefficient for each instrument. The ratio between the two coefficients in Randall and Price 2006 is 2.27. Thus a factor of 2.27 times the eRa-226 calibration will yield the eCs-137 calibration coefficient. Thus: α=0.245 eCs-137 (pCi/g)/(c/s)

Digital files condensed as Cal_SDGR-NaI_2009-v0.zip. This compressed file contains:

- Calibration raw data
- Spreadsheet data formatting

The undersigned certifies that the data archived in Cal_SDGR-NaI_2009-v0.zip were collected and evaluated in accordance with WHC-SD-EN-TI-293 (Randall and Stromswold 1995) and that the above-stated calibration coefficients are correct and applicable for the tool SD.NaI.1 effective March 21, 2009.

Signature:	Date:
/s/ Russel Randall, PhD	March 25, 2009
Three Rivers Scientific	

Figure 2. Green GM Calibration Certificate.

Certificate of Calibration
SD.Green.GM
March 17, 2009

Data were taken at the Hanford KUT models on March 17, 2009. SD.Green.GM is the designated Green GM tool. One model was used for the gross gamma calibration (SBH). Ten spectra were recorded in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation, refer to the files compressed: "StatisticsGGM.xls" for this analysis.

The instrument was covered with 0.38 inch wall-thickness probe-tubing.

The coefficient analysis is determined by the algorithm described in WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, Rev. 0 (Randall and Stromswold 1995). The gross gamma calibration for equivalent Ra-226 in pCi/g is a regression function and is generally defined by:

$$Ra = a*GR + b$$

where Ra is the eRa-226 in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficients of a & b are the fit coefficients. A more physical relationship constrains the intercept (b) to a zero value. This computation yields improved response extrapolated to low concentrations of K, U, and Th (clean zones). The coefficients were determined to be:

$$a = 363.9 \quad Eq.^{226}Ra\ pCi/g\ /\ (c/s)$$
$$b \equiv 0$$

The calibration for eCs-137 in pCi/g for the SD.Green.GM instrument is described in RPP-RPT-27605, *Gamma Surveys of Single Shell Tank Laterals for A and SX Tank Farm* (Randall and Price 2006). The gross gamma calibration for equivalent Cs-137 in pCi/g is a regression function and is generally defined by:

$$Cs = \alpha*GR$$

where Cs is the eCs-137 in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficient α is the fit coefficient.

There is a ratio of eRa-226 calibration coefficient to the eCs-137 calibration coefficient for each instrument. The ratio between the two coefficients is 4.81 (*Small Diameter Geophysical Logging In the 241-U Tank Farm,* Randall and Price 2008). Thus a factor of 4.81 times the eRa-226 calibration will yield the eCs-137 calibration coefficient and α=1746 eCs-137 (pCi/g)/(c/s)

Digital files condensed as Cal_SDGR-GrGM_2009-v0.zip. This compressed file contains:

- Calibration raw data
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_SDGR-GrGM_2009-v0.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-293 (Randall and Stromswold 1995), and that the above-stated calibration coefficients are correct and applicable for the tool SD.Green.GM effective March 17, 2009.

Signature:	Date:
/s/ Russel Randall, PhD	March 25, 2009
Three Rivers Scientific	

3.0 REFERENCES

Knoll, G., 1979, *Radiation Detection and Measurement*, John Wiley & Sons, Inc., New York, New York.

PNG, 2009, *Procedures: Calibration, Logging, Quality Assurance and Data Management*, Pacific Northwest Geophysics, Kennewick, Washington.

Randall, R. and D. Stromswold, 1995, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, WHC-SD-EN-TI-293, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Randall, R. and R. Price, 2006, *Gamma Surveys of Single-Shell Tank Laterals for A and SX Tank Farm,* RPP-RPT-27605, Rev. 0, Pacific Northwest Geophysics, Kennewick, Washington.

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DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-38927, COMPLETION REPORT FOR THE 241-CR-151 VAULT (UPR-200-E-81)

RPP-38406
Revision 0

Small Diameter Geophysical Logging for UPR-200-E-81

R. Randall
Three Rivers Scientific

R. Price
Pacific Northwest Geophysics

Date Published
July 2008

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

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-99RL14047

CH2MHILL
Hanford Group, Inc.
P.O. Box 1500
Richland, Washington

Release Approval _____ Date _____

RPP-38406
Revision 0

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RPP-38406, Rev. 0

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TERMS

Bgs	Below ground surface
DOE	U.S. Department of Energy
Energy*Solutions*	Energy*Solutions* Federal Services, Inc., Northwest Operations
PNG	Pacific Northwest Geophysics
VF	Volume Fraction

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RPP-38406, Rev. 0

SMALL DIAMETER GEOPHYSICAL LOGGING FOR UPR-200-E-81

1.0 INTRODUCTION

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter (slim-hole) logging at the unplanned release (UPR-200-E-81) near the 241-CR-151 Diversion Box. This logging was intended to aid in defining the extent of subsurface contamination resulting from apparent pipe failure, which caused the unplanned release. Logging surveys were conducted in five probeholes with a sodium-iodide (NaI) scintillation gross gamma detector and a neutron-neutron moisture probe. The surveys identified zones of interest for sample collection and laboratory analysis. A gyroscope survey was acquired in two deep probeholes: C6393 and C6399. This report includes the survey results for each of the probeholes, as well as the results of the gyroscope surveys (see Appendix A).

The NaI gross gamma detector was calibrated for the probehole conditions present at the investigation site. The calibration unit of equivalent radium-226 (Ra-226) (eRa-226 pCi/g) is used for background levels of the natural radionuclides. The calibration unit of equivalent cesium-137 (Cs-137) (eCs-137 pCi/g) is used for zones of elevated gamma activity (see Section 2.1).

The objective of the gamma survey logs was to identify depth intervals with elevated gamma activity (i.e., eCs-137 at concentrations greater than 10 pCi/g). Rapid scan gamma surveys (1.23 m/min [4 ft/min]) have a minimum detection threshold of 8 pCi/g for Cs-137.

Elevated gamma activity was detected in three of the project's probeholes: C6391, C6393, and C6395. The highest gamma activity was encountered in probehole C6393 with the maximum eCs-137 concentration of 45,000 pCi/g occurring at 1 m (3 ft) below ground surface (bgs). This contamination zone extended from 1 m to 13.4 m (3.3 ft to 44 ft) bgs.

Neutron-neutron moisture logs were also collected in the five probeholes. The moisture content in the five probeholes ranged from about 5 to over 20 percent volume fraction (% vf) moisture. This was determined using the neutron moisture detector that measures the distribution of hydrogen (moisture) in subsurface soils. Calibration of this detector is discussed in Section 2.2.

The gyroscope surveys were acquired to assess the degree of deviation from vertical for the deep probeholes. Discussions of the gyro equipment, data processing, and survey results are presented in Section 3.0.

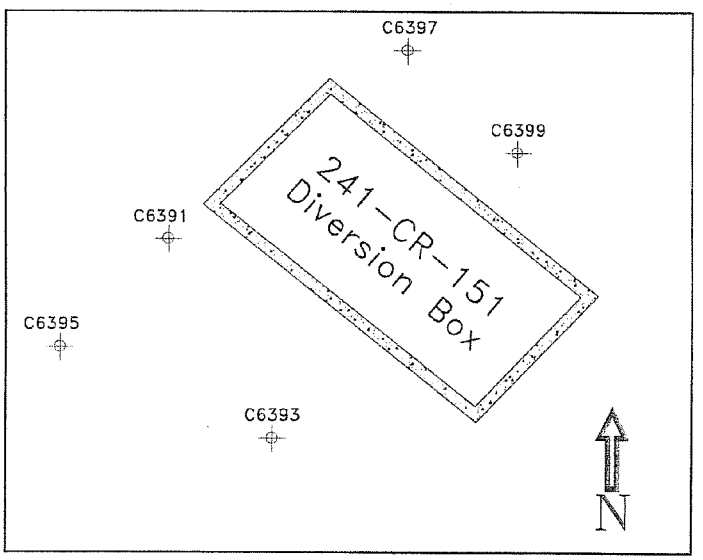
All calibrations, logging data acquisition, analysis and data management processes for this project were conducted in compliance with *Procedures: Calibration, Logging, Quality Assurance and Data Management* (PNG 2007) approved by Energy*Solutions* Federal Services, Inc., Northwest Operations (Energy*Solutions*).

2.0 GAMMA AND MOISTURE SURVEYS

The gamma and moisture logging surveys were recorded from the bottom of the probehole (maximum survey depth) to the ground surface. Zero depth reference is at the ground surface. A repeat measurement was acquired daily in at least one probehole to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed, and for all of the repeat intervals collected, the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probehole are presented as a depth-versus-concentration plot in Appendix A. The plots are in numeric order of the probeholes (C6391 – C6399). Appendix A also contains a table summarizing data for each probehole: detectors used, probehole depth, depth of maximum gamma activity, and maximum concentration of eCs-137 in pCi/g. Figure 1 shows a map view of the probehole locations.

Figure 1. Push Hole Locations at UPR-200-E-81 (241-CR-151 Diversion Box).



2.1 GROSS GAMMA CALIBRATION AND SURVEYS

The gross gamma scintillation detector uses a NaI crystal. The NaI crystal (2.54 cm [1 in.] long) is hydroscopic and is enclosed in a hermetically sealed can (2.54 cm [1-in.] diameter) to maintain its integrity. Other components of the gamma detector are the high-voltage supply, photo-multiplier tube, and the pre-amp and multi-channel analyzer. The settings of the detector components are fixed (i.e., set up during assembly, prior to calibration) and cannot be adjusted by the field logging engineer. The detector gain and lower threshold are set to record gamma ray activity with energies between 100 and 3000 keV. By comparison, the highest gamma ray from naturally occurring radionuclides is from thorium-232 (Th-232), and it occurs at 2614 keV. Coleman[1] lantern mantles containing Th-232 are used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (integrity) and energy calibration (amplifier gain).

The gross gamma calibration models located at the U.S. Department of Energy (DOE) Hanford Site near Richland, Washington, were used to perform the NaI detector calibrations. Calibration was performed in the (low-concentration) gross gamma calibration zone, identified as SBL. The calibration method incorporated the attenuation effect of the steel casing of the probeholes. A section of the steel drill tubing (1 m [3 ft] long and 0.97 cm [0.38 in.] thick) was installed over the detector during calibration measurements to acquire spectra that properly represent logging conditions and the varying gamma ray energy. The calibration data are summarized in Table 1. The calibration units are pCi/g of equivalent Ra-226 (eRa-226) (Steele and George 1986).

The NaI gross gamma detector was also calibrated for eCs-137 (pCi/g). The ratio between the calibration coefficients of eRa-226 and eCs-137 was identified previously (Randall and Price 2006) and was used to assign the eCs-137 conversion factor of 0.316 (pCi/g per cps) for casing thickness of 0.97 cm (0.38 in.). Figure 2 shows the calibration certificate.

Table 1. Gross Gamma Calibration Data.

Calibration Model	Concentration eRa-226 (pCi/g)	Gross Gamma Response[a] (cps)	Dead Time Corrected Gross Gamma Count-Rate[b] (cps)
SBA	61.2	416.5	417.9

[a]Count rates are mean of 10 sample measurements at 100 sec each, 0.38-in. casing, 4/19/2008.
[b]NaI detector system dead time is 8.92 microsecond.

The NaI gamma surveys were logged at 1.2 m/min (4 ft/min). A spectrum of 256 channels was collected each 0.15 m (0.5 ft) from the bottom of the probehole to the surface. The spectra were recorded in Ortec[2] PHA format with one spectrum per file (filename extension of "-.chn"). Detector count rates were dead time corrected and the gamma survey data was processed as gross gamma response to determine the concentration of eRa-226 in pCi/g.

[1]Coleman is a registered trademark of The Coleman Company, Inc., Wichita, Kansas.
[2]Ortec is a registered trademark of EG&G Ortec, Gouda, Netherlands.

The dead time correction is a nonparalysable relationship (Knoll 1979) and is described by the following equation:

$$C_t = \frac{C_{obs}}{1 - \varepsilon \cdot C_{obs}}$$

where C_t is the true or dead time-corrected count rate in c/s, C_{obs} is the observed count rate in c/s, and ε is the dead time factor of 8.92 μs. The dead time factor was determined when the detector was calibrated for eCs-137 in the Hanford vadose well 299-W10-72.

The calibration for eCs-137 was performed in Hanford vadose well 299-W10-72 (Cs-137 calibration standard). The Cs-137 in the well is stable, except for the 30-year half-life decay of the radioisotope. Also, distribution of Cs-137 ranges from less than 1 pCi/g to 40,000 pCi/g along the well path (depth). The concentrations of Cs-137 were established by two high-purity germanium detectors (70% and high rate tools, operated by Stoller Corporation). Casing in the well is 0.731 cm (0.288 in.) thick. In order to duplicate the 0.97 cm (0.38-in.) casing of the small diameter probeholes, a section of steel tubing 0.24 cm (0.095 in.) thick was installed over the detector for calibration.

2.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS

The neutron moisture sonde combines the PNG-owned thermal-neutron detector and a DOE-owned sealed neutron source (50 mCi AmBe). The DOE-owned neutron source was used because it was already on the Hanford Site and was managed by the DOE Radiation Management Program. The neutron source is an integral component of a neutron moisture detector that was manufactured by Campbell Pacific Nuclear, and is identified by the tool serial number H370608792.

The integrity of the sealed neutron source is always maintained when used in calibration and probehole logging activities. Source integrity is maintained by inserting the PNG-owned neutron detector module into the housing containing the sealed neutron source.

Calibration was performed in six borehole calibration models (Meisner and Randall 1995). Three of these models had a 15.24 cm (6-in.) hole size and three models had a 20.32 cm (8-in.) hole size. The moisture content was different for each borehole model within each set of three models (5, 12, and 20 percent by volume). The detector count rate in each of the six borehole calibration models is summarized in Table 2. The calibration certificate is shown in Figure 3.

Table 2. Moisture Calibration Data.

Moisture Content Percent – volume fraction	6 inch Models[a] (cps)	8 inch Models[a] (cps)
5% vf	105.20	82.78
12% vf	156.13	116.69
20% vf	196.27	141.46

[a]Count rates are mean of 10 sample measurements at 100 sec each, 11/7/2007.

The probehole size for this project was 6.35 cm (2.5 in.) outside diameter. Therefore, the moisture calibration was extrapolated to the correct hole size. Figure 4 shows the moisture calibration certificate for the 6.35 cm (2.5-in.) hole size.

The probehole moisture survey was collected at 0.61 m/min (2 ft/min) or slower. Processing of the survey data requires that the detector raw survey data be normalized to the thickness of the steel casing present in the calibration models (0.825 cm [0.325 in.]) Given that the probehole casing thickness is 0.97 cm (0.38 in.), a correction factor of 1.055 is required to increase (normalize) the observed neutron detector count rate to the conditions of the calibration model (Meisner et al. 1996).

3.0 GYROSCOPE BOREHOLE DEVIATION SURVEY

The gyroscope probe is designed to assay deviations in the path of both dipping and vertical boreholes. The gyroscope probe is 40 mm (1.575 in.) in diameter, 1.65 m (5.42 ft) long, and weighs 5.9 kg (13 lb). No centralizers are used in small diameter probeholes. Zero depth reference for the surveys is at ground level.

The gyroscope survey was recorded both as the sonde was lowered into the probehole (in-run) and as it was retrieved (out-run). Data from the sonde's sensors are recorded at the rate of two samples per second and the depth position of the sonde is recorded in feet. The logging probe speed is 9.1 m/min (30 ft/min) or less. At least four times each hour, during the survey, the hoist is momentarily halted to record the gyroscope drift rate at these stationary locations.

The gyroscope probe contains two high-precision components: an inclinometer and a gyroscope. The inclinometer records the probe tilt (dip) at the precision of 0.01 degree. The probe's orientation is determined by a very precise rate-gyro with a precision of 0.0001 degrees.

The path of the borehole is derived by post-processing of the raw survey data, which is performed as follows.

- Identify the gyroscope drift rate and remove the component from the survey data.
- Use X-Y data from the inclinometer to compute probe dip (vertical is -90 degrees).
- Compute path of borehole: Northing, Easting, elevation (vertical depth), and dip (tangent to borehole at each survey depth position).

The survey result is the probehole path, which is presented graphically with these components.

- 3-D trajectory plot of XYZ (Northing and Easting versus elevation).
- X and Y deviation plots (2D plots of Northing versus depth and Easting versus depth).
- Dip plot of tangential angle versus depth.
- Gyro Survey Information in text format:
  - Coordinates at survey Top,
  - Coordinates at survey Base,
  - Maximum deviation (dip) angle and depth location,
  - Measured depth and vertical depth at survey Base.

Figure 2. Gross Gamma Calibration Certificate (eRa-226 and eCs-137).

Certificate of Calibration
SD.GR.NaI.1
May 6, 2008

Data were taken at the Hanford KUT models on April 19, 2008, with the designated scintillator tool, SD.GR.NaI.1. The SBA model was used for the gross gamma calibration and at least ten spectra were recorded in the model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation; refer to the file "-Calibrations\NaI\2008\NaI-stats.xls" for this analysis.

The instrument was covered with 0.97 cm (0.38-in.) wall-thickness probe tubing.

The coefficient analysis is determined by the algorithm described in WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models* (Randall and Stromswold 1995). The gross gamma calibration for equivalent ^{226}Ra in pCi/g is a regression function and is generally defined by:

$$Ra = a*GR + b$$

Where Ra is the eRa-226 in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficients of a & b are the fit coefficients. A more physical relationship constrains the intercept (b) to a zero value. This computation yields improved response extrapolated to low concentrations of K, U, and Th (clean zones). The coefficients were determined to be:

$$a = .139 \text{ eRa-226 (pCi/g) / (c/s)}$$
$$b = 0$$

The calibration for eCs-137 for the SD.GR.NaI.1 instrument is described in RPP-RPT-27605, *Gamma Surveys of Single Shell Tank Laterals for A and SX Tank Farm* (Randall and Price 2006). The gross gamma calibration for equivalent ^{137}Cs in pCi/g is a regression function and is generally defined by:

$$Cs = \alpha*GR$$

Where Cs is the eCs-137 in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficient α is the fit coefficient.

There is a ratio of eRa-226 calibration coefficient to the eCs-137 calibration coefficient for each instrument. The resulting coefficient, a*Cs, was found to be .316 (Randall and Price 2006) for a ratio between the two coefficients of 2.27. Thus a factor of 2.27 times the eRa-226 calibration will yield the eCs-137 calibration coefficient. Thus: α=0.316 eCs-137 (pCi/g)/(c/s)

The digital files contain:

- Calibration raw data
- MathCad[a] data analysis files
- Spreadsheet data formatting

The undersigned certifies that the analysis files are archived in "SD-GR-NaI-1_2008.zip" and this file was evaluated in accordance with Randall and Price 2006 and that the above-stated calibration coefficients are correct and applicable for the SD.GR.NaI.1 tool, effective April 19, 2008.

Signature:

/s/ Russel Randall, PhD May 6, 2008
Three Rivers Scientific

[a]MathCAD is a registered trademark of Mathsoft Corporation, Cambridge, Massachusetts.

Figure 3. Moisture Calibration Certificate, 15.24 cm (6-in.) and 20.32 cm (8-in.) Hole.

Certificate of Calibration for
SD-Moist792 Instrument
November 7, 2007

Data were taken in the moisture models June 7, 2007, for the SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool #H370608792 was used with the passive neutron detector probe from PNG. This calibration is required for the small diameter logging, and funded by Energy*Solutions*, Master Ordering Agreement 017194.

Six models were used for moisture calibration, three for 15.24 cm (6-in.) casing and three for 20.32 cm (8-in.) casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation; for this analysis refer to the Stats-moist.xls file.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration* (Meisner et al. 1996). The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the dead time corrected observed total count rate, (c/s).

6-in. casing	**8-in. casing**
a = .0001748	**a = .00006272**
α = 2.203	**α = 2.555**

The undersigned certifies that the data archived in data file "SD-Moist792_2007.zip" were collected and evaluated in accordance with Meisner et al. 1996 and that the above-stated calibration coefficients are correct and applicable for the SD-Moist792 tool, effective November 7, 2007.

Signature:

/s/ Russel Randall, PhD — November 13, 2007
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

Moisture Calibration Extrapolation to 2.5-Inch Borehole
SD-Moist792 Instrument
November 7, 2007

Moisture calibration was performed in the Hanford physical models. These standards have 15.24 cm (6-in.) and 20.32 cm (8-in.) inside diameter casings. The Tank Farm Direct Push borehole is cased with a 6.35 cm (2.5 in.) outside diameter iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the dead time-corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 6.38 cm (2.51 in.) borehole diameter.

2.51-in. borehole
a = .0003057
α = 1.938

The undersigned certifies that the analysis files are archived in the "SD-Moist792_2007.zip" file that was evaluated in accordance with Energy*Solutions* procedures and that the above-stated calibration coefficients are correct and apply to the SD-Moist792 tool, effective November 7, 2007.

Signature:

/s/ Russel Randall, PhD — November 13, 2007
Three Rivers Scientific

4.0 CONCLUSION

Scintillation Gross Gamma and Neutron Moisture survey logs were collected in five probeholes installed at the UPR-200-E-81 investigation site near the 241-CR-151 Diversion Box. Two probeholes (C6393 and C6399) were driven to the depth of 73.8 m (242 ft). These two probeholes were also logged with the gyroscope sonde to document their path. The remaining three probeholes were driven to approximately 47.2 m (155 ft) bgs.

The rapid-scan gamma surveys of the probeholes can be summarized as follows.

- Two of the five probeholes (C6397 and C6399) showed only background activity from the natural radionuclides. Gamma activity, above background levels, was encountered in three probeholes (C6391, C6393, and C6395) with the highest activity occurring at shallow depths. The maximum depth of the gamma-emitting contamination was encountered in probehole C6393 at 13.4 m (44 ft) bgs. C6393 also contained the highest gamma activity. The maximum depth of gamma-emitting contamination was less than 3.6 m (12 ft) in the other two probeholes (C6391 and C6395).
- The maximum gamma activity encountered was 45,000 pCi/g of eCs-137 at 0.9 m (3 ft) bgs in probehole C6393.

The neutron moisture surveys for all probeholes had unique profiles when each log was examined in detail. However, a generalized review of the profiles of all probeholes reveals the following similarities (discussed below and shown in Table 3).

- All five of the probeholes have a clearly recognizable moisture peak at approximately 41 m (135 ft) bgs. See Column B in Table 3. This feature is accompanied by baseline character changes above and below the feature. The baseline (average moisture content) below the feature has fewer deflections and maintains moisture at approximately 5% vf; whereas, the baseline above the feature has a higher number of excursions (increases and decreases) in moisture content. This change in response character of the moisture log above and below along with a sharp identifiable and correlatable peak indicates a change in formation materials (e.g., more homogenous sediments below the feature as opposed to higher moisture content in a number of zones above). These changes in log character may indicate a dispositional or facies type change in the Hanford sediments encountered in this area.
- At the top of each probehole, a high-moisture zone is present that extends from the surface down to depths of 7.62 to 13.72 m (25 to 45 ft). The moisture content in this upper zone varies and is characteristic of stratigraphy-controlled conditions. The maximum depth of this upper moisture zone is shown in column C of Table 3.
- An intermediate zone of high-moisture content that varies between 16.15 and 20.42 m (53 and 67 ft) is shown in column D of Table 3.
- Probehole C6399 has a thin zone with high moisture content near the bottom of the hole at 72.16 m (236.75 ft). There is no corresponding high-moisture zone at the bottom of the other deep probehole (C6393). A review of the log response indicated it is not likely that the large

peak is an artifact of moisture condensation inside the tubing. The high-moisture zone in probehole C6399 occurs 0.30 m (1 ft) above the bottom of the probehole (at 72.47 m [237.76 ft]). This type of log response is not characteristic of moisture accumulation in the bottom of tubing.

Table 3. Moisture Survey Summary.

Probehole	Column B Lower Moisture Zone (meters, feet)	Column C Upper Moisture Zone (meters, feet)	Column D Intermediate Moisture Zone (meters, feet)
C6391	40.9 m, 134 ft	7.9 m, 26 ft	17.4 m, 57 ft
C6393	41.2 m, 135 ft	13.7 m, 45 ft	18.0 m, 59 ft
C6395	40.9 m, 134 ft	7.6 m, 25 ft	16.2 m, 53 ft
C6397	41.5 m, 136 ft	8.5 m, 28 ft	19.8 m, 65 ft
C6399	41.5 m, 136 ft	10.7 m, 35 ft	20.4 m, 67 ft

The gyroscope deviation surveys for probeholes C6393 and C6399 are shown in Appendix A. The plot shows both the in-run and out-run survey results that are summarized in Tables 4 and 5. The Closure Distance column shows the distance from the probehole Northing and Easting positions to the vertical position. The deviation (dip) is measured from vertical (0 degrees). The Depth column shows the distance measured down the probehole and the Elevation column shows the vertical depth computed from the gyro survey.

Table 4. Gyroscope Survey Results for C6393.

Depth (meters, feet)	Northing (feet)	Easting (feet)	Closure Distance (meters, feet)	Elevation (feet)	Dip (degrees)
0.0 m, 0 ft	0.00	0.00	0.00 m, 0.00 ft	0.0	0.24
15.24 m, 50 ft	-0.55	0.18	0.17 m, 0.6 ft	-50.0	1.00
30.49 m, 100 ft	-1.64	0.84	0.56 m, 1.8 ft	-99.9	1.90
45.73 m, 150 ft	-3.76	2.06	1.31 m, 4.3 ft	-149.8	3.64
60.98 m, 200 ft	-5.92	3.89	2.16 m, 7.1 ft	-199.8	3.12
72.04 m, 236.3 ft	-6.961	5.55	2.71m, 8.9 ft	-236.1	2.95

Table 5. Gyroscope Survey Results for C6399.

Depth (meters, feet)	Northing (feet)	Easting (feet)	Closure Distance (meters, feet)	Elevation (feet)	Dip (degrees)
0.0 m, 0 ft	0.00	0.00	0.00 m, 0.00 ft	0.0	0.60
15.24 m, 50 ft	-0.69	0.11	0.18 m, 0.6 ft	-50.0	1.59
30.49 m, 100 ft	-1.97	0.91	0.55 m, 1.8 ft	-100.0	1.84
45.73 m, 150 ft	-2.41	1.89	0.93 m, 3.1 ft	-150.0	1.55
60.98 m, 200 ft	-3.00	2.77	1.25 m, 4.1 ft	-200.0	0.78
71.74 m, 235.3 ft	-3.24	3.10	1.37m, 4.5 ft	-235.3	0.40

5.0 REFERENCES

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APPENDIX A
GAMMA AND MOISTURE SURVEY RESULTS

Survey plots follow for the five probeholes installed around the UPR-200-E-81 investigation site. Each probehole was surveyed with both the gross gamma and moisture sondes. The two deep probeholes, C6393 and C6399, were also surveyed with the gyroscope sonde. Also, the two deep probeholes, C6393 and C6399, are displayed twice: (1) at the standard depth scale of 47.2 m (155 ft) and (2) at the depth scale of 76.2 m (250 ft).

The gyro survey shows the borehole path in the following ways.

- 3-D trajectory plot of XYZ (Northing and Easting versus depth in meters). Also two projections are shown.
  - Blue dashed line from start location to ending location.
  - Gray solid line at surface as a rectangle that encompasses the starting location and projected ending location.
- X and Y deviation plots (2-D plots of Northing and Easting versus depth in meters).
- Dip plot of tangential angle (degrees) versus depth (meters).

The gross gamma survey data were dead time corrected and the results are converted to the two calibration units (i.e., eRa-226 and eCs-137). The results are plotted as either eRa-226 or eCs-137, depending on the gamma activity level.

- The Equivalent Ra-226 is used for low gamma ray activity, which is characteristic of Hanford sediments (brown solid line). The plot scale for eRa-226 is 0-25 pCi/g. The concentration of the natural radionuclides in the Hanford sediments is less than 5 pCi/g of eRa-226, and the low gamma activity zones are displayed as eRa-226 when the concentrations are less than 5 pCi/g. The higher gamma activity zones are displayed with the eCs-137 plot scale.
- Equivalent Cs-137 (orange dot-dashed line) is used for displaying gamma activity zones that have concentrations greater than the natural radionuclides (if present). The gamma activity is displayed as eCs-137 when high gamma activity zones are present and when the computed concentrations are greater than 4 pCi/g of eCs-137. The plot scale for eCs-137 is logarithmic from 1 to 100,000 (i.e., 10^0 to 10^5 or five orders of magnitude).

The neutron-neutron moisture survey data are shown with a blue dashed line. The moisture plot scale is 0-25 (% vf).

The plot legend is shown in Figure A1. The probehole survey summary is shown in Table A1.

Figure A1. Plot Legend.

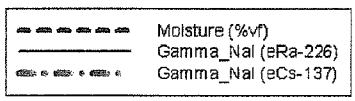


Table A1. Probehole Survey Summary.

Hole	Gross Gamma	Neutron Moisture	Hole Depth (meters, feet)	Depth Max Gamma Activity	Max eCs-137 (pCi/g)	Comment
C6391	**X**	**Moisture**	46.6 m, 153 ft	9 ft	500	
C6393	**X**	**Moisture**	72.2 m, 237 ft	3 ft	45,000	Deep Hole. Gyroscope Survey
C6395	**X**	**Moisture**	46.3 m, 152 ft	2 ft	45	
C6397	**X**	**Moisture**	46.6 m, 153 ft	Natural	Background	
C6399	**X**	**Moisture**	72.2 m, 237 ft	Natural	Background	Deep Hole. Gyroscope Survey

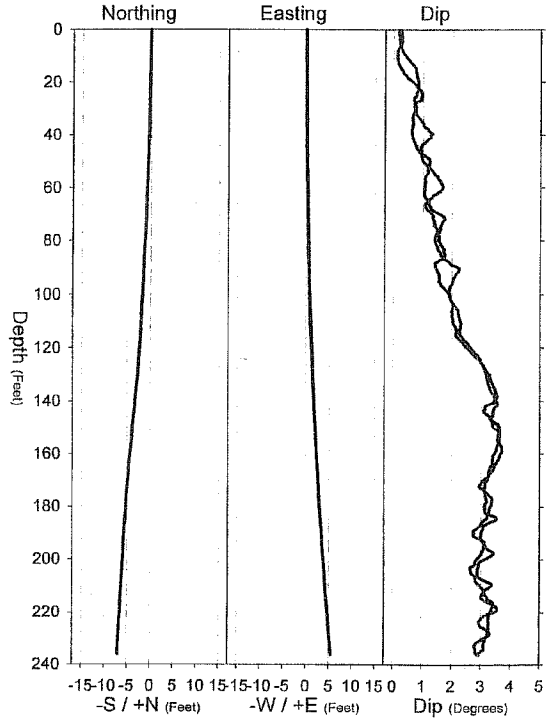
Gyroscope Hole Path Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

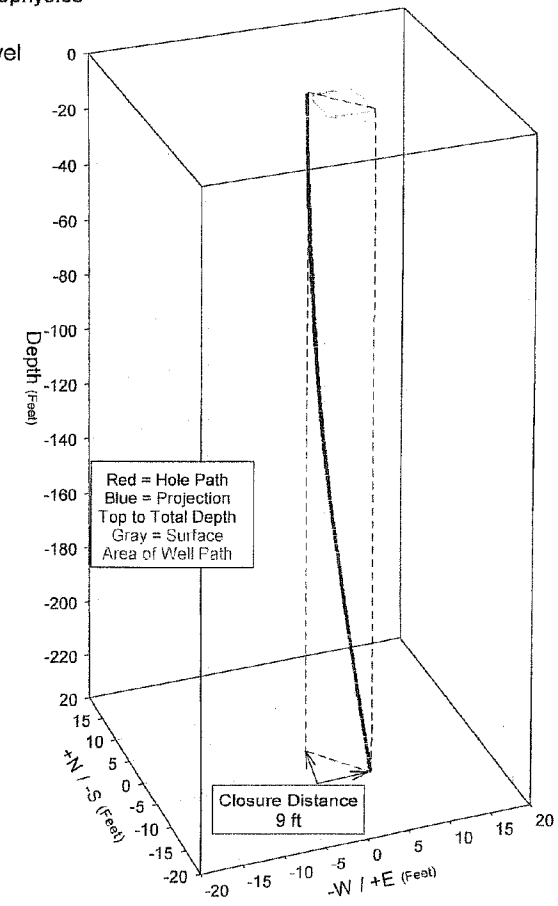
Project: UPR-200-E-81
Hole: C6393

Log Date: May 2008
Depth Ref: Ground Level

Top N0.0 E0.0 Depth 0.0
Base N-7 E5.5 Depth-236.1ft
Max Deviation: 3.6-Deg @ 159ft
Depth Meas.=236.35ft Vert.=236.13ft



3D Trajectory



RPP-RIP-83392, Rev. 0 DRAFT

E-5233

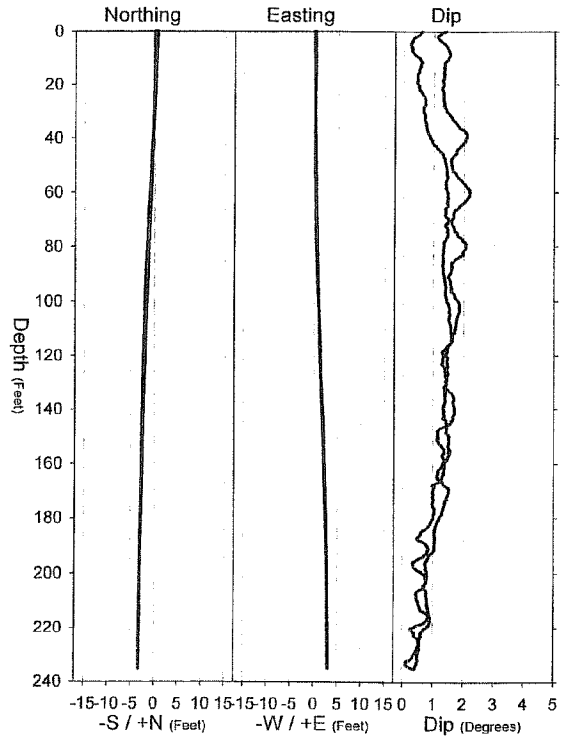
Gyroscope Hole Path Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

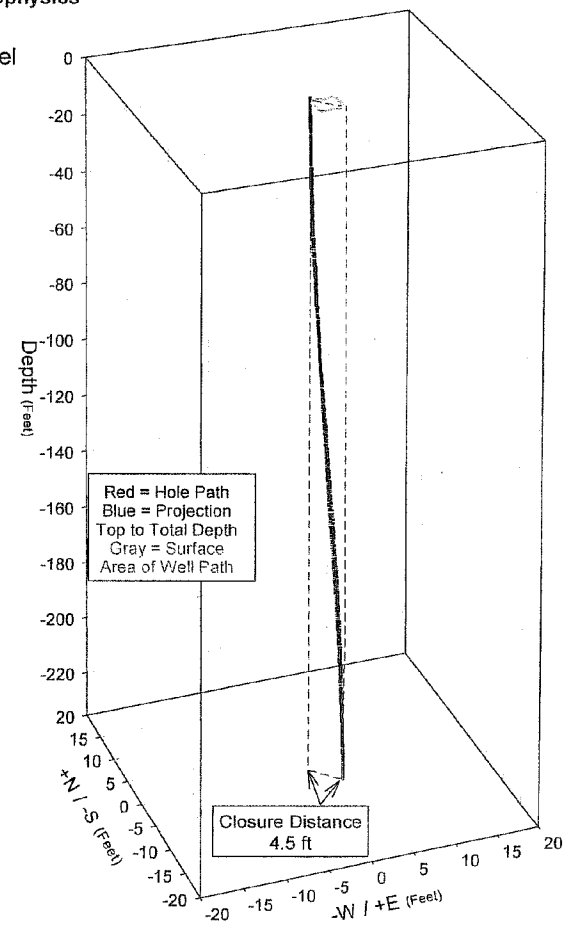
Project: UPR-200-E-81
Hole: C6399

Log Date: May 2008
Depth Ref: Ground Level

Top N0.0 E0.0 Depth 0.0
Base N-3.24 E3.10 Depth-235.29ft
Max Deviation: 2.2-Deg @ 60ft
Depth Meas.=235.34ft Vert.=235.29ft

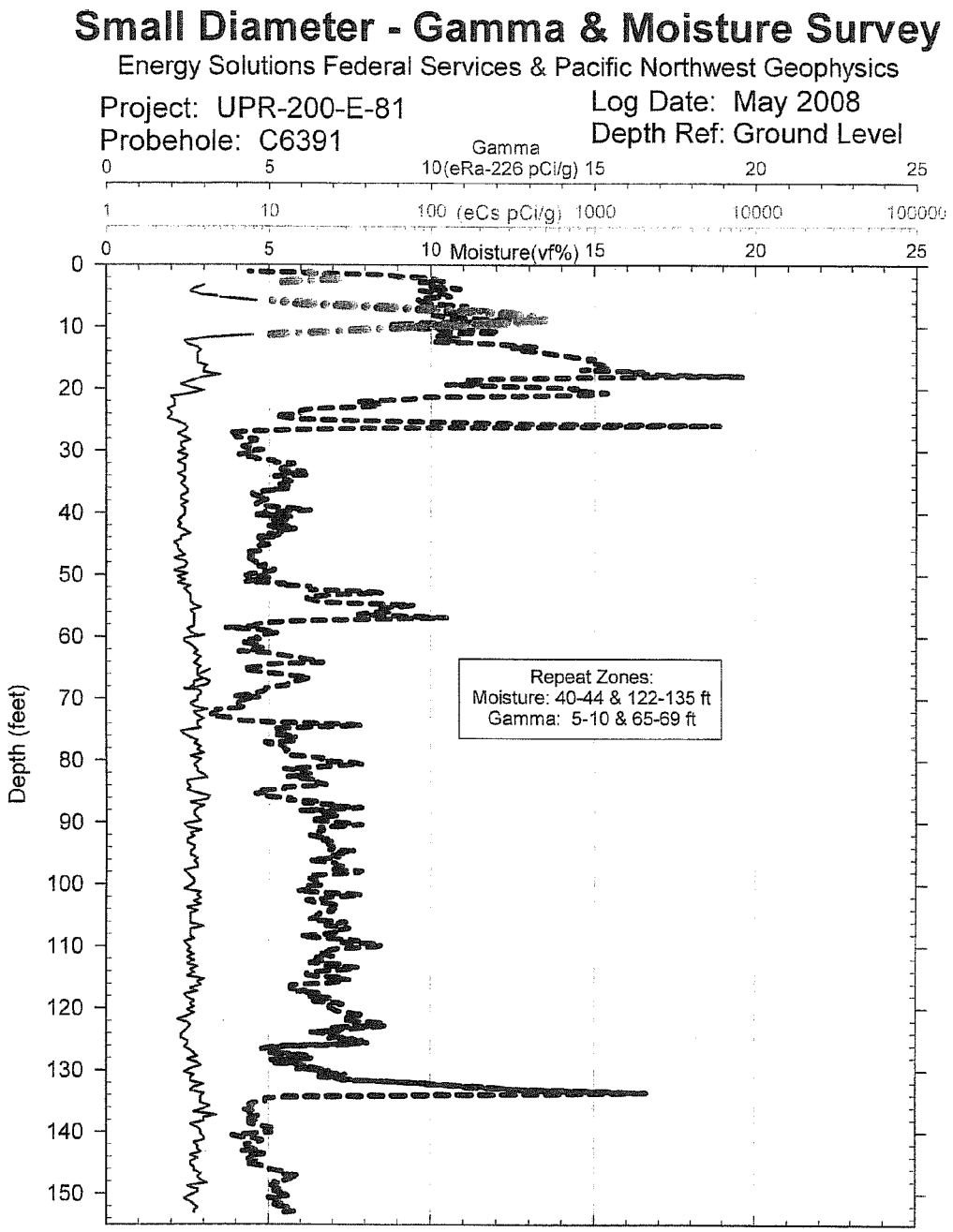


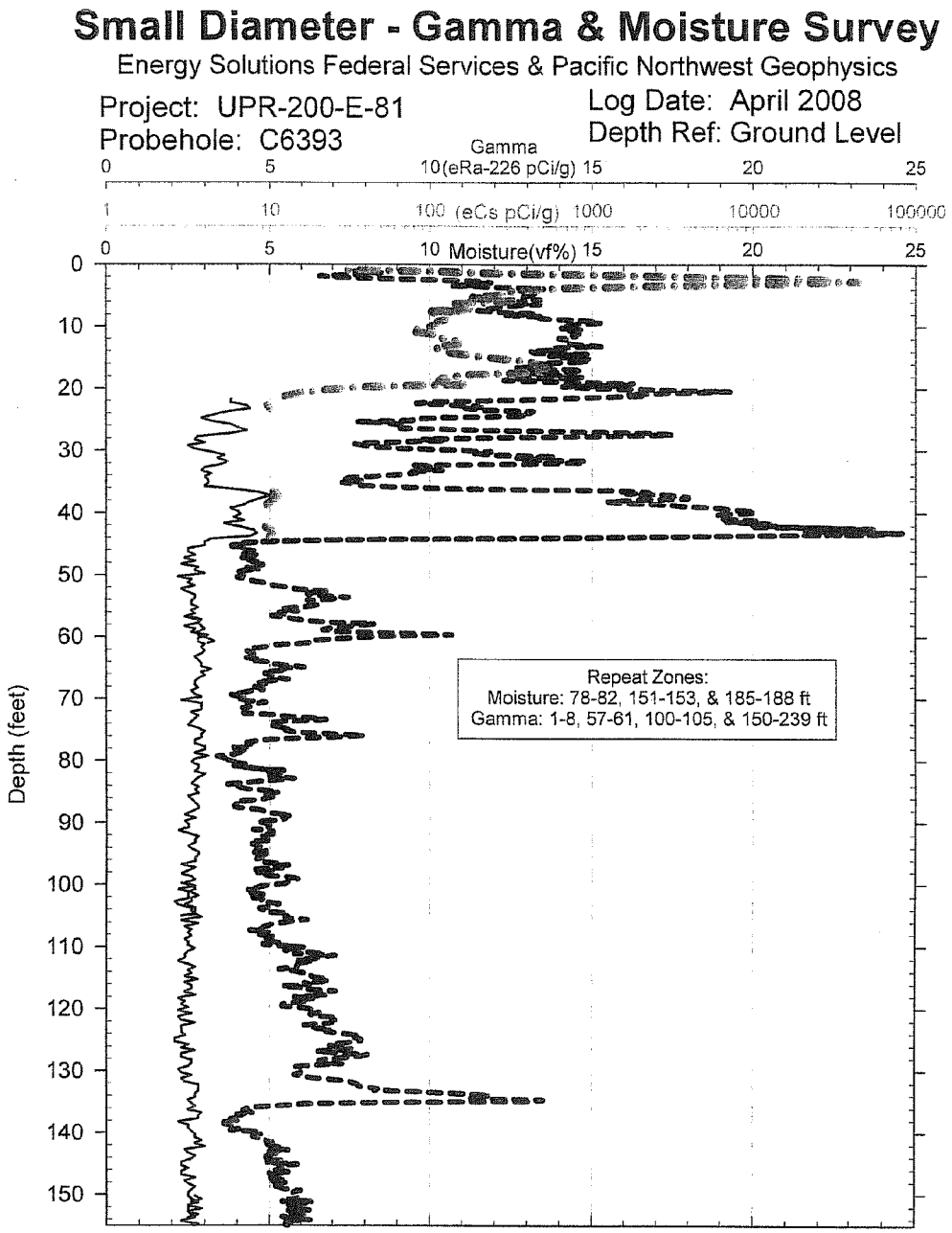
3D Trajectory

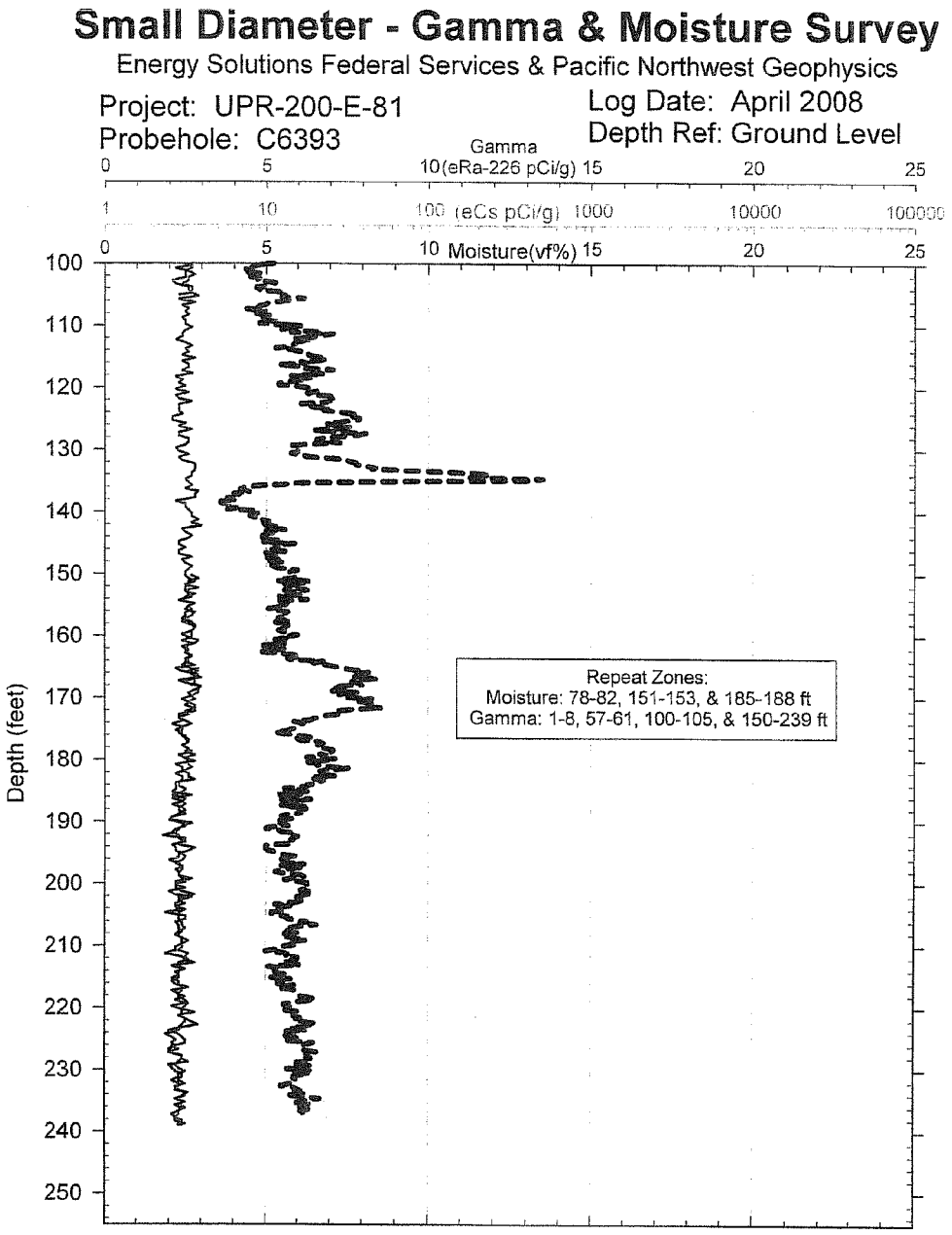


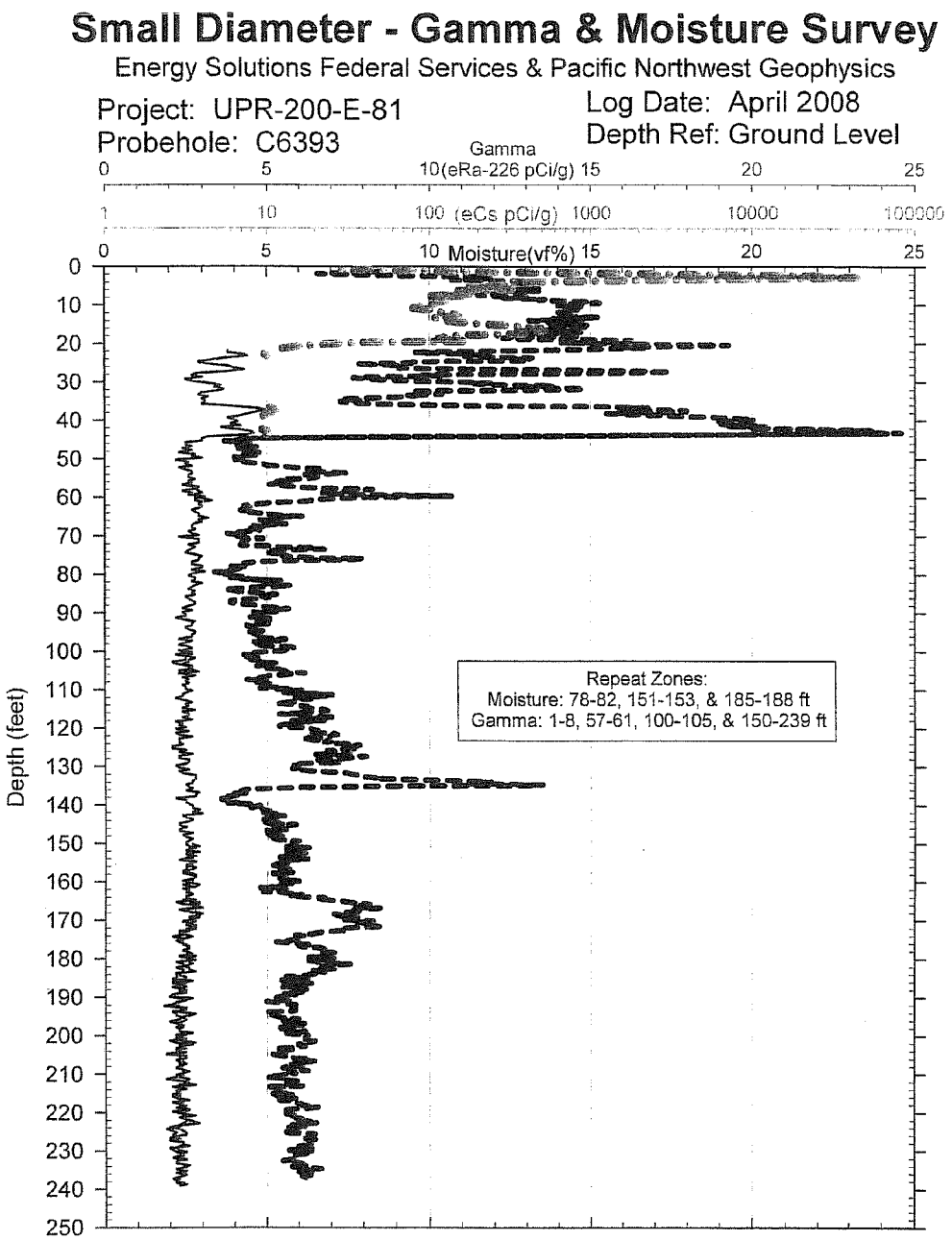
RPP-RPP-38406, Rev. 0 DRAFT

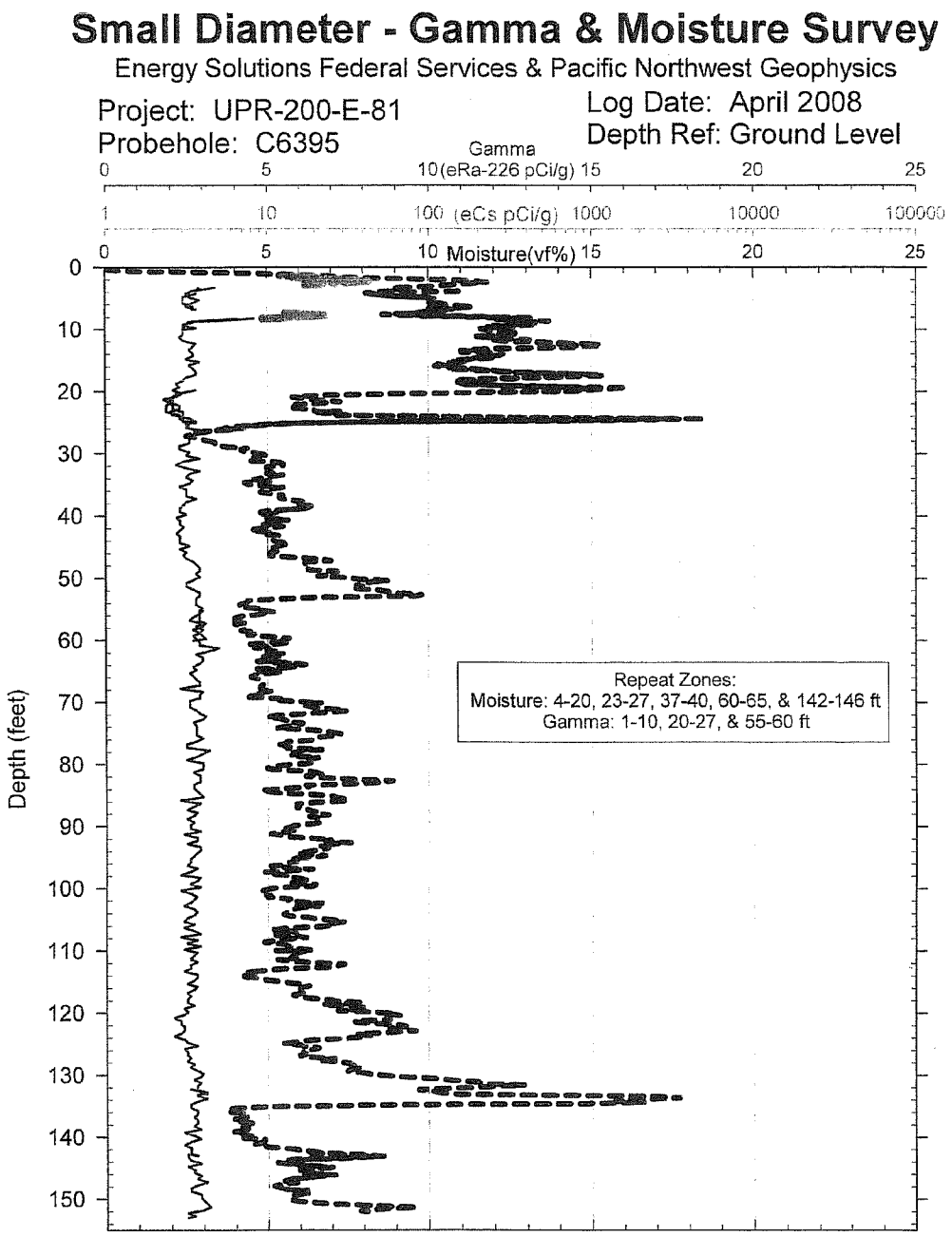
E-5324


Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6391
Log Date: May 2008
Depth Ref: Ground Level
Gamma
(eRa-226 pCi/g)
(eCs pCi/g)
Moisture(vf%)
Depth (feet)
Repeat Zones:
Moisture: 40-44 & 122-135 ft
Gamma: 5-10 & 65-69 ft


Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6393
Log Date: April 2008
Depth Ref: Ground Level
Gamma
(eRa-226 pCi/g)
(eCs pCi/g)
Moisture(vf%)
Depth (feet)
Repeat Zones:
Moisture: 78-82, 151-153, & 185-188 ft
Gamma: 1-8, 57-61, 100-105, & 150-239 ft


Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6393
Log Date: April 2008
Depth Ref: Ground Level
Gamma
10(eRa-226 pCi/g)
(eCs pCi/g)
Moisture(vf%)
Depth (feet)
Repeat Zones:
Moisture: 78-82, 151-153, & 185-188 ft
Gamma: 1-8, 57-61, 100-105, & 150-239 ft


Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6393
Log Date: April 2008
Depth Ref: Ground Level
Gamma
0 5 10(eRa-226 pCi/g) 15 20 25
1 10 100 (eCs pCi/g) 1000 10000 100000
0 5 10 Moisture(vf%) 15 20 25
Depth (feet)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
Repeat Zones:
Moisture: 78-82, 151-153, & 185-188 ft
Gamma: 1-8, 57-61, 100-105, & 150-239 ft

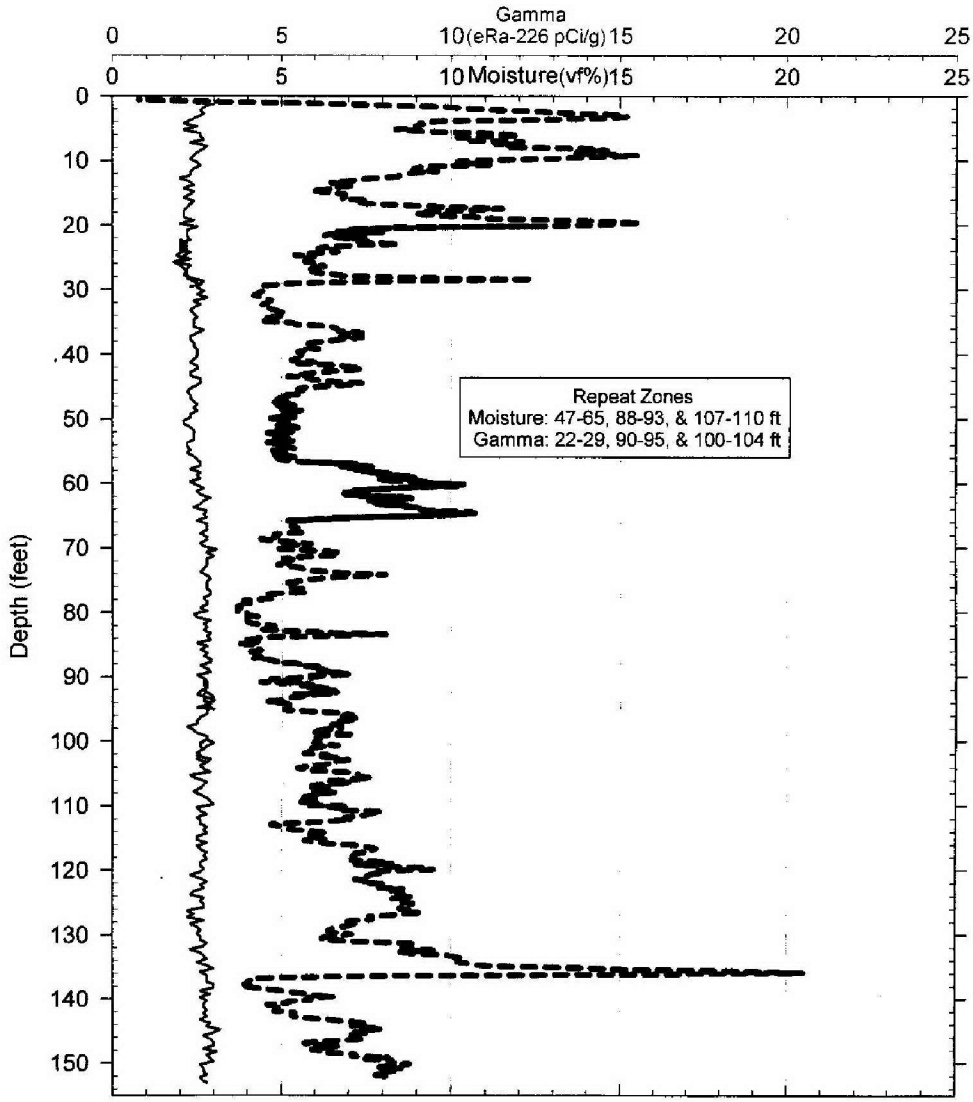

Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6395
Log Date: April 2008
Depth Ref: Ground Level
Gamma
(eRa-226 pCi/g)
(eCs pCi/g)
Moisture(vf%)
Depth (feet)
Repeat Zones:
Moisture: 4-20, 23-27, 37-40, 60-65, & 142-146 ft
Gamma: 1-10, 20-27, & 55-60 ft

Small Diameter - Gamma & Moisture Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

Project: UPR-200-E-81
Probehole: C6397

Log Date: May 2008
Depth Ref: Ground Level

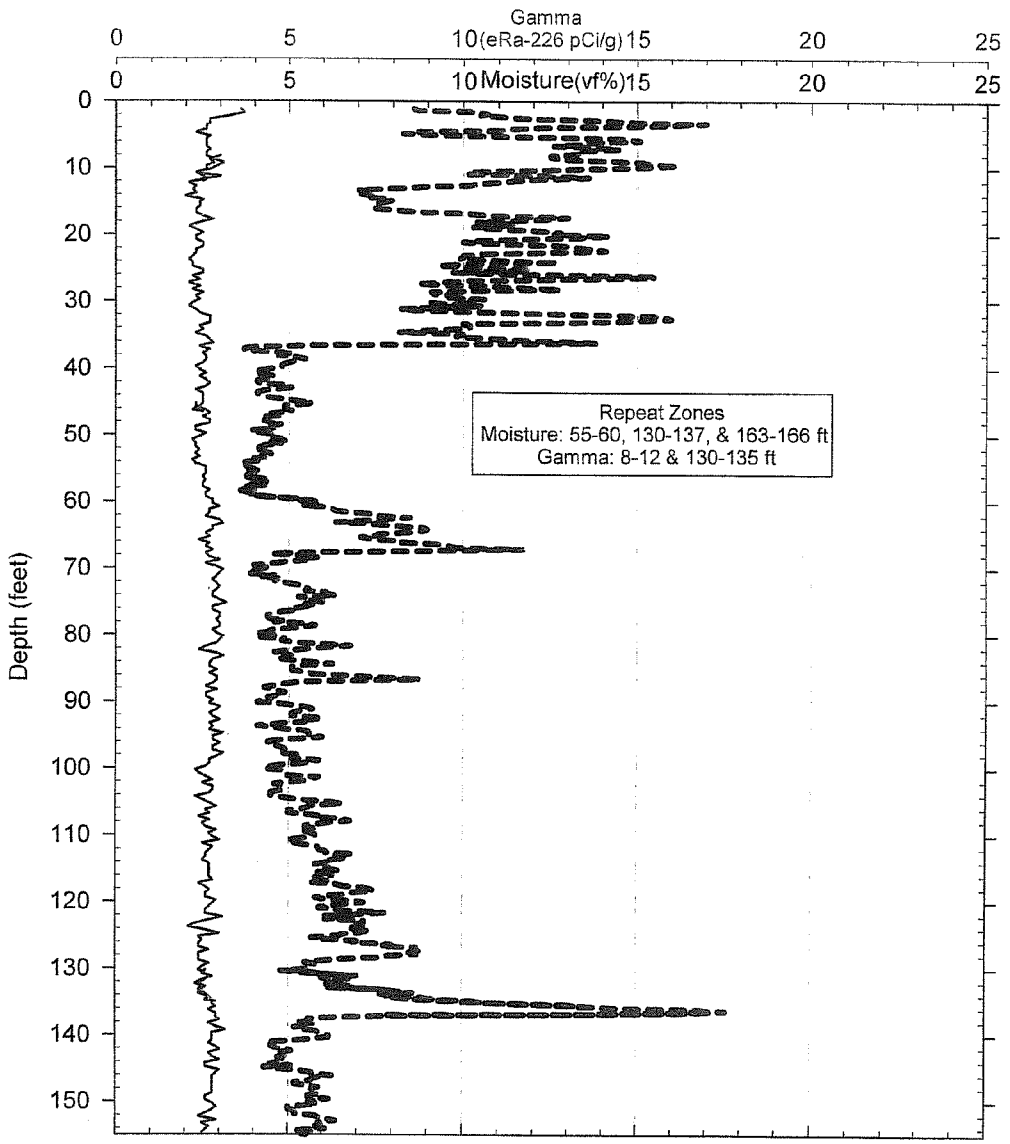


Small Diameter - Gamma & Moisture Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

Project: UPR-200-E-81
Probehole: C6399

Log Date: May 2008
Depth Ref: Ground Level

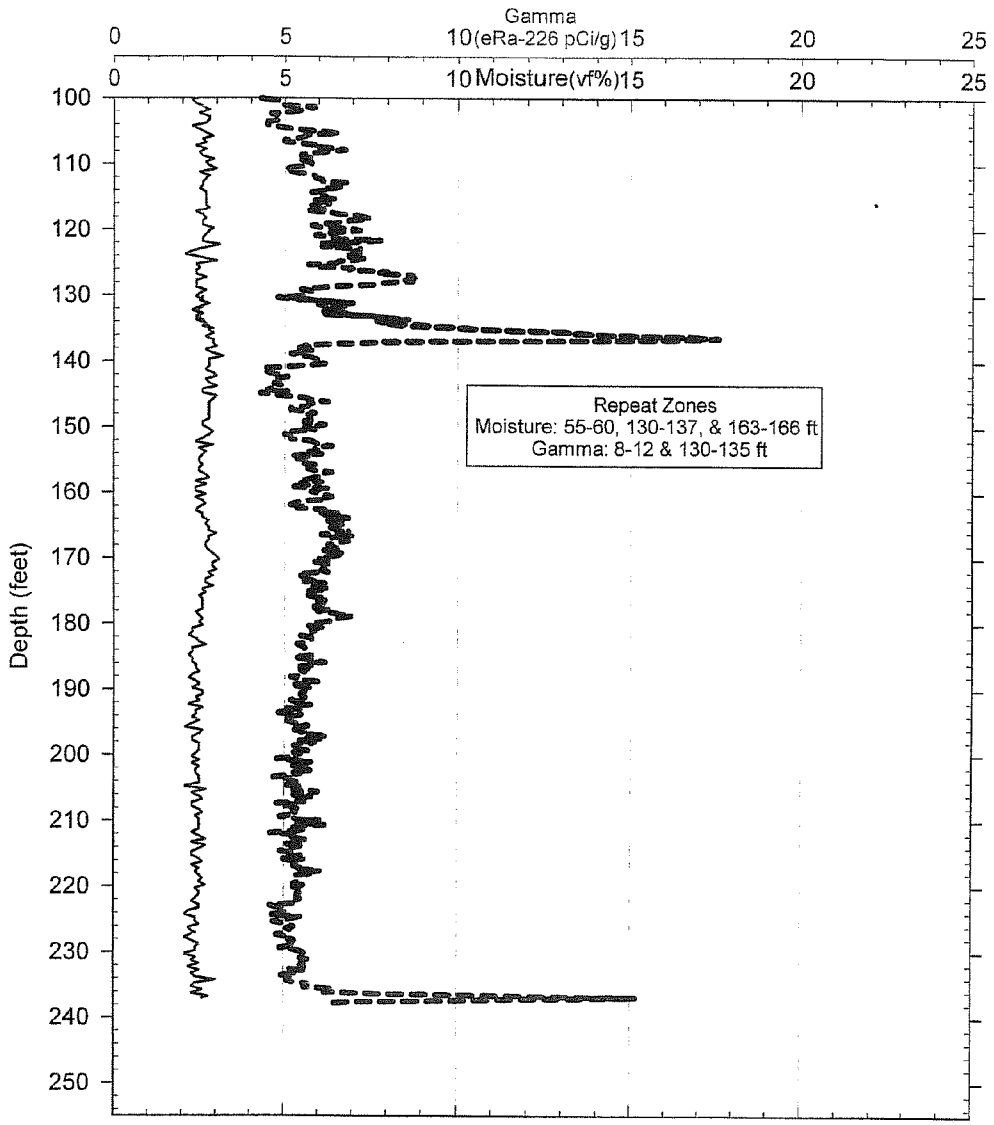


Small Diameter - Gamma & Moisture Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

Project: UPR-200-E-81
Probehole: C6399

Log Date: May 2008
Depth Ref: Ground Level

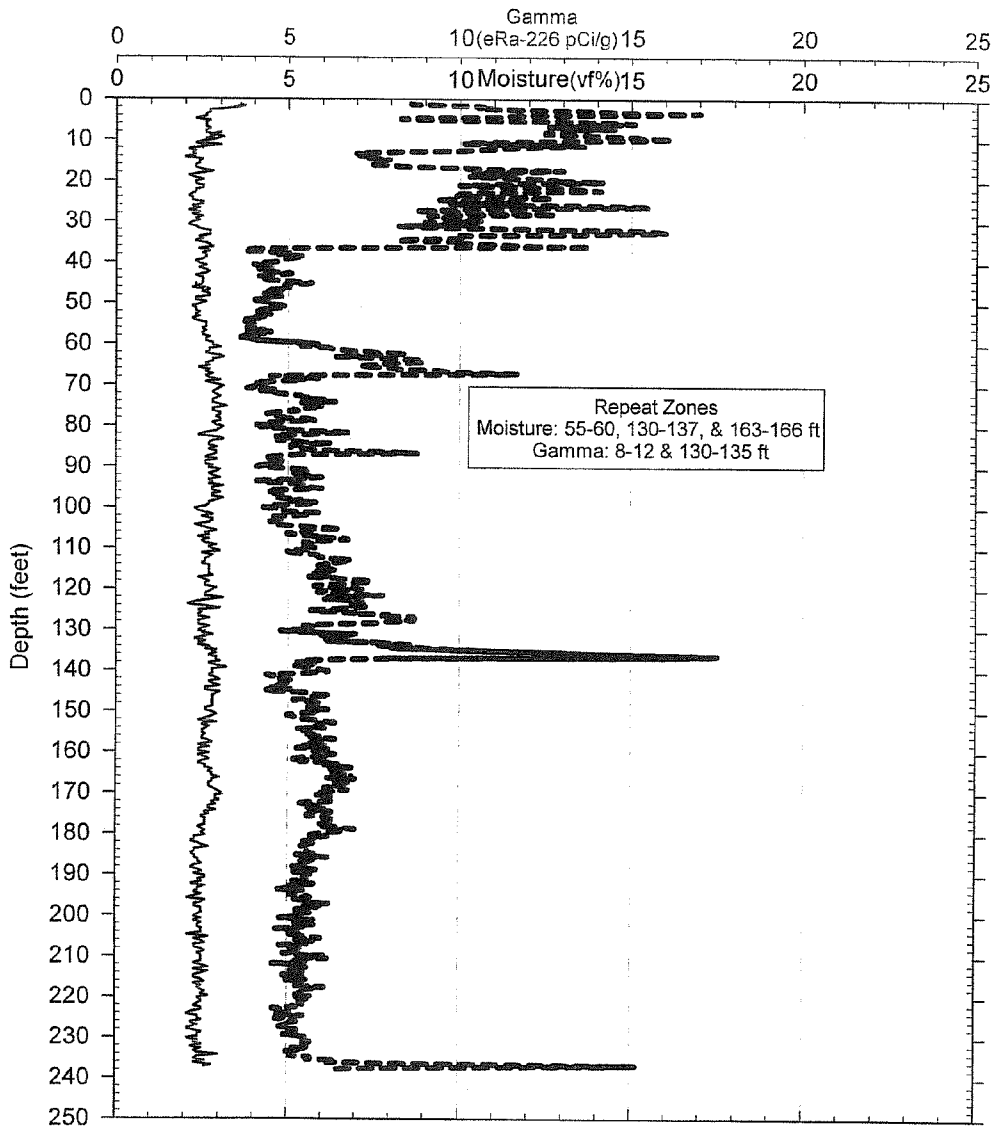


Small Diameter - Gamma & Moisture Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

Project: UPR-200-E-81
Probehole: C6399

Log Date: May 2008
Depth Ref: Ground Level



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DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-32073, COMPLETION REPORT FOR C4297 (C-105) C TANK FARM DRILLING AND SAMPLING

APPENDIX D

GEOPHYSICAL LOGS

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D1.0 STOLLER REPORT

Stoller
Hanford Office

DOE-EM/GJ622-2004

C4297
Log Data Report

Borehole Information:

Borehole: C4297			Site: 241-C-105		
Coordinates (Hanford Plant)		GWL (ft)[1]: Dry		GWL Date: 03/23/04	
North	West	Drill Date	Ground Level Elevation	Total Depth (ft)	Type
42819.84 ft	48359.79	03/04	Not Available	196.5	Percussion

Casing Information:

Casing Type	Stickup (ft)	Outer Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Top (ft)	Bottom (ft)
Threaded Steel	0.7	10 3/4	9 3/4	1/2	0	152.09
Threaded Steel	3.7	8 5/8	7 5/8	1/2	0	195.58

Borehole Notes:

Casing, drilling, and groundwater information were provided by the driller. The casing thickness of 0.5 in. was confirmed by e-mail from David Myers of CH2M HILL. The coordinates were also provided by CH2M HILL. Logging data acquisition is referenced to the ground surface.

Logging Equipment Information:

Logging System:	Gamma 1E		Type: SGLS (70%) SN: 34TP40587A
Calibration Date:	01/04	Calibration Reference:	GJO-2004-568-TAC
		Logging Procedure:	MAC-HGLP 1.6.5, Rev. 0

Logging System:	Gamma 2A		Type: SGLS (35%)
Calibration Date:	03/04	Calibration Reference:	Not yet available
		Logging Procedure:	MAC-HGLP 1.6.5, Rev. 0

Logging System:	Gamma 2F		Type: NMLS (SN: H380932510)
Calibration Date:	09/03	Calibration Reference:	GJO-2003-520-TAC
		Logging Procedure:	MAC-HGLP 1.6.5, Rev. 0

Spectral Gamma Logging System (SGLS) Log Run Information:

Log Run	3	4	5 Repeat	6	7
Date	03/03/04	03/03/04	03/03/04	03/19/04	03/19/04
Logging Engineer	Spatz	Spatz	Spatz	Spatz	Spatz
Start Depth (ft)	149.43	149.0	50.0	194.62	194.0

Log Run	3	4	5 Repeat	6	7
Finish Depth (ft)	149.93	0.0	35.0	194.62	145.0
Count Time (sec)	100	100	100	200	200
Live/Real	R	R	R	R	R
Shield (Y/N)	N	N	N	N	N
MSA Interval (ft)	None	1	1	None	1
ft/min	N/A[2]	N/A	N/A	N/A	N/A
Pre-Verification	AE098CAB	AE098CAB	AE098CAB	BA317CAB	BA317CAB
Start File	AE098000	AE098001	AE098151	BA317000	BA317001
Finish File	AE098000	AE098150	AE098166	BA317000	BA317050
Post-Verification	AE098CAA	AE098CAA	AE098CAA	BA317CAA	BA317CAA
Depth Return Error (in.)	N/A	-1	0	N/A	N/A
Comments	No fine-gain adjustment.	No fine-gain adjustment.	No fine-gain adjustment.	No fine-gain adjustment.	Fine-gain adjustment after: BA317003, -010, -022.

Log Run	8 Repeat				
Date	03/19/04				
Logging Engineer	Spatz				
Start Depth (ft)	160.0				
Finish Depth (ft)	155.0				
Count Time (sec)	200				
Live/Real	R				
Shield (Y/N)	N				
MSA Interval (ft)	1				
ft/min	N/A				
Pre-Verification	BA317CAB				
Start File	BA317051				
Finish File	BA317056				
Post-Verification	BA317CAA				
Depth Return Error (in.)	-0.25				
Comments	No fine-gain adjustment.				

Neutron Moisture Logging System (NMLS) Log Run Information:

Log Run	1	2 Repeat	9	10 Repeat	
Date	03/02/04	03/02/04	03/23/04	03/23/04	
Logging Engineer	Spatz	Spatz	Pearson	Pearson	
Start Depth (ft)	0.0	80.0	145.0	157.0	
Finish Depth (ft)	95.0	149.25	194.5	162.0	
Count Time (sec)	N/A	N/A	N/A	N/A	
Live/Real	N/A	N/A	N/A	N/A	
Shield (Y/N)	N/A	N/A	N/A	N/A	
Sample Interval (ft)	0.25	0.25	0.25	0.25	
ft/min	1.0	1.0	1.0	1.0	
Pre-Verification	BF161CAB	BF161CAB	BF162CAB	BF162CAB	
Start File	BF161000	BF161381	BF162000	BF162199	
Finish File	BF161380	BF161658	BF162198	BF162219	
Post-Verification	BF161CAA	BF161CAA	BF162CAA	BF162CAA	
Depth Return Error (in.)	N/A	+0.5	N/A	+.05	
Comments	No fine-gain adjustment.	Repeat 80-95 ft.	No fine-gain adjustment.	No fine-gain adjustment.	

Logging Operation Notes:

Spectral gamma and moisture logging were performed in this borehole during March 2004 on four separate days. SGLS G1E was used for logging runs 3, 4, and 5 and G2A for log runs 6, 7, and 8. Logging was conducted with a centralizer on the sonde. Logging measurements are referenced to ground surface. Repeat sections were collected in this borehole to evaluate system performance.

Analysis Notes:

Analyst:	Henwood	Date:	03/30/04	Reference:	GJO-HGLP 1.6.3, Rev. 0

Pre-run and post-run verifications for each logging system were performed for each day's log event. The acceptance criteria were met for all logging systems.

A casing correction for 0.5-in.-thick casing was applied for the steel casing to the total depth of the borehole. The 0.5-in. casing wall thickness is provided by CH2M HILL.

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 G2AFeb04.xls and G1EJan04.xls for the SGLSs, using efficiency functions and corrections for casing, water, and dead time as determined from annual calibrations. Dead time corrections are applied where dead times exceed 10.5 percent. Where SGLS dead time exceeds 40 percent, pulse pileup and peak spreading may occur in a spectrum that results in an underestimation of the concentration of man-made radionuclides. Dead time of 40 percent was exceeded in two depth intervals (13 and 14 ft). Because the interval of high dead time was thin, it was determined the HRLS could not be efficiently deployed to obtain data. No correction for water was necessary in this borehole.

NMLS log spectra were processed in batch mode using APTEC Supervisor to determine count rates. The volume fraction of water was not calculated because there is no valid calibration for a 10-in.-diameter borehole. However, increasing count rates are a reliable indicator of increasing moisture content.

Log Plot Notes:

Separate log plots are provided for the man-made radionuclides (^{137}Cs, ^{154}Eu, and ^{60}Co) detected in the borehole, naturally occurring radionuclides (^{40}K, ^{238}U, ^{232}Th [KUT]), a combination of man-made, KUT, and moisture, 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. Repeat log sections are also included.

Results and Interpretations:

^{137}Cs, ^{154}Eu, and ^{60}Co were the man-made radionuclides detected in this borehole. ^{137}Cs was detected between the ground surface and 19 ft in depth at concentrations between 0.3 and 1,700 pCi/g. ^{137}Cs was also detected at a few locations near its MDL of approximately 0.2 pCi/g.

^{60}Co was detected at 12 and 15 ft and between 40 ft and 65 ft. The maximum concentration measured was approximately 1 pCi/g at 15 ft.

^{154}Eu was detected between 11 and 16 ft. The maximum concentration measured was approximately 400 pCi/g at 13 ft.

The profile of the ^{137}Cs, ^{154}Eu, and ^{60}Co between approximately 11 and 16 ft is suggestive of a point source of contamination such as a pipeline. A 3-in. inlet line #V103 that connects to the southwest quadrant of tank C-105 lies a few feet northeast from the location of the borehole at a depth of 13.63 ft below grade. It is hypothesized that the log data reflect contamination inside this pipeline.

Recognizable changes in the KUT and total gamma logs occurred in this borehole. At 39 ft, there is a 3-pCi/g increase in ^{40}K concentration and a decrease in relative moisture content. This increase in apparent ^{40}K concentration corresponds with the base of the backfill. An interval between 40 and 65 ft appears to reflect alternating layers and mixtures of sand and gravel that coincide with the ^{60}Co contamination. At 65 ft the ^{40}K concentrations increase about 5 pCi/g and a thin fine-grained sediment layer exists where relatively higher moisture content is shown. The downward movement of the ^{60}Co is apparently retarded by this layer. Another thin sediment layer is shown at 75 ft by an increase in ^{40}K, ^{232}Th, and moisture. Between 130 and 135 ft increases in KUT and moisture are exhibited.

Log runs 3, 4, and 5 conducted March 3, 2004 show indications of enhanced radon as reflected by a slightly elevated naturally occurring ^{238}U concentration between the ground surface and 150 ft in depth. Where the casing size change occurs at approximately 150 ft, the moisture shows an increase in count rate. This increase in count rate is the result of a change from 10-in. to 8-in. casing and probably not a significant difference in moisture content.

The repeat sections indicated good agreement of the man-made radionuclides, naturally occurring KUT, and moisture.

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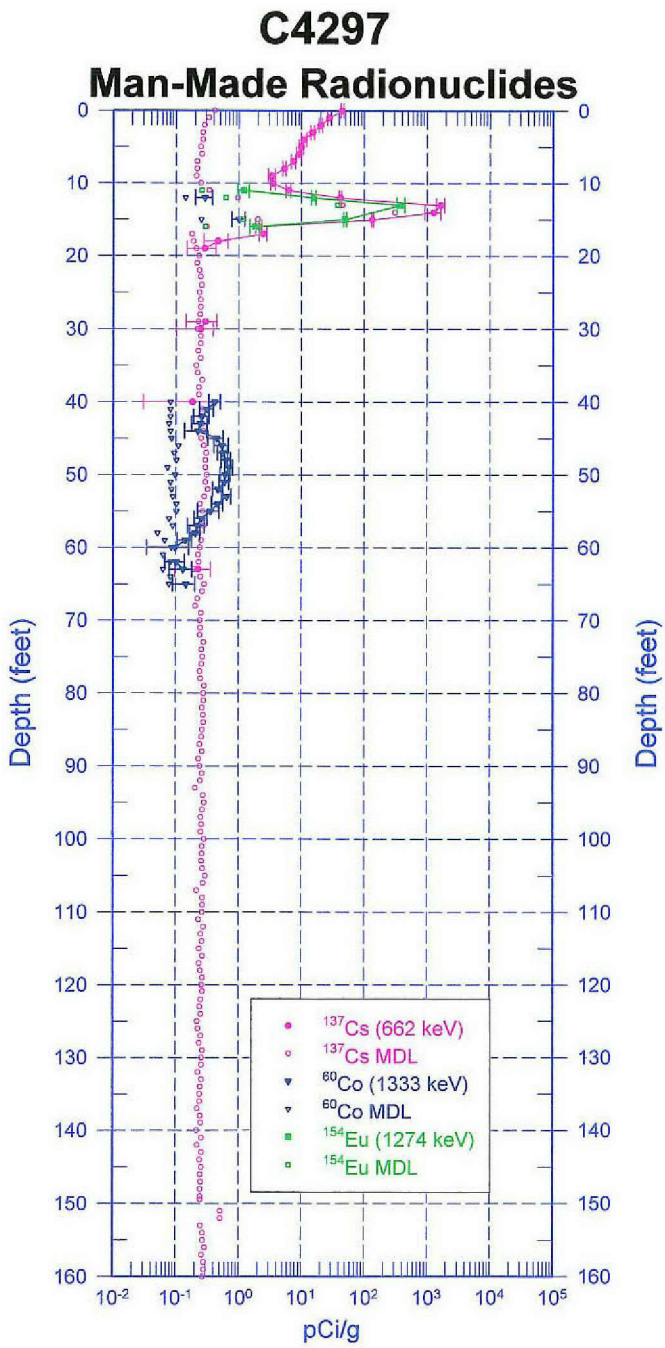
[1] GWL – groundwater level
[2] N/A – not applicable



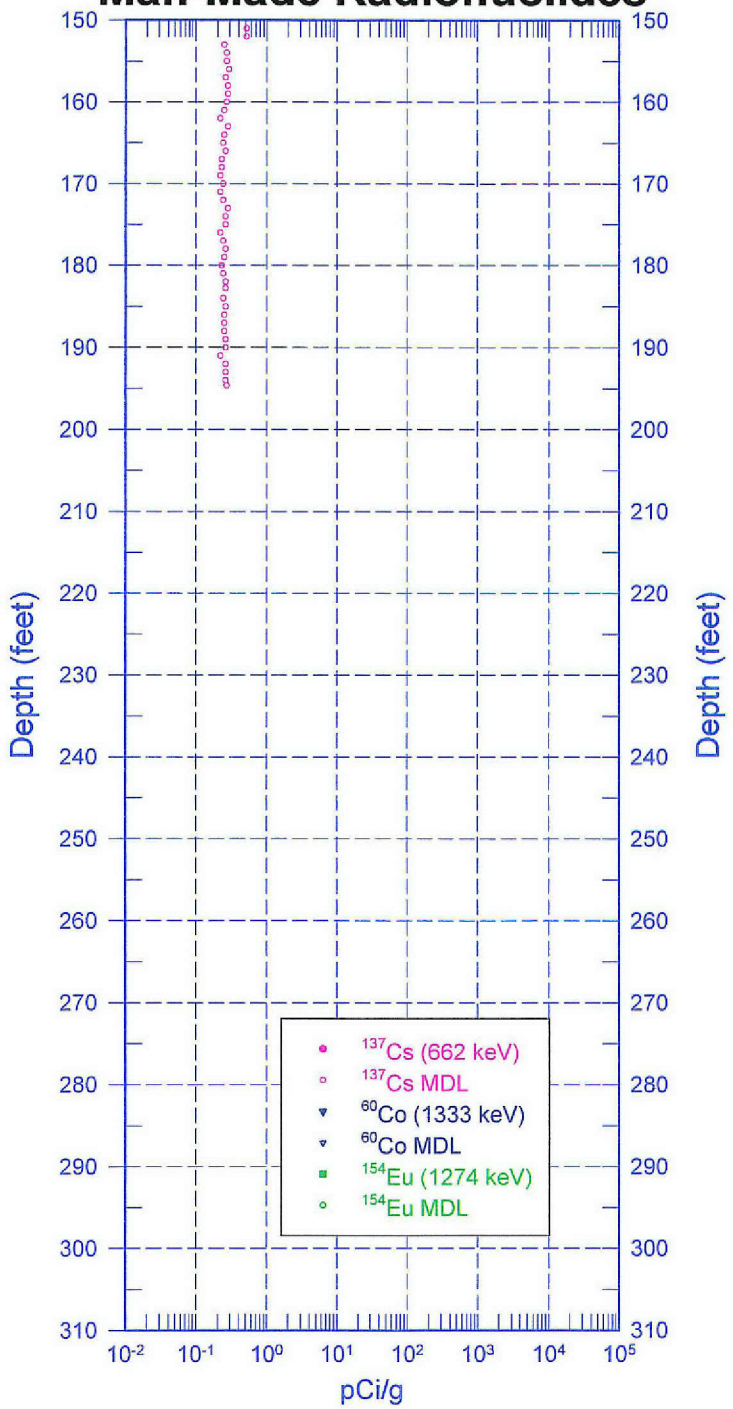
Zero Reference = Ground Surface

Depth scale: 1" = 20 ft

Last Log Date - 03/23/04

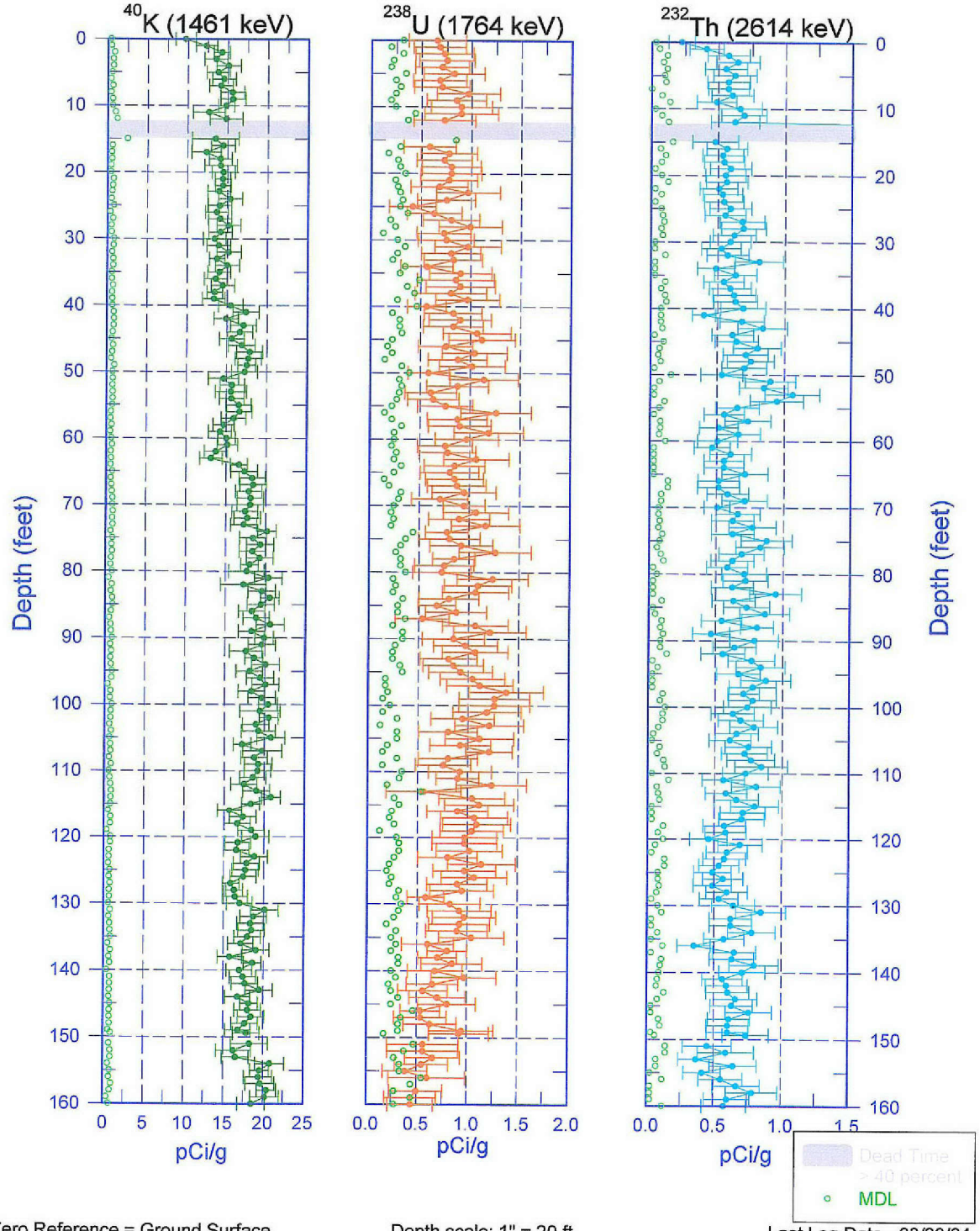
C4297

Man-Made Radionuclides



= Ground Surface Depth scale: 1" = 20 ft Last Log Date

C4297
Natural Gamma Logs

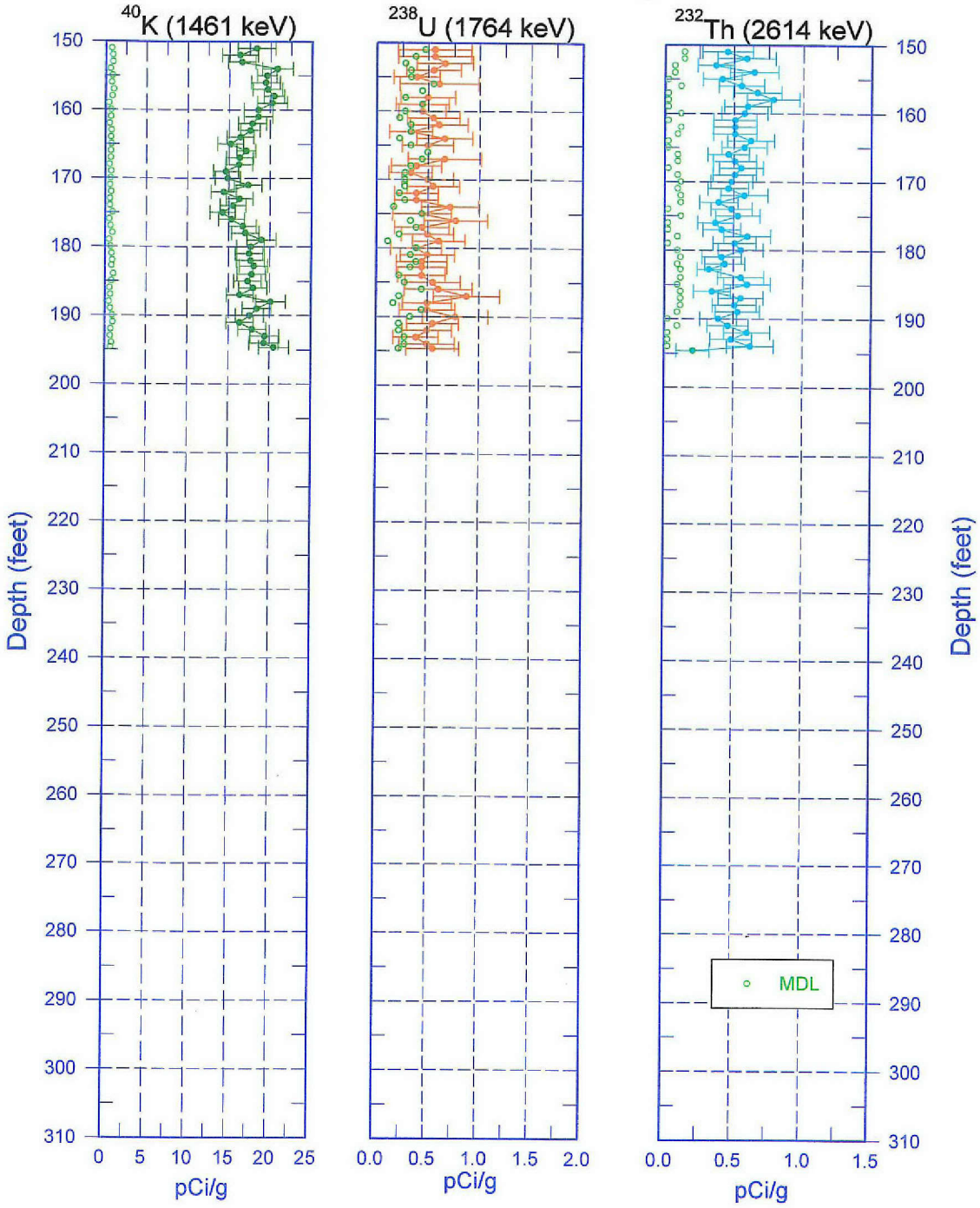


Zero Reference = Ground Surface

Depth scale: 1" = 20 ft

Last Log Date - 03/23/04

C4297
Natural Gamma Logs

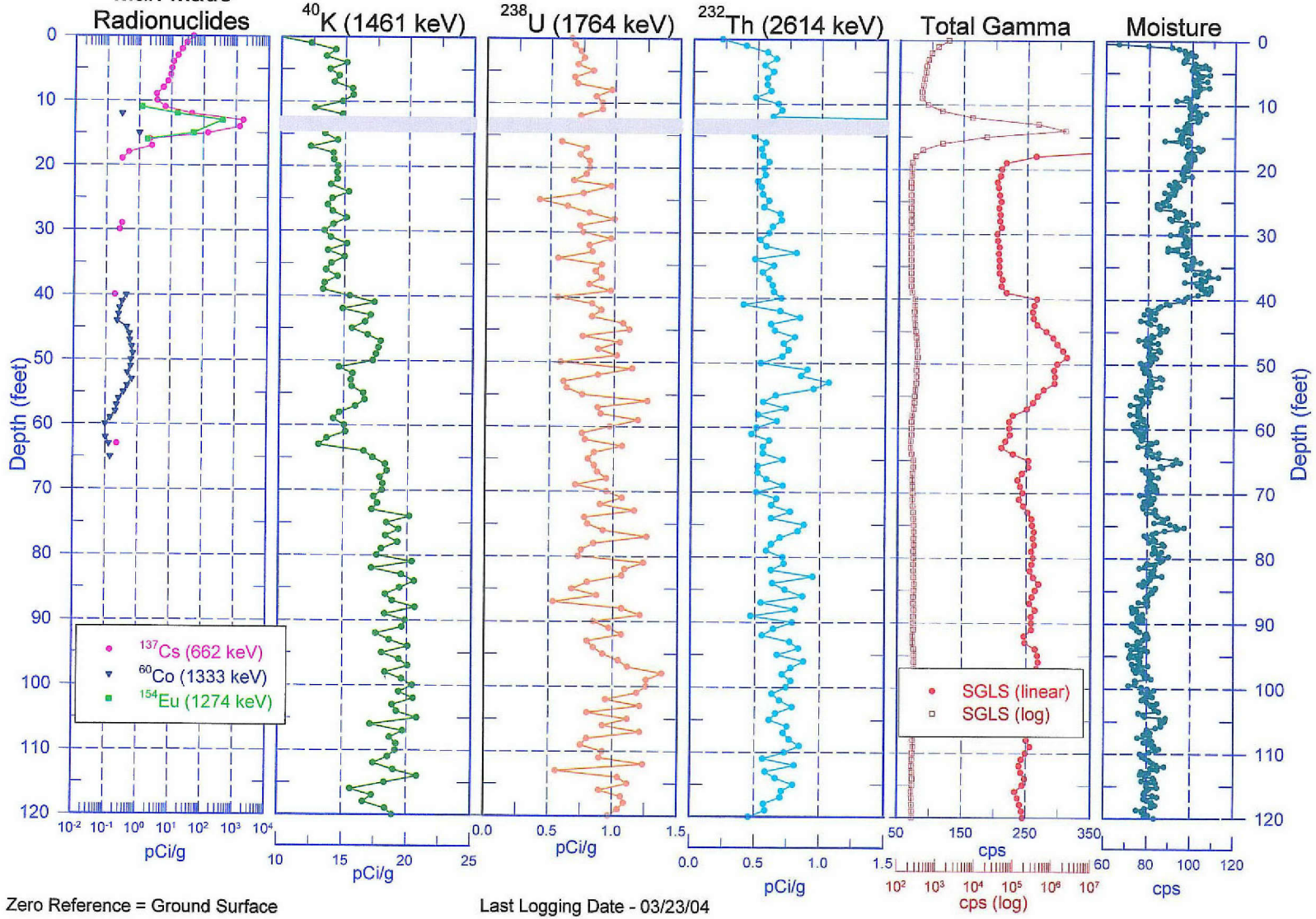


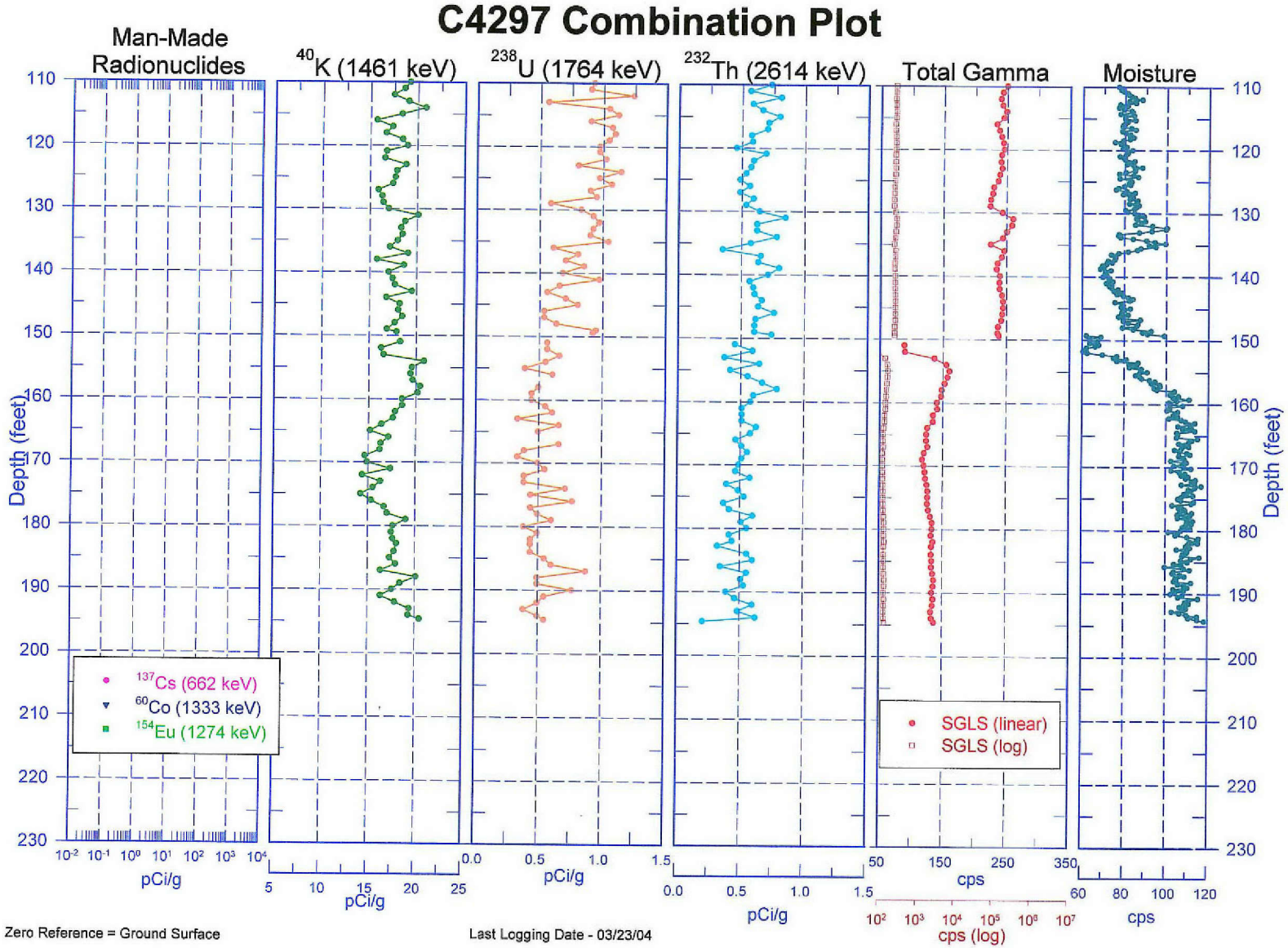
Zero Reference = Ground Surface

Depth scale: 1" = 20 ft

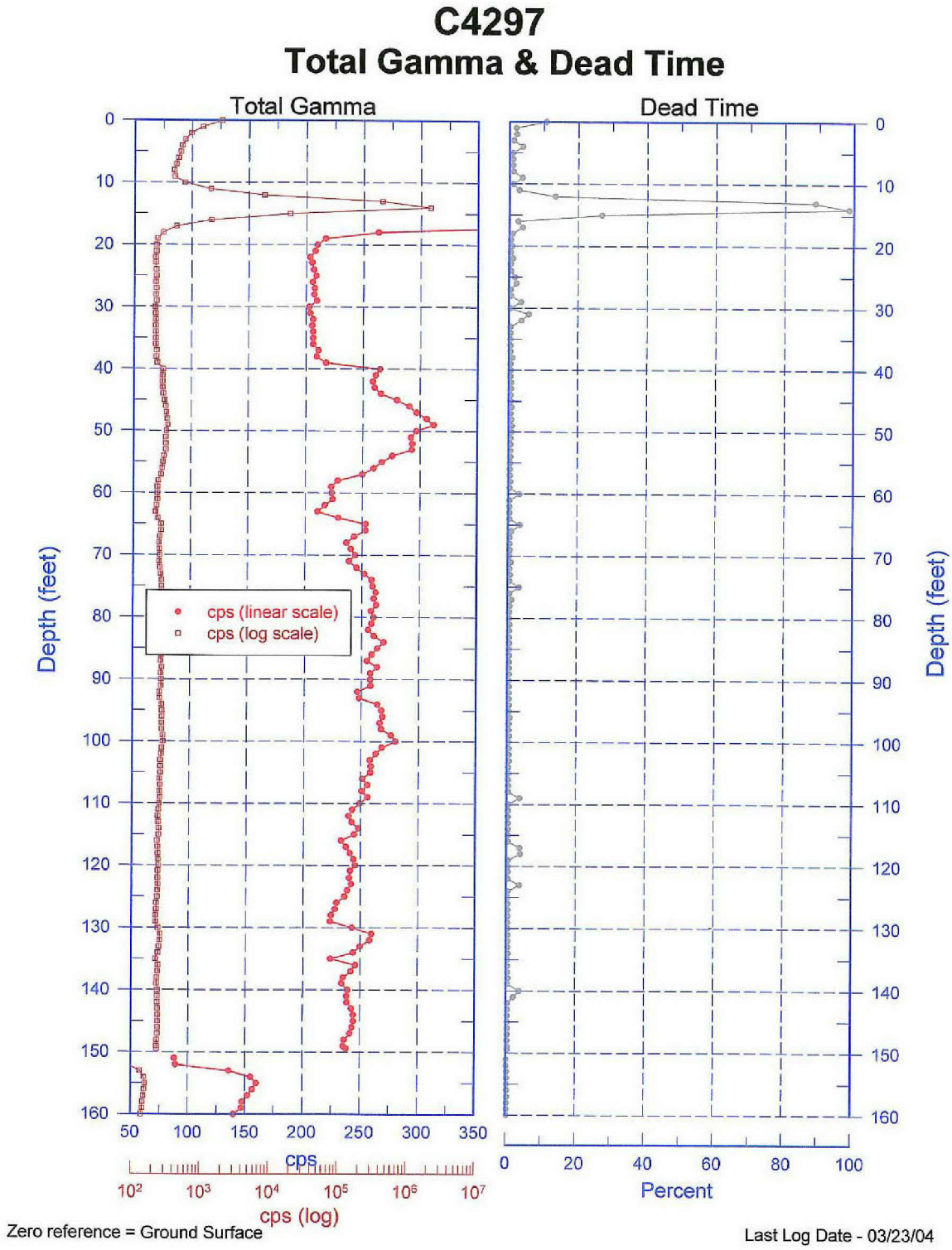
Last Log Date - 03/23/04

C4297 Combination Plot

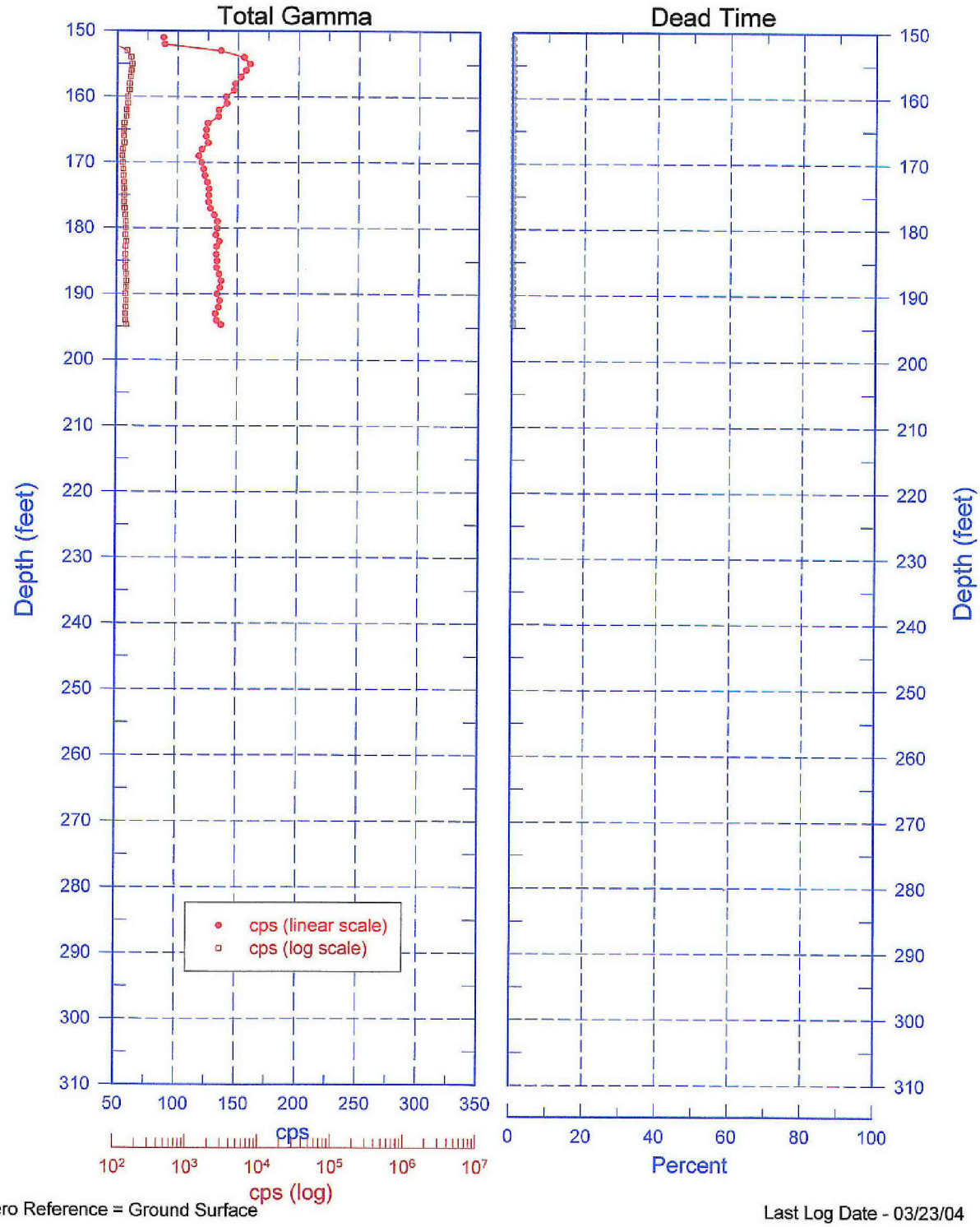



C4297 Combination Plot
Man-Made Radionuclides
40K (1461 keV)
238U (1764 keV)
232Th (2614 keV)
Total Gamma
Moisture
Depth (feet)
137Cs (662 keV)
60Co (1333 keV)
154Eu (1274 keV)
SGLS (linear)
SGLS (log)
pCi/g
cps
cps (log)
Zero Reference = Ground Surface
Last Logging Date - 03/23/04

D2.0 GROSS GAMMA LOGS



C4297
Total Gamma & Dead Time

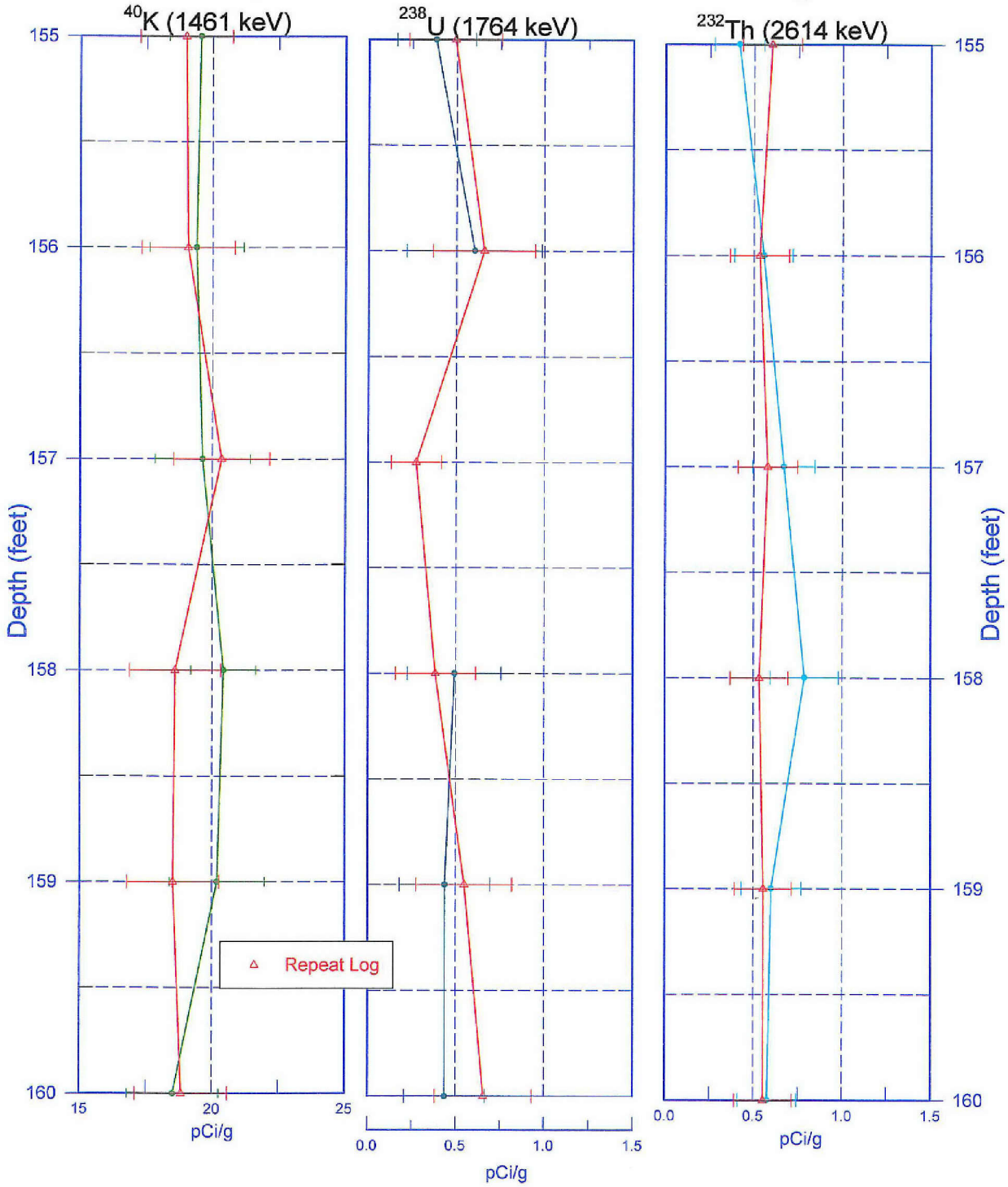


Zero Reference = Ground Surface

Last Log Date - 03/23/04

C4297

Repeat Section of Natural Gamma Logs

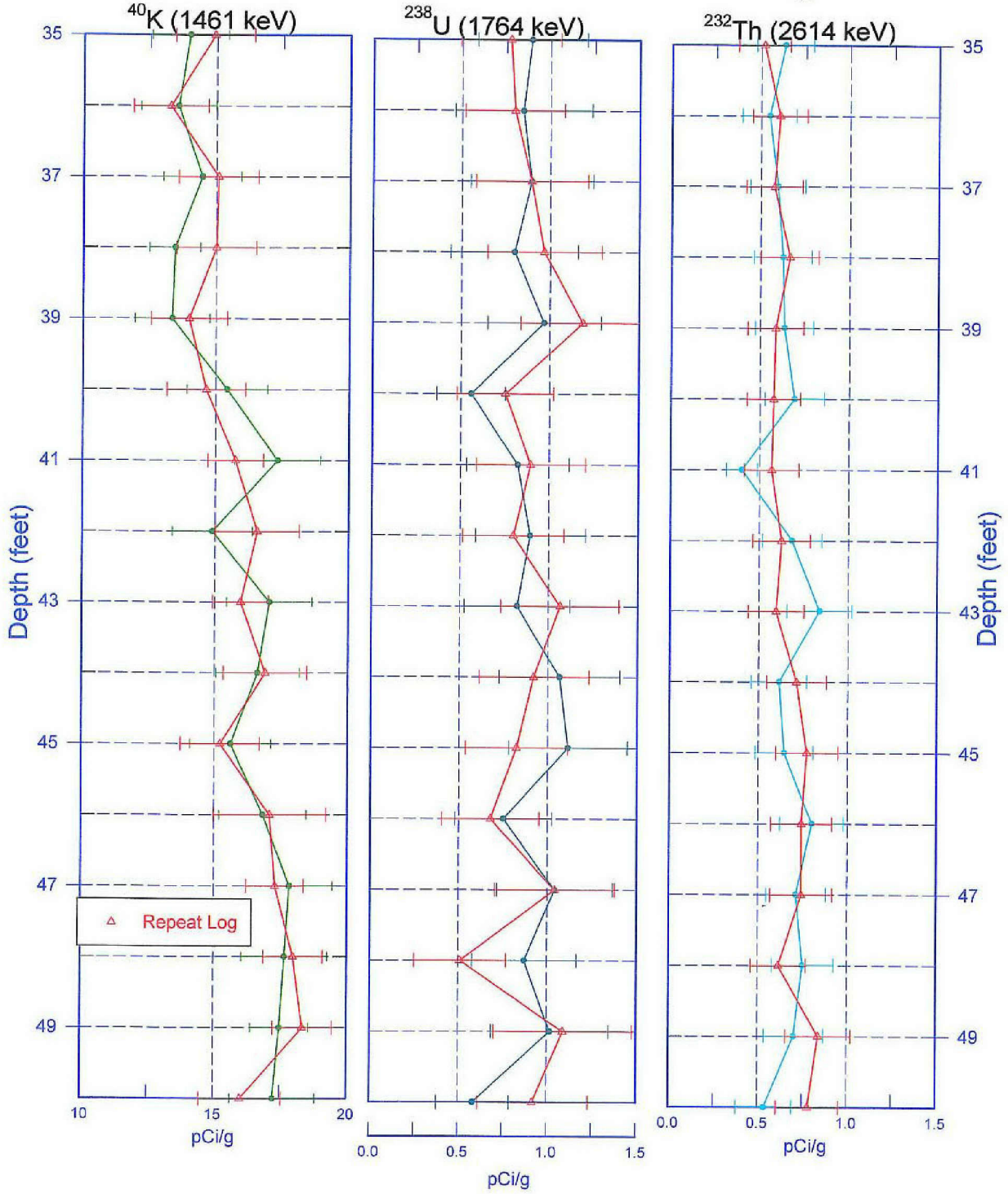


Zero Reference = Ground Surface

Last Log Date - 03/23/04

C4297

Repeat Section of Natural Gamma Logs

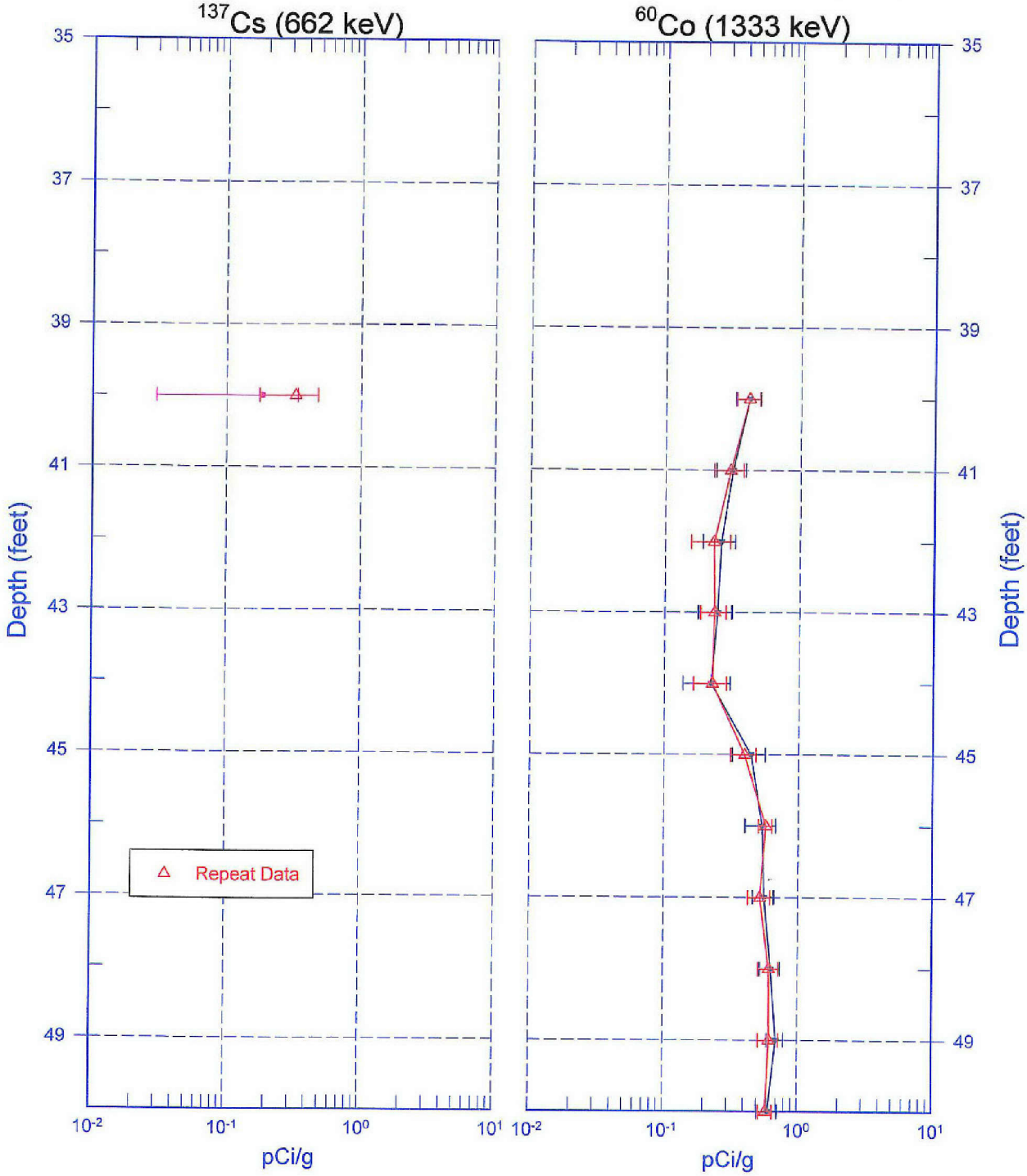


Zero Reference = Ground Surface

Last Log Date - 03/23/04

C4297

Repeat Section of Man-Made Radionuclides

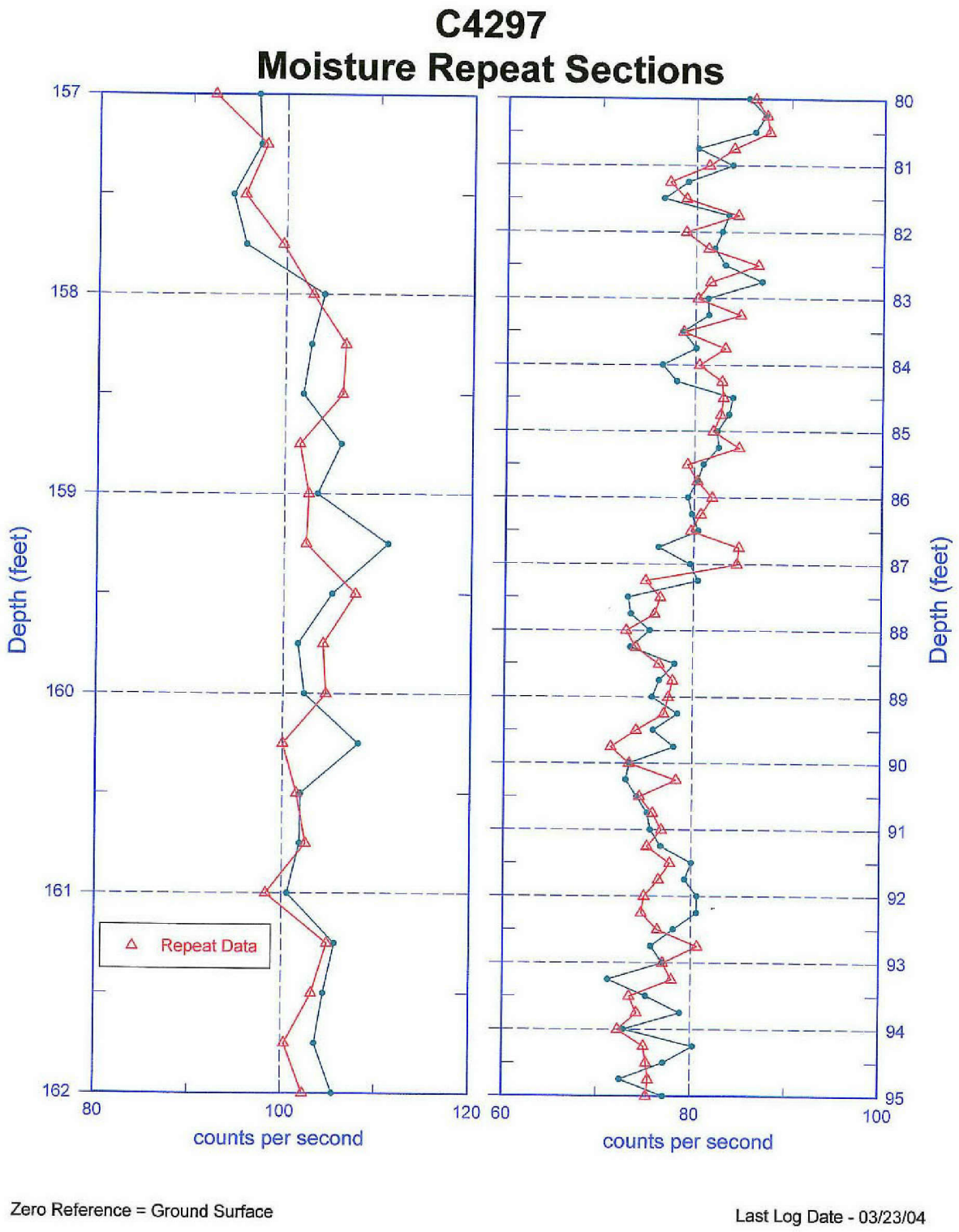


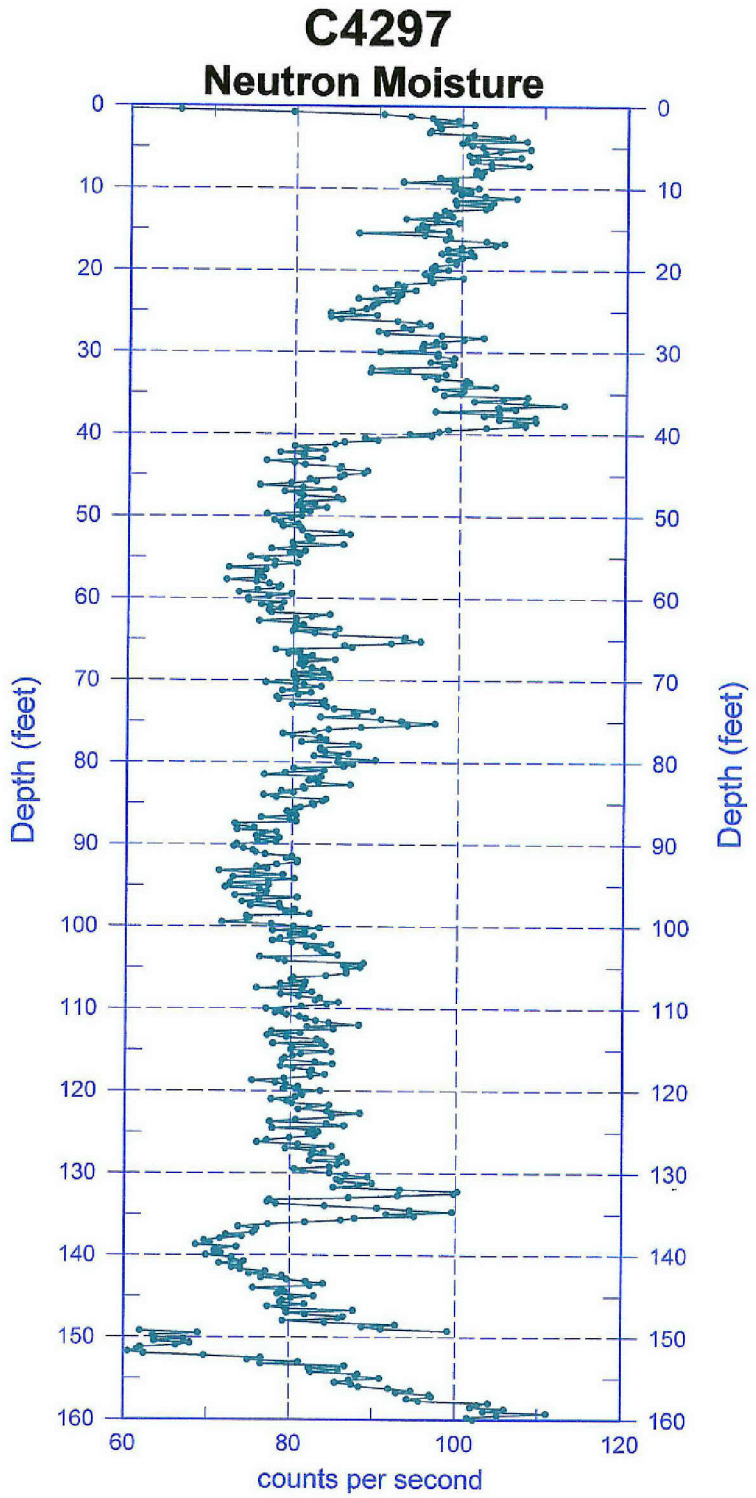
Zero Reference = Ground Surface

Depth scale: 1" = 20 ft

Last Log Date - 03/23/04

D3.0 MOISTURE LOGS

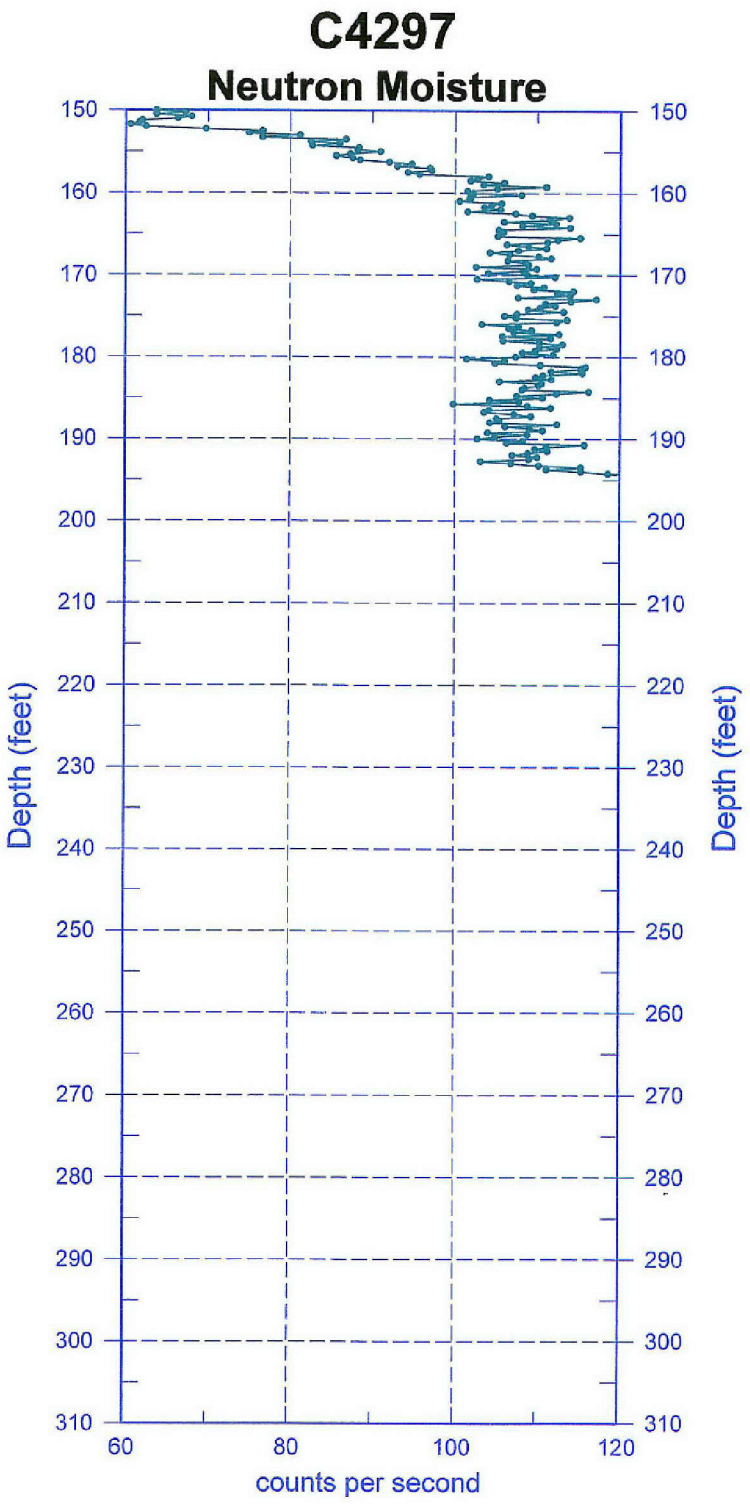




Zero Reference = Ground Surface

Depth scale: 1" = 20 ft

Last Log Date - 03/23/04



Zero Reference = Ground Surface

Depth scale: 1" = 20 ft

Last Log Date - 03/23/04

DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-42221, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR UPR-200-E-8A, PHASE 2

APPENDIX D

SMALL DIAMETER GEOPHYSICAL LOGGING FOR UPR-200-E-81, PHASE 2

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APPENDIX D
SMALL DIAMETER GEOPHYSICAL LOGGING FOR UPR-200-E-81, PHASE 2

Randall Price
Pacific Northwest Geophysics
4200 West 19th Avenue
Kennewick, Washington 99338

Russel Randall, PhD
Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

TERMS

bgs	below ground surface
BGO	Bismuth Germinate
MCNP	Monte Carlo neutron photon
VF	Volume Fraction (percent) of moisture content

D1.0 PROBEHOLE SURVEYS

Pacific Northwest Geophysics and Three Rivers Scientific provided small diameter logging in two probeholes for the phase II study of the UPR-200-E-81 investigation site, near the 241-CR-151 Diversion Box.

Logging surveys were conducted with a Bismuth Germinate (BGO) spectral gamma scintillation detector and a neutron-neutron moisture probe from the bottom of each probehole (maximum survey depth) to the ground surface. Zero depth reference is at the ground surface. The survey results for each probehole are presented as a depth-versus-concentration plot.

A repeat measurement was acquired to verify instrument repeatability. The computed results of the main and repeat intervals were reviewed and the results agree within the uncertainty of the measurement counting statistics. The repeat intervals are presented with the main log plot.

Table D1 summarizes the survey results for each probehole.

Table D1. Probehole Survey Summary.

Hole	Hole Depth (meters)	Hole Depth (feet)	Cs-137 (pCi/g) Max Detection
C6403	15.24	50	1,200,000 pCi/g (eCs-137) at 6 ft
C6405	73.15	240	11 pCi/g (Cs-137) at 4 ft

Detector calibration certificates are presented in Section D2.0, “Spectral Gamma,” and Section D3.0, “Neutron Moisture.”

The contamination zone in probehole C6405 has a distribution profile that is unusual. The distribution profile of this thin zone is discussed in Section D4.0, “Cs-137 Contamination Zone in Probehole C6405.”

Probehole C6403 was installed after the adjacent sampling probehole encountered high levels of contamination. The gamma activity encountered in C6403 exceeded the linear response range of the BGO detector system. The NaI and Green GM detectors were run in this probehole to measure the high levels of cesium-137 (Cs-137) at 1.83 m (6 ft).

The log survey results follow. The log plots show a maximum of 100 ft per page with a 10-ft overlap between page breaks.

UPR-200-E-81 C6403 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C6403	Log Date:	March 2009
Project:	UPR-81	Depth Ref:	Ground Surface

REPEAT/OVERLAP INTERVALS

Spectral:	25-20	Moisture	4-0
NaI:	12-8		
Green GM	8-4		

ISOTOPES ANALYZED (GAMMA)

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661
Eq.Cs-137	Gross produced equivalent

OBSERVATIONS

Spectral:

No Co-60 observed above MDL much higher due to high Cs interference
KUT values also skewed in high Cs interference zones.
Cs-137 observed, in some zones count rates exceeded tool specs (3-10 ft)

Moisture:

Moisture values range from 3-18%.

CALIBRATION CERTIFICATES

Spectral

Date:	Aug 30, 2008
Electronic File	Cal_SD-GR-2_2008-v0.zip

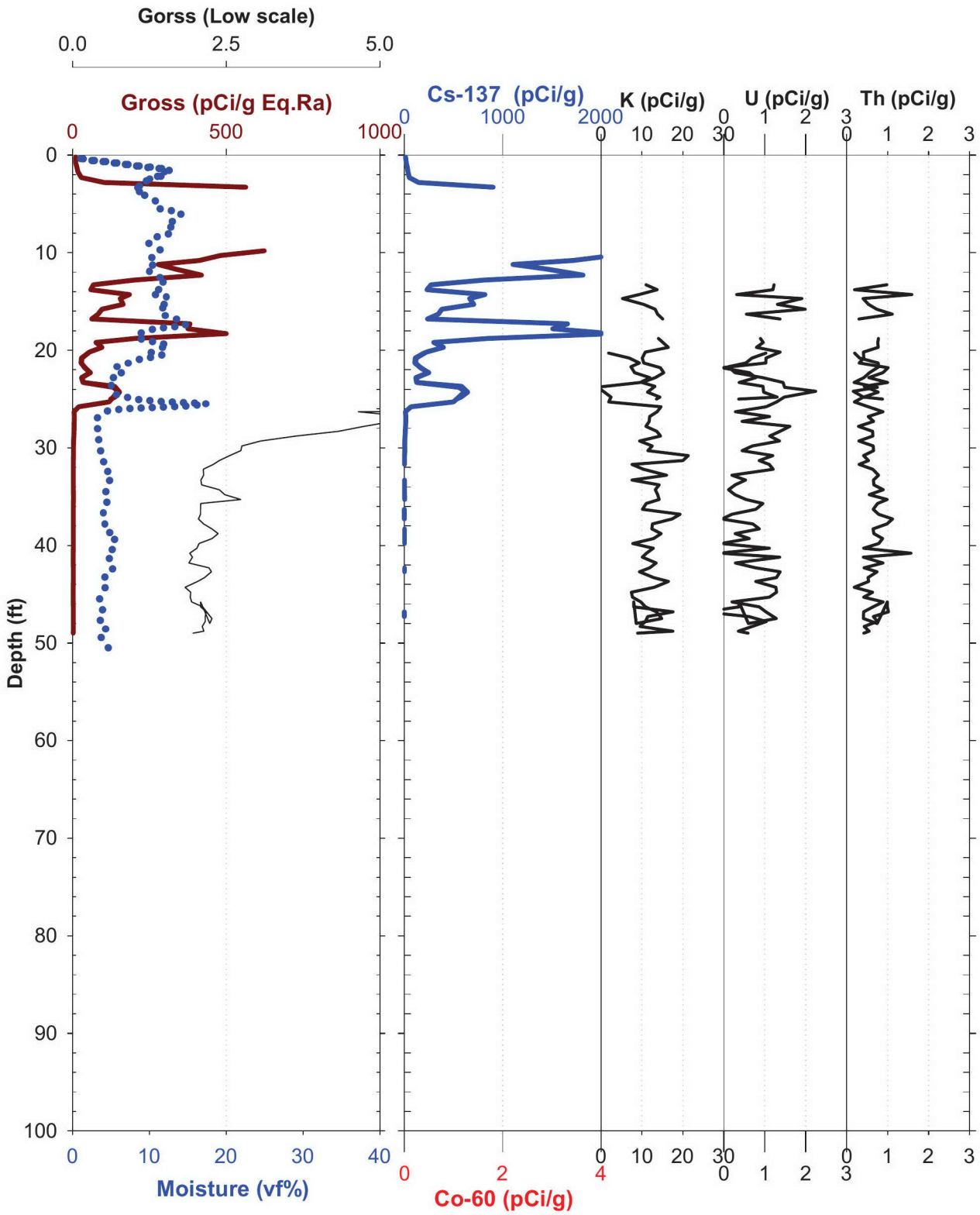
NaI and Green GM

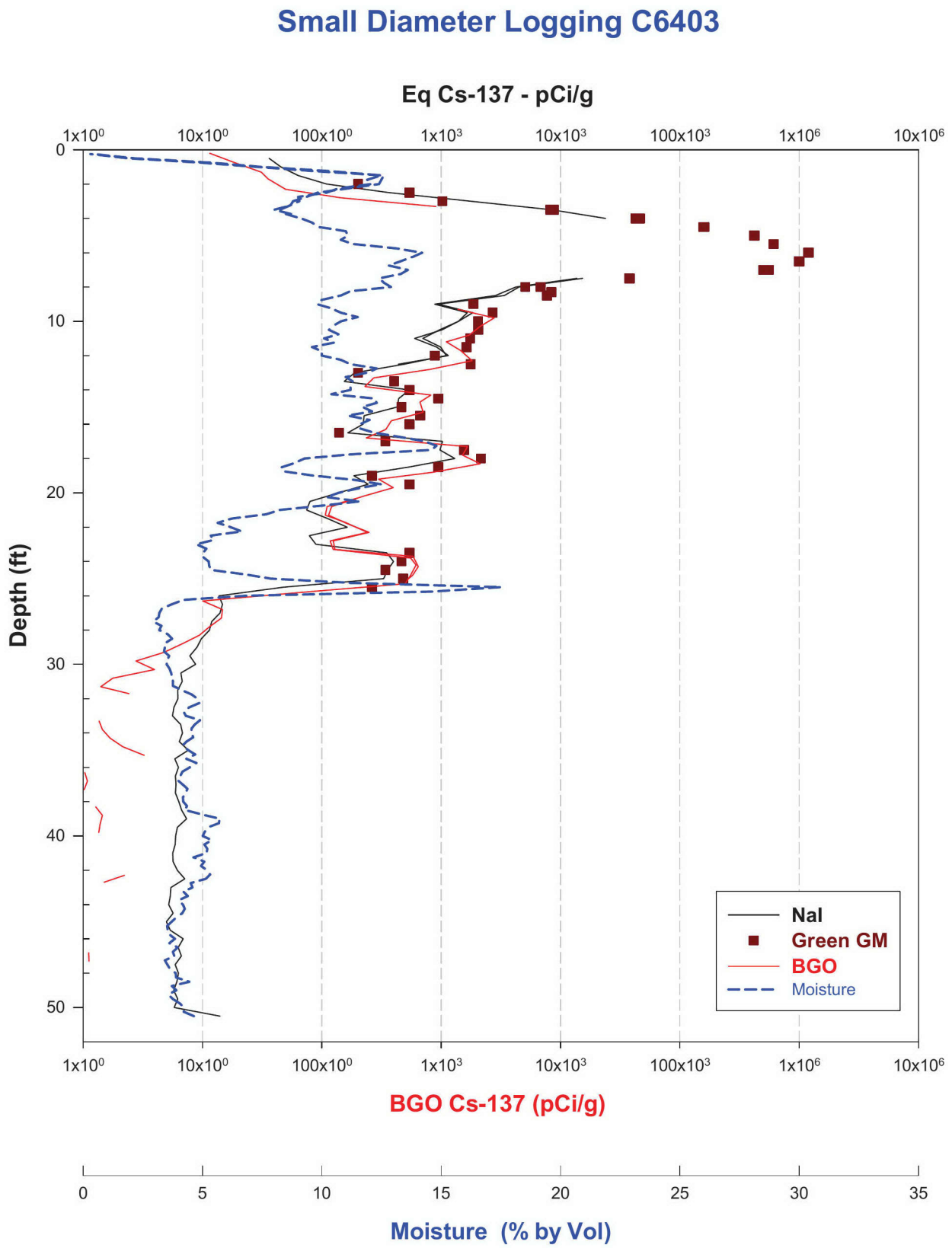
Date:	March 17, 2009
Electronic File	Cal_SDGR-NaI_2009-v0.zip
	Cal_SDGR-GrGM_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip

C6403 - Spectra Gamma & Moisture Survey




Small Diameter Logging C6403
Eq Cs-137 - pCi/g
1x10⁰
10x10⁰
100x10⁰
1x10³
10x10³
100x10³
1x10⁶
10x10⁶
Depth (ft)
0
10
20
30
40
50
NaI
Green GM
BGO
Moisture
BGO Cs-137 (pCi/g)
0
5
10
15
20
25
30
35
Moisture (% by Vol)

UPR-200-E-81 C6405 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C6405	Log Date:	March 2009
Project:	UPR-81	Depth Ref:	Ground Surface

REPEAT/OVERLAP INTERVALS

Spectral:	235-233	Moisture	240-239
	184-181		240-236
	135-133		162-157
	136-132		150-139
	73-69		72-71
	29-26		
	4-3		

ISOTOPES ANALYZED (GAMMA)

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

OBSERVATIONS

Spectral:

No Co-60 observed above MDL

Cs-137 observed and 1 abnormal thin zone

Moisture:

Moisture values range from 3-16%.

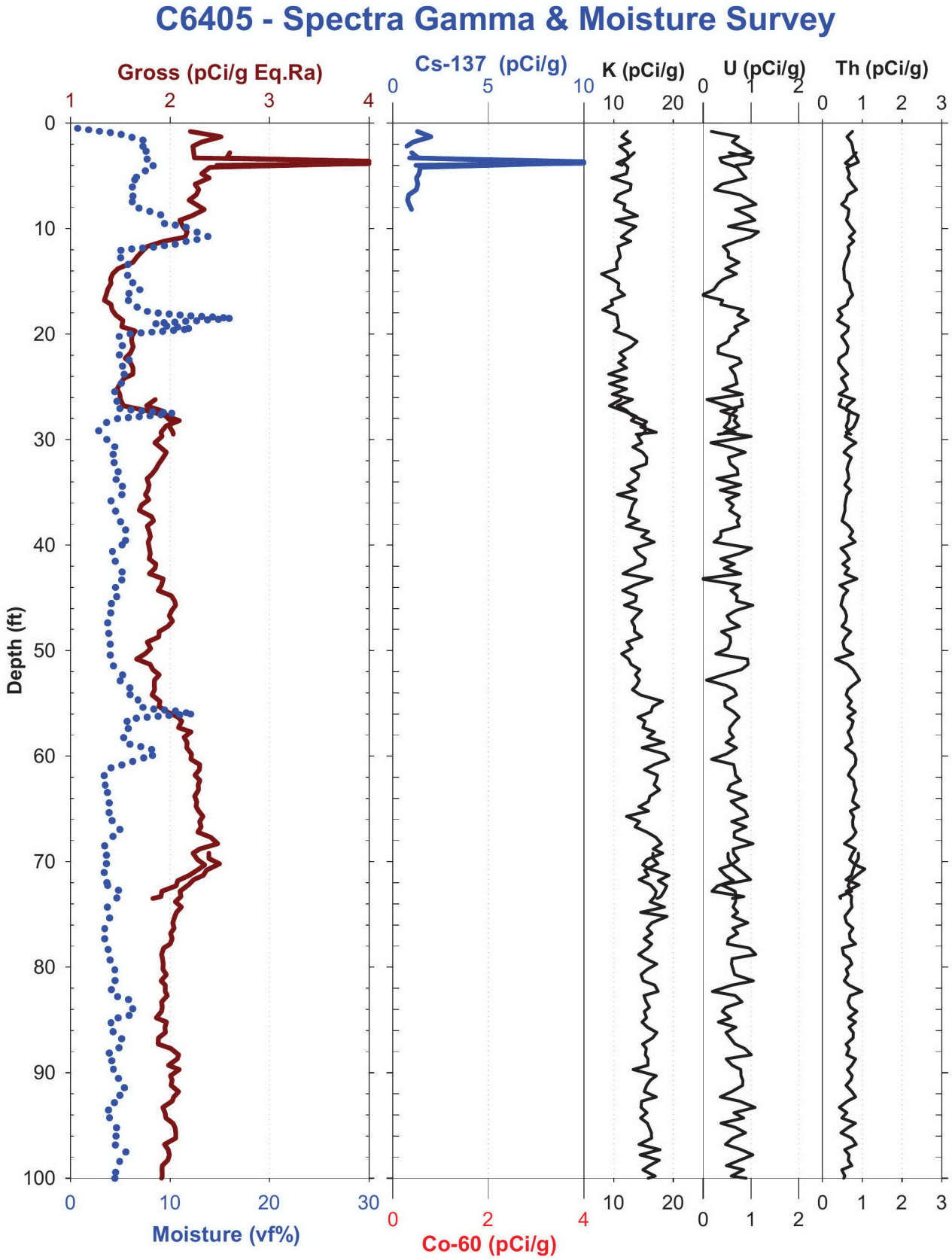
CALIBRATION CERTIFICATES

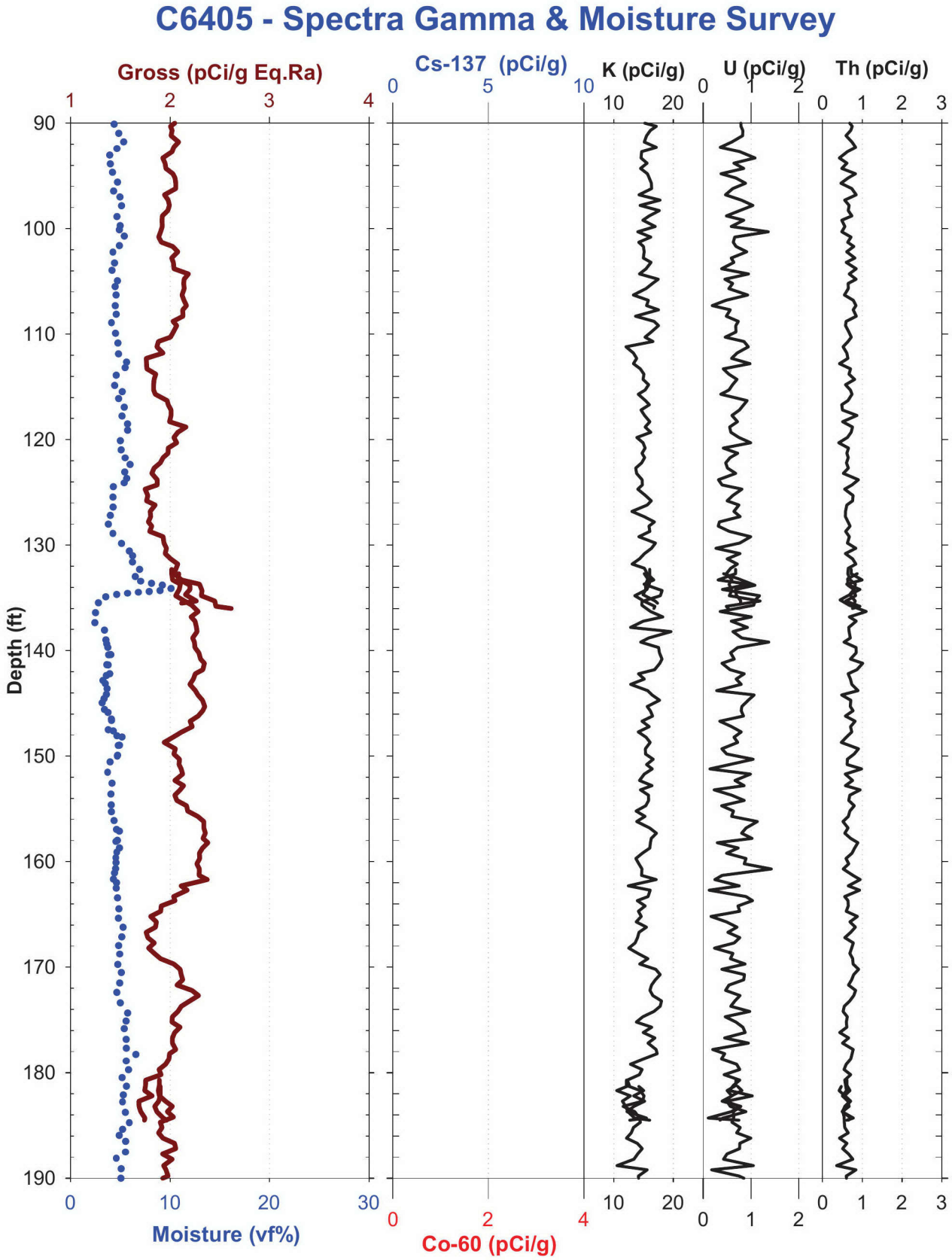
Spectral

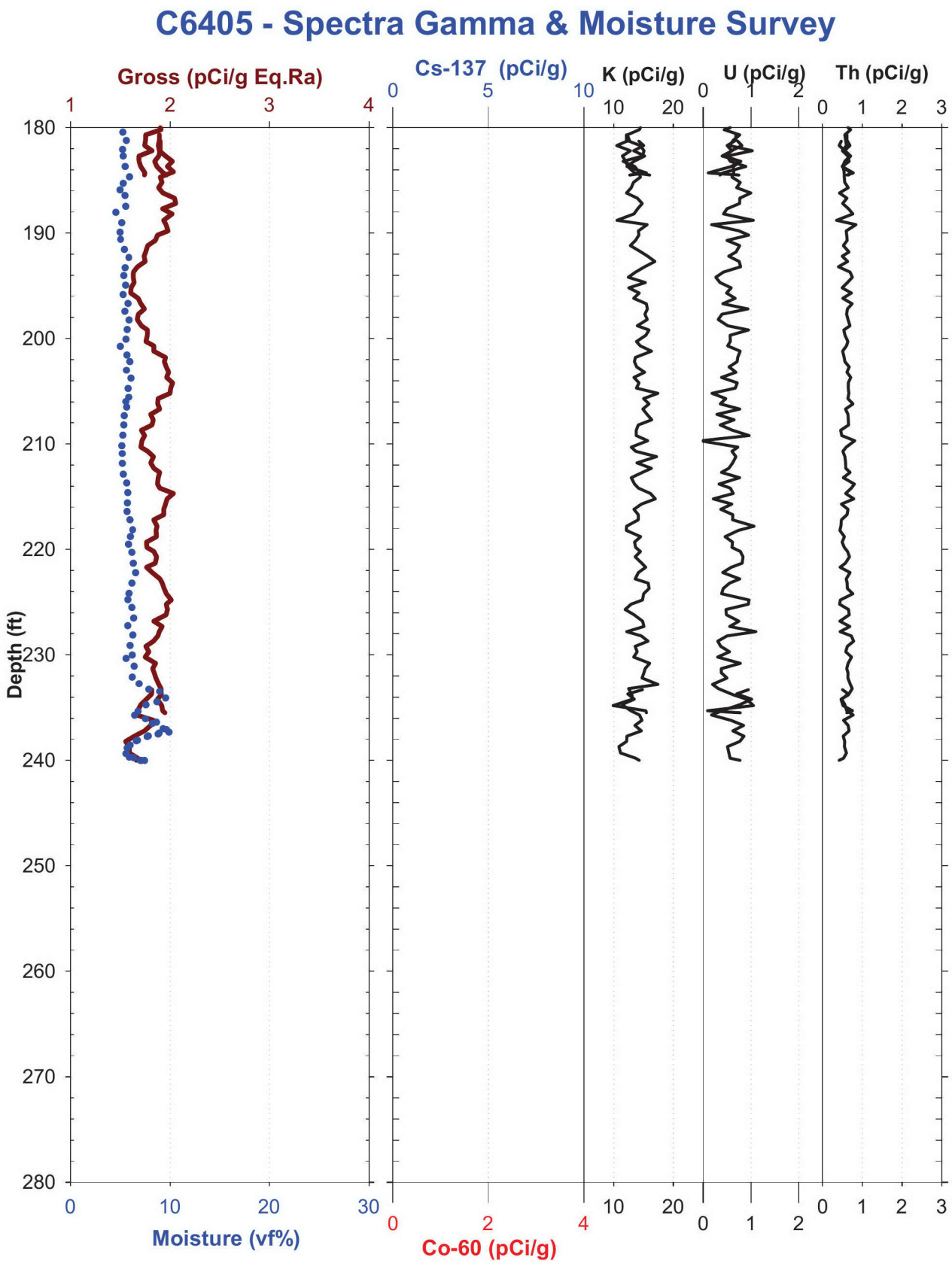
Date:	Aug 30, 2008
Electronic File	Cal_SD-GR-2_2008-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C6405 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)
Co-60 (pCi/g)


C6405 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)
Co-60 (pCi/g)


C6405 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)
Co-60 (pCi/g)

D2.0 SPECTRAL GAMMA CALIBRATION

The objective of the gamma survey logs was to identify depth intervals with elevated gamma activity (i.e., Cs-137 at concentrations greater than 2 pCi/g). The BGO spectral survey (100 seconds per 0.5 ft) has a minimum detection level (MDL) of 1 pCi/g for Cs-137.

The spectral gamma scintillation detector uses a BGO crystal that is 2.54 cm (1 in.) in diameter by 10.1 cm [4 in.] long. The gamma ray spectra with a measurement time of 100 seconds were collected each 0.15 m (0.5 ft) from the bottom of the probehole to the surface. The spectra records gamma ray energies between 200 and 2800 keV in a 256 channel spectra. Spectra were processed to quantify the concentration of the naturally occurring radionuclides (K, U, & Th) and to quantify Cs-137 when present above the minimum detection threshold. The calibration certificate is shown in Figure D1.

D3.0 NEUTRON MOISTURE CALIBRATION

The moisture detector measures the density of hydrogen (moisture) in subsurface soils. The units of measure are percent volume fraction moisture. Calibration was performed in six borehole calibration models (Meisner and Randall 1995). Three of these models had a 15.24 cm (6-in.) hole size and three models had a 20.32 cm (8-in.) hole size. The calibration certificate for these two hole sizes is presented in Figure D2.

The probehole size for this project was 6.35 cm (2.5 in.) outside diameter. Therefore, the moisture calibration was extrapolated to the correct hole size. Figure D3 shows the moisture calibration certificate for the 6.35 cm (2.5-in.) hole size.

The probehole moisture survey was collected at 0.61 m/min (2 ft/min) or slower. Processing of the survey data requires that the detector raw survey data be normalized to the thickness of the steel casing present in the calibration models (0.826 cm [0.325 in.]) Given that the probehole casing thickness is 0.94 cm (0.37 in.), a correction factor of 1.055 is required to increase (normalize) the observed neutron detector count rate to the conditions of the calibration model (Meisner et al. 1996).

Figure D1. BGO Calibration Certificate.

Certificate of Calibration
SDGR.2
August 30, 2008

Data were taken at the Hanford KUT models on Aug 30, 2008. SDGR.2 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Ten spectra were recorded for each model in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: AveOut2.XLS for this analysis. The instrument was covered with 0.37 inch wall thickness probe tubing.

The algorithm described in the document WHC-SD-EN-TI-293, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1320-1575 keV **U: 1650-2390 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**4.404*K**	**-3.84*U**	**3.478*T**
Concentration-U =	**0.0*K**	**1.343*U**	**-2.625*T**
Concentration-T =	**0.0*K**	**-0.040*U**	**1.859*T**

Where K U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_SD-GR-2_2008-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_SD-GR-2_2008-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-293, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models" and that the above stated calibration coefficients are correct and applicable for the tool SDGR.2 effective August 30, 2008.

Signature: Date:

/s/ Russel Randall, PhD September 2, 2008
Three Rivers Scientific

Figure D2. Moisture Calibration Certificate, 15.24 cm (6-in.) and 20.32 cm (8-in.) Hole.

Certificate of Calibration for
Instrument SD-Moist792

February 25, 2009

Data were taken in the Moisture models on February 25, 2009 for SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H370608792 was used with the passive neutron detector probe from Pacific Northwest Geophysics.

Six models were used for moisture calibration, 3 for 6"casing and 3 for 8" casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation, refer to the file MoistCal.xls for this analysis.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	**8" casing**
a = .0001586	**a = .00008287**
α = 2.229	**α = 2.504**

The undersigned certifies that the data archived in data file "SD-Moist792_2009.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-306, "Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration" and that the above stated calibration coefficients are correct and applicable for tool SD-Moist792, effective February 25, 2009.

Signature: Date:

/s/ Russel Randall, PhD February 28, 2009
Three Rivers Scientific

Figure D3. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument SD-Moist792

February 25, 2009

Moisture calibration was performed in the Hanford physical models. These standards have 6 and 8 inch ID casings. The Tank Farm Direct Push borehole is cased with a 2.5 inch outside diameter iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.5 inch borehole diameter.

2.51" borehole
a = .0002123
α = 2.010

The undersigned certifies that the analysis files are archived in the file "SD-Moist792_2009.zip" was evaluated in accordance with Energy Solutions procedures and that the above stated calibration coefficients are correct and applicable for tool SD-Moist792, effective February 25, 2009.

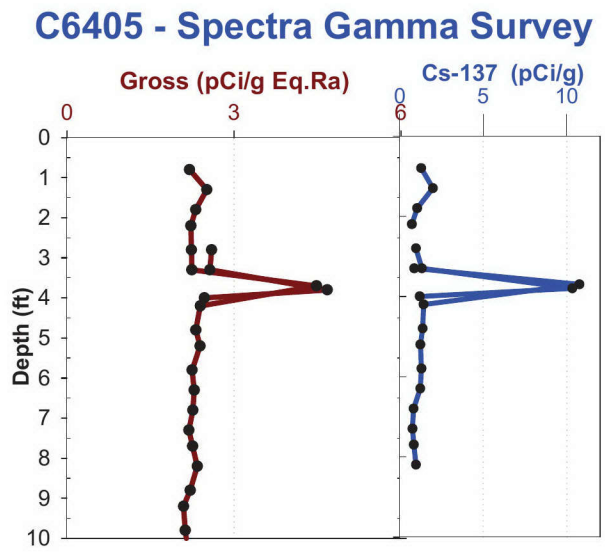
Signature: Date:

/s/ Russel Randall, PhD February 28, 2009
Three Rivers Scientific

D4.0 CS-137 CONTAMINATION ZONE IN PROBEHOLE C6405

At a quick glance, the contamination at 1.07 m (3.5 ft) for probehole C6405 looks like a thin zone. However, the distribution profile is not consistent with the normal profile for a thin zone. The observed depth profile is too thin for a uniformly distributed contamination zone.

Figure D4. Spectral Gamma Survey of C6405.

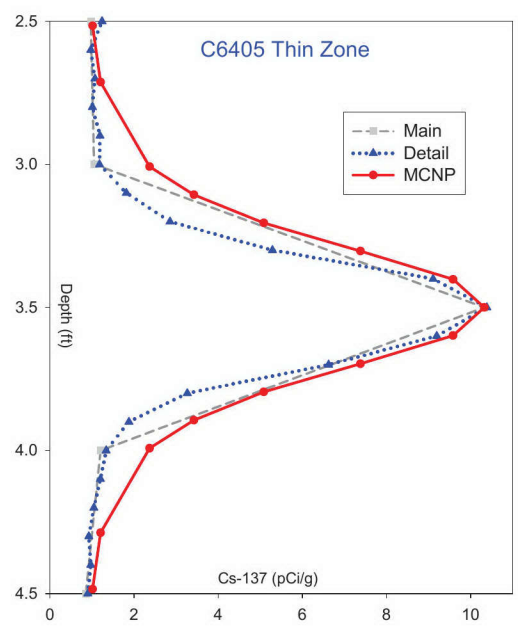


A short section of the BGO Spectral Gamma Survey for C6405 is shown in Figure D. The plot shows both the gross gamma count rate and Cs-137 concentration for the main log interval and the repeat section that was taken over the contamination interval.

The depth increment for a gamma survey is 0.15 m (0.5 ft) per depth sample location. The 0.15 m (0.5 ft) depth sample increment is specified to assure that a thin contamination zone would not be missed.

The Cs-137 contamination zone for probehole C6405 is represented by a single half foot depth sample location where the gamma activity is elevated above natural background. Normally a thin contamination zone is represented by at least two, and often three, depth sample locations with gamma count rates above the base line of the natural background radionuclides.

Figure D5. Compare Gamma Survey to MCNP



Given the unusual character of the spectral gamma survey in C6405, a detailed log survey was acquired with 0.03 m (0.1 ft) depth increment for the depth range of 0.76 m to 1.37 m (2.5 ft to 4.5 ft). Additionally, calculations were performed with a computer program to predict what the expected log survey profile would be for a thin contamination zone of Cs-137.

The calculations were performed using the Monte Carlo neutron photon (MCNP) computer modeling program. MCNP is the industry standard for predicting the characteristics of geophysical nuclear logging devices. The parameters supplied to MCNP are as follows.

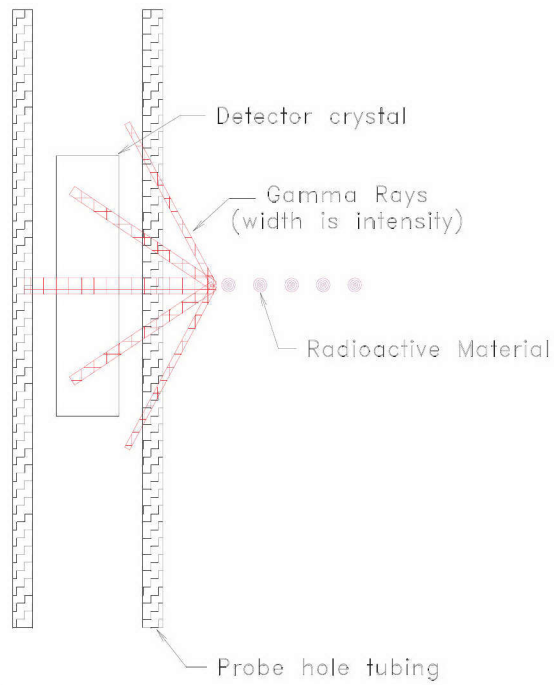
- Thin zone (0.03 m [0.1 ft] thick) of

Cs-137 contamination of infinite horizontal extent.

- Formation material, quartz sand (SiO_2) with the bulk density of 1.8 g/c^2 (0.06 oz/c^2) (which corresponds to vadose formation with 32% porosity).
- Detector (2.54 cm x 10.16 cm [1 in. x 4 in.]) BGO crystal.
- Casing (0.81 cm [0.32 in.] thick and 4.45 cm [1.75 in.] inside diameter).

The detailed gamma survey and MCNP calculation results are compared with the main gamma survey in Figure D5. The measurement location of the main log happened to occur at the location of the maximum gamma activity of the contamination zone. The detailed survey (0.03 m [0.1 ft] increment) confirms that the measured gamma activity has returned to background levels at 0.15 m (0.5 ft) away from the maximum count rate for this contamination zone. While the MCNP calculations show that at 0.15 m (0.5 ft) away from the maximum count rate, the log response would still be one-fifth of the maximum activity.

Figure D6. MCNP Model of Thin Zone.

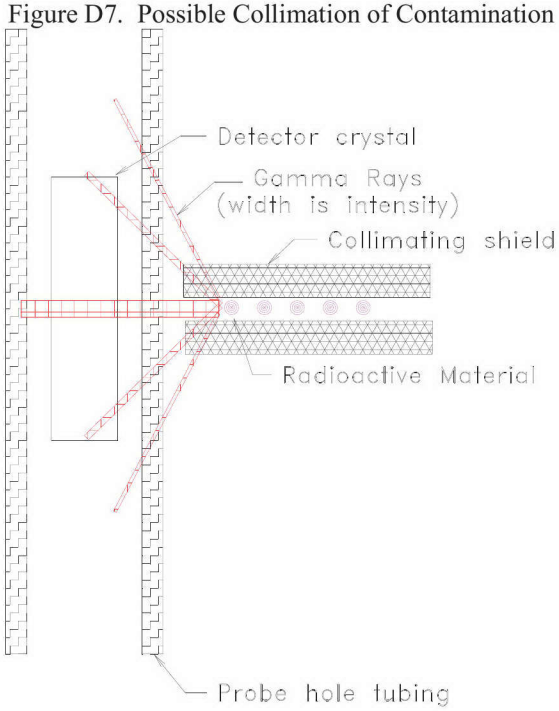


The MCNP calculation results show that the measured profile for this particular contamination zone is thinner than modeled. Measurements of the width of the log response plot at half of the maximum gamma activity show that the contamination zone at C6405 is four-fifths of the width that is characteristic of a thin zone. The only way to measure a thinner zone is for the source to be collimated.

A graphic model of MCNP calculation for thin zone is shown in Figure D6. The thickness (width) of the gamma rays' intensity (red) bars is intended to represent the reduced gamma ray activity that would result from attenuation as the gamma rays travel at higher angles, further through formation soils and steel casing of the probehole tubing to reach the detector crystal.

Figure D7 shows what a collimated source may look like to the gamma detector. A narrowed log profile would be measured when the radioactive material is collimated by higher density material both above and below the source, such as a box with an offset lid or a pipe with a crack.

Figure D7. Possible Collimation of Contamination



D5.0 REFERENCES

Meisner, James and Russel Randall, 1995, *Vadose Zone Moisture Measurement Through Steel Casing Evaluation*, WHC-SD-EN-TI-304, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Meisner, James, Randall Price, and Russel Randall, 1996, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, WHC-SD-EN-TI-306, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-RPT-42714, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR 241-C-103, PHASE 2

APPENDIX D

SMALL DIAMETER GEOPHYSICAL LOGGING FOR 241-C-103, PHASE 2

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APPENDIX
SMALL DIAMETER GEOPHYSICAL LOGGING FOR 241-C-103, Phase 2

Randall Price
Pacific Northwest Geophysics
4200 West 19th Avenue
Kennewick, Washington 99338

Russel Randall, PhD
Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

TERMS

Bgs	Below ground surface
OD	outside diameter
PNG	Pacific Northwest Geophysics
VF	Volume Fraction (percent) of Moisture content

1 PROBEHOLE SURVEYS

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in two probeholes for the phase II characterization study of the 241-C-103 investigation site, in the C Tank Farm.

Logging surveys were conducted with a Bismuth Germinate (BGO) spectral gamma scintillation detector and a neutron-neutron moisture probe from the bottom of each probehole (maximum survey depth) to the ground surface. Zero depth reference is at the ground surface. The survey results for each probehole are presented as a depth versus concentration plot.

A repeat measurement was acquired to verify instrument repeatability. The computed results of the main and repeat intervals were reviewed and the results agree within the uncertainty of the measurement counting statistics. The repeat intervals are presented with the main log plot.

Table 1 below contains a summary of the survey results for each probehole: maximum log depth, maximum detection level for Cs-137.

Table 1. Probehole Survey Summary.

Hole	Hole Depth (meters)	Hole Depth (feet)	Spectral Observations	Cs-137 (pCi/g) Max Detection
C7465	61.7	202.5	Cs-137 observed 5.8ft to surface	53 pCi/g at 0.5 ft
C7467	52.7	173	Cs-137 observed 2ft to 0.5ft	5.5 pCi/g at 0.8 ft

Detector calibration certificates are presented in sections 2 (Spectral Gamma) and 3 (Neutron Moisture).

The log survey results follow. The log plots show a maximum of 100 feet per page with a 10 ft overlap between page breaks.

C-FARM C7465 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7465	Log Date:	Jul 2009
Project:	C Farm	Depth Ref:	Ground Surface

REPEAT/OVERLAP INTERVALS

Spectral:	156-152	Moisture	145-139
	98-93		90-79
	57-53		10-0
	44-39		
	4-1		

ISOTOPES ANALYZED

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

OBSERVATIONS

Spectral:

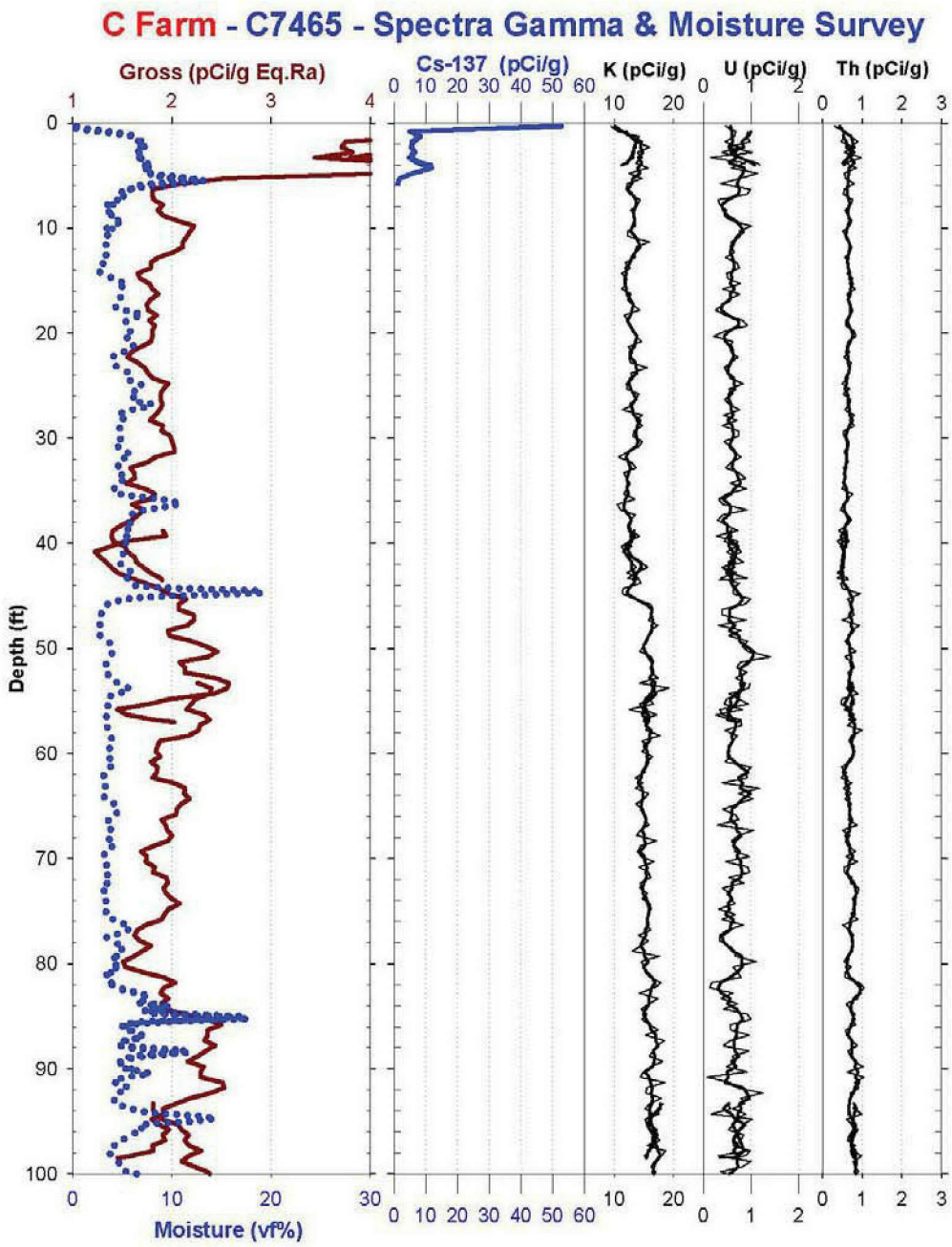
Cs-137 observed from 5.8ft to surface. Maximum Cs-137 is 53 pCi/g at 0.5ft, and the next maximum is 12 pCi/g at 4.5ft. The gross maximum is 21 Eq Ra-226 at 0.5ft and 6.2 Eq Ra-226 at 4.5ft. The gross response reflects the KUT and Cs-137 concentrations.

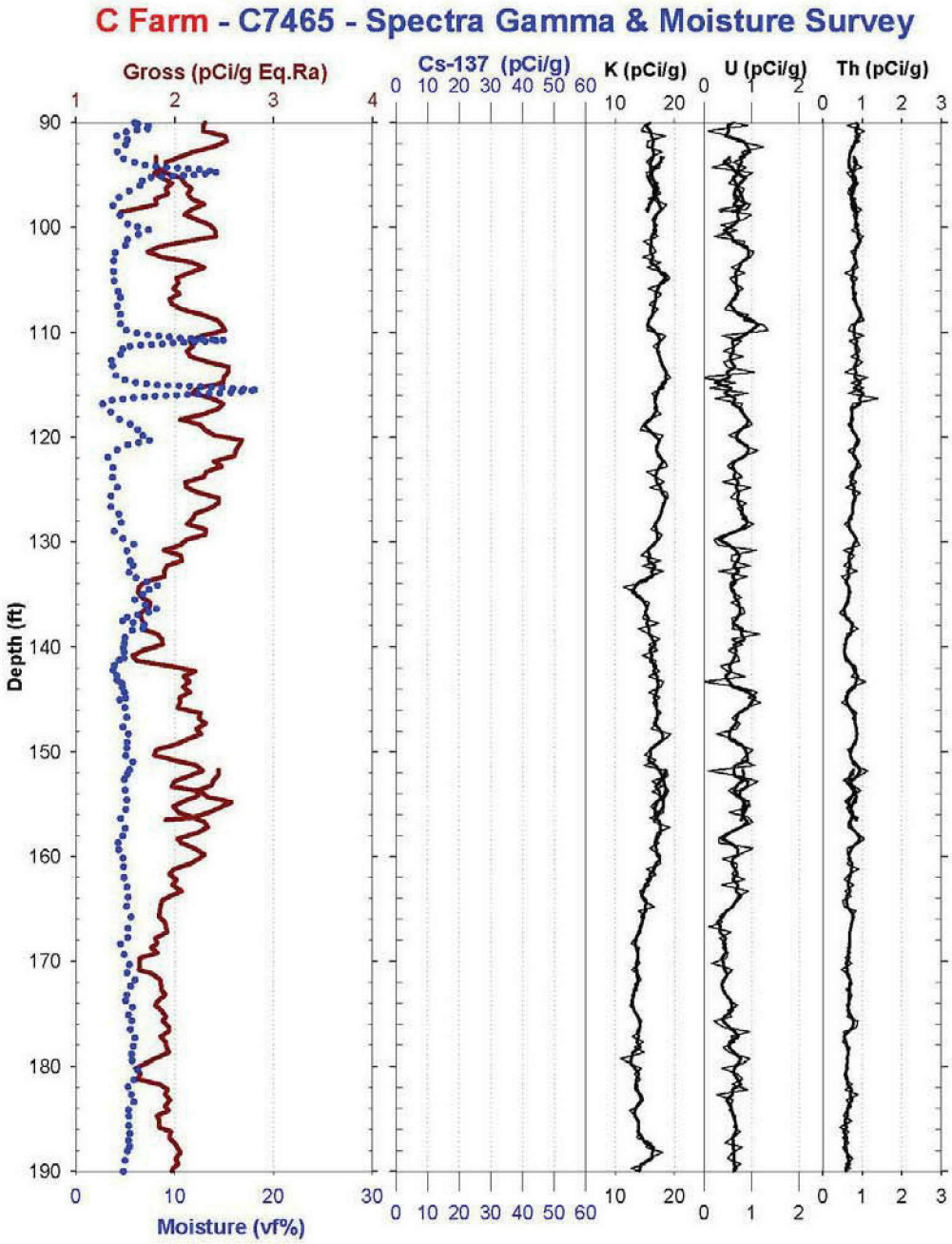
Moisture:

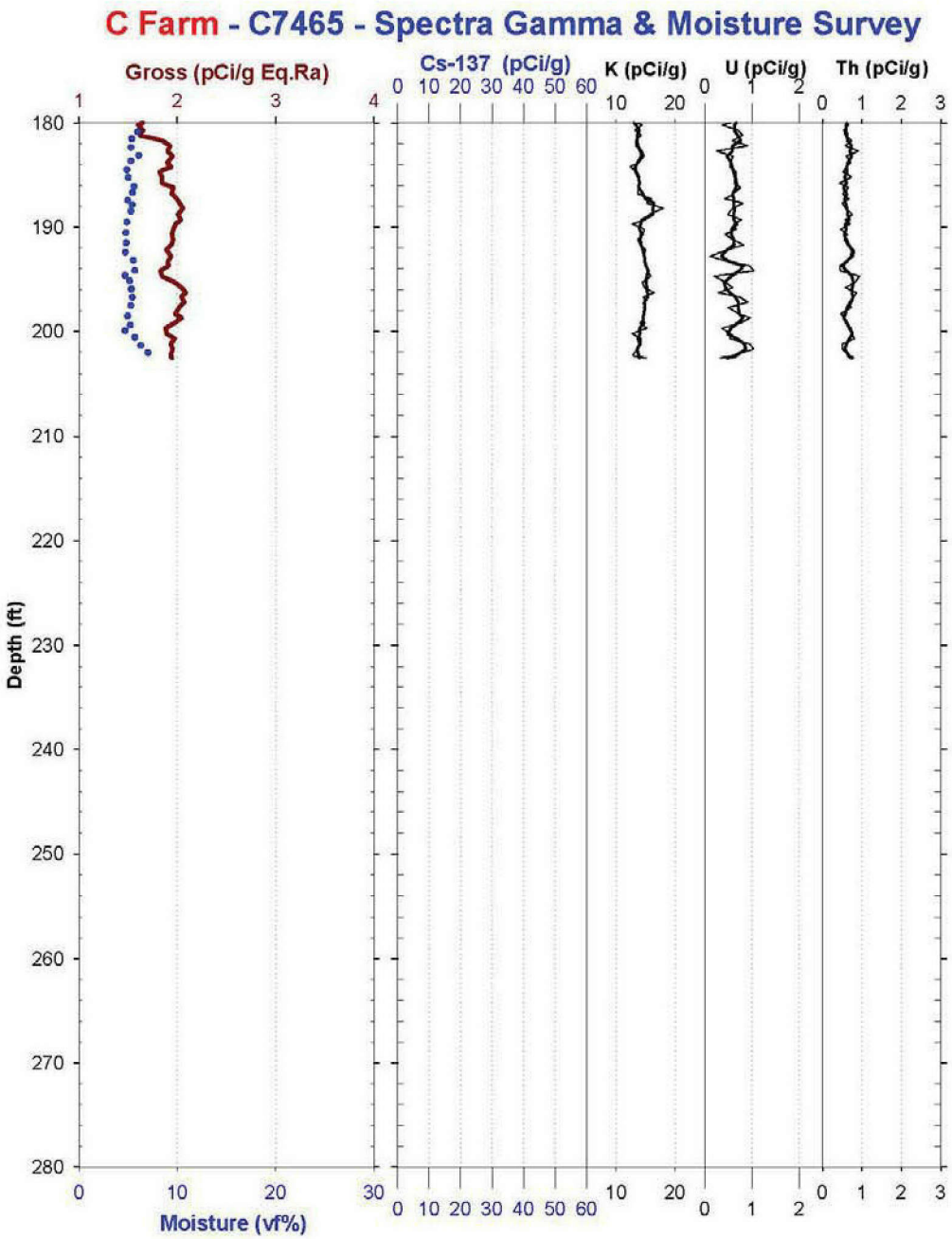
Moisture values range from 2.5-19.0%.

CALIBRATION CERTIFICATES

Spectral	
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip
Moisture	
Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C Farm - C7465 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C Farm - C7465 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C Farm - C7465 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7467 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7467	Log Date:	Jul 2009
Project:	C Farm	Depth Ref:	Ground Surface

REPEAT/OVERLAP INTERVALS

Spectral:	140-138	Moisture	100-90
	122-118		53-48
	105-103		47-40
	46-45		22-17

ISOTOPES ANALYZED

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

OBSERVATIONS

Spectral:

Cs-137 observed from 2-.5Ft. Maximum Cs-137 is 5.5 pCi/g at 1ft. The gross maximum is 3.2 Eq Ra-226 at 1ft. The gross response reflects the KUT and Cs-137 concentrations.

Moisture:

Moisture values range from 2.3-19.5%.

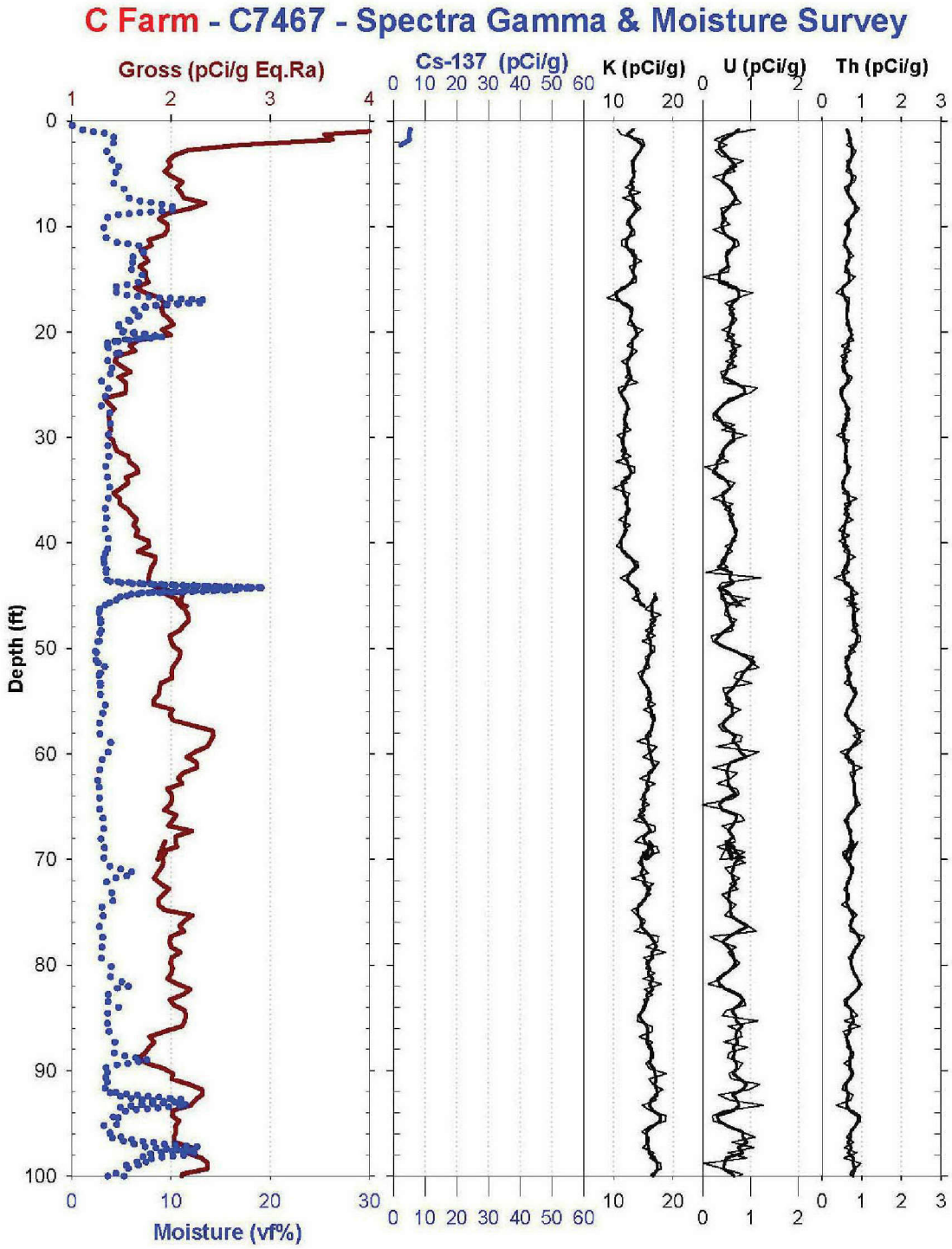
CALIBRATION CERTIFICATES

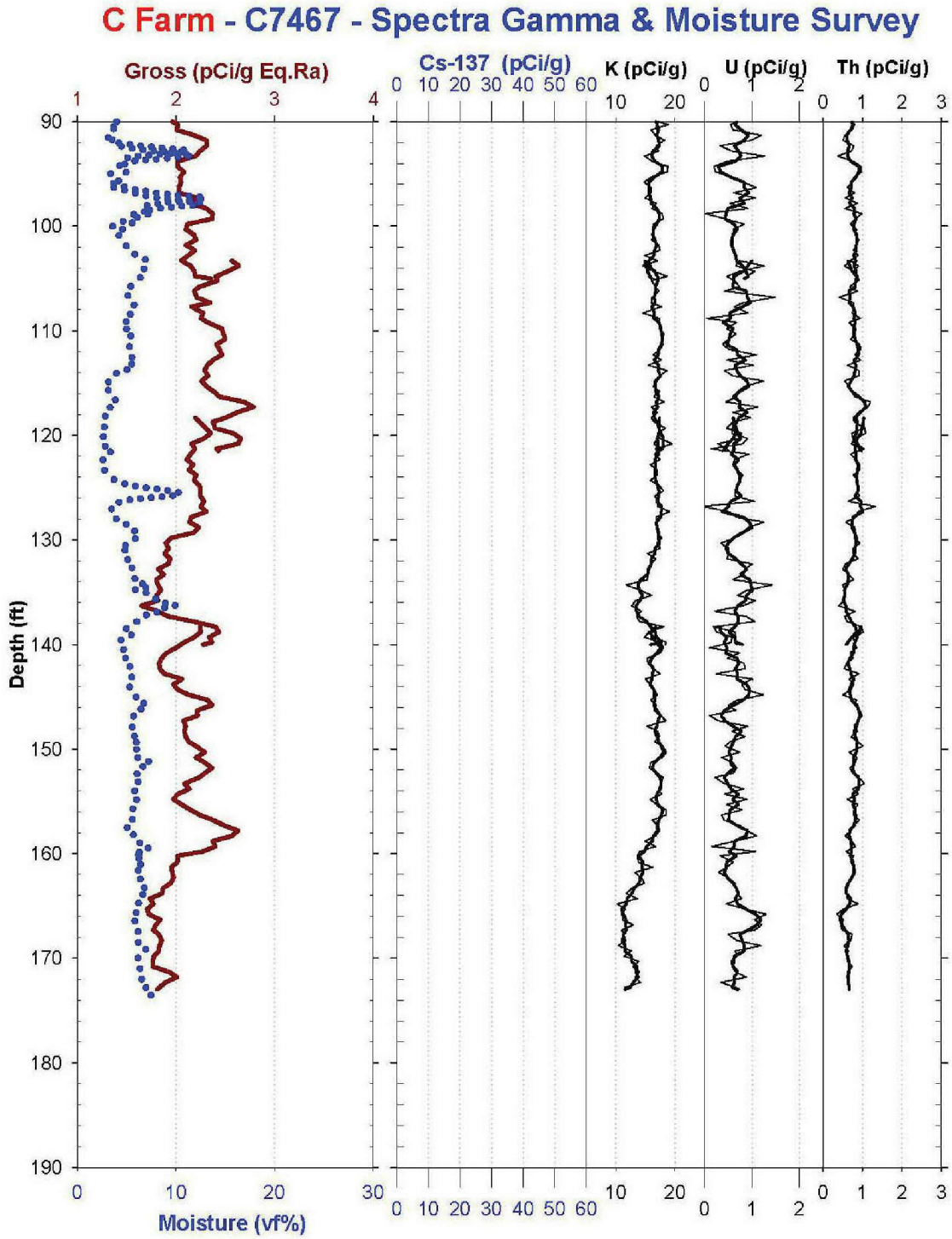
Spectral

Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C Farm - C7467 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C Farm - C7467 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

2 SPECTRAL GAMMA CALIBRATION

The objective of the gamma survey logs was to identify depth intervals with elevated gamma activity (i.e., Cs-137 at concentrations greater than 2 pCi/g). The BGO spectral survey (100 seconds per 0.5 ft) have a minimum detection level (MDL) of 1 pCi/g for Cs-137.

The spectral gamma scintillation detector uses a BGO crystal that is 2.54 cm [1 in.] diameter by 10.1 cm [4 in.] long. The gamma ray spectra with a measurement time of 100 seconds were collected each 0.15 m (0.5 ft) from the bottom of the probehole to the surface. The spectra records gamma ray energies between 200 and 2800 keV in a 256 channel spectra. Spectra were processed to quantify the concentration of the naturally occurring radionuclides (K, U, & Th) and quantify Cs-137 when present above the minimum detection threshold. The calibration certificate is shown in Figure 1.

3 NEUTRON MOISTURE CALIBRATION

The moisture detector measures the density of hydrogen (moisture) in subsurface soils. The units of measure are percent volume fraction (% vf) moisture. Calibration was performed in six borehole calibration models (Meisner and Randall 1995). Three of these models had a 15.24 cm (6-in.) hole size and three models had a 20.32 cm (8-in.) hole size. The calibration certificate for these two hole-sizes is presented in Figure 2.

The probehole size for this project was 6.35 cm (2.5 in.) outside diameter (OD). Therefore, the moisture calibration was extrapolated to the correct hole size. Figure 3 shows the moisture calibration certificate for the 6.35 cm (2.5-in.) hole size.

The probehole moisture survey was collected at 0.61 m/min (2 ft/min) or slower. Processing of the survey data requires that the detector raw survey data be normalized to the thickness of the steel casing present in the calibration models (0.325 in.) Given that the probehole casing thickness is 0.94 cm (0.37 in.), a correction factor of 1.055 is required to increase (normalize) the observed neutron detector count rate to the conditions of the calibration model (Meisner et al. 1996).

Figure 1. BGO Calibration Certificate.

Certificate of Calibration
SDGR.BGO.2
Apr 21, 2009

Data were taken at the Hanford KUT models on April 21, 2009. SDGR.BGO.2 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Ten spectra were recorded for each model in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: AveOut2.XLS for this analysis. The instrument was covered with 0.37 inch wall thickness probe tubing.

The algorithm described in the document WHC-SD-EN-TI-293, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1320-1575 keV **U: 1650-2390 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**4.712*K**	**-4.297*U**	**4.057*T**
Concentration-U =	**0.0*K**	**1.431*U**	**-2.998*T**
Concentration-T =	**0.0*K**	**-0.052*U**	**2.032*T**

Where K U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_SD-GR-2_2009-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_SD-GR-2_2009-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-293, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models" and that the above stated calibration coefficients are correct and applicable for the tool SDGR.BGO.2 effective April 21, 2009.

Signature: Date:

/s/ Russel Randall, PhD April 23, 2009
Three Rivers Scientific

Figure 2. Moisture Calibration Certificate, 15.24 cm (6-in.) and 20.32 cm (8-in.) Hole.

Certificate of Calibration for
Instrument SD-Moist792

February 25, 2009

Data were taken in the Moisture models on February 25, 2009 for SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H370608792 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, 3 for 6"casing and 3 for 8" casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation, refer to the file MoistCal.xls for this analysis.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	**8" casing**
a = .0001586	**a = .00008287**
α = 2.229	**α = 2.504**

The undersigned certifies that the data archived in data file "SD-Moist792_2009.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-306, "Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration" and that the above stated calibration coefficients are correct and applicable for tool SD-Moist792, effective February 25, 2009.

Signature:	Date:
/s/ Russel Randall, PhD Three Rivers Scientific	February 28, 2009

Figure 3. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument SD-Moist792

February 25, 2009

Moisture calibration was performed in the Hanford physical models. These standards have 6 and 8 inch ID casings. The Tank Farm Direct Push borehole is cased with a 2.5 inch OD iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.5 inch borehole diameter.

2.51" borehole
a = .0002123
α = 2.010

The undersigned certifies that the analysis files are archived in the file "SD-Moist792_2009.zip" was evaluated in accordance with Energy Solutions procedures and that the above stated calibration coefficients are correct and applicable for tool SD-Moist792, effective February 25, 2009.

Signature: Date:

/s/ Russel Randall, PhD February 28, 2009
Three Rivers Scientific

4 REFERENCES

Meisner, James and Russel Randall, 1995, *Vadose Zone Moisture Measurement Through Steel Casing Evaluation*, WHC-SD-EN-TI-304, Rev.0, Westinghouse Hanford Company, Richland, Washington.

Meisner, James, Randall Price, and Russel Randall, 1996, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, WHC-SD-EN-TI-306, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Price, Randall, 2008, *Procedures: Calibration, Logging, Quality Assurance and Data Management*, Pacific Northwest Geophysics, Kennewick, Washington.

R. Randall and D. Stromswold, 1995, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models", WHC-SD-EN-TI-293, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

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DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-RPT-47461, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR PHASE 2, 241-C TANK FARM CHARACTERIZATION, THREE SITES

APPENDIX D

SMALL DIAMETER GEOPHYSICAL LOGGING FOR PHASE TWO, 241-C TANK FARM CHARACTERIZATION, THREE SITES

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SMALL DIAMETER GEOPHYSICAL LOGGING FOR PHASE TWO 241-C TANK FARM CHARACTERIZATION, THREE SITES

by

Russel Randall, PhD and Randall Price

to

Energy*Solutions* Federal Services, Inc.
2345 Stevens Drive
Richland, Washington 99354

January 2010

Pacific Northwest Geophysics
4200 West 19th Avenue
Kennewick, Washington 99338

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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TERMS

BGO	Bismuth Germinate
KUT	potassium, uranium and thorium
PNG	Pacific Northwest Geophysics

SMALL DIAMETER GEOPHYSICAL LOGGING FOR PHASE TWO 241-C TANK FARM CHARACTERIZATION, THREE SITES

1.0 PROBEHOLE SURVEYS

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in probeholes installed at three sites of the Phase 2 Characterization of the 241-C Tank Farm.

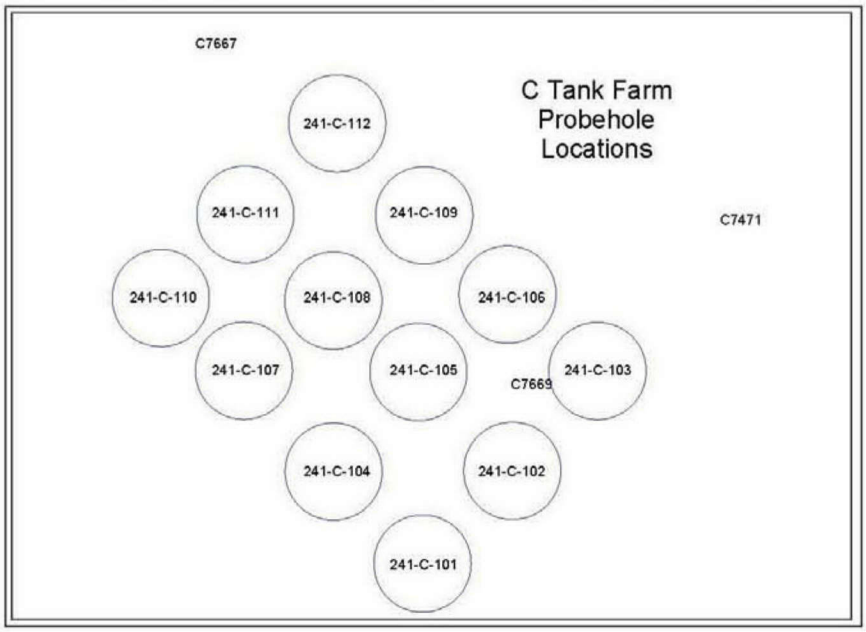
Logging surveys were conducted in three small diameter probeholes with a Bismuth Germinate (BGO) spectral gamma scintillation detector and a neutron-neutron moisture probe. Detector calibration certificates for the BGO and neutron-moisture detectors are presented in Section 2.0, "Gamma and Moisture Surveys." The survey results for each probehole are presented in Appendix A.

2.0 GAMMA AND MOISTURE SURVEYS

The gamma and moisture logs were collected according to approved procedures (PNG 2009). The surveys were recorded from the bottom of the probehole (maximum survey depth) to the ground surface. Zero depth reference is at the ground surface. A repeat measurement was acquired daily in at least one probehole to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed and for all of the intervals collected, the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probehole are presented as a depth–versus-concentration plot in Appendix A. The plots are in numeric order of the probeholes (C7471 – C7669). Appendix A also contains a table summarizing data for each probehole: probehole depth, maximum concentration of Cs-137 in pCi/g, and maximum detected depth of Cs-137. Figure 1 shows a map view of the approximate probehole locations relative to the underground storage tanks within the investigation site.

Figure 1. Location of Three Probeholes in the 241-C Tank Farm Phase 2 Characterization.



2.1 GAMMA CALIBRATION AND SURVEYS

The spectral gamma scintillation detector uses a BGO crystal that is 2.54 cm (1 in.) in diameter by 10.1 cm (4 in.) long. Other components of the gamma logging probe are the high-voltage supply, photo-multiplier tube, pre-amp, and multi-channel analyzer. The settings of the detector components are fixed (i.e., set up during assembly, prior to calibration) and cannot be adjusted by the field-logging engineer. The detector gain and lower threshold are set to record gamma ray activity with energies between 200 and 3000 keV. Lantern mantles containing Th-232 are used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (integrity) and energy calibration (amplifier gain).

The spectral gamma surveys were logged at 100 seconds per 0.15 m (0.5 ft). A spectrum of 256 channels was collected each 0.15 m (0.5 ft) from the bottom of the probehole to the surface. The spectra were recorded in Ortec[1] PHA format with one spectrum per file (filename extension: "-.chn"). Spectra were processed to quantify the concentration of the naturally occurring radionuclides (K, U, & Th) and quantify Cs-137 when present above the minimum detection threshold. The minimum detection level (MDL) for Cs-137 is 1 pCi/g. The calibration certificate is shown in Figure 2. Also the gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in pCi/g. Calibration was for the probehole conditions present at the investigation site.

[1]Ortec is a registered trademark of EG&G Ortec, Gouda, Netherlands.

2.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS

The neutron moisture sonde combines the PNG-owned thermal-neutron detector and a DOE-owned sealed neutron source (50 mCi AmBe). The DOE-owned neutron source was used because it was already on the Hanford Site and was managed by the DOE Radiation Management Program. The neutron source is an integral component of a neutron moisture detector, manufactured by Campbell Pacific Nuclear, and is identified by the tool serial number H370608792.

The integrity of the sealed neutron source is always maintained when used in calibration and probehole logging activities. Source integrity is maintained by inserting the PNG-owned neutron detector module into the housing containing the sealed neutron source.

Calibration was performed in six borehole calibration models (Meisner and Randall 1995). Three of these models had a 15.24 cm (6-in.) hole size and three models had a 20.32 cm (8-in.) hole size. The moisture content was different for each borehole model within each set of three models (5, 12, and 20 percent by volume). The detector count rate in each of the six borehole calibration models is summarized in Table 1. The calibration certificate is shown in Figure 3.

Table 1. Moisture Calibration Data.

Moisture Content Percent – volume fraction	6-inch Models[a] (cps)	8-inch Models[a] (cps)
5% vf	103.87	81.1
12% vf	155.11	114.92
20% vf	191.9	140.17

[a]Count rates are mean of 10 sample measurements at 60-sec each, 2/25/2009.

The probehole size for this project was 6.35 cm (2.5 in.) outside diameter (OD). Therefore, the moisture calibration was extrapolated to the correct hole size. Figure 4 shows the moisture calibration certificate for the 6.35 cm (2.5-in.) hole size.

The probehole moisture survey was collected at 0.30 m/min (1 ft/min). Processing of the survey data requires that the detector raw survey data be normalized to the thickness of the steel casing present in the calibration models (0.826 cm [0.325 in.]) Given that the probehole casing thickness is 0.97 cm (0.38 in.), a correction factor of 1.055 is required to increase (normalize) the observed neutron detector count rate to the conditions of the calibration model (Meisner et al. 1996).

Figure 2. BGO Calibration Certificate.

Certificate of Calibration
SDGR.BGO.2
April 21, 2009

Data were taken at the Hanford KUT models on April 21, 2009. SDGR.BGO.2 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Ten spectra were recorded in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: AveOut2.XLS for this analysis. The instrument was covered with 0.94 cm (0.37-inch) wall thickness probe tubing.

The algorithm described in WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, Rev. 0, determines the coefficient analysis. The following three energy windows are used for each of the KUT radionuclides:

K: 1320-1575 keV **U: 1650-2390 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**4.712*K**	**-4.297*U**	**4.057*T**
Concentration-U =	**0.0*K**	**1.431*U**	**-2.998*T**
Concentration-T =	**0.0*K**	**-0.052*U**	**2.032*T**

Where K, U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_SD-GR-2_2009-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_SD-GR-2_2009-v0.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-293 and that the above stated calibration coefficients are correct and applicable for the SDGR.BGO.2 tool effective April 21, 2009.

Signature:

/s/ Russel Randall, PhD April 23, 2009
Three Rivers Scientific

Figure 3. Moisture Calibration Certificate, 15.24 cm (6-in.) and 20.32 cm (8-in.) Hole.

Certificate of Calibration for
Instrument SD-Moist792

February 25, 2009

Data were taken in the Moisture models on February 25, 2009, for SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool #H370608792 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, three for 6-in. casing and three for 8-in. casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation; refer to the file MoistCal.xls for this analysis.

The coefficient generation is determined by the algorithm described WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6-in. casing	**8-in. casing**
a = .0001586	**a = .00008287**
α = 2.229	**α = 2.504**

The undersigned certifies that the data archived in data file "SD-Moist792_2009.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-306 and that the above-stated calibration coefficients are correct and applicable for the SD-Moist792 tool, effective February 25, 2009.

Signature:

/s/ Russel Randall, PhD February 28, 2009
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument SD-Moist792

February 25, 2009

Moisture calibration was performed in the Hanford physical models. These standards have 6-in. and 8-in. ID casings. The Tank Farm Direct Push borehole is cased with a 5.08 cm (2.5-in.) outside diameter iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 5.08 cm (2.5-in.) borehole diameter.

2.51-in. borehole
a = .0002123
α = 2.010

The undersigned certifies that the analysis files archived in the file "SD-Moist792_2009.zip" were evaluated in accordance with Energy*Solutions* procedures and that the above-stated calibration coefficients are correct and applicable for the SD-Moist792 tool, effective February 25, 2009.

Signature:

/s/ Russel Randall, PhD — February 28, 2009
Three Rivers Scientific

3.0 REFERENCES

Meisner, James and Russel Randall, 1995, *Vadose Zone Moisture Measurement Through Steel Casing Evaluation*, WHC-SD-EN-TI-304, Rev.0, Westinghouse Hanford Company, Richland, Washington.

Meisner, James, Randall Price, and Russel Randall, 1996, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, WHC-SD-EN-TI-306, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

PNG, 2009, *Procedures: Calibration, Logging, Quality Assurance and Data Management*, Pacific Northwest Geophysics, Kennewick, Washington.

Randall, R. and D. Stromswold, 1995, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, WHC-SD-EN-TI-293, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A
SPECTRAL GAMMA AND MOISTURE SURVEY RESULTS

Survey plots follow for the three probeholes installed for the C Tank Farm Phase 2 Characterization. Each probehole was surveyed with both the BGO spectral gamma and moisture probes. Each log plot is preceded by a header information page that shows the repeat/overlap intervals, isotopes analyzed, observations, and logging probe calibration dates. The log plots show a maximum of 100 feet per page with a 10-ft overlap between page breaks.

The spectral gamma survey data were processed to quantify the naturally occurring radionuclides (K, U, & Th), and the man-made radionuclide of Cs-137 (blue solid line). The spectra were processed both as individual spectra for each survey depth and as a moving sum of three spectra (i.e., sum of the individual survey depth and the two adjacent spectra, above and below the current depth position). Both results are presented on the results plot. The results for the 3-spectra sum are plotted as a wide line. Also the gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in a scale of 1 to 5 pCi/g (brown line).

The neutron-neutron moisture survey data are shown with a blue dotted line. The moisture plot scale is 0–40 (% vf).

Table A1 contains a summary of the survey results for each probehole: maximum log depth, maximum detection level for Cs-137, maximum depth of Cs-137 detection, and special observations by the analyst to flag the detection of other isotopes in addition to the natural radionuclides and Cs-137.

Table A1. Probehole Survey Summary.

Probehole ID.	Hole Depth (meters)	Hole Depth (feet)	Cs-137 (pCi/g) Max Detection	Cs-137 Max Detected Depth	Flag Isotopes Other Than Naturals and Cs-137
C7471	67.8	222.5	3.6 pCi/g at 1 ft	5 ft	None
C7667	67.7	222	722 pCi/g at 13.5 ft	13.5 ft	None
C7669	67.7	222	11 pCi/g at 0.5 ft	5.5 ft	None

C-FARM C7471 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7471	Log Date:	Dec 2009
Project:	C Farm	Depth Ref:	Ground Surface

Repeat/Overlap Intervals

Spectral:	181-178	Moisture	80-85
	164-167		80-85
	76-82		
	80-83		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

Cs-137 observed at two locations, one near the surface and at 5 ft. The maximum content (3.6 pCi/g) of Cs-137 was measured at 1 ft. The concentration of Cs-137 at 5 ft is at the MDL level of 1 pCi/g

Moisture:

Moisture values range from 1.9–22.9%. There are several zones from 90 to 132 ft that have higher moisture content.

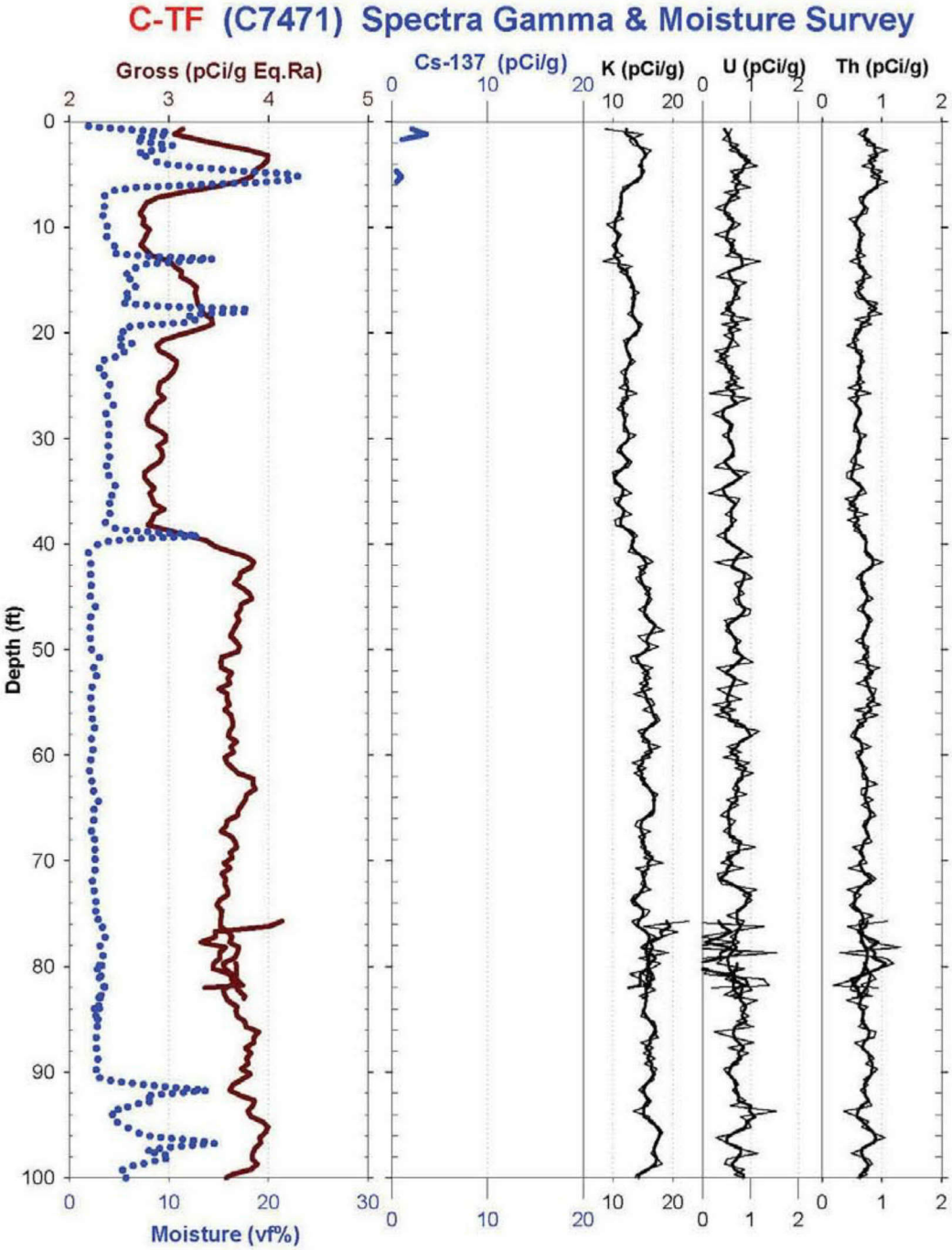
Calibration Certificates

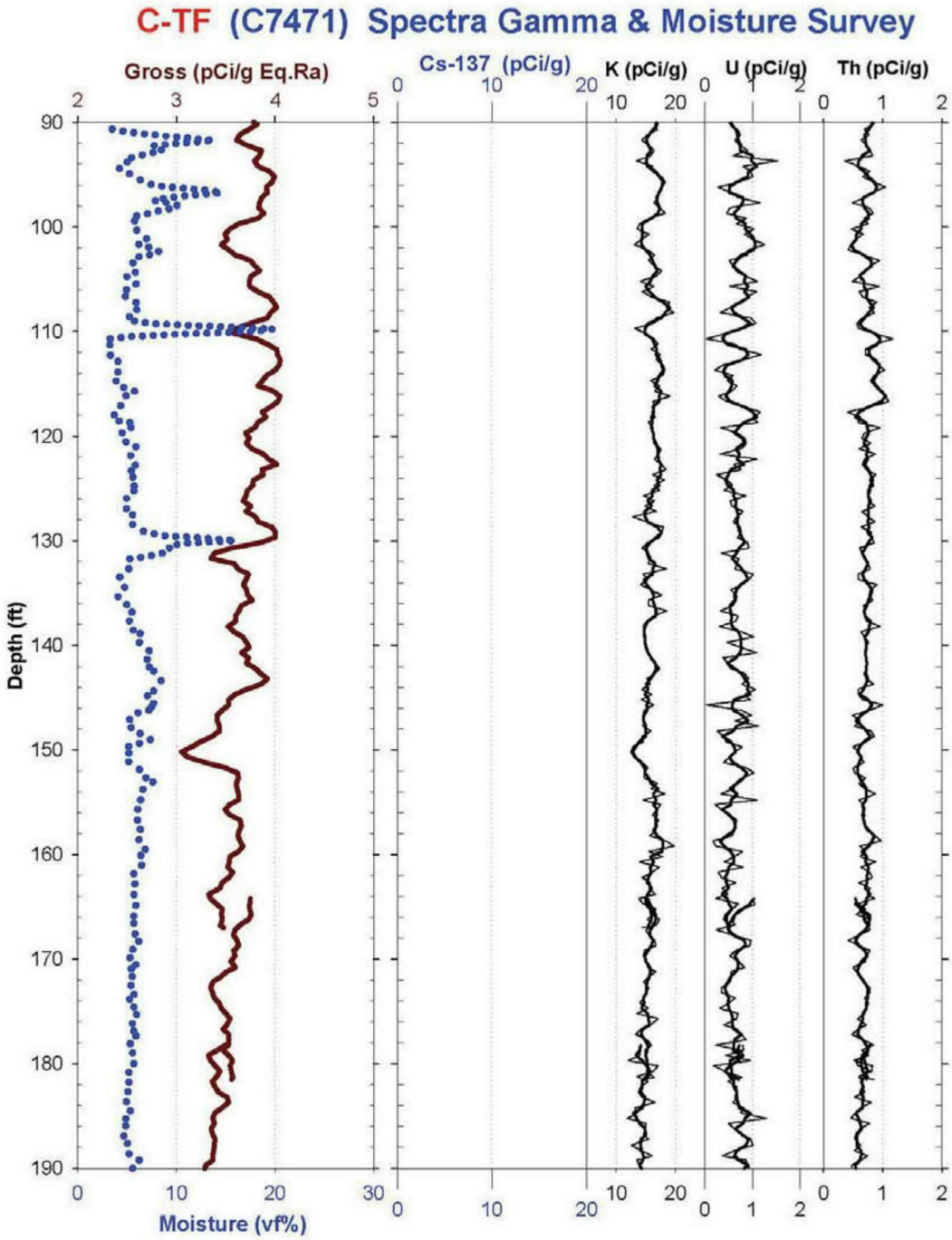
Spectral

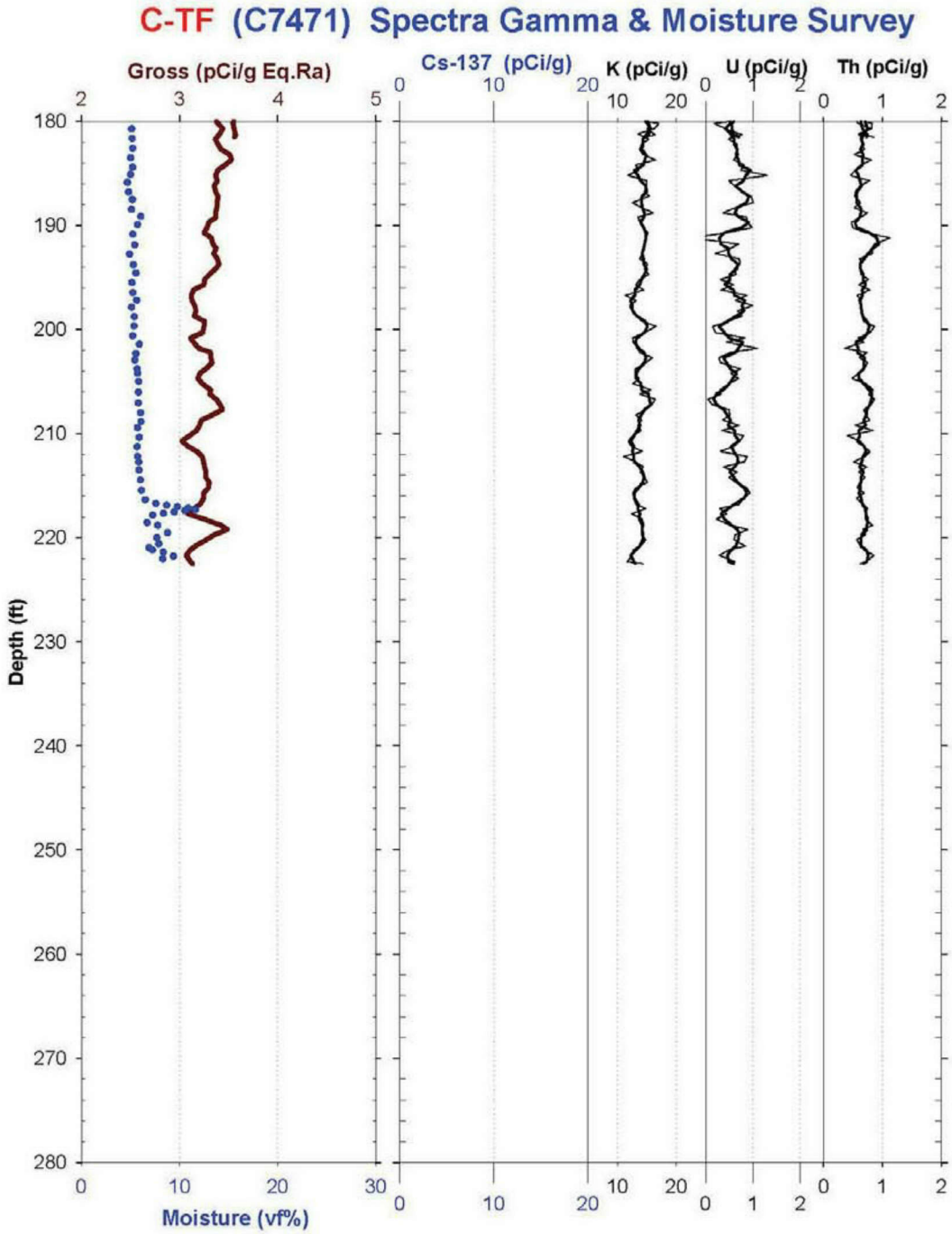
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C-TF (C7471) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C-TF (C7471) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C-TF (C7471) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7667 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7667	Log Date:	Dec 2009
Project:	C Farm	Depth Ref:	Ground Surface

Repeat/Overlap Intervals

Spectral:	136-134	Moisture	102-95
	70-66		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

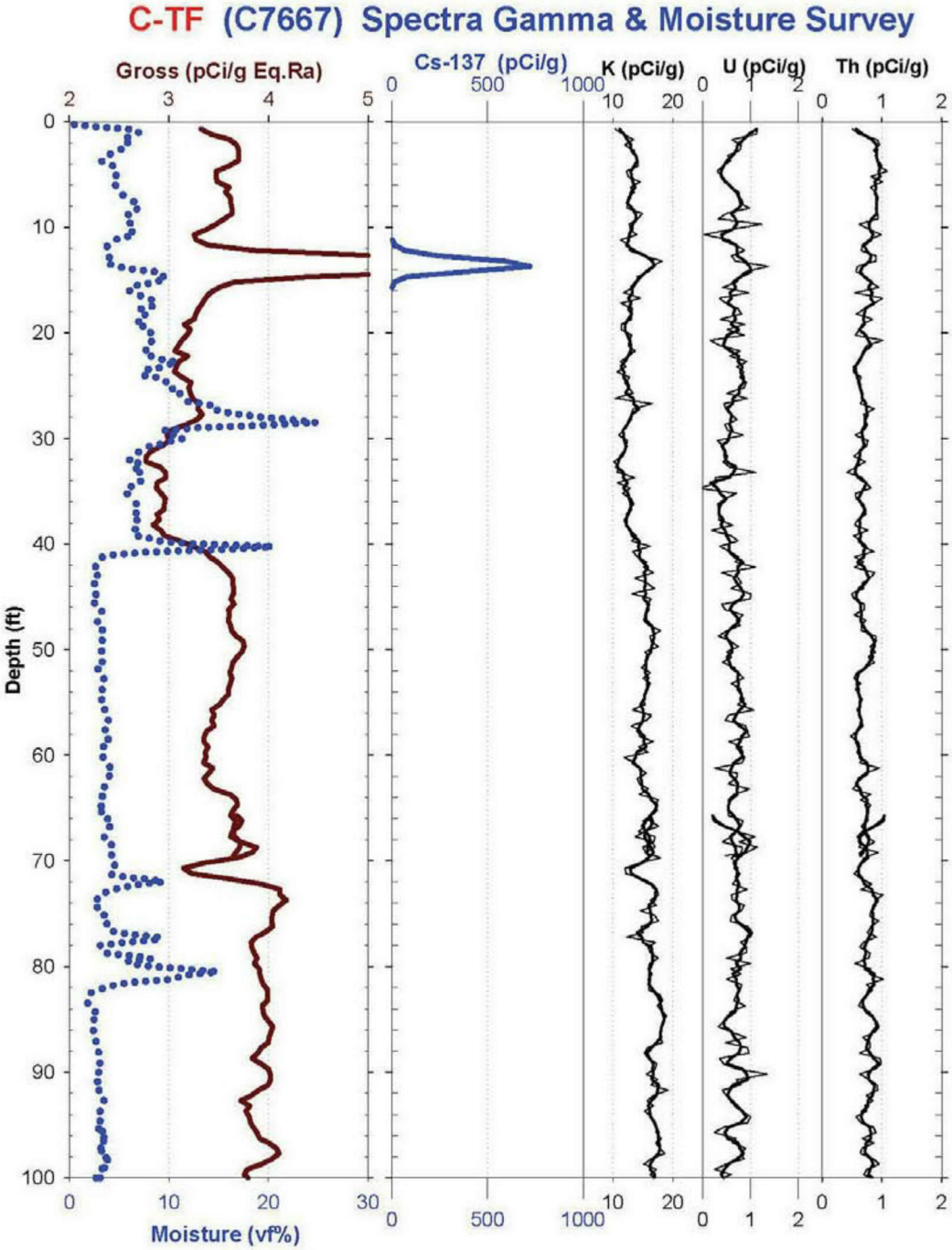
Cs-137 observed at the surface and over the interval 11.2 to 15.7 ft. The spectral signature over the entire depth of 11.2 to 15.7 ft is due to a strong Cs-137 source removed from the borehole vicinity. Maximum Cs-137 reading is 722 pCi/g, but the true levels are much higher due to the remote signal and non-uniform distribution.

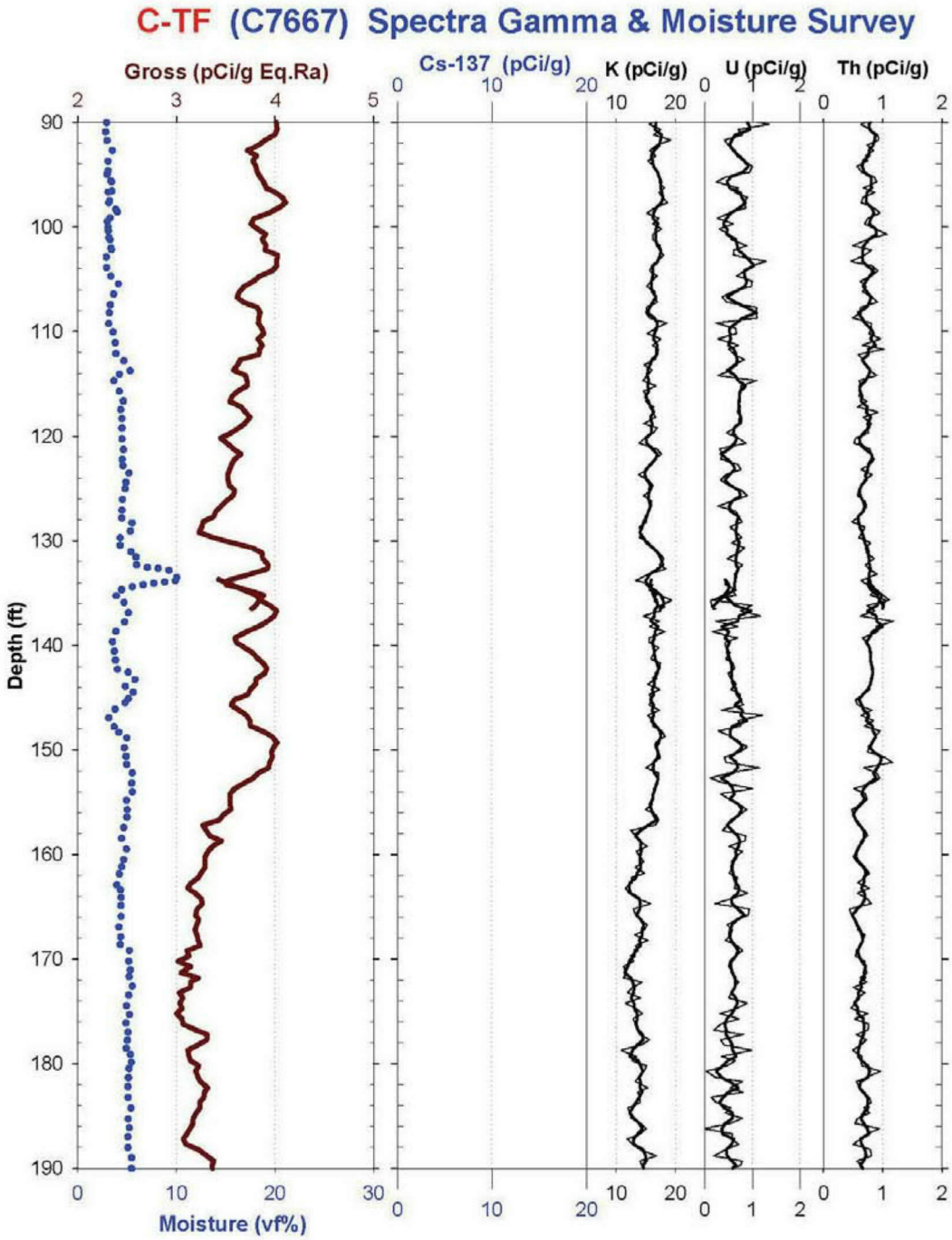
Moisture:

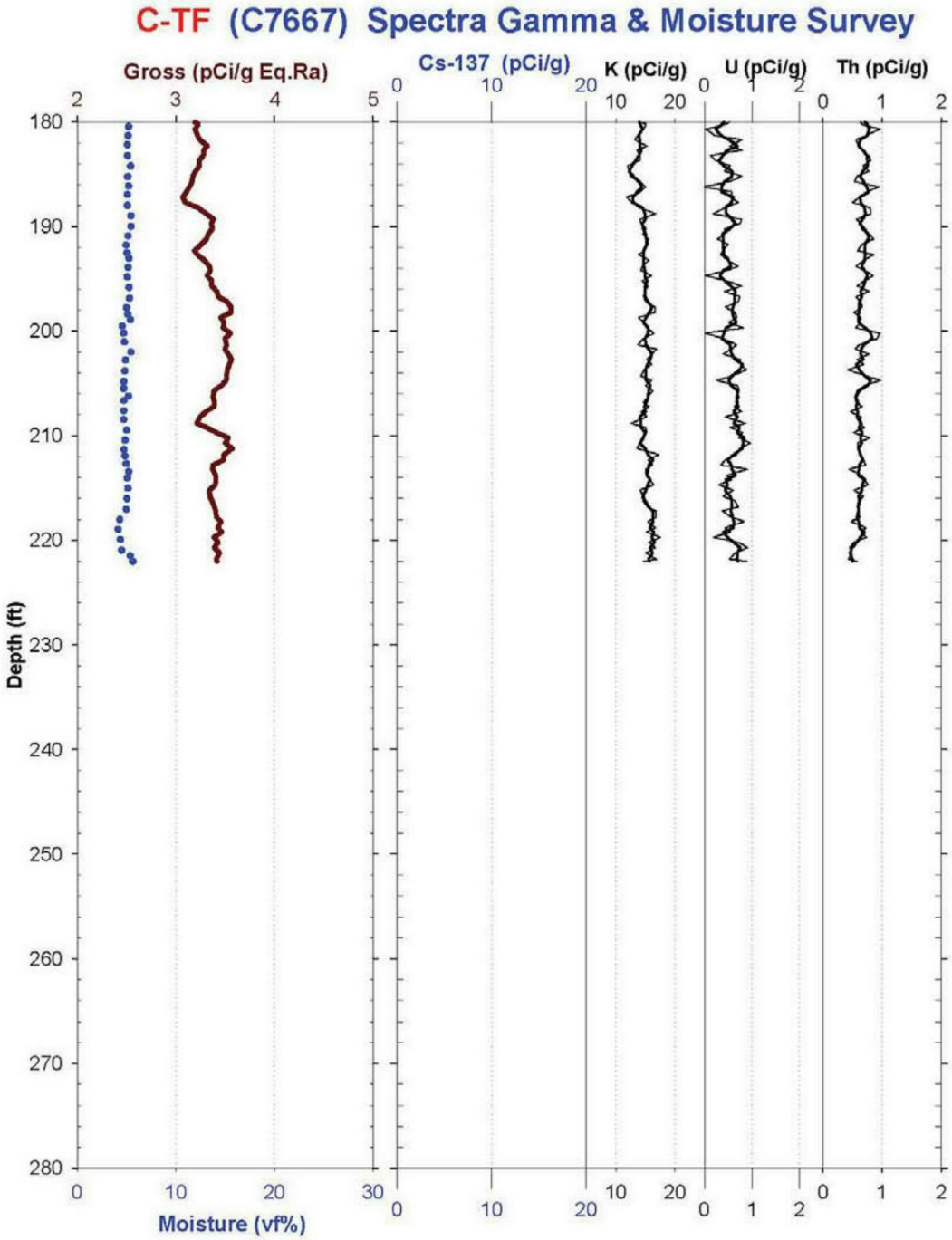
Moisture values range from 1.7-24.8%. The moisture response from 85ft to the bottom is low and there are no high moisture content zones.

Calibration Certificates

Spectral	
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip
Moisture	
Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C-TF (C7667) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C-TF (C7667) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C-TF (C7667) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7669 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7669	Log Date:	Dec 2009
Project:	C Farm	Depth Ref:	Ground Surface

Repeat/Overlap Intervals

Spectral:	137-134	Moisture	139-144
	62-66	55-59	

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

Cs-137 observed at two locations, one near the surface and at 5.5 ft. The maximum content (11 pCi/g) of Cs-137 was measured at the last survey depth of 0.5ft. The concentration of Cs-137 at 5.5 ft is at the MDL level of 1 pCi/g

Moisture:

Moisture values range from 1.5-16.8%. The moisture response from 90ft to the bottom is low and there are no high moisture content zones.

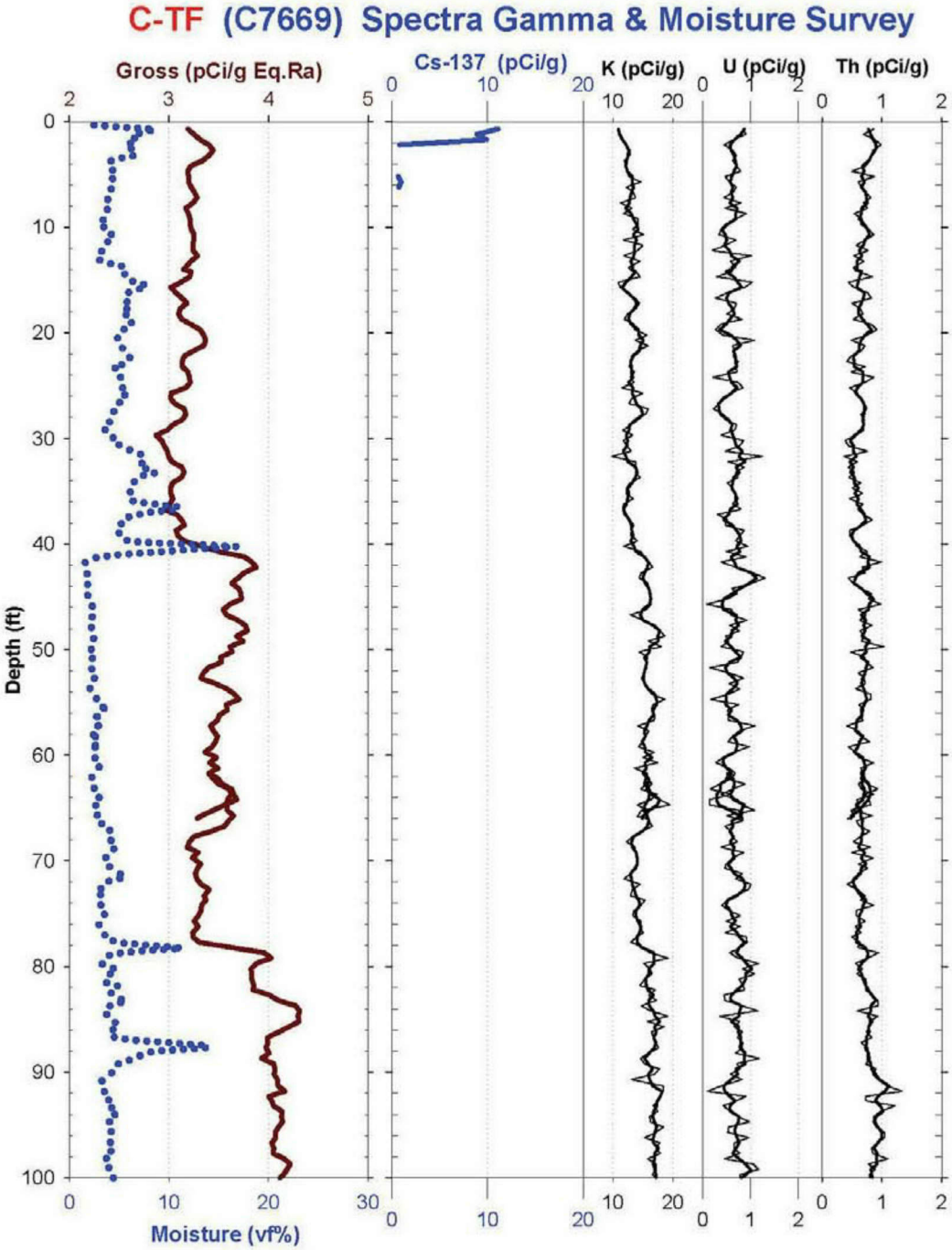
Calibration Certificates

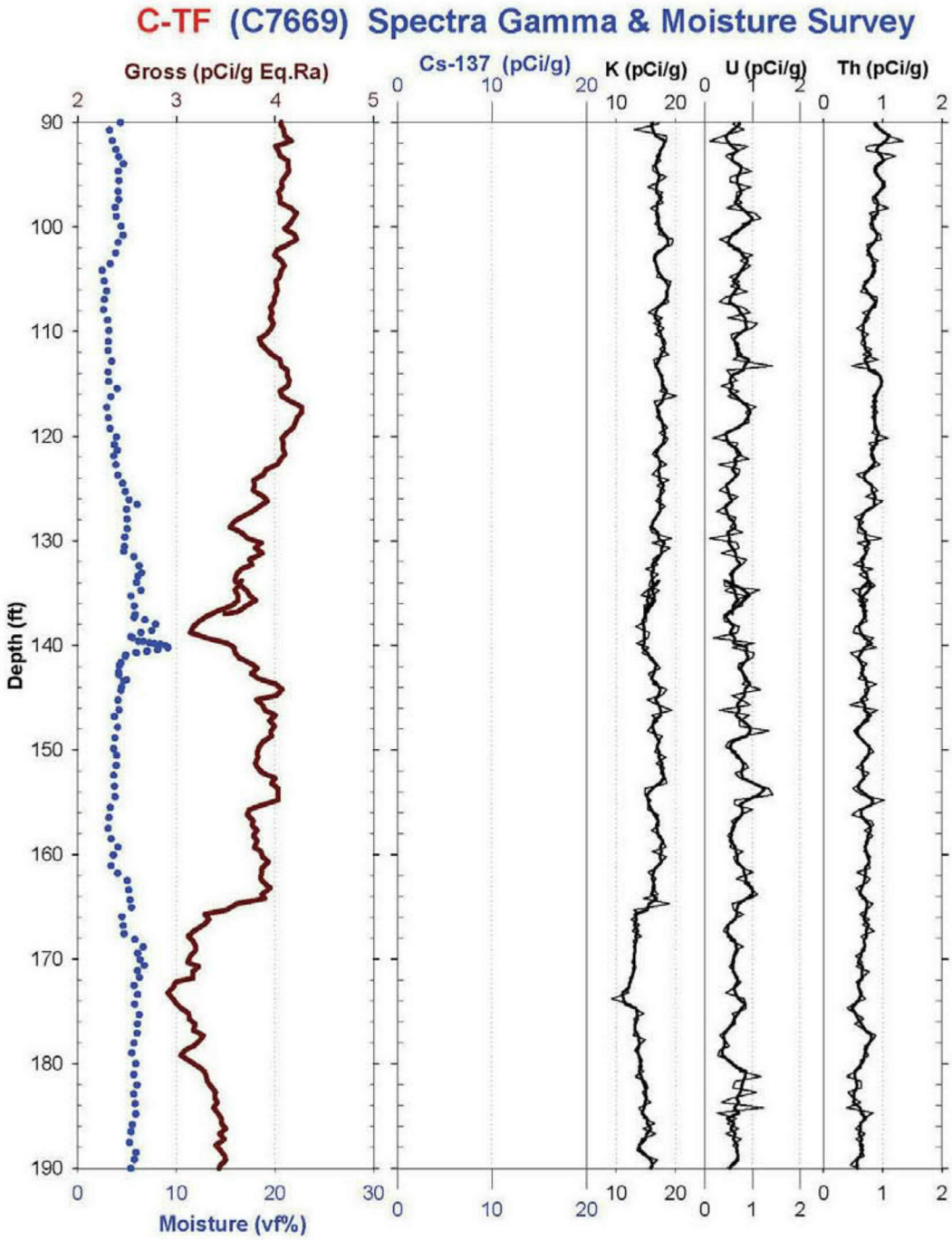
Spectral

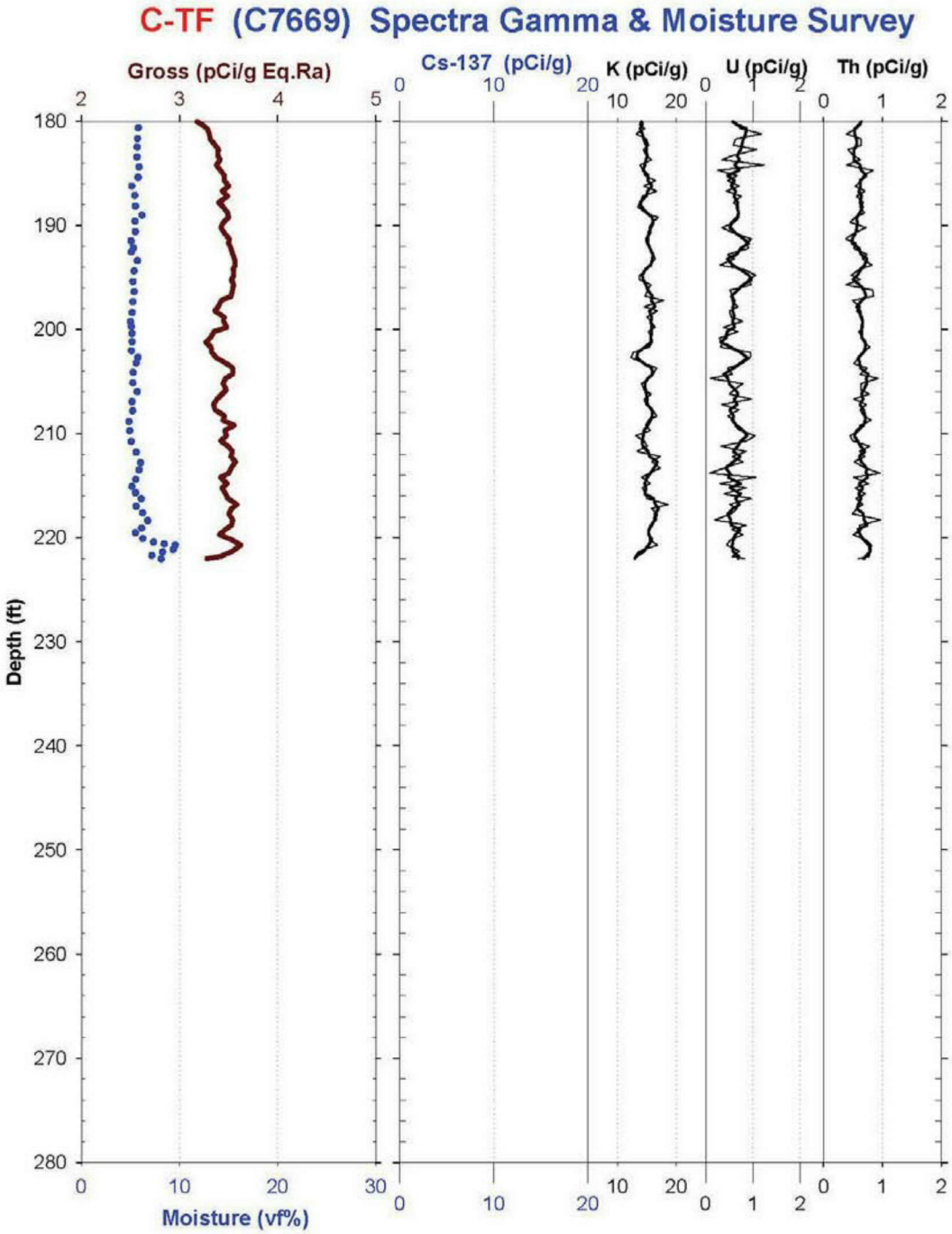
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C-TF (C7669) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C-TF (C7669) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C-TF (C7669) Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

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DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-RPT-48029, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR 241-C TANK FARM CHARACTERIZATION PHASE 2

SMALL DIAMETER GEOPHYSICAL LOGGING OF FOUR ADDITIONAL PROBEHOLES FOR 241-C TANK FARM CHARACTERIZATION PHASE 2

by

Russel Randall, PhD and Randall Price

to

EnergySolutions Federal Services, Inc.
2345 Stevens Drive
Richland, Washington 99354

August 2010

Pacific Northwest Geophysics
4200 West 19th Avenue
Kennewick, Washington 99338

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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TERMS

BGO	Bismuth Germinate Oxide
KUT	potassium, uranium and thorium
PNG	Pacific Northwest Geophysics

SMALL DIAMETER GEOPHYSICAL LOGGING OF FOUR ADDITIONAL PROBEHOLES FOR 241-C TANK FARM CHARACTERIZATION PHASE 2

1.0 PROBEHOLE SURVEYS

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in probeholes installed at four additional sites of the Phase 2 Characterization within the 241-C Tank Farm.

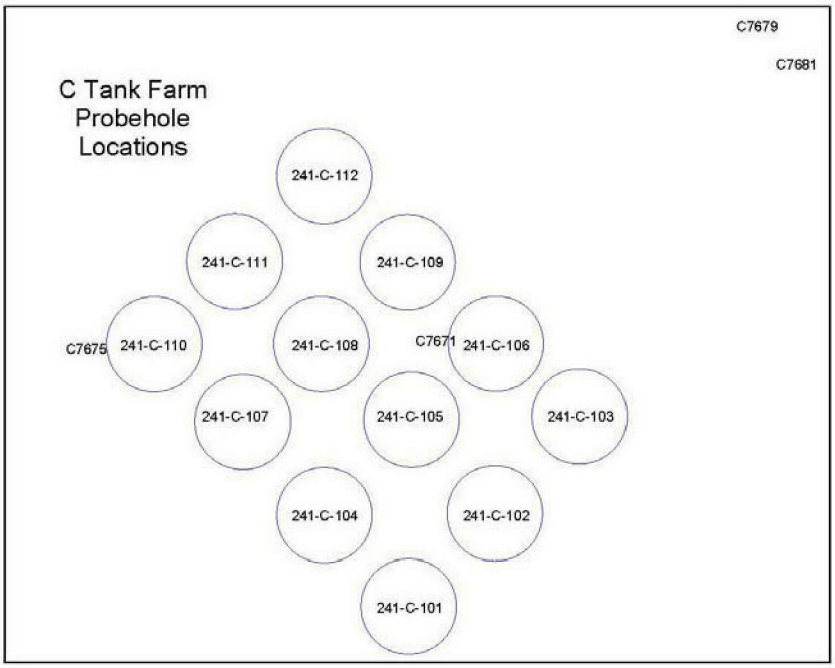
Logging surveys were conducted in each small diameter probehole with a Bismuth Germinate Oxide (BGO) spectral gamma scintillation detector and a neutron-neutron moisture probe. Detector calibration certificates for the BGO and neutron-moisture detectors are presented in Section 2.0, "Gamma and Moisture Surveys." The survey results are presented in Appendix A for each probehole.

2.0 GAMMA AND MOISTURE SURVEYS

The gamma and moisture logs were collected according to approved procedures (PNG 2009). The surveys were recorded from the maximum depth that the logging probe could achieve to the ground surface. Zero depth reference is at the ground surface. The maximum log depth in two probeholes (C7671 and C7679) was less than the bottom of the probehole, due to joint failure within the drive tubing string. A repeat measurement was acquired daily in at least one probehole to verify instrument repeatability. The main log and repeat intervals, as applicable, are presented on the same plot. The computed results of the main and repeat intervals were reviewed and for all of the intervals collected, the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probehole are presented as a depth-versus-concentration plot in Appendix A. Appendix A also contains a table summarizing data for each probehole: probehole depth, maximum concentration of Cs-137 in pCi/g, and maximum detected depth of Cs-137. Figure 1 shows a map of the probehole locations relative to the underground storage tanks within the investigation site. Two probeholes (C7679 and C7681) were located outside the perimeter fence of the 241-C Tank Farm, northeast of the underground tanks.

Figure 1. Location of Additional Probeholes in 241-C Tank Farm Phase 2 Characterization.



2.1 GAMMA CALIBRATION AND SURVEYS

The spectral gamma scintillation detector uses a BGO crystal that is 2.54 cm (1 in.) diameter by 10.1 cm (4 in.) long. Other components of the gamma logging probe are the high-voltage supply, photo-multiplier tube, pre-amp, and multi-channel analyzer. The settings of the detector components are fixed (i.e., set up during assembly, prior to calibration) and cannot be adjusted by the field-logging engineer. The detector gain and lower threshold are set to record gamma ray activity with energies between 300 and 3000 keV. Lantern mantles containing Th-232 are used as a field verifier at the beginning and ending of each day's logging activities to check the detector resolution (integrity) and energy calibration (amplifier gain).

The spectral gamma surveys were logged at 100 seconds per 0.15 m (0.5 ft). A spectrum of 256 channels was collected each 0.15 m (0.5 ft) from the bottom of the probehole to the surface. The spectra were recorded with one spectrum per file in Ortec[1] PHA format. Spectra were processed to quantify the concentration of the naturally occurring radionuclides (K, U, & Th) and quantify Cs-137 when present above the minimum detection threshold. The minimum detection

[1]Ortec is a registered trademark of EG&G Ortec, Gouda, Netherlands.

level for Cs-137 is 1 pCi/g. The calibration certificate is shown in Figure 2. Also the gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in pCi/g. Calibration was performed under the same conditions as at the investigation site.

2.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS

The neutron moisture sonde combines the PNG-owned thermal-neutron detector and a DOE-owned sealed neutron source (50 millicuries americium and beryllium). The DOE-owned neutron source was used because it was already on the Hanford Site and is managed by the DOE Radiation Management Program. The neutron source is an integral component of a neutron moisture detector, manufactured by Campbell Pacific Nuclear, and is identified by the tool serial number H370608792.

The integrity of the sealed neutron source is always maintained when used in calibration and probehole logging activities. Source integrity is maintained by inserting the PNG-owned neutron detector module into the housing containing the sealed neutron source.

Calibration was performed in six borehole calibration models (Meisner and Randall 1995). Three of these models had a 15.24 cm (6-in.) hole size and three models had a 20.32 cm (8-in.) hole size. The moisture content was different for each borehole model within each set of three models (5, 12, and 20 percent by volume). The detector count rate in each of the six borehole calibration models is summarized in Table 1. The calibration certificate is shown in Figure 3.

Table 1. Moisture Calibration Data.

Moisture Content Percent—volume fraction (vf)	6-inch Models[a] (counts per second)	8-inch Models[a] (counts per second)
5% vf	103.87	81.1
12% vf	155.11	114.92
20% vf	191.9	140.17

[a]Count rates are the mean of 10 sample measurements at 60-sec each, 2/25/2009.

The probehole size for this project was 6.35 cm (2.5 in.) outside diameter. Therefore, the moisture calibration was extrapolated to the correct hole size. Figure 4 shows the moisture calibration extrapolation for the 6.35 cm (2.5-in.) hole size.

The probehole moisture survey was collected at 0.30 m/min (1 ft/min). Processing of the survey data requires that the detector raw survey data be normalized to the thickness of the steel casing present in the calibration models (0.826 cm [0.325 in.]) Given that the probehole casing thickness is 0.97 cm (0.38 in.), a correction factor of 1.055 is required to increase (normalize) the observed neutron detector count rate to the conditions of the calibration model (Meisner et al. 1996).

Figure 2. BGO Calibration Certificate.

Certificate of Calibration
SDGR.BGO.2

April 21, 2009

Data were taken at the Hanford KUT models on April 21, 2009. SDGR.BGO.2 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Ten spectra were recorded in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: AveOut2.XLS for this analysis. The instrument was covered with 0.94 cm (0.37-in.) wall thickness probe tubing.

The algorithm described in WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1320-1575 keV **U: 1650-2390 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**4.712*K**	**-4.297*U**	**4.057*T**
Concentration-U =	**0.0*K**	**1.431*U**	**-2.998*T**
Concentration-T =	**0.0*K**	**-0.052*U**	**2.032*T**

Where K, U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_SD-GR-2_2009-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_SD-GR-2_2009-v0.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-293 and that the above-stated calibration coefficients are correct and applicable for the tool SDGR.BGO.2 effective April 21, 2009.

Signature:

/s/ Russel Randall, PhD April 23, 2009
Three Rivers Scientific

Figure 3. Moisture Calibration Certificate, 15.24 cm (6-in.) and 20.32 cm (8-in.) Hole.

Certificate of Calibration for
Instrument SD-Moist792

February 25, 2009

Data were taken in the Moisture models on February 25, 2009, for SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H370608792 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, three for 15.24 cm (6-in.) casing and three for 20.32 cm (8-in.) casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation. Refer to the file MoistCal.xls for this analysis.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6-in. casing	**8-in. casing**
a = .0001586	**a = .00008287**
α = 2.229	**α = 2.504**

The undersigned certifies that the data archived in data file "SD-Moist792_2009.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-306 and that the above-stated calibration coefficients are correct and applicable for tool SD-Moist792, effective February 25, 2009.

Signature:

/s/ Russel Randall, PhD — February 28, 2009
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument SD-Moist792

February 25, 2009

Moisture calibration was performed in the Hanford physical models. These standards have 15.24 cm and 20.32 cm (6-in. and 8–in.) inside diameter casings. The Tank Farm Direct Push borehole is cased with a 5.08 cm (2.5-in.) outside diameter iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration,* Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 5.08 cm (2.5-in.) borehole diameter.

2.51-in. borehole
a = .0002123
α = 2.010

The undersigned certifies that the analysis files are archived in the file "SD-Moist792_2009.zip" and were evaluated in accordance with Energy*Solutions* procedures and that the above-stated calibration coefficients are correct and applicable for tool SD-Moist792, effective February 25, 2009.

Signature:

/s/ Russel Randall, PhD — February 28, 2009
Three Rivers Scientific

3.0 REFERENCES

Meisner, James and Russel Randall, 1995, *Vadose Zone Moisture Measurement Through Steel Casing Evaluation*, WHC-SD-EN-TI-304, Rev.0, Westinghouse Hanford Company, Richland, Washington.

Meisner, James, Randall Price, and Russel Randall, 1996, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, WHC-SD-EN-TI-306, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

PNG, 2009, *Procedures: Calibration, Logging, Quality Assurance and Data Management*, Pacific Northwest Geophysics, Kennewick, Washington.

Randall, R. and D. Stromswold, 1995, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, WHC-SD-EN-TI-293, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A
SPECTRAL GAMMA AND MOISTURE SURVEY RESULTS

Survey plots follow for the four additional probeholes installed for the C Tank Farm Characterization Phase 2. Each probehole was surveyed with both the BGO spectral gamma and moisture probes. Each log plot is preceded by a header information page that shows the repeat/overlap intervals, isotopes analyzed, observations, and logging probe calibration dates. The log plots show a maximum of 100 feet per page with a 10 ft overlap between page breaks.

The spectral gamma survey data were processed to quantify the naturally occurring radionuclides (K, U, & Th), and the man-made radionuclide of Cs-137 (blue solid line). The spectra were processed both as individual spectra for each survey depth and as a moving sum of three spectra (i.e., sum of the individual survey depth and the two adjacent spectra, above and below the current depth position). Both results are presented on the results plot. The results for the 3-spectra sum are plotted as a wide line. Also the gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in a scale of 2 to 5 pCi/g (brown line).

The neutron-neutron moisture survey data are shown with a blue dotted line. The moisture plot scale is 0-30 (% vf).

Table A1 contains a summary of the survey results for each probehole: maximum log depth, maximum detection level for Cs-137, maximum depth of Cs-137 detection, and special observations by the analyst to flag the detection of other isotopes in addition to the natural radionuclides and Cs-137.

Table A1. Probehole Survey Summary.

Probehole Identification	Hole Depth (meters)	Hole Depth (feet)	Cs-137 (pCi/g) Max Detection	Cs-137 Max Detected Depth	Flag Isotopes Other Than Naturals and Cs-137
C7671	39.9	131	218 pCi/g at surface	2 ft	None
C7675	67.7	222	9 pCi/g at surface	1 ft	None
C7679	54.3	178	None	None	None
C7681	67.1	220	None	None	None

C-FARM C7671 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7671	Log Date:	Jun 2010
Project:	C Farm	Depth Ref:	Ground Surface

Repeat/Overlap Intervals

Spectral:	132-121	Moisture:	20-14
	44-43		
	54-49		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

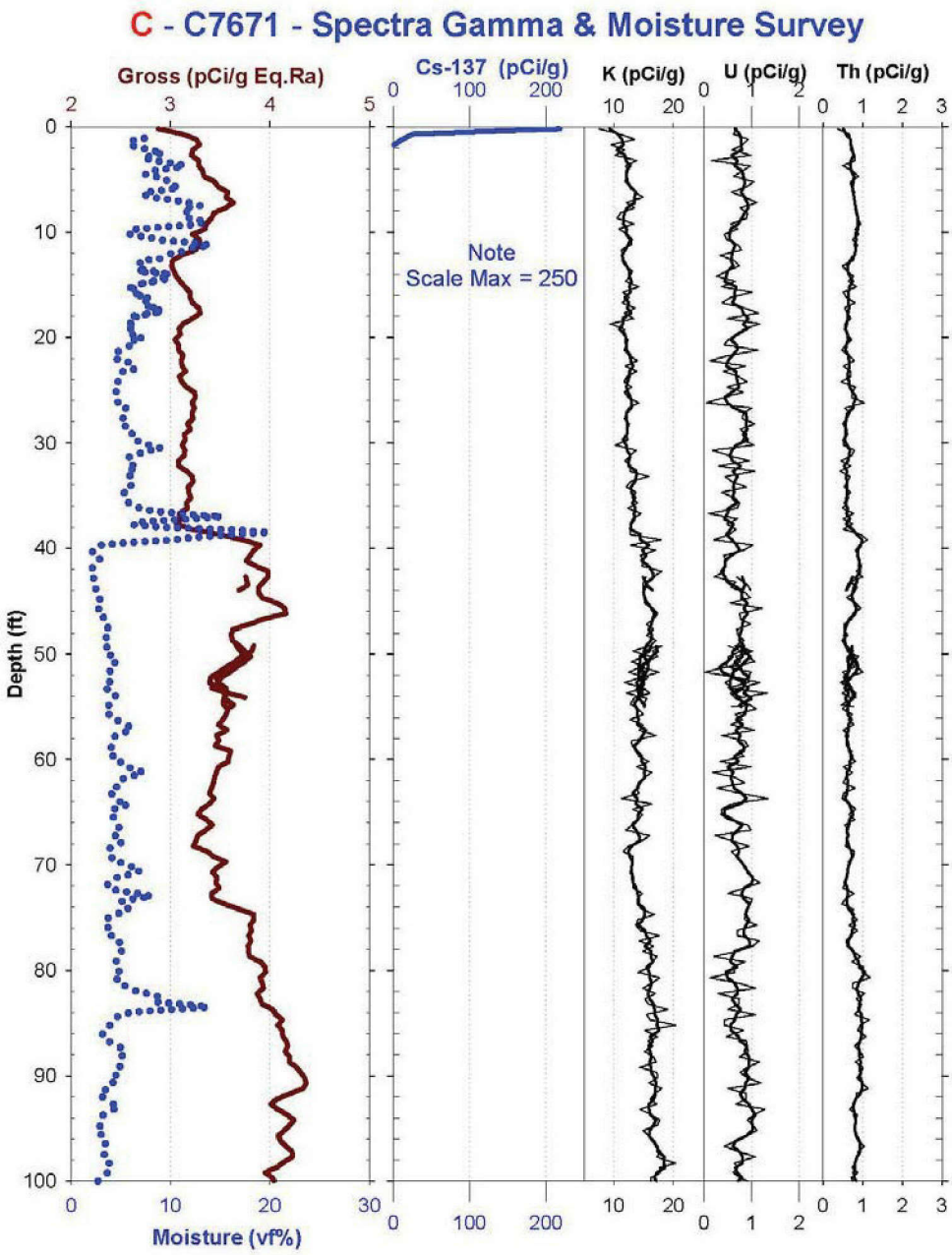
Cs-137 was observed at the surface, with a maximum reading of 218 pCi/g. Cs-137 does not show a response in the Eq-Ra226 because the energy threshold used 1000keV, which is above the Cs-137 gamma emitted.

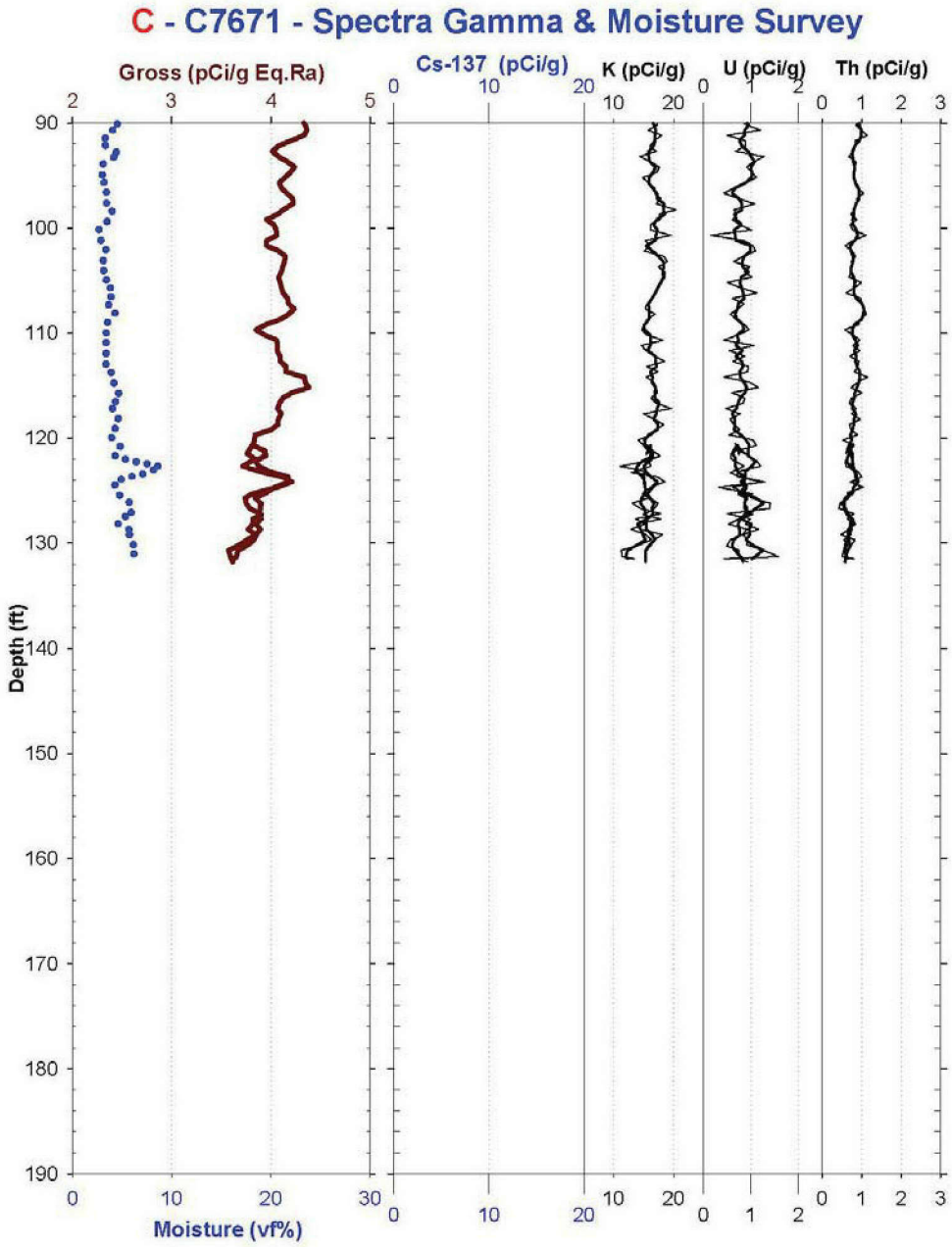
Moisture:

Moisture values range from 2-20%.

Calibration Certificates

Spectral	
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip
Moisture	
Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C - C7671 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)
Note
Scale Max = 250


C - C7671 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7675 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7675	Log Date:	Jun 2010
Project:	C Farm	Depth Ref:	Ground Surface

Repeat/Overlap Intervals

Spectral:	37-32	Moisture:	35-30
	35-24		
	13-5		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

Cs-137 was observed at the surface, with a maximum reading of 8.6 pCi/g. Cs-137 does not show a response in the Eq-Ra226 because the energy threshold used 1000keV, which is above the Cs-137 gamma emitted.

Moisture:

Moisture values range from 3-23%.

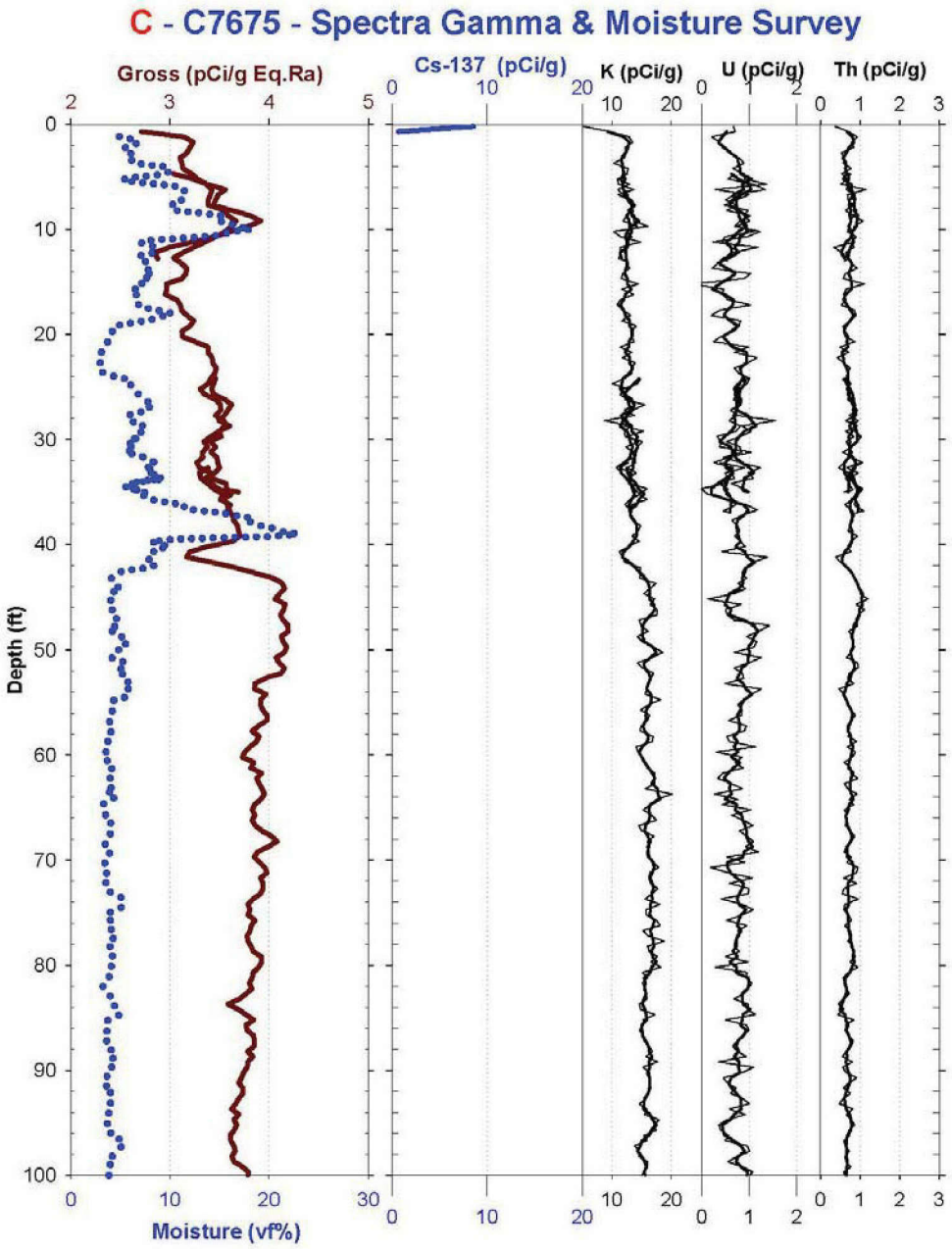
Calibration Certificates

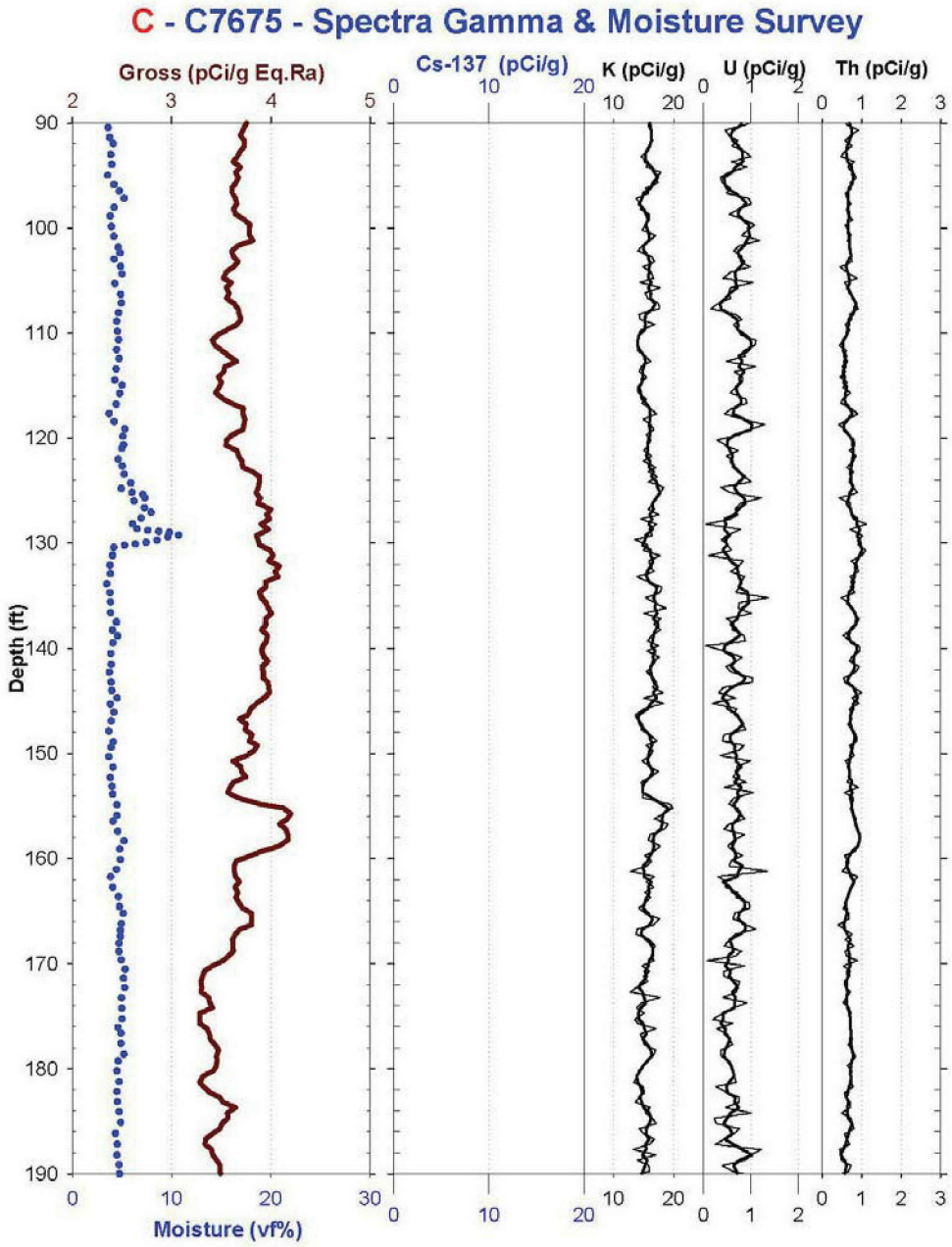
Spectral

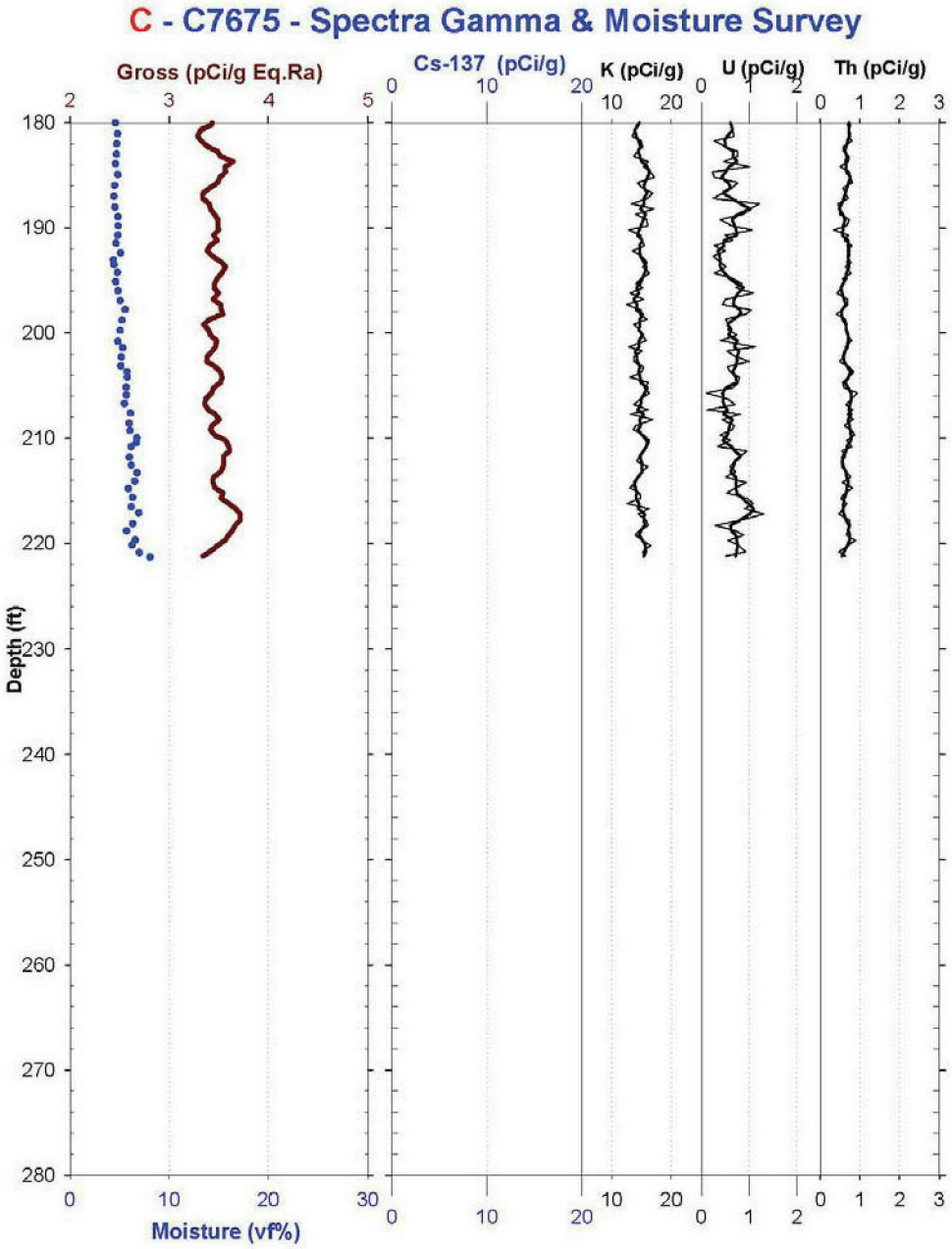
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C - C7675 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7675 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7675 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7679 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7679	Log Date:	Jul 2010
Project:	C Farm	Depth Ref:	Ground Surface

Repeat/Overlap Intervals

Spectral:	135-131	Moisture:	70-64
	35-29		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

Cs-137 was not observed.

Moisture:

Moisture values range from 2-26%. The thin higher moisture lens at 115ft corresponds to a slight increase in K, and higher increases in both U and Th. Note that the gamma response is not as depth resolved as the moisture.

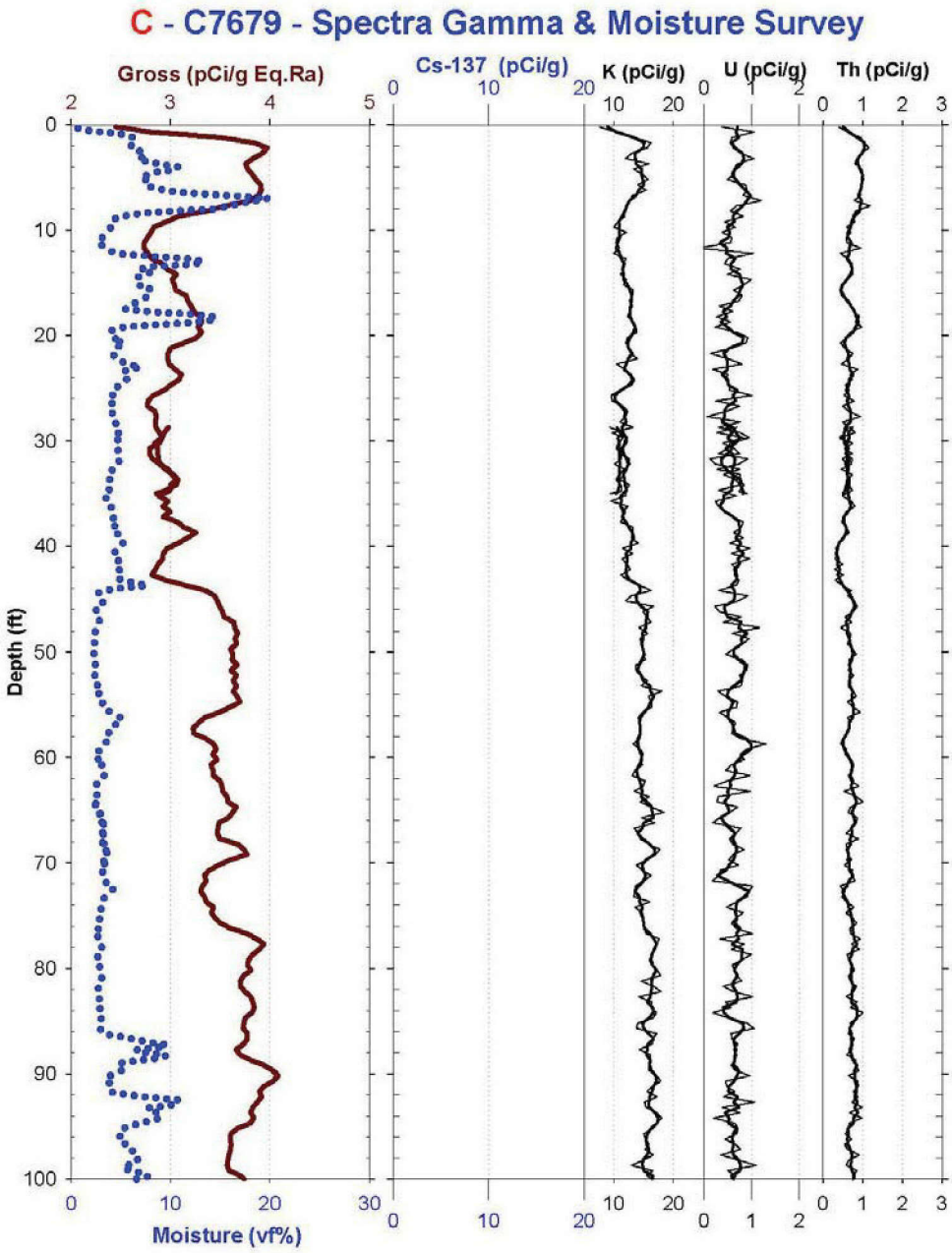
Calibration Certificates

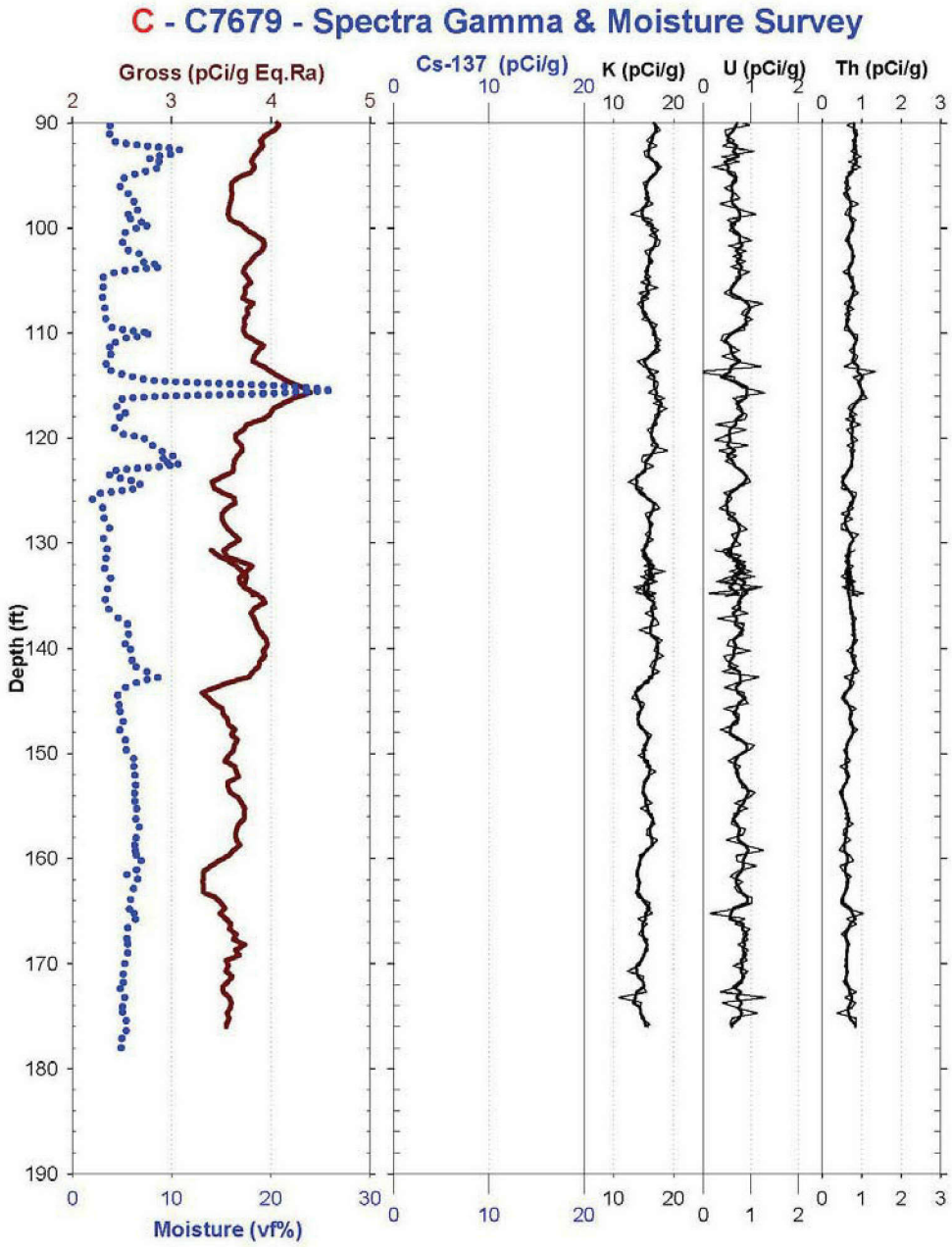
Spectral

Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C - C7679 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7679 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7681 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7681	Log Date:	Jun 2010
Project:	C Farm	Depth Ref:	Ground Surface

Repeat/Overlap Intervals

Spectral:	99-94	Moisture:	35-28
	33-25		22-15
	26-25		
	7-6		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

Cs-137 was not observed.

Moisture:

Moisture values range from 2-24%.

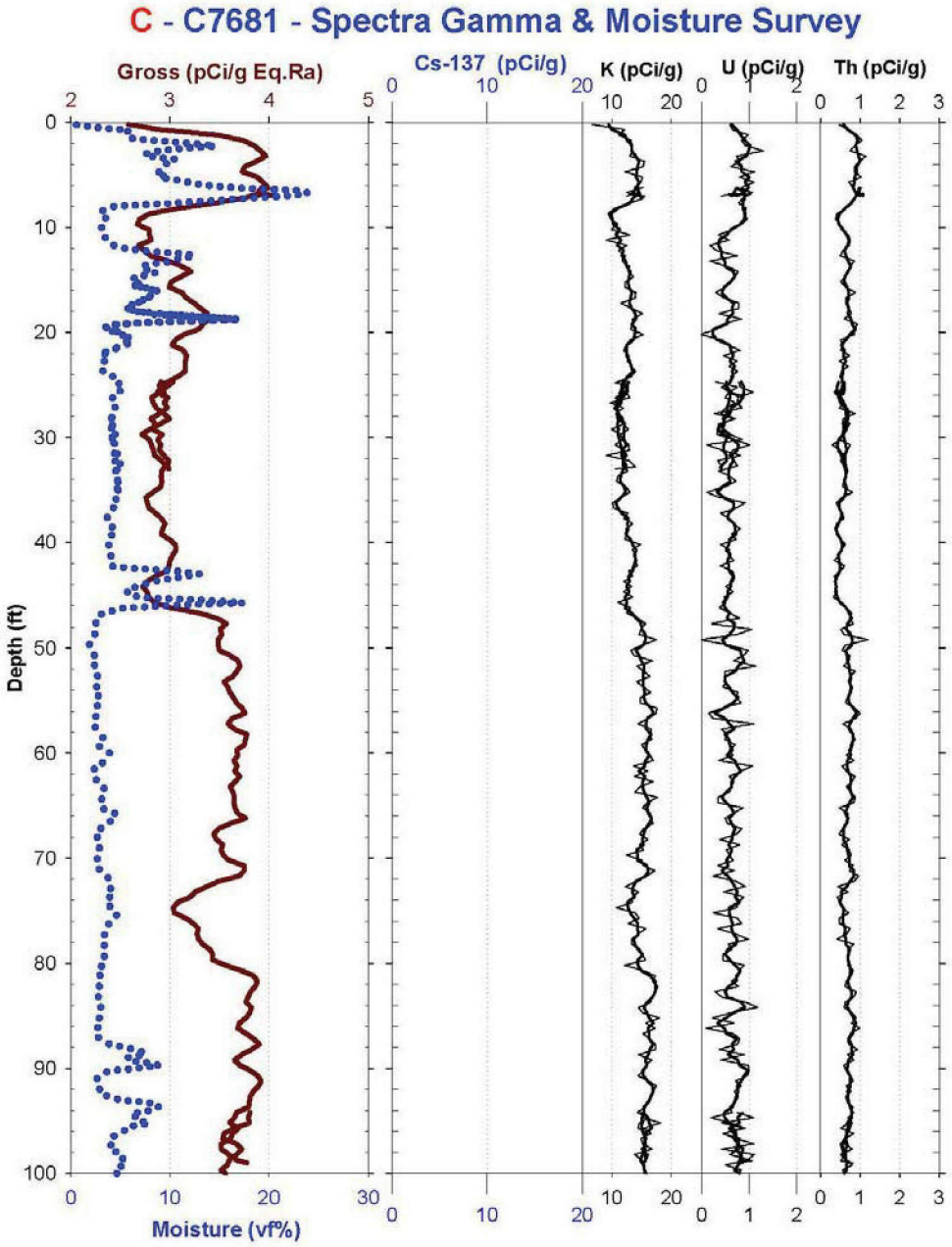
Calibration Certificates

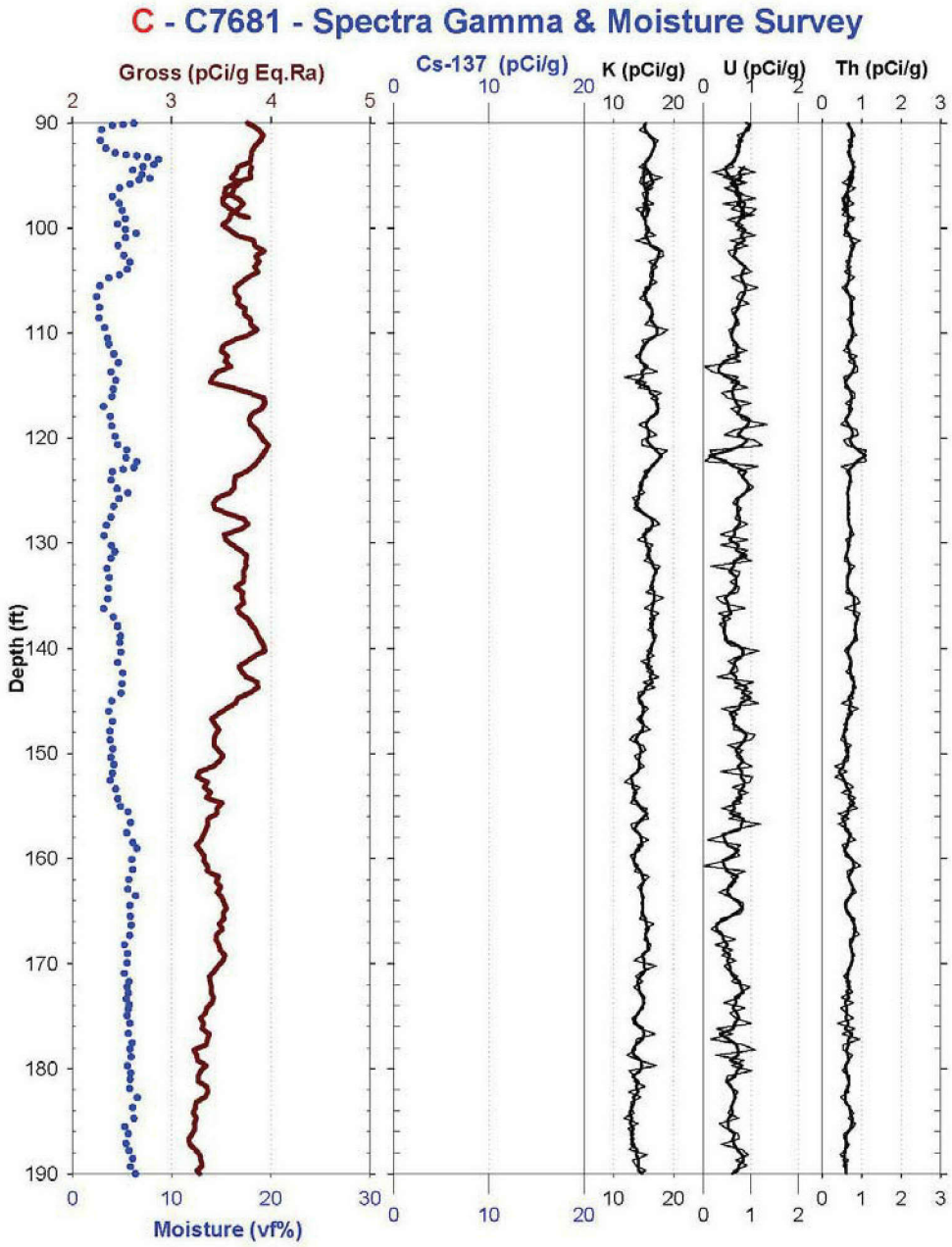
Spectral

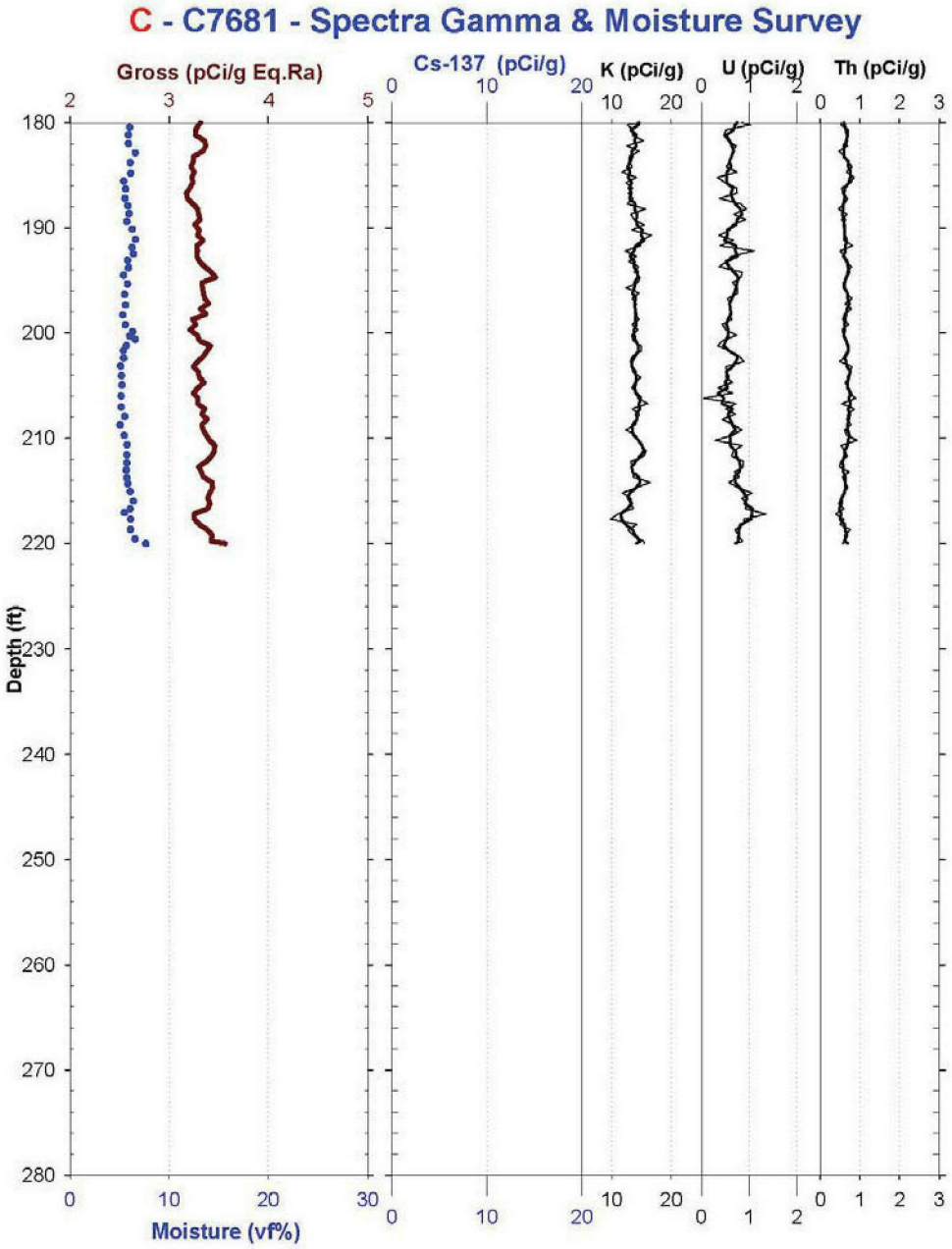
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C - C7681 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7681 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7681 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

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DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-48609, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR 241-C TANK FARM (ADJACENT TO UPR-200-E-82)

SMALL DIAMETER GEOPHYSICAL LOGGING OF FOUR PROBEHOLES IN THE 241-C TANK FARM ADJACENT TO UPR-200-E-82

by

Russel Randall, PhD and Randall Price

to

EnergySolutions Federal Services, Inc.
2345 Stevens Drive
Richland, Washington 99354

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Pacific Northwest Geophysics
4200 West 19th Avenue
Kennewick, Washington 99338

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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TERMS

BGO	Bismuth Germinate Oxide
DOE	U.S. Department of Energy
KUT	potassium, uranium and thorium
PNG	Pacific Northwest Geophysics

SMALL DIAMETER GEOPHYSICAL LOGGING OF FOUR PROBEHOLES IN THE 241-C TANK FARM ADJACENT TO UPR-200-E-82

1.0 PROBEHOLE SURVEYS

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in probeholes installed adjacent to the C-152 diversion box (UPR-200-E-82) within the 241-C Tank Farm.

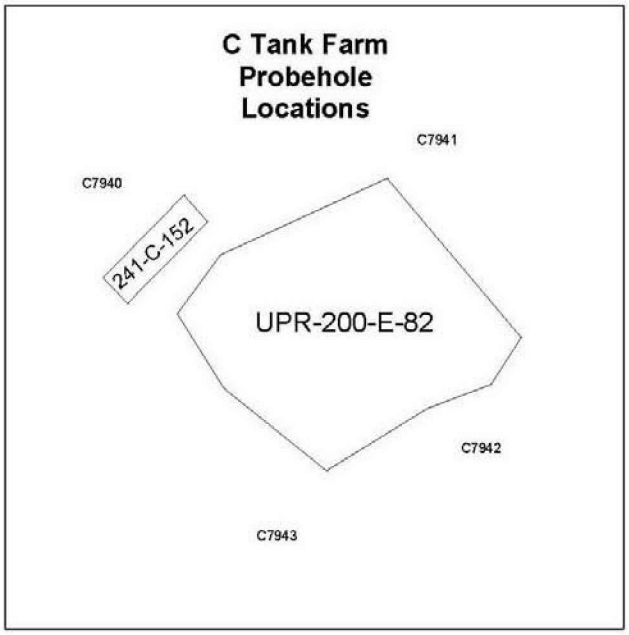
Logging surveys were conducted in each small diameter probehole with a Bismuth Germinate Oxide (BGO) spectral gamma scintillation detector and a neutron-neutron moisture probe. Detector calibration certificates for the BGO and neutron-moisture detectors are presented in Section 2.0, "Gamma and Moisture Surveys." The survey results for each probehole are presented in Appendix A.

2.0 GAMMA AND MOISTURE SURVEYS

The gamma and moisture logs were collected according to approved procedures (PNG 2009). The surveys were recorded from the bottom of the probehole to the ground surface. Zero depth reference is at the ground surface. A repeat measurement was acquired daily in at least one probehole to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed and for all of the intervals collected, the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probehole are presented as a depth-versus-concentration plot in Appendix A. The plots are in numeric order of the probeholes (C7940–C7943). Appendix A also contains a table summarizing data for each probehole: probehole depth, maximum concentration of Cs-137 in pCi/g, and maximum detected depth of Cs-137. Figure 1 shows a map view of the probehole locations within the investigation site relative to the underground C-52 diversion box and UPR-200-E-82 cover. One probehole (C7941) was located in the radioactive material area (i.e., outside the perimeter fence of the 241-C Tank Farm).

Figure 1. Probehole Locations adjacent to C-152 Diversion Box at 241-C Tank.



2.1 GAMMA CALIBRATION AND SURVEYS

The spectral gamma scintillation detector uses a BGO crystal that is 2.54 cm (1 in.) in diameter by 10.1 cm (4 in.) long. Other components of the gamma logging probe are the high-voltage supply, photo-multiplier tube, pre-amp, and multi-channel analyzer. The settings of the detector components are fixed (i.e., set up during assembly, prior to calibration) and cannot be adjusted by the field-logging engineer. The detector gain and lower threshold are set to record gamma ray activity with energies between 300 and 3000 keV. Lantern mantles containing Th-232 are used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (integrity) and energy calibration (amplifier gain).

The spectral gamma surveys were logged at 100 seconds per 0.15 m (0.5 ft). A spectrum of 256 channels was collected each 0.15 m (0.5 ft) from the bottom of the probehole to the surface. The spectra were recorded with one spectrum per file (filename extension: "-.chn") in Ortec[1] PHA format. Spectra were processed to quantify the concentration of the naturally occurring radionuclides (K, U, & Th) and quantify Cs-137 when present above the minimum detection threshold. The minimum detection level for Cs-137 is 1 pCi/g. The calibration certificate is shown in Figure 2. Also the gross gamma was calibrated to the industry standard of equivalent

[1]Ortec is a registered trademark of EG&G Ortec, Gouda, Netherlands.

radium-226 (Eq.Ra) in pCi/g. Calibration was for the probehole conditions present at the investigation site.

2.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS

The neutron moisture sonde combines the PNG-owned thermal-neutron detector and a U.S. Department of Energy (DOE)-owned sealed neutron source (50 millicuries americium and beryllium). The DOE-owned neutron source was used because it was already on the Hanford Site and was managed by the DOE Radiation Management Program. The neutron source is an integral component of a neutron moisture detector manufactured by Campbell Pacific Nuclear and is identified by the tool serial number H370608792.

The integrity of the sealed neutron source is always maintained when used in calibration and probehole logging activities. Source integrity is maintained by inserting the PNG-owned neutron detector module into the housing containing the sealed neutron source.

Calibration was performed in six borehole calibration models (Meisner and Randall 1995). Three of these models had a 15.24 cm (6-in.) hole size and three models had a 20.32 cm (8-in.) hole size. The moisture content was different for each borehole model within each set of three models (5, 12, and 20 percent by volume). The detector count rate in each of the six borehole calibration models is summarized in Table 1. The calibration certificate is shown in Figure 3.

Table 1. Moisture Calibration Data.

Moisture Content Percent – volume fraction	6 inch Models[a] (cps)	8 inch Models[a] (cps)
5% vf	103.87	81.1
12% vf	155.11	114.92
20% vf	191.9	140.17

[a]Count rates are mean of 10 sample measurements at 60-sec each, 2/25/2009.

The probehole size for this project was 6.35 cm (2.5 in.) in outside diameter. Therefore, the moisture calibration was extrapolated to the correct hole size. Figure 4 shows the moisture calibration certificate for the 6.35 cm (2.5-in.) hole size.

The probehole moisture survey was collected at 0.30 m/min (1 ft/min). Processing of the survey data requires that the detector raw survey data be normalized to the thickness of the steel casing present in the calibration models (0.826 cm [0.325 in.]) Given that the probehole casing thickness is 0.97 cm (0.38 in.), a correction factor of 1.055 is required to increase (normalize) the observed neutron detector count rate to the conditions of the calibration model (Meisner et al. 1996).

Figure 2. BGO Calibration Certificate.

Certificate of Calibration
SDGR.BGO.2

April 21, 2009

Data were taken at the Hanford KUT models on April 21, 2009. SDGR.BGO.2 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Ten spectra were recorded in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: AveOut2.XLS for this analysis. The instrument was covered with 0.94 cm (0.37 in.) wall thickness probe tubing.

The algorithm described in WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1320-1575 keV U: 1650-2390 keV T: 2475-2765 keV

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**4.712*K**	**-4.297*U**	**4.057*T**
Concentration-U =	**0.0*K**	**1.431*U**	**-2.998*T**
Concentration-T =	**0.0*K**	**-0.052*U**	**2.032*T**

Where K U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_SD-GR-2_2009-v0.zip. This compressed file contains:

- Calibration raw data
- Mathcad* data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_SD-GR-2_2009-v0.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-293, and that the above-stated calibration coefficients are correct and applicable for the tool SDGR.BGO.2 effective April 21, 2009.

*Mathcad is a registered trademark of Parametric Technology Corporation, Needham, Massachusetts.

Signature:

/s/ Russel Randall, PhD April 23, 2009
Three Rivers Scientific

Figure 3. Moisture Calibration Certificate, 15.24 cm (6-in.) and 20.32 cm (8-in.) Hole.

Certificate of Calibration for
Instrument SD-Moist792

February 25, 2009

Data were taken in the Moisture models on February 25, 2009, for the SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H370608792 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, three for 15.24 cm (6-in.) casing and three for 20.32 cm (8-in.) casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation, refer to the file MoistCal.xls for this analysis.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration,* Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6-in. casing	**8-in. casing**
a = .0001586	**a = .00008287**
α = 2.229	**α = 2.504**

The undersigned certifies that the data archived in data file "SD-Moist792_2009.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-306, and that the above-stated calibration coefficients are correct and applicable for tool SD-Moist792, effective February 25, 2009.

Signature:

/s/ Russel Randall, PhD — February 28, 2009
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument SD-Moist792

February 25, 2009

Moisture calibration was performed in the Hanford physical models. These standards have 15.24 cm and 20.32 cm (6-in. and 8-in.) inside diameter casings. The Tank Farm Direct Push borehole is cased with a 5.08 cm (2.5 in.) outside diameter iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration,* Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 5.08 cm (2.5-in.) borehole diameter.

2.51-in. borehole
a = .0002123
α = 2.010

The undersigned certifies that the analysis files are archived in the file "SD-Moist792_2009.zip" and were evaluated in accordance with Energy*Solutions* procedures and that the above-stated calibration coefficients are correct and applicable for tool SD-Moist792, effective February 25, 2009.

Signature:

/s/ Russel Randall, PhD — February 28, 2009
Three Rivers Scientific

3.0 REFERENCES

Meisner, James and Russel Randall, 1995, *Vadose Zone Moisture Measurement Through Steel Casing Evaluation*, WHC-SD-EN-TI-304, Rev.0, Westinghouse Hanford Company, Richland, Washington.

Meisner, James, Randall Price, and Russel Randall, 1996, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, WHC-SD-EN-TI-306, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

PNG, 2009, *Procedures: Calibration, Logging, Quality Assurance and Data Management*, Pacific Northwest Geophysics, Kennewick, Washington.

Randall, R. and D. Stromswold, 1995, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, WHC-SD-EN-TI-293, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A
SPECTRAL GAMMA AND MOISTURE SURVEY RESULTS

Survey plots follow for the four probeholes installed adjacent to the C-152 diversion box (UPR-200-E-82) within the C Tank Farm. Each probehole was surveyed with both the BGO spectral gamma and moisture probes. Each log plot is preceded by a header information page that shows the probehole coordinates, repeat/overlap intervals, isotopes analyzed, observations, and logging probe calibration dates. The log plots show a maximum of 100 feet per page with a 10-ft overlap between page breaks.

The spectral gamma survey data were processed to quantify the naturally occurring radionuclides (K, U, & Th) and the man-made radionuclide of Cs-137 (blue solid line). The spectra were processed both as individual spectra for each survey depth and as a moving sum of three spectra (i.e., sum of the individual survey depth and the two adjacent spectra, above and below the current depth position). Both results are presented on the results plot. The results for the 3-spectra sum are plotted as a wide line. Also the gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in a scale of 2 to 5.5 pCi/g (brown line).

The neutron-neutron moisture survey data are shown with a blue dotted line. The moisture plot scale is 0-35 (% vf).

Table A1 contains a summary of the survey results for each probehole: maximum log depth, maximum detection level for Cs-137, and maximum depth of Cs-137 detection, and special observations by the analyst to flag the detection of other isotopes in addition to the natural radionuclides and Cs-137.

Table A1. Probehole Survey Summary.

Probehole ID.	Hole Depth (meters)	Hole Depth (feet)	Cs-137 (pCi/g) Max Detection	Cs-137 Max Detected Depth	Flag Isotopes Other Than Naturals and Cs-137
C7940	61.9	203	1.2 pCi/g at surface	1 ft	None
C7941	61.6	202	16 pCi/g at surface	1 ft	None
C7942	61.9	203	14 pCi/g at surface	1 ft	None
C7943	61.9	203	None	None	None

C-FARM C7940 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7940	Northing:	136545.1	Depth Ref:
Log Date:	Oct 2010	Easting:	575022.1	Ground Surface
Project:	C Farm	Elevation:	202.955	

Repeat/Overlap Intervals

Spectral: 158-155
141-138
50-46

Moisture: 110-104

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

-Spectral:

Cs-137 was observed at the surface, with a reading of 1.2 pCi/g. The plotted gross uses an energy threshold of 1000keV, and does not respond to Cs-137.

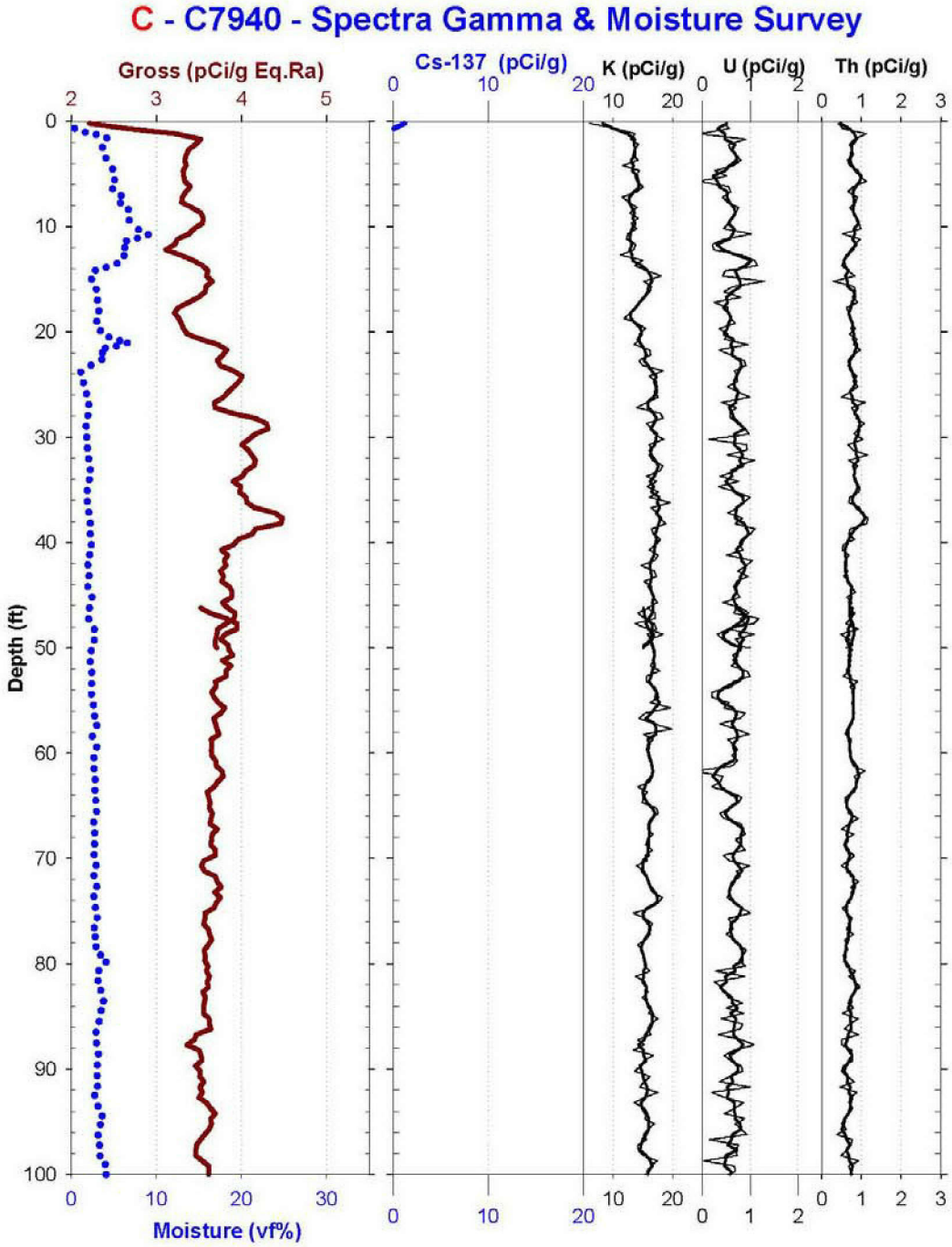
Moisture:

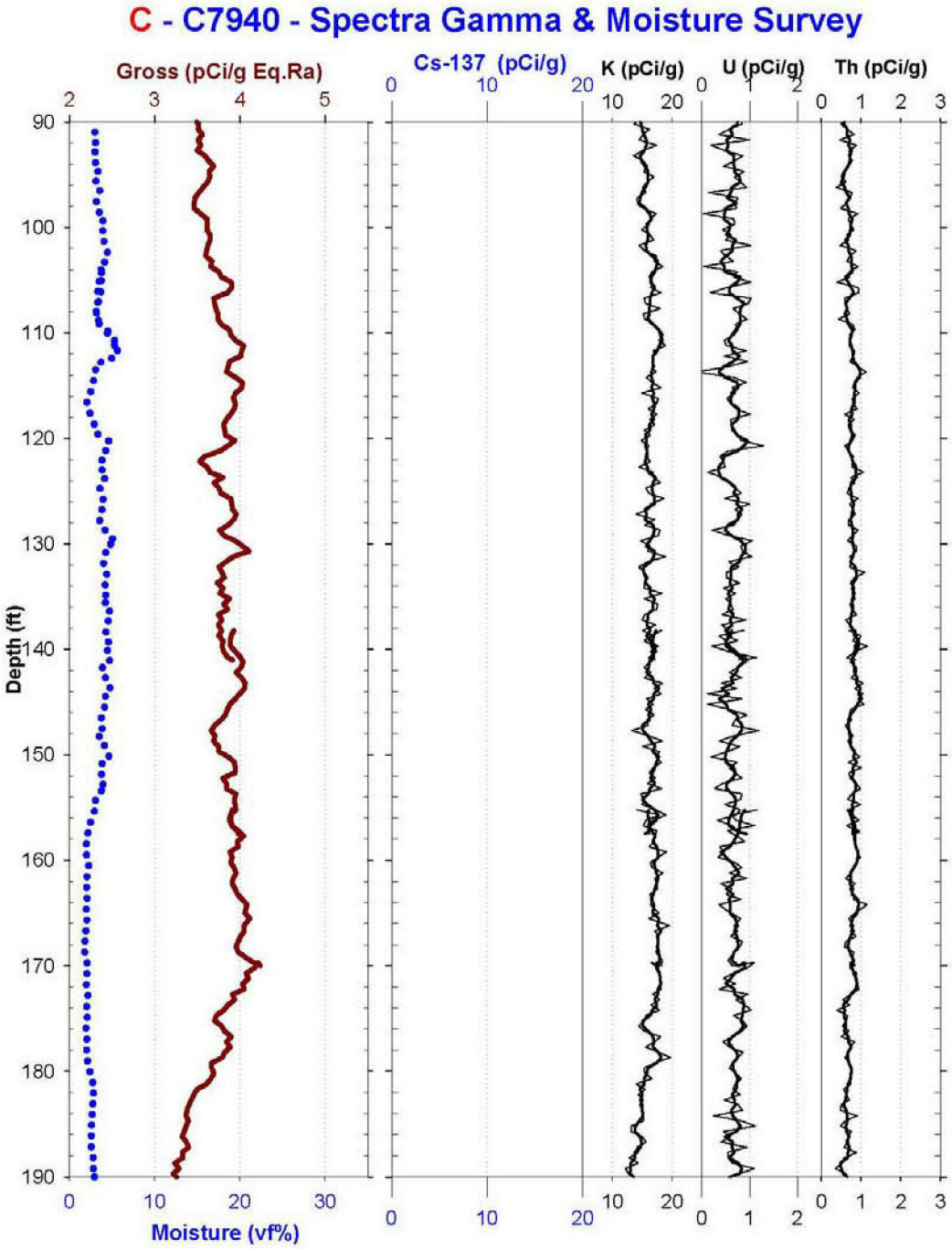
Moisture values range from 2-9%.

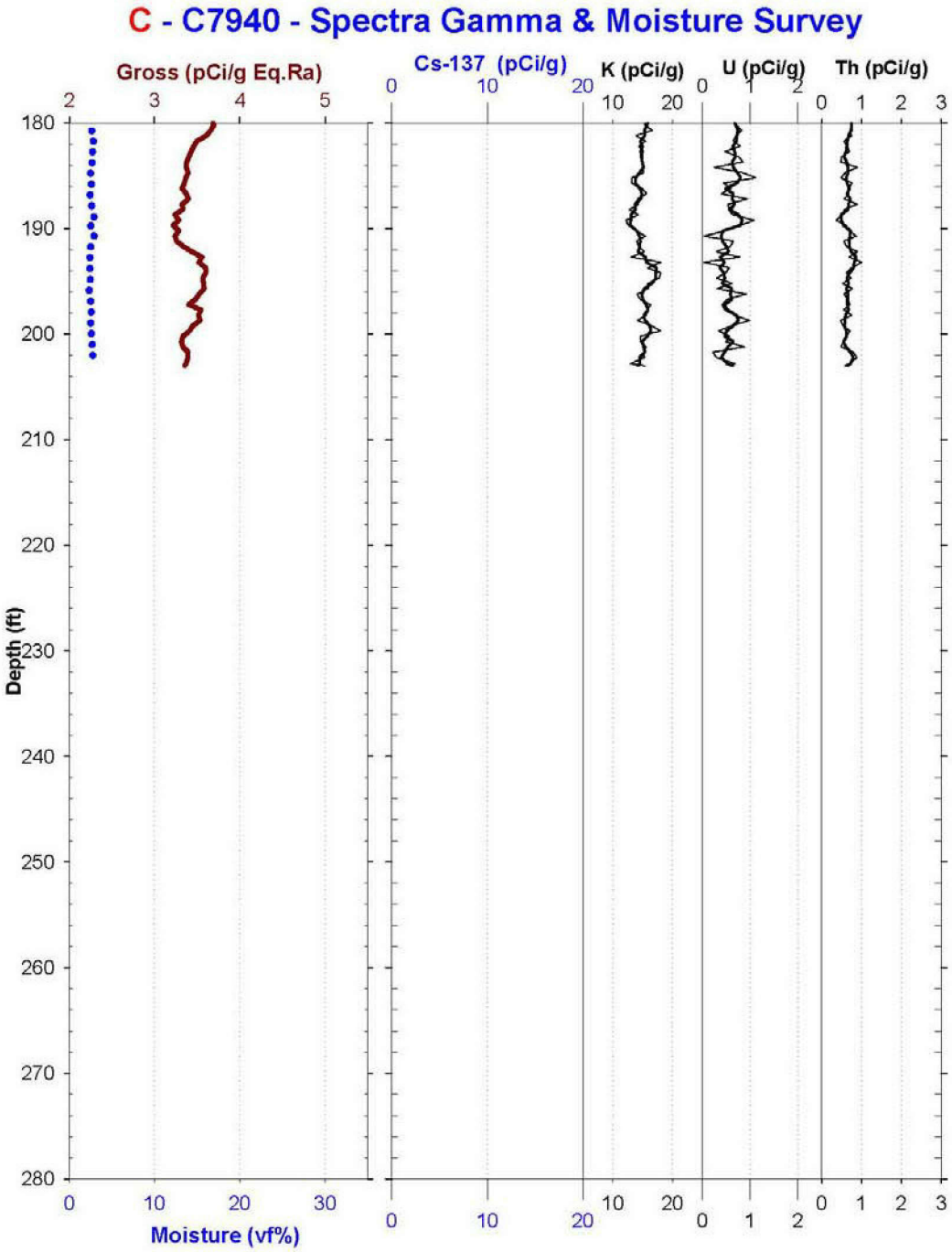
Calibration Certificates

Spectral
Date: Apr 21, 2009
Electronic File: Cal_SD-GR-2_2009-v0.zip

Moisture
Date: Feb 25, 2009
Electronic File: SD-Moist792_2009.zip


C - C7940 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7940 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7940 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7941 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7941	Northing:	136548.2	Depth Ref:
Log Date:	Oct 2010	Easting:	575046.5	Ground Surface
Project:	C Farm	Elevation:	201.95	

Repeat/Overlap Intervals

Spectral: 75-72
71-70

Moisture: 109-102

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

-Spectral:

Cs-137 was observed at the surface, with a maximum of 15.7 pCi/g. The plotted gross uses an energy threshold of 1000keV, and does not respond to Cs-137.

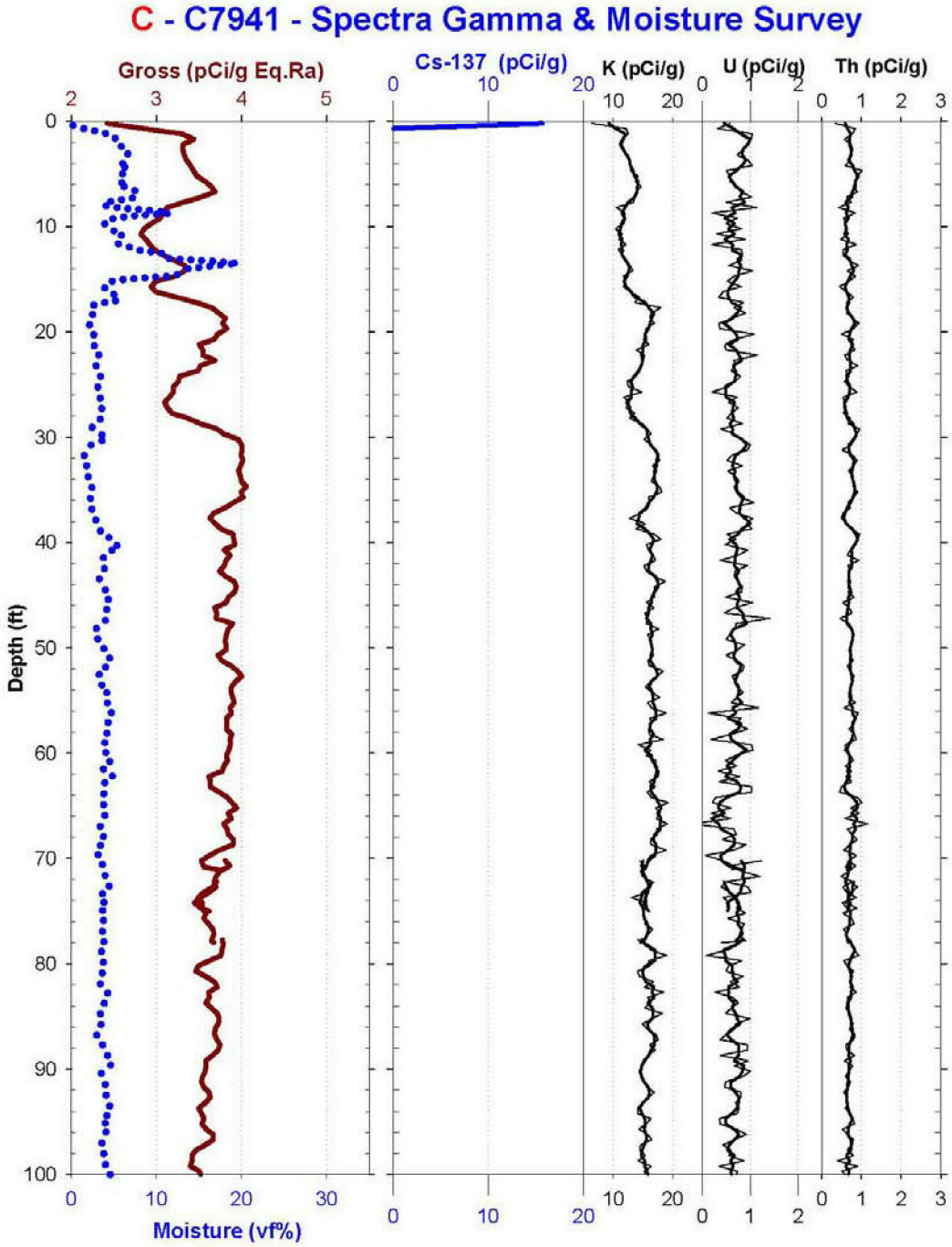
Moisture:

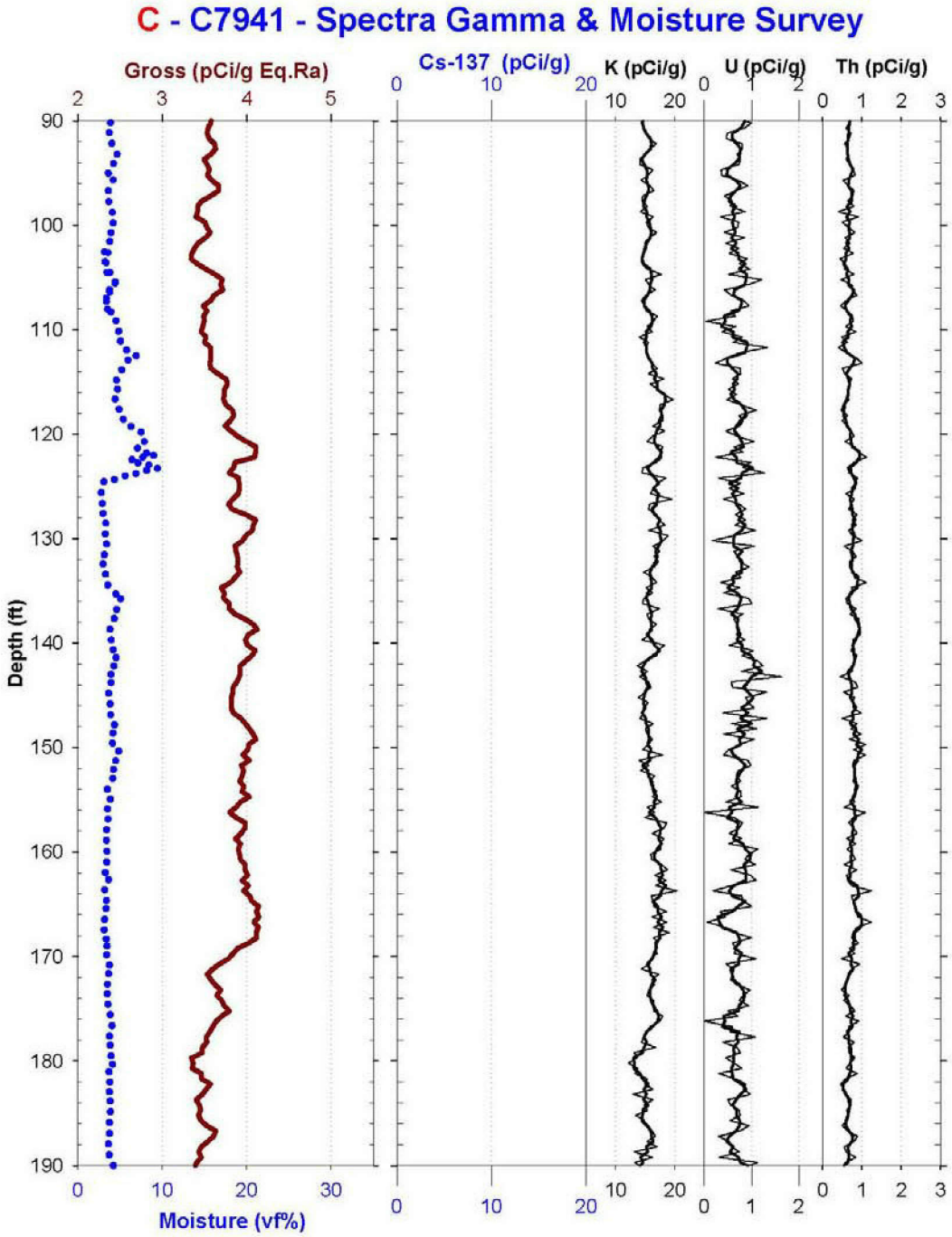
Moisture values range from 1-20%.

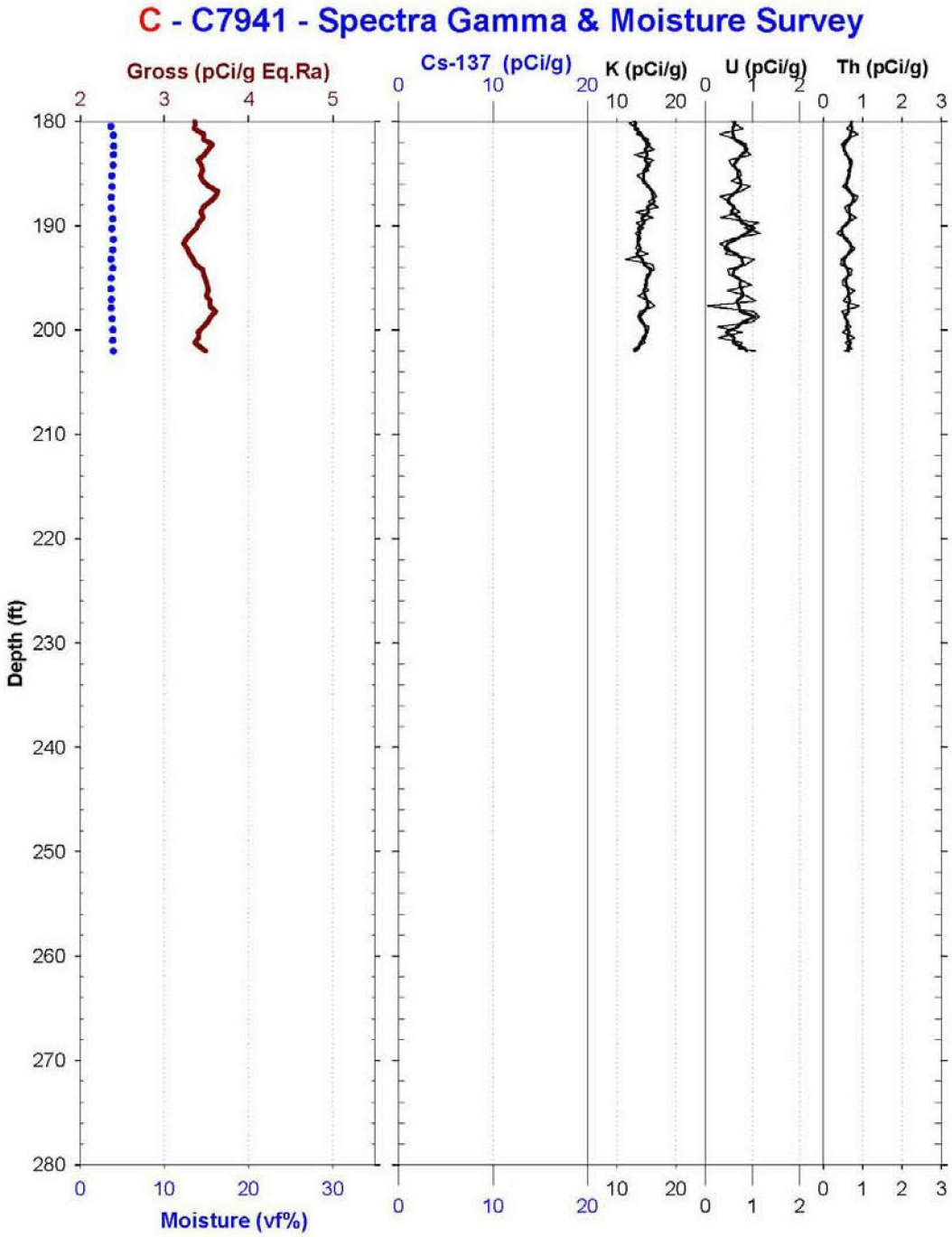
Calibration Certificates

Spectral
Date: Apr 21, 2009
Electronic File: Cal_SD-GR-2_2009-v0.zip

Moisture
Date: Feb 25, 2009
Electronic File: SD-Moist792_2009.zip


C - C7941 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7941 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7941 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7942 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7942	Northing:	136526.1	Depth Ref:
Log Date:	Oct 2010	Easting:	575049.6	Ground Surface
Project:	C Farm	Elevation:	202.649	

REPEAT/OVERLAP INTERVALS

Spectral:	137-134	Moisture:	134-127
	122-118		30-23
	83-80		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

-Spectral:

Cs-137 was observed from surface to 1ft, with a maximum of 13.7 pCi/g. The plotted gross uses an energy threshold of 1000keV, and does not respond to Cs-137.

Moisture:

Moisture values range from 3-16%.

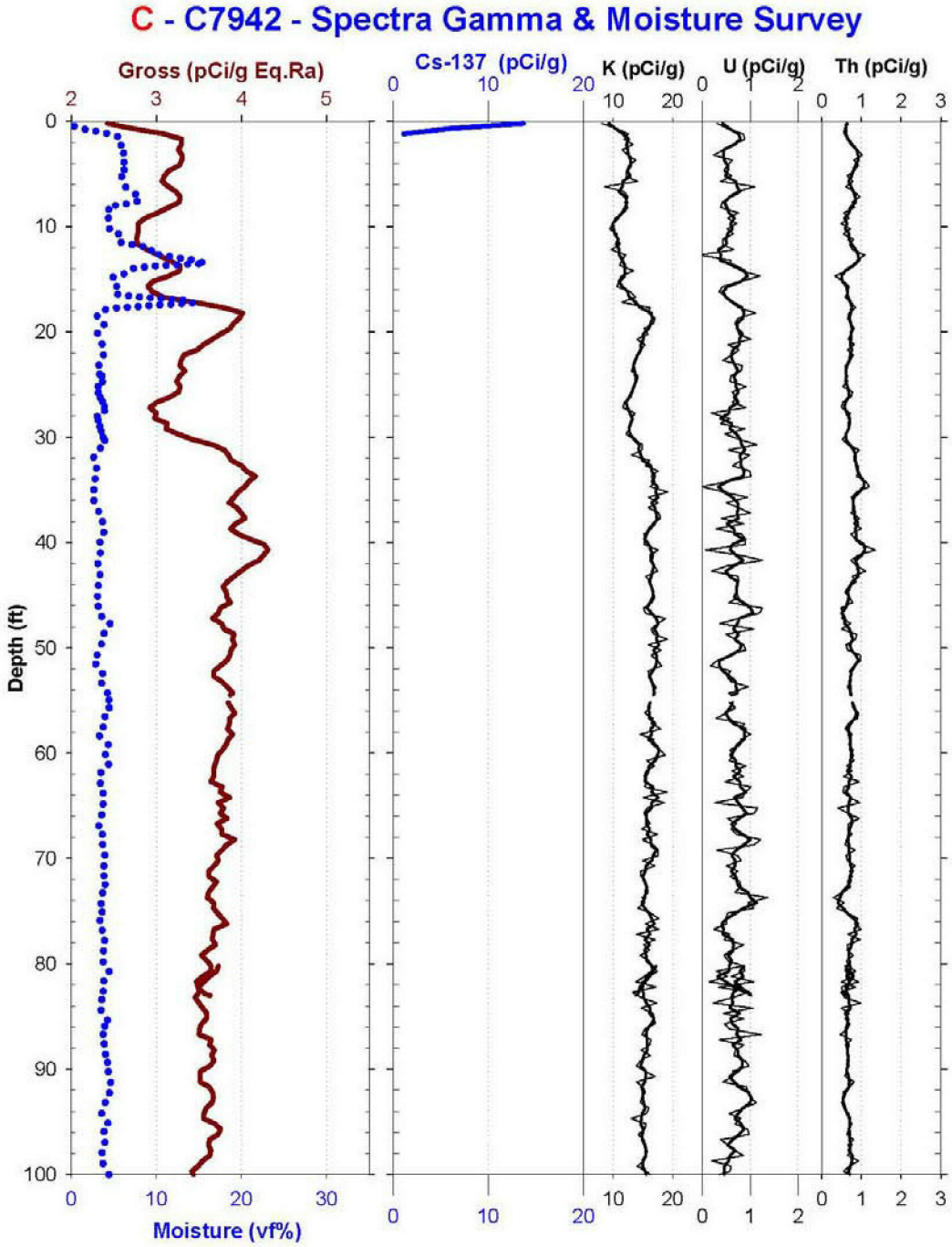
Calibration Certificates

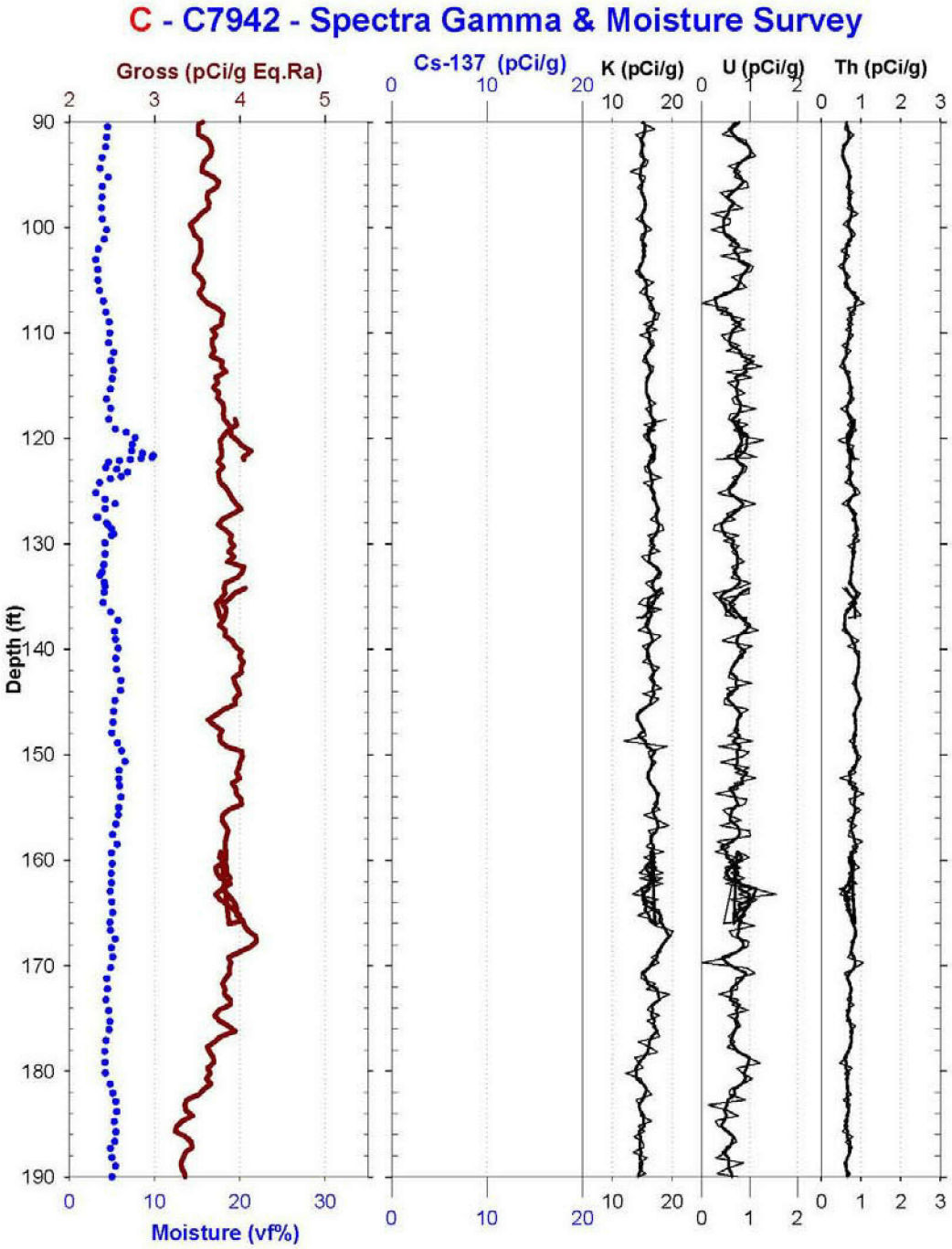
Spectral

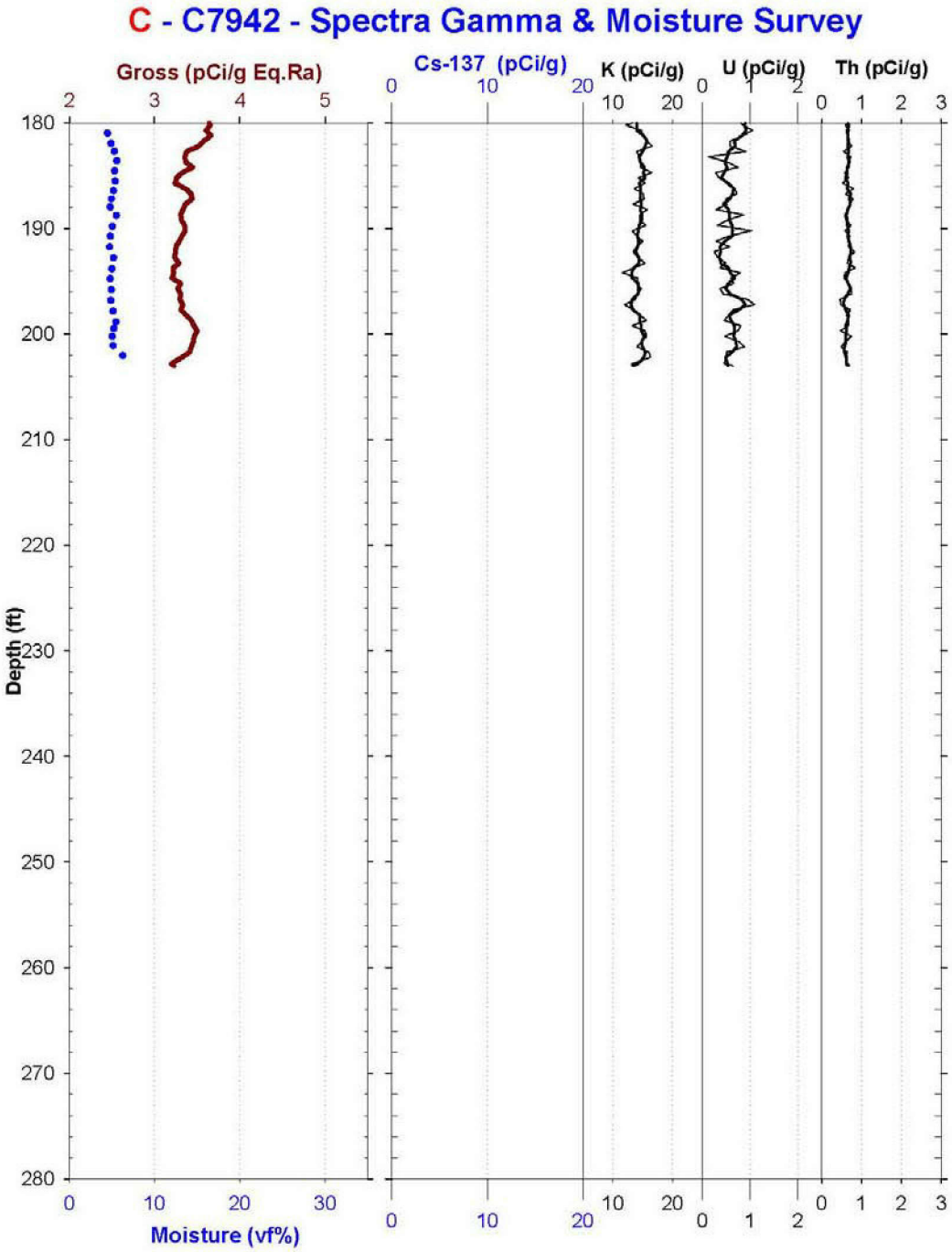
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C - C7942 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7942 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7942 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-FARM C7943 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C7943	Northing:	136519.7	Depth Ref:
Log Date:	Oct 2010	Easting:	575034.7	Ground Surface
Project:	C Farm	Elevation:	203.147	

Repeat/Overlap Intervals

Spectral:	152-147	Moisture:	140-132
	150-148		55-53
	75-71		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

Cs-137 was not observed. The plotted gross uses an energy threshold of 1000keV, and does not respond to Cs-137.

Moisture:

Moisture values range from 2-20%.

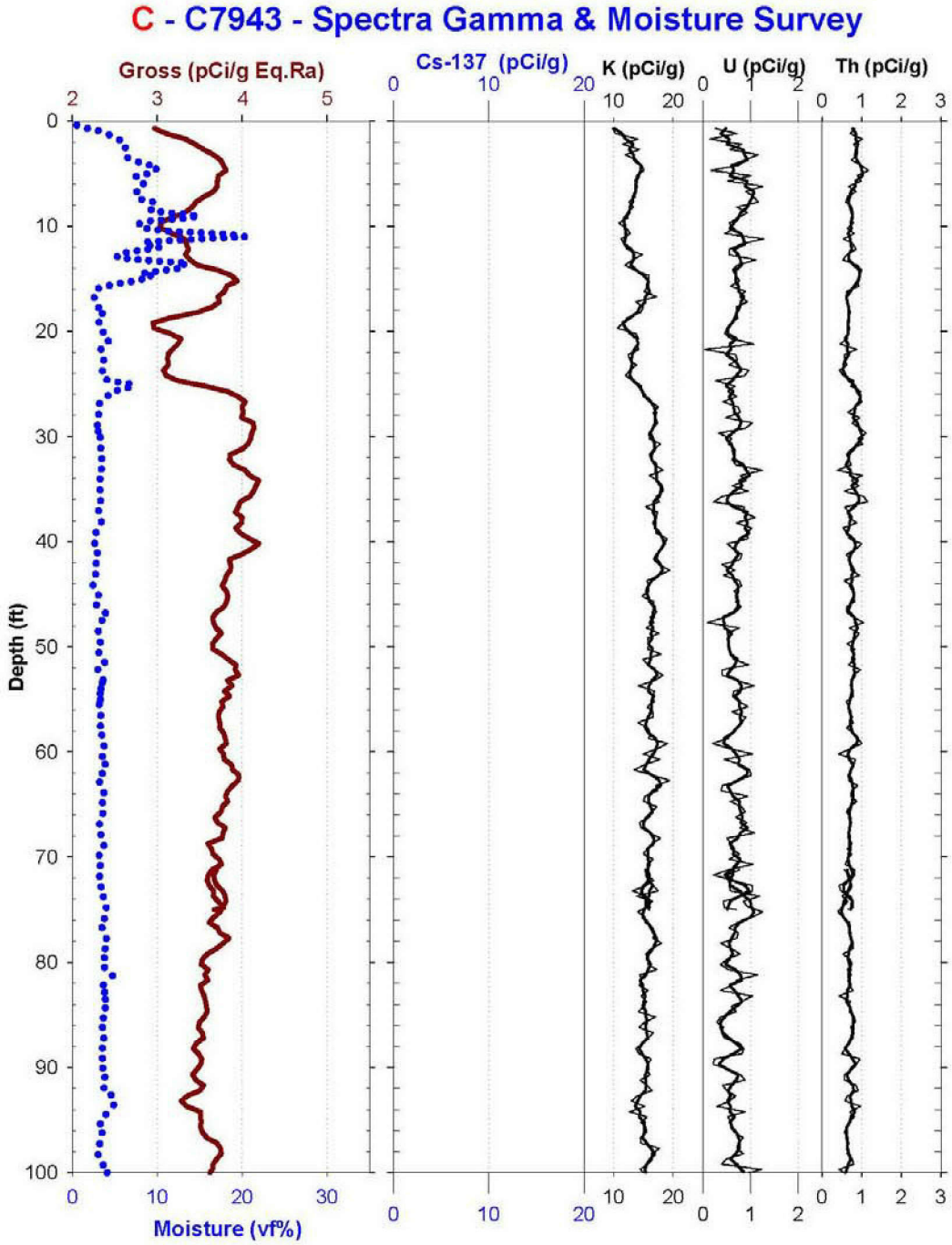
Calibration Certificates

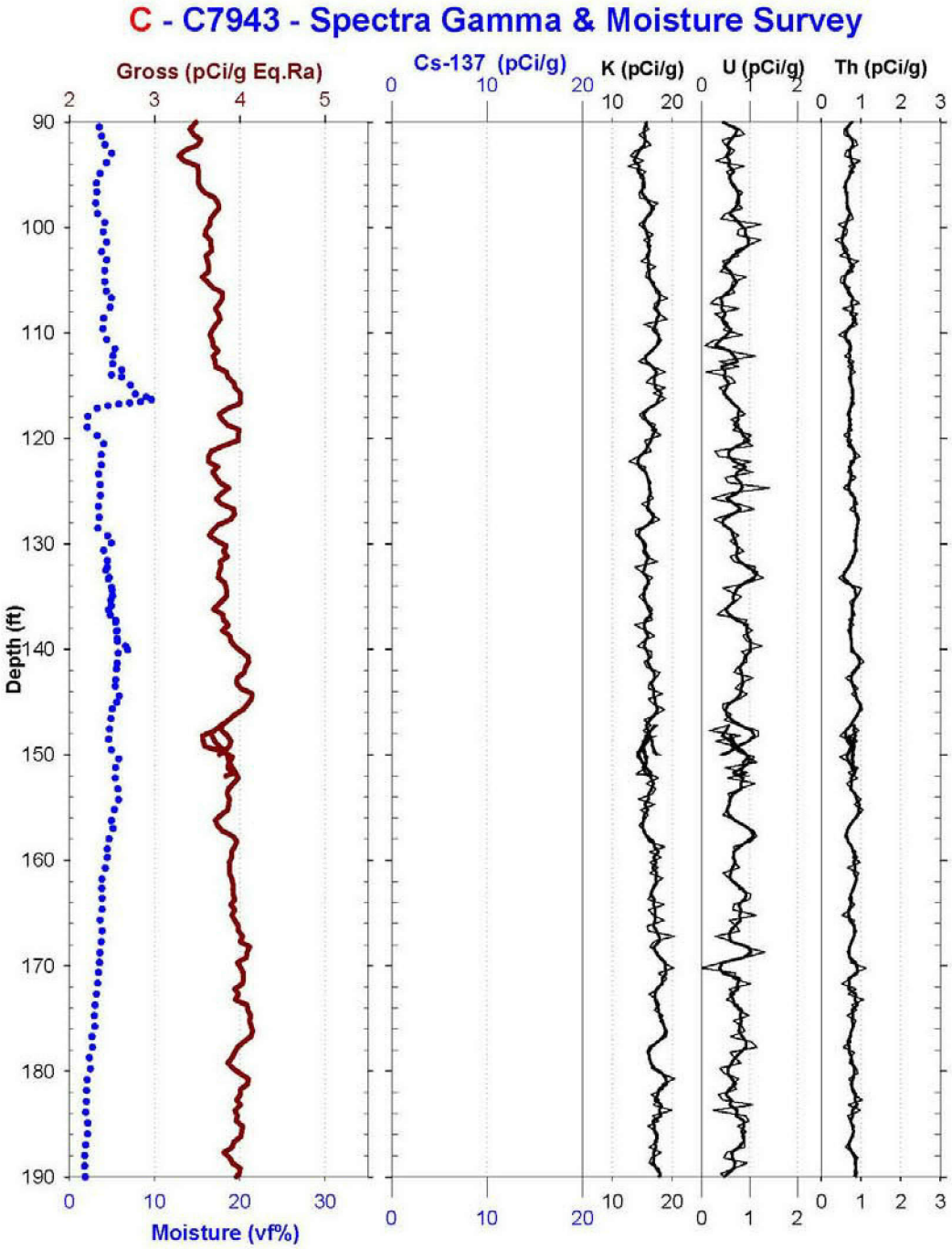
Spectral

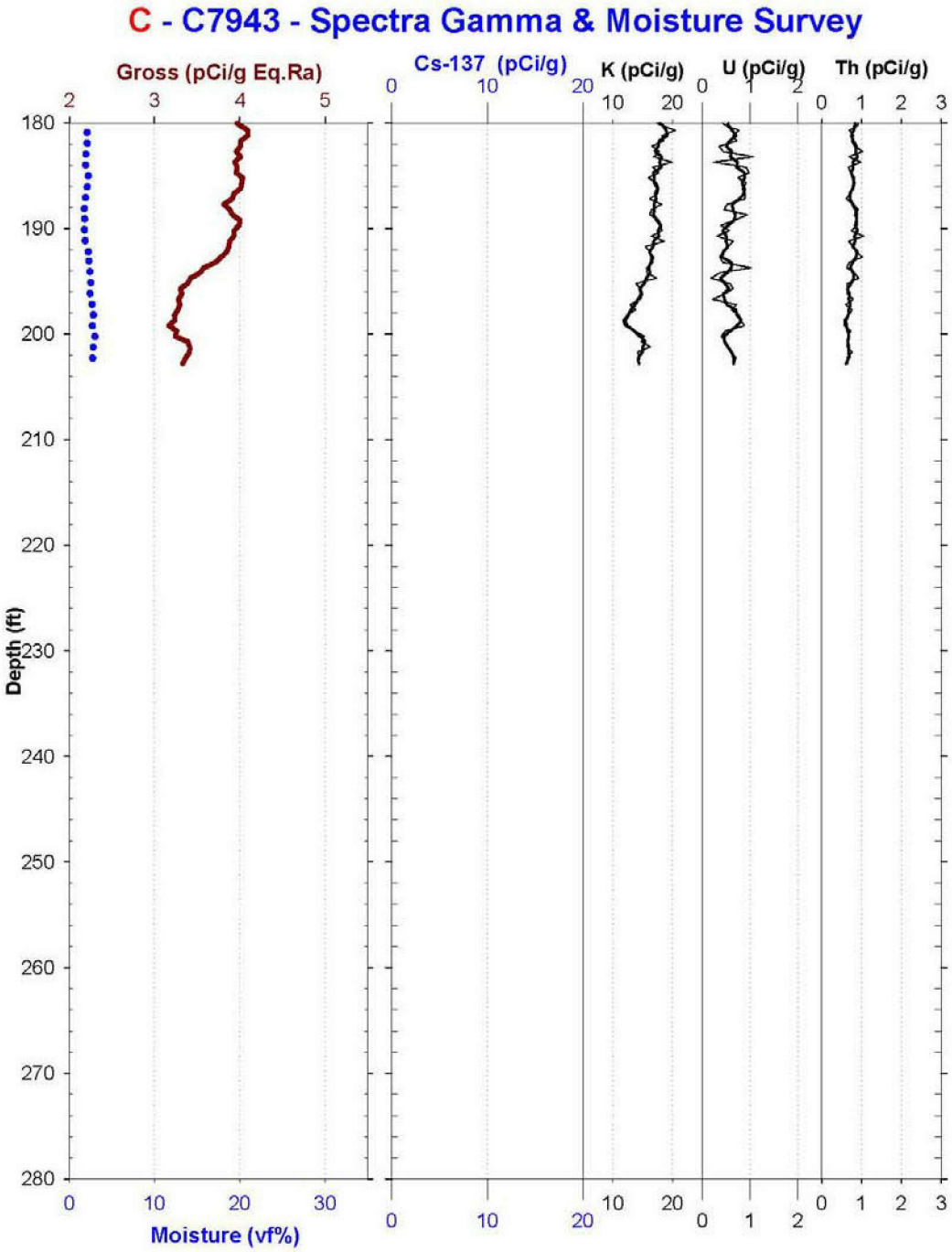
Date:	Apr 21, 2009
Electronic File:	Cal_SD-GR-2_2009-v0.zip

Moisture

Date:	Feb 25, 2009
Electronic File:	SD-Moist792_2009.zip


C - C7943 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7943 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C7943 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

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DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-RPT-49956, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR FY 2011, C-104 ANGLE DIRECT PUSH, 241-C FARM CHARACTERIZATION

RPP-RPT-58339, Rev. A DRAFT

APPENDIX D

SMALL DIAMETER GEOPHYSICAL LOGGING FOR FY 2011, C-104 ANGLE DIRECT PUSH, 241 C FARM CHARACTERIZATION

RPP-RPT-58339, Rev. 0 DRAFT

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SMALL DIAMETER GEOPHYSICAL LOGGING FOR FY 2011, C-104 ANGLE DIRECT PUSH, 241 C FARM CHARACTERIZATION

by

Russel Randall, PhD and Randall Price

to

EnergySolutions Federal Services, Inc.
2345 Stevens Drive
Richland, Washington 99354

June 2011

Pacific Northwest Geophysics
4200 West 19th Avenue
Kennewick, Washington 99338

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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RPP-RPT-58339, Rev. A DRAFT

TERMS

BGO	Bismuth Germinate
KUT	potassium, uranium and thorium
PNG	Pacific Northwest Geophysics

SMALL DIAMETER GEOPHYSICAL LOGGING FOR FY 2011, C-104 ANGLE DIRECT PUSH, 241 C FARM CHARACTERIZATION

1.0 PROBEHOLE SURVEYS

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in two direct-push angle probeholes installed for characterization of the vadose zone near Tank C-104 at the 241-C Tank Farm.

The logging surveys conducted in the first probehole (C8099) were more extensive than the surveys conducted in the second probehole (C8100) which was installed for sample retrieval. The small diameter probehole log surveys described in this report include:

(1) Gyroscope survey of the probehole path,
(2) Bismuth Germinate (BGO) spectral gamma scintillation detector survey, and
(3) Neutron-neutron moisture probe survey.

A summary of the gyroscope results is discussed in Section 2.0, "Gyroscope Probehole Path Surveys". The gyroscope reports for each probehole are presented in Appendix A .

Detector calibration certificates for the BGO and neutron-moisture detectors are presented in Section 3.0, "Gamma and Moisture Surveys." The survey results are presented in Appendix B for each probehole.

Figure 1 shows a map plan-view of the probehole starting locations, gyro survey depths (black dots) and probehole angle path direction (red lines) relative to the underground storage tanks within the investigation site.

2.0 GYROSCOPE PROBEHOLE PATH SURVEYS

Gyroscope surveys were collected according to approved procedures (PNG 2010). Gyroscope surveys were acquired at periodic times during probehole installation to track its path and compute the distance (deviation) between the target path and actual probehole path. Zero depth reference is at ground surface. Multiple gyroscope log runs (usually four) were recorded during each survey event (set of surveys) to show system repeatability.

The slim-hole gyroscope logging sonde is a high precision instrument, manufactured by IFG Corporation of Toronto, Ontario, Canada. The dimensions of the sonde are: (1) diameter 44mm (1.57in), (2) length 1.83m (6ft). The measure point is midway along its length. Three sensor components are recorded continuously during a gyroscope log survey at 2 samples per second: (1) Depth (distance in feet from the sonde measure point to ground surface, i.e. pipe-run length), (2) Inclinometer (2-axis tilt meter), and (3) differential change between the gyroscope axis system and the logging sonde axis system (2-axis, precision = 0.0001 degrees).

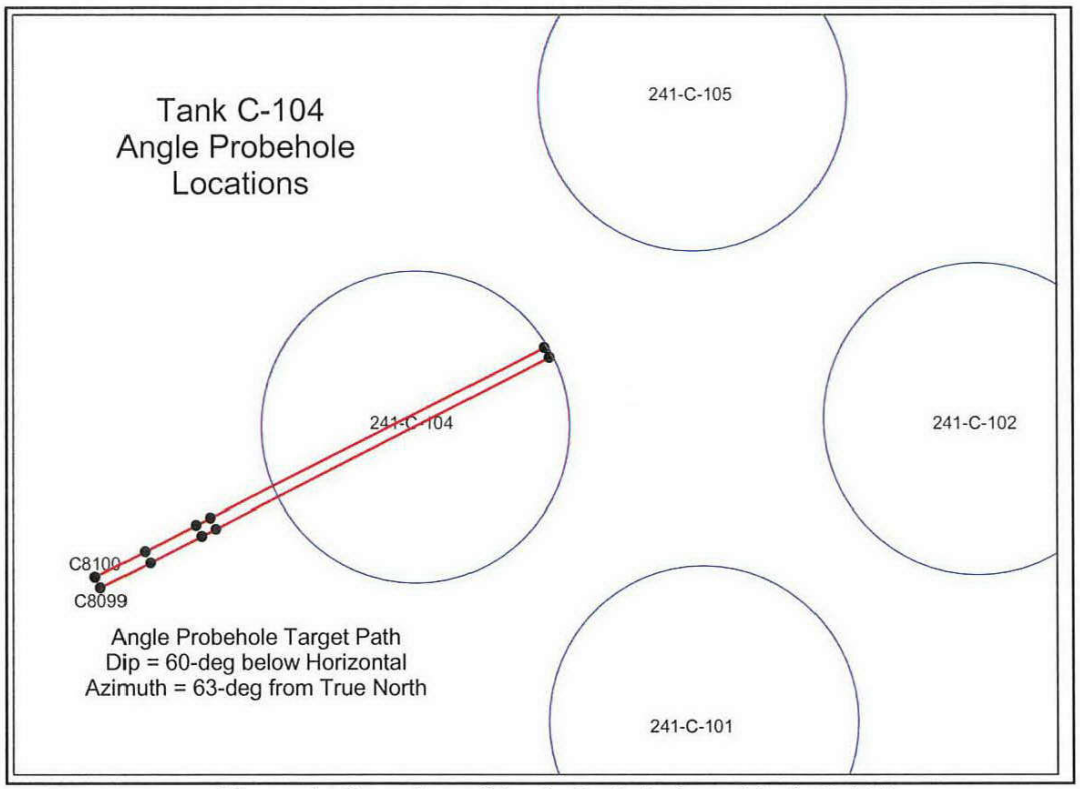

Figure 1. Location of Angle Probeholes at Tank C-104

The path of the probehole is reconstructed from the sonde movements as it is lowered to the bottom of the probehole (In-Run) and as it is withdrawn back to the ground surface (Out-Run). The cable speed is 20 feet/minute (maximum) during sonde movement. Additionally, the winch is halted after 5 minutes or less of cable movement for stationary recording of the sonde sensor outputs. The stationary measurements are a minimum of 20 seconds. Thus, a gyroscope survey contains sensor readings with the sonde both moving and stationary. The gyroscope survey processing program separates the stationary readings from the moving sonde data. The stationary readings are used to remove the minor amount of gyroscope precession (wobble) from the moving sonde data. The gyroscope wobble, which is inherent to all gyroscope systems, is less than $1/30^{th}$ of a degree per second.

The gyroscope survey processing program uses the raw survey data and two input parameters to construct the probehole path. The input parameters, which define the starting probehole location, are: (1) Dip (inclination below horizontal in degrees), and (2) Azimuth (compass bearing from true north in degrees). The processing program reports the path of the probehole in two forms: (1) X,Y,Z coordinates (Northing, Easting, Elevation) relative to (normalized to) the beginning entry location, and (2) probehole dip (degrees below horizontal) and azimuth (degrees from true north) at each survey depth reading (feet of pipe-run length).

The initial probehole starting location (program input parameter) is determined as follows:

- Dip (inclination below horizontal) of probe tubing is measured with a digital angle gauge whose accuracy was confirmed with a bubble level before each set of gyroscope surveys. The precision of the dip measurement is 0.1 degrees. The angle gauge measurement was verified by flipping the device 180 degrees. The two readings may differ by up to 0.2 degrees. The average of the two readings was input as the dip angle.
- Azimuth (true north compass bearing) of the probe tubing is maintained by the guide tube in the foot plate for the drill-rig. The orientation of the foot plate is established by two predetermined Global Positioning System (GPS) survey points, one at six meters behind and the other at one meter forward of the probehole entry location.

Please see Appendix A for individual gyroscope reports.

3.0 GAMMA AND MOISTURE SURVEYS

The gamma and moisture logs were collected according to approved procedures (PNG 2010). The surveys were recorded from the bottom of the probehole (maximum survey depth) to the ground surface. Zero depth reference is at the ground surface. A repeat measurement was acquired daily in at least one probehole to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed and for all of the intervals collected, the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probehole are presented as a depth versus concentration plot in Appendix C. The plots are in numeric order of the probeholes (C8099 – C8100). Appendix C also contains a table summarizing data for each probehole: probehole depth, maximum concentration of Cs-137 in pCi/g, and maximum detected depth of Cs-137

3.1 GAMMA CALIBRATION AND SURVEYS

The spectral gamma scintillation detector uses a BGO crystal that is 2.54 cm [1 in.] diameter by 10.1 cm [4 in.] long. Other components of the gamma logging probe are the high-voltage supply, photo-multiplier tube, pre-amp, and multi-channel analyzer. The settings of the detector components are fixed (i.e., set up during assembly, prior to calibration) and cannot be adjusted by the field-logging engineer. The detector gain and lower threshold are set to record gamma ray activity with energies between 300 and 3000 keV. Lantern mantles containing Th-232 are used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (integrity) and energy calibration (amplifier gain).

The spectral gamma surveys were logged at 100 second per 0.5 ft. A spectrum of 256 channels was collected each 0.15 m (0.5 ft) from the bottom of the probehole to the surface. The spectra were recorded with one spectrum per file (filename extension: "-.chn") in Ortec[1] PHA format.

[1]Ortec is a registered trademark of EG&G Ortec, Gouda, Netherlands.

Spectra were processed to quantify the concentration of the naturally occurring radionuclides (K, U, & Th) and quantify Cs-137 when present above the minimum detection threshold. The minimum detection level (MDL) for Cs-137 is 1 pCi/g, in Hanford soils with nominal levels of radionuclides. The calibration certificate is shown in Figure 2. Also the gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in pCi/g. Calibration was for the probehole conditions present at the investigation site.

3.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS

The neutron moisture sonde combines the PNG-owned thermal-neutron detector and a DOE-owned sealed neutron source (50 mCi AmBe). The DOE-owned neutron source was used because it was already on the Hanford Site and was managed by the DOE Radiation Management Program. The neutron source is an integral component of a neutron moisture detector, manufactured by Campbell Pacific Nuclear, and is identified by the tool serial number H370608792.

The integrity of the sealed neutron source is always maintained when used in calibration and probehole logging activities. Source integrity is maintained by inserting the PNG-owned neutron detector module into the housing containing the sealed neutron source.

Calibration was performed in six borehole calibration models (Meisner and Randall 1995). Three of these models had a 15.24 cm (6-in.) hole size and three models had a 20.32 cm (8-in.) hole size. The moisture content was different for each borehole model within each set of three models (5, 12, and 20 percent by volume). The detector count rate in each of the six borehole calibration models is summarized in Table 1. The calibration certificate is shown in Figure 3. The calibration is specific to the exact combination of source, (H370608792) and detector (tool "SD-Moist792." The 792 at the end reflects the last three digits of the source serial number.

Table 1. Moisture Calibration Data.

Moisture Content Percent – volume fraction	6 inch Models[a] (cps)	8 inch Models[a] (cps)
5% vf	99.67	78.36
12% vf	146.15	110.59
20% vf	183.63	133.22

[a]Count rates are mean of 10 sample measurements at 60-sec each, 10/28/2010.

The probehole size for this project was 6.35 cm (2.5 in.) outside diameter (OD). Therefore, the moisture calibration was extrapolated to the correct hole size. Figure 4 shows the moisture calibration certificate for the 6.35 cm (2.5-in.) hole size.

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The probehole moisture survey was collected at 0.30 m/min (1 ft/min). Processing of the survey data requires that the detector raw survey count rates to be corrected to the thickness of the steel casing present in the calibration models (0.325 in.) Given that the probehole casing thickness is 0.97 cm (0.38 in.), a correction factor of 1.055 is required to correct the observed neutron detector count rate to the conditions of the calibration model (Meisner et al. 1996).

Certificate of Calibration
SDGR.BGO.2
Nov 1, 2010

Data were taken at the Hanford KUT models on November 1, 2010. SDGR.BGO.2 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Ten spectra were recorded for each model in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: Stats.XLS for this analysis. The instrument was covered with 0.37 inch wall thickness probe tubing.

The algorithm described in the document WHC-SD-EN-TI-293, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1320-1575 keV **U: 1650-2390 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**4.745*K**	**-4.204*U**	**3.815*T**
Concentration-U =	**0.0*K**	**1.445*U**	**-2.839*T**
Concentration-T =	**0.0*K**	**-0.049*U**	**1.988*T**

Where K U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_SD-GR-2_2010-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_SD-GR-2_2010-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-293, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models" and that the above stated calibration coefficients are correct and applicable for the tool SDGR.BGO.2 effective Nov 1, 2010.

Signature: Date: November 9, 2010

Company: Three Rivers Scientific

Figure 2. BGO Calibration Certificate.

Figure 3. Moisture Calibration Certificate, 15.24 cm (6-in.) and 20.32 cm (8-in.) Hole.

Certificate of Calibration for
Instrument SD-Moist792

October 28, 2010

Data were taken in the Moisture models on October 28, 2010 for SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H370608792 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, 3 for 6"casing and 3 for 8" casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation; refer to the file MoistCal.xls for this analysis.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	**8" casing**
a = .0001582	**a = .00006587**
α = 2.251	**α = 2.575**

The undersigned certifies that the data archived in data file "SD-Moist792_2010.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-306, "Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration" and that the above stated calibration coefficients are correct and applicable for tool SD-Moist792, effective October 28, 2010.

Signature: Date:

November 9, 2010

Russel Randall, PhD
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument SD-Moist792

October 28, 2010

Moisture calibration was performed in the Hanford physical models. These standards have 6 and 8 inch ID casings. The Tank Farm Direct Push borehole is cased with a 2.5 inch OD iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.5 inch borehole diameter.

2.51" borehole
a = .0002531
α = 1.998

The undersigned certifies that the analysis files are archived in the file "SD-Moist792_2010.zip" was evaluated in accordance with Energy Solutions procedures and that the above stated calibration coefficients are correct and applicable for tool SD-Moist792, effective October 28, 2010.

Signature: Date:

November 9, 2010

Russel Randall, PhD
Three Rivers Scientific

4.0 REFERENCES

Meisner, James and Russel Randall, 1995, *Vadose Zone Moisture Measurement Through Steel Casing Evaluation*, WHC-SD-EN-TI-304, Rev.0, Westinghouse Hanford Company, Richland, Washington.

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PNG, 2010, *Procedures: Calibration, Logging, Quality Assurance and Data Management*, Pacific Northwest Geophysics, Kennewick, Washington.

Randall, R. and D. Stromswold, 1995, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, WHC-SD-EN-TI-293, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A
GYROSCOPE SURVEY RESULT DETAILS

Up to four gyroscope surveys define a set of surveys (during the same day). A constant azimuth value is used for all survey sets (source is GPS survey points to orient the foot plate, six meters behind and one meter forward of the borehole entry location, azimuth. The azimuth (bearing) of C 8099 and C 8100 was plotted at 63 degrees from true north. The dip of the drive casing was measured (via digital angle gauge) for each set of gyroscope surveys (the target dip is 60 degrees below horizontal, i.e. 30 degrees from vertical).

The four tables and two plots below present the detail results for the two probeholes (C8099 and C8100) installed under tank C-104 (two tables per probehole). The first table shows the GPS and offset (delta) coordinates for the target borehole path. The second table presents the survey end-point coordinates for each gyroscope survey (relative to the probehole starting location). The data for probehole C8099 are presented in the first two tables and the data for C8100 are presented in the last two tables. The casing (pipe run) in C 8099 was driven to a total length of 221.3 feet. The borehole gyroscope would not pass a pipe run length of 173 feet because of a bend/deviation in the pipe. Collected data only extends to 170+ feet of pipe run and the path of the pipe is projected in Gyroscope Results and Projection for C8099 by Dr. Randall below. For probehole C8100 the data sets show a repeated section that is the result of the tubing be extracted and re-driven after collection of data on 3/8/2011 at 56+ feet below ground surface.

The plots (one per probehole) are the 3D view that compares the target path (blue line) with the actual probehole path (red line). The black dots are the coordinates for the probehole starting and ending locations as well as the intermediate gyroscope survey locations. The rectangle at the surface (wide gray line at 0 feet) encloses the surface area of the target probehole path. The red line at the surface is the plan view projection of the actual probehole path. The brown dashed-line rectangle encloses the target probehole projection from the top (surface) to its total depth.

Table A1 Probehole C8099 - GPS Coordinates of Target Borehole

Probehole	Gyro Survey Pipe-Run (ft)	Northing (m)	Easting (m)	Elevation (ft)	Δ North=Y -S / +N (ft)	Δ East=X -W / +E (ft)	Δ Elev.=Z -(Deep) / +(Shallow) (ft)
		Target Path			Distance from Start Coordinates		
C8099	Surface	136514.24	575116.69	664.00			
C8099	27.7	136516.15	575120.48	640.00	6.27	12.43	-24.00
C8099	56.58	136518.14	575124.40	615.00	12.80	25.30	-49.00
C8099	66.66	136518.69	575125.50	608.00	14.60	28.90	-56.00
C8099	173.1 (a)	136526.18	575140.24	514.09	39.17	77.28	-149.91
C8099	252.88	136531.68	575151.10	445.00	57.22	112.89	-219.00

(a) Gyro probe encountered refusal at 173.1 ft. Target Coordinates at 252.88 are included for information purposes..

Table A2 Probehole C8099- Individual Gyroscope Survey Results

	Gyro Survey End-Point Results						Difference (Survey - Target)			Distance to Target	
Date	Pipe-Run (ft)	North Offset (ft)	East Offset (ft)	Elev. Offset (ft)	Dip (Deg)	Azimuth (Deg)	North -S / +N (ft)	East -W / +E (ft)	Elev -(Deep) / +(Shallow) (ft)	(ft)	(m)
Target End-Points		**6.27**	**12.43**	**-24.00**			Dip = 59.9 Deg at top probehole				
1/13/2011	27.68	6.15	12.41	-23.96	-59.95	63.39	-0.11	-0.02	0.04	0.12	0.04
	27.70	6.21	12.50	-23.93	-59.84	63.56	-0.06	0.06	0.07	0.11	0.03
	27.71	6.23	12.40	-23.98	-59.88	63.18	-0.03	-0.04	0.02	0.05	0.02
	27.69	6.25	12.40	-23.96	-59.78	63.16	-0.02	-0.04	0.04	0.06	0.02
Average	**27.70**	**6.21**	**12.43**	**-23.96**	**-59.86**	**63.32**	**-0.06**	**0.01**	**0.04**	**0.09**	**0.02**
Target End-Points		**12.80**	**25.30**	**-49.00**			Dip = 60.0 Deg at top probehole				
1/28/2011	56.61	13.07	25.48	-48.83	-58.74	62.94	0.27	0.19	0.17	0.37	0.11
	56.57	12.88	25.52	-48.82	-58.74	63.53	0.08	0.22	0.18	0.30	0.09
	56.60	12.99	25.58	-48.79	-58.65	63.29	0.19	0.29	0.21	0.40	0.12
	56.60	13.01	25.55	-48.80	-58.69	63.19	0.22	0.26	0.20	0.39	0.12
Average	**56.60**	**12.99**	**25.53**	**-48.81**	**-58.71**	**63.24**	**0.19**	**0.24**	**0.19**	**0.37**	**0.11**
Target End-Points		**14.60**	**28.90**	**-56.00**			Dip = 59.7 Deg at top probehole				
1/31/2011	64.63	14.85	29.49	-55.56	-58.25	63.47	0.25	0.58	0.44	0.77	0.24
	64.70	14.86	29.46	-55.65	-58.23	63.34	0.26	0.55	0.35	0.70	0.21
	64.59	14.85	29.30	-55.61	-58.15	63.14	0.25	0.40	0.39	0.61	0.19
	64.67	14.82	29.40	-55.66	-58.06	63.32	0.22	0.49	0.34	0.64	0.20
Average	**64.65**	**14.85**	**29.41**	**-55.62**	**-58.17**	**63.32**	**0.25**	**0.51**	**0.38**	**0.68**	**0.21**
Target End-Points		**39.17**	**77.28**	**-149.91**	**Probe Refusal**		Dip = 59.9 Deg at top probehole				
2/7/2011	173.11	45.10	84.22	-144.03	-48.48	57.69	5.93	6.95	5.87	10.86	3.31
	173.12	45.45	84.62	-143.68	-48.24	57.62	6.29	7.34	6.23	11.50	3.50
	173.07	45.16	84.63	-143.72	-48.30	57.66	5.99	7.35	6.19	11.33	3.45
	173.13	45.40	84.59	-143.73	-48.31	57.33	6.23	7.31	6.18	11.42	3.48
Average	**173.11**	**45.28**	**84.52**	**-143.79**	**-48.33 (b)**	**57.58 (b)**	**6.11**	**7.24**	**6.12**	**11.28**	**3.44**

(b) Significant end-point drift at 173ft; Dip=-48.3 Deg and Azimuth=57.58 Deg.

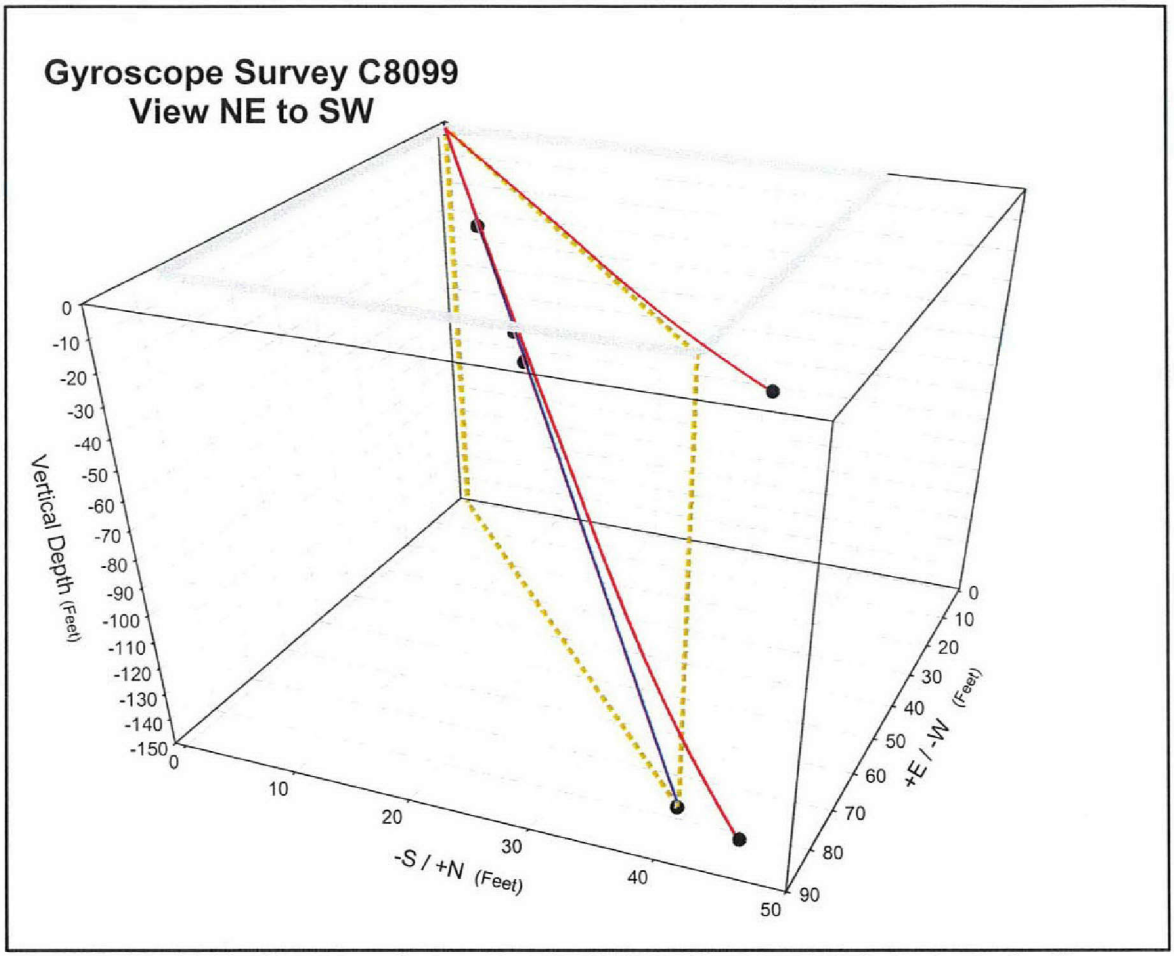


Figure A1 Gyroscope Survey Results C8099 (Pipe Run 173 ft, Probe Refusal)

Table A3. Probehole C8100 - GPS Coordinates of Target Probehole

Probehole	Gyro Survey Pipe-Run (ft)	Northing (m)	Easting (m)	Elevation (ft)	Δ North=Y -S / +N (ft)	Δ East=X -W / +E (ft)	Δ Elev=Z -(Deep) / +(Shallow) (ft)
		Target Path			Distance from Start Coordinates		
C8100	0	136515.05	575116.28	664.00			
C8100	27.7	136516.98	575120.06	640.00	6.33	12.40	-24.00
C8100	56.58	136518.97	575123.98	615.00	12.86	25.26	-49.00
C8100	66.66	136519.53	575125.07	608.00	14.70	28.84	-56.00
C8100	220.0 (c)	136530.17	575146.24	473.47	49.61	98.30	-190.53
C8100	252.88	136532.43	575150.72	445.00	57.02	112.99	-219.00

(c) Drill Rig encountered refusal at 220 ft. Target Coordinates at 252.88 are included for information purposes..

Table A4 Probehole C8100 – Individual Gyroscope Survey Results

	Gyro Survey End-Point Results						Difference (Survey - Target)			Distance to Target	
Date	Pipe-Run (ft)	North Offset (ft)	East Offset (ft)	Elev Offset (ft)	Dip (Deg)	Azimuth (Deg)	North -S / +N (ft)	East -W / +E (ft)	Elev -(Deep) / +(Shallow) (ft)	(ft)	(m)
Target End-Points		**6.33**	**12.40**	**-24.00**			Dip = 60.6 Deg at top probehole				
3/2/2011	27.69	6.28	12.15	-24.08	-60.10	62.09	-0.05	-0.25	-0.08	0.27	0.08
	27.70	6.24	12.11	-24.12	-60.37	62.38	-0.09	-0.29	-0.12	0.33	0.10
	27.71	6.25	12.11	-24.13	-60.37	62.49	-0.09	-0.29	-0.13	0.33	0.10
	27.71	6.25	12.13	-24.12	-60.27	62.34	-0.08	-0.27	-0.12	0.31	0.09
Average	**27.70**	**6.26**	**12.13**	**-24.11**	**-60.28**	**62.33**	**-0.08**	**-0.28**	**-0.11**	**0.31**	**0.09**
Target End-Points		**12.86**	**25.26**	**-49.00**			Dip = 60.7 Deg at top probehole				
3/7/2011	56.60	12.95	24.82	-49.19	-59.85	62.71	0.09	-0.44	-0.19	0.49	0.15
	56.70	13.18	24.99	-49.16	-59.39	61.59	0.32	-0.27	-0.16	0.45	0.14
	56.59	13.12	24.92	-49.09	-59.71	62.19	0.26	-0.35	-0.09	0.44	0.14
	56.60	13.10	25.02	-49.06	-59.44	62.55	0.24	-0.25	-0.06	0.35	0.11
Average	**56.62**	**13.09**	**24.94**	**-49.13**	**-59.60**	**62.26**	**0.23**	**-0.33**	**-0.13**	**0.43**	**0.14**
Target End-Points		**14.70**	**28.84**	**-56.00**			Dip = 60.5 Deg at top probehole				
3/8/2011	64.58	15.09	28.42	-55.99	-59.28	61.82	0.39	-0.42	0.01	0.57	0.17
	64.70	15.24	28.39	-56.10	-59.37	61.91	0.54	-0.44	-0.10	0.71	0.22
	64.65	15.26	28.50	-55.99	-59.19	61.90	0.56	-0.34	0.01	0.65	0.20
	64.68	15.28	28.47	-56.03	-59.29	61.88	0.58	-0.37	-0.03	0.69	0.21
Average	**64.65**	**15.22**	**28.45**	**-56.03**	**-59.28**	**61.88**	**0.52**	**-0.39**	**-0.03**	**0.66**	**0.20**
Target End-Points		**12.86**	**25.26**	**-49.00**			Dip = 60.75 Deg at top probehole				
3/15/2011	56.63	13.17	24.90	-49.12	-59.44	61.79	0.31	-0.37	-0.12	0.50	0.15
	56.61	13.13	24.95	-49.08	-59.45	61.93	0.27	-0.31	-0.08	0.42	0.13
	56.60	13.17	25.01	-49.04	-59.31	61.94	0.30	-0.25	-0.04	0.39	0.12
	56.61	13.20	24.94	-49.07	-59.43	61.86	0.33	-0.32	-0.07	0.47	0.14
Average	**56.61**	**13.17**	**24.95**	**-49.08**	**-59.41**	**61.88**	**0.30**	**-0.31**	**-0.08**	**0.45**	**0.14**
Target End-Points		**36.53**	**72.39**	**-140.30**			Dip = 60.6 Deg at top probehole				
3/22/2011	162.04	41.24	73.78	-138.16	-55.26	56.62	4.71	1.40	2.14	5.36	1.63
	161.96	40.93	73.85	-138.13	-55.39	56.91	4.40	1.46	2.17	5.12	1.56
	162.02	41.20	73.80	-138.14	-55.49	56.82	4.67	1.41	2.15	5.34	1.63
Average	**162.01**	**41.12**	**73.81**	**-138.14**	**-55.38**	**56.78**	**4.59**	**1.42**	**2.15**	**5.27**	**1.61**
Target End-Points		**49.61**	**98.30**	**-190.53**	**Drill Refusal**		Dip = 60.6 Deg at top probehole				
3/28/2011	220.06	61.09	103.28	-184.03	-51.63	51.35	11.48	4.98	6.50	14.10	4.30
	220.01	61.63	103.51	-183.65	-51.46	51.59	12.02	5.21	6.87	14.80	4.51
	220.03	60.60	103.95	-183.76	-51.52	51.80	11.00	5.65	6.76	14.09	4.29
Average	**220.03**	**61.11**	**103.58**	**-183.81**	**-51.54 (d)**	**51.58 (d)**	**11.50**	**5.28**	**6.71**	**14.33**	**4.37**

(d) Significant end-point drift at 220ft; Dip=-51.5 Deg and Azimuth=51.6 Deg.

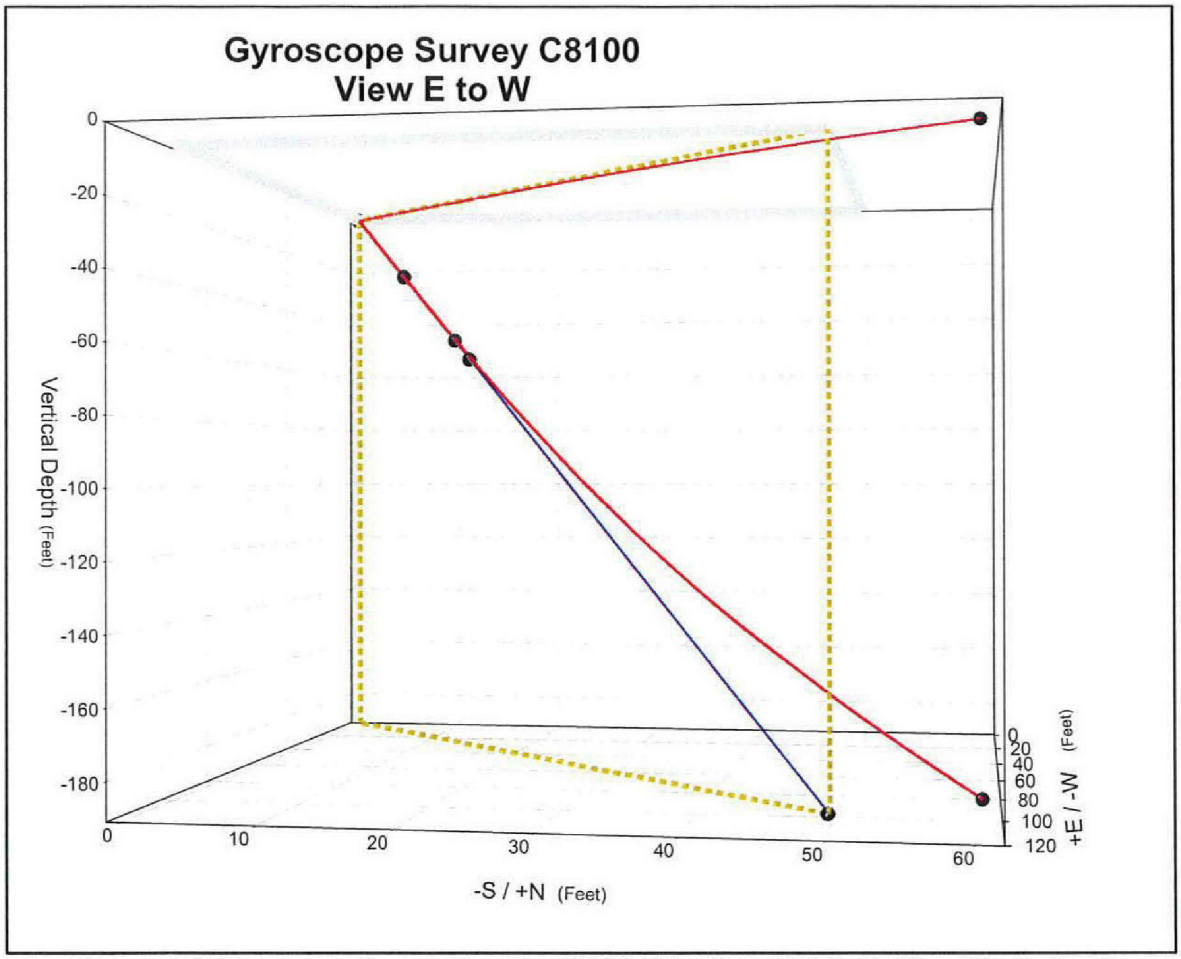


Figure A2 Gyroscope Survey Results C8100 (Pipe Run 220 ft, Drilling Rig Refusal)

Gyroscope Results and Projection for C8099
Russ Randall, PhD
Feb 23, 2011

Introduction

Energy Solutions conducted slant direct push operations to collect data adjacent to and under tank C-104, borehole ID C8099, in the C tank farm. The starting pipe dip angle was -60° from horizontal, 30° from vertical. The starting azimuth was 63° from North. The dip angle began changing at about 10 feet of pipe length (vertical depth 8.66 feet) and continued to change to a measured pipe length of 173 feet (143.7 feet vertical). The azimuth angle remained fairly constant until about 135 feet of pipe length. At this point the azimuth angle began changing from the 63^0 degree planned bearing and began deviation to the north. The borehole was pushed to a total of 255 feet pipe length. The gyroscope stopped at a pipe length of approximately 173 and would not pass to bottom because of a localized deviation in the pipe calculated to be greater than $.2^0$.

This report describes the projection of gyroscopic data to predict the coordinates of the end point of the pipe.

Method of Projection

Four sets of gyroscope log surveys were conducted at various depths during the push operations. During the collection of the final data set at a total pipe length of 255+ feet the tool could not get past the deviation/bend at 173 feet of pipe run. Four sets of data were collected from surface to 173 feet. Table 1 contains the coordinates for each survey end point closest to 173 feet. The average is also provided in the last row.

Table 1. Gyroscopic Coordinates for Four Different Surveys

log run	Depth	Northing	Easting	Elevation	Dip	Azimuth
D4	173.034	45.36	84.54	-143.67	-48.34	57.33
D3	173.016	45.14	84.6	-143.68	-48.32	57.66
D2	173.012	45.42	84.56	-143.61	-48.28	57.62
D1	173.002	45.06	84.16	-143.95	-48.51	57.68
mean	173.016	45.25	84.47	-143.73	-48.36	57.57

The units for Depth, Northing, Easting, and Elevation are in feet. The dip and azimuth are in degrees. The distances are referenced from the starting point of the push. Using the mean values, the end point of the log data is:

- True vertical depth of 143.7ft down from surface
- Horizontal distance towards the east of 84.5 ft from start point
- Horizontal distance towards the north of 45.2 ft from start point

Because the borehole was pushed to a pipe run depth of 255 feet, an additional 82 feet of pipe exists beyond the end point of the gyroscopic data listed in Table 1. Because the gyroscope could not pass beyond the 173 foot pipe run depth, a projection of the push end point coordinates was calculated, assuming that the dip and azimuth angles continue to change at the rate observed at the end of the final surveys. Figure 1 shows the dip angles as a function of pipe depth over the 173 feet of gyroscopic data.

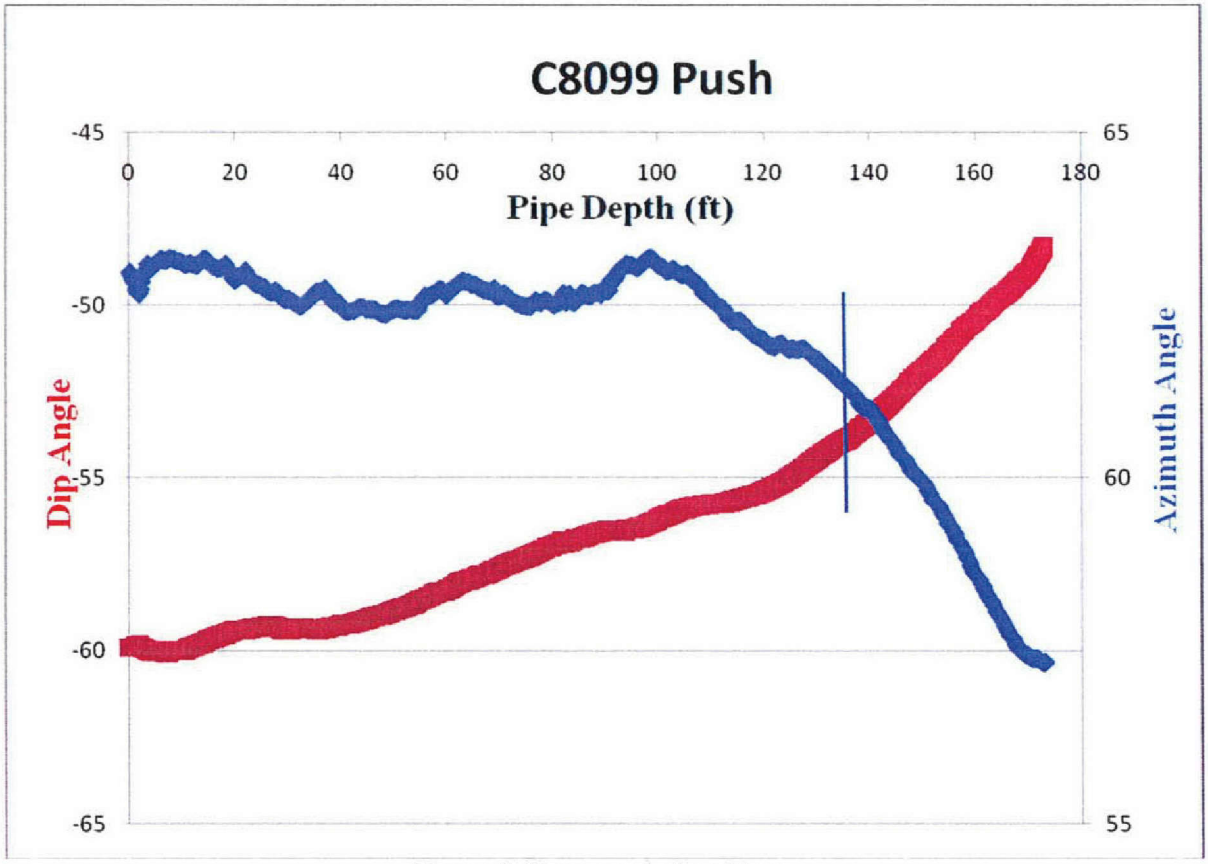


Figure 2 Gyroscopic Log Data

The dip angle from about 135ft to the end at 173ft is changing at a relatively constant rate of change. The dip data from 135-173 ft were least square fit for a linear rate of change. This same rate of change was then used to continue the projection out to the pipe end of 255ft. The azimuth angle was observed to remain relatively constant over the first 100 feet of pipe with an onset of constant angle change with pipe depth from 135-173 ft. Likewise, the azimuth data were least square fit for a linear change and this rate was used in the projection to the end of pipe.

Figure 2 is a 3D plot of the length of pipe using gyroscopic data from surface to 173 ft and the above projections for the remainder of pipe length. These data and projections are plotted in

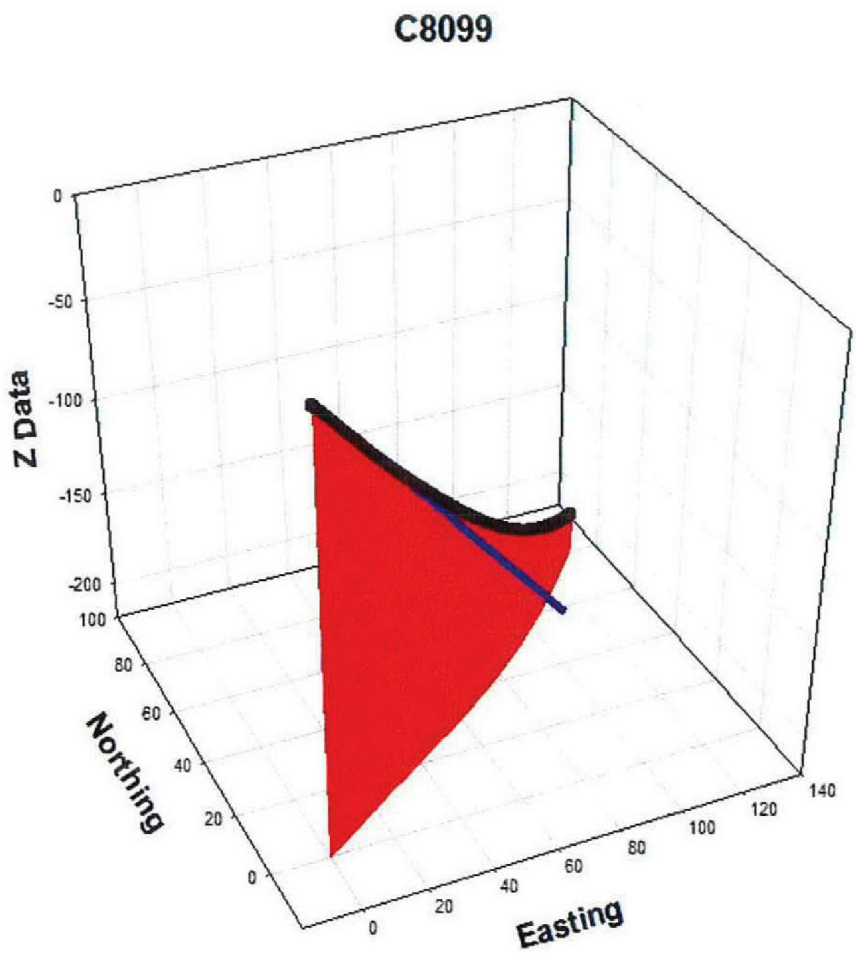


Figure 3 Borehole path

black, and the straight line projection with the target path is plotted in blue. The black data points of the borehole-path have added red drop lines straight down to the x-y plane (Easting-Northing relative coordinates). This yields a visualization of the x-y path.

Table 2 contains the relative coordinates of the projected and target end points of the pipe, given a pipe run depth of 254.97ft as observed. The original design called for a slightly less pipe run depth than what occurred.

Table 2. End Point Projection

Coordinate	Projected End Point (ft)	Straight Push Endpoint	Original Designed
pipe length	254.97	254.97	252.88
Easting	131.665	113.59	112.66
Northing	81.783	57.88	57.40
Elevation	-199.478	-220.81	-219.00

While the assumption of a constant rate of change in dip and azimuth is reasonable, it is known that at 173ft there is a bend/deviation in the pipe which was sufficient in displacement to not allow the gyroscope to pass. A pipe deviation (known to be greater than 0.2° over a 6 foot length) occurred at this pipe length. A variance in offset angles was estimated at this point. The direction of the kick or bend is not known, thus a possible kick in both up and down as well as left and right were calculated.

The basis of estimating this kick angle is the following:

- The minimum kick angle is 0.2° due to the gyroscopic tool length and drift angle inside the push pipe.
- The pipe cannot experience too large of a bend and retain integrity (e.g. not collapse, refuse to advance or cause a bend sufficient to not allow retrieval). The estimated maximum non catastrophic bend is 0.5°.

A cone of projection can be computed using the additional assumption of a one-time kick in the angles. Table 3 has the coordinates for the four extremes of the projected cone and the center point estimated and listed in Table 2. Table 3 also contains the coordinates of the four extremes of this cone. The last column of Table 3 contains what the end point coordinates would have been if there had been no change in original angles.

Table 3. Projection of pipe end point and tolerance

Coordinate	Center	Z top	Z bottom	Azimuth +	Azimuth-	Straight
pipe length	254.97	254.97	254.97	254.97	254.97	254.97
Easting	131.665	132.045	131.282	131.345	131.982	113.59
Northing	81.783	82.074	81.49	82.193	81.37	57.88
Elevation	-199.478	-198.954	-199.997	-199.478	-199.478	-220.81

Conclusion

Coordinates of the end of pipe for C8099 cannot be measured due to a bend in pipe at 173 feet which would not allow the gyroscopic tool to pass. A projection of the possible end point

coordinate was calculated assuming angle changes continuing as measured over the deepest 38 ft (135-173 ft) of gyroscopic data, and a projection of possible variance of this end point due to an addition 0.5° kick at the bend of 173ft of pipe was computed. As shown in Table 3, it is clear the variance of a 0.5° kick is insignificant when compared to the possible changes in dip and azimuth angles. Variance of the dip and azimuth from the assumed constant rates of change will affect the final coordinates much more than a bend at 173ft of pipe.

APPENDIX B
SPECTRAL GAMMA AND MOISTURE SURVEY RESULTS

Survey plots follow for the two angle probeholes installed for Tank C-104 Characterization. Probehole C8099 was surveyed with both the BGO spectral gamma and moisture probes. Probehole C8100 was surveyed with the moisture probe. Each log plot is preceded by a header information page that shows the probehole coordinates, repeat/overlap intervals, isotopes analyzed, observations, and logging probe calibration dates. The log plots show a maximum of 100 feet per page with a 10 ft overlap between page breaks.

The spectral gamma survey data were processed to quantify the naturally occurring radionuclides (K, U, & Th), and the man-made radionuclide of Cs-137 (blue solid line). The spectra were processed both as individual spectra for each survey depth and as a moving sum of three spectra (i.e. sum of the individual survey depth and the two adjacent spectra, above and below the current depth position). Both results are presented on the results plot. The results for the 3-spectra sum are plotted as a wide line. Also the gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in scale of 2 to 6 pCi/g (brown line).

The neutron-neutron moisture survey data are shown with a blue line. The moisture plot scale is 0-30 (% vf).

Table C1 below contains a summary of the survey results for each probehole: maximum log depth, maximum detection level for Cs-137, maximum depth of Cs-137 detection, and special observations by the analyst to flag the detection of other isotopes in additions to the natural radionuclides and Cs-137.

Table C1. Probehole Survey Summary.

Probehole ID.	Hole Depth (meters)	Hole Depth (feet)	Cs-137 (pCi/g) Max Detection	Cs-137 Max Detected Depth	Flag Isotopes Other Than Naturals and Cs-137
C8099	77.7	255	5.8 pCi/g at surface	17 ft	None
C8100	67.1	220	n/a	n/a	n/a

C-FARM C8099 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C8099	Northing:	136514.24	Depth Ref:
Log Date:	Feb 2011	Easting:	575116.69	Ground Surface
Project:	C Farm	Elevation:	202.39m	

Repeat/Overlap Intervals

Spectral: 255-252
184-178

Moisture: 255-247

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

-Spectral:

Cs-137 was observed at the surface, with a maximum of 5.8 pCi/g, and over depth of 17-16ft with a maximum of 2.2 pCi/g. The plotted gross uses an energy threshold of 1000keV, and does not respond to Cs-137. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole.

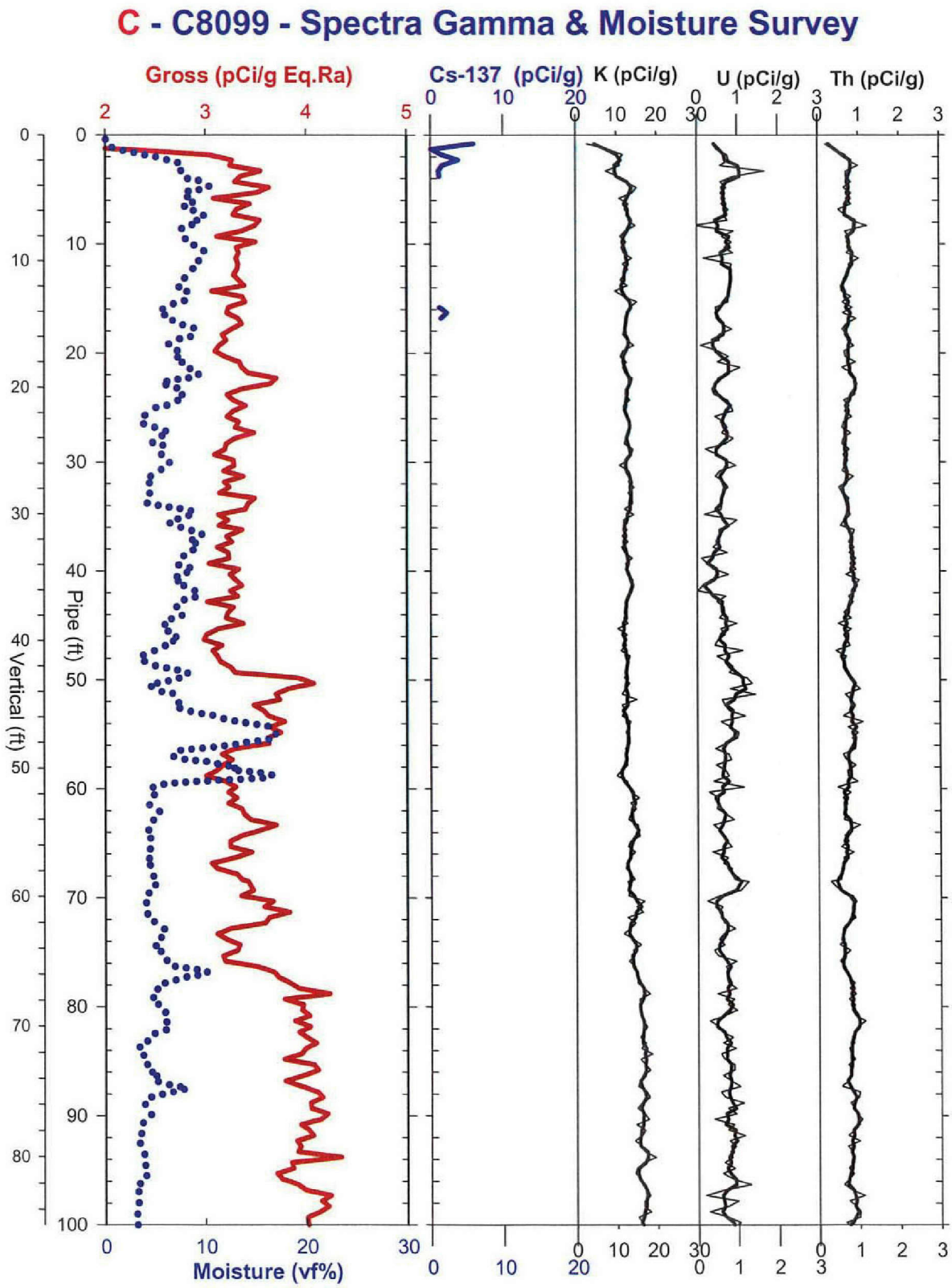
Moisture:

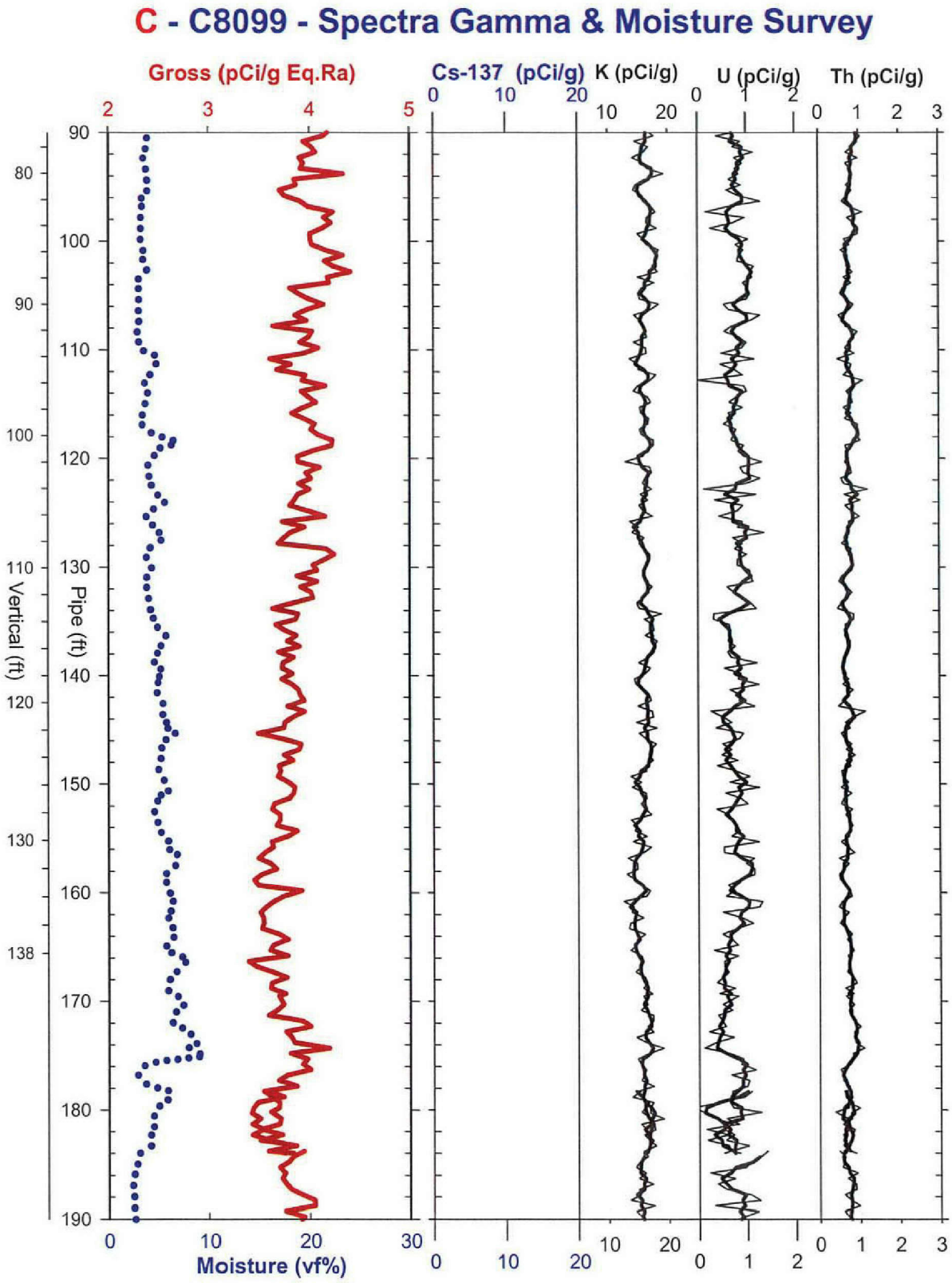
Moisture values range from 2.3-17%. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole.

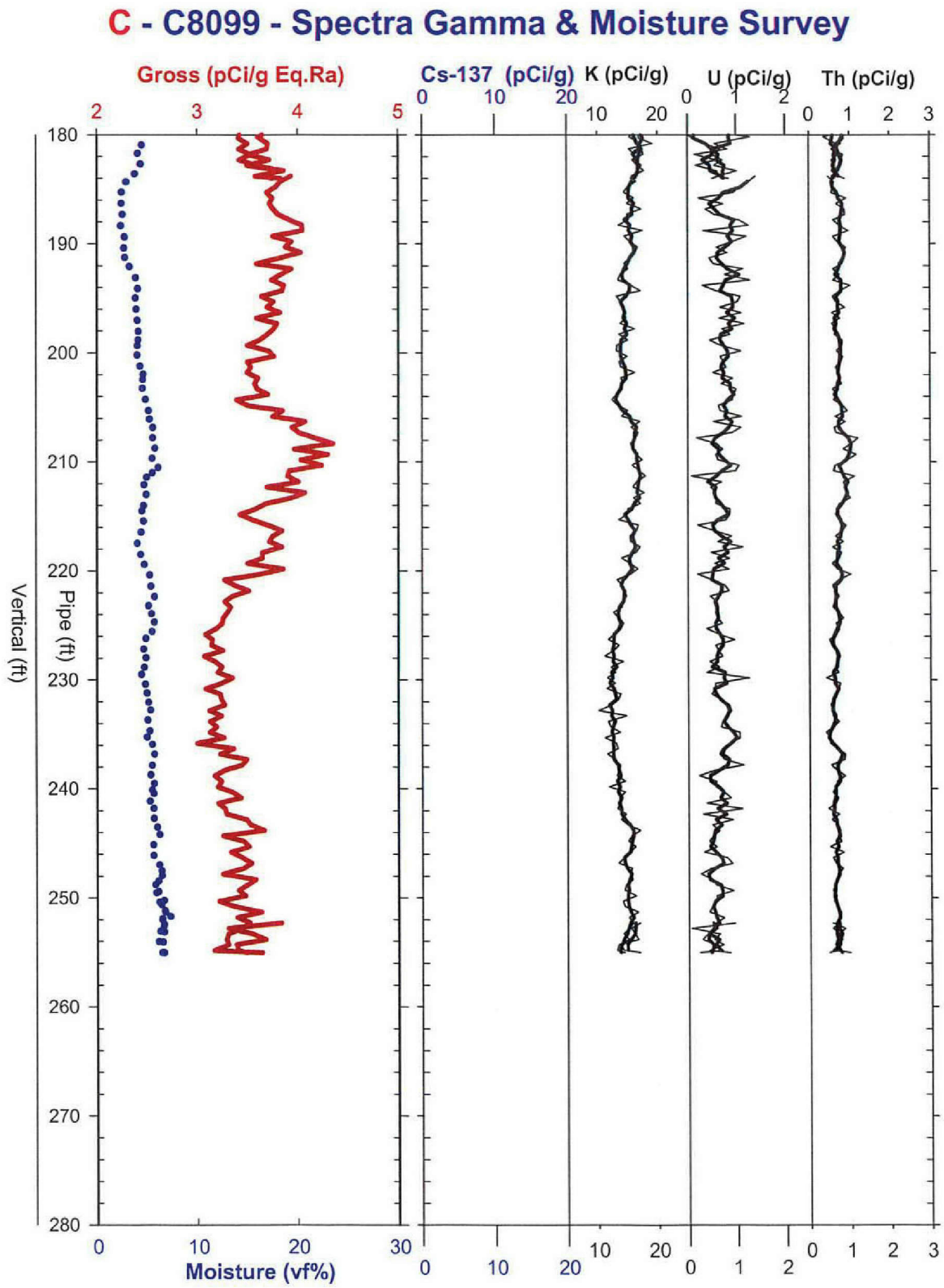
Calibration Certificates

Spectral
Date: Nov 1, 2010
Electronic File: Cal_SD-GR-2_2010-v0.zip

Moisture
Date: Oct 28, 2010
Electronic File: SD-Moist792_2010.zip


C - C8099 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Vertical (ft)
Pipe (ft)
Moisture (vf%)


C - C8099 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Vertical (ft)
Pipe (ft)
Moisture (vf%)


C - C8099 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Vertical (ft)
Pipe (ft)
Moisture (vf%)

C-FARM C8100 HEADER INFORMATION

Small Diameter – Moisture Survey

Probehole:	C8100	Northing:	136515.05	Depth Ref:
Log Date:	Mar 2011	Easting:	575116.28	Ground Surface
Project:	C Farm	Elevation:	202.39	

Repeat/Overlap Intervals

Spectral:	none	Moisture:	125-120
			125-120

Observations

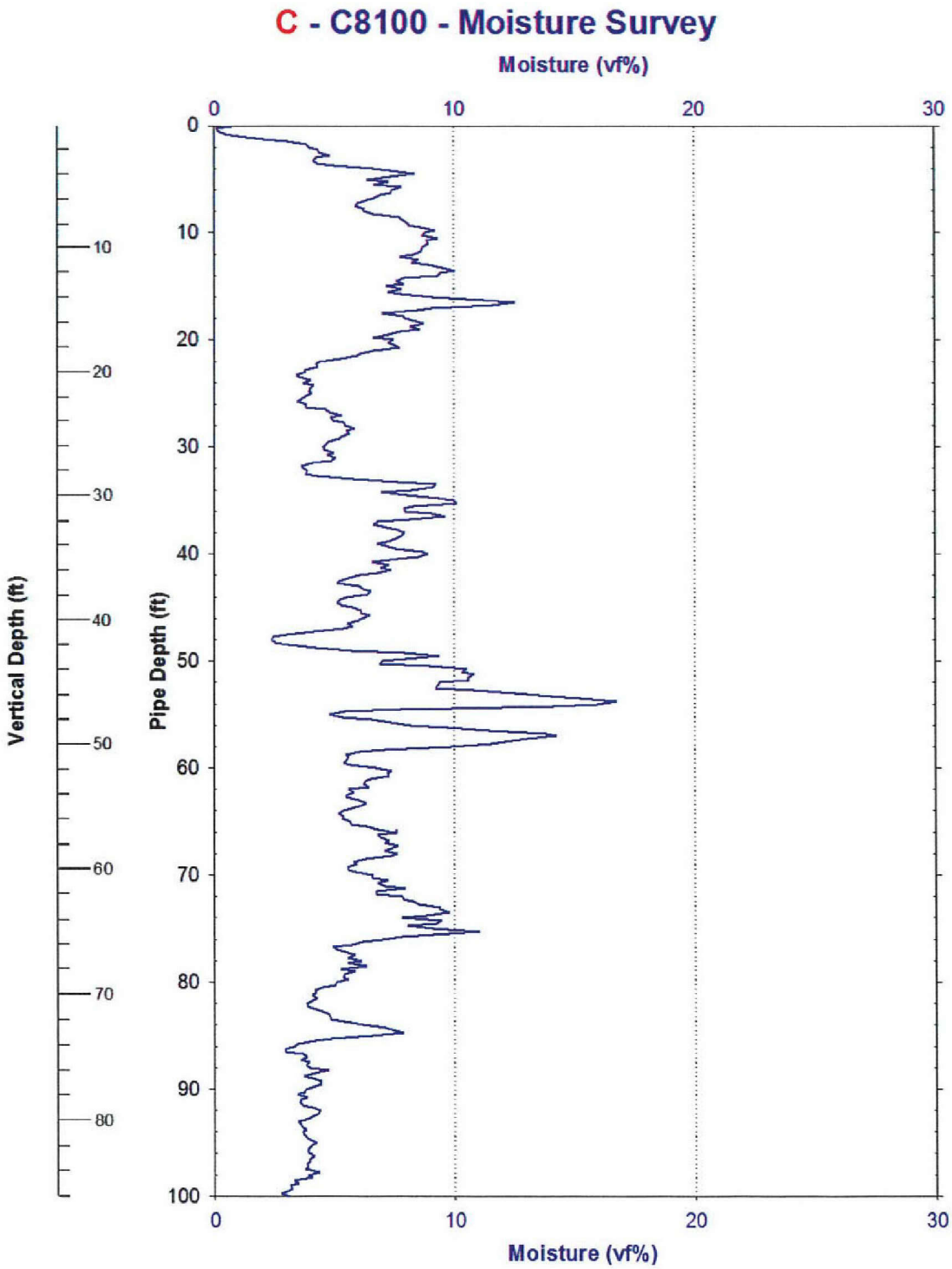
Moisture:

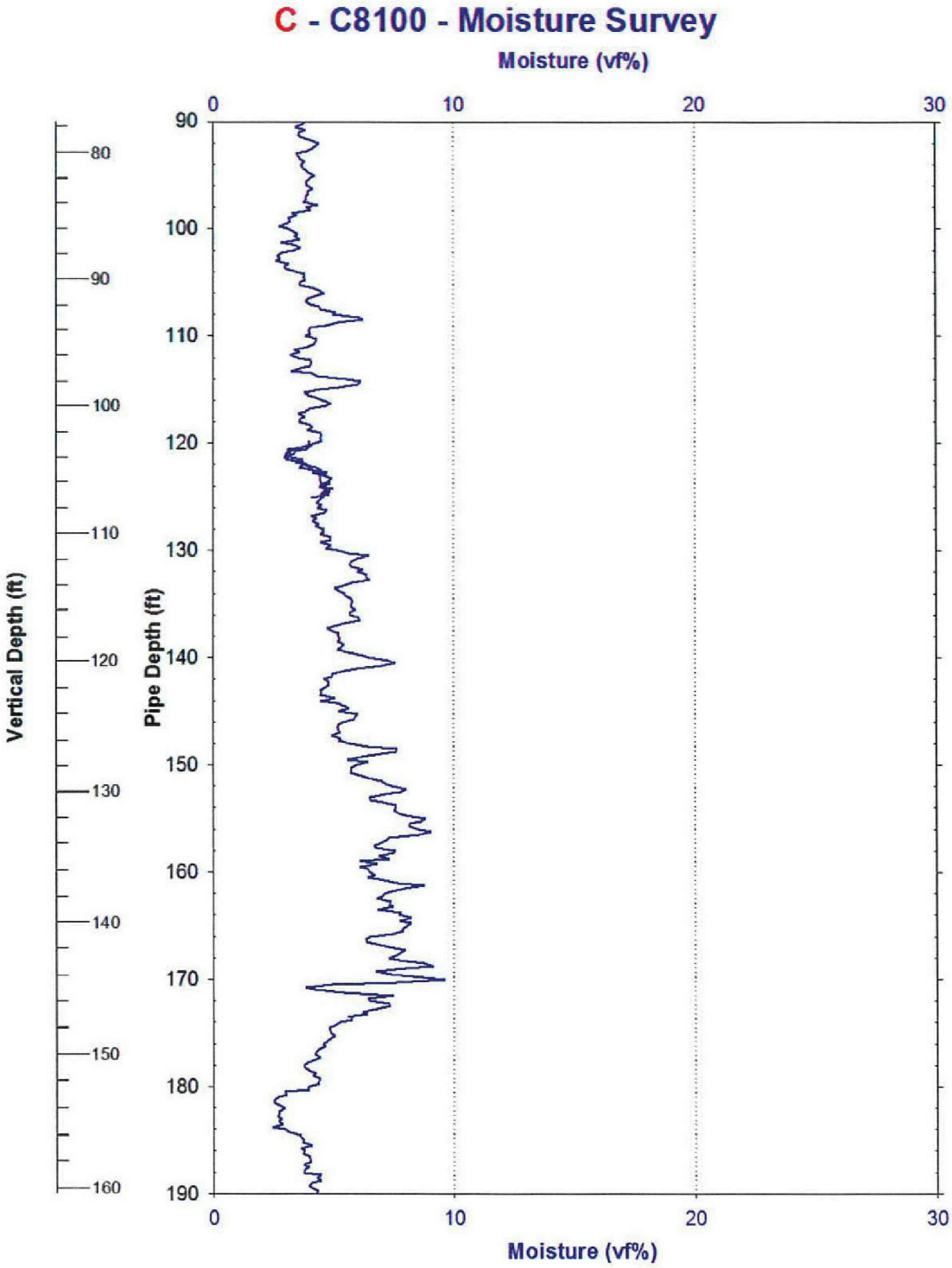
Moisture values range from 2.4-15.9%. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole. Several relatively thin zones have noted variations (16, 54, 58, 170 ft for examples), thus the actual variations are predicted to be stonger.

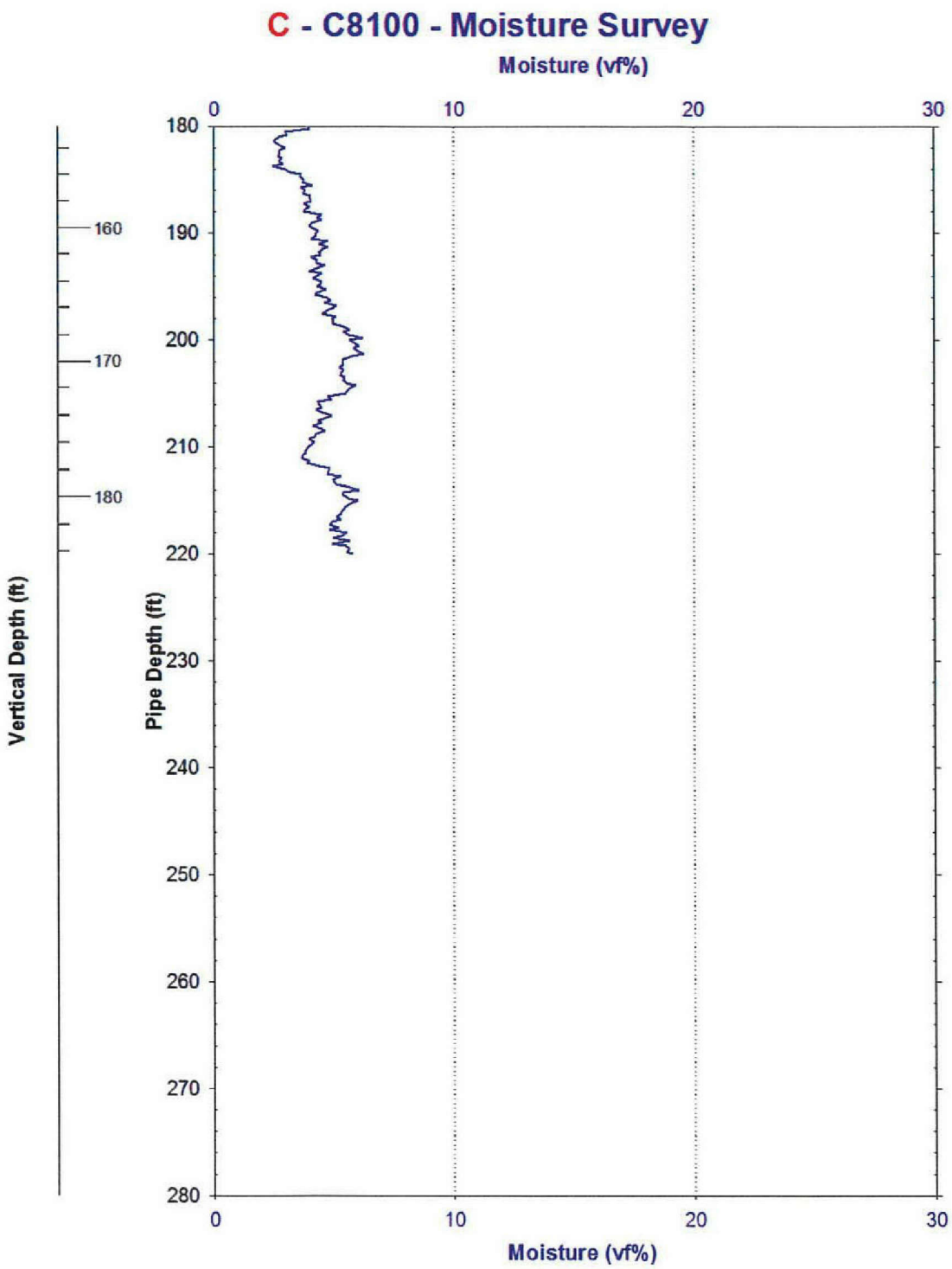
Calibration Certificates

Moisture

Date:	Oct 28, 2010
Electronic File:	SD-Moist792_2010.zip


C - C8100 - Moisture Survey
Moisture (vf%)
0
10
20
30
Vertical Depth (ft)
10
20
30
40
50
60
70
80
Pipe Depth (ft)
0
10
20
30
40
50
60
70
80
90
100
Moisture (vf%)


C - C8100 - Moisture Survey
Moisture (vf%)
0
10
20
30
Vertical Depth (ft)
80
90
100
110
120
130
140
150
160
Pipe Depth (ft)
90
100
110
120
130
140
150
160
170
180
190
Moisture (vf%)


C - C8100 - Moisture Survey
Moisture (vf%)
0
10
20
30
180
190
200
210
220
230
240
250
260
270
280
Pipe Depth (ft)
Vertical Depth (ft)
160
170
180
Moisture (vf%)

RPP-RPT-58339, Rev. A DRAFT

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D-712

DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-RPT-50581, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR C-101 SITES A & B ANGLE DIRECT PUSHES, 241-C FARM FY2011 CHARACTERIZATION

APPENDIX D

SMALL DIAMETER GEOPHYSICAL LOGGING FOR, C-101 SITES A & B ANGLE DIRECT PUSHES, 241 C FARM FY2011 CHARACTERIZATION

RPP-RPT-58581, Rev. 0

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SMALL DIAMETER GEOPHYSICAL LOGGING FOR C-101 (SITES A & B) ANGLE DIRECT PUSHES, 241 C FARM FY2011 CHARACTERIZATION

by

Russel Randall, PhD and Randall Price

to

EnergySolutions Federal Services, Inc.
2345 Stevens Drive
Richland, Washington 99354

August 2011

Pacific Northwest Geophysics
4200 West 19th Avenue
Kennewick, Washington 99338

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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2 GAMMA AND MOISTURE SURVEYS 2
2.1 GAMMA CALIBRATION AND SURVEYS 2
2.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS 3
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TERMS

BGO	Bismuth Germinate
KUT	potassium, uranium and thorium
PNG	Pacific Northwest Geophysics

SMALL DIAMETER GEOPHYSICAL LOGGING FOR C-101 (SITES A & B) ANGLE DIRECT PUSHES, 241 C FARM FY2011 CHARACTERIZATION

1 PROBEHOLE SURVEYS

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in four angle direct-push probeholes installed for characterization of the soil near the tank C-101 at the 241-C Tank Farm (Vadose Zone location A and B). This activity is intended to provide subsurface data adjacent to and under the overflow ports and near tank 241-C-101.

Up to three types of geophysical survey measurements were collected in the small diameter probeholes. They were the (1) bismuth germinate oxide (BGO) spectral gamma scintillation detector survey, (2) neutron-neutron moisture probe survey, and (3) gyroscopic survey for coordinate measurements of the probehole path. The BGO and moisture survey data are included in this report. The gyroscope surveys are included in separate reports. The gyroscope surveys are integrated with the BGO and moisture surveys via a second depth scale in the survey results. The two depth scales show the pipe run length and the vertical depth below ground surface.

Two probeholes were installed at each of the two drill sites (Site A and Site B). The first probehole at each site (C8101 and C8103) were logged with the BGO, moisture, and gyroscope probes. The second probehole at each site (C8102 and C8104) was pushed for sample retrieval and additionally were logged with the gyroscope and moisture probes.

The survey results for each probehole are presented in Appendix A. Detector calibration certificates for the BGO and neutron-moisture instruments are presented at the end of Section 2, "Gamma and Moisture Surveys."

Figure 1 is a plan-view of the probehole starting locations (black dots) and angle probehole target path direction (red lines) relative to the underground storage tanks within the investigation site.

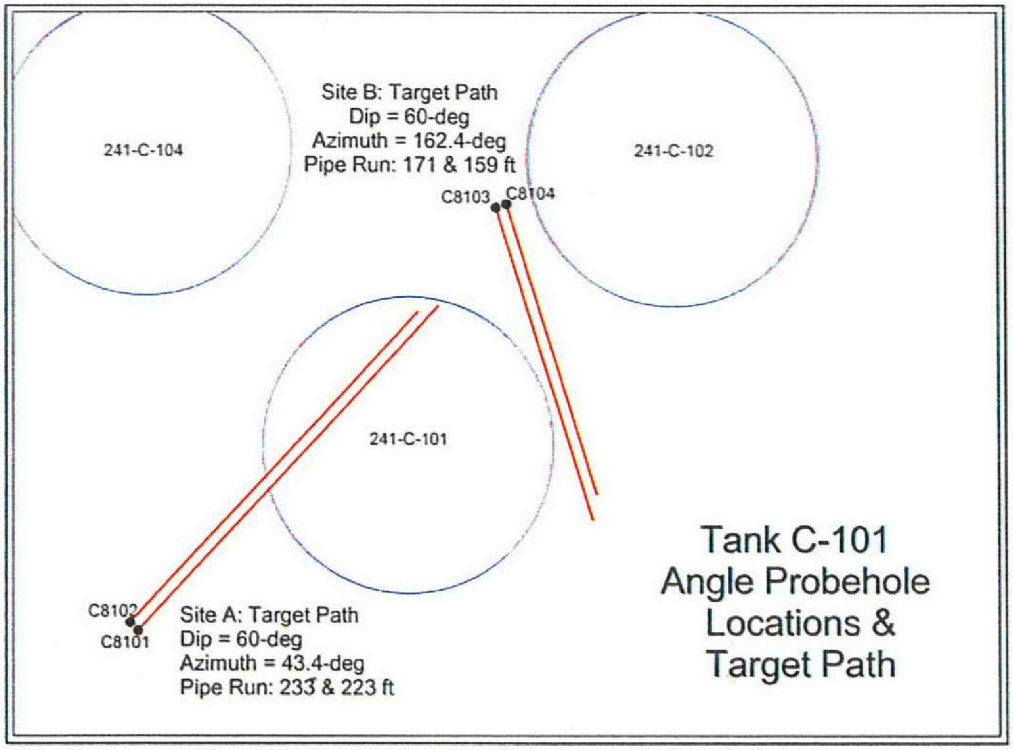


Figure 1. Location of Probeholes at Tank 241-C-101

2 GAMMA AND MOISTURE SURVEYS

The gamma and moisture logs were collected according to approved procedures (PNG 2010). The surveys were recorded from the bottom of the probehole to the ground surface. Zero depth reference is at the ground surface. A repeat measurement was acquired daily to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed and the results agree within the operational specifications for all log responses. The operational specifications are: (1) 2 times the predicted counting statistics for the gross gamma (equivalent radium-226), (2) predicted counting statistics for the spectral components of the BGO survey, and (3) predicted counting statistics for the moisture.

The survey results for each probehole are presented as a depth versus concentration plot in Appendix A. The appendix also contains a table summarizing data for each probehole: probehole depth, maximum concentration of Cs-137 in pCi/g, and depth of maximum Cs-137.

2.1 GAMMA CALIBRATION AND SURVEYS

The spectral gamma surveys were logged at 100 seconds per 0.5 foot. Each spectrum file was subsequently processed to quantify the concentration of the naturally occurring radionuclides (K,

U, & Th) and quantify Cs-137 when present above the minimum detection threshold. The nominal minimum detection level (MDL) for Cs-137 is 1 pCi/g.

All spectral calibrations were performed for the probehole conditions of the investigation site. The gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in pCi/g. The calibration certificate is shown in Figure 2. Lantern mantles containing Th-232 were used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (detector integrity) and energy calibration (amplifier gain).

2.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS

The moisture surveys were logged at 15 seconds per 0.25 foot. The field plot shows the observed count rate of the moisture instrument. Subsequent processing converts the gross count rate to a volume of moisture in percent. Pre- and post-job verifications were run each day with the source in the carrying vessel to check detector integrity.

Two sets of moisture logging probe electronics were used for the four probehole data sets presented in this report. Intermittent electronic noise was identified while logging the third probehole, C8103, and the detector electronics was subsequently replaced. Therefore, there are two calibration certificates for the moisture instrument.

The moisture calibration was performed in borehole conditions different from the logging conditions onsite. Two conditions are different: borehole size and casing thickness. Moisture calibration was performed on six and eight inch casings; the calibration certificates for the two moisture probes are shown in Figure 3 and Figure 5. The push tubing for this project has an outside diameter of 2.5 inches. The calibration was extrapolated to this smaller diameter push tubing. Figure 4 and Figure 6 show the respective moisture calibration certificates for the 6.35cm (2.5 in) hole size. A referenced (Meisner et al. 1996) casing thickness correction is performed during data processing for moisture volume. The casing correction factor for the push tubing thickness is 1.045 times the observed count rate.

Certificate of Calibration
SDGR.BGO.2
Nov 1, 2010

Data were taken at the Hanford KUT models on November 1, 2010. SDGR.BGO.2 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Ten spectra were recorded for each model in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: Stats.XLS for this analysis. The instrument was covered with 0.37 inch wall thickness probe tubing.

The algorithm described in the document WHC-SD-EN-TI-293, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1320-1575 keV **U: 1650-2390 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**4.745*K**	**-4.204*U**	**3.815*T**
Concentration-U =	**0.0*K**	**1.445*U**	**-2.839*T**
Concentration-T =	**0.0*K**	**-0.049*U**	**1.988*T**

Where K U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_SD-GR-2_2010-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_SD-GR-2_2010-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-293, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models" and that the above stated calibration coefficients are correct and applicable for the tool SDGR.BGO.2 effective Nov 1, 2010.

Signature: Date: November 9, 2010
Company: Three Rivers Scientific

Figure 2. BGO Calibration Certificate.

Certificate of Calibration for
Instrument SD-Moist792

October 28, 2010

Data were taken in the Moisture models on October 28, 2010 for SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H370608792 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, 3 for 6"casing and 3 for 8" casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation; refer to the file MoistCal.xls for this analysis.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	**8" casing**
a = .0001582	**a = .00006587**
α = 2.251	**α = 2.575**

The undersigned certifies that the data archived in data file "SD-Moist792_2010.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-306, "Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration" and that the above stated calibration coefficients are correct and applicable for tool SD-Moist792, effective October 28, 2010.

Signature: Date:

November 9, 2010

Russel Randall, PhD
Three Rivers Scientific

Figure 3. Moisture Calibration Certificate, 15.2 and 20.3 cm (6 & 8-in.) Hole (2010)

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument SD-Moist792

October 28, 2010

Moisture calibration was performed in the Hanford physical models. These standards have 6 and 8 inch ID casings. The Tank Farm Direct Push borehole is cased with a 2.5 inch OD iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.5 inch borehole diameter.

2.51" borehole
a = .0002531
α = 1.998

The undersigned certifies that the analysis files are archived in the file "SD-Moist792_2010.zip" was evaluated in accordance with Energy Solutions procedures and that the above stated calibration coefficients are correct and applicable for tool SD-Moist792, effective October 28, 2010.

Signature: Date:

November 9, 2010

Russel Randall, PhD
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole (2010).

Certificate of Calibration for
Instrument SD-Moist2.792

June 16, 2011

Data were taken in the Moisture models on June 16, 2011 for SD-Moist2.792 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H370608792 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, 3 for 6"casing and 3 for 8" casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variations; refer to the file "stats.xlsx" for this analysis.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	**8" casing**
a = .0001732	**a = .00007726**
α = 2.21	**α = 2.516**

The undersigned certifies that the data archived in data file "SD-Moist2.792_2011.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-306, "Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration" and that the above stated calibration coefficients are correct and applicable for tool SD-Moist2.792, effective June 16, 2011.

Signature: Date:

June 19, 2011

Russel Randall, PhD
Three Rivers Scientific

Figure 5. Moisture Calibration Certificate, 15.2 & 20.3 cm (6 & 8-in.) Hole (2011).

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument SD-Moist2.792

June 16, 2011

Moisture calibration was performed in the Hanford physical models. These standards have 6 and 8 inch ID casings. The Tank Farm Direct Push borehole is cased with a 2.5 inch OD iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.5 inch borehole diameter.

2.51" borehole
a = .0002619
α = 1.971

The undersigned certifies that the analysis files are archived in the file "SD-Moist2.792_2011.zip" was evaluated in accordance with Energy Solutions procedures and that the above stated calibration coefficients are correct and applicable for tool SD-Moist2.792, effective June 16, 2011.

Signature: Date:

June 19, 2011

Russel Randall, PhD
Three Rivers Scientific

Figure 6. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole (2011).

3 REFERENCES

Meisner, James, Randall Price, and Russel Randall, 1996, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, WHC-SD-EN-TI-306, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

PNG, 2010, *Procedures: Calibration, Logging, Quality Assurance and Data Management*, Pacific Northwest Geophysics, Kennewick, Washington.

Randall, R. and D. Stromswold, 1995, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, WHC-SD-EN-TI-293, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A

SPECTRAL GAMMA AND MOISTURE SURVEY RESULTS

Survey plots follow for the four angle probeholes installed for characterization of the Tank C-101 at the 241-C Tank Farm (Vadose Zone locations A and B). Probeholes C8101 and C8103 were surveyed with both the BGO spectral gamma and moisture probes. Probeholes C8102 and C8104 were surveyed with the moisture probe. Each log plot is preceded by a header information page that shows the probehole coordinates, repeat/overlap intervals, isotopes analyzed, observations, and logging probe calibration dates.

The log plot has two depth scales. The main depth scale shows the pipe run length (below ground surface). The alternate depth scale (from the gyroscope survey) shows the vertical depth below ground surface. The log plots show a maximum of 100 feet per page with a 10 foot overlap between page breaks.

The spectral gamma survey data were processed to quantify the naturally occurring radionuclides (K, U, & Th), and the man-made radionuclide of Cs-137 (blue solid line). The spectra were processed both as individual spectra for each survey depth and as a moving sum of three spectra (i.e. sum of the individual survey depth and the two adjacent spectra, above and below the current depth position). Both results are presented on the results plot. The results for the 3-spectra sum are plotted as a wide line. Also the gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in scale of 2 to 5 pCi/g (brown line).

The neutron-neutron moisture survey data are shown with a blue line. The moisture plot scale is 0-30 volume fraction per cent moisture (vf %).

Table A1 below contains a summary of the survey results for each probehole: maximum log depth, maximum detection level for Cs-137, maximum depth of Cs-137 detection, and special observations by the analyst to flag the detection of other isotopes in additions to the natural radionuclides and Cs-137.

Table A1. Probehole Survey Summary.

Probehole ID.	Hole Depth (meters)	Hole Depth (feet)	Cs-137 (pCi/g) Max Detection	Cs-137 Max Detected Depth	Flag Isotopes Other Than Naturals and Cs-137
C8101	70.7	233	2.2 pCi/g at surface	2 ft	None
C8102	68.0	223	n/a	n/a	n/a
C8103	52.3	171.5	30 pCi/g at 0.7ft	8 ft	None
C8104	48.5	159	n/a	n/a	n/a

C-Farm C8101 Header Information

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C8101	Northing:	136488.43m	Depth Ref:
Log Date:	May 2011	Easting:	575140.04m	Ground Surface
Project:	C Farm	Elevation:	202.49m	

Repeat/Overlap Intervals

Spectral:	233-228	Moisture:	192-185
	138-136		87-85
	136-132		
	20-16		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

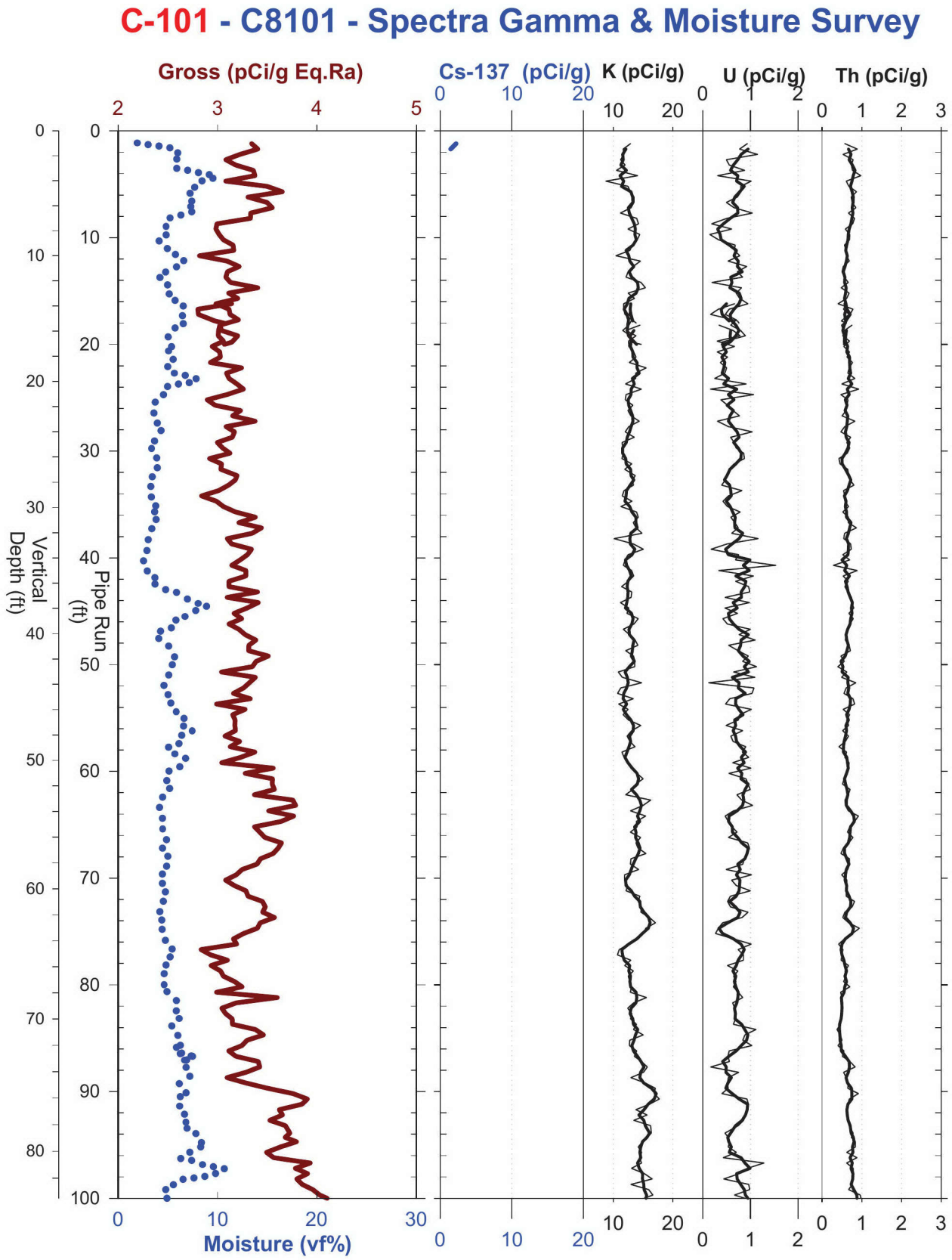
Cs-137 was observed at the surface, with a maximum of 2.2 pCi/g. The plotted gross uses an energy threshold of 1000keV, and does not respond to Cs-137. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole.

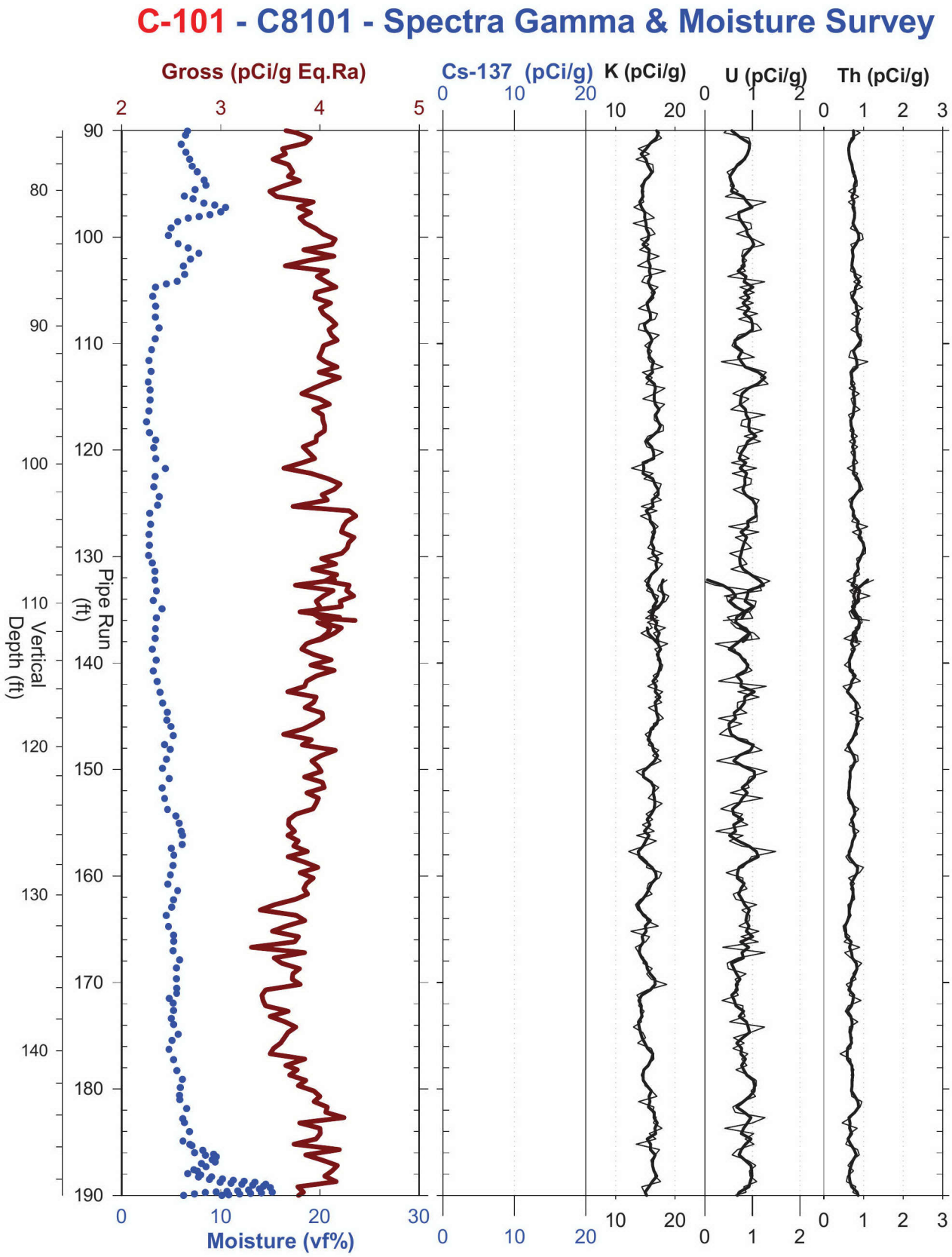
Moisture:

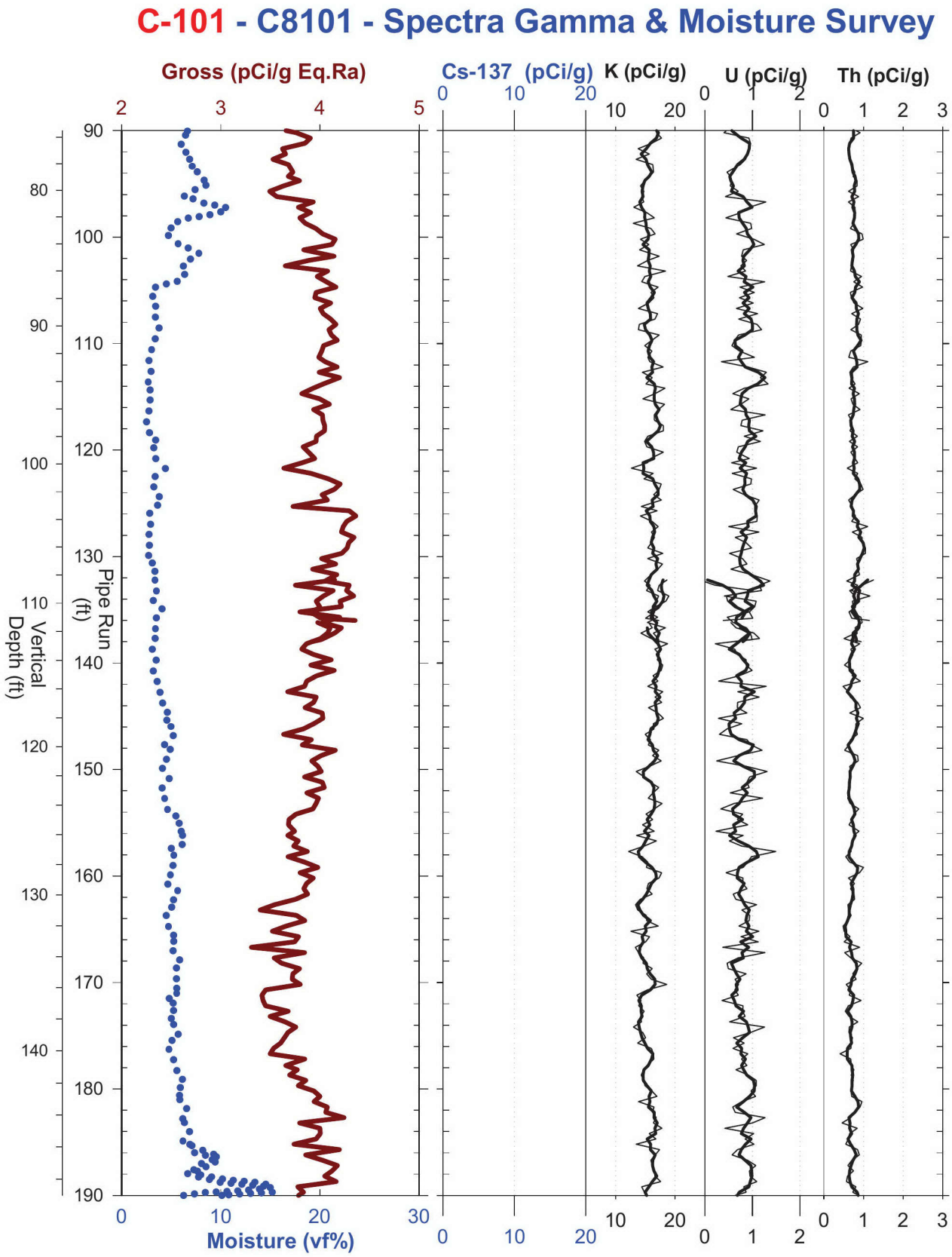
Moisture values range from 2.5-15 vf %. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole. The depth of the repeat from 192-185 appears to have shifted.

Calibration Certificates

Spectral	
Date:	Nov 1, 2010
Electronic File:	Cal_SD-GR-2_2010-v0.zip
Moisture	
Date:	Oct 28, 2010
Electronic File:	SD-Moist792_2010.zip


C-101 - C8101 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Vertical Depth (ft)
Pipe Run (ft)
Moisture (vf%)


C-101 - C8101 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Pipe Run (ft)
Vertical Depth (ft)
Moisture (vf%)


C-101 - C8101 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Pipe Run (ft)
Vertical Depth (ft)
Moisture (vf%)

C-Farm C8102 Header Information

Small Diameter –Moisture Survey

Probehole:	C8102	Northing:	136489.07m	Depth Ref:
Log Date:	June 2011	Easting:	575139.41m	Ground Surface
Project:	C Farm	Elevation:	202.49m	

Repeat/Overlap Intervals

Moisture: 220-210
112-110
108-104

Observations

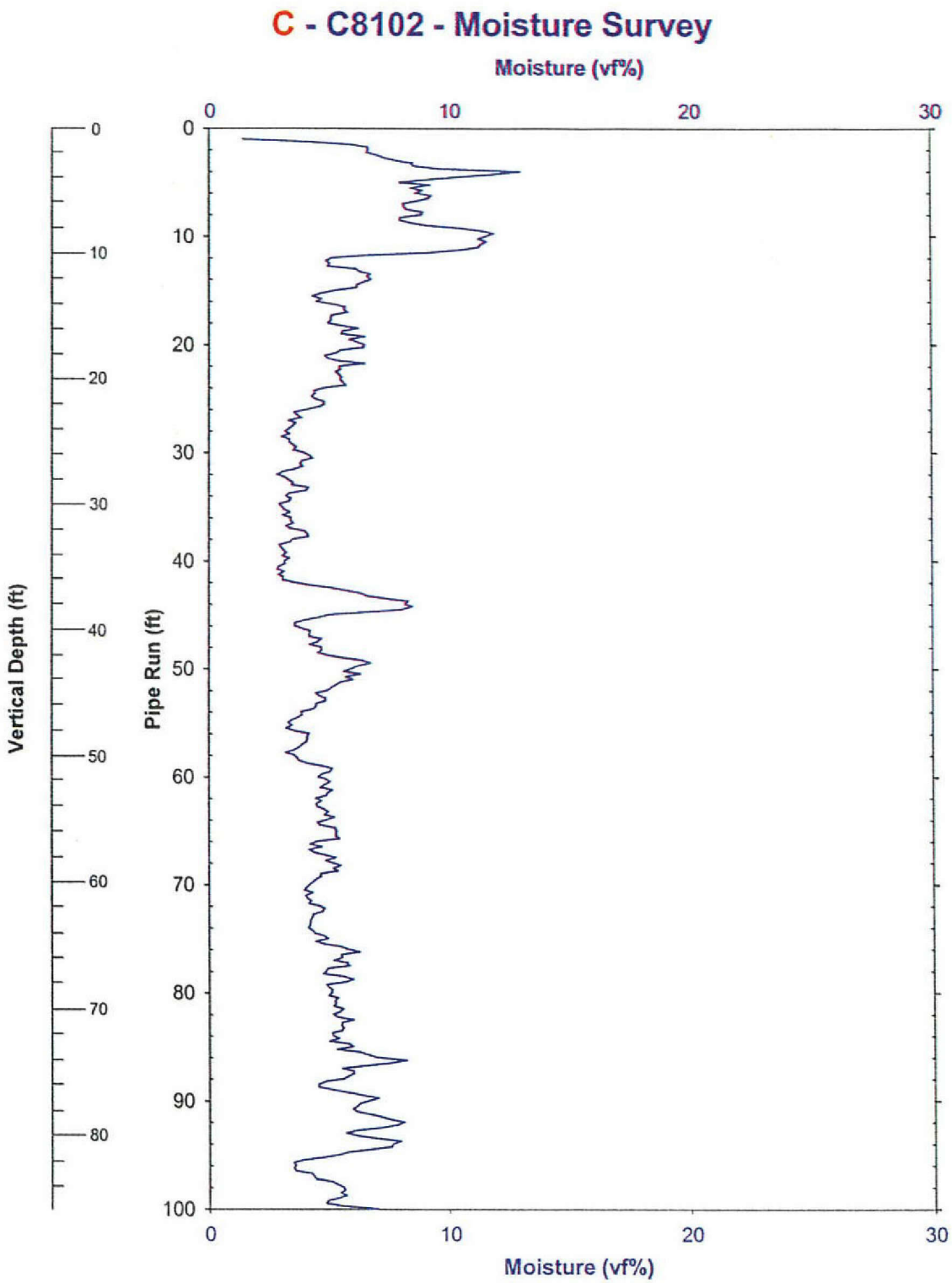
Moisture:

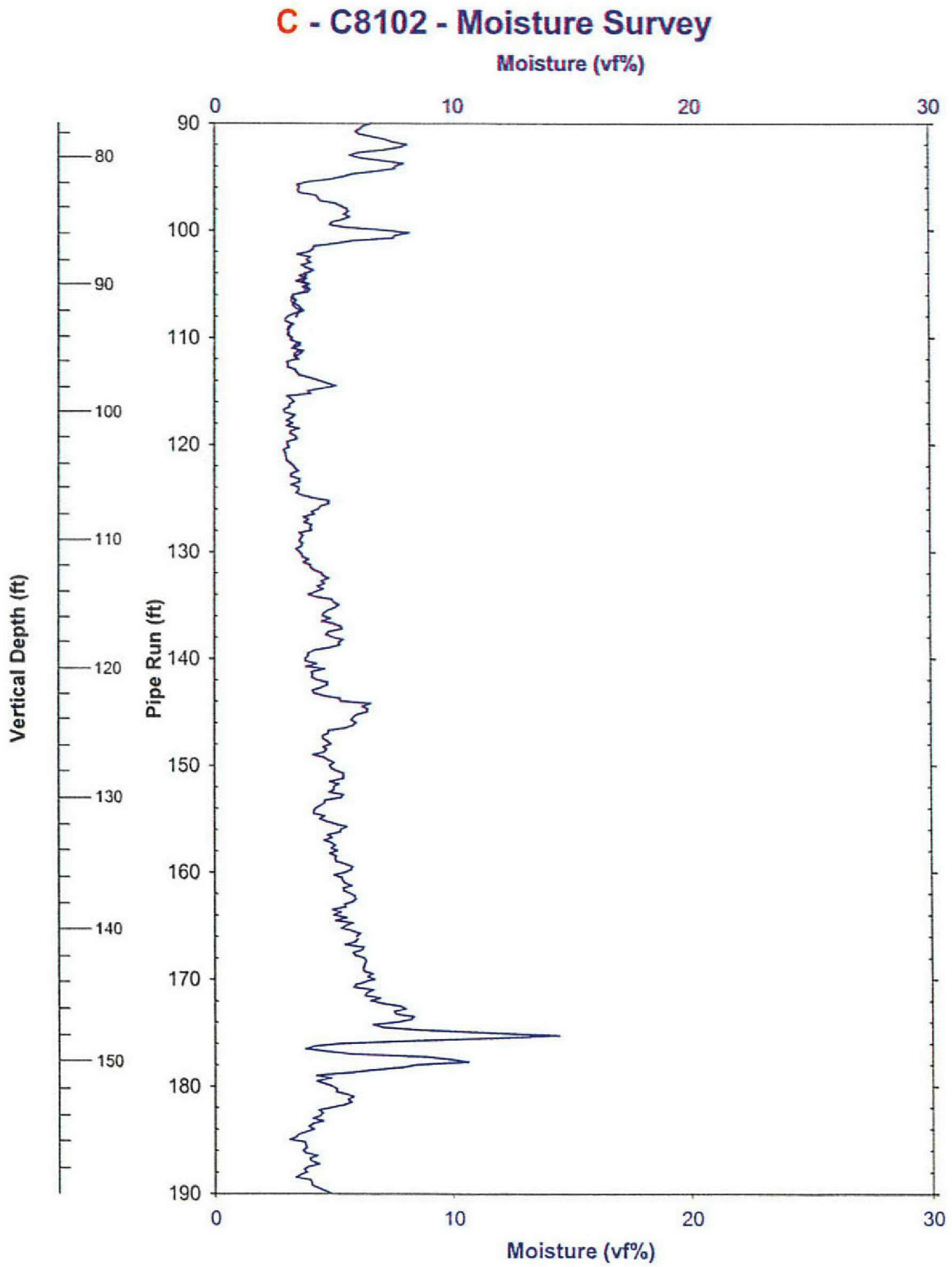
Moisture values range from 3-14.4 vf%. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole.

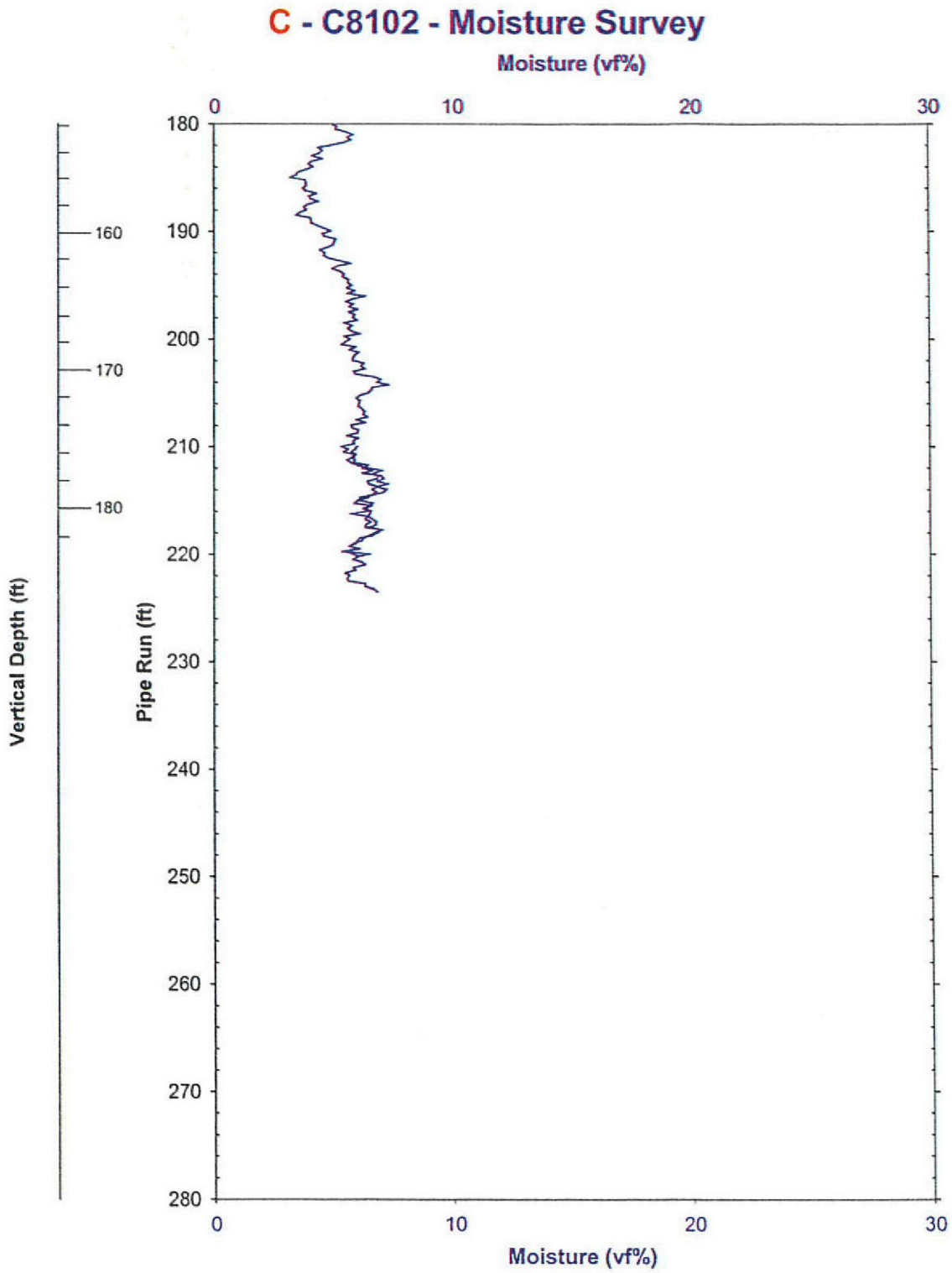
Calibration Certificates

Moisture

Date:	Oct 28, 2010
Electronic File:	SD-Moist792_2010.zip


C - C8102 - Moisture Survey
Moisture (vf%)
0
10
20
30
Vertical Depth (ft)
0
10
20
30
40
50
60
70
80
Pipe Run (ft)
0
10
20
30
40
50
60
70
80
90
100
Moisture (vf%)


C - C8102 - Moisture Survey
Moisture (vf%)
0
10
20
30
Vertical Depth (ft)
80
90
100
110
120
130
140
150
Pipe Run (ft)
90
100
110
120
130
140
150
160
170
180
190
Moisture (vf%)


C - C8102 - Moisture Survey
Moisture (vf%)
0
10
20
30
180
190
200
210
220
230
240
250
260
270
280
Pipe Run (ft)
Vertical Depth (ft)
160
170
180
Moisture (vf%)

C-Farm C8103 Header Information

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C8103	Northing:	136522.15m	Depth Ref:
Log Date:	June 2011	Easting:	575169.19m	Ground Surface
Project:	C Farm	Elevation:	198.05m	

Repeat/Overlap Intervals

Spectral:	171-167	Moisture:	90-89
	32-31		10-9
	32-30		

Isotopes Analyzed

Elements:	Energies Used (keV)
K-40	1462
Natural Uranium	1650-2390
Natural Thorium	2614
Cs-137	661

Observations

Spectral:

Cs-137 was observed near the surface (0.7ft), with a maximum of 30 pCi/g. The plotted gross uses an energy threshold of 1000keV, and does not respond to Cs-137. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole.

Moisture:

Moisture values range from 2-18 vf%. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole. Note: Three moisture measurement values (i.e. 111.0ft, 110.5ft, and 108.5ft.) contained electronic noise that was removed during data processing.

Calibration Certificates

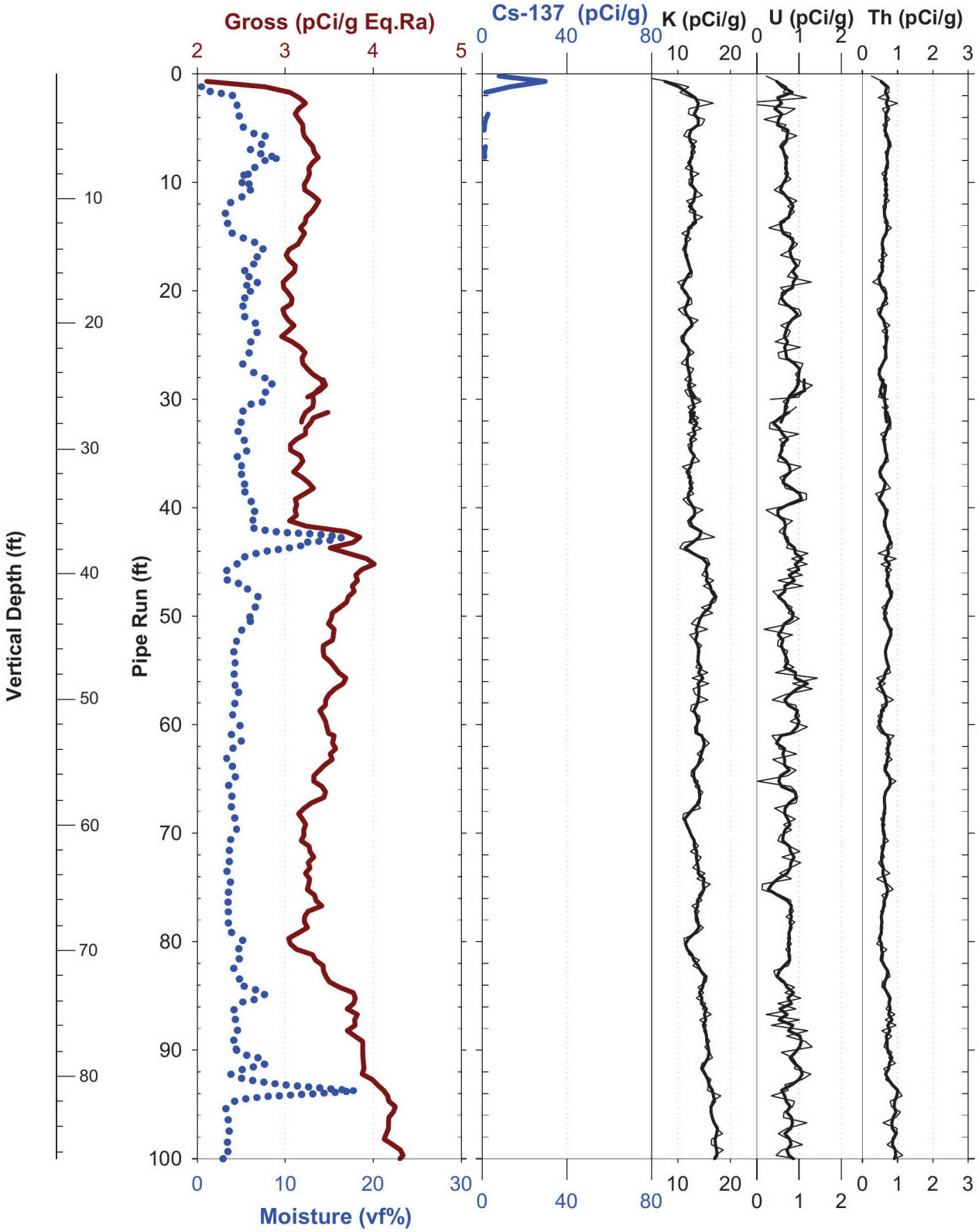
Spectral

Date:	Nov 1, 2010
Electronic File:	Cal_SD-GR-2_2010-v0.zip

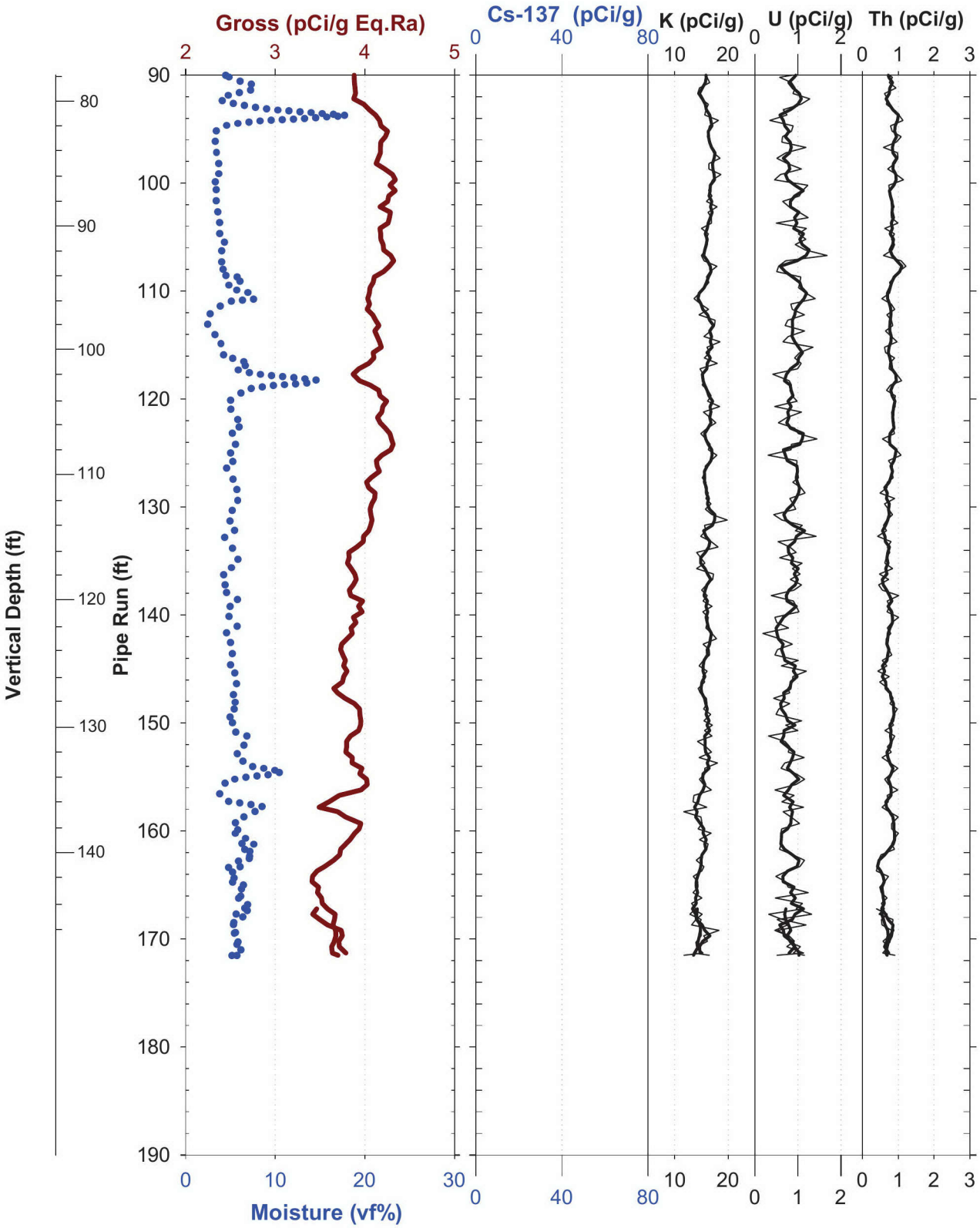
Moisture

Date:	Oct 28, 2010
Electronic File:	SD-Moist792_2010.zip

C - C8103 - Spectra Gamma & Moisture Survey



C - C8103 - Spectra Gamma & Moisture Survey



C-Farm C8103 Header Information

Small Diameter –Moisture Survey

Probehole:	C8104	Northing:	136522.43m	Depth Ref:
Log Date:	July 2011	Easting:	575170.06m	Ground Surface
Project:	C Farm	Elevation:	198.05m	

Repeat/Overlap Intervals

Moisture: 95-90

Observations

Moisture:

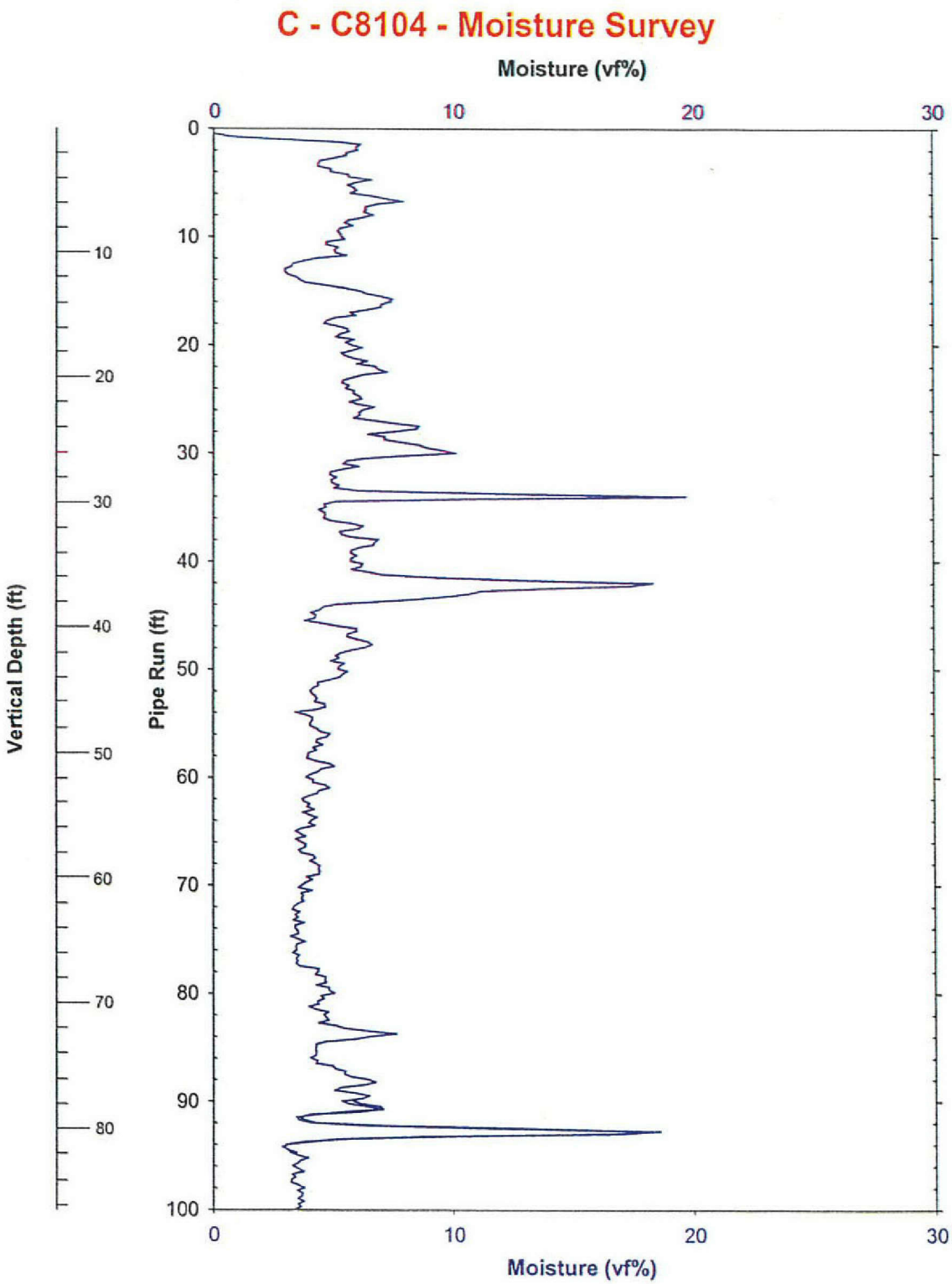
Moisture values range from 2.9-19.6 vf%. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole. Thus the zone at 34.0 ft would read much higher if corrected for both angle and thin bed response.

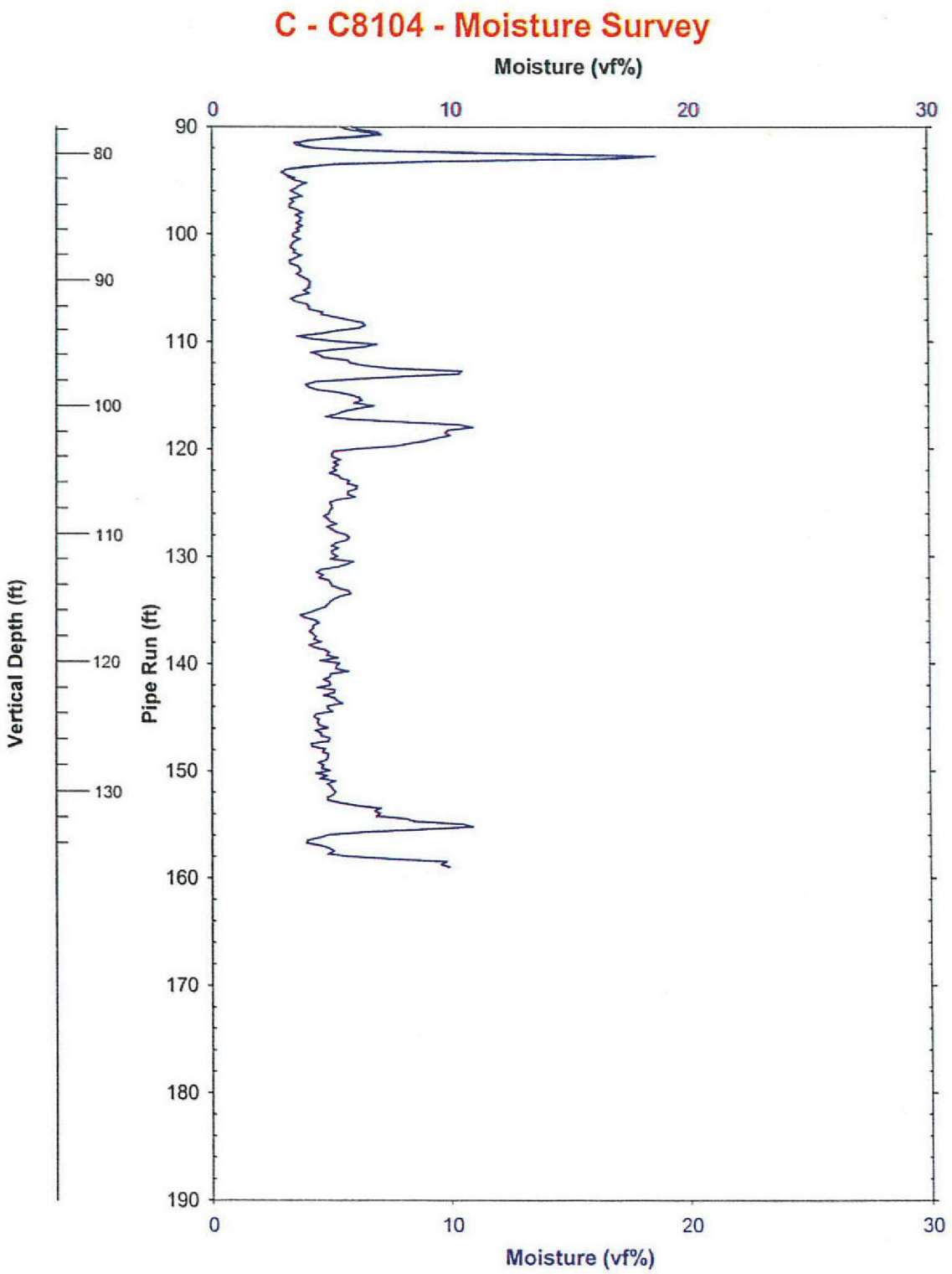
At the end of the log data collection, the operator noted a depth return error. Thus the repeat pass was depth corrected by -0.25 ft to match the main pass. After depth correction the repeat is within operational specifications.

Calibration Certificates

Moisture

Date:	Jun 16, 2011
Electronic File:	SD-Moist2.792_2011.zip


C - C8104 - Moisture Survey
Moisture (vf%)
0
10
20
30
Vertical Depth (ft)
10
20
30
40
50
60
70
80
Pipe Run (ft)
0
10
20
30
40
50
60
70
80
90
100
Moisture (vf%)


C - C8104 - Moisture Survey
Moisture (vf%)
0
10
20
30
Vertical Depth (ft)
80
90
100
110
120
130
Pipe Run (ft)
90
100
110
120
130
140
150
160
170
180
190
Moisture (vf%)

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DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-RPT-51384, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR FY2011 C-203 ANGLE DIRECT PUSH, 241-C FARM CHARACTERIZATION

APPENDIX D

SMALL DIAMETER GEOPHYSICAL LOGGING FOR FY 2011,
C-203 ANGLE DIRECT PUSH, 241 C FARM CHARACTERIZATION

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Gyro Survey - C8105
168 ft Push Depth
(Sept 16, 2011)

Summary

The final gyro surveys for C8105 were conducted on September 16, 2011. The total pipe run length was 168 ft. The final planned check point was at a pipe run length of 166.6 ft. The planned coordinates are listed in Table 1, and the fourth row contains the targeted coordinates of the final check point. The 4 check point survey results and their average distances are listed in Table 2. The average gyro measurements at the 166.6 ft pipe run length are different than the final planned check point by the following amounts:

- Measured elevation is 1.37m (4.16ft) shallow of target
- Measured northing is 0.82m (2.69ft) south of target
- Measured easting is 1.02m (3.36ft) west of target

Discussion

The initial dip of the C8105 push was measured at -28.0° from horizontal, and an azimuth of 235.0° from North. Table 1 contains the listing of planned check points during the push and at the end of the push. Table 2 lists the gyro survey results (all x,y,z values are in ft relative to starting point at surface).

Table 1. Planned coordinates at check points of Push C8105

Northing	Easting	Elevation (msl) m	Elevation (msl) ft	Data collection point length from surface (m)	Data collection point length from surface (m)
136641.24	575184.94	193.65	635.33	-0- surface	0
136633.35	575173.78	186.24	611.00	15.22	49.90
136615.60	575148.70	170.16	558.59	50.79	166.60

Table 2. Measured distances from origin

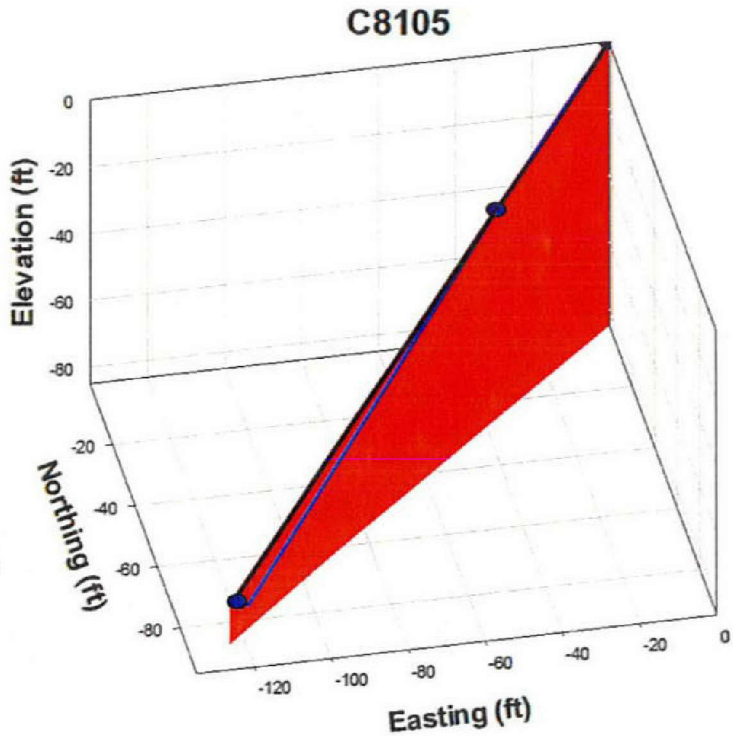
C8105	Pipe Length (ft)	Northing (ft)	Easting (ft)	Elevation (ft)	Dip	Azimuth
1	166.615	-87.290	-121.966	-72.454	-23.425	232.113
2	166.622	-86.755	-122.630	-71.991	-23.295	232.974
3	166.643	-87.291	-121.664	-73.032	-23.827	232.313
4	166.647	-85.918	-122.777	-72.834	-23.972	233.540
mean	166.6318	-86.8135	-122.2593	-72.5777	-23.6297	232.7350
rms ft	0.0157	0.6482	0.5310	0.4588	0.3215	0.6507
% rms (m/m)	0.0094%	0.7466%	-0.4343%	-0.6322%	-1.3604%	0.2796%

The repeatability of the gyro data is at most 1.4% root mean square deviations of depths or angles. Thus the tool is operating within specifications.

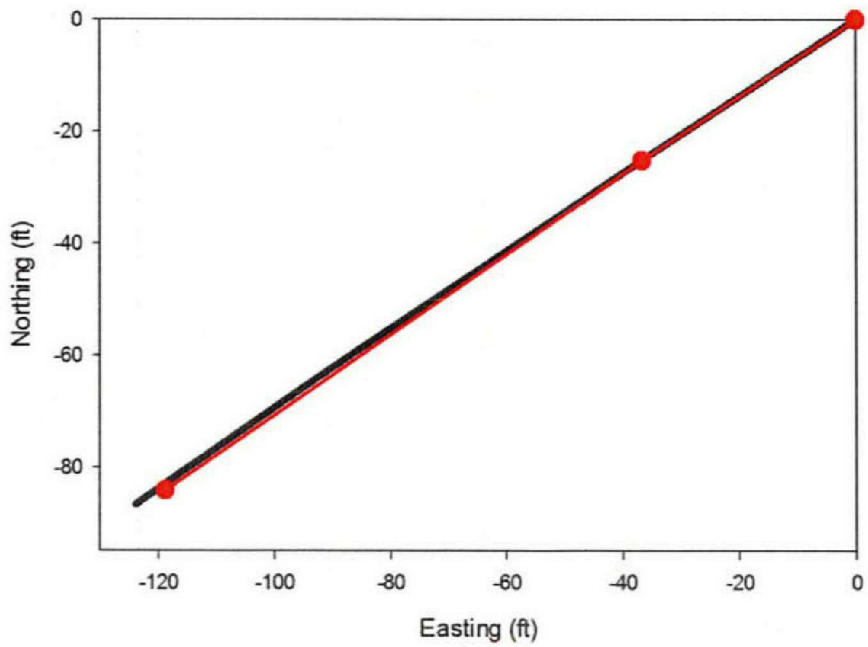
Table 3 lists the gyro results converted to coordinates and the 4th (final) check point target coordinates.

Table 3. WA state plane measured & planned coordinates

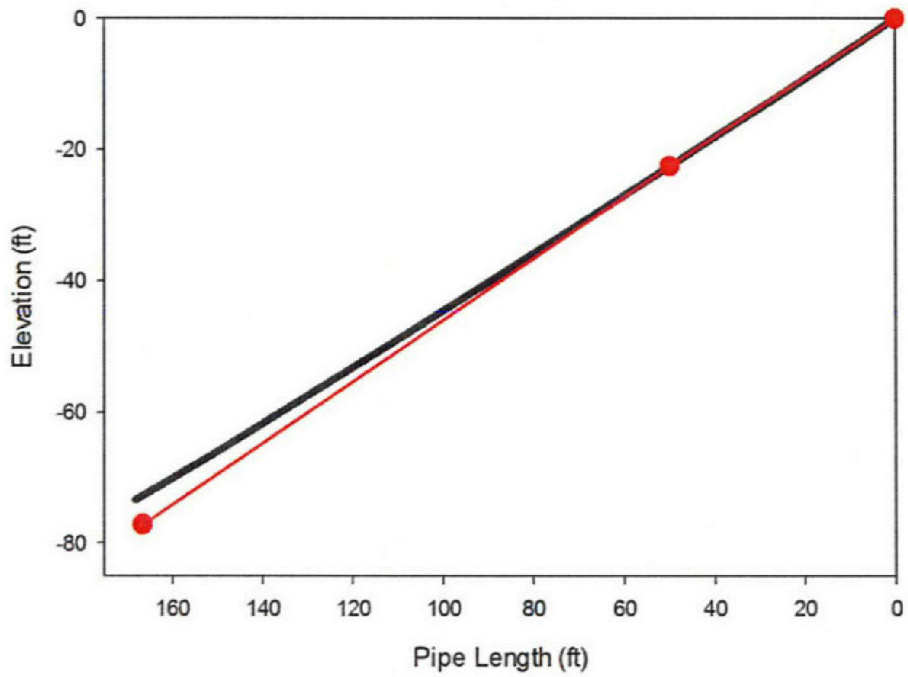
Case	Pipe Depth (ft)	Northing (m)	Easting (m)	Elevation (m)	Elevation (ft)
Gyro Average	166.63	136614.78	575147.68	171.53	562.75
Planned Check Point	166.60	136615.60	575148.70	170.16	558.59



The black trace is a plot of the gyro log data with red drop lines, the blue dots are the gyro check points, and the blue line is the planned projection.



The above figure is a top down view of the Northing & Easting foot print of the push path. The black line is a plot of the gyro log data, the red line is the planed footprint, and the red dots are the planned check points.



The plot above is a cross-section view of possible elevation deviations from push path as measured with gyro versus the planned path. The black line is a plot of the gyro log data, the red line is the planned cross-section, and the red dots are the planned check points.

Gyro Survey - C8106
168 ft Push Depth
(Sept 19, 2011)

Summary

The final gyro surveys for C8106 were conducted on September 19, 2011. The total pipe run length was 168 ft. The final planned check point was at a pipe run length of 164.4 ft. The planned coordinates are listed in Table 1, and the fourth row contains the targeted coordinates of the final check point. The 4 check point survey results and their average distances are listed in Table 2. The average gyro measurements at the 166.6 ft pipe run length are different than the final planned check point by the following amounts:

- Measured elevation is 0.70 (2.29 ft) shallow of target
- Measured northing is 0.47m (1.54 ft) south of target
- Measured easting is 0.06 m (0.20 ft) east of target

Discussion

The initial dip of the C8105 push was measured at -28.0° from horizontal, and an azimuth of 235.0° from North. Table 1 contains the listing of planned check points during the push and at the end of the push. Table 2 lists the gyro survey results (all x,y,z values are in ft relative to starting point at surface).

Table 1. Planned coordinates at check points of Push C8106

Northing	Easting	Elevation (msl) m	Elevation (msl) ft	Data collection point length from surface (m)	Data collection point length from surface (ft)
136640.5	575185.46	193.68	635.43	-0- surface	0
136633.64	575174.19	186.24	611.00	13.16	43.18
136614.86	575149.23	170.16	558.25	50.12	164.4

Table 2. Gyroscope Data

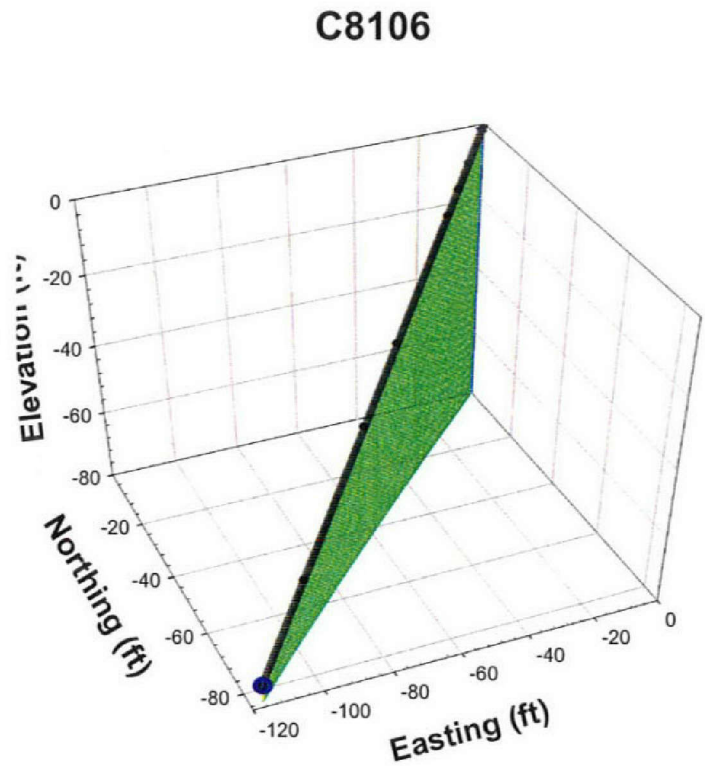
C8106	Depth (ft)	Northing (ft)	Easting (ft)	Elevation (ft)	Dip	Azimuth
1	161.608	-83.43	-116.41	-74.76	-24.56	232.23
2	161.584	-83.52	-116.29	-74.80	-24.70	232.77
3	161.135	-82.72	-116.04	-75.11	-25.33	232.67
4	161.148	-83.03	-115.88	-75.05	-25.28	232.64
mean	161.44	-83.23	-116.25	-74.89	-24.86	232.56
rms ft	0.27	0.44	0.19	0.19	0.41	0.29
rms %	0.00	-0.01	0.00	0.00	-0.02	0.00

The repeatability of the gyro data is in excellent agreement for all measured parameters and is operating within specifications.

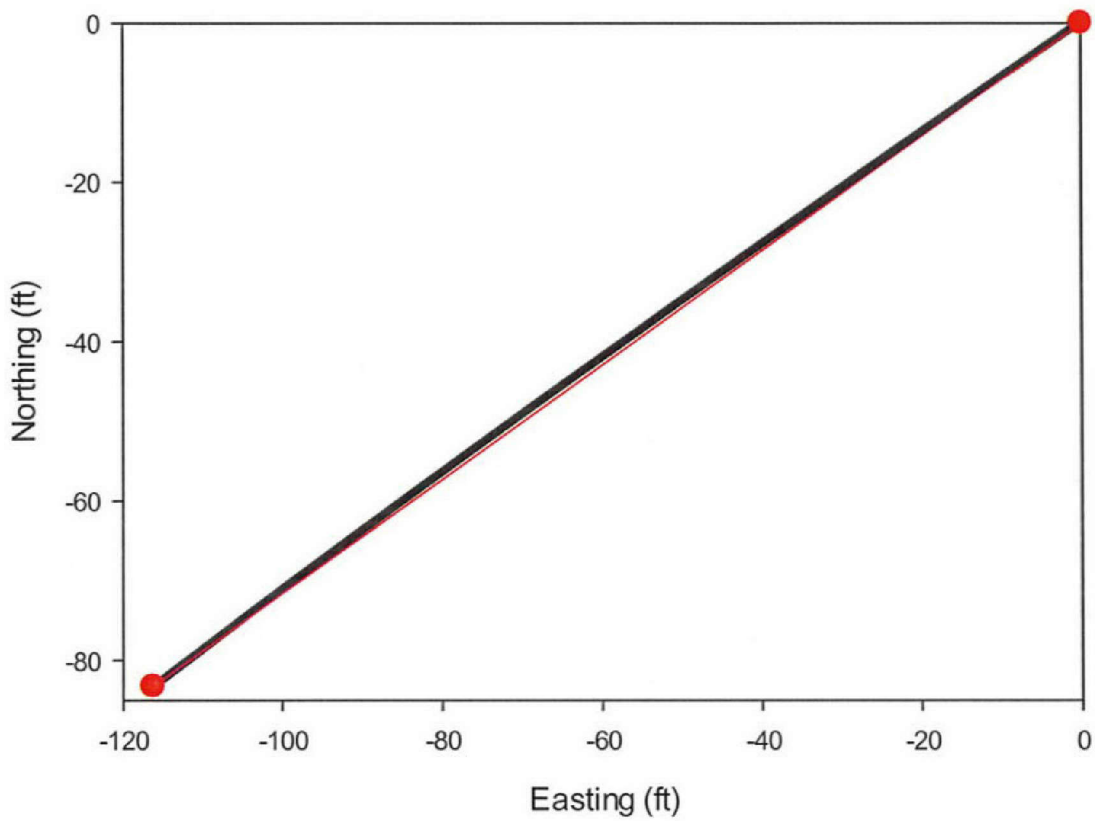
Table 3 lists the gyro results converted to coordinates and the 4th (final) check point target coordinates.

Table 2. WA state plane measured & planned coordinates

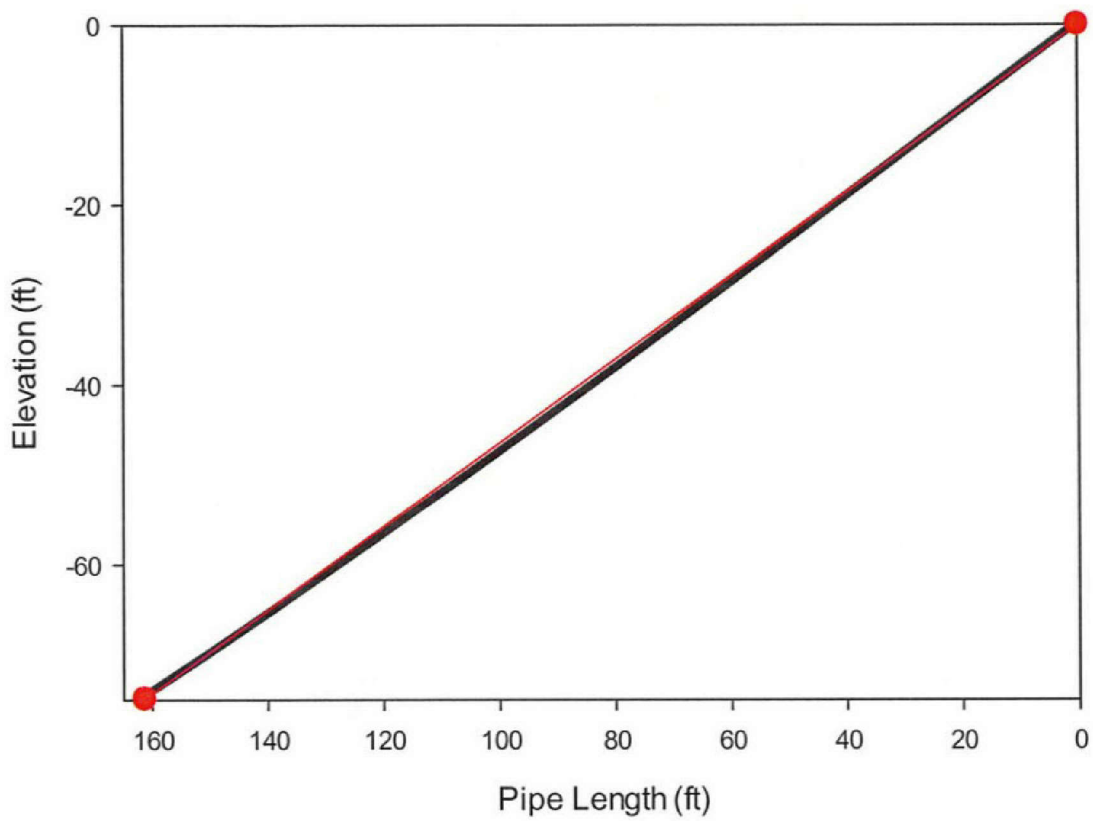
Case	Pipe Depth (ft)	Northing (m)	Easting (m)	Elevation (m)	Elevation (ft)
Gyro Average	161.44	136615.13	575150.03	170.85	560.54
Planned Check Point	161.30	136615.60	575149.97	170.16	558.25



The black trace is a plot of the gyro log data with green drop lines, the black line is the planned projection, and the black circles are soil sample collection zones. No significant deviation from the planned path can be observed at this scale of projection.



The above figure is a top down view of the Northing & Easting foot print of the push path. The black line is a plot of the gyro log data, the red line is the planed footprint.



The plot above is a cross-section view of elevation deviations from push path as measured with gyro versus the planned path. The black line is a plot of the gyro log data, the red line is the planned cross-section. The actual path first deviates blow the projected/planned path and as the probe nears total depth comes back to planned and at final position is slightly higher than planned.

SMALL DIAMETER GEOPHYSICAL LOGGING IN DIRECT PUSH PROBEHOLES FOR TANK 241-C-203 CHARACTERIZATION

by

Russel Randall, PhD

for

Energy*Solutions* Federal Services, Inc.
2345 Stevens Drive
Richland, Washington 99354

January 24, 2012

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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TERMS

KUT	potassium, uranium and thorium
LaBr	lanthanum bromide
PNG	Pacific Northwest Geophysics

SMALL DIAMETER GEOPHYSICAL LOGGING IN DIRECT PUSH PROBEHOLES FOR TANK 241-C-203 CHARACTERIZATION

1 PROBEHOLE SURVEYS

Three Rivers Scientific with Energy*Solutions* labor support provided small diameter logging in two direct-push probeholes installed for characterization of the 241-C-203 tank located in 241-C Tank Farm. This report contains two types small diameter geophysical measurements, they are: (1) lanthanum bromide (LaBr) spectral gamma scintillation detector survey, and (2) neutron-neutron moisture probe survey.

The survey results for each probehole are presented in Appendix A. Detector calibration certificates for the LaBr and neutron-moisture instruments are presented in Appendix B.

2 SUMMARY OF RESULTS

Two low angle pushes (28° from horizontal) were made and subsequently logged during the September thru November 2011 time frame. C8105 was logged twice with a small diameter gyroscope, one at check point and second at total depth. LaBr high resolution spectral gamma and moisture were also run in C8105. C8106 was logged twice with a small diameter gyroscope, one at check point and second at total depth and a neutron-neutron moisture probe.

Appendix A contains the moisture and high resolution gamma log data plots for both boreholes. There are clear indications of moisture zones at 92 ft (pipe run) and several from 5 to 28 ft (pipe run) in C8105. These same moisture zones appear in C8106, but at shallower pipe depths. The moisture zones do correlate well in both boreholes with true vertical depth. The apparent offset of moisture response with pipe depth is caused by the very shallow dip angle; which magnifies any small difference in actual dip.

3 GAMMA AND MOISTURE SURVEYS

Appendix B contains copies of the calibration certificates. Calibration data were collected for the LaBr high resolution spectral gamma tool on October 13, 2011, and moisture calibration data were collected on September 21, 2011. C8105 log data using the LaBr tool were collected on October 5-7, 2011. Just prior to C8105 LaBr log data collection, it was discovered that the section of tubing placed over the LaBr tool during data collection on September 20, 2012 for the initial instrument calibrations was of a thinner wall thickness than the casing used actual push logging. Use of a thinner wall for characterization of the tool would result in a small, but different set of calibration coefficients. Because of this difference, a post-logging calibration data set was collected on October 13, 2011.

The log data collected in C8105 were processed with the post log calibration coefficients. The pre-job verification was compared with the post calibration verification and confirmed that the

tool had not changed from start of the logging job to end of calibration data collection. The post-calibration verification performed on ground surface measured a total gross count rate of 1759 c/s with thorite over tool, and a background count rate of 57 c/s. The pre-logging-job verification had 2098 c/s and 348 c/s with thorite and background respectively at push site. The push site ground surface background is higher than background at calibration models due to Cs-137 contamination (which is clearly visible in the background spectra). The net count rate for pre-logging-job was 1750 c/s and the post-calibration-verification net count rate is 1702 c/s, only 2.8% difference, well within statistical precision and environmental differences. The QA requirement, as per logging procedures of verification differences, is ±20% between site verification and calibration standard verification.

The gamma and moisture logs were collected according to approved procedures provided by Energy*Solutions* (PNG 2010). The surveys were recorded from the bottom of the probehole to the ground surface. Zero depth reference is at the ground surface. A repeat measurement was acquired daily to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed and the results agree within the operational specifications for all log responses. The operational specifications are: (1) two times the predicted counting statistics for the gross gamma (equivalent radium-226), (2) predicted counting statistics for the spectral components of the LaBr survey, and (3) predicted counting statistics for the moisture.

The survey results for each probehole are presented as a depth versus concentration plot in Appendix A. The appendix also contains a table summarizing data for each probehole: probehole depth, maximum concentration of Cs-137 in pCi/g, and maximum depth of Cs-137.

3.1 GAMMA CALIBRATION AND SURVEYS

The spectral gamma surveys were logged at 100 seconds per 0.5 ft. Each spectrum file was subsequently processed to quantify the concentration of the naturally occurring radionuclides (K, U, & Th) and quantify Cs-137 when present above the minimum detection threshold. The nominal minimum detection level (MDL) for Cs-137 is approximately .5 to 1 pCi/g.

All spectral calibrations were performed for the probehole conditions of the investigation site. The gross gamma was calibrated to the industry standard of equivalent radium-226 (Eq.Ra) in pCi/g. The LaBr calibration certificate is shown in Figure 1, Appendix B, and Figure 2 is the Gross Gamma logging calibration certificate. A check source thorite is used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (detector integrity) and energy calibration (amplifier gain).

3.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS

The moisture surveys were logged at 15 seconds per 0.25 ft. Pre- and post-job verifications were run each day with the source in the carrying vessel to check detector integrity. Processing of the logging measurements converts the detector gross count rate to a volume of moisture in percent.

The moisture calibration was performed in borehole conditions different from the logging conditions onsite. Two conditions are different: borehole size and casing thickness. Moisture calibration was performed on six and eight inch casings; the calibration certificate is shown in Figure 3. The push tubing for this project has an outside diameter of 2.5 in. The calibration was extrapolated to this smaller diameter push tubing. Figure 4 shows the moisture calibration certificate for the 6.35cm (2.5 in.) hole size. A referenced (Meisner et al. 1996) casing thickness correction is performed during data processing for moisture volume. The casing correction factor for the push tubing thickness is 1.045 times the observed count rate.

4 REFERENCES

Meisner, James, Randall Price, and Russel Randall, 1996, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, WHC-SD-EN-TI-306, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

PNG, 2010, *Procedures: Calibration, Logging, Quality Assurance and Data Management*, Pacific Northwest Geophysics, Kennewick, Washington.

Randall, R. and D. Stromswold, 1995, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models*, WHC-SD-EN-TI-293, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A

SURVEY RESULTS FOR C8105 AND C8106

C-FARM C8105 HEADER INFORMATION

Small Diameter –Moisture Survey

Probehole:	C8105	Log Date:	Oct 2011
Project:	C Farm	Depth Ref:	Ground Surface

1 REPEAT/OVERLAP INTERVALS

Gamma:	170-164 170-165 32-30	Moisture:	170-164

2 OBSERVATIONS

Gamma:

Cs-137 is observed from surface to 6ft, with a maximum reading of 18c/s. The gross gamma threshold is set at 50keV and therefore responsive to the presence of Cs-137.

Moisture:

Moisture values range from 3-27%. Thin bed responses are visible at 92 pipe-ft and several from 28-5 pipe-ft.

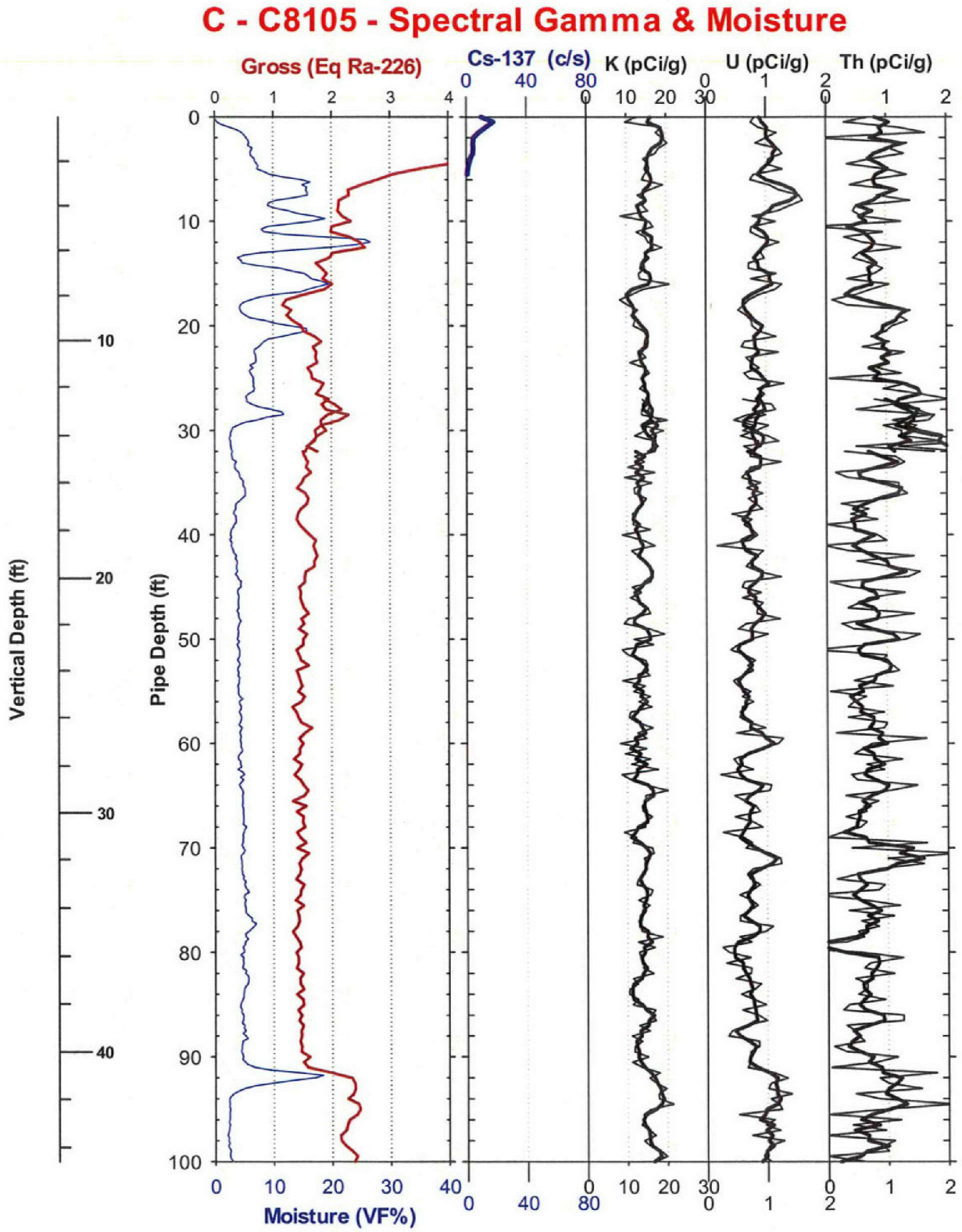
3 CALIBRATION CERTIFICATES

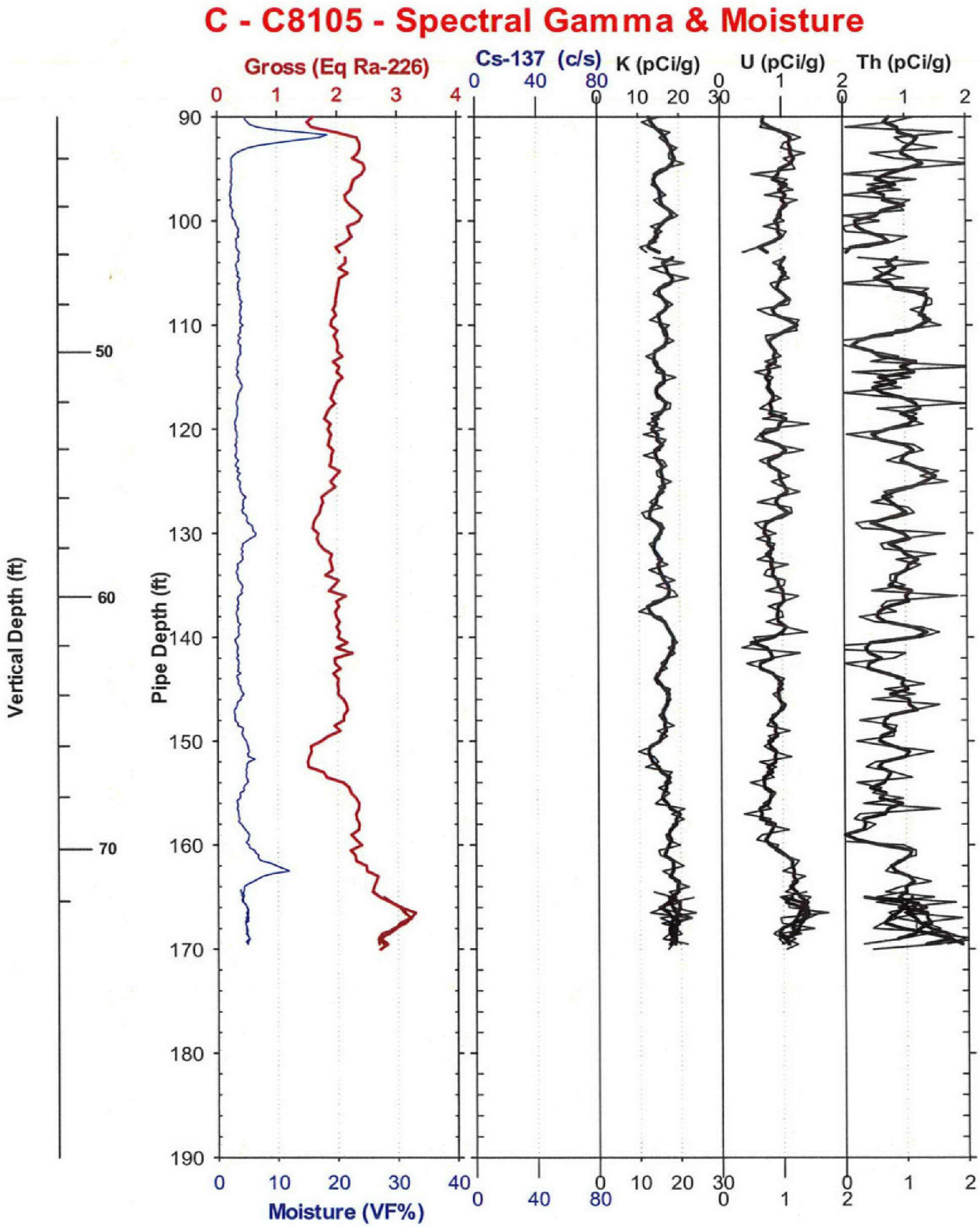
Moisture

Date:	Sep 21, 2011
Electronic File:	ES-Moist792_2011.zip

Gamma LaBr

Date:	Oct 13, 2011
Electronic File:	Cal_Es-GR-1_2011-v0.zip


C - C8105 - Spectral Gamma & Moisture
Gross (Eq Ra-226)
Cs-137 (c/s)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Vertical Depth (ft)
Pipe Depth (ft)
Moisture (VF%)


C - C8105 - Spectral Gamma & Moisture
Gross (Eq Ra-226)
Cs-137 (c/s)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Vertical Depth (ft)
Pipe Depth (ft)
Moisture (VF%)

C-FARM C8106 HEADER INFORMATION

Small Diameter – Spectral Gamma & Moisture Survey

Probehole:	C8106	Log Date:	Nov 2011
Project:	C Farm	Depth Ref:	Ground Surface

4 REPEAT/OVERLAP INTERVALS

Moisture: 162-157
30-28

5 OBSERVATIONS

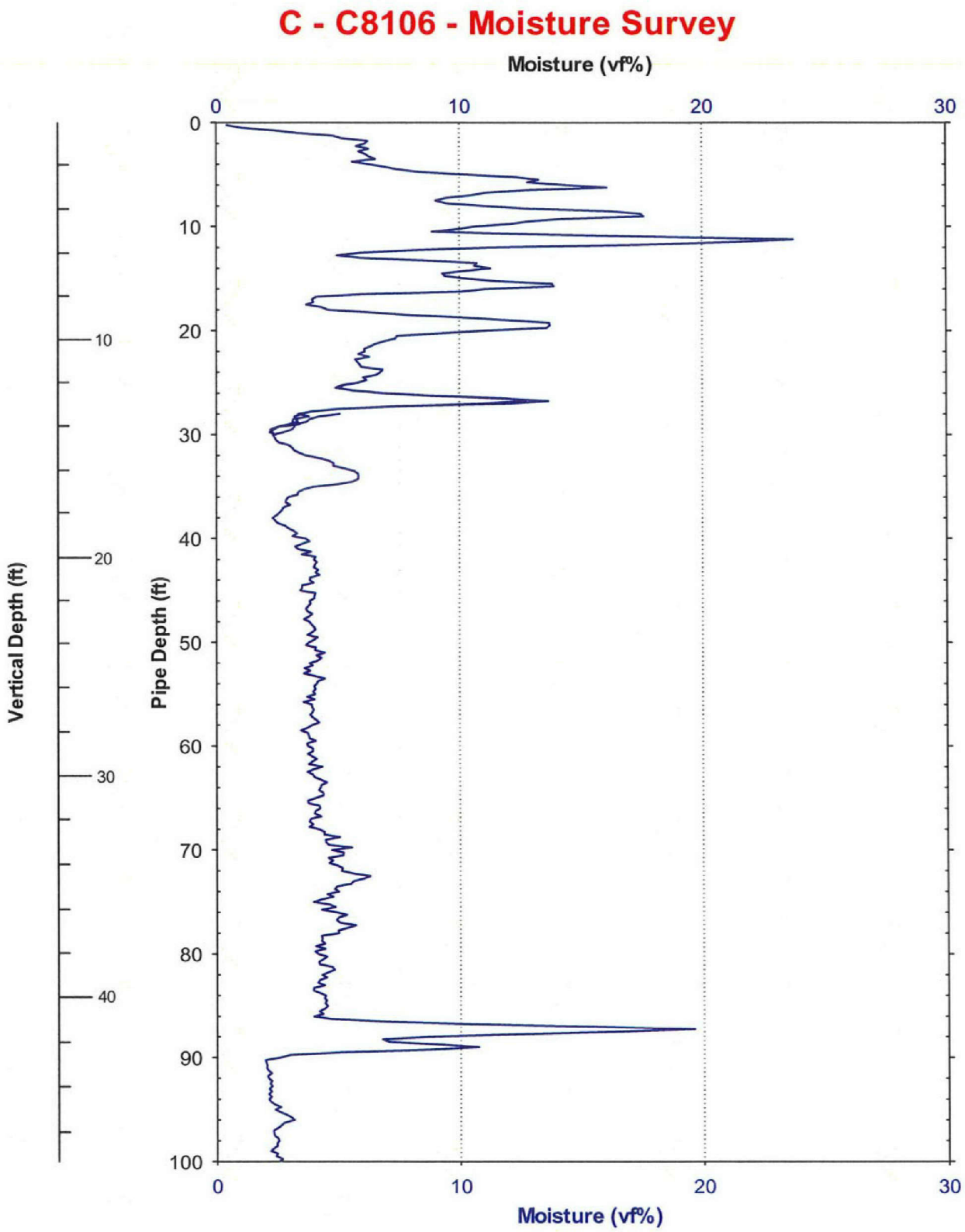
Moisture:

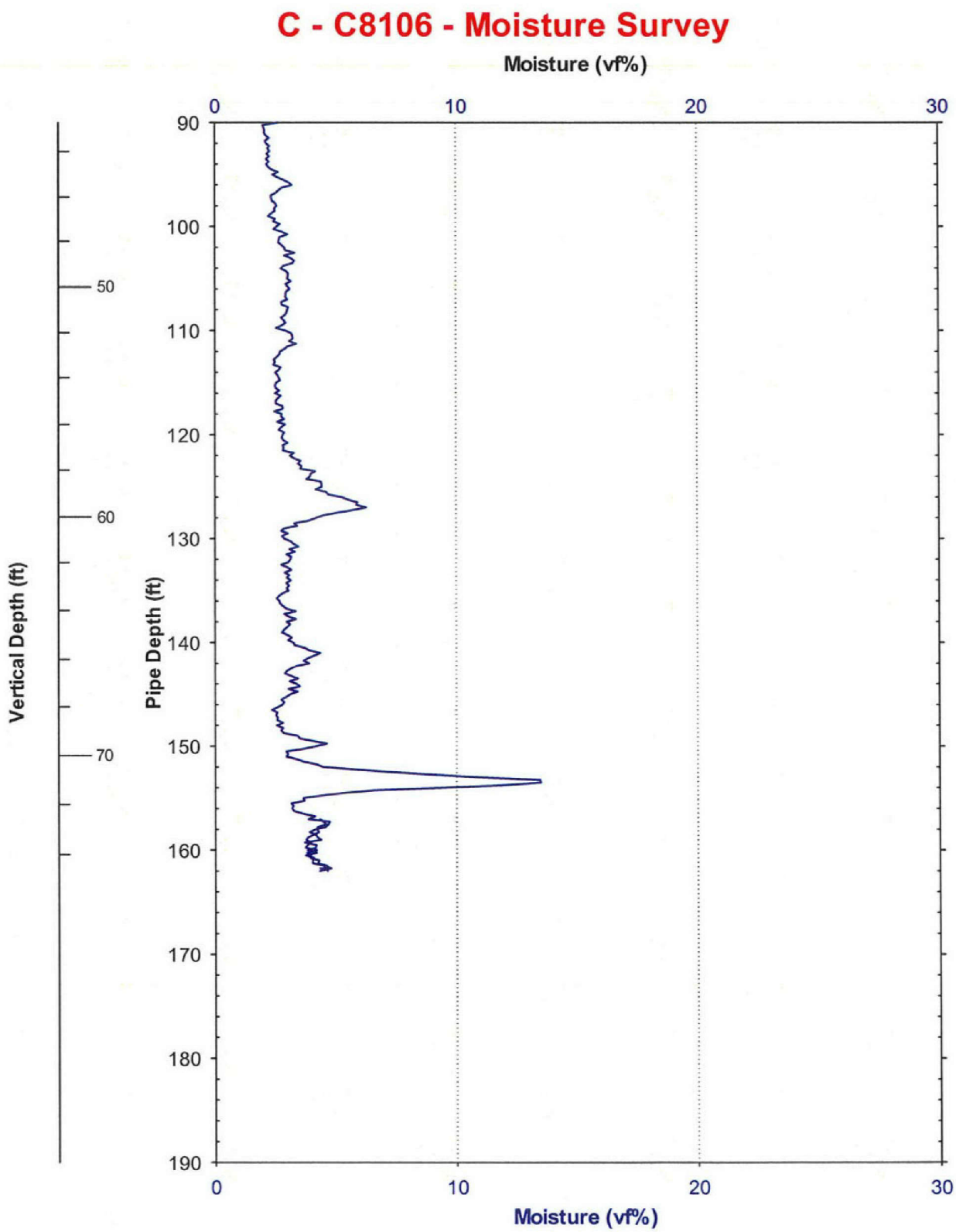
Moisture values range from 2.3-17%. Thin bed responses are washed out in both depth resolution and magnitude of response change when the beds are aligned at an angle different from perpendicular to the borehole.

6 CALIBRATION CERTIFICATES

Moisture

Date:	Sep 21, 2011
Electronic File:	ES-Moist792_2011.zip


C - C8106 - Moisture Survey
Moisture (vf%)
0
10
20
30
Pipe Depth (ft)
0
10
20
30
40
50
60
70
80
90
100
Vertical Depth (ft)
10
20
30
40
Moisture (vf%)


C - C8106 - Moisture Survey
Moisture (vf%)
0
10
20
30
90
100
110
120
130
140
150
160
170
180
190
Pipe Depth (ft)
Vertical Depth (ft)
50
60
70
Moisture (vf%)

APPENDIX B

CALIBRATION CERTIFICATES

Certificate of KUT Calibration
For Tool ESGR.S.1

Oct 13, 2011

Data were taken at the Hanford KUT models on October 13, 2011. ESGR.S.1 is the designated Scintillator tool (Lanthanum Bromide spectral detector). Four models were used for Spectral KUT calibration. Ten spectra were recorded for each model in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: Stats.XLS for this analysis. The instrument was covered with 0.37 inch wall thickness probe tubing.

The algorithm described in the document WHC-SD-EN-TI-293, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1376-1546 keV **U: 1546-2475 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K = **13.99* (K - 1.8)**
Concentration-U = **1.003*(U - 2.8 – 0.2*T)**
Concentration-T = **4.99* (T – 0.7)**

Where K U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_ESGR-2_2011-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_ES-GR-1_2011-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-293, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models" and that the above stated calibration coefficients are correct and applicable for the tool ESGR.S.1 effective Oct 13, 2011.

Signature: Roger Randall Date: October 15, 2011

Company: Three Rivers Scientific

Figure 1. LaBr Calibration Certificate.

Certificate of Gross Calibration
For Tool ESGR.S.1

Oct 13, 2011

Data were taken at the Hanford KUT models on October 13, 2011. ESGR.S.1 is the designated Scintillator tool (Lanthanum Bromide spectral detector). The SBU and SBA models were used for the gross gamma calibration. Ten spectra were recorded for each model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation, refer to the files compressed: Stats.xls for this analysis.

The instrument was covered with 0.37 inch wall-thickness probe-tubing.

The coefficient analysis is determined by the algorithm described in the document WHC-SD-EN-TI-293, Rev. 0. The gross gamma calibration for equivalent ^{226}Ra in pCi/g is a regression function and is generally defined by:

$$Ra = a*GR + b$$

Where Ra is the Eq. ^{226}Ra in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficients of a & b are the fit coefficients. The coefficients were determined to be:

$$a = .0719 \quad Eq.^{226}Ra\ pCi/g\ /\ (c/s)$$
$$b = -3.15\ Eq.^{226}Ra\ pCi/g$$
$$\text{at energy threshold of 130keV}$$

Digital files condensed as Cal_ES-GR-1_2011-v0.zip. This compressed file contains:

- Calibration raw data
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_ES-GR-1_2011-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-293, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models" and that the above stated calibration coefficients are correct and applicable for the tool ESGR.S.1 effective Oct 13, 2011.

Signature: Russel Randall Date: Oct 15, 2011

Russel Randall PhD

Company: Three Rivers Scientific

Figure 2. Gross Gamma Calibration Certificate.

Certificate of Calibration for
Instrument ES-Moist792
Sep 21, 2011

Data were taken in the Moisture models on September 21, 2011 for ES-Moist097 neutron-neutron moisture tool. The neutron source from DOE moisture tool ID of H370608792 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, 3 for 6"casing and 3 for 8" casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation; refer to the file Stats.xls for this analysis.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	**8" casing**
a = .0001452	**a = .00005399**
α = 2.228	**α = 2.567**

The undersigned certifies that the data archived in data file "ES-Moist792_2011.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-306, "Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration" and that the above stated calibration coefficients are correct and applicable for tool ES-Moist792, effective Sep 21, 2011.

Signature: Date:

Sep 25, 2011

Russel Randall, PhD
Three Rivers Scientific

2011 ES-Moist792 Calibration Certificate

Figure 3. Moisture Calibration Certificate, 15.2 cm (6-in.) and 20.3 cm (8-in.) Hole.

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument ES-Moist792

September 21, 2011

Moisture calibration was performed in the Hanford physical models. These standards have 6 and 8 inch ID casings. The Tank Farm Direct Push borehole is cased with a 2.5 inch OD carbon-steel casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.5 inch borehole diameter.

2.51" borehole
a = .000254
α = 1.966

The undersigned certifies that the analysis files are archived in the file "ES-Moist792_2011.zip" was evaluated in accordance with Energy Solutions procedures and that the above stated calibration coefficients are correct and applicable for tool ES-Moist792, effective Sep 21, 2011.

Signature: Date:

Sep 25, 2011

Russel Randall, PhD
Three Rivers Scientific

2011 ES-Moist792 Calibration Certificate

Figure 4. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

DIRECT PUSH GEOPHYSICAL LOGGING RESULTS FROM RPP-RPT-55481, COMPLETION REPORT FOR SMALL DIAMETER GEOPHYSICAL LOGGING FOR C TANK FARM

APPENDIX D

SMALL DIAMETER GEOPHYSICAL LOGGING FOR C TANK FARM

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Geophysical Logging in the 241-C Tank Farm

by

Russ Randall, PhD

to

Energy*Solutions*
Richland, Washington 99354

June 2013

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

Geophysical Logging in the 241-C Tank Farm

1 Introduction

Energy*Solutions* (ES) and Three Rivers Scientific provided small diameter (slim hole) logging in support of field activities at the 241-C Tank Farm. Logging surveys were conducted with three detectors: BGO and LaBr (both scintillation), and a neutron-neutron moisture tool. This report includes the results of these surveys for the 4 probe holes installed at the investigation site (see Appendix A).

The BGO and LaBr instruments were run in combination during the logging run, and spectral data were recorded for both. The energy resolution of the LaBr is superior to the BGO, but the BGO efficiency for KUT naturals is superior to the LaBr. Thus the data from the BGO are used to measure gross gamma and concentrations of KUT, and the LaBr data are used to identify and measure the concentrations of other selected radionuclides. The targeted radionuclides for this project were ^{137}Cs and enriched ^{238}U.

Both of the gamma tools were calibrated for the probe hole conditions present at the investigation site. The moisture tool was calibrated in the 6 and 8 inch cased calibration standards. Casing thickness correction is applied to the extrapolated casing diameter calibrations for the moisture response.

2 Survey Results

Log surveys were recorded from the bottom of the probe hole (maximum survey depth) to the ground surface. Zero depth reference is at ground surface. A daily repeat measurement was acquired to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed and the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probe hole are presented as a depth versus concentration plot in Appendix A. The plots are in numeric order of the probe holes (C8763, C8765, C8766 and C8767).

3 Geophysical Logging System

The logging system is a portable unit powered by either an on-site generator (120v AC) or site-supplied power. A laptop computer allocated to the logging unit was used to monitor encoder depth positions, control the winch motor, and record detector responses.

3.1 Gross Gamma Calibration and Surveys

The gross gamma is obtained using the efficiency superior BGO instrument response. The settings of the detector components are fixed (i.e., set up during assembly, prior to calibration) and are not adjustable by the field-logging engineer. The detector gain and lower threshold are set to record gamma ray activity with energies between 20 and 3000 keV. By comparison, the highest gamma ray from naturally occurring radionuclides is from ^{232}Th and occurs at 2614 keV. A ^{60}Co was used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (integrity) and energy calibration (amplifier gain).

The BGO detector is calibrated in gross gamma borehole calibration models located at the U.S.-DOE Hanford site near Richland, Washington. Calibration data were collected in the two most appropriate (lowest concentration) gross gamma calibration zones (SBA and SBU). The detector was covered with a 4-ft long section of the probe/drill tubing (0.37-inch thick). The calibration data are summarized in Table 1. The calibration units are pCi/g of equivalent Radium-226 ($e^{226}Ra$). See Appendix B for the calibration certificate.

Table 1. Gross Gamma Calibration Data

Calibration Model	Concentration $e^{226}Ra$ (pCi/g)	Dead-Time Corrected Gross Gamma Count-Rate[1] (cps)
SBA	61.2	2517 ± 2
SBU	186	7347 ± 3.5
Count rates are mean of 50 sample measurements at 10-sec each. 1-BGO Detector system dead time is 7.2 microsec		

The BGO/LaBr gamma surveys were logged at 0.5 ft depth increments and 100 sec per station.. A spectrum of 1024 channels was collected each 0.5 ft from the bottom of the probe hole to the surface. The spectra were recorded in comma delimited format with all spectra per file. Detector count rates were dead-time corrected and the gamma survey data were processed as gross gamma response to determine the concentration of $e^{226}Ra$ in pCi/g.

The dead time correction is a nonparalyzeable relationship (Knoll, 1979) and described by the following equation:

$$C_t = \frac{C_{obs}}{1 - \varepsilon \cdot C_{obs}}$$

where C_t is the true or dead time corrected count rate in c/s, C_{obs} is the observed count rate in c/s, and ε is the dead time factor of 7.2μs.

3.2 Spectral Gamma Calibrations and Surveys

Calibration of the BGO logging system was performed in the four spectral gamma borehole calibration models located at the U.S.-DOE Hanford Site near Richland, Washington and according to Hanford Site procedures for scintillation-type spectral gamma ray borehole detectors (Randall & Stromswold, 1995). The four calibration models contain elevated concentrations of the naturally occurring radionuclides (potassium, uranium or radium in secular equilibrium with uranium, and thorium, aka KUT). The radionuclide concentrations are traceable to NIST standards, (Steele & George, 1986). Table 2 lists the radionuclide concentration in each of the gamma calibration models. The uncertainty is quoted at the 2-sigma (95%) confidence level.

Table 2. Hanford Calibration Model Values for KUT

Model	^{40}K Concentration (pCi/g)	^{226}Ra Concentration (pCi/g)	^{232}Th Concentration (pCi/g)
SBK	53.50 ± 1.67	1.16 ± 0.11	0.11 ± 0.02
SBU	10.72 ± 0.84	190.52 ± 5.81	0.66 ± 0.06
SBT	10.63 ± 1.34	10.02 ± 0.48	58.11 ± 1.44
SBM	41.78 ± 1.84	125.79 ± 4.00	39.12 ± 1.07

Calibration was performed with a section of the steel drill tubing (4-ft long) 0.37-in. thick (2.5-in. OD) installed over detector (4-in. long) during calibration measurements. Calibration with the casing installed over the detector is more

rigorous than calibration in an open hole and applying correction factor to the probe hole survey to correct for the presence of casing.

During logging, the gamma peak at 1461 keV from potassium (^{40}K) is almost always present as the dominant peak in each spectra. The second best peak is the 2614 keV peak from ^{232}Th. Both of these peaks are used to monitor for spectra gain changes. During data processing the spectra gain is adjusted to track the reference gamma peaks.

Borehole survey spectra (100 seconds each) were measured each 0.5 ft between the selected depth intervals in move-stop-acquire logging mode, the results are presented on the plot for each of the corresponding probe holes. (Refer to Appendix A for logging results).

3.3 Spectral Photo Peak Calibrations and Surveys

The LaBr spectral data are processed differently than the BGO data, and thus the LaBr calibration is different. The LaBr calibration and data processing is performed in the same manner that the HPGe log data are calibrated and processed (Randall, 1994). The basic concept involves the non-linear least square fitting of a linear background plus a Gaussian photo peak over a small region of the spectra containing the target gamma ray. The discussion in this report will cover the target gamma ray of ^{137}Cs (661 keV), but the same technique can be applied to any other gamma ray.

The SBU calibration model was used to measure the LaBr detector efficiency for the 609 keV peak from a daughter product of ^{238}U. It is known that the gamma ray detection efficiency of LaBr is a function of energy, thus a method of correcting the measured efficiency at 609 to the efficiency at 661 keV was developed. MCNP (Monte Carlo N-Particle) (RSICC) code for making Monte Carlo gamma transport calculations was used to compute the ratio of detector efficiencies between 609 and 661 keV. This ratio is then applied to the measure efficiency at 609 keV to obtain the ^{137}Cs gamma ray efficiency. The tool geometry of the modeling was the same used in the SBU calibration, and the source was set to both a 609 and 661 keV distributed throughout an SBU matrix.

The dead time for the LaBr instrument was measured to be 1.06 μs. The measured detector efficiency for the 661 keV is 0.588 (c/s)/pCi/g (Appendix B contains the calibration certificate). The measured Full Width at Half Maximum (FWHM) % for the ^{137}Cs photo peak is 4.17% at 661 keV.

The log data processing for ^{137}Cs is performed using a MathCad file. The steps to process data are the following:

1. The energy calibration is established.
2. Based upon the 661 keV energy, the predicted peak channel is computed from the energy calibration.
3. A MathCad file is used to fit a linear background plus a Gaussian (with the energy computed centroid, and established peak width) to each spectral record.
4. Within the same MathCad file the photo peak count rate is computed, dead time corrected, and calibration coefficients applied and the ^{137}Cs concentrations and depths output to a comma delimited file.
5. Survey plots are made with only those computed ^{137}Cs that are above minimum detect levels (MDL), which is conservatively set at 0.7 pCi/g, based upon statistical merits of the fitting.

4 Conclusion

Scintillation gross, spectral gamma, and moisture survey logs were collected in four probe holes installed in the 241-C Tank Farm. All probe holes were pushed to their target depth. All four probe holes were pushed to approximately 210 feet in depth, with well C8763 going to 218 feet in depth.

The man-made contaminant ^{137}Cs was identified above MDL, in the probe holes logged. All detections of ^{137}Cs were near the surface. No ^{238}U was detected above MDL (using only the 1001keV gamma); but some zones looked like possible candidates for the uranium contamination.

5 References

Knoll, G., 1979, "Radiation Detection and Measurement", Copyright 1979 by John Wiley & Sons, Inc. ISBN "0-471-49545-X"

Randall, Russel R. PhD and Stromswold, David C. PhD, 1995, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models", Westinghouse Hanford Co., Richland, WA.

Steele, W. Douglas and George, David C., 1986, "Field Calibration Facilities for Environmental Measurement of Radium, Thorium, and Potassium", Bendix Field Engineering Corp., Grand Junction, CO.

Randall, Russel R., 1994 "Calibration of the Radionuclide Logging System Germanium Detector", Westinghouse Hanford Co., Richland, WA

RSICC Computer Code Collection, MCNP4B2, "Monte Carlo N-Particle Transport Code System," Transport Methods Group Los Alamos National Lab, Los Alamos, New Mexico, distributed by Oak Ridge Nat Lab.

Appendix A Gamma Survey Results

Gross gamma, KUT spectral, ^{137}Cs, and moisture responses are shown in the survey plots follow for the four probe holes installed in the 241-C Tank Farm. All detector count rates were dead-time corrected and the results are converted using the calibration coefficients. The plots with header information follow.

C-Farm C8763 Header Information

Small Diameter –Moisture Survey

Probehole:	C8763	Log Date:	Apr 2013
Project:	C Farm	Depth Ref:	Ground Surface
Point#:	2845	Northing(Y):	136589.938
Easting(X):	575178.598	Elevation(Z):	648.77 ft

Repeat/Overlap Interval

Gamma:	215-210	Moisture:	218.5-213.5
	196.5-191.5		213-208
	150.5-145.5		111-106
	99.5-94.5		
	46.5-41.5		

Observations

Gamma:

Cs-137 is observed from surface to 3 ft, with a peak concentration of 23.7 pCig at surface in this probe hole.

Moisture:

Moisture values range from 4-23%. There are numerous thin bed responses throughout the entire logged interval.

Calibration Certificates

Moisture

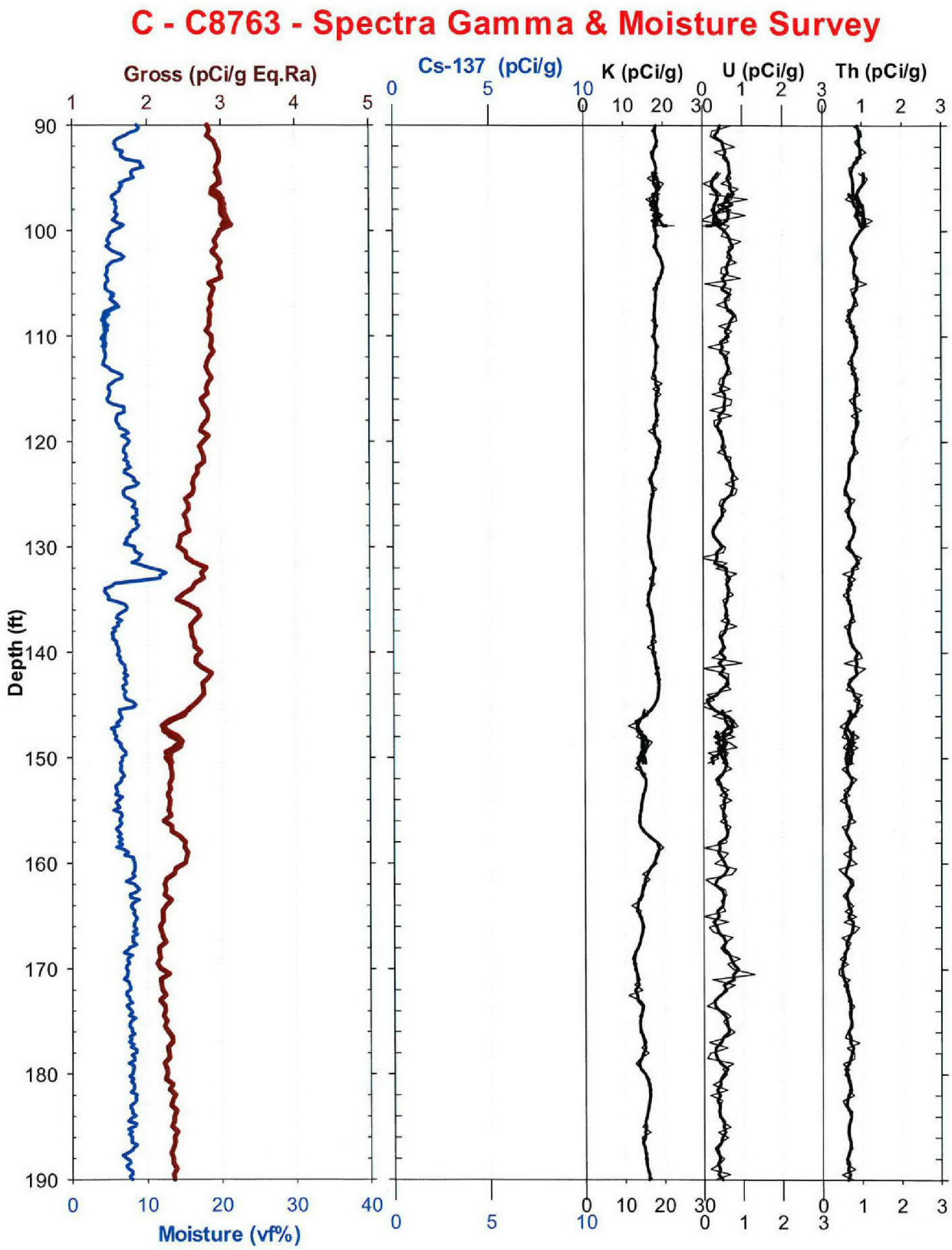
Date:	Jan 25, 2013
Electronic File:	N2_097_2013-v0.zip

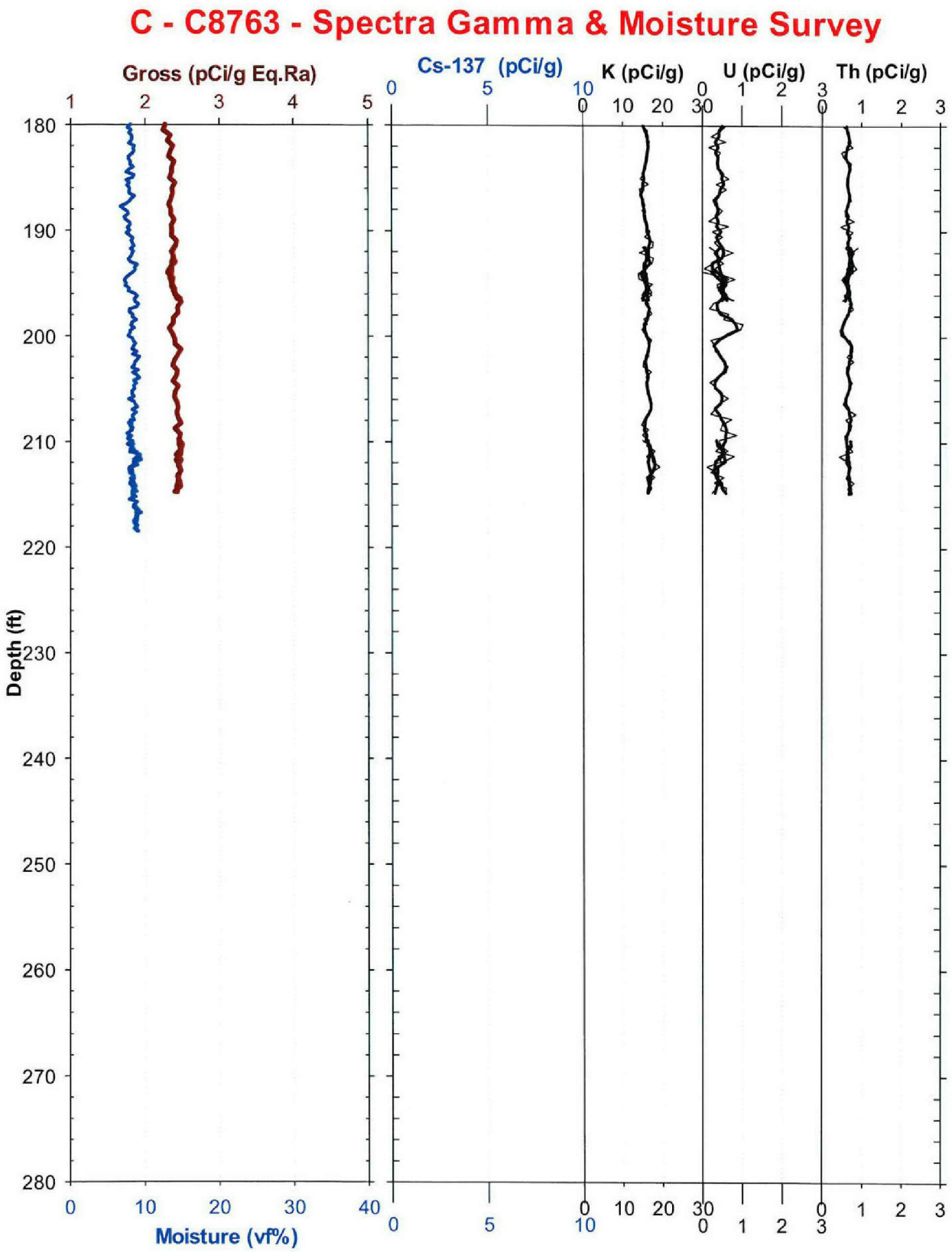
Gamma BGO

Date:	Feb 4, 2013
Electronic File:	BGO-1_2013-v0.zip

LaBr

Date:	Sep 13, 2012
Electronic File:	LaBr-1 2013-v0.zip


C - C8763 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C8763 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-Farm C8765 Header Information

Small Diameter –Moisture Survey

Probehole:	C8765	Log Date:	June 2013
Project:	C Farm	Depth Ref:	Ground Surface
Point#:	2841	Northing(Y):	136629.197
Easting(X):	575194.454	Elevation(Z):	636.58ft

Repeat/Overlap Intervals

Gamma:	166.5-171.5 128.5-133.5 45.5-50.5	Moisture:	132-127

Observations

Gamma:

Cs-137 is observed in this probe hole from surface to 17 ft with a peak concentration of 11.7 pCig at 0.5 ft.

Moisture:

Moisture values range from 4-22%. There are numerous thin bed responses throughout the entire logged interval.

Calibration Certificates

Moisture

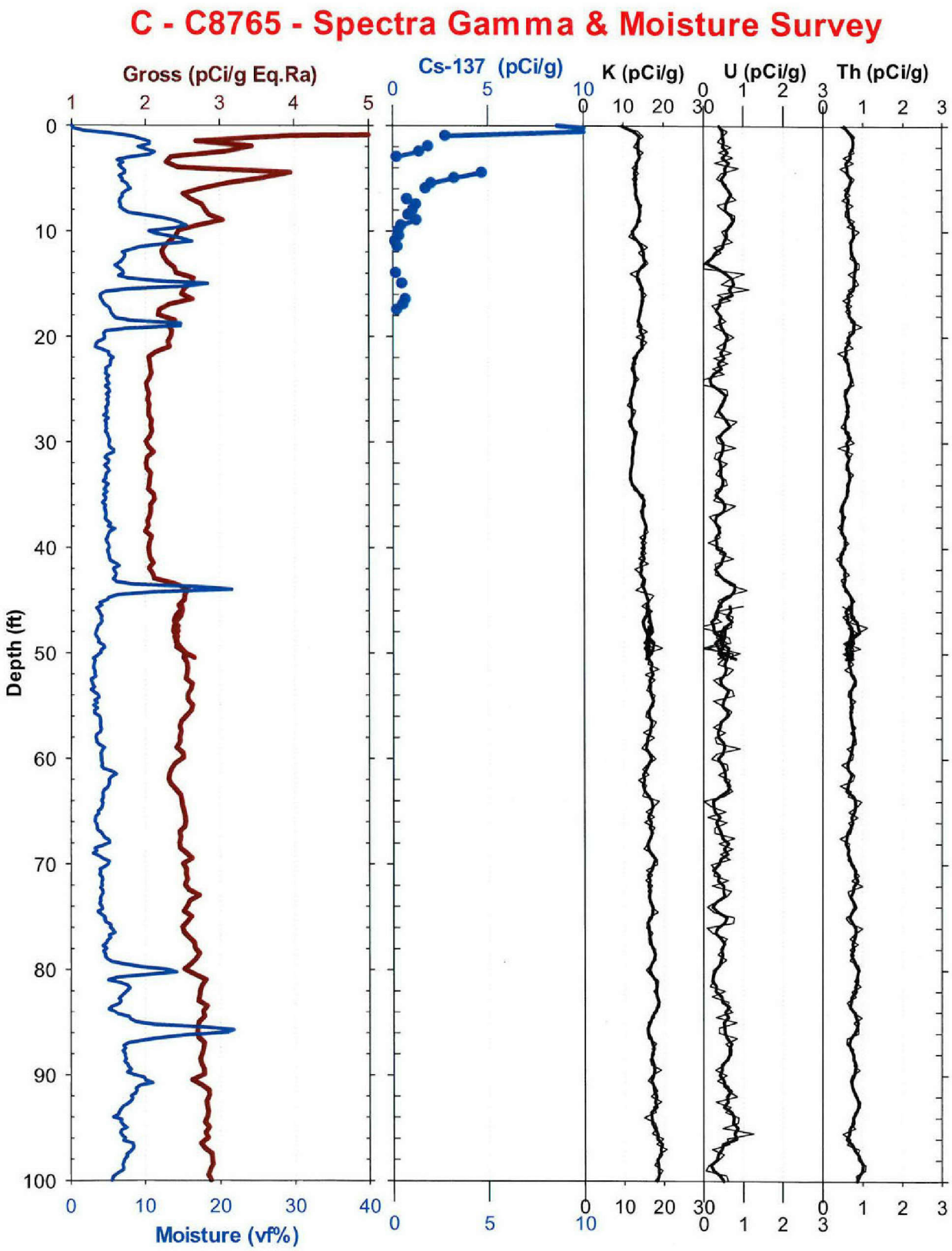
Date:	Jan 25, 2013
Electronic File:	N2_097_2013-v0.zip

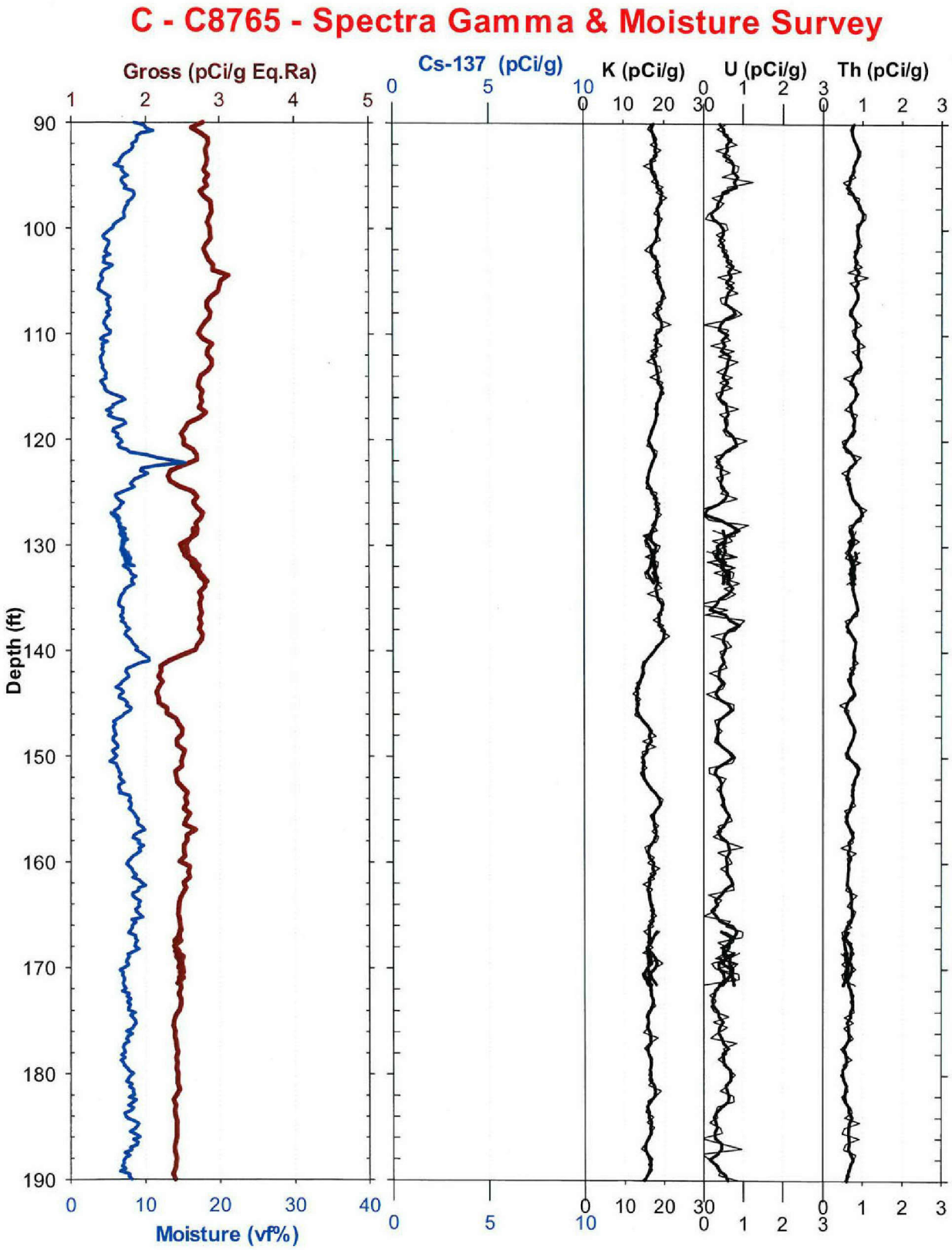
Gamma BGO

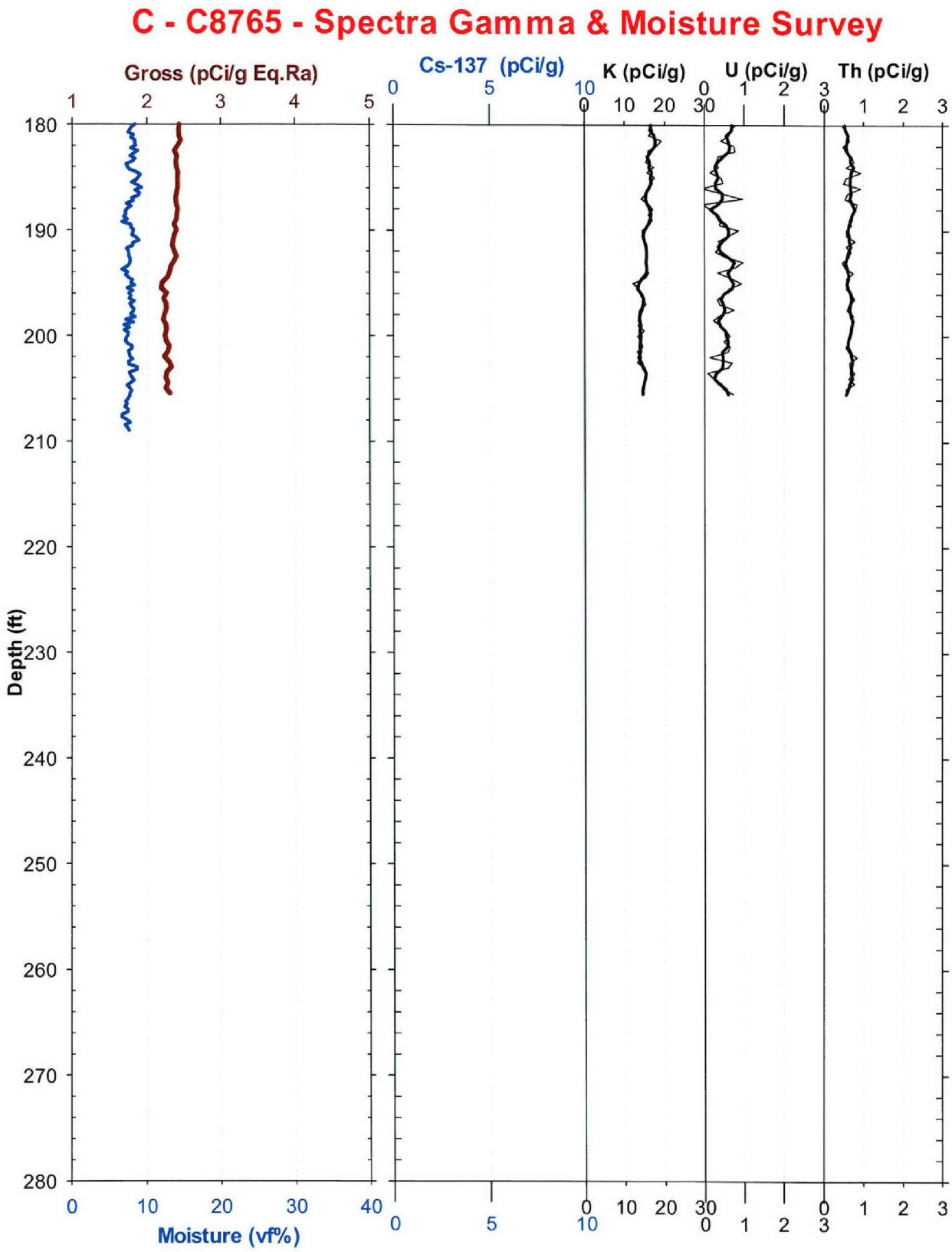
Date:	Feb 4, 2013
Electronic File:	BGO-1_2013-v0.zip

LaBr

Date:	Sep 13, 2012
Electronic File:	LaBr-1_2013-v0.zip


C - C8765 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C8765 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C8765 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-Farm C8766 Header Information

Small Diameter –Moisture Survey

Probehole:	C8766	Log Date:	May 2013
Project:	C Farm	Depth Ref:	Ground Surface
Point#:	2836	Northing(Y):	136616.347
Easting(X):	575205.484	Elevation(Z):	638.91

Repeat/Overlap Intervals

Gamma: 197-205
195-200
133-137
65-70
23-28

Moisture:204-209
165-170
58-63

Observations

Gamma:

Cs-137 is observed in this probe hole for surface to 7 ft, with a peak concentration of 67.6 pCig at 1 ft.

Moisture:

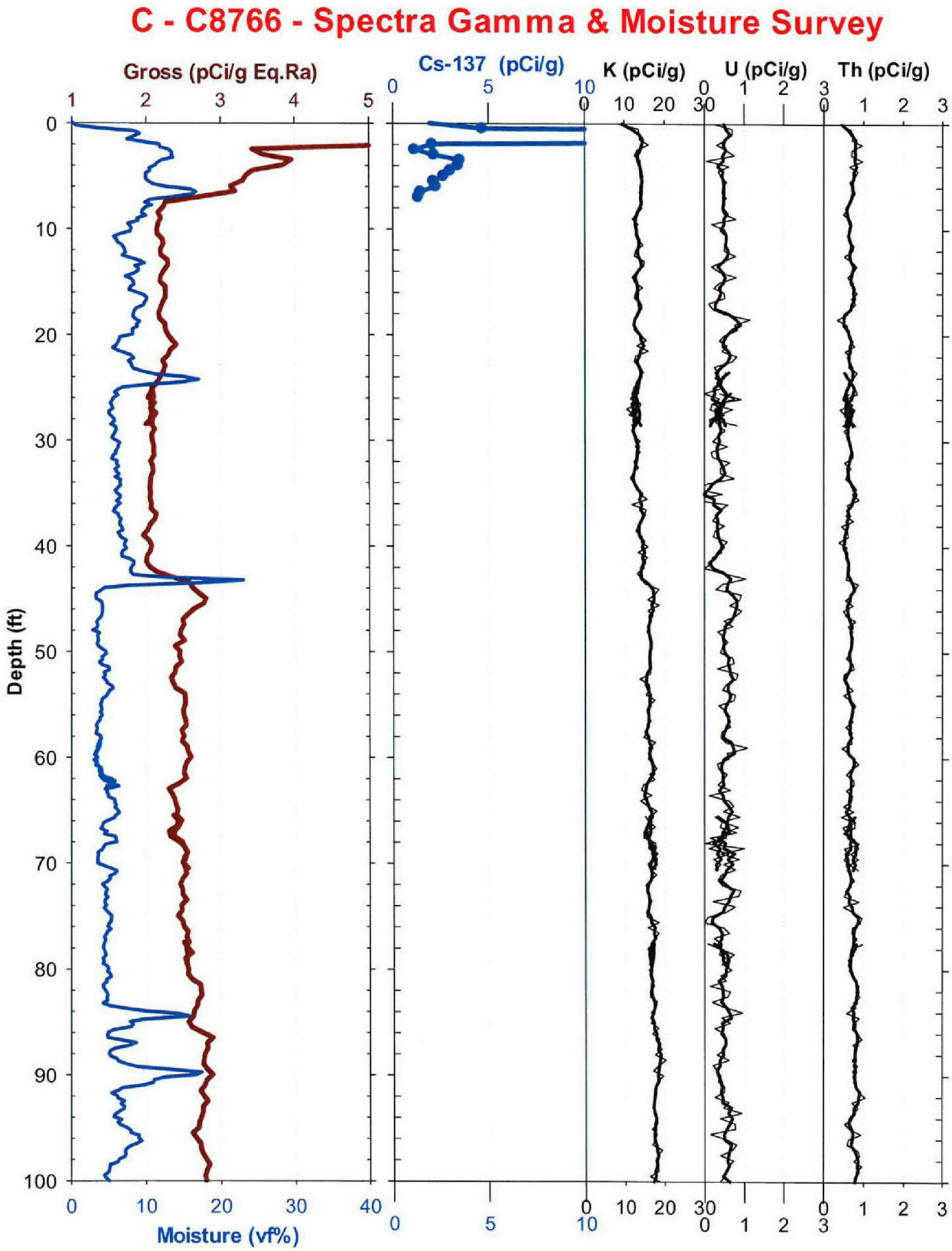
Moisture values range from 4-23%. There are numerous thin bed responses throughout the entire logged interval.

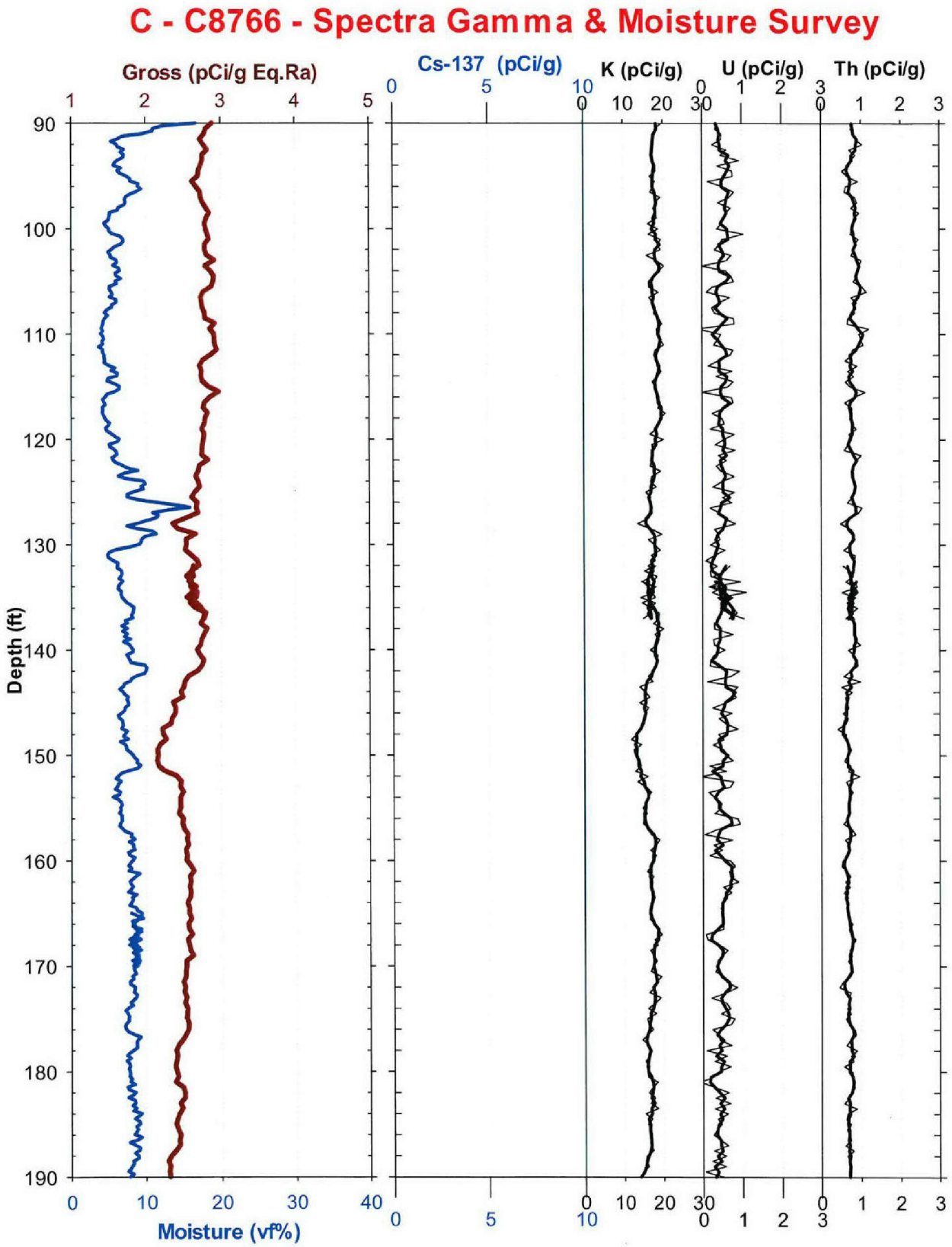
Calibration Certificates

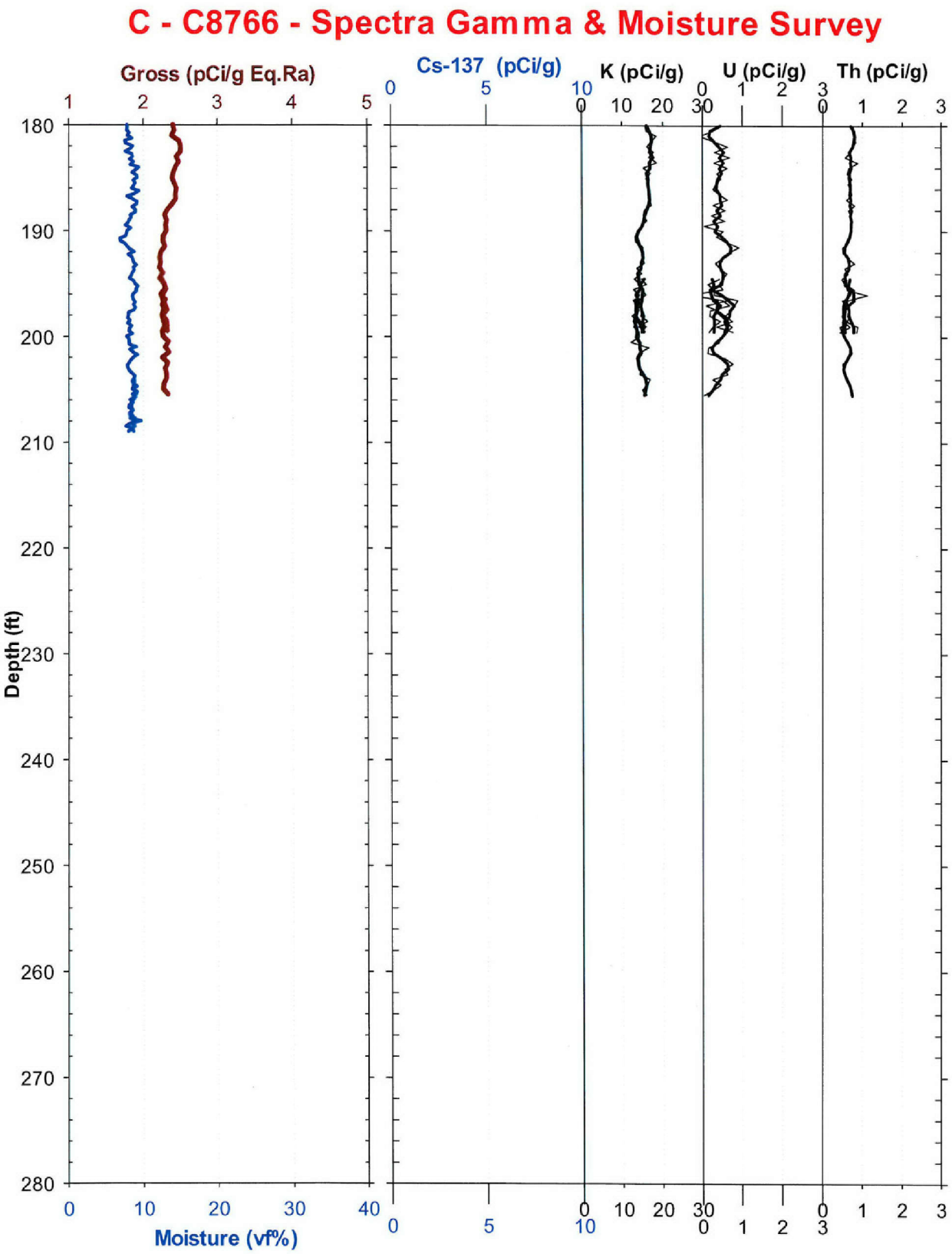
Moisture
Date: Jan 25, 2013
Electronic File: N2_097_2013-v0.zip

Gamma BGO
Date: Feb 4, 2013
Electronic File: BGO-1_2013-v0.zip

LaBr
Date: Sep 13, 2012
Electronic File: LaBr-1_2013-v0.zip


C - C8766 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C8766 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C8766 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

C-Farm C8767 Header Information

Small Diameter –Moisture Survey

Probehole:	C8767	Log Date:	May 2013
Project:	C Farm	Depth Ref:	Ground Surface
Point#:	2835	Northing(Y):	136609.301
Easting(X):	575211.468	Elevation(Z):	639.83ft

Repeat/Overlap Intervals

Gamma:	200-205	Moisture:	204-209
	157-162		78-83
	110-115		
	83-88		
	41-46		

Observations

Gamma:

Cs-137 is observed in this probe hole from surface to 5.5 ft, with a maximum concentration of 4.2 pCig.

Moisture:

Moisture values range from 4-20%. There are numerous thin bed responses throughout the entire logged interval.

Calibration Certificates

Moisture

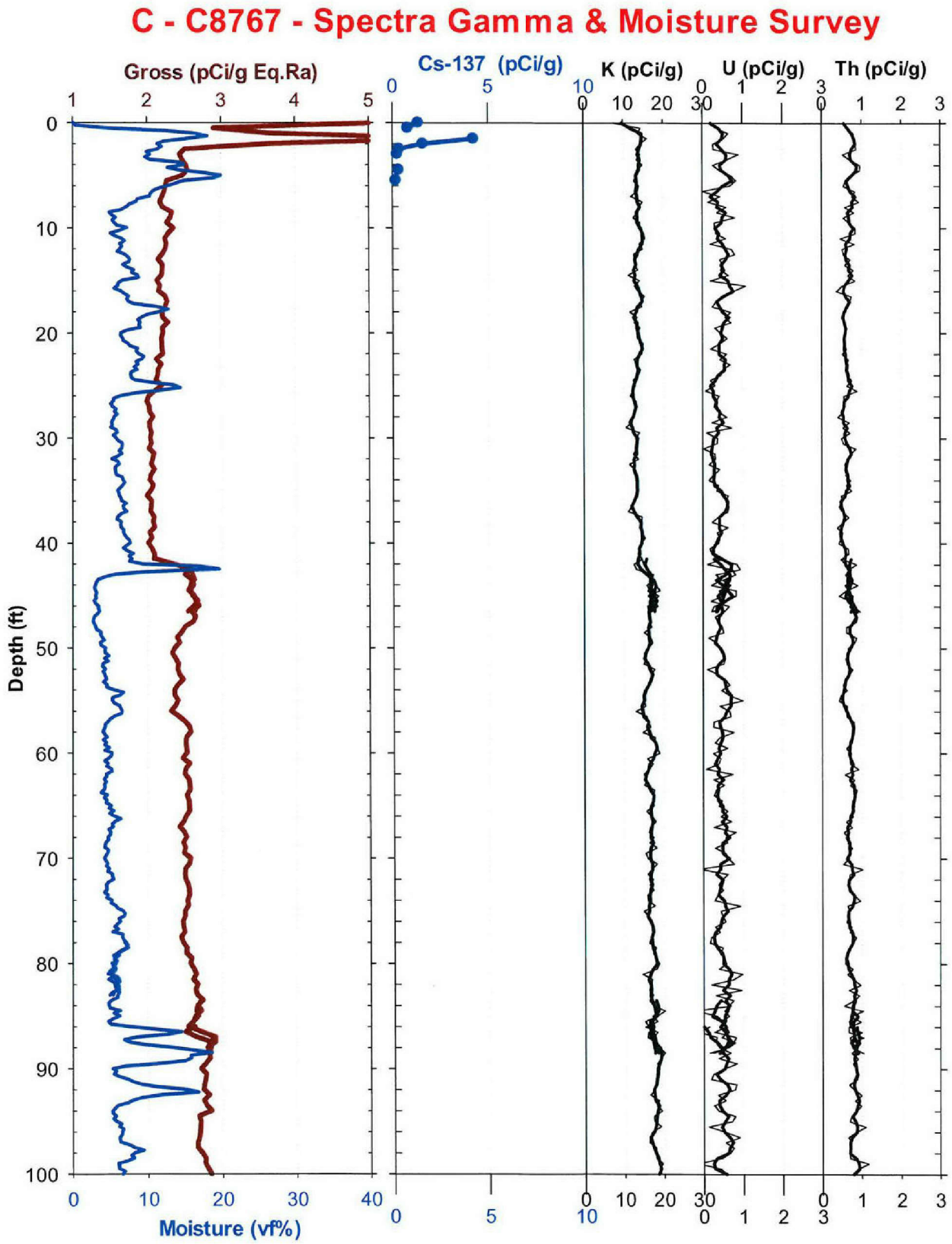
Date:	Jan 25, 2013
Electronic File:	N2_097_2013-v0.zip

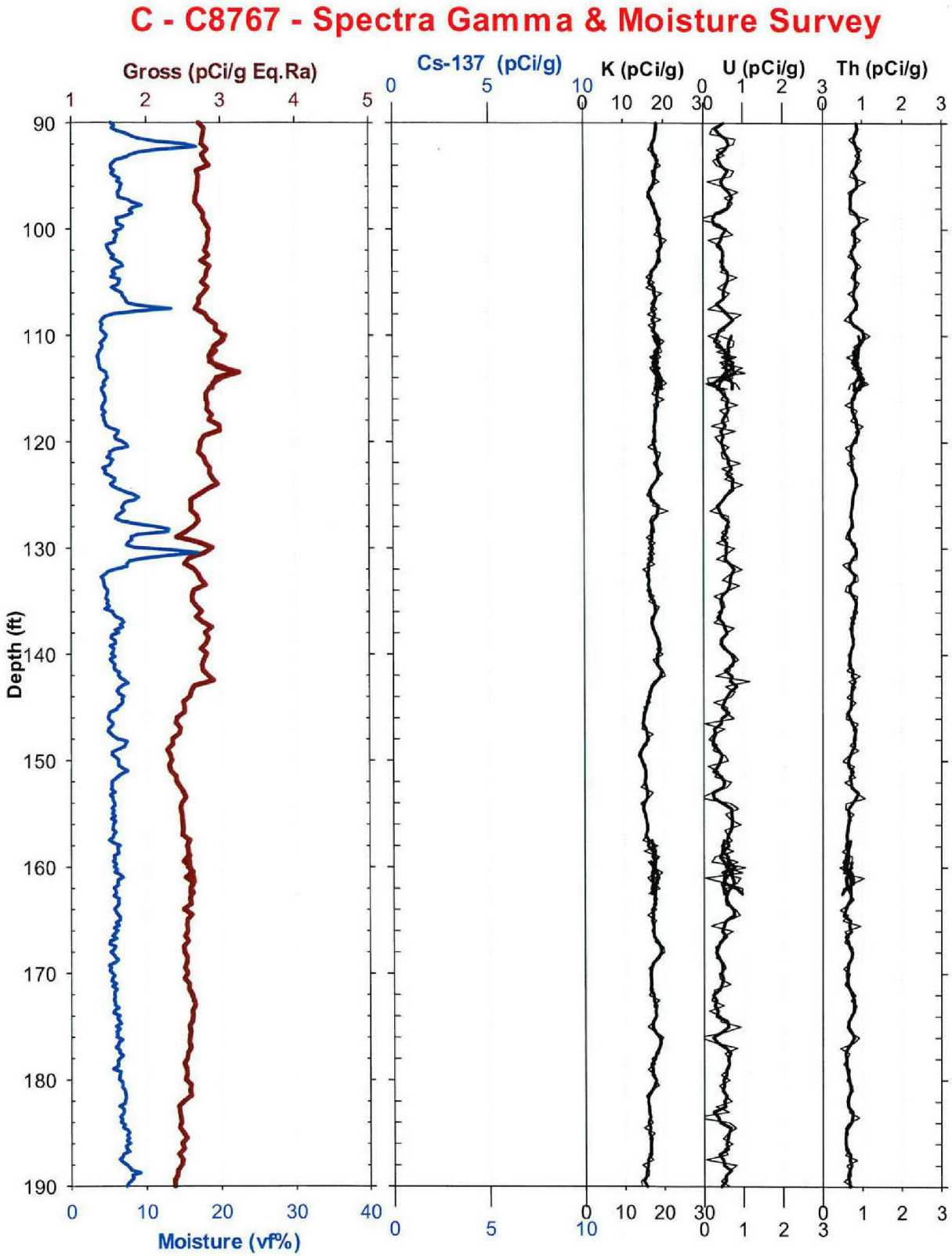
Gamma BGO

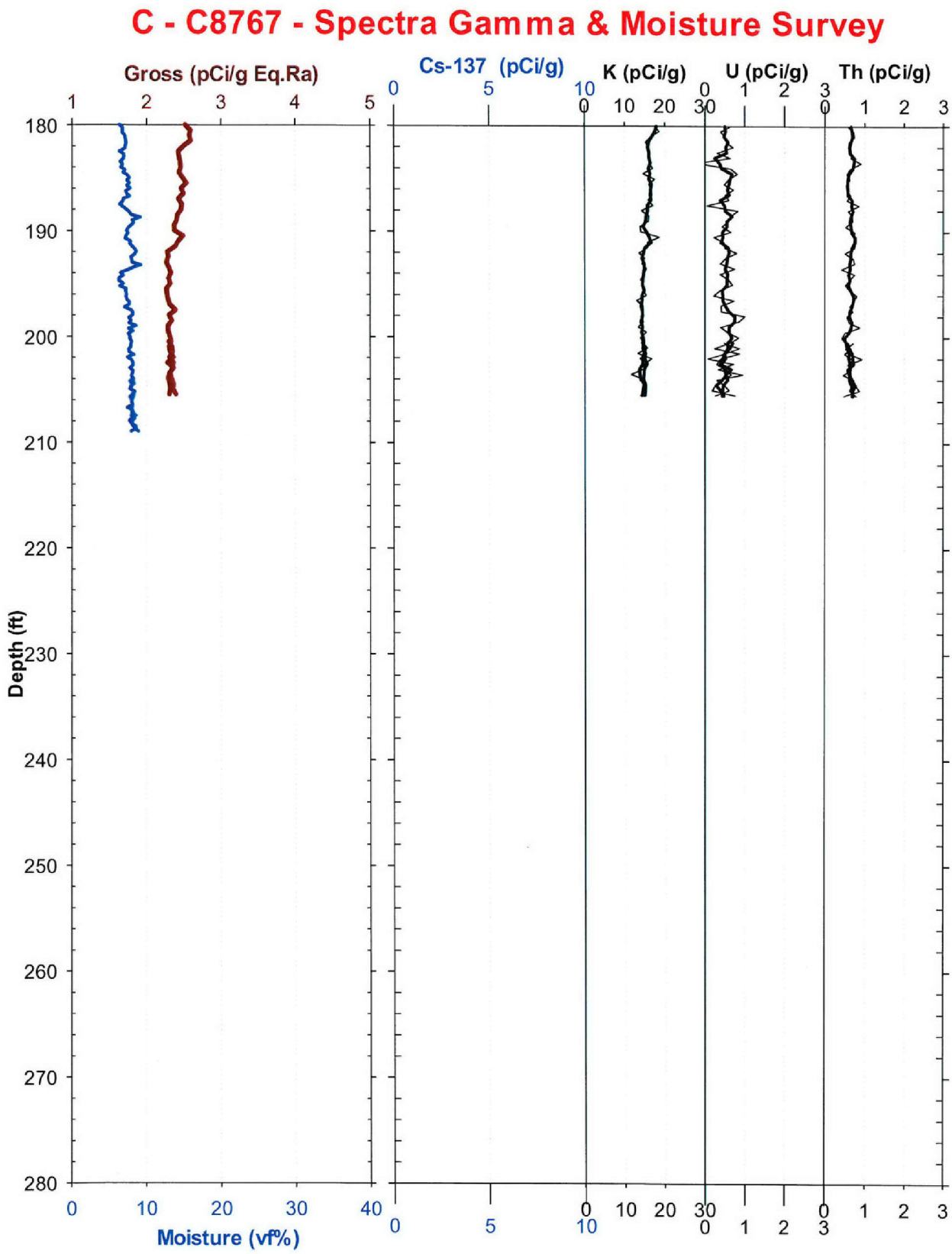
Date:	Feb 4, 2013
Electronic File:	BGO-1_2013-v0.zip

LaBr

Date:	Sep 13, 2012
Electronic File:	LaBr-1_2013-v0.zip


C - C8767 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C8767 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)


C - C8767 - Spectra Gamma & Moisture Survey
Gross (pCi/g Eq.Ra)
Cs-137 (pCi/g)
K (pCi/g)
U (pCi/g)
Th (pCi/g)
Depth (ft)
Moisture (vf%)

Appendix B Calibration Certificates

The following pages contain the following calibration certificates:

1. BGO gross gamma
2. BGO KUT spectral
3. LaBr Cs-137 spectral
4. Neutron-neutron moisture
5. Moisture calibration extrapolated to push tubing size
6. Hoist unit-depth calibration

Certificate of Calibration
BGO-1
Feb 4, 2013

COPY

Data were taken at the Hanford KUT models on Feb 4, 2013. BGO-1 is the designated Scintillator tool. The SBA model was used for the gross gamma calibration. Fifty spectra were recorded for the model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation, refer to the files compressed: Stats.xls for this analysis.

The instrument was covered with 0.37 inch wall-thickness probe-tubing.

The coefficient analysis is determined by the algorithm described in the document WHC-SD-EN-TI-293, Rev. 0. The gross gamma calibration for equivalent ^{226}Ra in pCi/g is a regression function and is generally defined by:

$$Ra = a*GR + b$$

Where Ra is the Eq. ^{226}Ra in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficients of a & b are the fit coefficients. A more physical relationship constrains the intercept (b) to a zero value. This computation yields improved response extrapolated to low concentrations of K, U, and Th (clean zones). The coefficients were determined to be:

$$a = .0243 \quad Eq.^{226}Ra\ pCi/g\ /\ (c/s)$$
$$b \equiv 0$$
$$\text{at energy threshold of 0keV}$$

$$a = .194 \quad Eq.^{226}Ra\ pCi/g\ /\ (c/s)$$
$$b \equiv 0$$
$$\text{at energy threshold of 800keV}$$

Digital files condensed as Cal_SD-GR-2_2010-v0.zip. This compressed file contains:

- Calibration raw data
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_BGO-1_2013-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-293, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models" and that the above stated calibration coefficients are correct and applicable for the tool BGO-1 effective Feb 4, 2013.

Signature: Russel Randall Date: Feb 5, 2013
Russel Randall PhD

Company: Three Rivers Scientific

Certificate of Calibration
BGO-1
Feb 4, 2013

COPY

Data were taken at the Hanford KUT models on Feb 4, 2013. BGO-1 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Fifty spectra were recorded for each model in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, refer to the files compressed: Stats.XLS for this analysis. The instrument was covered with 0.37 inch wall thickness probe tubing.

The algorithm described in the document WHC-SD-EN-TI-293, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1320-1575 keV **U: 1650-2390 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**4.077*K**	**-3.382*U**	**2.957*T**
Concentration-U =	**0.0*K**	**1.351*U**	**-2.585*T**
Concentration-T =	**0.0*K**	**-0.034*U**	**1.655*T**

Where K U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_BGO-1_2013-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file "Cal_BGO-1_2013-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-293, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models" and that the above stated calibration coefficients are correct and applicable for the tool BGO-1 effective Feb 4, 2013.

Signature: Date: Feb 5, 2013

Company: Three Rivers Scientific

Certificate of Calibration
LaBr-1
Cs-137 Photo Peak
Sep 13, 2012

Data were taken at the Hanford KUT models on Sep 13, 2012. LaBr-1 is the designated Scintillator tool. The SBA and SBU models were used for the gross gamma calibration. Ten spectra were recorded for each model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation, refer to the files compressed: Stats.xls for this analysis.

The instrument was covered with 0.33 inch wall-thickness probe-tubing.

The coefficient analysis is determined by the algorithm described in the document WHC-SD-EN-TI-292, Rev. 0. The photo peak stripping method of radionuclide calibration is generally defined by:

$$C = A/(\varepsilon * N)$$

Where C is the radionuclide concentration in pCi/g, A is the deadtime corrected photo peak count rate, ε is the detector efficiency, and N is the number of gamma rays emitted per decay. The coefficient ε is the fit coefficient. The LaBr scintillator has superior energy resolution, but internal to the crystal a small but observable radioactivity that produces a background. This background does not affect the photo peak stripping method. The coefficient was determined to be:

$$\varepsilon = .588 \quad (c/s) \ / \ pCi/g$$

Digital files condensed as Cal_ES-Cs-1_2012-v0.zip. This compressed file contains:

- Calibration raw data
- Spreadsheet data formatting
- MCNP output
- Mathcad files

The undersigned certifies that the data archived in the file "Cal_ES-Cs-1_2012-v0.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-292, "Calibration of the Radionuclide Logging System Germanium Detector" and that the above stated calibration coefficient is correct and applicable for the tool LaBr-1 effective Sep 13, 2012.

Signature: Russel Randall Date: Sep 16, 2012

Russel Randall PhD

Company: Three Rivers Scientific

Certificate of Calibration for
Instrument N-2_097
Jan 25, 2013

Data were taken in the Moisture models on Jan 25, 2013 for N-2_097 neutron-neutron moisture tool. The neutron source from DOE moisture tool ID of 78-1097 was used with the passive neutron detector probe from PNG.

Six models were used for moisture calibration, 3 for 6"casing and 3 for 8" casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation; refer to the file Stats.xls for this analysis.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	8" casing
a = .0001671	a = .00009656
α = 2.202	α = 2.44

The undersigned certifies that the data archived in data file "N-2_097_2013.zip" were collected and evaluated in accordance with procedures WHC-SD-EN-TI-306, "Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration" and that the above stated calibration coefficients are correct and applicable for tool N-2_097, effective Jan 25, 2013.

Signature: Date:

Jan 30, 2013

Russel Randall, PhD
Three Rivers Scientific

2013 N-2_097 Calibration Certificate

Moisture Calibration Extrapolation to 2.5 Inch Borehole
Instrument N-2_097

Jan 25, 2013

Moisture calibration was performed in the Hanford physical models. These standards have 6 and 8 inch ID casings. The Tank Farm Direct Push borehole is cased with a 2.5 inch OD iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.5 inch borehole diameter.

2.51" borehole
a = .0002184
α = 2.00

The undersigned certifies that the analysis files are archived in the file "N-2_097_2013.zip" was evaluated in accordance with Energy Solutions procedures and that the above stated calibration coefficients are correct and applicable for tool N-2_097, effective Jan 25, 2013.

Signature: Date:

Jan 30, 2013

Russel Randall, PhD
Three Rivers Scientific

2013 N-2_097 Calibration Certificate

Certificate of Depth Calibration

Unit ES-hoist1

Sep 15, 2012

Calibration data were taken at a test push on Energy Northwest property on Sep 15, 2012 for logging unit ES-hoist1. This calibration is the required yearly quality performance.

A standard steel tape was used to measure at selected depths into and out of the borehole, recording steel tape points and previous logging unit (computer generated) log depths. Standard encoder coefficient analysis results in a new value of depth coefficient.

The coefficient analysis is determined by the algorithm described in the Pacific Northwest Geophysics operating procedures. The depth encoder function is defined by

$$D = E * a$$

Where D is the depth in feet, E are the encoder pulses delivered to the computer unit. The coefficient, a, is the fit coefficient in units of pulses per foot. The new result for a is:

a=0.001304322

The previous coefficient was 0.001316801 for a change of nearly 1%. The rms of the new fit and the collected data is 0.18 inches over the 50 foot interval, both logging down and logging up to repeat the zero reference.

The undersigned certifies that the data archived in file "dep-ES-Sep-12.zip" were collected and evaluated in accordance with rigorous scientific principals and that the above stated calibration coefficient is correct and applicable for PNG-02 logging unit effective Sep 15, 2012.

Signature

Sep 16, 2012

Russel Randall, PhD

2012_ES-hoist1 Depth Calibration Certificate

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DIRECT PUSH GEOPHYSICAL LOGGING RESULTS

FROM

RPP-34643, Rev. 0, COMPLETION REPORT FOR SMALL DIAMETER SLANT-HOLE LOGGING AT THE 241-C-152 DIVERSION BOX

CH2M HILL DOCUMENT RELEASE FORM

(1) Document Number: RPP-34643	(2) Revision Number: 0	(3) Effective Date: Release Date	
(4) Document Type: ☐ Digital Image ☐ Hard copy ☑ PDF ☐ Video	(a) Number of pages (including the DRF) or number of digital images	22 jda 8/21	
(5) Release Type ☒ New ☐ Cancel	☐ Page Change	☐ Complete Revision	
(6) Document Title: SMALL DIAMETER SLANT-HOLE LOGGING AT THE C-152 DIVERSION BOX 241 jda 8/21			
(7) Change/Release Description: Initial Release			
(8) Change Justification: NA			
(9) Associated Structure, System, and Component (SSC) and Building Number:	(a) Structure Location: NA	(c) Building Number: NA	
	(b) System Designator: NA	(d) Equipment ID Number (EIN): NA	

(10) Impacted Documents:	(a) Document Type	(b) Document Number	(c) Document Revision
	NA	NA	NA

(11) Approvals:

(a) Author (Print/Sign): Harold Sydnor	Date: 08/15/07
(b) Responsible Manager (Print/Sign): John Kristofzski J G Field for JGK	Date: 08/15/07
(c) Reviewer (Optional, Print/Sign):	Date:
(d) Reviewer (Optional, Print/Sign):	Date:

(12) Distribution:

(a) Name	(b) MSIN	(a) Name	(b) MSIN
F.M. Mann	H6-03	R. Khaleel	E6-17
D.A. Myers	H6-03	J.R. Serne	P7-22
H.A. Sydnor	H6-03	J.M. Zachara	K8-96
Mike Connelly	H6-03	Randy Price	G1-62
K.D. Reynolds	G1-62	Jim Field	H6-03
M.I. Wood	H8-44	John Kristofzski	H6-03
V.J. Rohay	E6-44		

Release Stamp: AUG 21 2007 DATE: STA: 15 HANFORD RELEASE ID: 65

(13) Clearance	(a) Cleared for Public Release	(b) Restricted Information?	(c) Restriction Type:
	☑ Yes ☐ No	☐ Yes ☑ No	

(14) Clearance Review (Print/Sign): J. D. Aardal / Janis Aardal Date: 08/21/2007

A-6003-881 (05/05)

RPP 34643, Rev. 0

SMALL DIAMETER GEOPHYSICAL LOGGING AT THE 241-C-152 DIVERSION BOX

Russ Randall, PhD and Randall Price
CH2M Hill Hanford Group, Inc.
Richland, WA 99352
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Abstract: The report gives the gamma, neutron moisture and gyroscope results for 6 angled probe holes in 241-C Tank farm near diversion box 241-C-152.

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RPP-34643 Rev. 0

Small Diameter Slant-Hole Logging at the 241-C-152 Diversion Box

by

Russ Randall, Phd and Randall Price

to

Energy Solutions
345 Hills Street
Richland, Washington 99354

November 2006

Pacific Northwest Geophysics
4200 W 19th Avenue
Kennewick, Washington 99338

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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1.0 INTRODUCTION

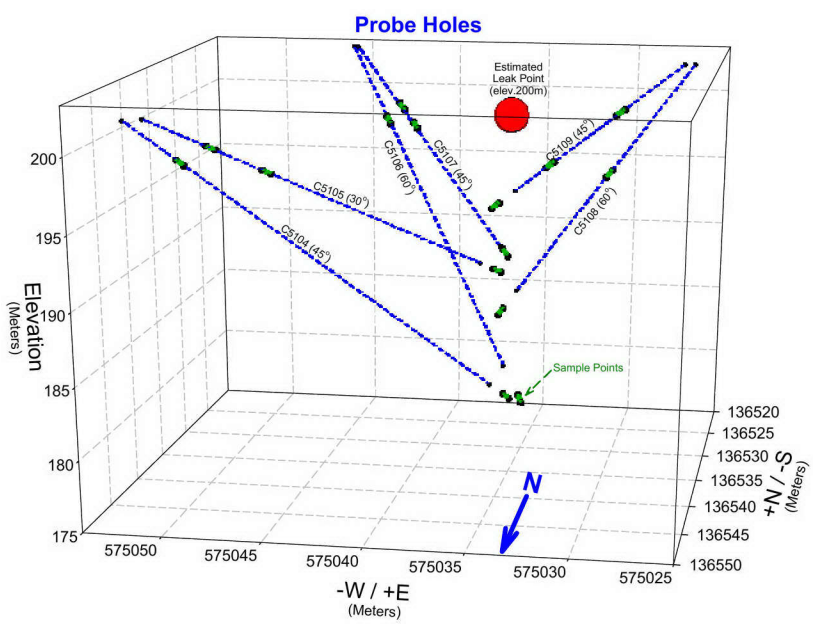
Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in support of slant-hole probing and sampling activities at the C-152 Diversion Box (C Tank Farm) to investigate the extent of subsurface contamination. Logging surveys were conducted with two detectors: NaI (scintillation) gross gamma and neutron moisture. This report presents the results of these surveys for the 6 slant holes installed at the investigation site. A 3-D view of the probe-hole locations (copied from the gyro survey report) shows the slant hole drive angle, probe direction, and sample locations (see Figure 1).

The NaI gross gamma and neutron moisture logging sondes were calibrated in their respective borehole calibration models and the calibrations were (1) either performed at, or (2) extrapolated to, the probe hole conditions present at the investigation site (see section 2.0).

Log surveys were recorded at various times during the drilling, to track the predicted sub-surface soil conditions, so that the target sample locations (depths) would be collected for laboratory analysis. All log intervals and repeats are presented on the same plot, they confirm the precision (repeatability) of the logging system.

The survey results for each probe hole are presented graphically as depth versus detector response (in Appendix A). The plots are in numeric order of the probe holes (C5104 – C5109). The appendix also includes a table that summarizes for each probe hole: survey dates, detector type, and survey depth range.

Figure 1. C-152 Slant Hole Locations, Drive Angle, and Direction



2.0 GEOPHYSICAL LOGGING SYSTEM

The small-diameter logging unit deployed to the investigation site, is a portable unit (i.e. mounted on a wagon). The system is powered by the on-site generator (120v AC). The system contains a laptop computer that monitors encoder depth positions, controls the winch motor, and records detector responses.

The NaI gamma and neutron moisture detectors contain their own signal processing/counting hardware and each respond directly to the laptop computer communication commands, this configuration enhances detector stability, simplifies system setup, and improves calibration by minimizing the travel distance of detector signals before conversion to digital mode.

2.1 GROSS GAMMA CALIBRATION AND SURVEYS

The gross gamma scintillation detector is a sodium-iodide (NaI) crystal. The NaI crystal (1-in. long) is hydroscopic and is enclosed in a hermetically sealed can (1-in. diameter) to maintain its integrity. Other components of the gamma detector are the high-voltage supply, photo-multiplier tube, pre-amp, and multi-channel analyzer. The settings of the detector components are fixed (i.e. set up during assembly, prior to calibration) and are not adjustable by the field-logging engineer. The detector gain and lower threshold are set to record gamma ray activity of energies between 100 and 3000 keV. By comparison, the highest gamma ray encountered during logging is from a naturally occurring radionuclide (thorium-232) and it occurs at 2614 keV. Coleman lantern mantles containing thorium-232 are used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (integrity) and energy calibration (amplifier gain).

The NaI detector is calibrated in Gross gamma borehole calibration models located at the U.S.-DOE Hanford site near Richland, Washington. Calibration was performed in the two most appropriate (lowest concentration) gross gamma calibration zones (SBA and SBU). The detector was covered with a 4-ft long section of the probe/drill tubing (0.37-inch thick). The calibration data are summarized in Table 1. The calibration units are pCi/g of equivalent Radium-226 (eRa-226). See Figure 2 for the calibration certificate.

Table 1. Gross Gamma Calibration Data

Calibration Model	Concentration eRa-226 (pCi/g)	Gross Gamma Response[1] (cps)	Dead-Time Corrected Gross Gamma Count-Rate[2] (cps)
SBA	61.2	476.0	477.8
SBU	186	1396.6	1412.7

1-Count rates are mean of 10 sample measurements at 100-sec each.

2-NaI Detector system dead time is 8.15 microsecond

Figure 2. Gross Gamma Calibration Certificate

Certificate of Calibration
SDGR-4N4-NaI1
July 7, 2005

Data were taken at the Hanford KUT models on July 7, 2005. SDGR-4N4-NaI1 is the designated Scintillator tool. Two models were used for the gross gamma calibration (SBU and SBA). Ten spectra were recorded for each model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation, for this analysis, refer to the compressed files: Gross.xls.

This calibration is required for the Direct Push logging, and it is funded by subcontract 013661.

The instrument was covered with 0.37 inch wall-thickness probe-tubing.

The coefficient analysis is determined by the algorithm described in WHC-SD-EN-TI-293, Rev. 0. The gross gamma calibration for equivalent ^{226}Ra in pCi/g is a regression function and is generally defined by:

$$\mathbf{Ra = a*GR + b}$$

Where Ra is the Eq. ^{226}Ra in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficients of a & b are the fit coefficients. A more physical relationship constrains the intercept (b) to a zero value. This computation yields improved response extrapolated to low concentrations of K, U, and Th (clean zones). The coefficients were determined to be:

$$\mathbf{a = .131\ Eq.^{226}Ra\ pCi/g\ /\ (c/s)}$$
$$\mathbf{b \equiv 0}$$

Digital files condensed as Cal_SD-GR-02_2005-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file “Cal_SD-GR-02_2005-v0.zip” were collected and evaluated in accordance with WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models* and that the above stated calibration coefficients are correct and applicable for the tool SDGR-4N4-NaI1 effective July 7, 2005.

Signature: Russel Randall PhD Date: July 8, 2005

Company: Three Rivers Scientific

The NaI gamma surveys were acquired at 3 ft/minute. A spectrum of 256 channels was collected each 0.5 feet from the bottom of the probe-hole to the surface. The spectra were recorded in Ortec PHA "-.chn" format with one spectra per file. Detector count rates were dead-time corrected and the gamma survey data was processed as gross gamma response to determine the concentration of equivalent Radium-226 (eRa-226) in pCi/g.

The dead time correction is a nonparalyzeable relationship (Knoll, 1979) and described by the following equation:

$$C_t = \frac{C_{obs}}{1 - \varepsilon \cdot C_{obs}}$$

where C_t is the true or dead time corrected count rate in c/s, C_{obs} is the observed count rate in c/s, and ε is the dead time factor of 8.25μs (Randall & Price, 2006).

Also, the NaI gross gamma detector was calibrated for eCs-137 (pCi/g) in addition to the primary calibration for eRa-226 (Randall & Price, 2005). The calibration for eCs-137 was to report elevated gamma count-rate zones in units commonly encountered in Hanford soils. Calibration for eCs-137 was performed in Hanford well 299-W10-72 (a standard identified by Stoller Corporations' logging group). The Cs-137 in the well is stable, except for the 30 year half life decay of the radio-isotope. Also, distribution of Cs-137 ranges from less than 1 pCi/g to 40,000 pCi/g along the depth of the well. The concentrations of Cs-137were established by two HPGe detectors (the 70% tool and the High Rate tool). The conversion factor from detector count rate (cps) to eCs-137 is 0.373 (pCi/g per cps) for casing thickness of 0.40-in.

2.2 NEUTRON-MOISTURE CALIBRATION AND SURVEYS

The neutron-moisture sonde combines the PNG-owned thermal-neutron detector and a DOE-owned sealed neutron source (50 mCi AmBe). The neutron source is an integral component of a neutron-moisture detector and calibration factors are tied-to each neutron source. The neutron source is identified by the tool serial number (H38068291).

The integrity of the sealed neutron source was always maintained when it was used in calibration activities and in probe hole logging activities. Source integrity was achieved by inserting the PNG owned neutron detector module into the housing containing the sealed neutron source, manufactured by Campbell Pacific Nuclear.

Calibration was performed in six borehole calibration models (Meisner & Randall, 1995). Three models have 6-in. hole-size and three models have 8-in hole-size. The moisture content of each model in a set of three borehole models is different (5, 12, or 20 percent by volume). The detector count rate in each of the six borehole calibration models is summarized in Table 2. The calibration certificate is shown in Figure 3.

Table 2. Moisture Calibration Data

Moisture Content Percent – volume fraction	6-inch Models* (cps)	8-inch Models* (cps)
5% vf	96.2	75.7
12% vf	142.7	106.5
20% vf	179.0	129.7

*Count rates are mean of 10 sample measurements at 60-sec each.

The probe holes size for this project was 2.51-inch. Therefore, the moisture calibration was extrapolated to the correct hole-size. The moisture calibration certificate for 2.51-in hole-size is shown in Figure 4.

The probe hole survey was collected at 1.5 ft/minute. Processing of the moisture survey data requires that the borehole survey data be normalized to the thickness of the steel casing present in the calibration models (0.325-in). Given that the probe hole casing thickness is 0.37-in, a correction factor of 1.055 is required to increase (normalize) the observed detector count rate to the conditions of the calibration model (Meisner, et al. 1996).

Figure 3. Moisture Calibration Certificate, Hole Size: 6-in. and 8-in.

Certificate of Calibration for Instrument SD-Moist291-2

June 6, 2005

On June 6, 2005 data were taken in the Moisture models for the SD-Moist291-2 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H38068291 was used with the passive neutron detector probe from PNG. This calibration is required for the Direct Push logging, and it is funded by subcontract 013661.

Six models were used for moisture calibration, three for 6-in. casing and three for 8-in. casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation (refer to the file Stats-moist.xls for this analysis).

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{a}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	**8" casing**
a = .0002069	a = .00008067
α = 2.210	α = 2.550

The undersigned certifies that the data archived in data file "SD-Moist291_2005.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-306 and that the above stated calibration coefficients are correct and applicable for tool SD-Moist291-2, effective June 6, 2005.

Signature: Date:

Russel Randall, PhD July 1, 2005
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, Hole Size 2.51-in.

Moisture Calibration Extrapolation to 2.51 Inch Borehole
Instrument SD-Moist291-2
June 6, 2005

Moisture calibration was performed in the Hanford physical models. These standards have 6-in. and 8-in. inside diameter (ID) casings. The Tank Farm Direct Push borehole is cased with a 2.51-in. outside diameter (OD) iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.51 inch borehole diameter.

2.51" borehole
a = .000343
α = 1.951

The undersigned certifies that the analysis files are archived in the file "SD-Moist291_2005.zip" which was evaluated in accordance with DTS procedures and that the above stated calibration coefficients are correct and applicable for tool SD-Moist291-2, effective June 6, 2005.

Signature: Date:

Russel Randall, PhD July 12, 2005
Three Rivers Scientific

3.0 CONCLUSION

Scintillation Gross Gamma and Neutron Moisture survey logs were collected in 6 slanted probe holes installed in the investigation site at the C-152 Diversion Box. All probe holes were pushed to their target depth. The survey results are presented in Appendix A and a 3D view of the probe-hole locations showing the drive angle and direction is shown in Figure 1.

The probe holes are paired as a consequence of their initial starting location, i.e. (C5104, C5105), (C5106, C5107), and (C5108, C5109). These paired holes may be examined together by overlaying the plots. The gamma activities in all probe holes indicate low activity, (count rate levels are at or near the natural background activity), except for C5109 which encountered one zone with elevated count rate. However, the moisture surveys show significant variations with depth. The paired probe holes have similar distribution profiles. Except for the pair (C5108, C5109) which show the most difference between the depth range (elevation): 194 to 199 meters.

The moisture content is higher near the surface and significantly dryer 6-meters below ground surface in all probe holes. The dry zones are where the probe holes extend below the protective barrier that was placed over the C-152 Diversion Box.

The moisture content changed between logging runs on three probe holes (C5106 at 198.7 meters), (C5108 at 196.67 meters), and (C5109 at 197 meters). In each of these three occasions, the moisture change is between log runs where a soil sample was collected. During sampling, the drive tubing was retrieved to extract the sample. The moisture change probably occurred when then the drive-tubing was re-inserted, which permitted materials in the subsurface to be moved around. The consistency of moisture content between log runs and soil sampling events may support discussions in support of the probe hole driving technique.

The survey results show that the soil samples were collected at subsurface locations where moisture transition content was transitioning from high to low.

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APPENDIX A: GAMMA SURVEY RESULTS

Gamma and Moisture Survey Plots follow for the 6 slant probe holes installed around the C-152 Diversion Box. The plots have two depth scales (y axis). (1) The vertical depth (elevation in meters) is presented on the left side of the plot. All plots have the same elevation depth range. (2) The measured distance along the slant hole (in feet) is presented on the right side of the plot.

Table 3 presents inclination and elevation information for each probe hole. Zero depth reference is at ground surface. Soil sample locations are shown on the plots as a wide green line connecting two black dots, one at the top and one at the bottom of the sample depths. Each probe hole was sampled at its maximum depth.

The neutron moisture survey results are presented in %-volume-fraction units, the plot scale is 0-25 %vf (green line). The plot scale for the gross gamma results are shifted to improve interpretation of the survey data and minimize overlap of the plotted curves, in zones with low moisture content (same for all plots). The gross gamma survey data were dead-time corrected and the results are converted to two calibration units

(1) Eq Ra-226 for natural radionuclides (concentrations less than 5 pCi/g), plot scale 1-26 pCi/g (blue line) and

(2) Eq Cs-137 for contamination zones (concentrations greater than 4 pCi/g), plot scale 0-100 pCi/g (red line). The scale is linear and only probe hole C5109 encountered gamma emitting contamination (greater than 5 pCi/g of eRa-226). No spectral gamma measurements were acquired.

Table 3. Slant Hole Inclination, Elevation at Ground Level, and True Vertical Depth

Hole	Inclination Angle (degrees) (90=vertical) (0=horizontal)	Sine (angle) Factor: TVD / Slant Hole	Elevation at Ground-Level (m)	Sample Max. Depth (Slant Hole ft)	Sample Vertical Depth (ft)	Sample Elevation Max Depth (m)
C5104	44	0.6947	201.76	110.5	76.76	178.36
C5105	31.5	0.5225	201.76	85	44.41	188.22
C5106	58	0.848	203.08	92	78.02	179.30
C5107	45.4	0.712	203.08	61	43.43	189.84
C5108	60.5	0.8704	203.15	68	59.18	185.11
C5109	45.4	0.712	203.19	47	33.47	192.99

Table 4. Probe Hole Survey Summary

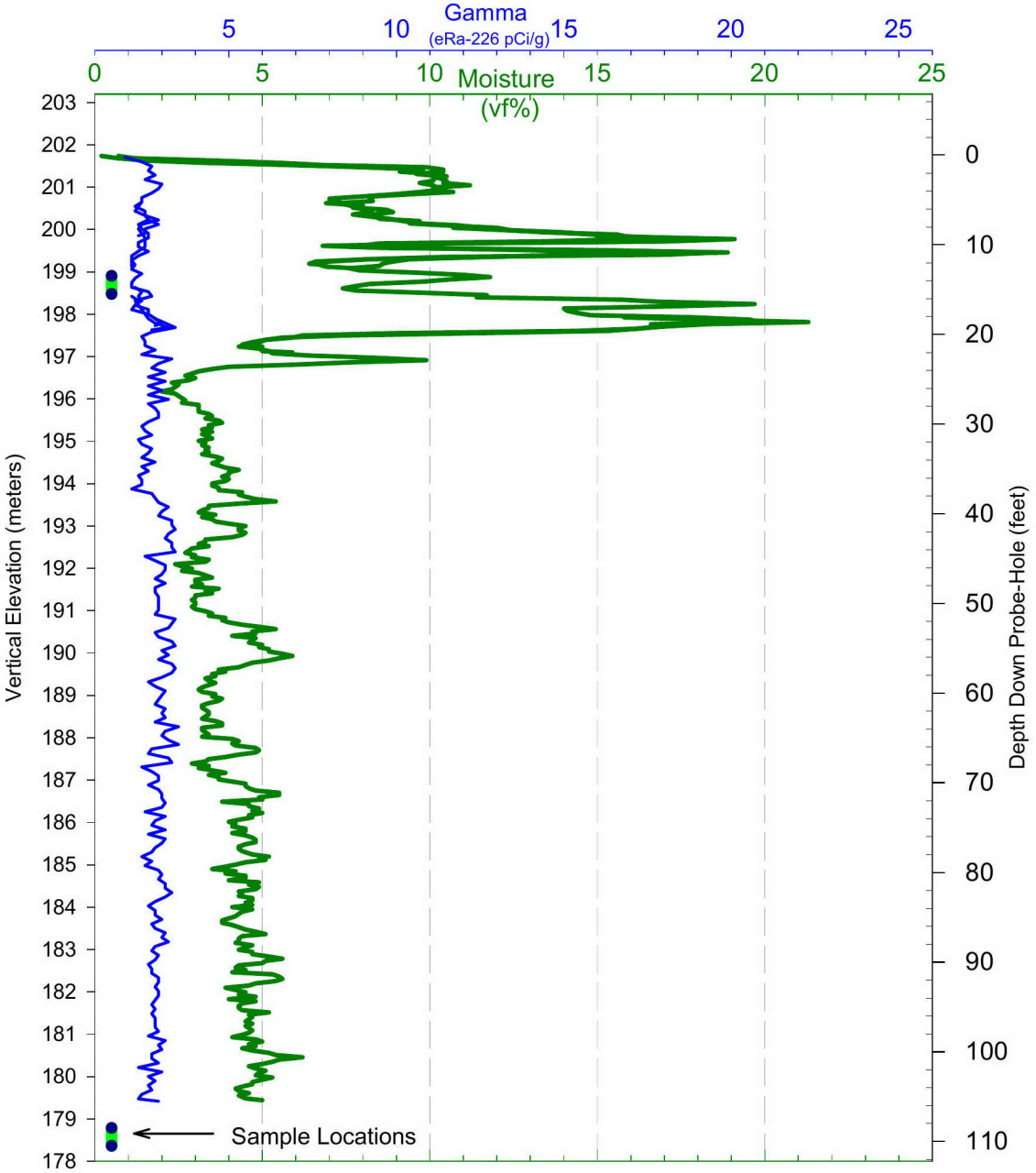
Probe Hole	Log Date	Gross Gamma	Moisture	Survey Bottom Depth	Survey Top Depth
C5104	5/2/2006		Moist	12.6	0.0
C5104	5/2/2006	Gamma		12.5	0.0
C5104	5/3/2006	Gamma		105.5	7.0
C5104	5/4/2006		Moist	105.4	0.0
C5105	5/23/2006	Gamma		12.0	0.0
C5105	5/26/2006	Gamma		25.3	8.0
C5105	5/30/2006	Gamma		79.0	19.0
C5105	6/1/2006		Moist	79.3	0.0
C5106	4/10/2006	Gamma		17.5	0.0
C5106	4/10/2006		Moist	17.8	0.0
C5106	4/12/2006		Moist	84.0	13.0
C5106	4/13/2006	Gamma		84.0	12.0
C5107	4/19/2006	Gamma		6.9	0.0
C5107	4/19/2006	Gamma		15.7	5.0
C5107	4/20/2006	Gamma		21.5	14.0
C5107	4/25/2006	Gamma		55.4	16.5
C5107	4/25/2006		Moist	55.5	0.0
C5108	3/21/2006		Moist	30.0	2.0
C5108	3/22/2006	Gamma		26.5	0.0
C5108	3/22/2006		Moist	26.4	0.5
C5108	3/27/2006	Gamma		63.5	16.0
C5108	3/28/2006		Moist	63.4	19.5
C5109	3/30/2006	Gamma		13.1	0.0
C5109	4/3/2006	Gamma		30.0	5.0
C5109	4/3/2006		Moist	30.0	0.0
C5109	4/5/2006	Gamma		41.7	25.0
C5109	4/5/2006		Moist	41.8	33.3

Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5104 (45-degrees)

Log Date: May 2006
Depth Ref: Ground Level

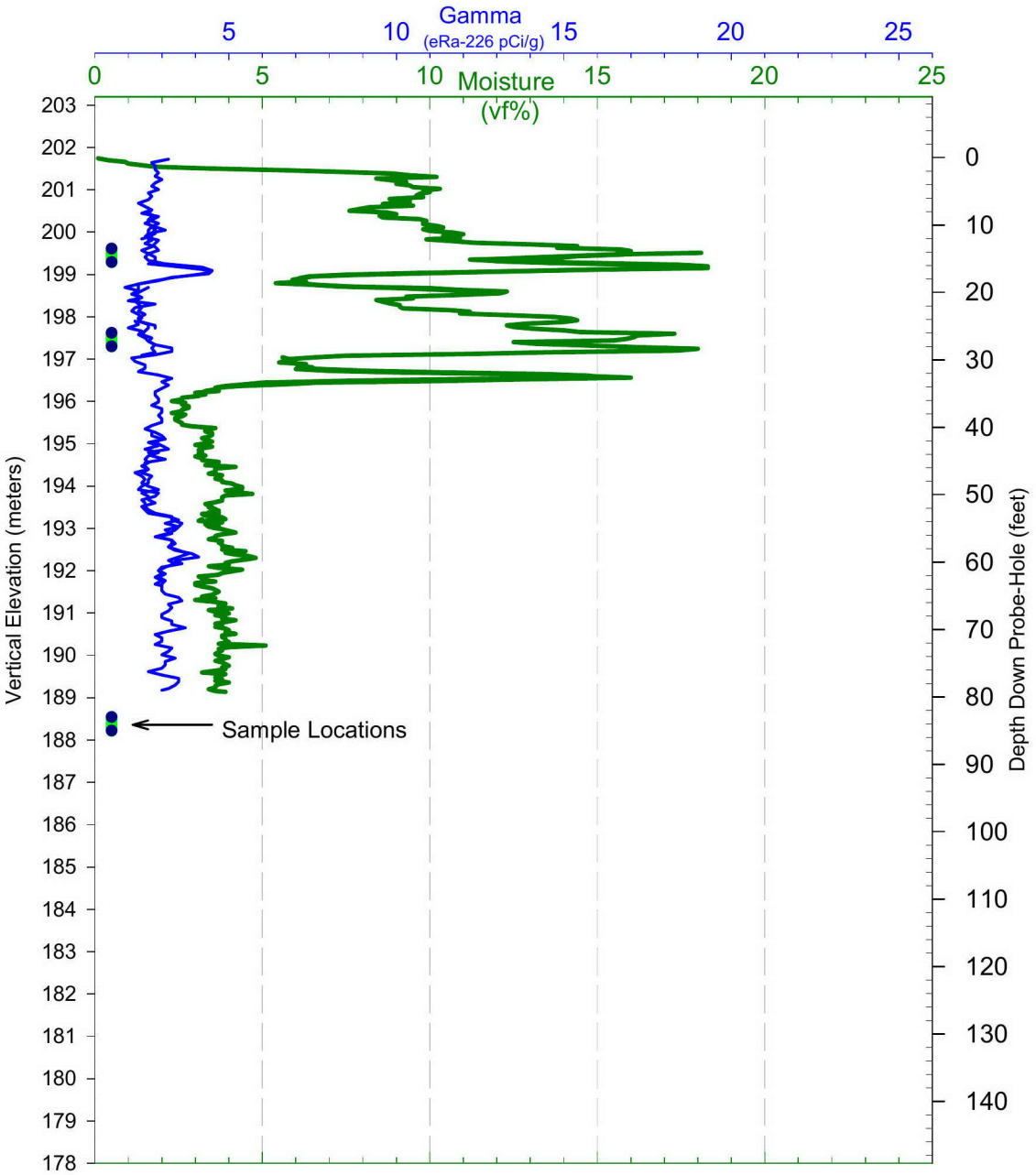


Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5105 (30-degrees)

Log Date: June 2006
Depth Ref: Ground Level

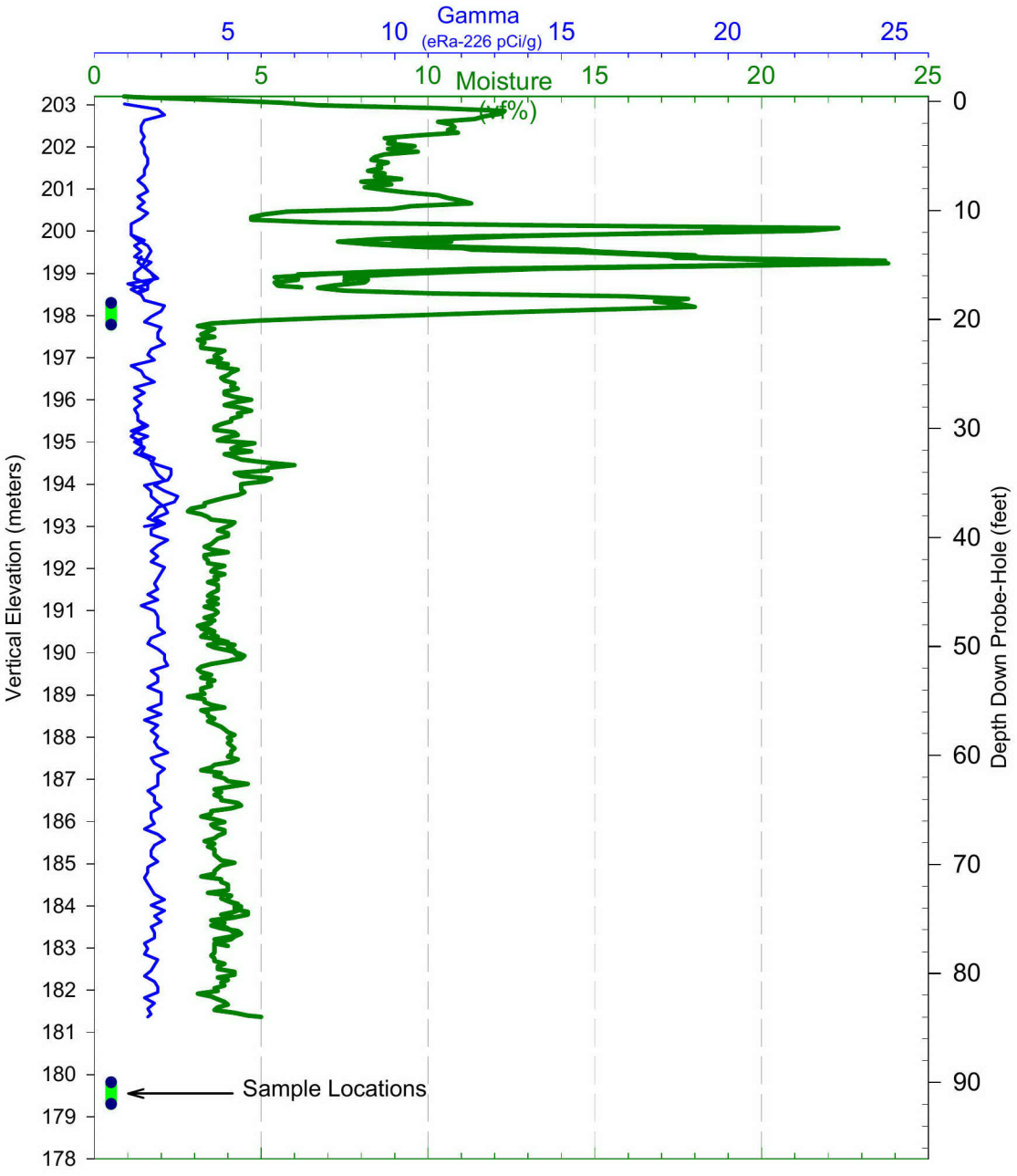


Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5106 (60-degrees)

Log Date: April 2006
Depth Ref: Ground Level

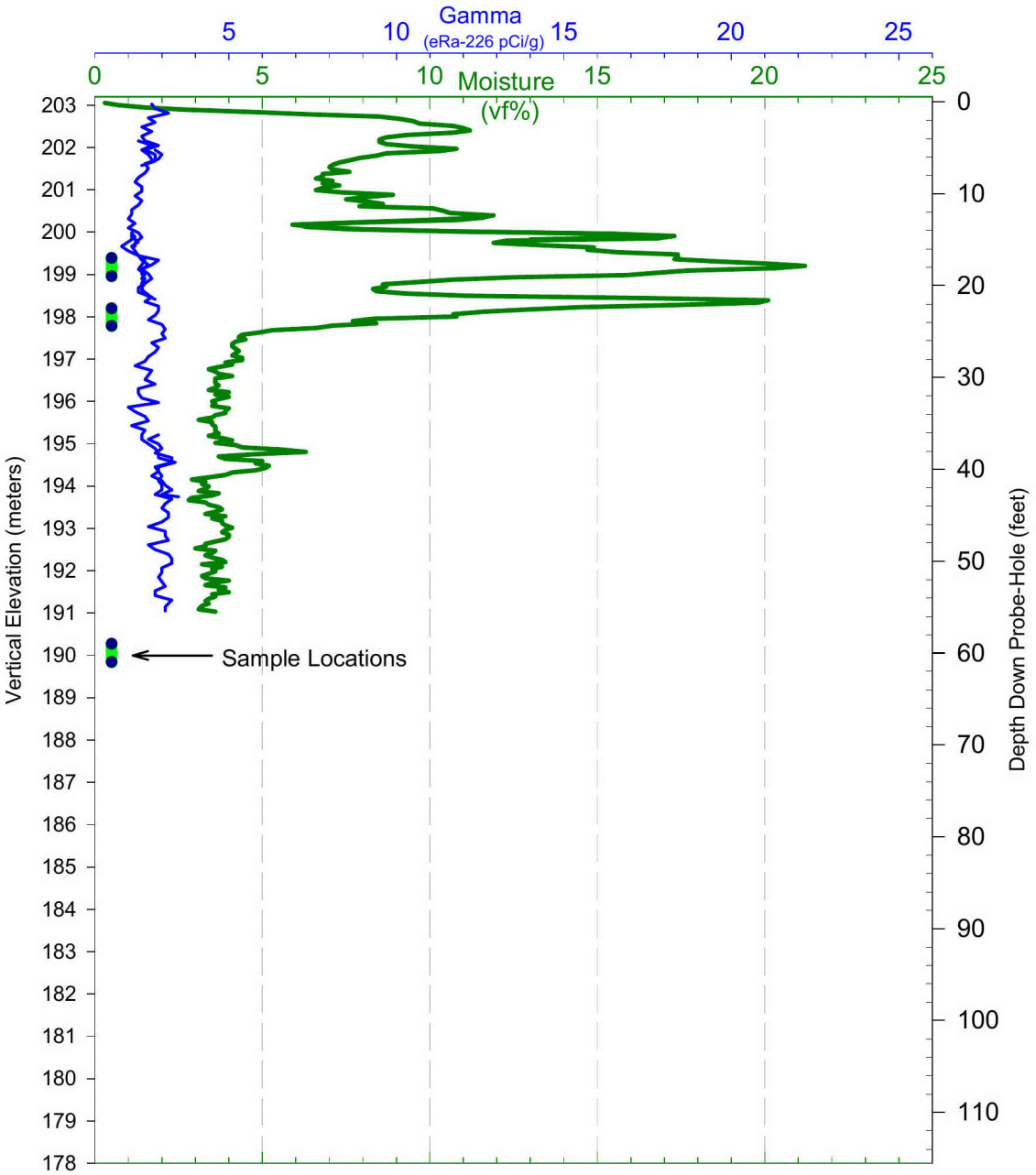


Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5107 (45-degrees)

Log Date: April 2006
Depth Ref: Ground Level

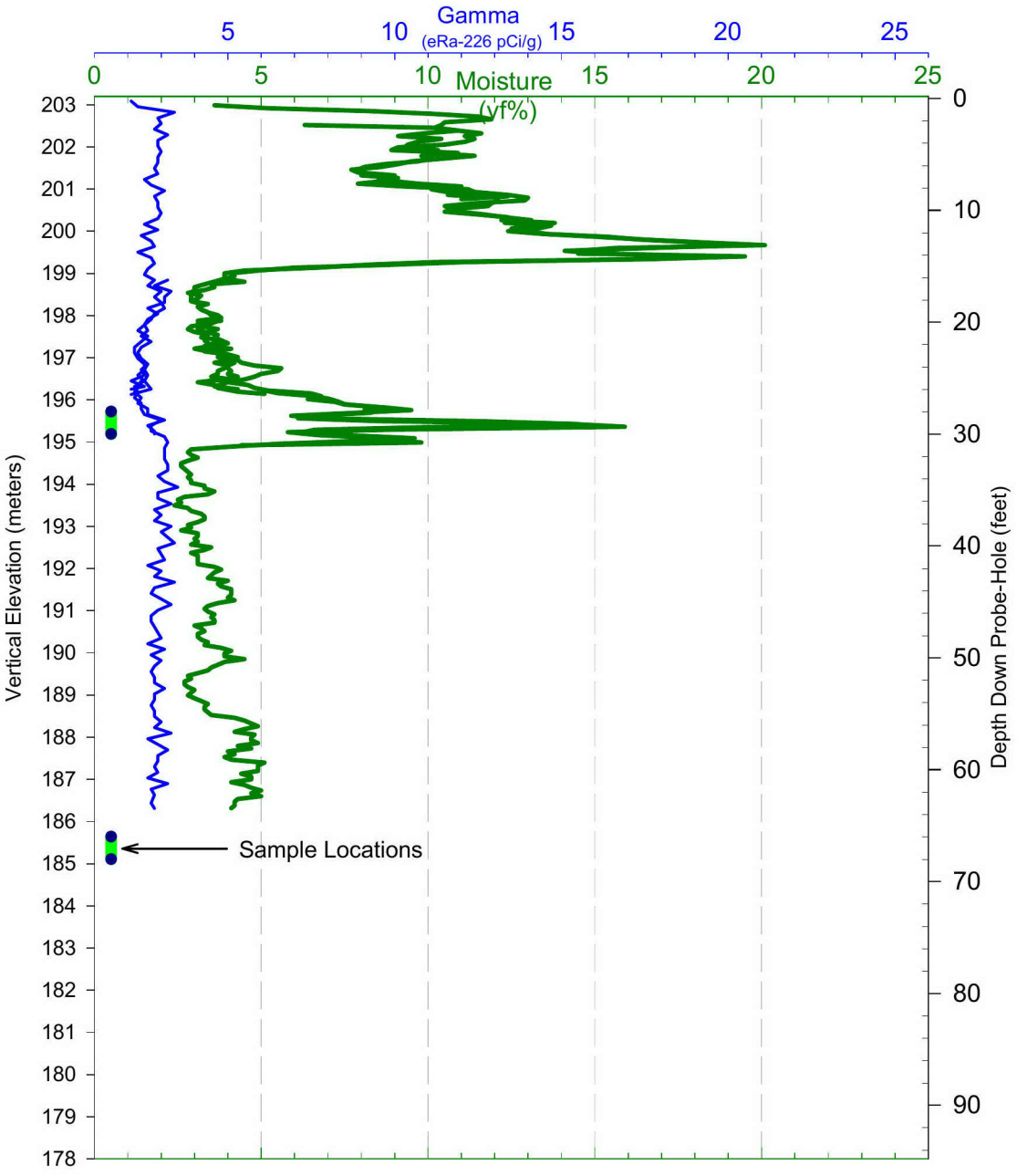


Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5108 (60-degrees)

Log Date: March 2006
Depth Ref: Ground Level



Small Diameter - Gamma & Moisture Survey

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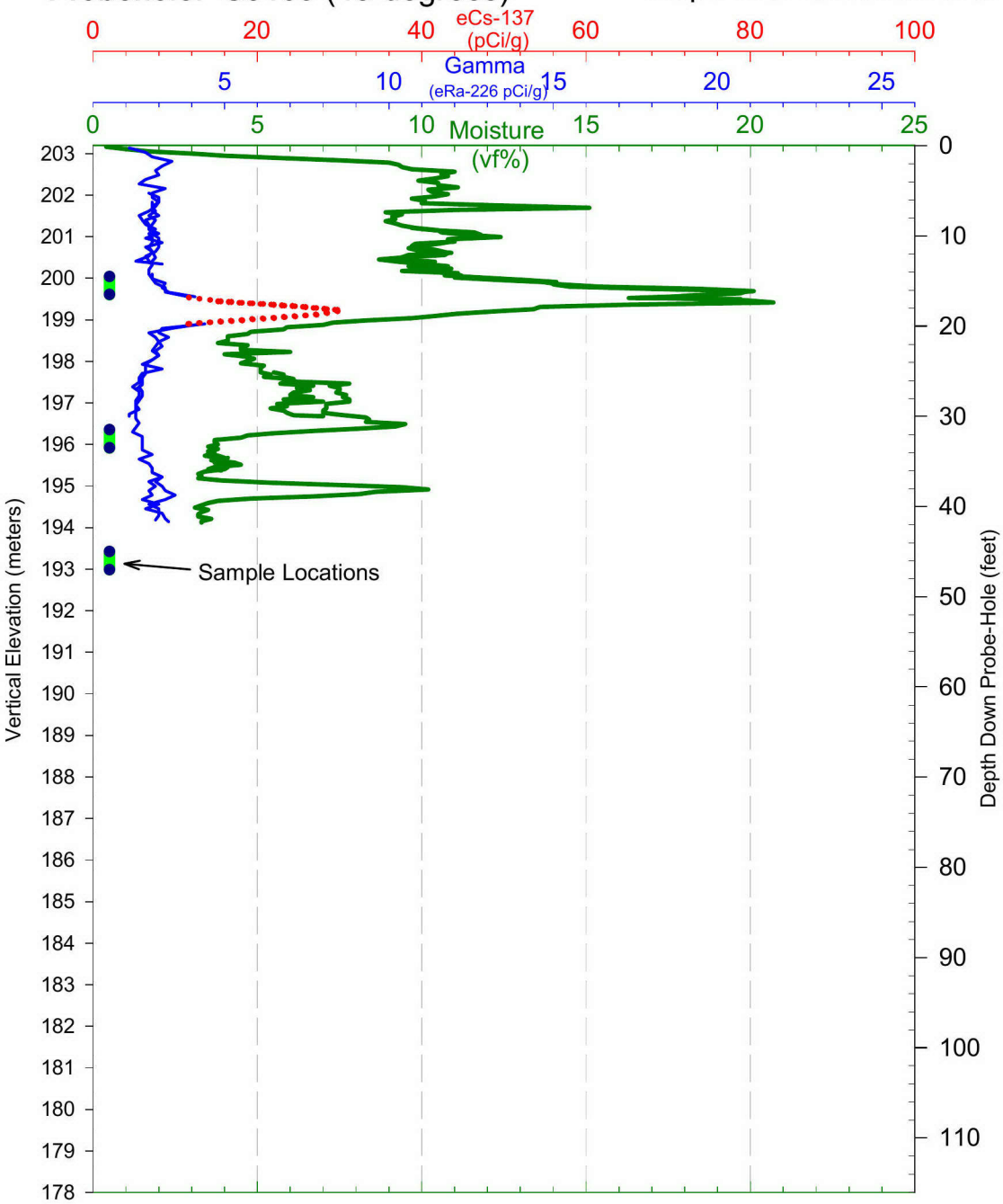
Project: Tank Farm C-152 | Log Date: April 2006

Probehole: C5109 (45-degrees) | Depth Ref: Ground Level



DIRECT PUSH GEOPHYSICAL LOGGING RESULTS

FROM

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CH2M HILL DOCUMENT RELEASE FORM

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Russ Randall, PhD and Randall Price
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Abstract: The report gives the gamma and neutron moisture logging results for 20 probe holes in 241-C Tank Farm near diversion box 241-C-152.

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Small Diameter Geophysical Logging At the 241-C-152 Diversion Box

by

Russ Randall, PhD and Randall Price

to

Duratek Technical Services
345 Hills Street
Richland, Washington 99354

September 2005

Pacific Northwest Geophysics
4200 W 19th Avenue
Kennewick, Washington 99338

Three Rivers Scientific
3740 Grant Court
West Richland, Washington 99353

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1.0 INTRODUCTION

To investigate the extent of subsurface contamination at the 241-C-152 Diversion Box, Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter (slim hole) logging in support of field activities. Logging surveys were conducted with three detectors: neutron-moisture (moisture gauge), gross gamma, and spectral gamma. The surveys assisted in identifying zones of interest for sample collection and laboratory analysis. This report includes the results of these surveys for the 20 probe holes installed around the investigation site.

Moisture surveys measure the distribution of moisture in the subsurface soils. Previous drilling and sampling programs have shown that contamination from liquid waste is more likely to be present in zones with high moisture content than in zones of low moisture content. The moisture content ranged from less than 5 to over 20 percent volume fraction moisture.

The main gamma-ray emitting constituent of the liquid waste that leaked from the 241-C-152 Diversion Box is Cesium-137. The objective of the gamma survey logs is to identify the presence of Cs-137 at concentrations greater than 10 pCi/g and to highlight high concentration zones that must be avoided for sample collections (RWP limiting condition of 100,000 DPM). Rapid scan gamma surveys (4 ft/minute) satisfy the Cs-137 detection threshold and the results are reported as gross gamma logs.

Through selected intervals in two probe holes, spectral gamma ray surveys were collected to identify the concentrations of the naturally occurring radionuclides.

Each logging unit (moisture, gross gamma, and spectral gamma) was calibrated for the probe hole conditions present at the investigation site (see section 0).

2.0 SURVEY RESULTS

Log surveys were recorded from the bottom of the probe hole (maximum survey depth) to the ground surface. Zero depth reference is at ground surface. A daily repeat measurement was acquired in at least one probe hole to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed and the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probe hole are presented as a plot in Appendix A. The plots are in numeric order of the probe holes (C4401 - C4447). Appendix A also contains a table that summarizes for each probe hole, the survey date, detector, maximum/minimum survey depth, and repeat intervals. Cesium-137 was not detected in any probe hole.

Unfortunately, the rapid scan gamma detector exhibited intermittent noise in the spectra on a few of the probe hole surveys. These data values were masked out in the final presentation and were replaced by an appropriate comment. Repeat logs in the holes were useful to confirm the background radioactive component of the formation. Repeat logs are presented with the main log runs, both agree within counting statistics, and confirm background activity of the subsurface formation.

3.0 GEOPHYSICAL LOGGING SYSTEM

Three small-diameter logging units were deployed to the investigation site. The logging systems were portable units (i.e. mounted on a wagon) powered by a 120v AC electrical cord connected to the on-site generator. A laptop computer allocated to each logging unit was used to monitor encoder depth positions, control the winch motor, and record detector responses.

The moisture and gross gamma (NaI) detectors are more advanced than the older spectral gamma (BGO) system. The older BGO sonde transmits each detector response as an analog (voltage) pulse through the logging cable to the up-hole amplifier and multi-channel-analyzer (MCA).

The more advanced moisture and NaI gamma detectors are connected to their own multi-channel analyzers that are installed in the small diameter logging sonde. Detector responses are converted to digital format within the logging tool, which significantly improves system stability. These two detectors are interchangeable between the two winch units because digital detector responses are not influenced by up-hole logging equipment (winch motor, depth encoder, etc.).

3.1 NEUTRON-MOISTURE CALIBRATION AND SURVEYS

The neutron-moisture sonde combines the PNG-owned thermal-neutron detector and a DOE-owned sealed neutron source (50 mCi AmBe). The DOE-owned neutron source was used because it was already on the Hanford site and was managed by the DOE radiation management program. The neutron source is an integral component of a neutron-moisture detector, manufactured by Campbell Pacific Nuclear. The neutron source is identified by the tool serial number (H38068291).

The integrity of the sealed neutron source was always maintained when it was used in calibration activities and in probe hole logging activities. Source integrity was achieved by inserting the PNG owned neutron detector module into the housing containing the sealed neutron source.

Calibration was performed in six borehole calibration models (Meisner & Randall, 1995). Three models have 6-in. hole-size and three models have 8-in hole-size. The moisture content of each model in a set of three borehole models is different (5, 12, or 20 percent by volume). The detector count rate in each of the six borehole calibration models is summarized in Table 1. The calibration certificate is shown in Figure 1.

The probe holes size for this project was 2.51-inch. Therefore, the moisture calibration was extrapolated to the correct hole-size. The moisture calibration certificate for 2.51-in hole-size is shown in Figure 2.

Table 1. Moisture Calibration Data

Moisture Content Percent – volume fraction	6-inch Models* (cps)	8-inch Models* (cps)
5% vf	96.2	75.7
12% vf	142.7	106.5
20% vf	179.0	129.7

*Count rates are mean of 10 sample measurements at 60-sec each.

The probe hole survey was collected at 1 ft/minute. Processing of the moisture survey data requires that the borehole survey data be normalized to the thickness of the steel casing present in the calibration models (0.325-in). Given that the probe hole casing thickness is 0.37-in, a correction factor of 1.055 is required to increase (normalize) the observed detector count rate to the conditions of the calibration model (Meisner, et al. 1996).

3.2 GROSS GAMMA CALIBRATION AND SURVEYS

The gross gamma scintillation detector is a sodium-iodide (NaI) crystal. The NaI crystal (1-in. long) is hydroscopic and is enclosed in a hermetically sealed can (1-in. diameter) to maintain its integrity. Other components of the gamma detector are the high-voltage supply, photo-multiplier tube, pre-amp, and multi-channel analyzer. The settings of the detector components are fixed (i.e. set up during assembly, prior to calibration) and are not adjustable by the field-logging engineer. The detector gain and lower threshold are set to record gamma ray activity with energies between 100 and 3000 keV. By comparison, the highest gamma ray from naturally occurring radionuclides is from thorium-232 and it occurs at 2614 keV. Coleman lantern mantles containing thorium-232 are used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (integrity) and energy calibration (amplifier gain).

Figure 1. Moisture Calibration Certificate, Hole Size: 6-in. and 8-in.

Certificate of Calibration for Instrument SD-Moist291-2

June 6, 2005

On June 6, 2005 data were taken in the Moisture models for the SD-Moist291-2 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H38068291 was used with the passive neutron detector probe from PNG. This calibration is required for the Direct Push logging, and it is funded by subcontract 013661.

Six models were used for moisture calibration, three for 6-in. casing and three for 8-in. casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation (refer to the file Stats-moist.xls for this analysis).

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{a}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	**8" casing**
a = .0002069	a = .00008067
α = 2.210	α = 2.550

The undersigned certifies that the data archived in data file "SD-Moist291_2005.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-306 and that the above stated calibration coefficients are correct and applicable for tool SD-Moist291-2, effective June 6, 2005.

Signature: Date:

Russel Randall, PhD July 1, 2005
Three Rivers Scientific

Figure 2. Moisture Calibration Certificate, Hole Size 2.51-in.

Moisture Calibration Extrapolation to 2.51 Inch Borehole
Instrument SD-Moist291-2
June 6, 2005

Moisture calibration was performed in the Hanford physical models. These standards have 6-in. and 8-in. inside diameter (ID) casings. The Tank Farm Direct Push borehole is cased with a 2.51-in. outside diameter (OD) iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.51 inch borehole diameter.

2.51" borehole
a = .000343
α = 1.951

The undersigned certifies that the analysis files are archived in the file "SD-Moist291_2005.zip" which was evaluated in accordance with DTS procedures and that the above stated calibration coefficients are correct and applicable for tool SD-Moist291-2, effective June 6, 2005.

Signature: Date:

Russel Randall, PhD July 12, 2005
Three Rivers Scientific

The NaI detector is calibrated in Gross gamma borehole calibration models located at the U.S.-DOE Hanford site near Richland, Washington. Calibration was performed in the two most appropriate (lowest concentration) gross gamma calibration zones (SBA and SBU). The detector was covered with a 4-ft long section of the probe/drill tubing (0.37-inch thick). The calibration data are summarized in Table 2. The calibration units are pCi/g of equivalent Radium-226 (eRa-226). See Figure 3 for the calibration certificate.

Table 2. Gross Gamma Calibration Data

Calibration Model	Concentration eRa-226 (pCi/g)	Gross Gamma Response[1] (cps)	Dead-Time Corrected Gross Gamma Count-Rate[2] (cps)
SBA	61.2	476.0	477.8
SBU	186	1396.6	1412.7

1-Count rates are mean of 10 sample measurements at 100-sec each.

2-NaI Detector system dead time is 8.15 microsecond

The NaI gamma surveys were logged at 4 ft/minute. A spectrum of 256 channels was collected each 0.5 feet from the bottom of the probe-hole to the surface. The spectra were recorded in Ortec PHA "-.chn" format with one spectra per file. Detector count rates were dead-time corrected and the gamma survey data was processed as gross gamma response to determine the concentration of equivalent Radium-226 (eRa-226) in pCi/g.

The dead time correction is a nonparalysable relationship (Knoll, 1979) and described by the following equation:

$$C_t = \frac{C_{obs}}{1 - \varepsilon \cdot C_{obs}}$$

where C_t is the true or dead time corrected count rate in c/s, C_{obs} is the observed count rate in c/s, and ε is the dead time factor of 8.15μs (Randall & Price, 2005).

Also, the NaI gross gamma detector was calibrated for eCs-137 (pCi/g) in addition to the primary calibration for eRa-226. The calibration for eCs-137 was to identify high concentration zones that must be avoided for sample collection (i.e. RWP limiting condition of 100,000 DPM). Calibration for eCs-137 was performed in Hanford well 299-W10-72 (a new standard proposed by Stoller Corporations' logging group). The distribution of Cs-137 varied along the depth of the well, therefore, the concentrations were established by two HPGe detectors (the 70% tool and the High Rate tool). The conversion factor from detector count rate (cps) to eCs-137 is 0.373 (pCi/g per cps) for casing thickness 0.40-in.

Figure 3. Gross Gamma Calibration Certificate

Certificate of Calibration
SDGR-4N4-NaI1
July 7, 2005

Data were taken at the Hanford KUT models on July 7, 2005. SDGR-4N4-NaI1 is the designated Scintillator tool. Two models were used for the gross gamma calibration (SBU and SBA). Ten spectra were recorded for each model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation, for this analysis, refer to the compressed files: Gross.xls.

This calibration is required for the Direct Push logging, and it is funded by subcontract 013661.

The instrument was covered with 0.37 inch wall-thickness probe-tubing.

The coefficient analysis is determined by the algorithm described in WHC-SD-EN-TI-293, Rev. 0. The gross gamma calibration for equivalent ^{226}Ra in pCi/g is a regression function and is generally defined by:

$$\mathbf{Ra = a*GR + b}$$

Where Ra is the Eq. ^{226}Ra in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficients of a & b are the fit coefficients. A more physical relationship constrains the intercept (b) to a zero value. This computation yields improved response extrapolated to low concentrations of K, U, and Th (clean zones). The coefficients were determined to be:

$$\mathbf{a = .131\ \ Eq.^{226}Ra\ pCi/g\ /\ (c/s)}$$
$$\mathbf{b \equiv 0}$$

Digital files condensed as Cal_SD-GR-02_2005-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file “Cal_SD-GR-02_2005-v0.zip” were collected and evaluated in accordance with WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models* and that the above stated calibration coefficients are correct and applicable for the tool SDGR-4N4-NaI1 effective July 7, 2005.

Signature: Russel Randall PhD Date: July 8, 2005

Company: Three Rivers Scientific

The NaI gamma detector upper limit for identifying samples that will not exceed the RWP with the HPT survey instruments is estimated as follows:

Given:

a. The background activity 50 CPM = 500 DPM with the HPT survey meter (in a zone with no contamination at the surface).
b. The RWP limit is 100,000 DPM = 10,000 CPM with the HPT survey meter (200 times above background of 50 CPM).
c. The background activity is 25 cps with the 1x1-inch NaI Gamma detector in the 0.37-inch thick steel probe-hole casing.

Therefore: The suggested limit on the NaI gamma detector for avoiding samples that exceed 100,000 DPM is 25 * 200 = 5000 cps (dead time corrected) or 4800 cps (observed) count rate (conservative upper limit). Using the eCs-137 conversion factor (0.373 pCi/g per cps) this translates to about 1900 pCi/g of Cs-137.

3.3 SPECTRAL GAMMA CALIBRATION AND SURVEYS

Calibration of the BGO logging system was performed in the four spectral gamma borehole calibration models located at the U.S.-DOE Hanford Site near Richland, Washington and according to Hanford Site procedures for scintillation type spectral gamma ray borehole detectors (Randall & Stromswold, 1995). The four calibration models contain elevated concentrations of the naturally occurring radionuclides (potassium, uranium or radium in secular equilibrium with uranium, and thorium, aka KUT). The radionuclide concentrations are traceable to NIST standards, (Steele & George, 1986). Table 3 lists the radionuclide concentration in each of the gamma calibration models. The uncertainty is quoted at the 2-sigma (95%) confidence level.

Table 3. Hanford Calibration Model Values for KUT

Model	^{40}K Concentration (pCi/g)	^{226}Ra Concentration (pCi/g)	^{232}Th Concentration (pCi/g)
SBK	53.50 ± 1.67	1.16 ± 0.11	0.11 ± 0.02
SBU	10.72 ± 0.84	190.52 ± 5.81	0.66 ± 0.06
SBT	10.63 ± 1.34	10.02 ± 0.48	58.11 ± 1.44
SBM	41.78 ± 1.84	125.79 ± 4.00	39.12 ± 1.07

Calibration was performed with a section of the steel drill tubing (4-ft long) 0.37-in. thick (2.5-in. OD) installed over detector (4-in. long) during calibration measurements. Calibration with the casing installed over the detector is more rigorous than calibration with open hole and

applying casing correction to the probe hole survey to correct for the presence of casing. See Figure 4 for the spectral gamma Calibration Certificate.

During logging the gamma peak at 1461 keV from potassium (K-40) is almost always present as the dominant peak in each spectra and is used to monitor for spectra gain changes. During data processing the spectra gain is adjusted to track the reference gamma peak.

Borehole survey spectra (200 seconds each) were measured each 0.5 feet between the selected depth intervals in two probe holes (C4409 and C4417) in move-stop-acquire logging mode and the results are presented in Appendix B.

Figure 4. Spectral Gamma Calibration Certificate

Certificate of Calibration
SDGR.02
July 7, 2005

Data were taken at the Hanford KUT models on July 7, 2005. SDGR.02 is the designated Scintillator tool. Four models were used for Spectral KUT calibration. Ten spectra were recorded for each model in order to perform statistical analysis. The observed statistical deviations were seen to be within the theoretically predicted variation, for this analysis, refer to the compressed file: AveOut.XLS. The instrument was covered with 0.37 inch wall thickness probe tubing.

This calibration is required for the Direct Push logging, and it is funded by subcontract 013661.

The algorithm described in WHC-SD-EN-TI-293, Rev. 0, determines the coefficient analysis. Three energy windows are used for each potassium, uranium and thorium (K U & T), and these are:

K: 1320-1575 keV **U: 1650-2390 keV** **T: 2475-2765 keV**

The concentration for each of the three elements is a linear combination of the count rates in the three windows. The resulting coefficients for each of the three elements are:

Concentration-K =	**3.472*K**	**-2.916*U**	**2.146*T**
Concentration-U =	**-0.0086*K**	**1.071*U**	**-1.931*T**
Concentration-T =	**-0.00099*K**	**-0.035*U**	**1.433*T**

Where K U & T are the count rates (c/s) in the listed energy windows and the resulting concentration values are in pCi/g.

Digital files condensed as Cal_SD-GR-02_2005-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file “Cal_SD-GR-02_2005-v0.zip” were collected and evaluated in accordance with WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models* and that the above stated calibration coefficients are correct and applicable for the tool SDGR.02 effective July 7, 2005.

Signature: Russel Randall, PhD Date: September 8, 2005

4.0 CONCLUSION

Neutron-Moisture and Passive Gross Gamma survey logs were collected in 20 probe holes installed around the 241-C-152 Diversion Box. All probe holes were pushed to their target depth, none were aborted because of refusal to advance. Nine of the probe holes were pushed to approximately 30 feet in depth, the remaining eleven holes were pushed to approximately 60 feet in depth.

The moisture surveys identified several zones typically above 30 feet with moisture content greater then 10 %vf, many were very thin zones with moisture content greater than 20 %vf. The moisture content below 30 feet is typically less than 8 %vf, except for one zone in C4431 at 37-ft that approaches 9 %vf.

The rapid-scan gamma surveys encountered only background activity from the natural radionuclides. No surveys encountered Cs-137 or any other anthropogenic radionuclide at concentrations approaching the targeted minimum detection threshold of 10 pCi/g.

Spectral gamma surveys were acquired in selected depth intervals in two probe holes (C4409 and C4417). The survey depth interval was selected to span a transition in the gamma response and moisture content. Changes in concentration of potassium and thorium were measured with each survey. Unfortunately, the variations in concentration of uranium in the formation are less than the precision of the logging measurement.

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APPENDIX A: MOISTURE AND GROSS GAMMA SURVEYS

Moisture and Gross Gamma Survey Plots follow for the 20 probe holes installed around the 241-C-152 Diversion Box. The gamma survey results are plotted with the scale of 0-25 pCi/g for some probe holes and the scale is 1-26 pCi/g for other probe holes. The scale was changed (adjusted) to prevent confusion from overlap with moisture results.

Table 4. Probe Hole Survey Summary

Probe Hole	Log Date	Detector	Max Depth (ft)	Min Depth (ft)	Repeat Zone(s) (ft)	Comment
C4401	11/1/2004	BGO Gamma	60	0		
C4401	11/1/2004	Moisture	60	0		
C4403	7/7/2005	Moisture	58.6	0		
C4403	7/14/2005	Gross Gamma	58.7	1	38-35	
C4405	7/7/2005	Moisture	30.4	0		Depth increment 0.5 ft
C4405	7/11/2005	Moisture	30.2	0.25		Depth increment 0.25 ft
C4405	7/14/2005	Gross Gamma	31	1	14-11	
C4407	7/12/2005	Moisture	59.2	0.25		
C4407	7/14/2005	Gross Gamma	58.7	1	13-9	
C4409	7/12/2005	Gross Gamma	30.7	1		
C4409	7/12/2005	Moisture	30.7	0.25	26-22	
C4409	7/25/2005	Spectral Gamma	30	21	23.5-25	
C4411	7/14/2005	Gross Gamma	66	1	26-20	
C4411	7/15/2005	Moisture	66.2	1	15-9	
C4413	7/15/2005	Gross Gamma	30.4	0.5	16-8	
C4413	7/15/2005	Moisture	30.5	1	16-11	
C4415	7/15/2005	Gross Gamma	58.3	1	32-28	
C4415	7/19/2005	Moisture	58.1	1	17-13	
C4417	7/15/2005	Gross Gamma	58	1	20-14	
C4417	7/19/2005	Moisture	58.6	1	19-14	
C4417	7/26/2005	Spectral Gamma	20	14	16.5-15.5	
C4419	7/19/2005	Gross Gamma	57.5	1	35-30	

Table 4. Probe Hole Survey Summary

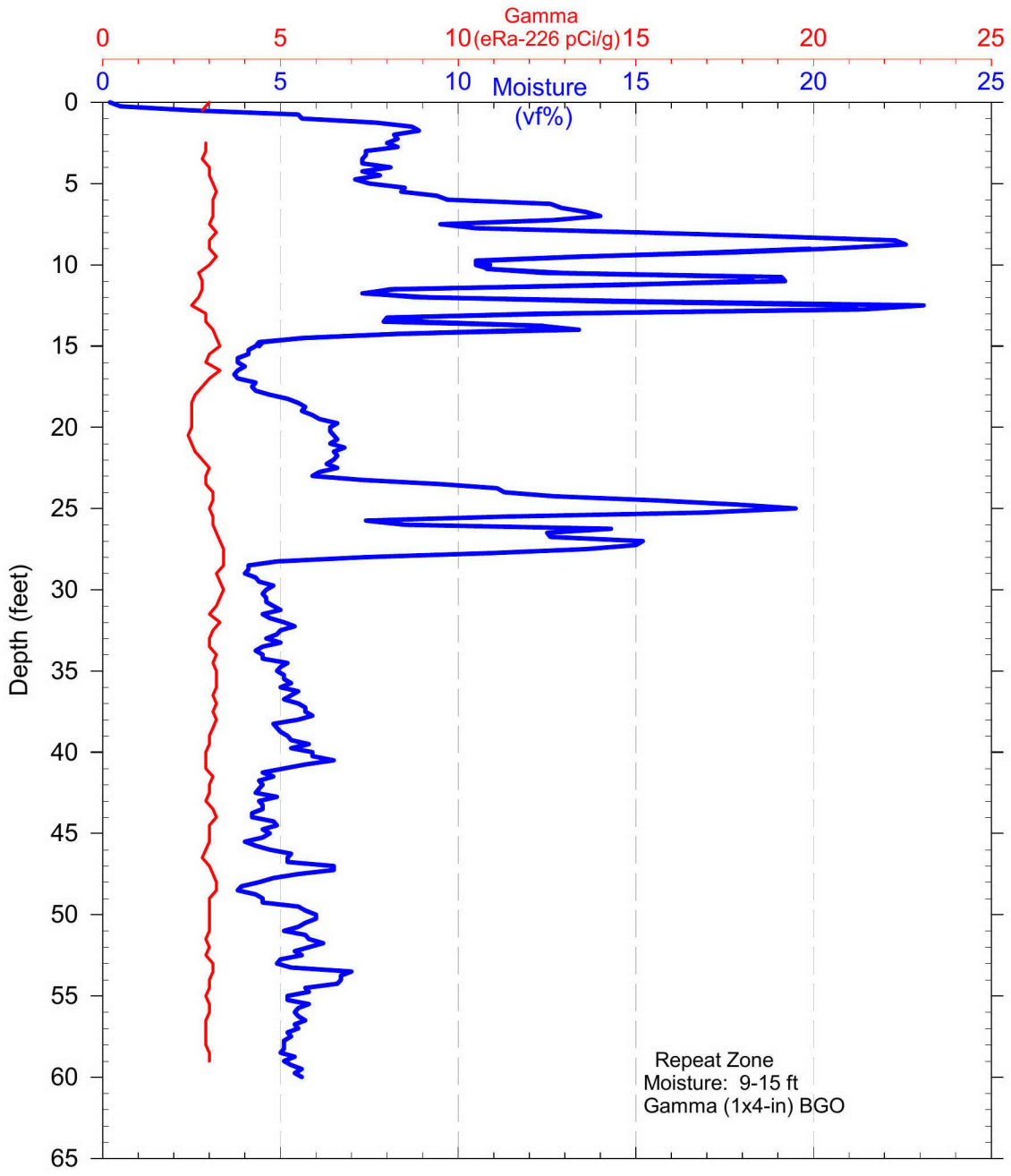
Probe Hole	Log Date	Detector	Max Depth (ft)	Min Depth (ft)	Repeat Zone(s) (ft)	Comment
C4419	7/21/2005	Moisture	57.5	1	19-14	
C4421	7/19/2005	Gross Gamma	58.1	1	22-18, 25-12	
C4421	7/21/2005	Moisture	58	15		
C4421	7/22/2005	Moisture	21	0	9-5.5	Complete Survey (next day)
C4425	8/18/2005	Gross Gamma	30	0.5	10.5-7	
C4425	8/19/2005	Moisture	30	0.5	8.5-5.5	
C4427	8/24/2005	Gross Gamma	32	0.5		Intermittent Noise
C4427	8/29/2005	Gross Gamma	32	0.5	32-22	Intermittent Noise
C4427	8/25/2005	Moisture	32	0.5		
C4429	8/16/2005	Moisture	58	0.5	5.5-3.5	
C4429	8/17/2005	Gross Gamma	58	0.5		
C4431	8/25/2005	Moisture	59	0.5	8.5-4	
C4431	8/29/2005	Gross Gamma	59	0.5	26-20	
C4433	8/16/2005	Moisture	31	0.5	13.5-11	
C4433	8/18/2005	Gross Gamma	32	0.5	18.5-14	
C4435	8/18/2005	Gross Gamma	32	0.5	19.5-14	
C4435	8/19/2005	Moisture	32	0.5	14.25-10.75	
C4437	8/17/2005	Moisture	59	9.5		
C4437	8/19/2005	Moisture	13.25	0.5		
C4437	8/18/2005	Gross Gamma	59	0.5	18.5-12	
C4439	8/17/2005	Moisture	32	0.5	19-16	
C4439	8/18/2005	Gross Gamma	32	0.5	20-10	
C4447	8/24/2005	Gross Gamma	27	0.5	27-1, 27-1, 27-1	Intermittent Noise
C4447	8/24/2005	Gross Gamma	23	0.5	23-0.5	Intermittent Noise
C4447	8/29/2005	Gross Gamma	27	0.5	15-5, 20-0.5	
C4447	8/25/2005	Moisture	27	0.5	11-5	

Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4401

Log Date: Nov 2004
Depth Ref: Ground Level

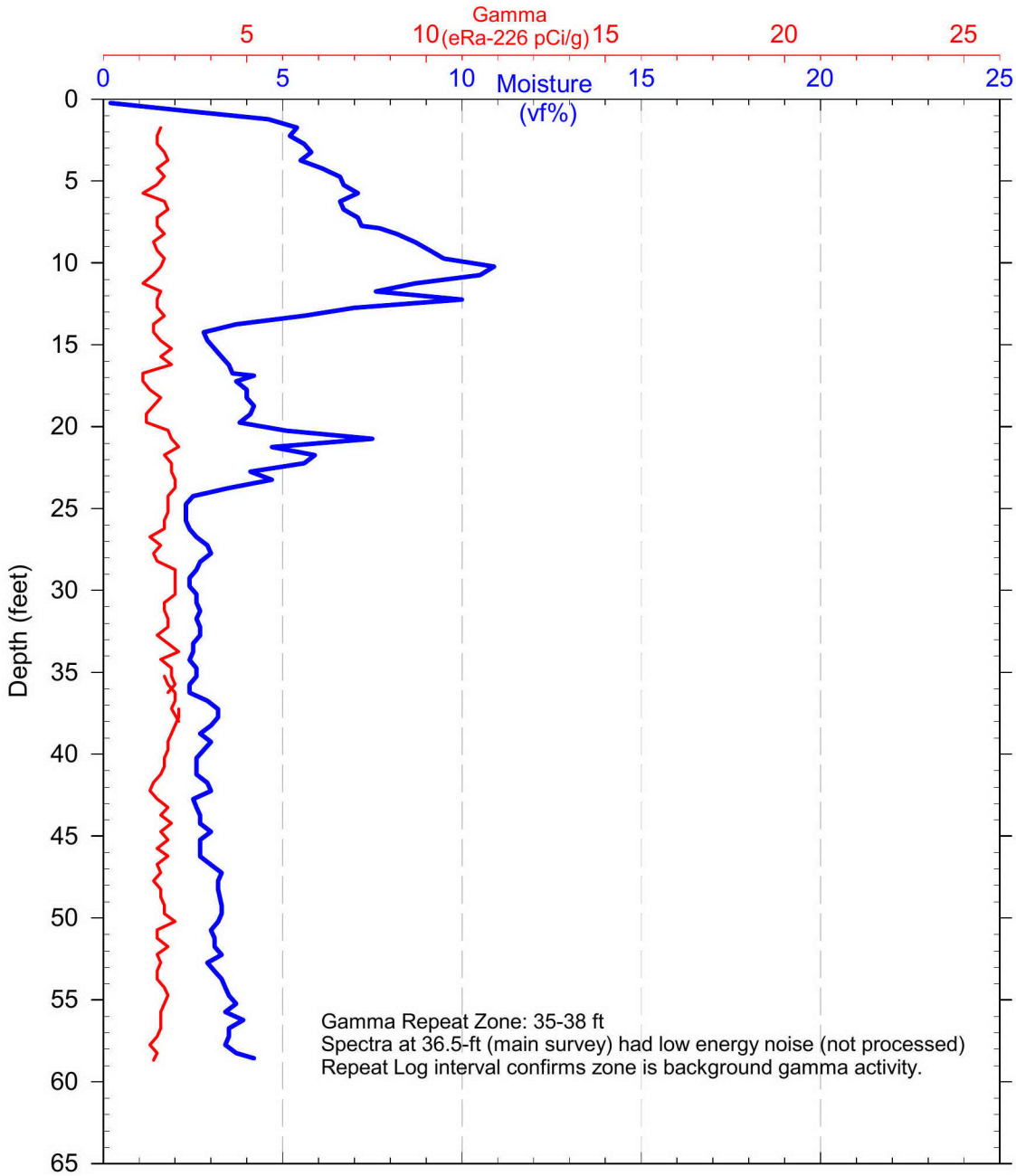


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4403

Log Date : July 2005
Depth Ref: Ground Level

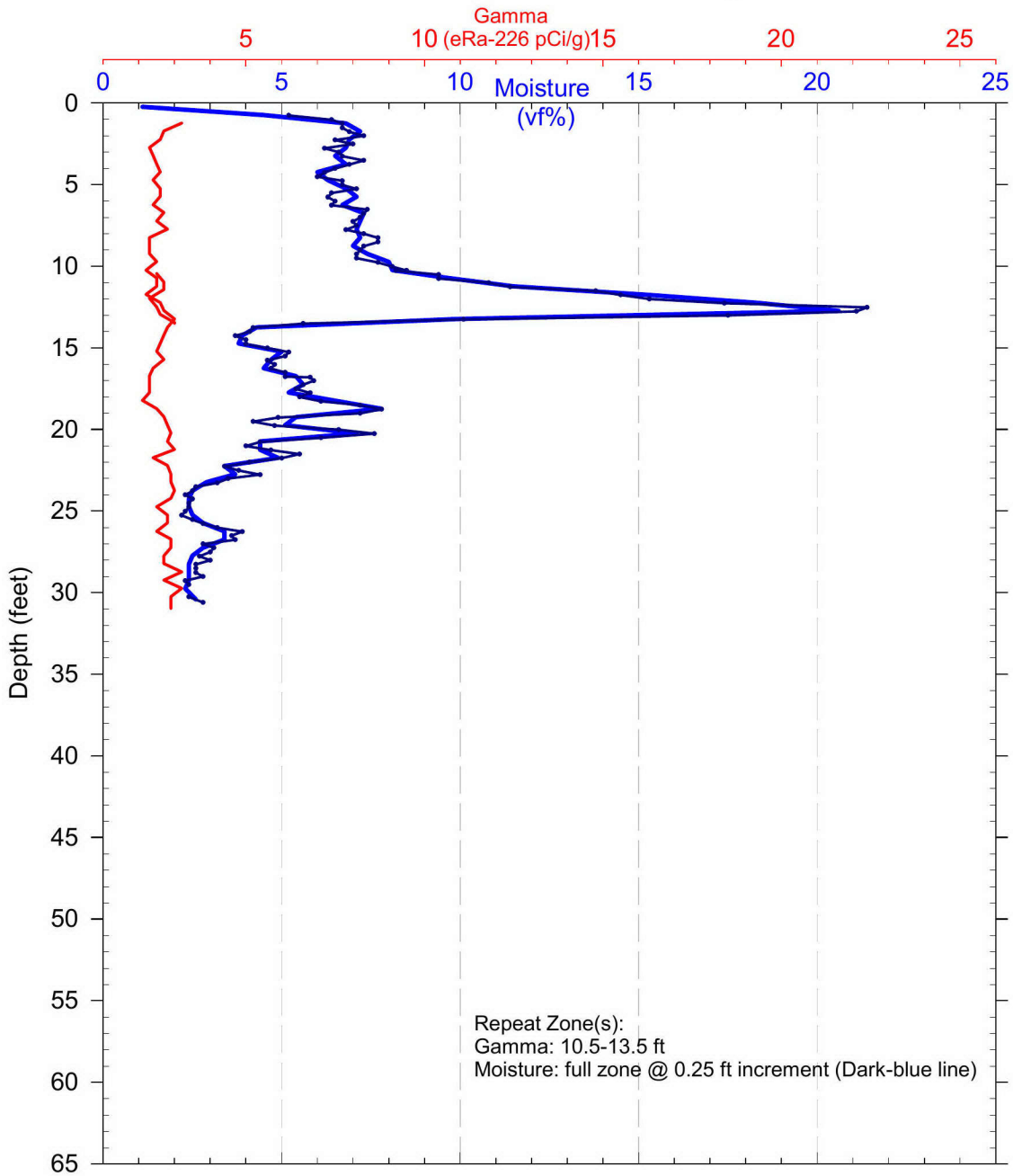


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4405

Log Date : July 2005
Depth Ref: Ground Level

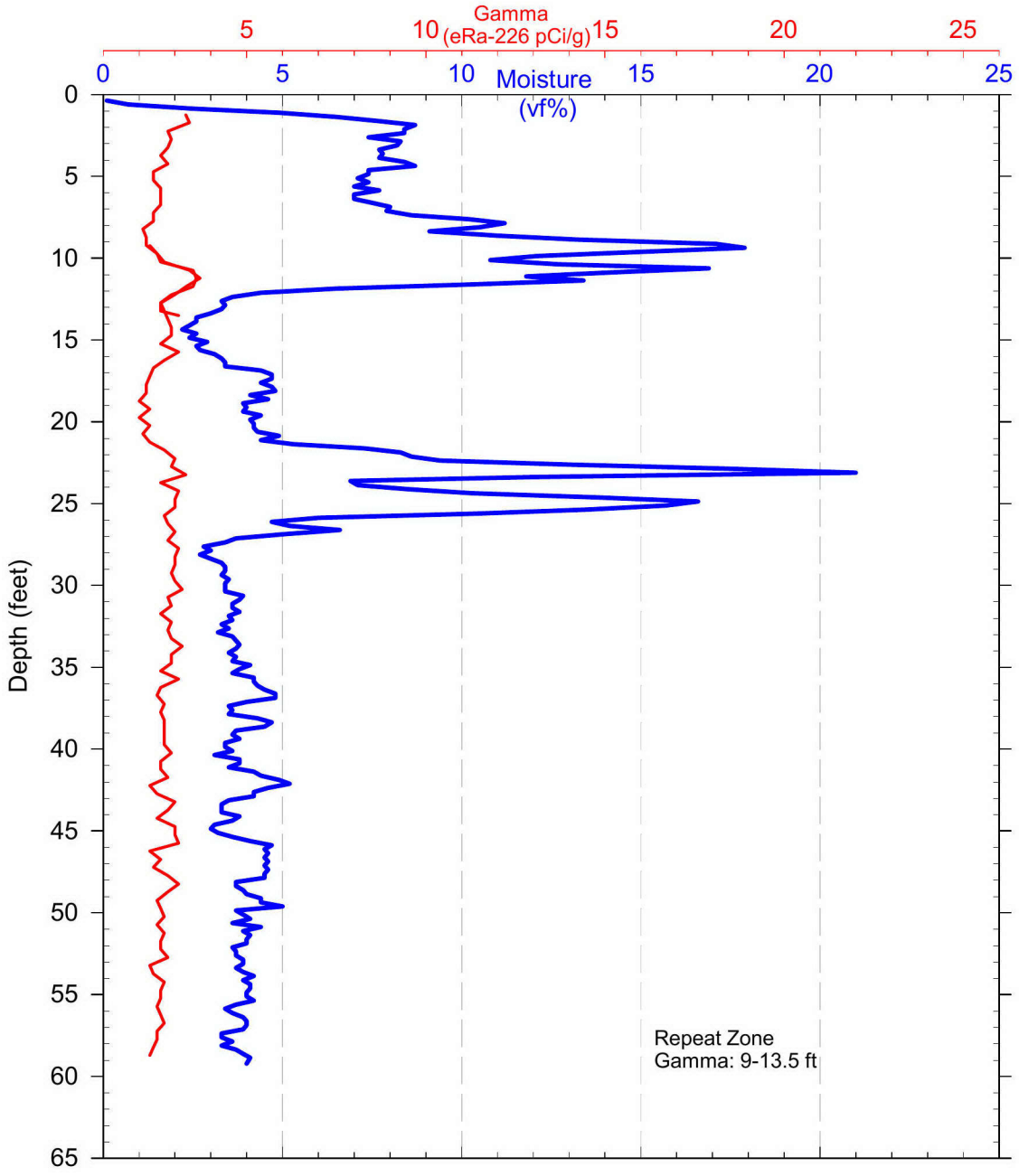


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4407

Log Date : July 2005
Depth Ref: Ground Level

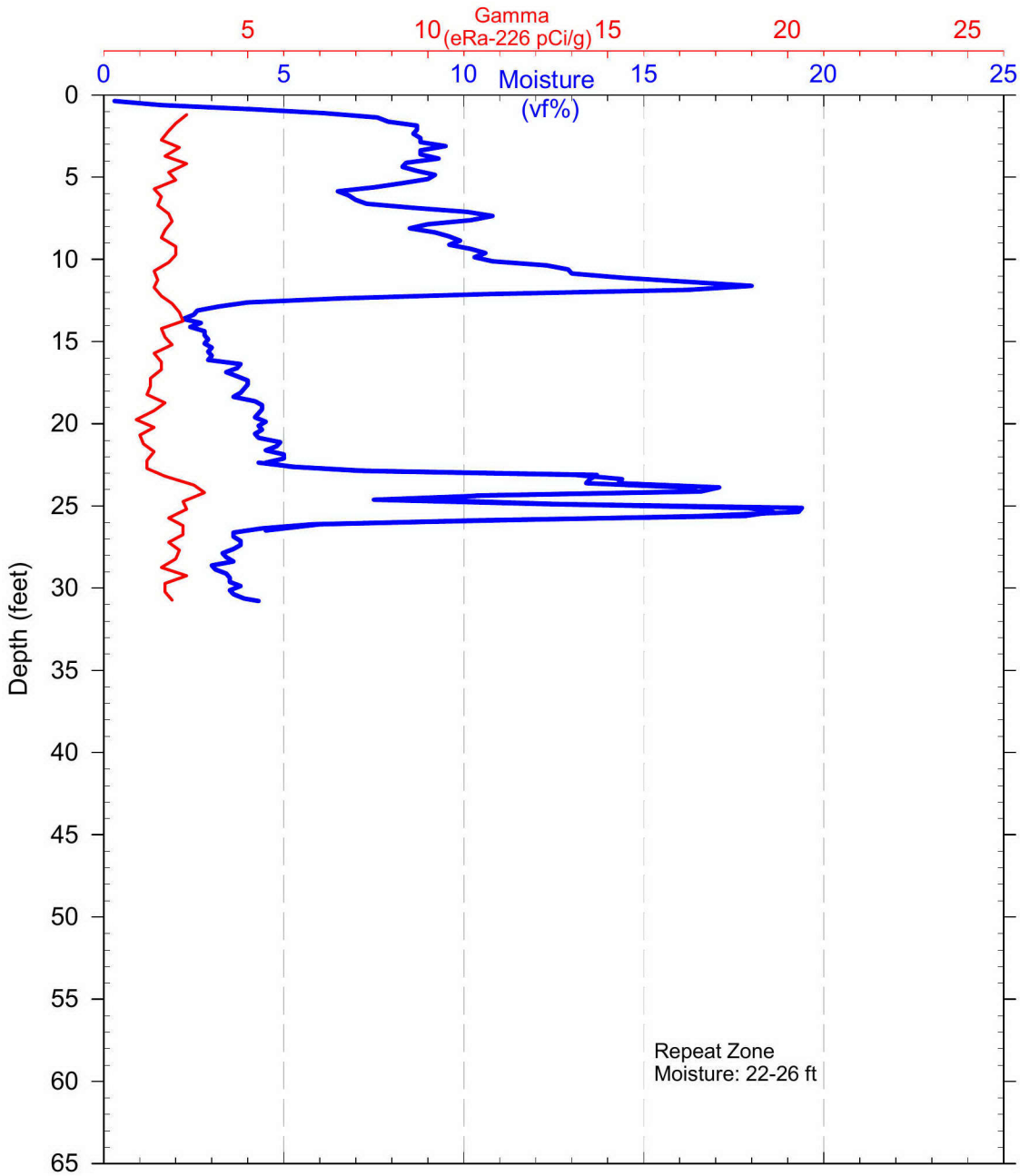


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4409

Log Date : July 2005
Depth Ref: Ground Level

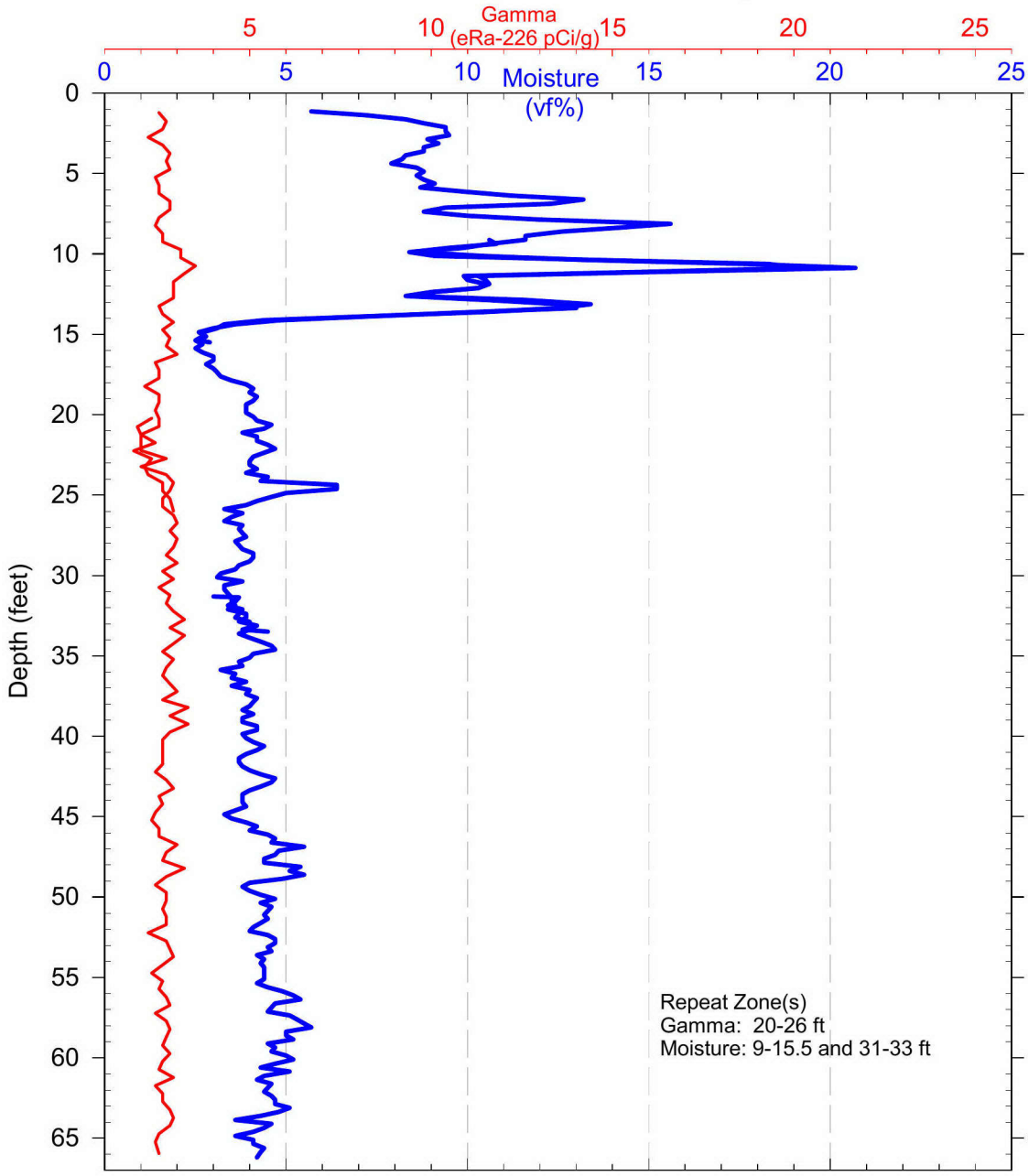


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4411

Log Date : July 2005
Depth Ref: Ground Level

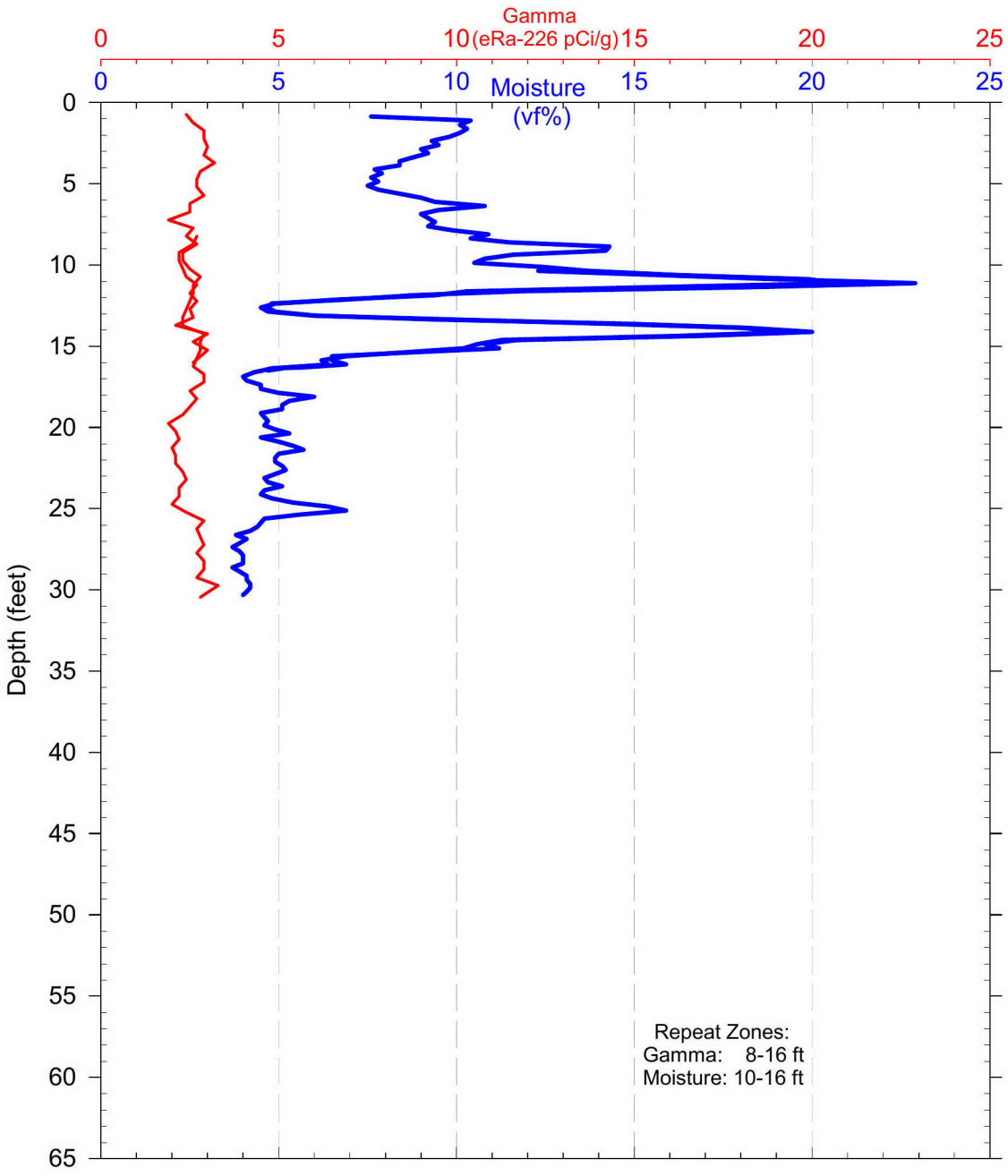


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4413

Log Date : July 2005
Depth Ref: Ground Level

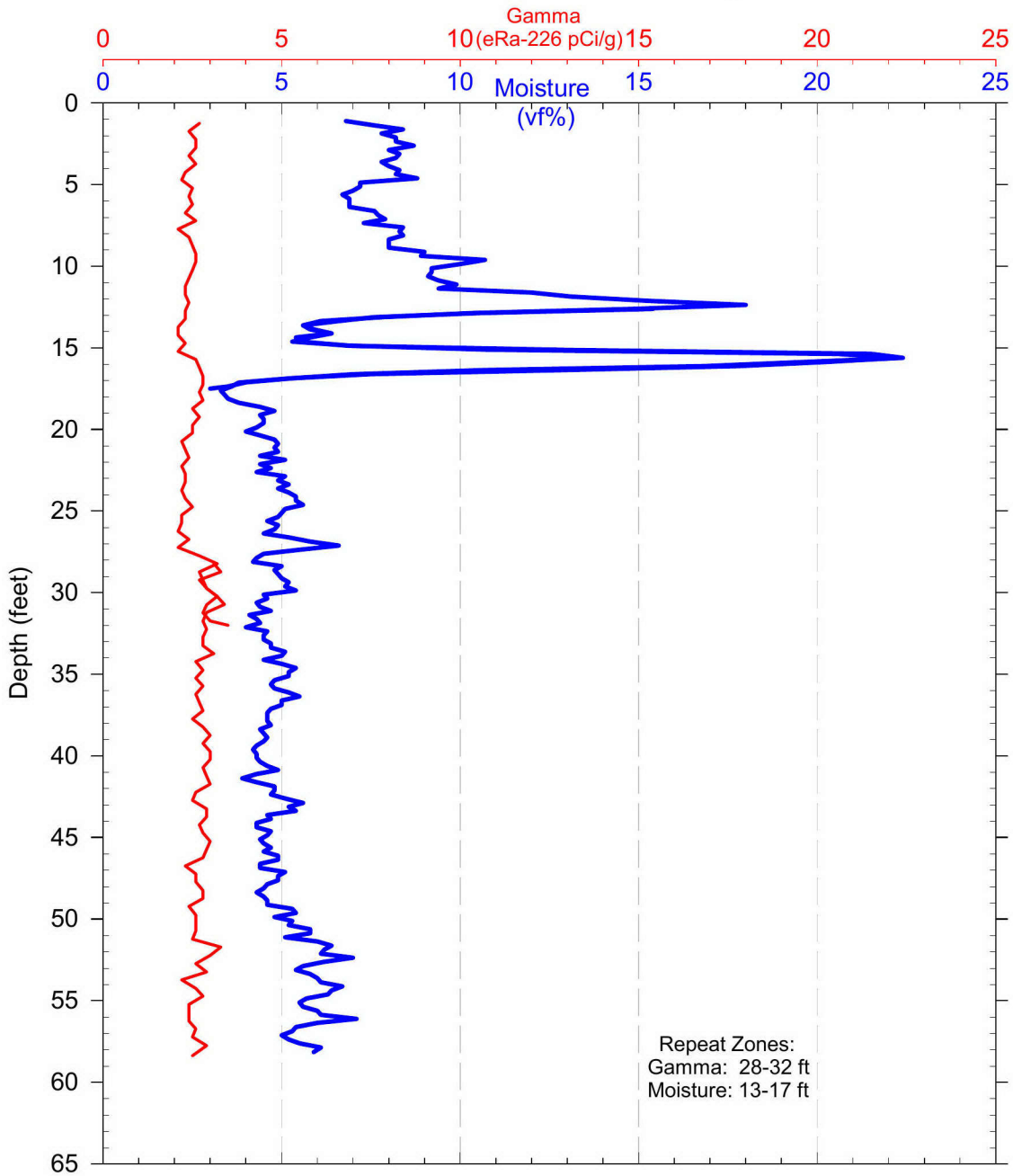


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4415

Log Date : July 2005
Depth Ref: Ground Level

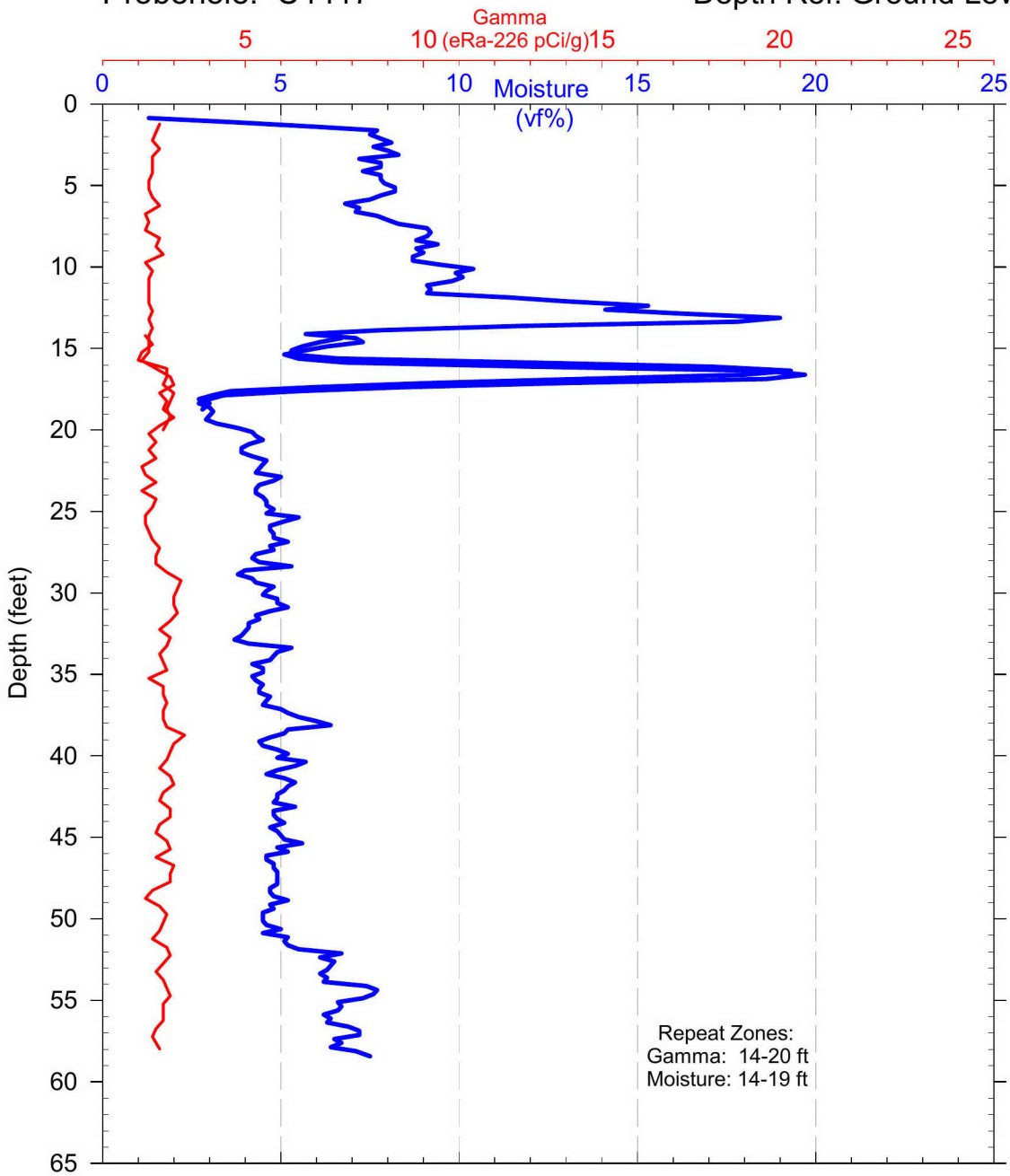


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4417

Log Date : July 2005
Depth Ref: Ground Level

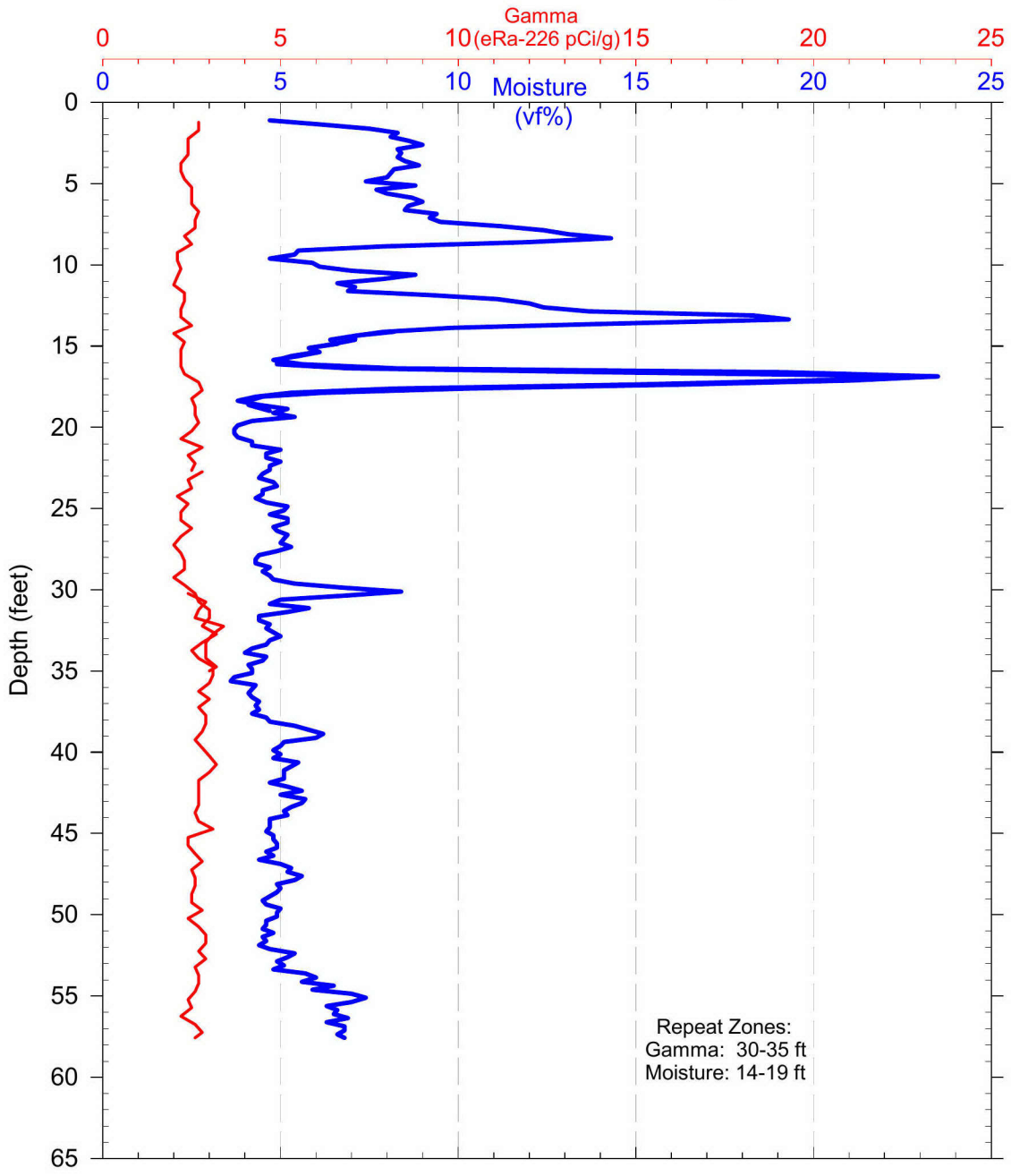


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4419

Log Date : July 2005
Depth Ref: Ground Level

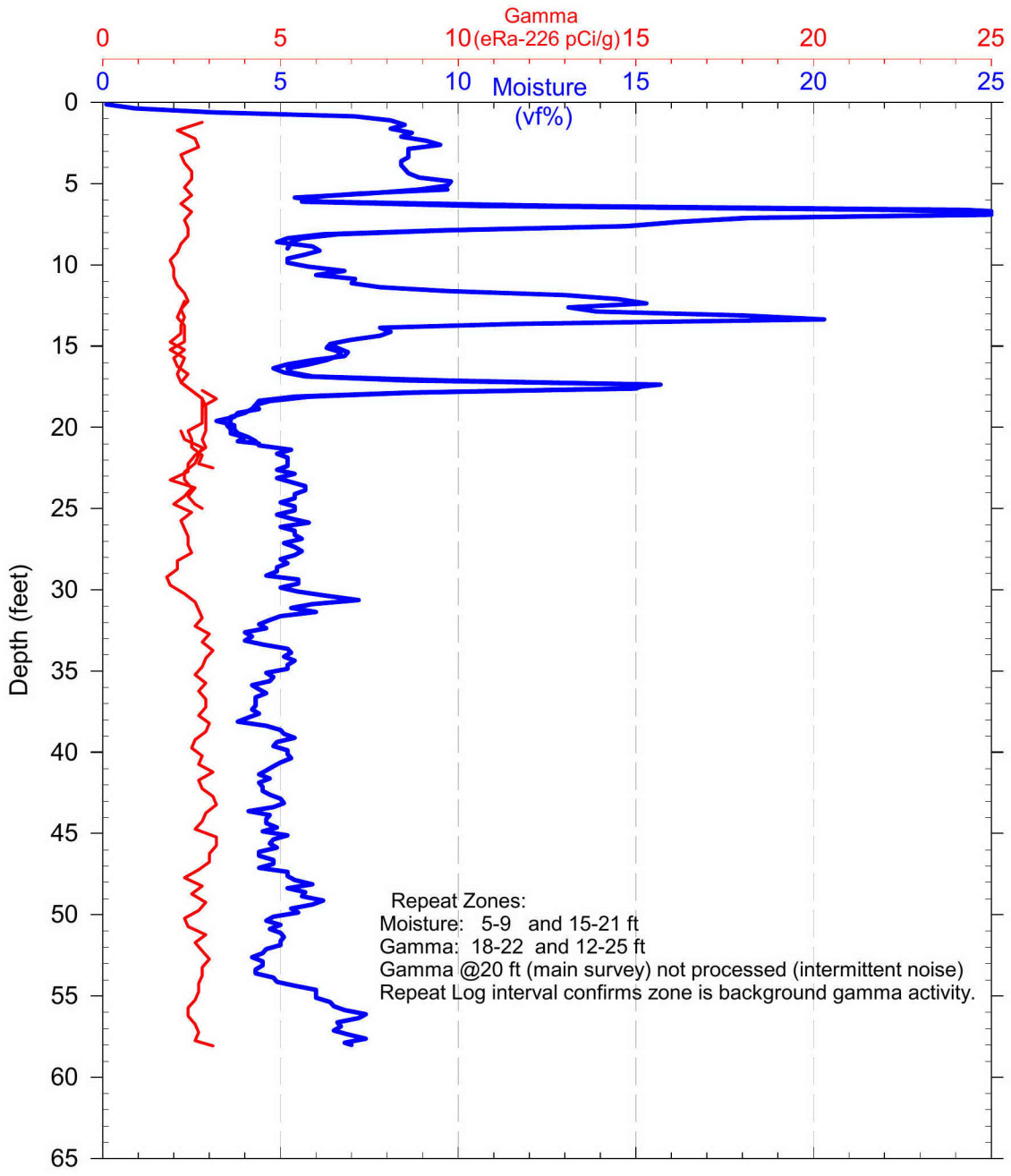


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4421

Log Date : July 2005
Depth Ref: Ground Level

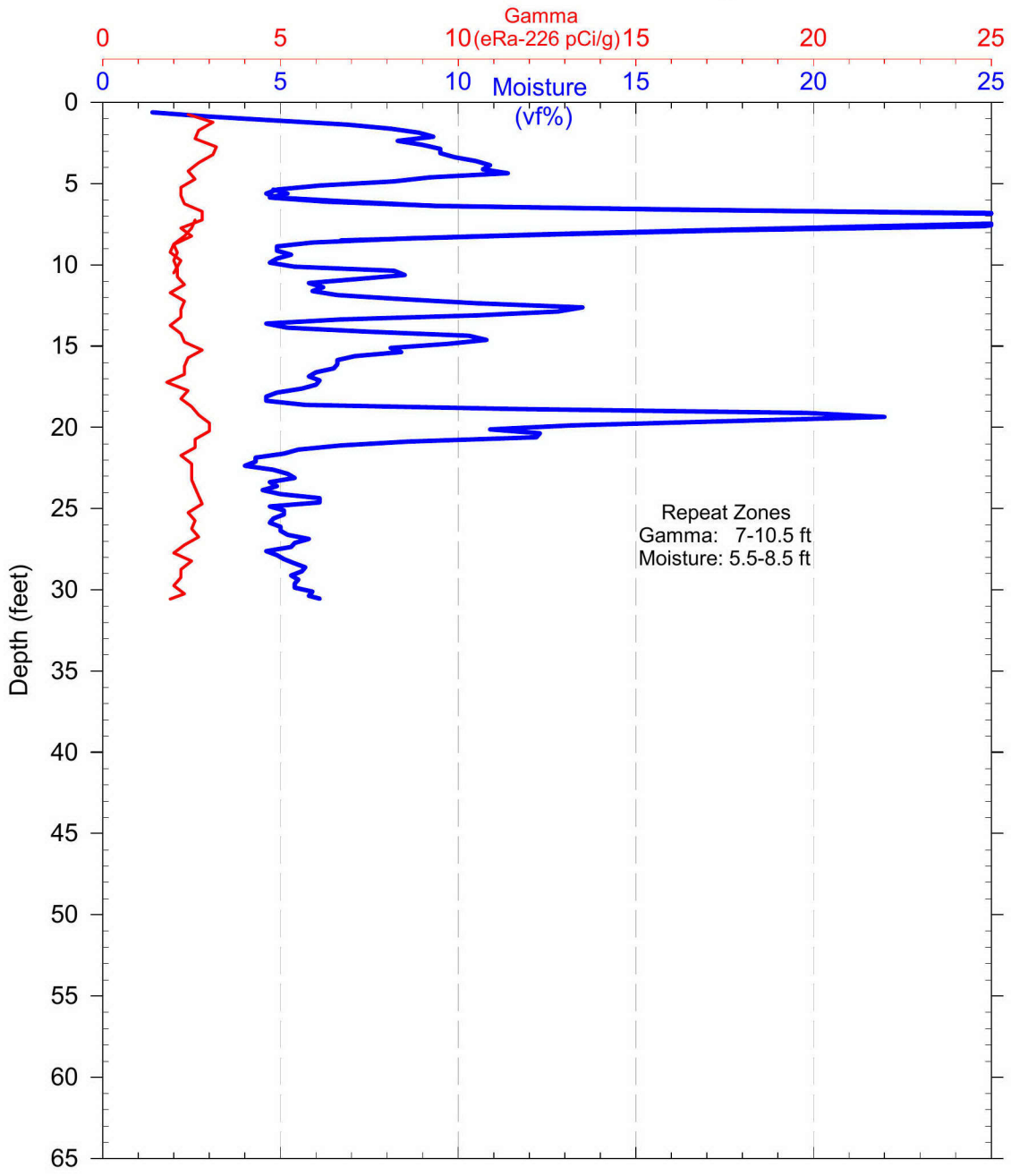


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4425

Log Date: August 2005
Depth Ref: Ground Level

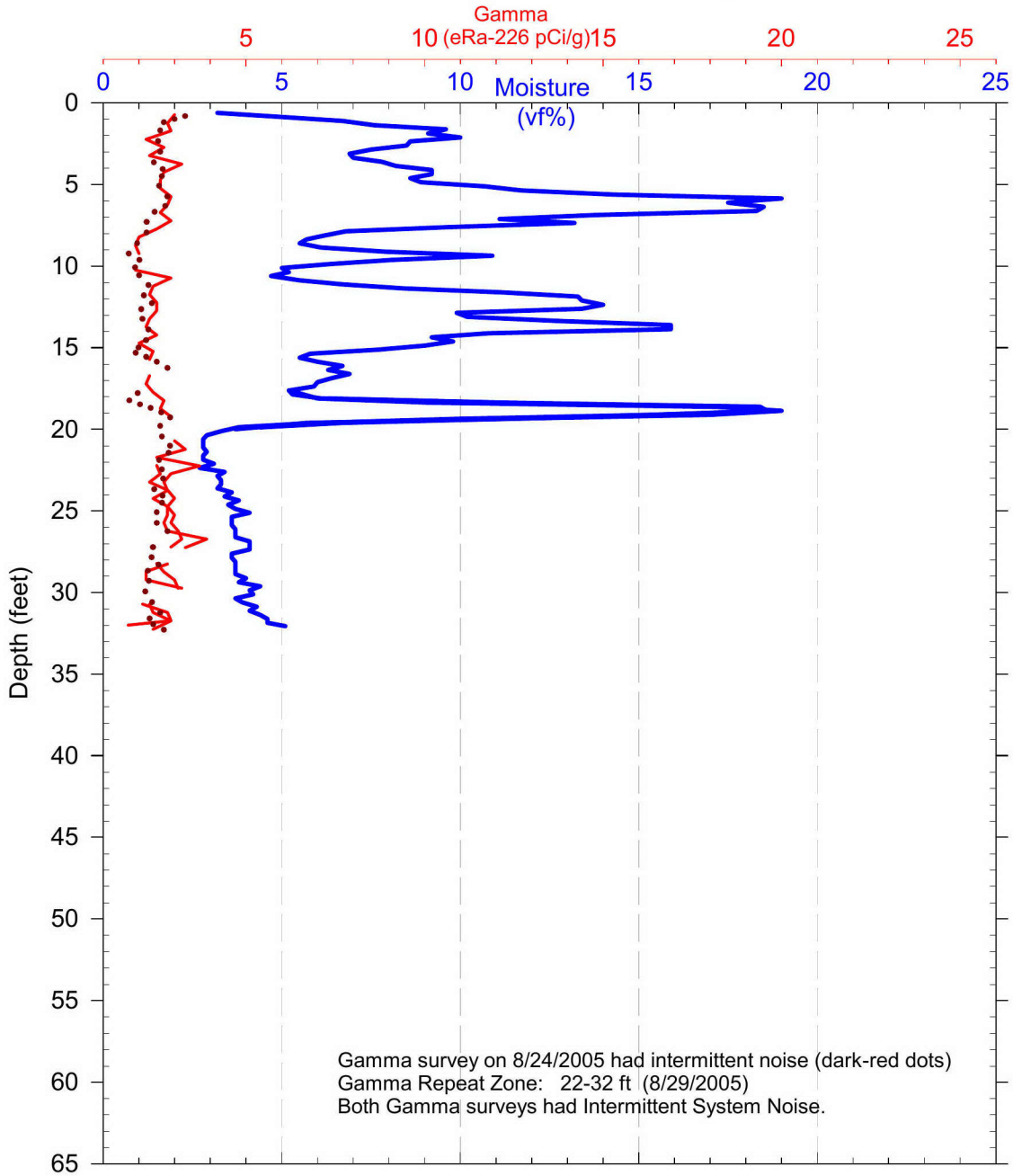


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4427

Log Date: August 2005
Depth Ref: Ground Level

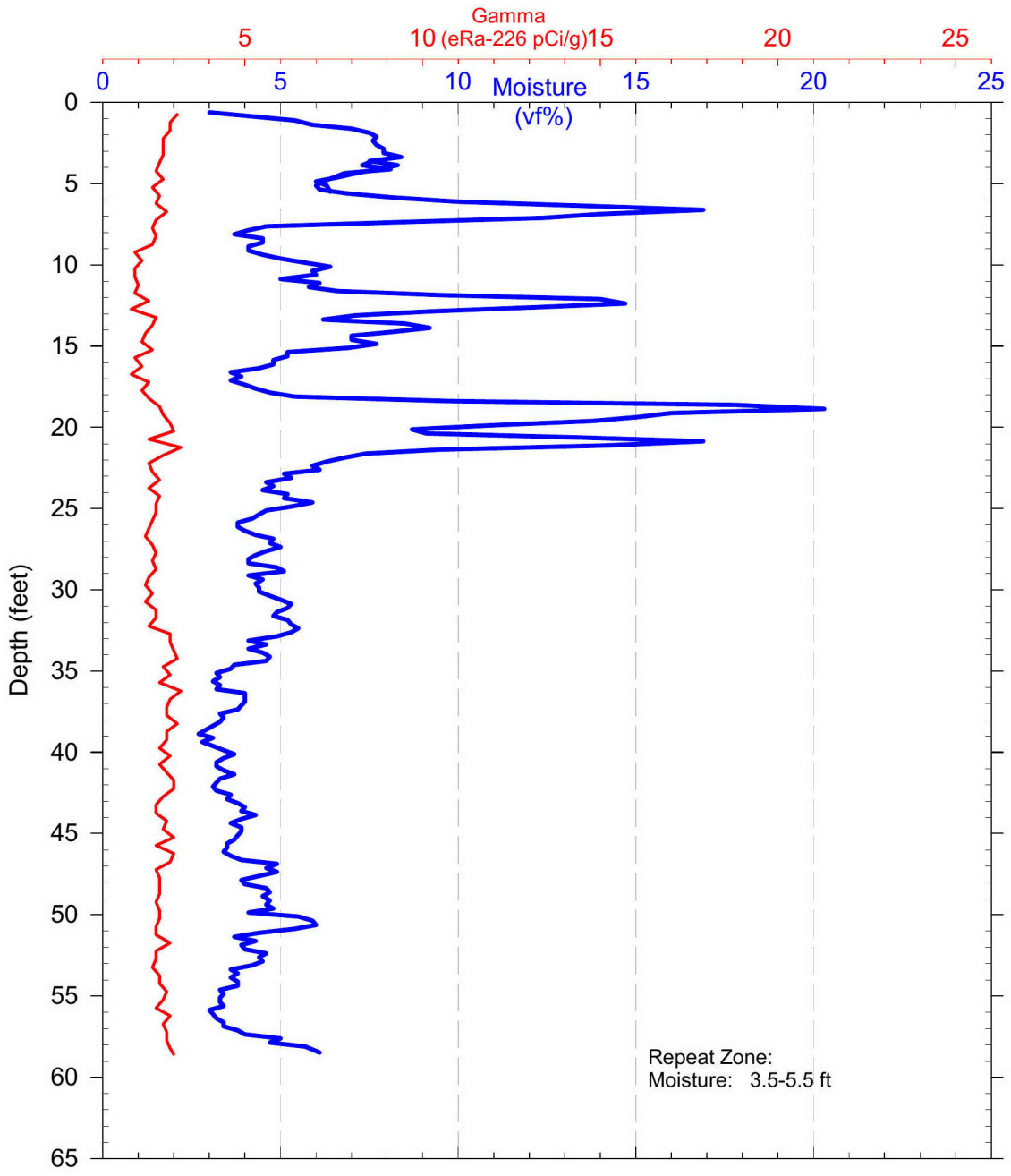


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4429

Log Date: August 2005
Depth Ref: Ground Level

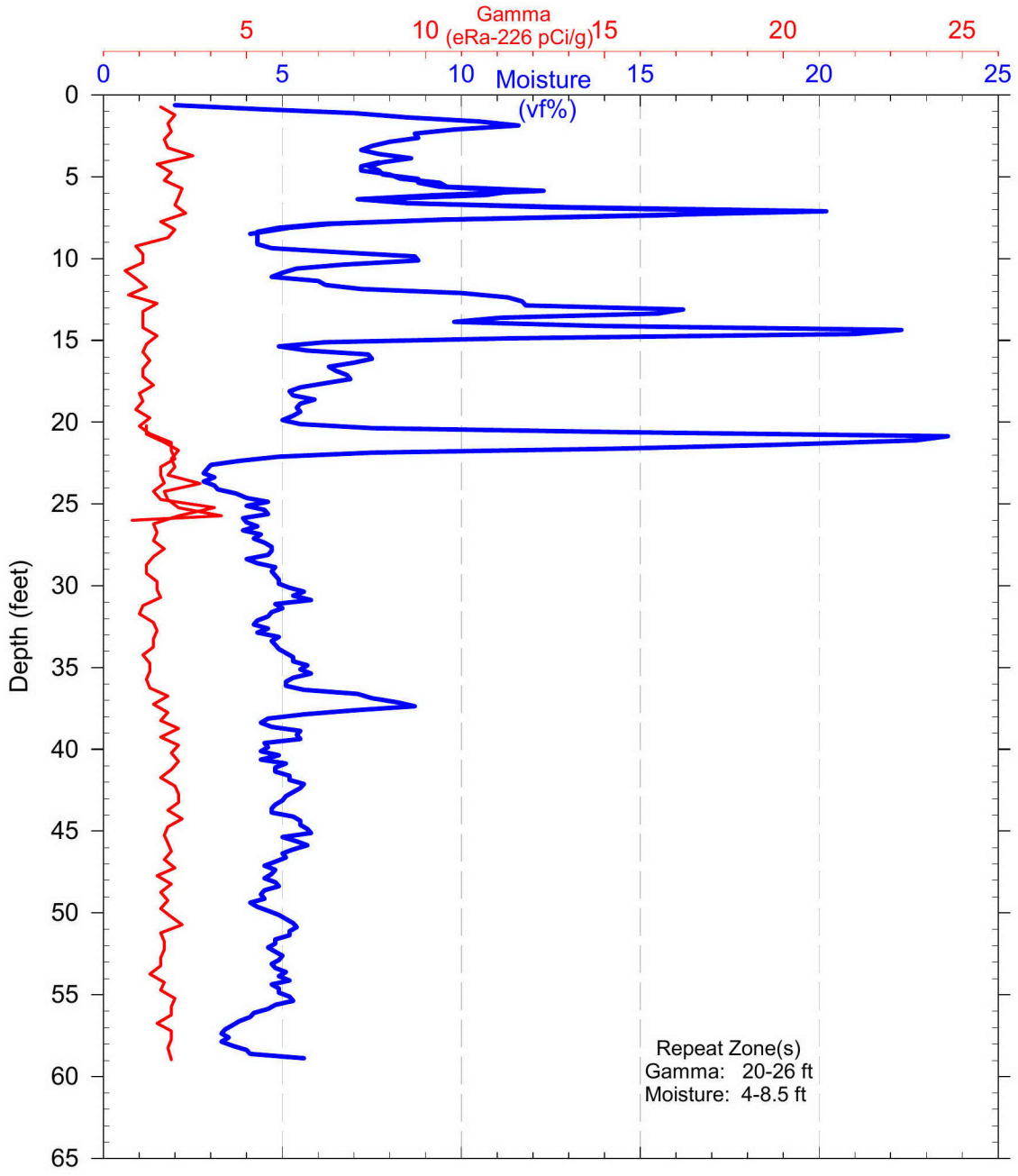


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4431

Log Date: August 2005
Depth Ref: Ground Level

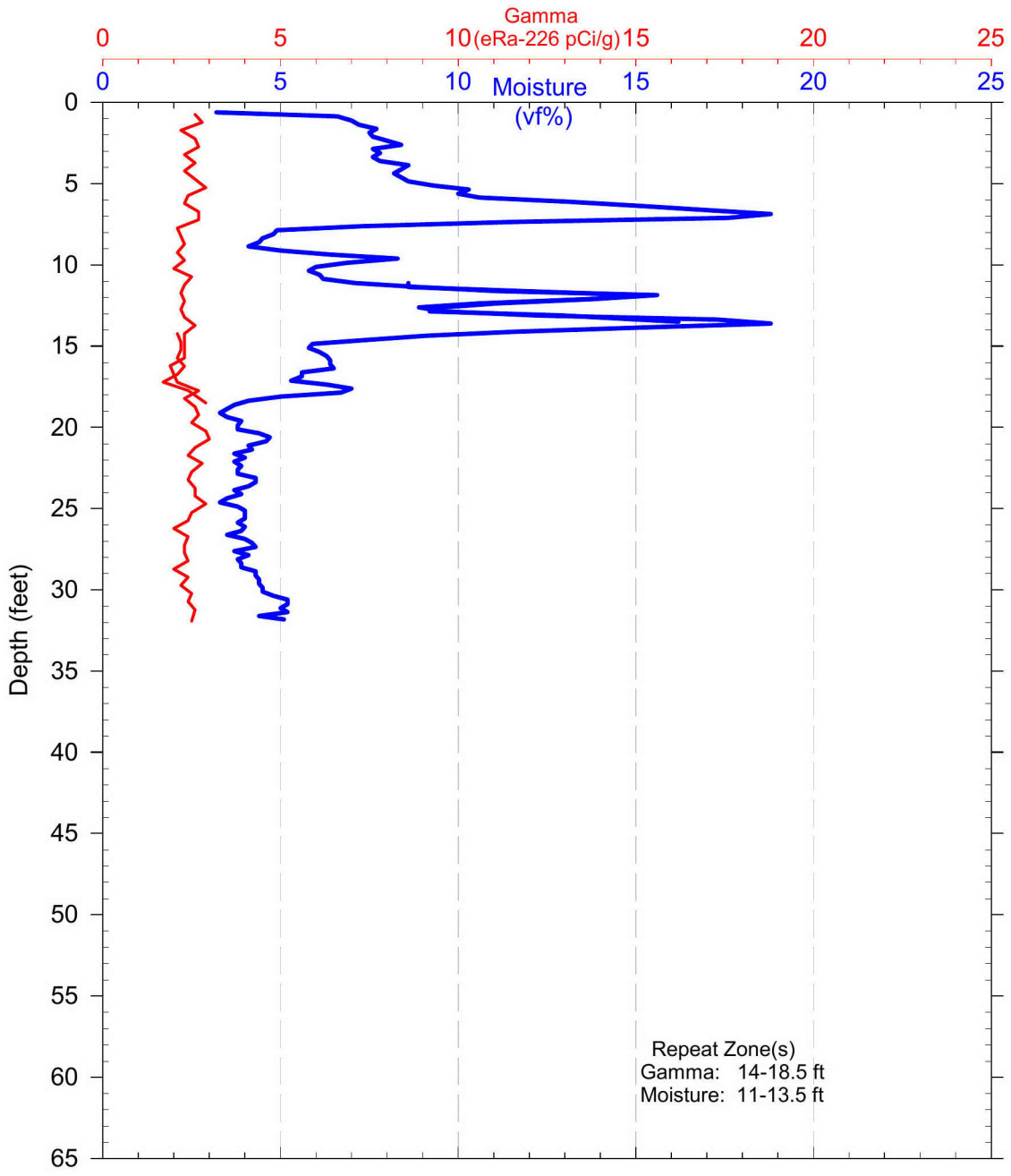


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4433

Log Date: August 2005
Depth Ref: Ground Level

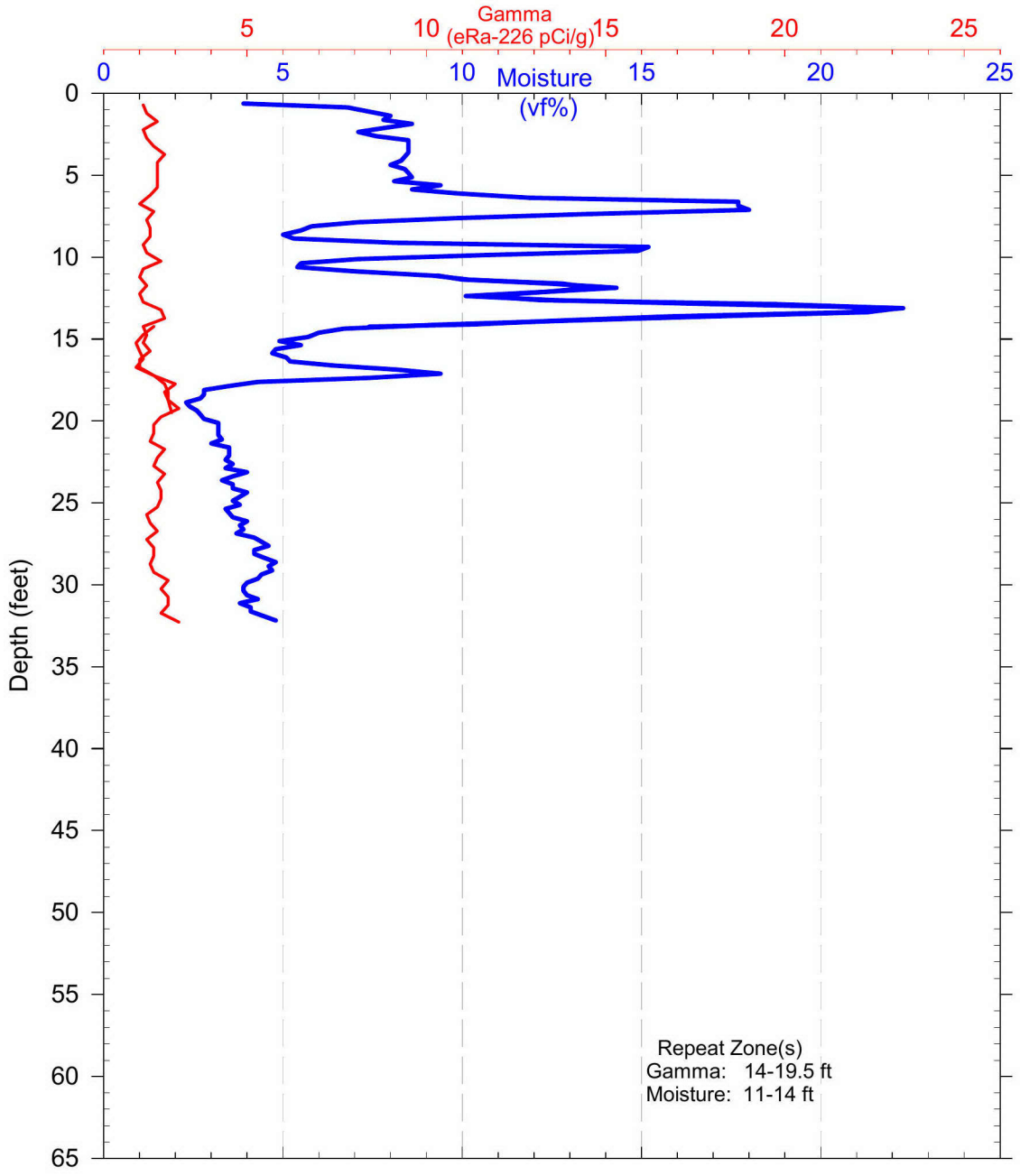


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4435

Log Date: August 2005
Depth Ref: Ground Level

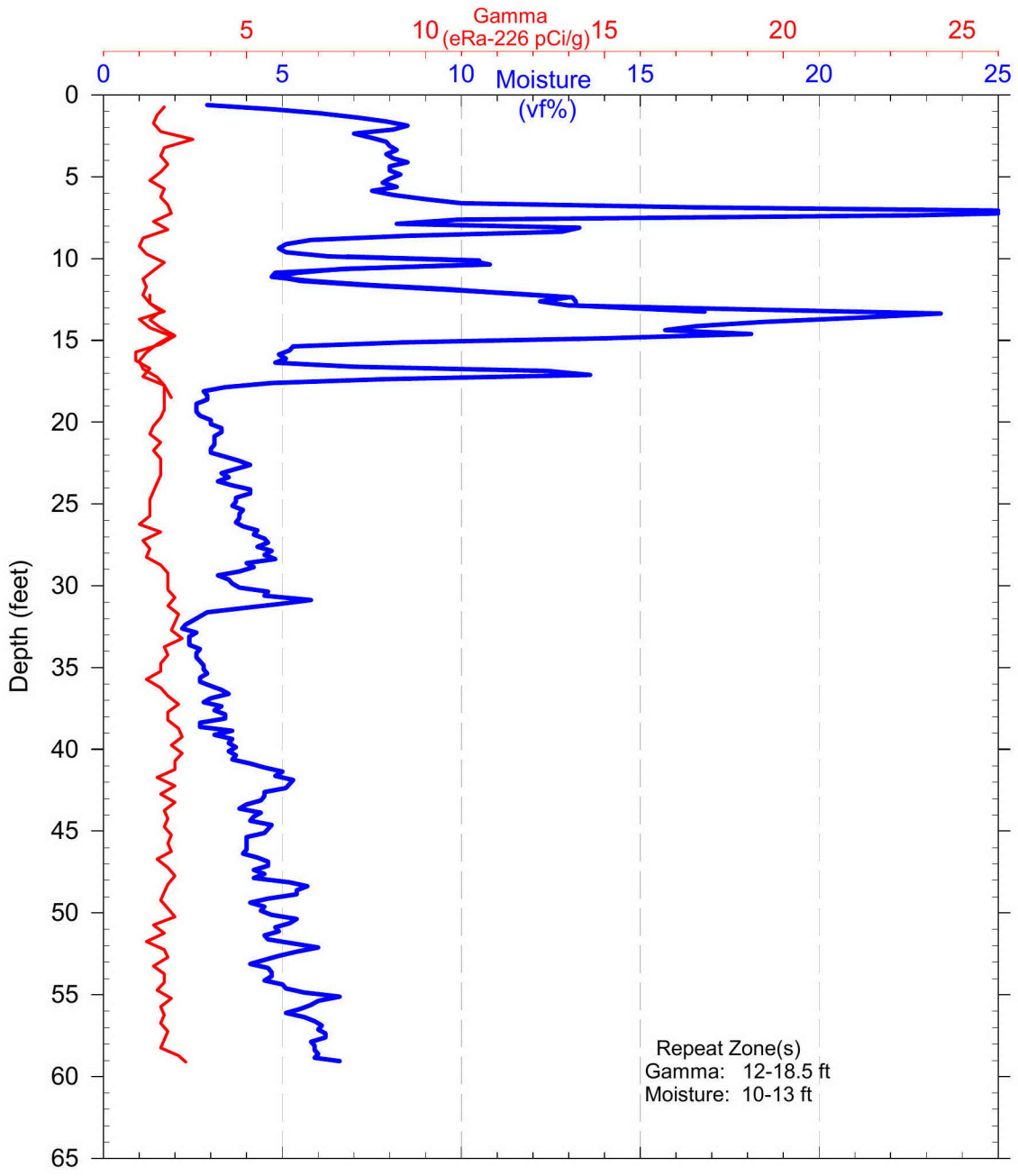


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4437

Log Date: August 2005
Depth Ref: Ground Level

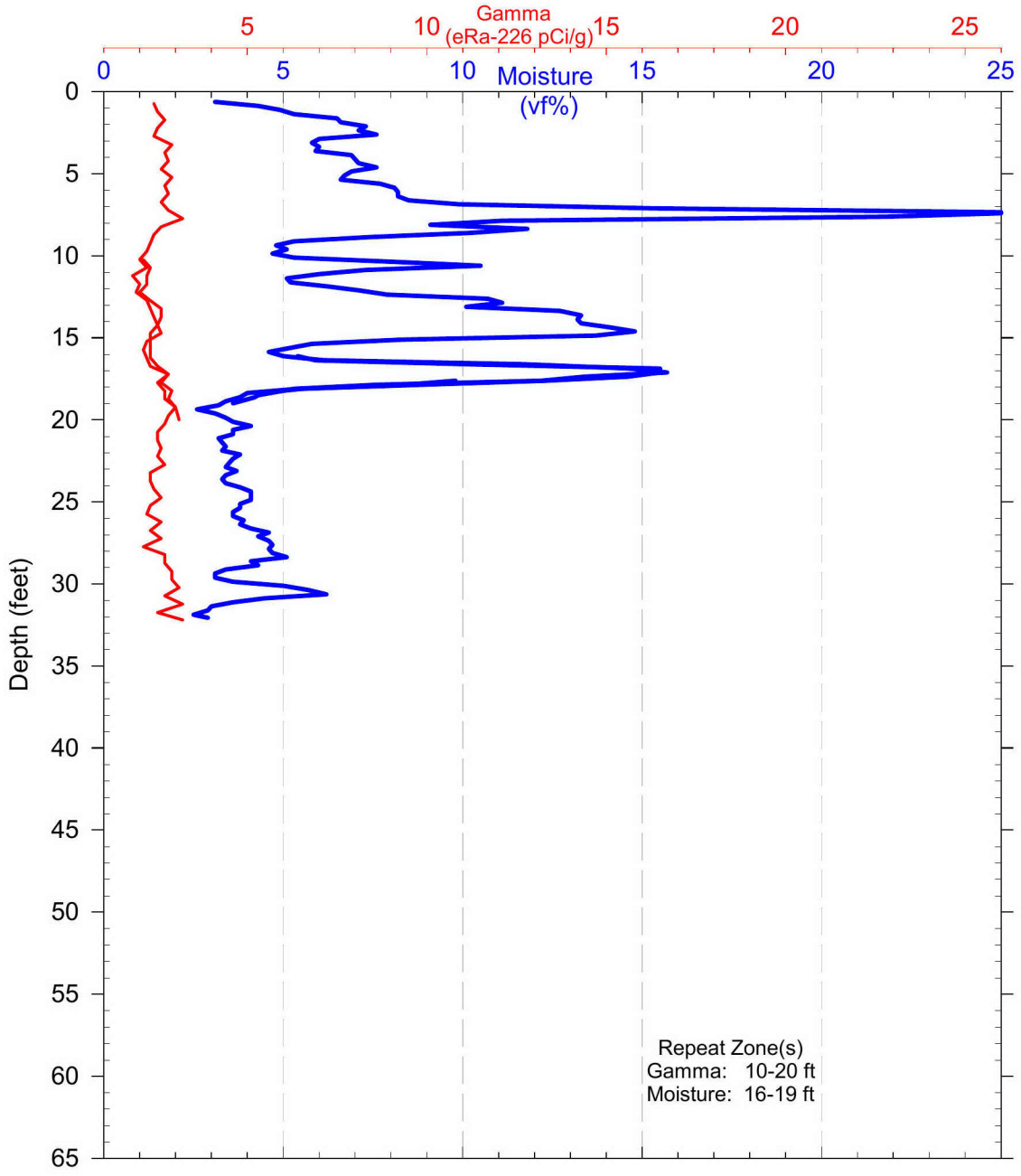


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4439

Log Date: August 2005
Depth Ref: Ground Level

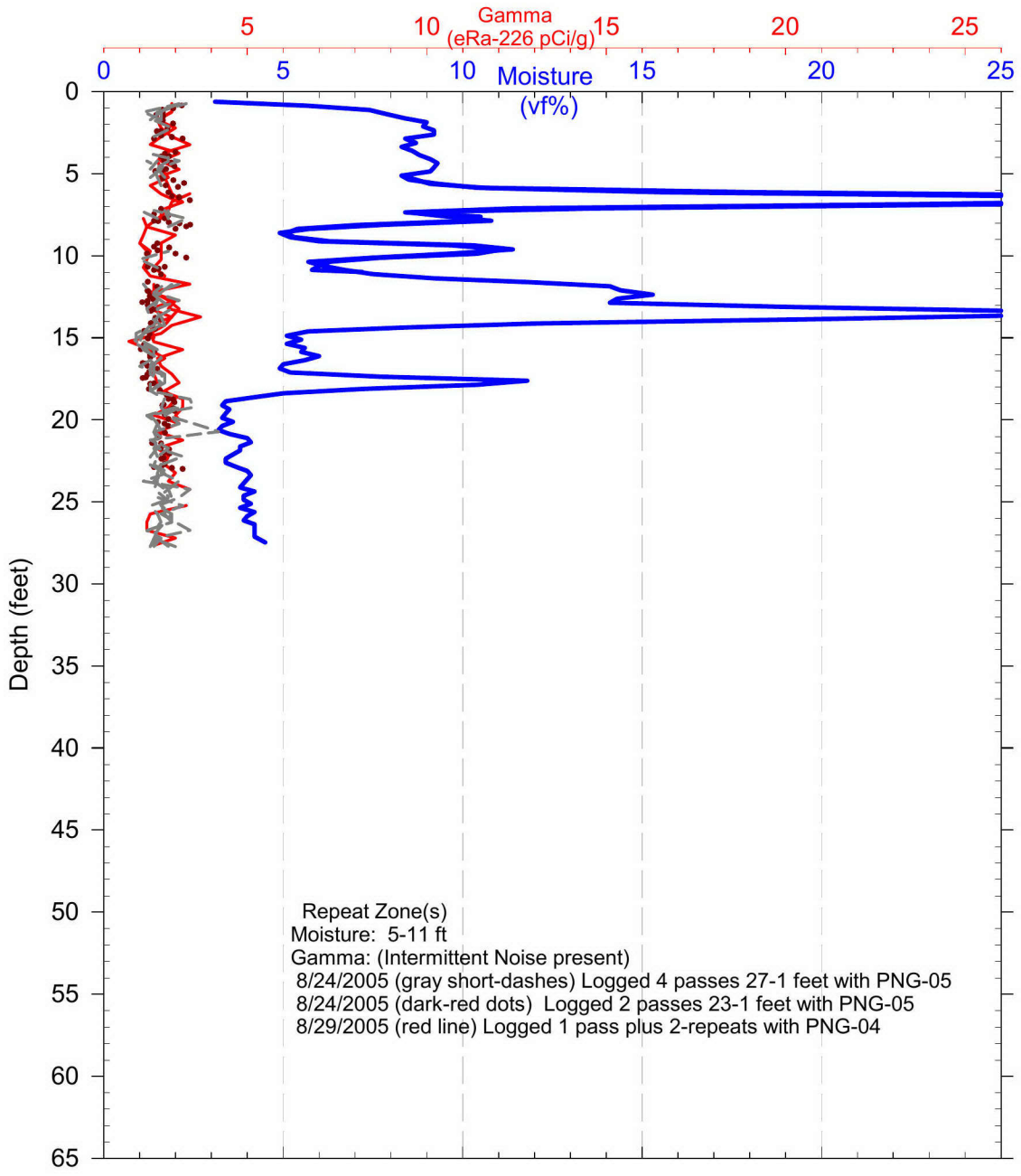


Small Diameter - Gamma & Moisture Survey

Duratek Federal Services & Pacific Northwest Geophysics

Project: Tank Farm Push, C-152
Probehole: C4447

Log Date: August 2005
Depth Ref: Ground Level



APPENDIX B: SPECTRAL GAMMA SURVEY RESULTS

Spectral Gamma surveys were collected in two probe holes. The survey interval in each probe hole (C4409:21-30 ft and C4417:14-20 ft) was selected based on a transition from lower to higher activity identified in the gross gamma survey and significant moisture content changes (from low to high) within the interval.

The spectral gamma survey data were processed to quantify the concentrations of KUT (the three natural radionuclides) and are presented graphically below. These log responses are typical of spectral gamma surveys from other detector types (i.e. high purity germanium) that are collected with comparable counting times. If better precision is desired then longer counting times are required.

The Gross Gamma response for both surveys clearly shows the transition in the gamma activity of the subsurface formation materials. Review of the KUT log responses with the gross gamma response reveals some interesting points.

- The potassium values show a relatively smooth response (confirming the good precision) with small incremental change between successive depth locations. The potassium distribution follows the general trend of the gross gamma response, however detail differences are quickly observed. This general trend indicates that a significant percentage of the gross gamma response is generated from potassium.
- The relatively high concentrations of potassium (range from 12 to 20 pCi/g) contribute to the good measurement precision. The concentration of uranium and thorium are both much lower (less than 1 pCi/g) and the computed concentrations have lower precision (high uncertainty) as a percentage of the concentration.
- The thorium values show lower precision as indicated by large incremental change between values at successive depth locations and by the noticeable difference in values between the main survey and repeat spectra measurements. The general trend of thorium compares relatively well with the gross gamma response, which indicates that a percentage of the gross gamma response is generated from the low concentration of thorium.

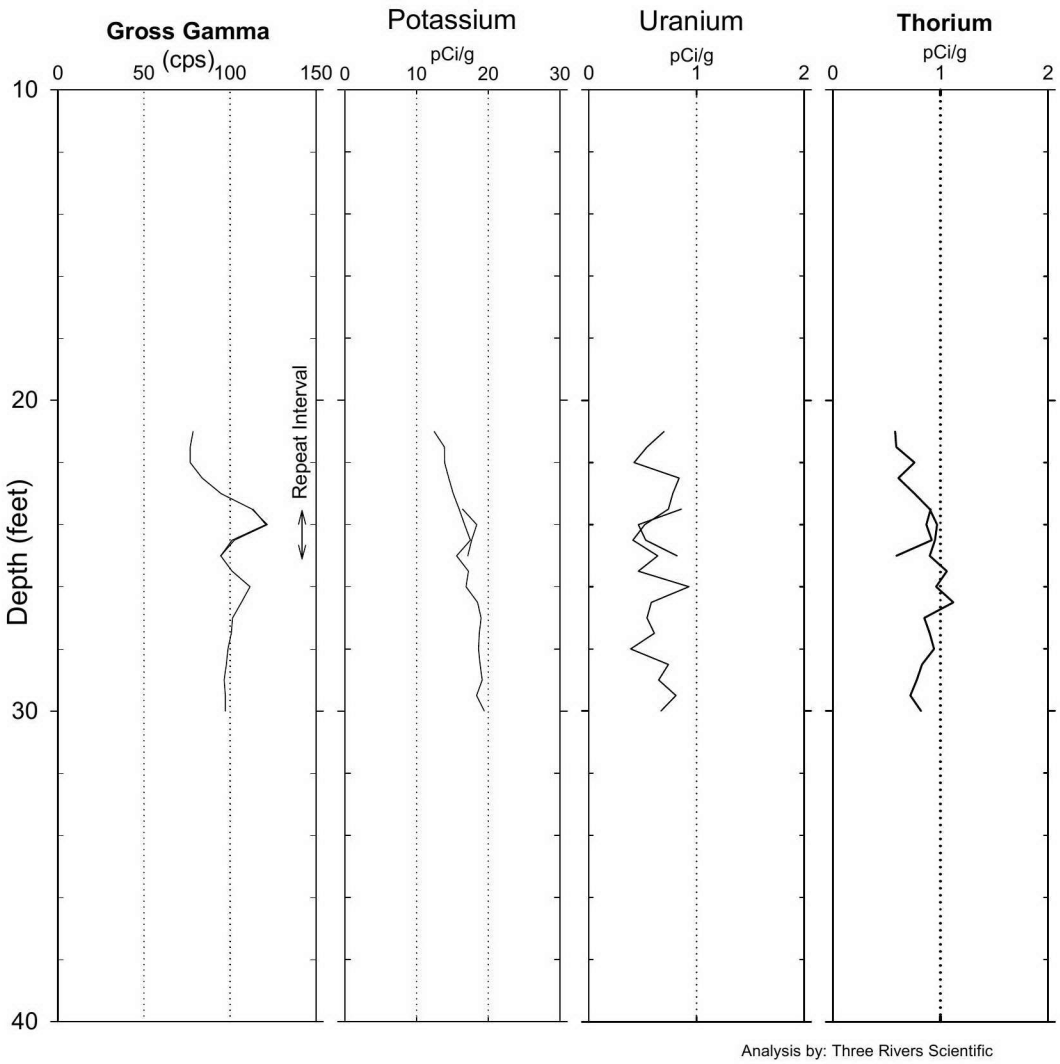
- The uranium values show the lowest precision of the three radionuclides. This is indicated by (1) large difference between the main and repeat survey measurements, (2) very large incremental changes between the sample depths, (3) no noticeable change in the apparent uranium concentration, within the survey interval, which also confirms the large measurement uncertainties, (4) the large uncertainty in uranium concentration is masking the minor concentration changes that may be present in the subsurface formation materials, and (5) the lack of noticeable change in uranium concentration within the survey interval, which means that the computed uranium content can not be used to construct a computed gross gamma response.

Small Diameter Logging Service
BGO Scintillator Survey

Pacific Northwest Geophysics / Three Rivers Scientific

Project: C-152 Diversion Box
Probe hole: C4409

Log Date: August 2005
Gamma Emitting Radionuclides

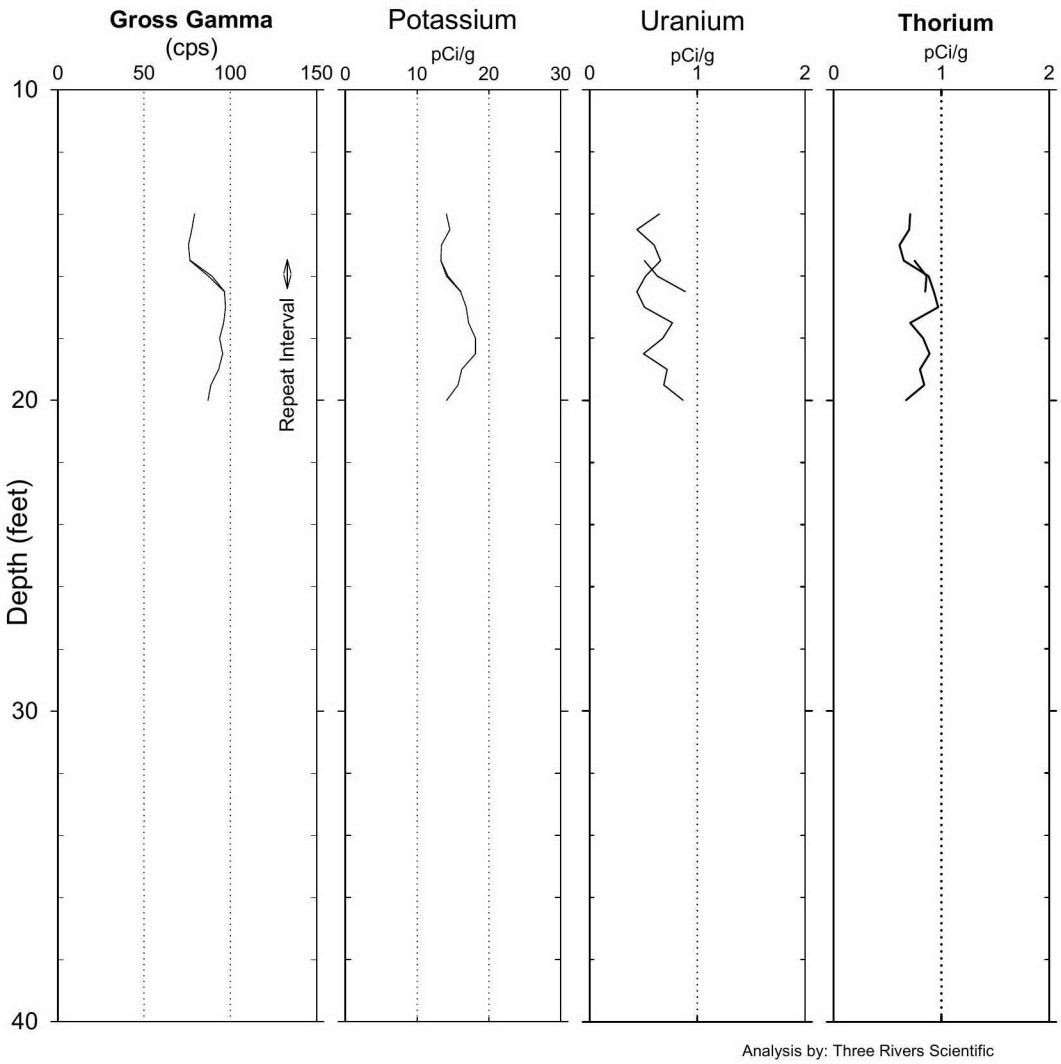


Small Diameter Logging Service
BGO Scintillator Survey

Pacific Northwest Geophysics / Three Rivers Scientific

Project: C-152 Diversion Box
Probe hole: C4417

Log Date: August 2005
Gamma Emitting Radionuclides



APPENDIX U

SUPPLEMENTAL INFORMATION ON GROUNDWATER CONSTITUENTS OF INTEREST AT WMA C

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APPENDIX U
SUPPLEMENTAL INFORMATION ON GROUNDWATER CONSTITUENTS OF INTEREST AT WMA C

This appendix provides supplemental information on the seven constituents of interest for groundwater at WMA C that were identified in RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C*. RPP-RPT-58297 documents a high-level evaluation that was conducted to support the WMA C RFI process as well as the baseline risk assessment for the 200-BP-5 groundwater OU. It should be noted that the constituents of interest identified in RPP-RPT-58297are not necessarily those that will be identified as risk drivers in the baseline risk assessment for the 200-BP-5 OU.

From the 55 constituents reviewed as part of the screening-level evaluation, seven constituents were considered likely to be of interest for assessing the potential for cancer risks or noncancerous hazards or investigating potential groundwater contamination sources at WMA C. The seven constituents of interest for the WMA C data set are cyanide, nitrate, sulfate, nickel, vanadium, ^{129}I, and ^{99}Tc.

This appendix provides the concentration trend plots for each constituent of interest in each well that were originally included in RPP-RPT-58297. Figure U-1 provides a summary information for all seven constituents (i.e., constituents in wells that potentially correlate with a local release) and Figure U-2 through U-8 shows time versus trend plots for each constituents at the wells around WMA C. This appendix additionally present cross sections of WMA C. These cross sections are presented in Figures U-9 through U-20 and include:

- Geologic interpretation, consistent with the interpretations provided in RPP-RPT-56356, *Development of Alternative Digital Geologic Models of Waste Management Area C* (i.e., Alternative Geologic Model 1 (modified) with water level data from June 2013).

- Vadose zone soil concentrations for the seven groundwater constituents of interest

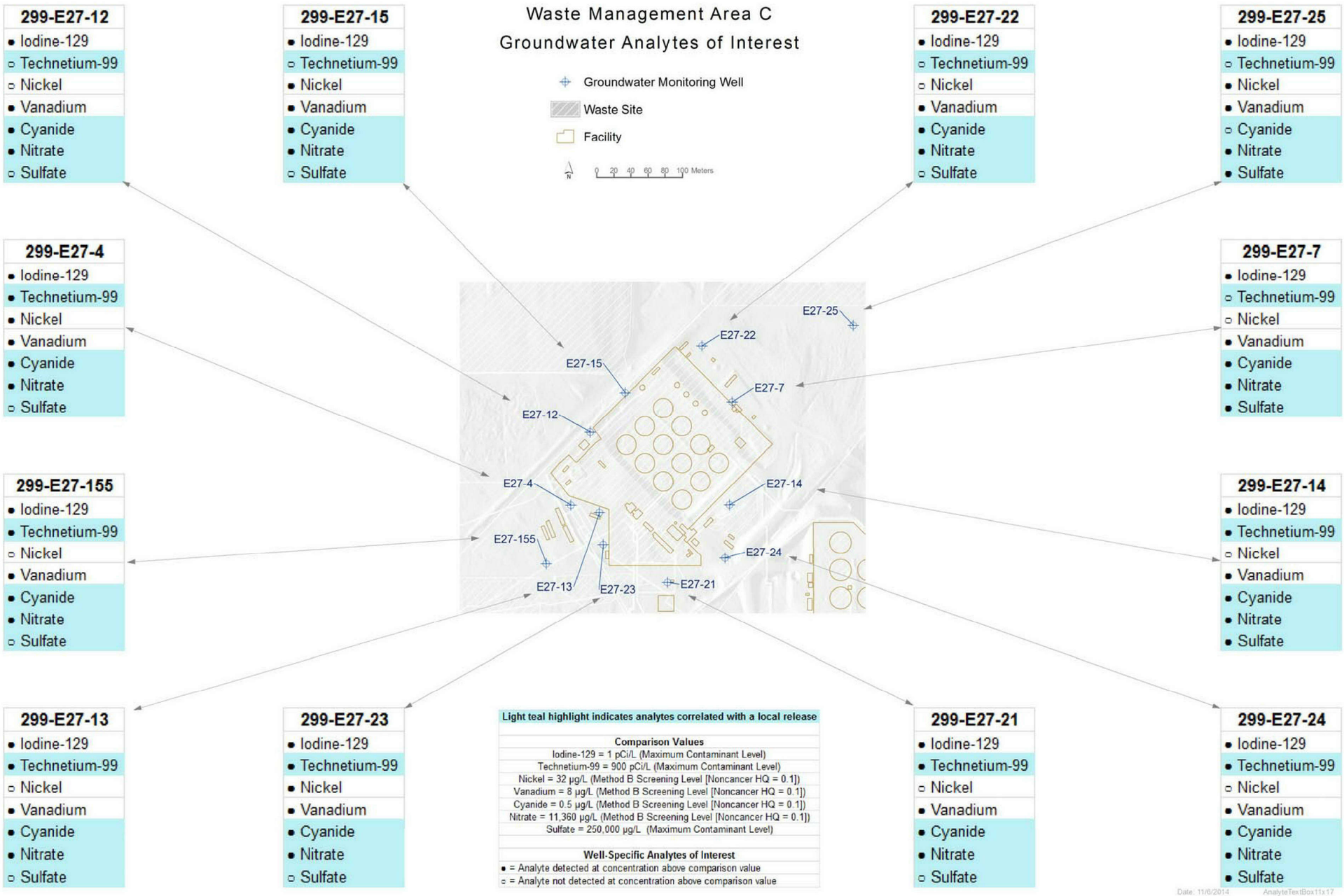
- Groundwater concentrations for the seven groundwater constituents of interest. Concentrations are from the last sampling event of 2013 from groundwater wells, as available.

There are six cross section lines presented for WMA C: L1 to L1', L2 to L2', L3 to L3', L4 to L4', L5 to L5', and L6 to L6'. The seven constituents are grouped in the following manner:

- Technetium-99 and nitrate concentrations are presented together.
- Cyanide, iodine-129, nickel, sulfate, and vanadium are presented together.

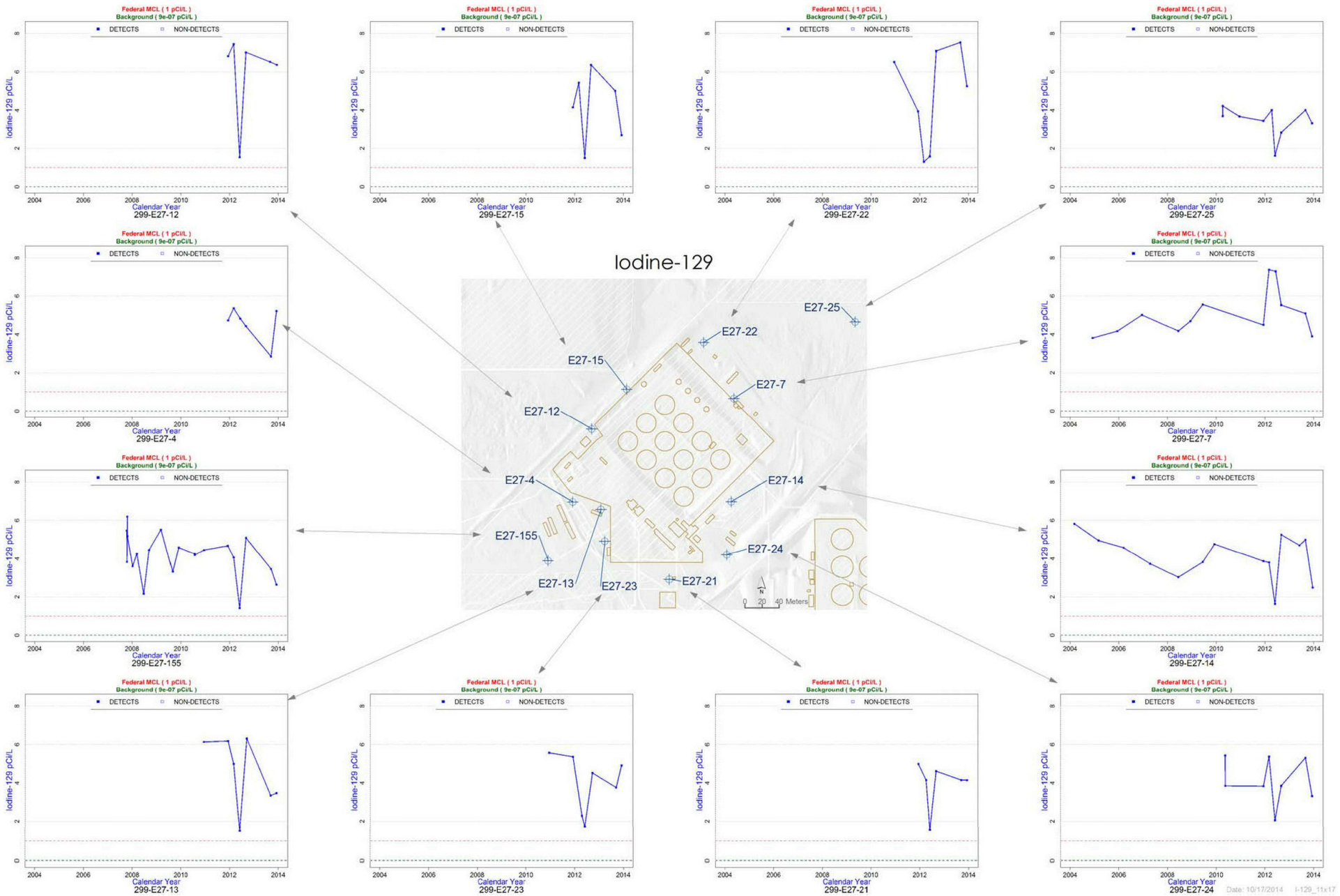
These graphs are cross sections are used to supplement the discussion in Section 5.4 of the document.

Figure U-1. Well-Specific Analytes of Interest in the Vicinity of WMA C (2004 through 2013)



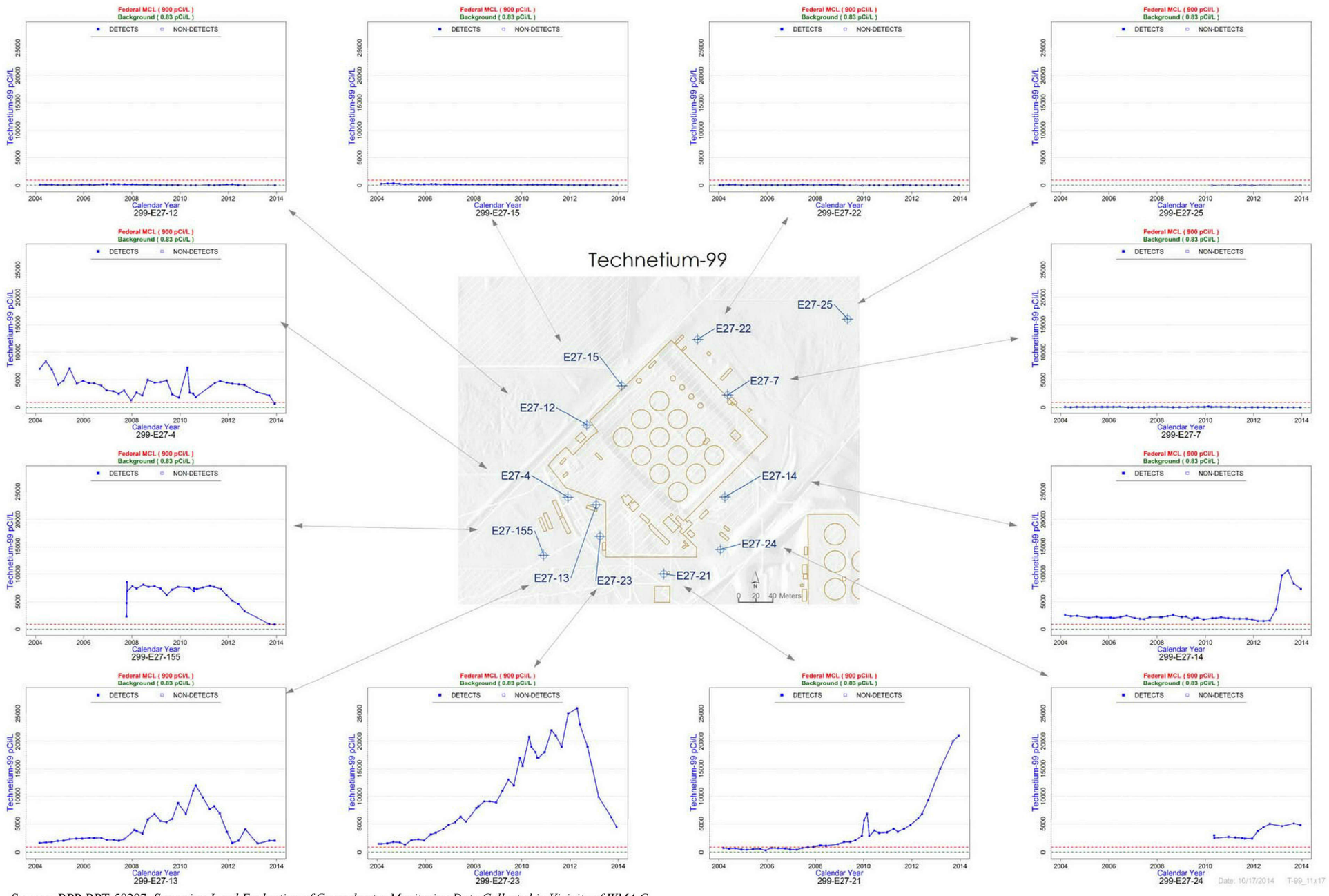
Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C.*

Figure U-2. Iodine-129 Trends in Wells Monitoring the Unconfined Aquifer in the Vicinity of WMA C (2004 through 2013)



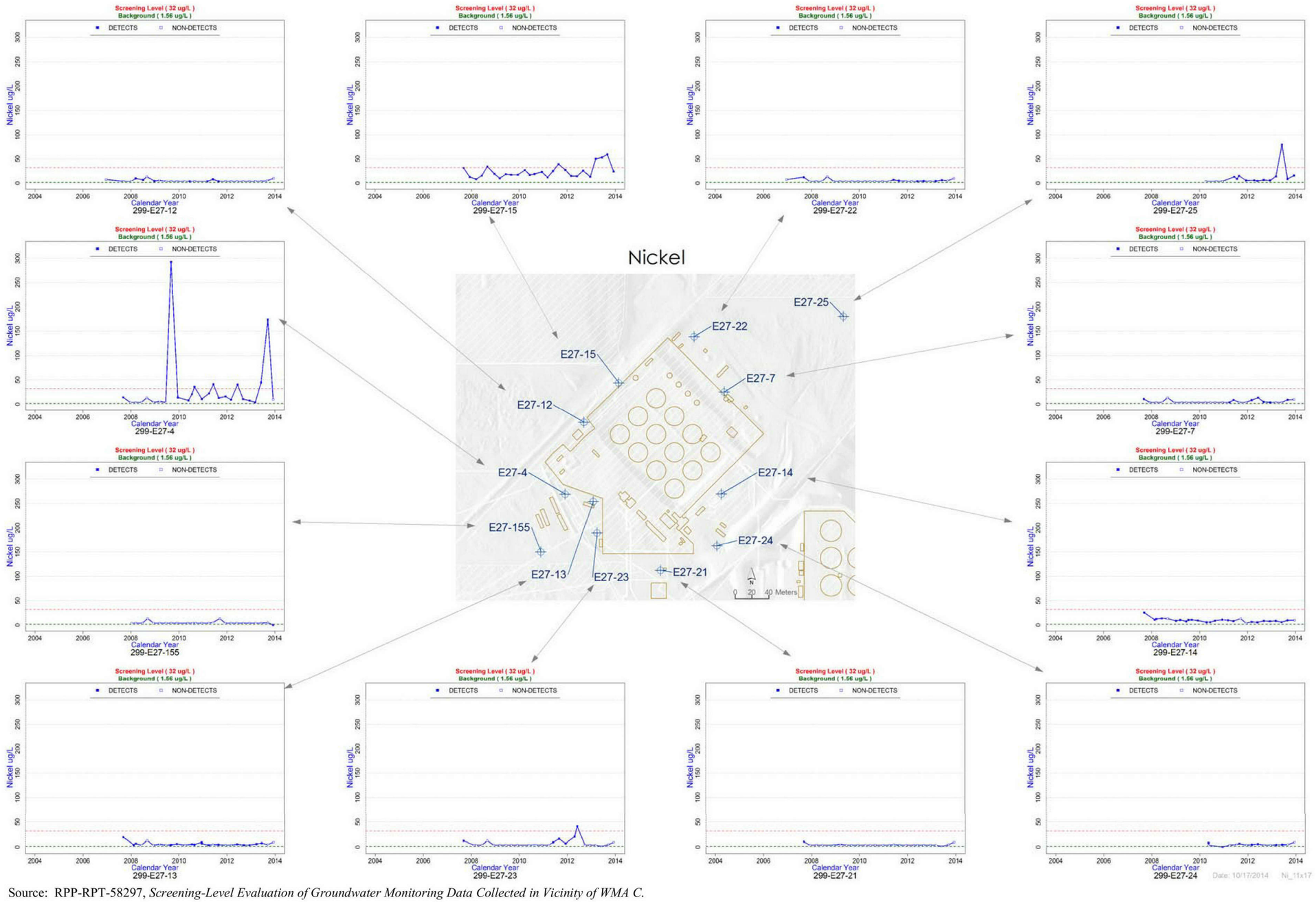
Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C.*

Figure U-3. Technetium-99 Trends in Wells Monitoring the Unconfined Aquifer in the Vicinity of WMA C (2004 through 2013)



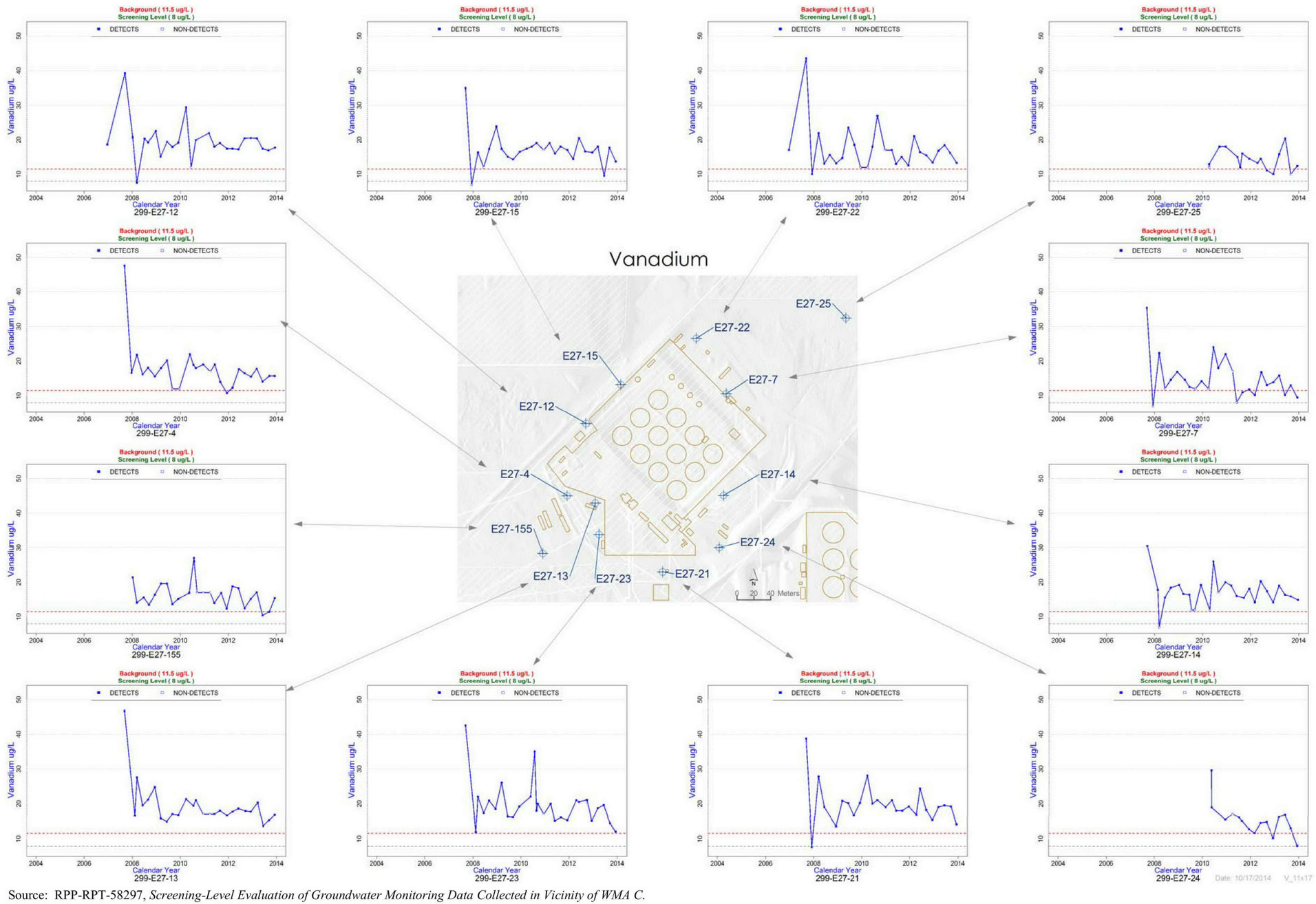
Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C.*

Figure U-4. Nickel Trends in Wells Monitoring the Unconfined Aquifer in the Vicinity of WMA C (2004 through 2013)



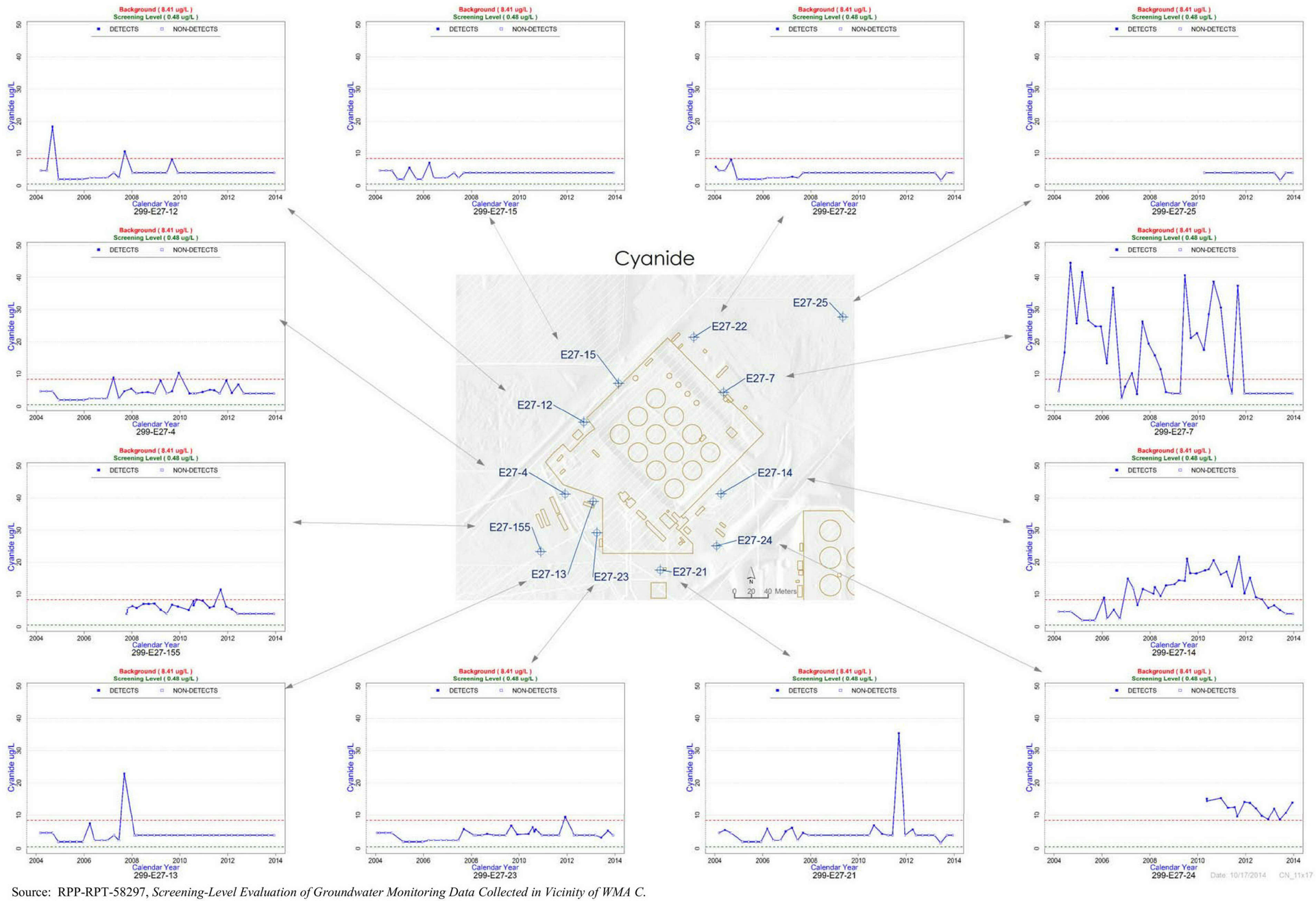
Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C.*

Figure U-5. Vanadium Trends in Wells Monitoring the Unconfined Aquifer in the Vicinity of WMA C (2004 through 2013)



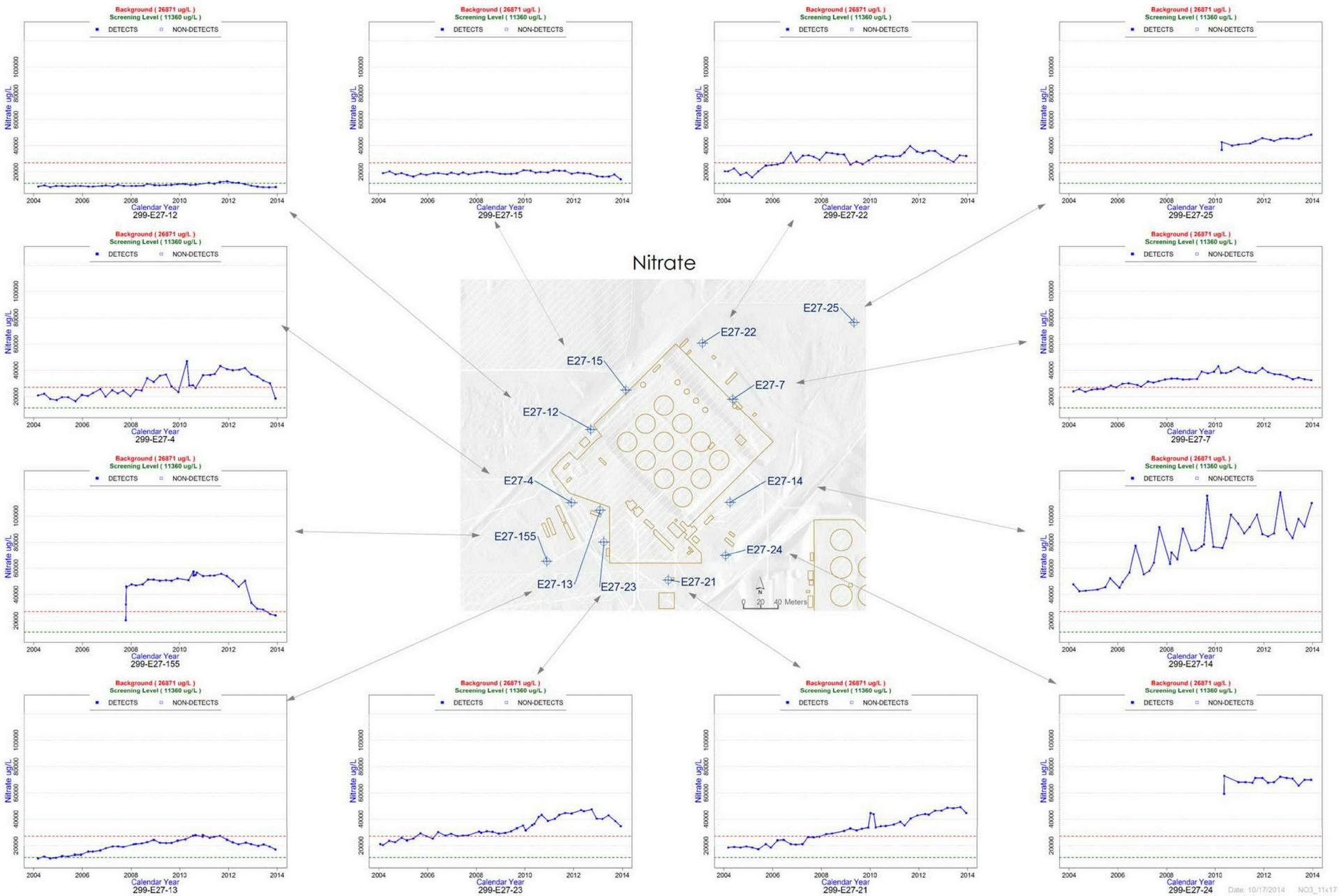
Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C.*

Figure U-6. Cyanide Trends in Wells Monitoring the Unconfined Aquifer in the Vicinity of WMA C (2004 through 2013)



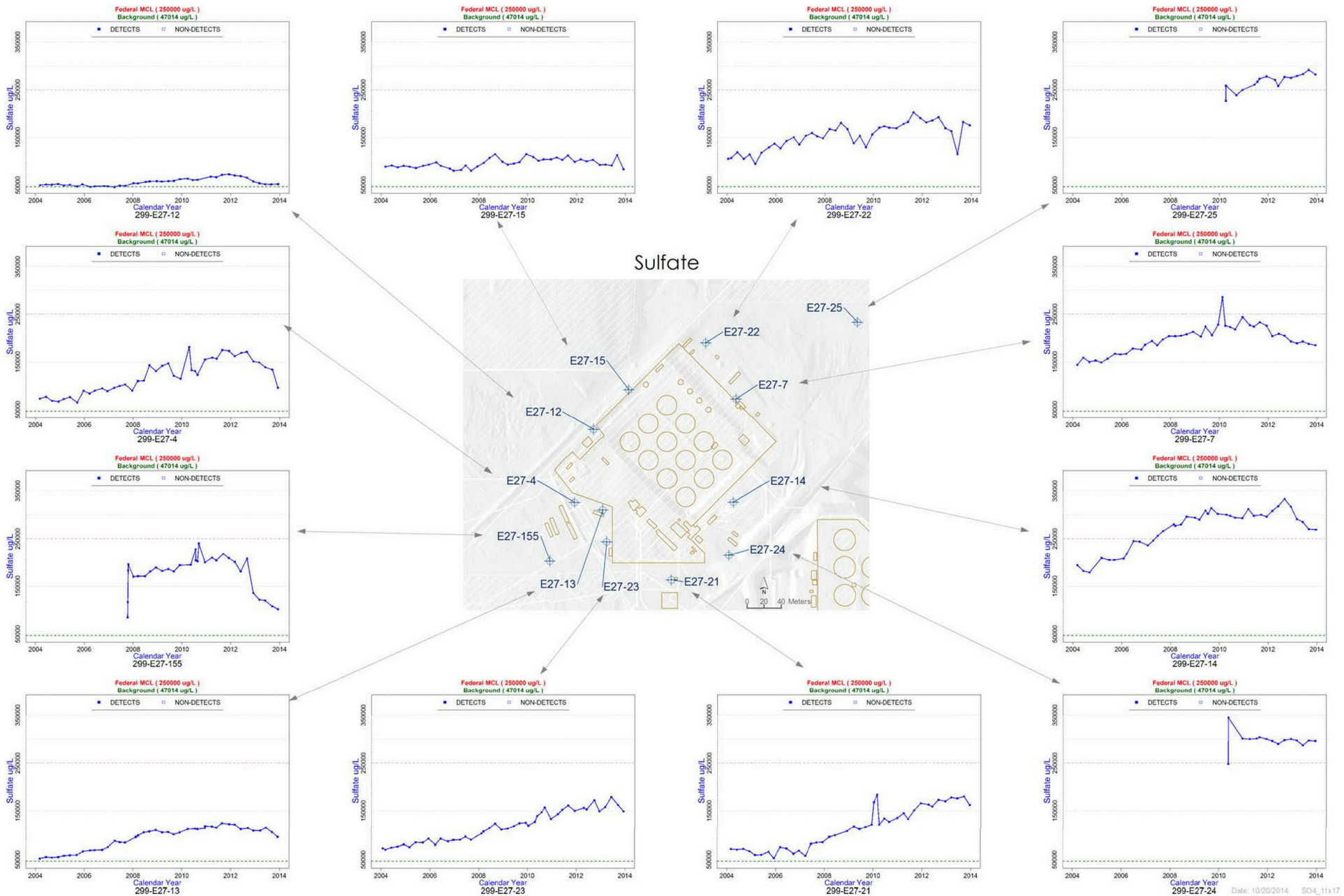
Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C.*

Figure U-7. Nitrate Trends in Wells Monitoring the Unconfined Aquifer in the Vicinity of WMA C (2004 through 2013)



Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C.*

Figure U-8. Sulfate Trends in Wells Monitoring the Unconfined Aquifer in the Vicinity of WMA C (2004 through 2013)



Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C.*

Figure U-9. Nitrate and Technetium-99 Concentrations for Cross-Section L1 to L1'

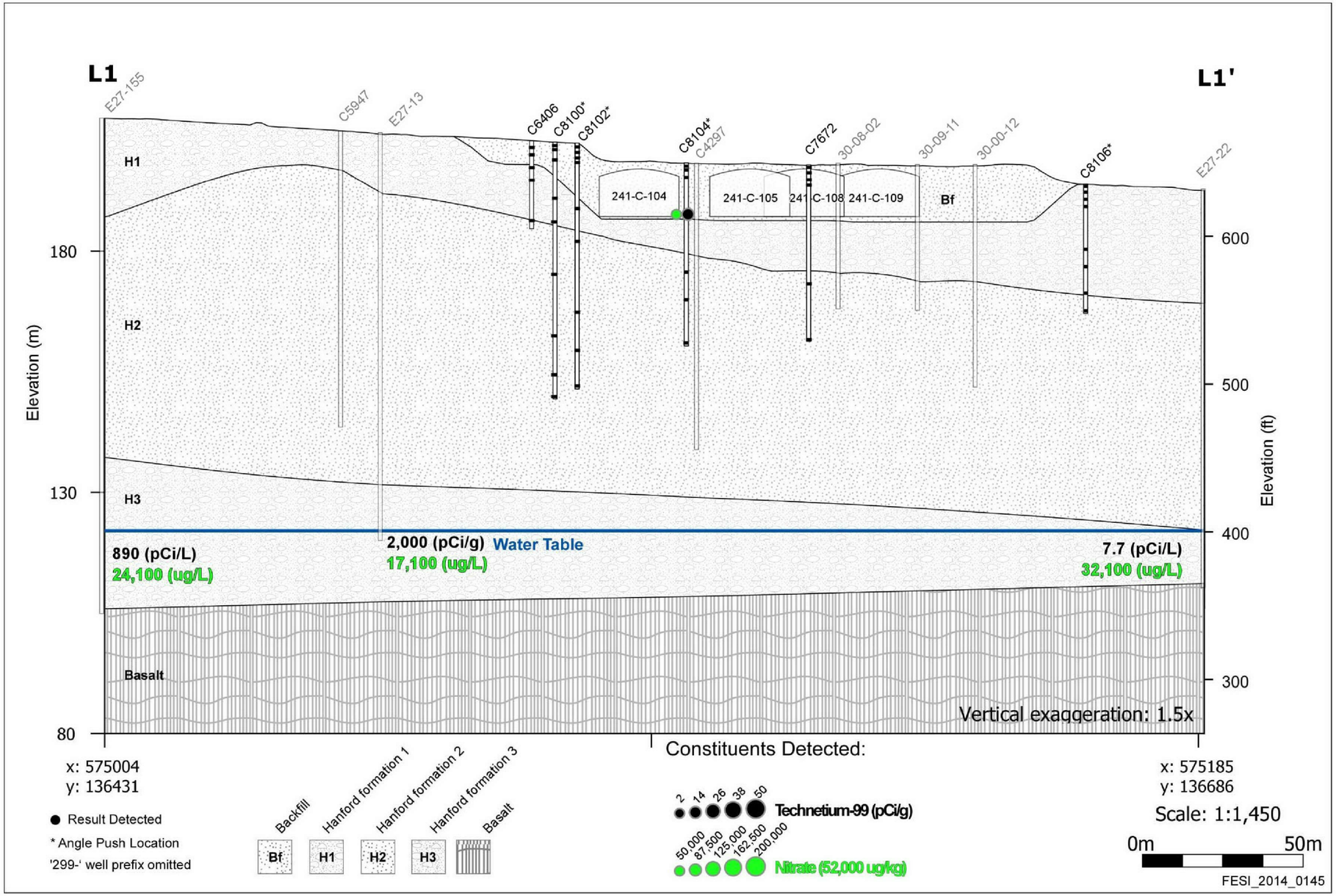


Figure U-10. Cyanide, Iodine-129, Nickel, Sulfate, and Vanadium Concentrations for Cross-Section L1 to L1'

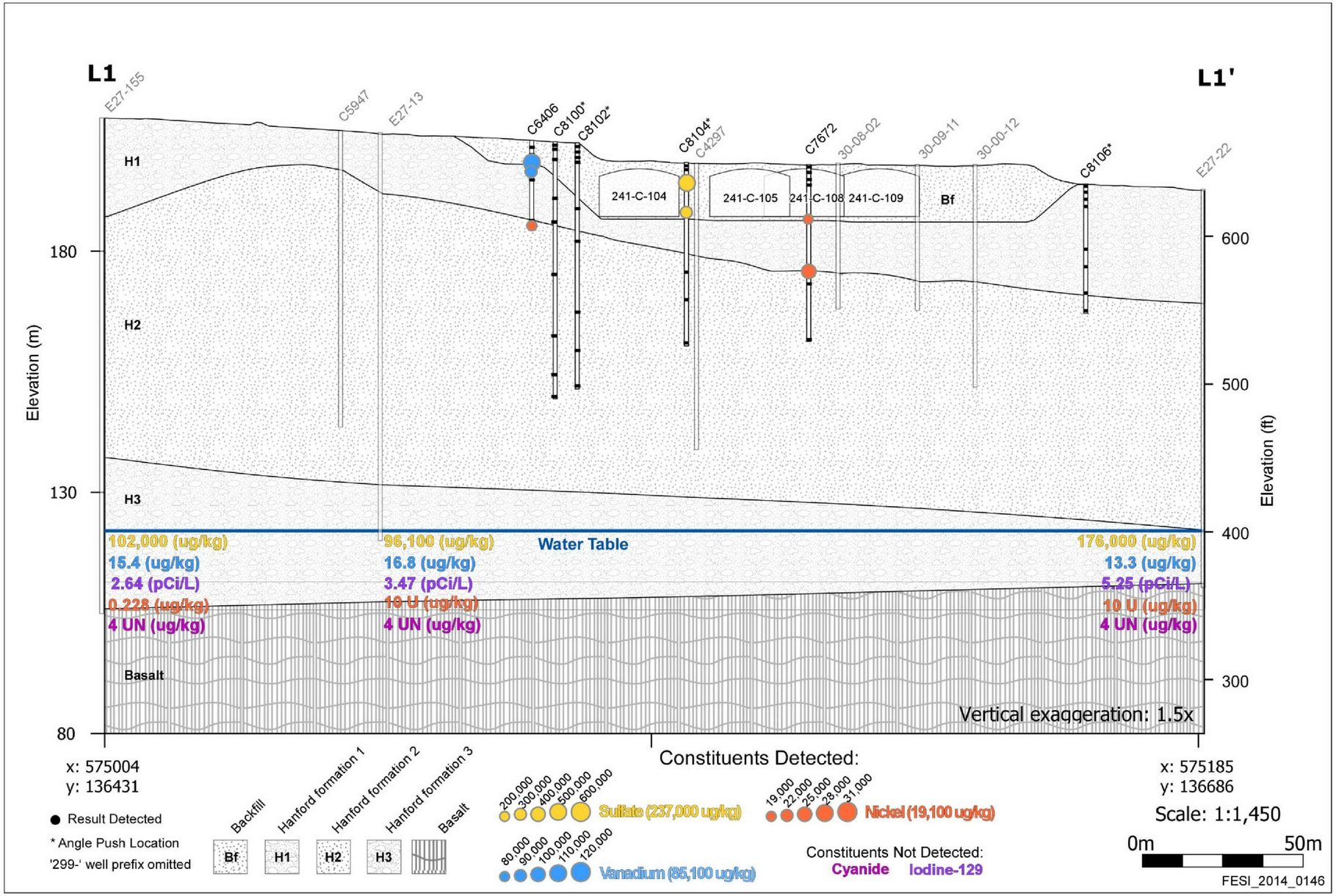


Figure U-11. Nitrate and Technetium-99 for Cross-Section L2 to L2'

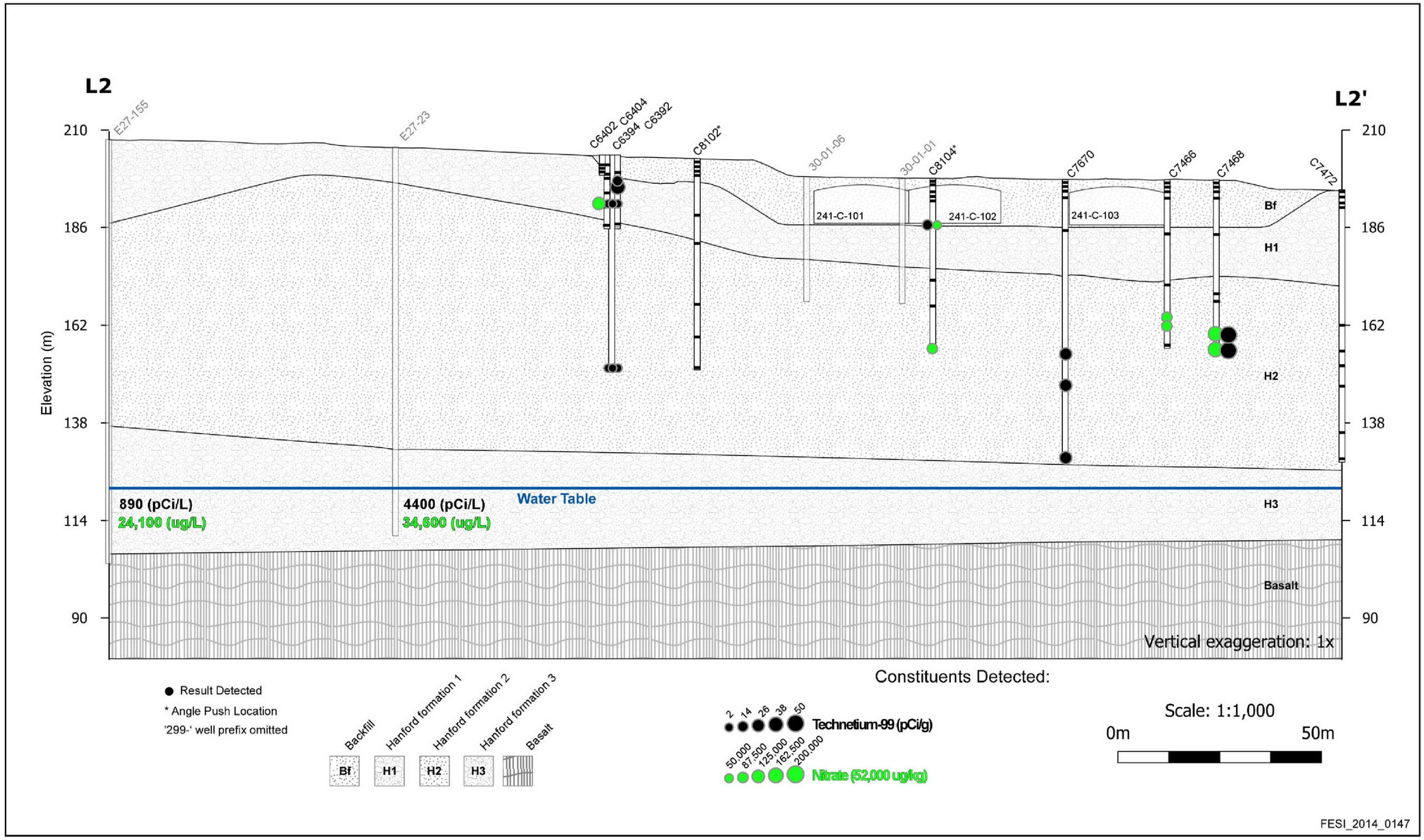


Figure U-12. Cyanide, Iodine-129, Nickel, Sulfate, and Vanadium Concentrations for Cross-Section L2 to L2'

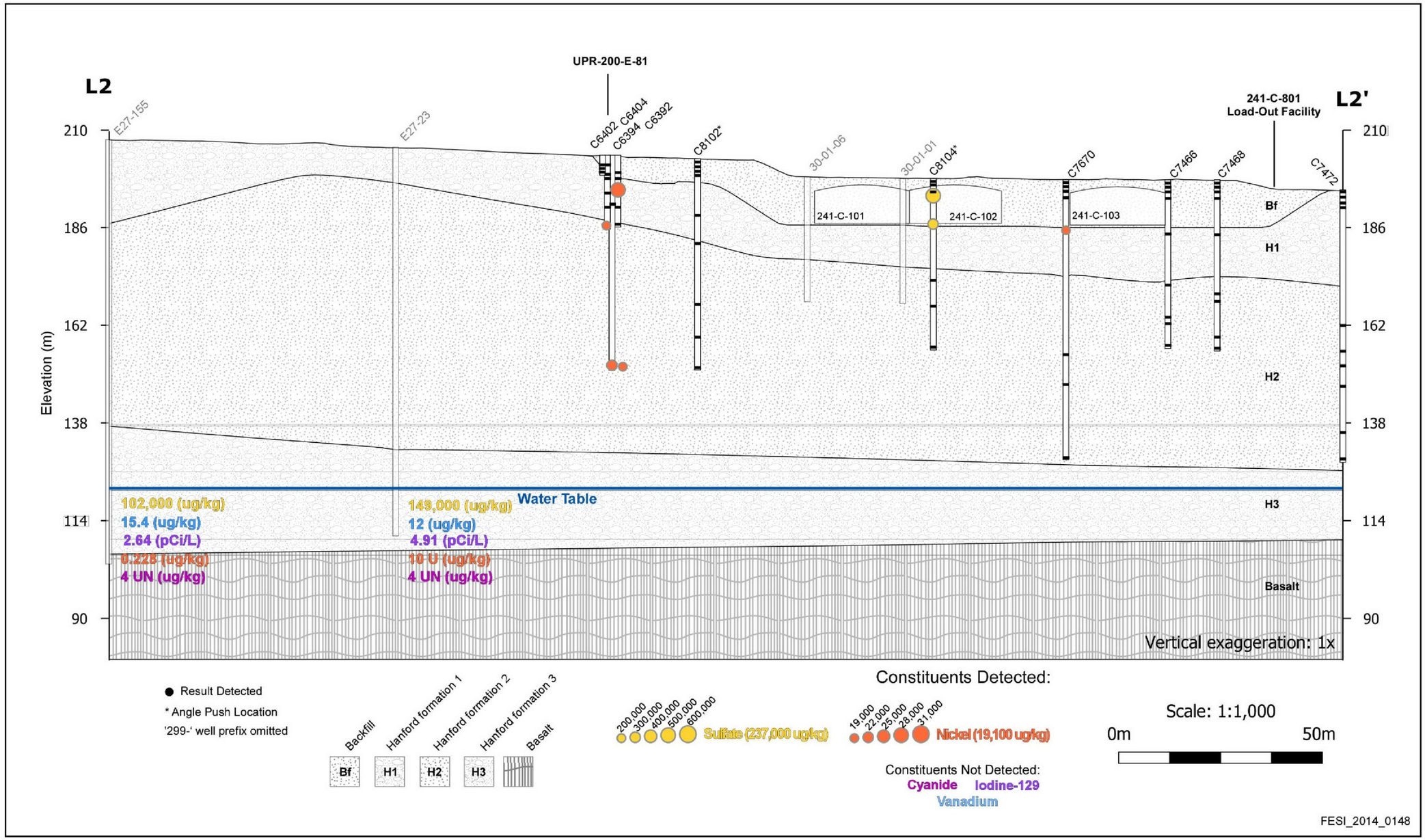


Figure U-13. Nitrate and Technetium-99 Concentrations for Cross-Section L3 to L3'

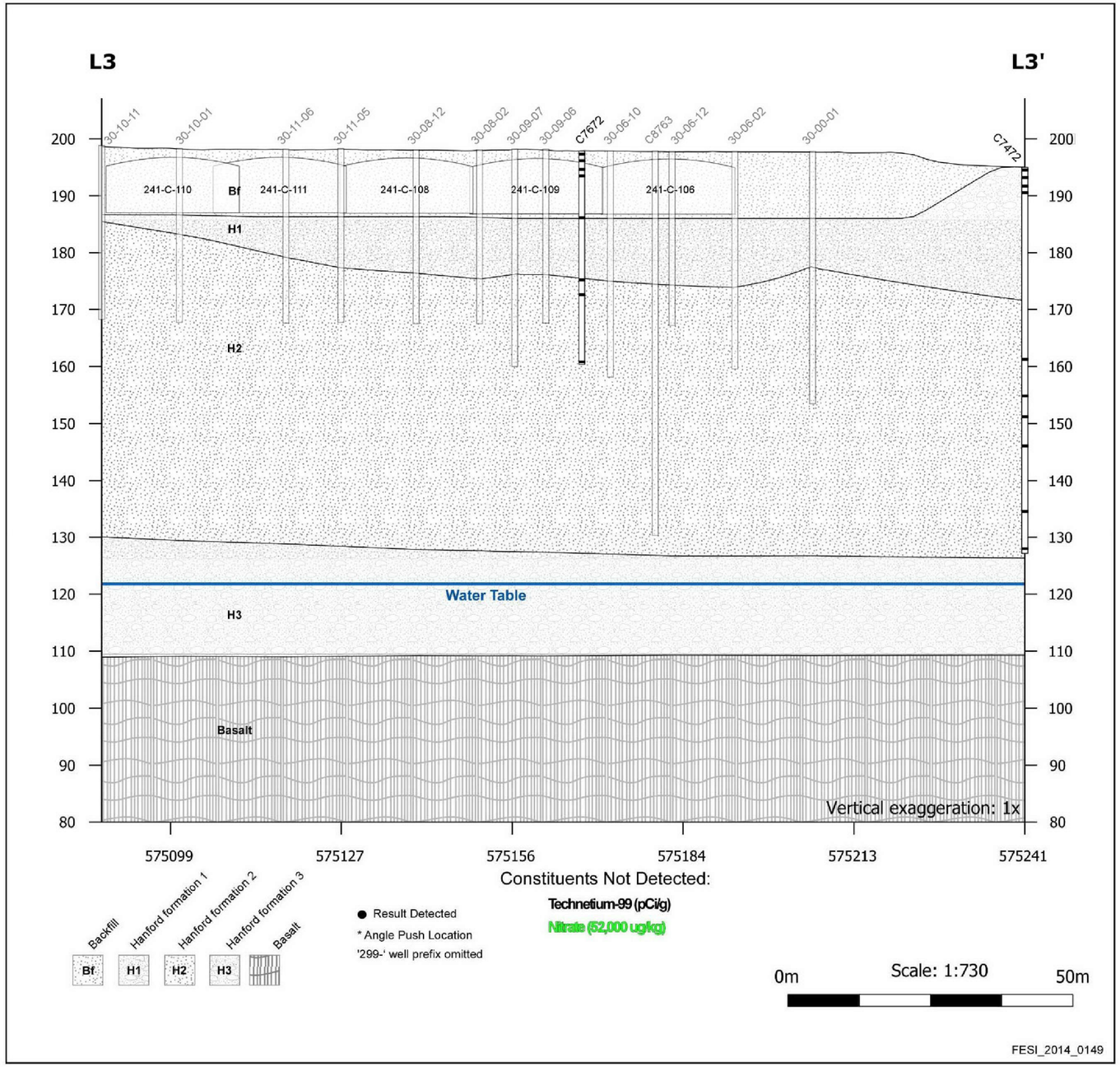


Figure U-14. Cyanide, Iodine-129, Nickel, Sulfate, and Vanadium Concentrations for Cross-Section L3 to L3'

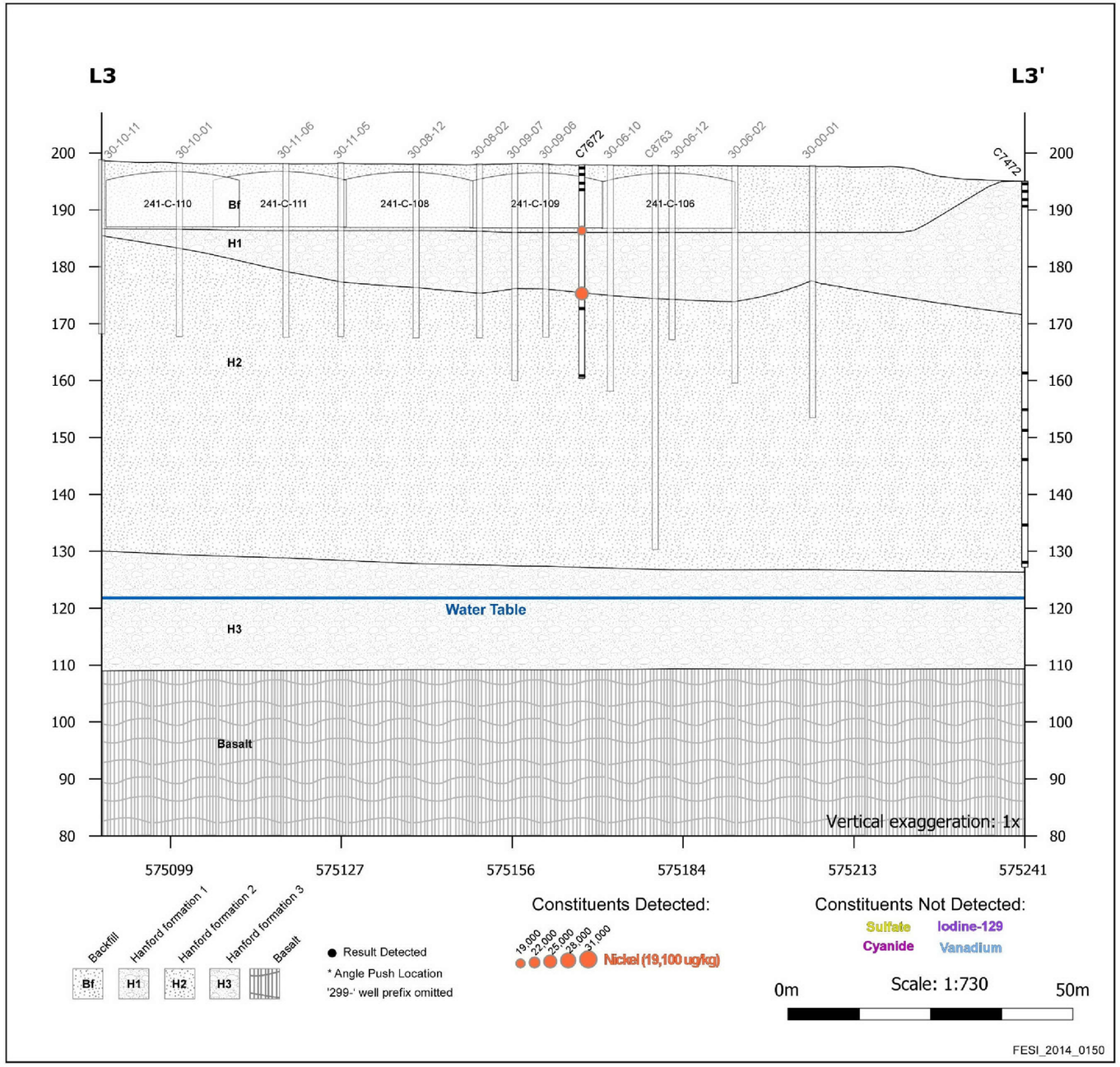


Figure U-15. Nitrate and Technetium-99 Concentrations for Cross-Section L4 to L4'

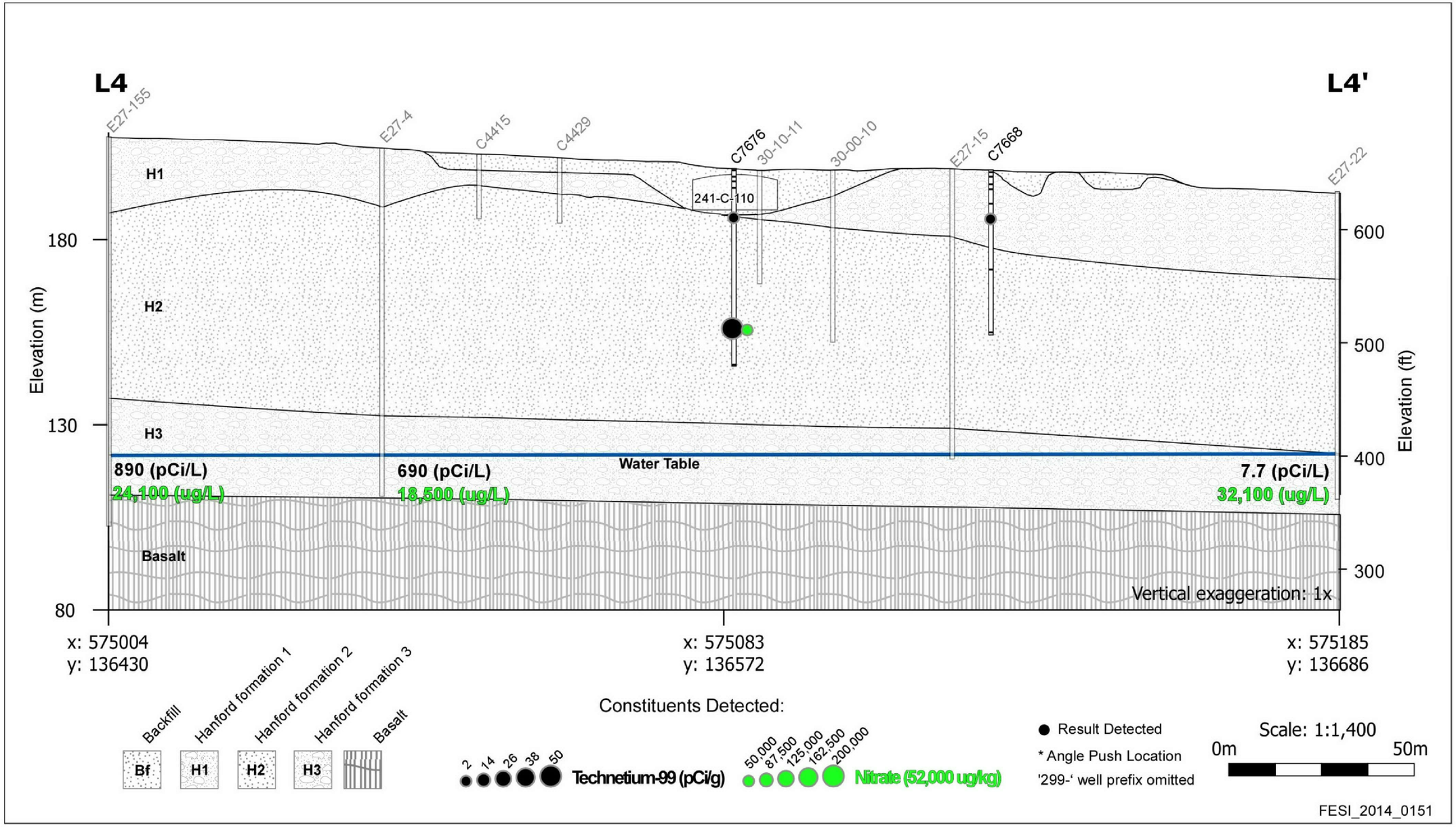


Figure U-16. Cyanide, Iodine-129, Nickel, Sulfate, and Vanadium Concentrations for Cross-Section L4 to L4'

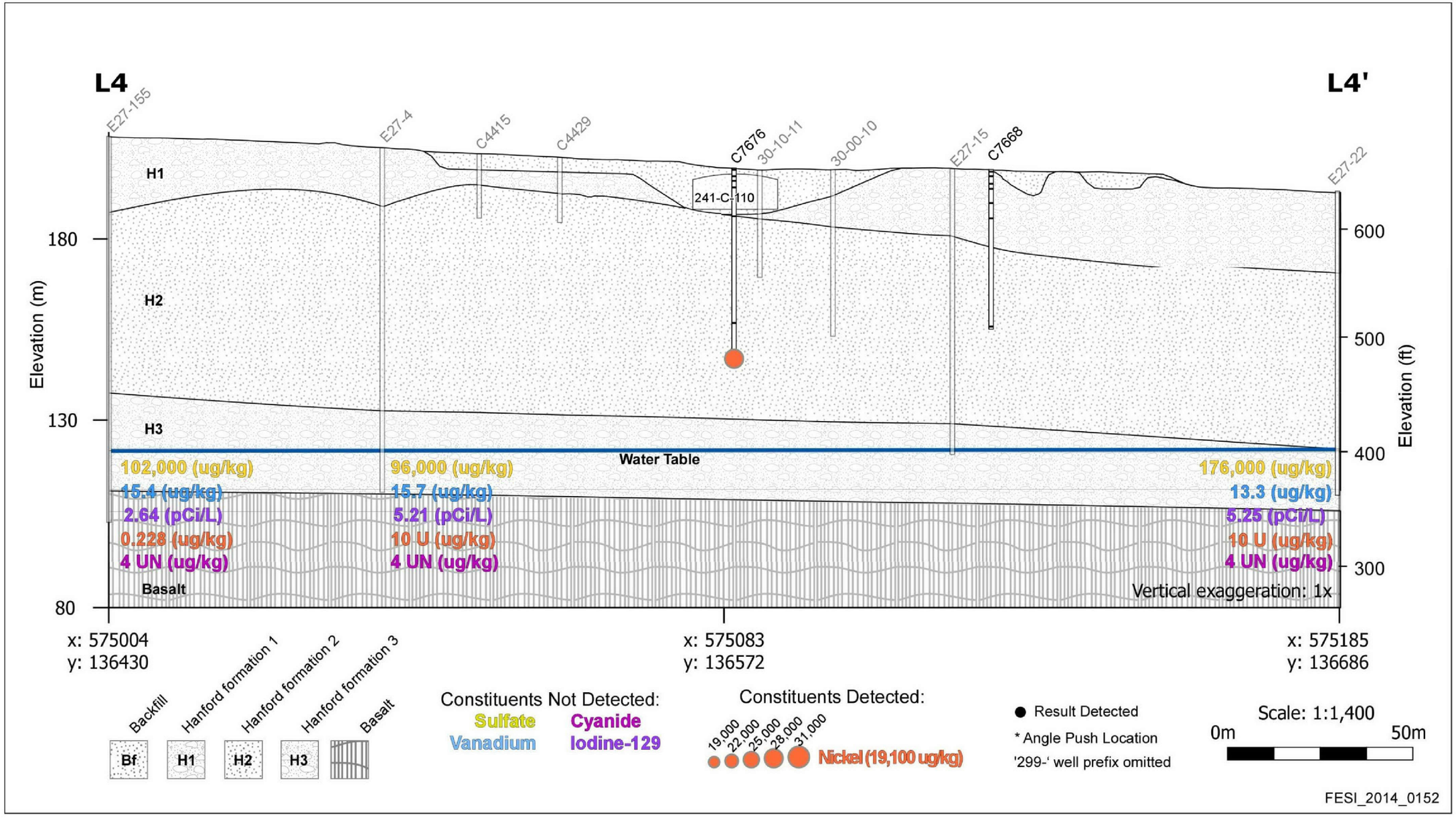


Figure U-17. Nitrate and Technetium-99 Concentrations for Cross-Section L5 to L5'

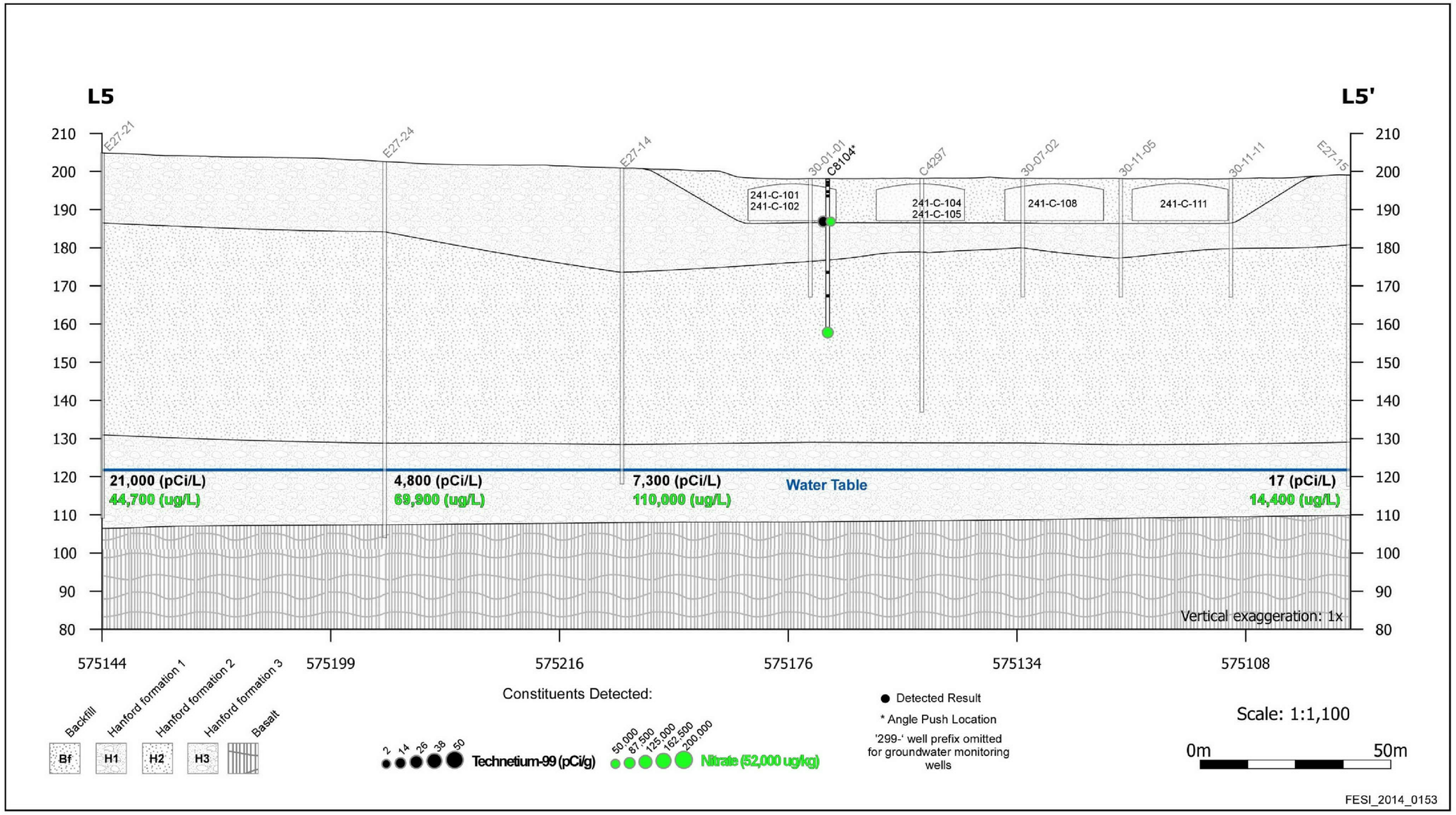


Figure U-18. Cyanide, Iodine-129, Nickel, Sulfate, and Vanadium Concentrations for Cross-Section L5 to L5'

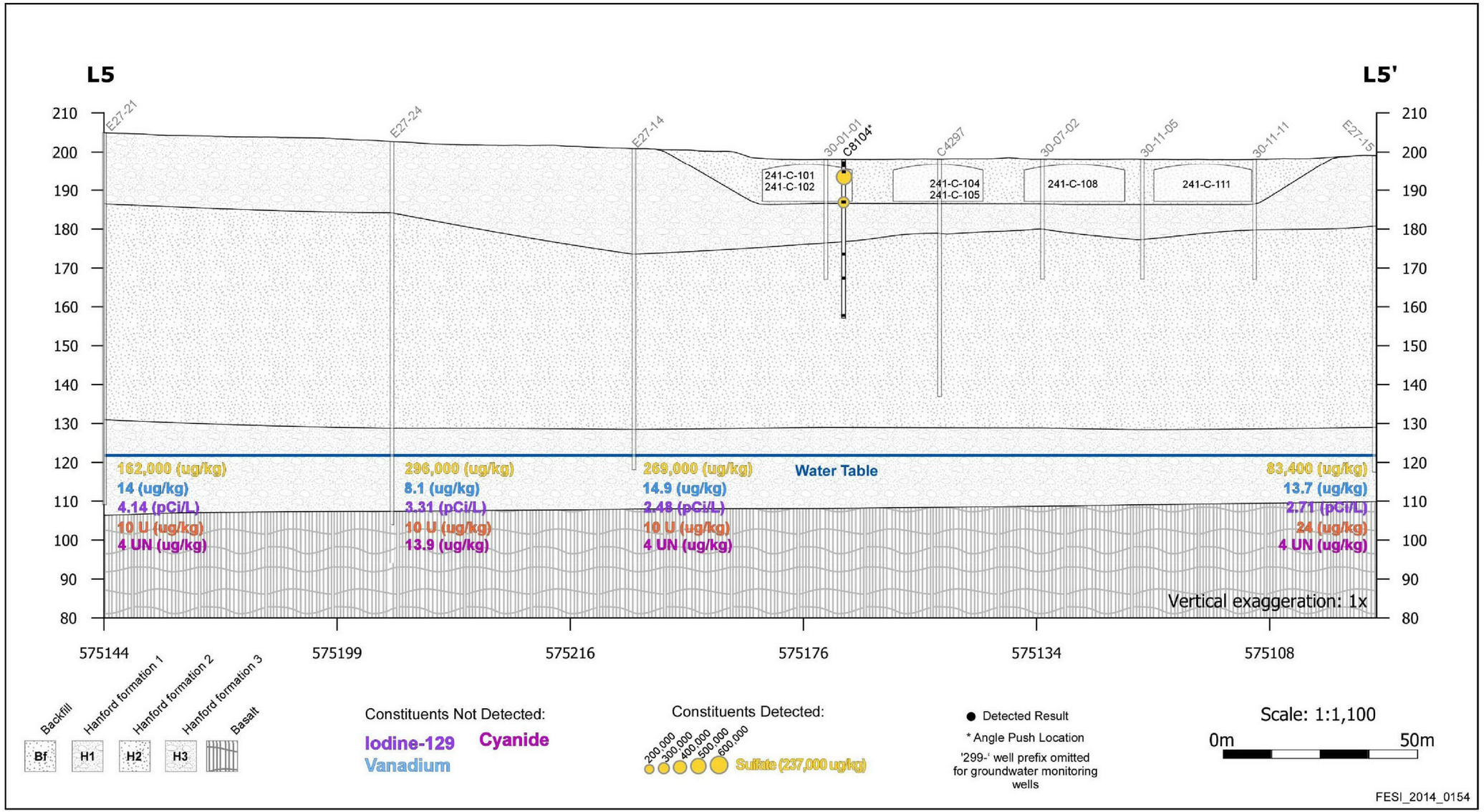


Figure U-19. Nitrate and Technetium-99 Concentrations for Cross-Section L6 to L6'

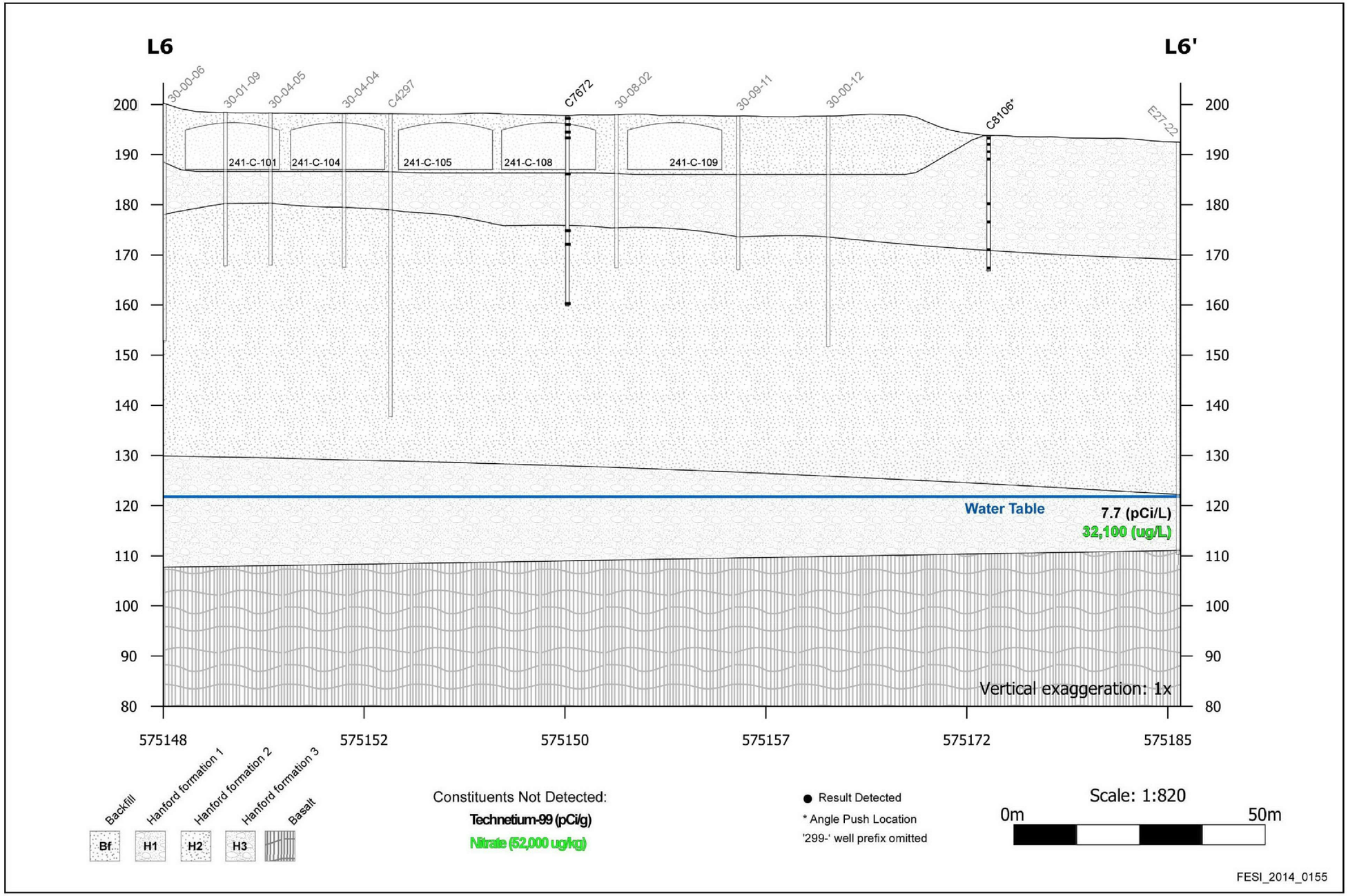
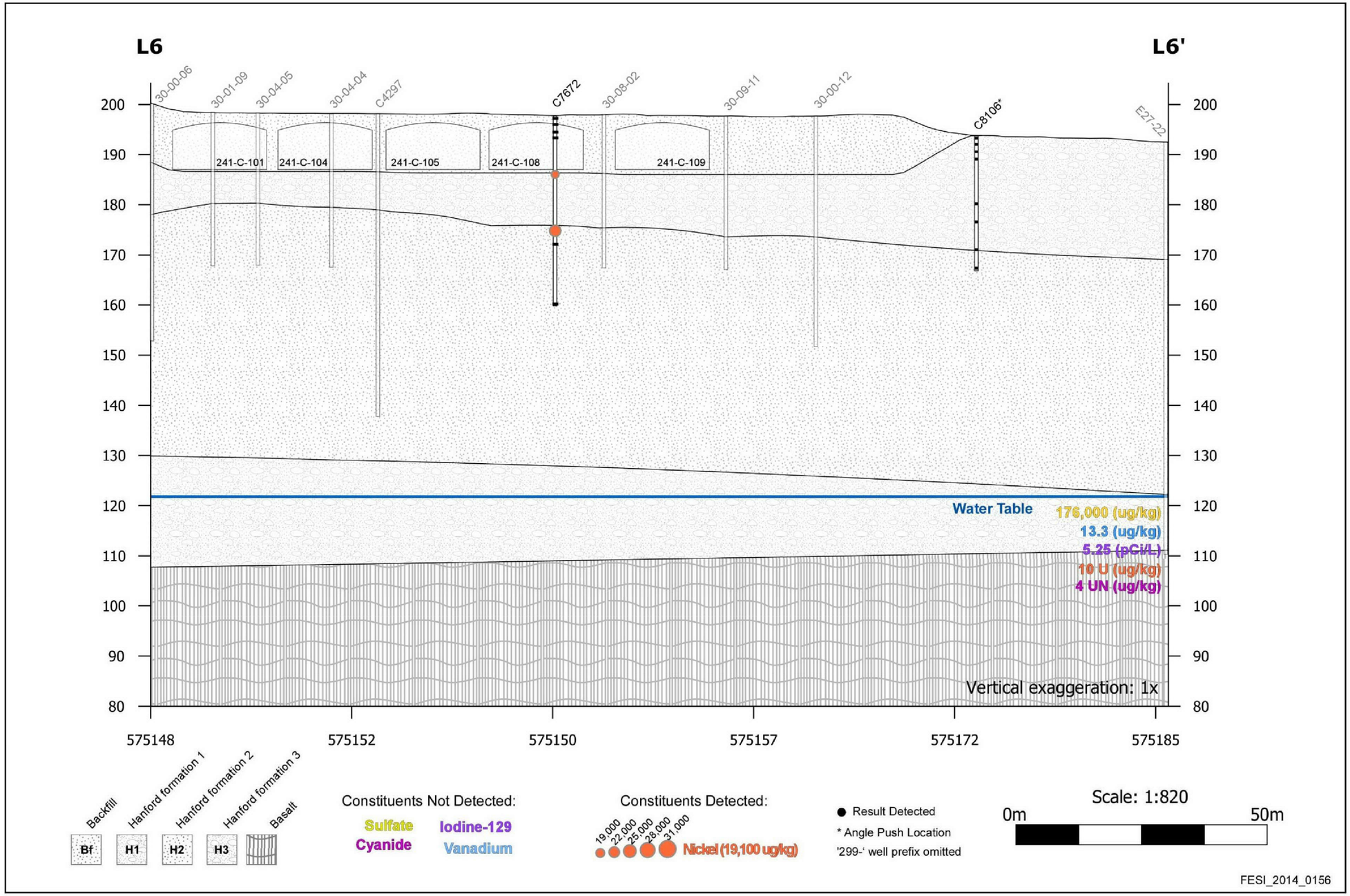


Figure U-20. Cyanide, Iodine-129, Nickel, Sulfate, and Vanadium Concentrations for Cross-Section L6 to L6'



APPENDIX V

SUMMARY OF EXTENT OF SOIL CONTAMINATION FOR SELECT CONSTITUENTS

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APPENDIX V
SUMMARY OF EXTENT OF SOIL CONTAMINATION FOR SELECT CONSTITUENTS

This appendix provides information for the select constituents identified in Section 5.6. Tables V-1 and V-2 present the vertical extent of contamination for select constituents reported above background or reported as detected when no background value is available for comparison (i.e., exceedances). Results are reported by constituent, including analyte-specific Hanford Site background value (if applicable), measurement reporting units, and the frequency of results reported above background (or reported as detected if no available background).

Extent of contamination is expressed in terms of the range of concentrations (minimum, maximum) with corresponding depths, and the extent concentration, which is the maximum depth of concentration above background (or depth of detection if no background available) and its corresponding depth.

Shading in the tables identifies locations with the highest frequency of exceedances and maximum concentrations across all locations sampled.

Figures V-1 and V-2 summarize the occurrence of shallow and deep soil exceedances for the select constituents identified in Section 5.6.

Figures

Figure V-1. Summary of Shallow and Deep Soil Exceedances for Select Radiological Constituents
Figure V-2. Summary of Shallow and Deep Soil Exceedances for Select Inorganic Constituents

Tables

Table V-1. Summary of Extent of Contamination for Select Constituents
Table V-2. Summary of Extent of Contamination for Select Constituents by Investigation Site/Group

Table Heading Descriptions

Column Heading	Description
Investigation Group	Identifies the Investigation Group for which the results are reported
Analyte	Analyte Name
Background Value	Hanford Site Background Value
Units	Analytical Units of Background/Result reported
Frequency greater than background	Number of results exceeding background (or detected if no background available) over the total number of results reported.

Table Heading Descriptions

Column Heading	Description
decimal frequency	Frequency greater than background reported as a decimal value
Minimum Concentration	Minimum concentration reported by location
Minimum Concentration Depth (ft bgs)	Depth where minimum concentration was encountered
Maximum Concentration	Maximum concentration reported by location
Maximum Concentration Depth (ft bgs)	Depth where maximum concentration was encountered
Extent Concentration	Value of the deepest detected result (or deepest result above background if all results were non-detect)
Extent Depth (ft bgs)	Depth of the deepest detected result

Result Qualifier Descriptions

Qualifier	Description
B	INORGANICS/WETCHEM: The analyte was detected at value less than the contract required detection limit (RDL), but greater than or equal to the IDL/MDL (as appropriate) ORGANICS: The analyte was detected in both the associated QC blank and in the sample RADIONUCLIDES: The associated QC sample blank has a result greater than or equal to the MDA, and after corrections, the result is greater than or equal to the MDA for this sample.
C	INORGANICS/WETCHEM: The analyte was detected in both the sample and the associated QC blank and the sample concentration was less than or equal to 5X the blank concentration
E	(1) Concentration exceeds the calibration range of the instrument, or (2) Reported value is estimated due to interferences. See comment in narrative.
J	Estimated value; see case narrative for more detail
J-	(1) Estimated value due to low LCS Recovery, or (2) The sample was analyzed out of hold time but before 2X hold time
M	Duplicate precision criteria not met
N	Spike and/or duplicate sample recovery is outside control limits
T	Spike and/or spike duplicate sample recovery is outside of control limits
U	Analyzed for but not detected above limiting criteria
X	The result-specific translation of this qualifier code is provided in the hardcopy data report and/or case narrative.
Y	Same as X flag if more than one flag is required

Figure V-1. Summary of Shallow and Deep Soil Exceedances for Select Radiological Constituents

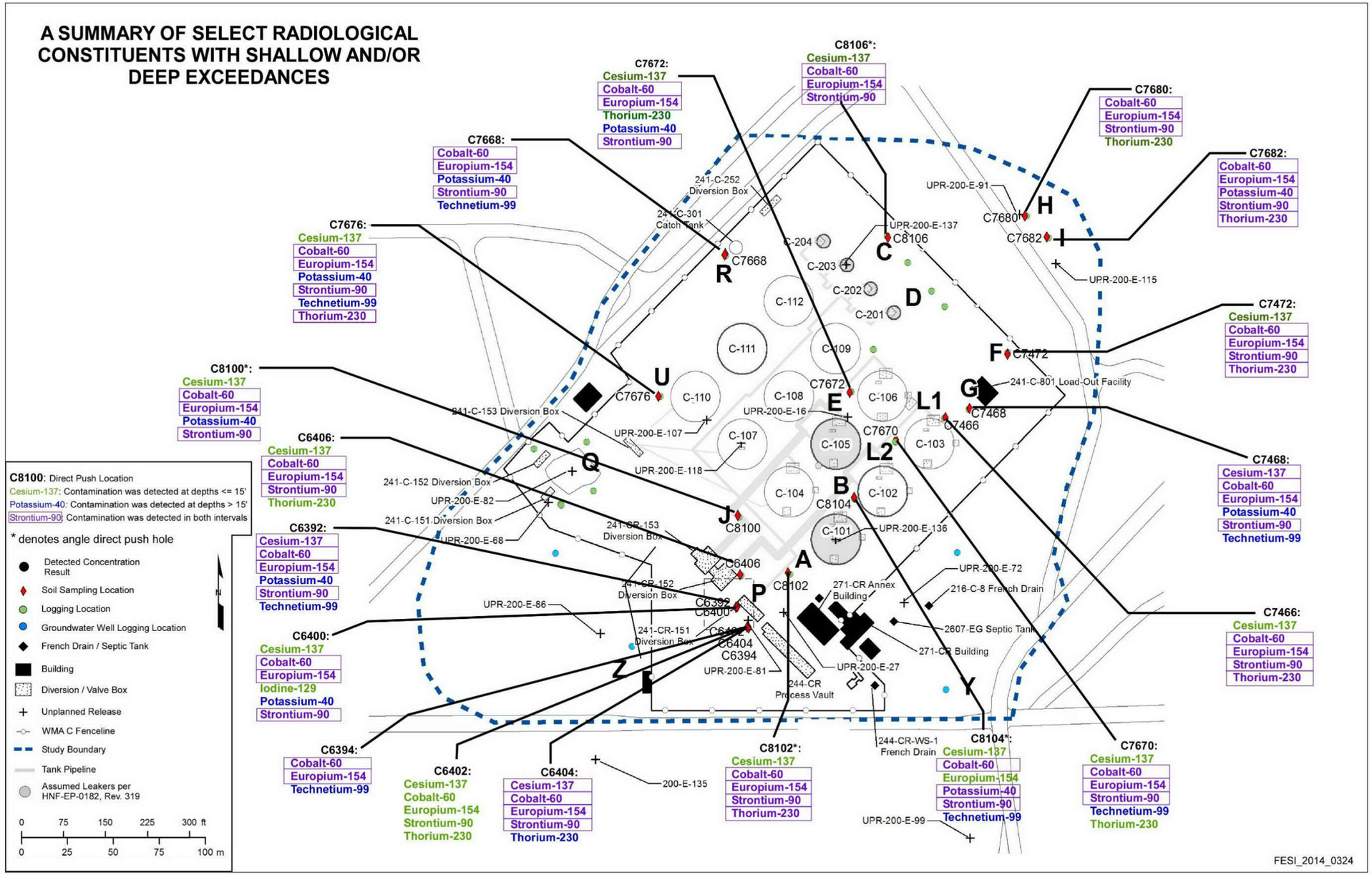

Figure V-2. Summary of Shallow and Deep Soil Exceedances for Select Inorganic Constituents

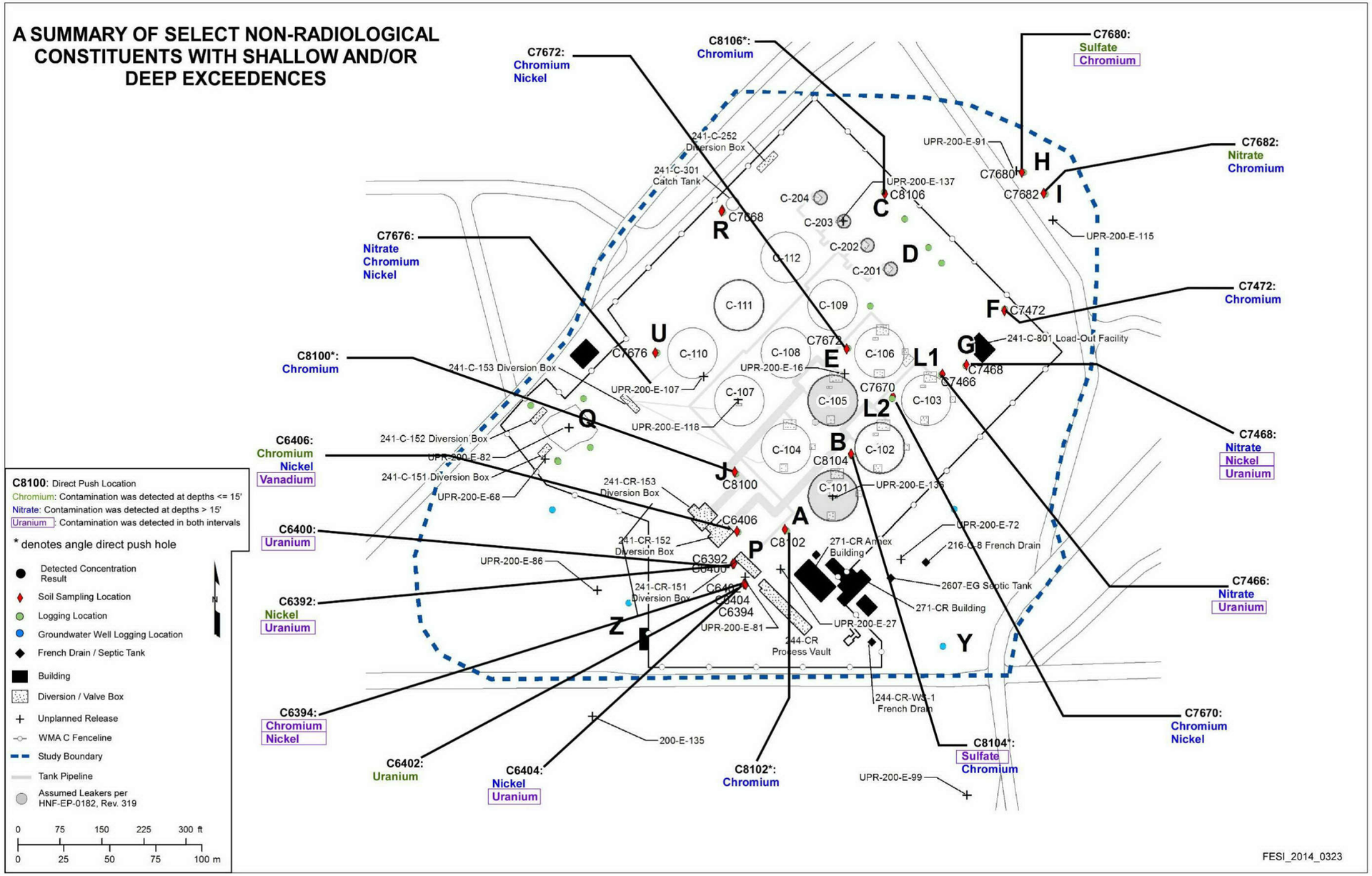

Table V-1. Summary of Extent of Contamination for Select Constituents

IG	Analyte	Background Value	Units	Frequency greater than background	Minimum Concentration	Minimum Concentration Depth (ft bgs)	Maximum Concentration	Maximum Concentration Depth (ft bgs)	Extent Concentration	Extent Depth (ft bgs)
C	Calcium	17200000	ug/kg	1/9	7520000	45.6	17500000	6.5	17500000	6.5
A+B	Calcium	17200000	ug/kg	1/19	6620000	169.7	32200000	36.0	32200000	36.0
F+G	Calcium	17200000	ug/kg	1/21	4800000	217	19600000	6	19600000	6
P	Cesium-137	1.1	pCi/g	13/30	0.292 U	133.3	73.1	15	1.64	43
U	Cesium-137	1.1	pCi/g	2/8	0.486 U	158	2.06	0.5	2.06	0.5
F+G	Cesium-137	1.1	pCi/g	5/21	0.235 U	126	4.75	0.5	0.555	44.5
C	Cesium-137	1.1	pCi/g	2/9	0.104 U	11.5	7.09	0.5	7.09	0.5
E	Cesium-137	1.1	pCi/g	2/9	0.374 U	38	5.13	0.5	5.13	0.5
A+B	Cesium-137	1.1	pCi/g	4/19	-0.036 U	11.1	27.7	0.5	27.7	0.5
L1+L2	Cesium-137	1.1	pCi/g	4/19	0.181 U	0.5	7.52	0.5	0.444	6
J	Cesium-137	1.1	pCi/g	2/10	0.066 U	173.3	5.71	0.5	5.71	0.5
C	Chromium	18500	ug/kg	3/9	8700	0.5	22200	16.5	21400	87.8
E	Chromium	18500	ug/kg	3/9	7440	0.5	29800	38	20300	123
A+B	Chromium	18500	ug/kg	5/19	5970 B	14.1	27700	81.4	26400	137.0
H+I	Chromium	18500	ug/kg	5/19	5340 M	11	28700 M	93	28700 M	93
P	Chromium	18500	ug/kg	5/30	4470 0	11	32700	169	32700	169
L1+L2	Chromium	18500	ug/kg	3/19	6960 MJ	0.5	32200	222	32200	222
F+G	Chromium	18500	ug/kg	3/21	4740	15	22100	217	22100	217
U	Chromium	18500	ug/kg	1/8	7260	0.5	44500	158	44500	158
J	Chromium	18500	ug/kg	1/10	8490	0.5	27400	173.3	27400	173.3
C	Cobalt-60	0.0084	pCi/g	9/9	0.0614 U	16.5	0.134 U	57.3	0.13 U	87.8
E	Cobalt-60	0.0084	pCi/g	9/9	0.304 U	38	0.384 U	6	0.305 U	123
F+G	Cobalt-60	0.0084	pCi/g	21/21	0.206 U	126	0.411 U	98	0.261 U	217
H+I	Cobalt-60	0.0084	pCi/g	19/19	0.277 U	0.5	0.446 U	0.5	0.304 U	143
J	Cobalt-60	0.0084	pCi/g	10/10	0.0795 U	131.8	0.101 U	0.5	0.0858 U	173.3
L1+L2	Cobalt-60	0.0084	pCi/g	19/19	0.162 U	0.5	0.497 U	110.5	0.274 U	222
P	Cobalt-60	0.0084	pCi/g	30/30	0.2 U	11	3.13 U	7	0.309 U	169
R	Cobalt-60	0.0084	pCi/g	7/7	0.27 U	81	0.337 U	0.5	0.297 U	133
U	Cobalt-60	0.0084	pCi/g	8/8	0.338 U	0.5	0.463 U	129	0.346 U	158
A+B	Cobalt-60	0.0084	pCi/g	16/19	-0.017 U	5.1	0.157 U	118.7	0.0712 U	169.7
C	Europium-154	0.033	pCi/g	9/9	0.235 U	11.5	0.411 U	57.3	0.363 U	87.8
E	Europium-154	0.033	pCi/g	9/9	0.95 U	123	1.24 U	6	0.95 U	123
F+G	Europium-154	0.033	pCi/g	21/21	0.641 U	126	1.09 U	98	0.806 U	217
H+I	Europium-154	0.033	pCi/g	19/19	0.884 U	143	1.46 U	6	0.884 U	143
J	Europium-154	0.033	pCi/g	10/10	0.122 U	131.8	0.165 U	38.8	0.131 U	173.3
L1+L2	Europium-154	0.033	pCi/g	19/19	0.539 U	0.5	1.48 U	115	0.896 U	222
P	Europium-154	0.033	pCi/g	30/30	0.631 U	11	9.45 U	11	1.05 U	169
R	Europium-154	0.033	pCi/g	7/7	0.847 U	16	1.03 U	40	0.939 U	133
U	Europium-154	0.033	pCi/g	8/8	1.04 U	16	1.49 U	129	1.17 U	158
A+B	Europium-154	0.033	pCi/g	14/19	-0.064 U	36.0	0.305 U	0.5	0.0775 U	169.7
P	Iodine-129	no background	pCi/g	1/25	0.114 U	11	0.808 B	6	0.808 B	6.0
E	Nickel	19100	ug/kg	2/9	7820 B	6	25300	74	25300	74
P	Nickel	19100	ug/kg	5/30	6710 0	7	30600 J	26	22400 B	169
U	Nickel	19100	ug/kg	1/8	6680 B	11	29400	158	29400	158
L1+L2	Nickel	19100	ug/kg	1/19	7330	11	20200 MJ	40	20200 MJ	40
U	Nitrate	52000	ug/kg	1/8	4490	158	71600	129	71600	129
H+I	Nitrate	52000	ug/kg	2/19	2750	11	54600	0.5	53000	0.5
L1+L2	Nitrate	52000	ug/kg	2/19	1920 B	15	90300	115	90300	115
F+G	Nitrate	52000	ug/kg	2/21	1940 B	93	192000	126	173000	136

Table V-1. Summary of Extent of Contamination for Select Constituents

IG	Analyte	Background Value	Units	Frequency greater than background	Minimum Concentration	Minimum Concentration Depth (ft bgs)	Maximum Concentration	Maximum Concentration Depth (ft bgs)	Extent Concentration	Extent Depth (ft bgs)
P	Nitrate	52000	ug/kg	1/31	3060 0	60	143000 M	43	143000 M	43.0
C	Potassium-40	17	pCi/g	9/9	9.95	11.5	15.8	87.8	15.8	87.8
A+B	Potassium-40	17	pCi/g	6/19	6.63 X	0.5	31	81.4	12.6	169.7
H+I	Potassium-40	17	pCi/g	3/15	8.09	11	20	0.5	17	93
U	Potassium-40	17	pCi/g	1/6	8.84	0.5	21.7	158	21.7	158
P	Potassium-40	17	pCi/g	3/19	7.9	32	19.4	57	17	169
E	Potassium-40	17	pCi/g	1/7	7.62	38	17.6	84	17.6	84
R	Potassium-40	17	pCi/g	1/7	8.93	28	18.1	81	18.1	81
J	Potassium-40	17	pCi/g	1/10	9.26	0.5	17.4	90.1	13.4	173.3
F+G	Potassium-40	17	pCi/g	1/21	8.72	15	19.1	126	19.1	126
P	Sodium	690000	ug/kg	8/30	140000 B	58	1930000	15	888000	43
E	Sodium	690000	ug/kg	1/9	185000	74	972000	38	972000	38
E	Strontium-90	0.18	pCi/g	9/9	0.183 U	38	2.5	0.5	0.647 U	123
F+G	Strontium-90	0.18	pCi/g	21/21	0.182 U	130	4.06 UJ	6	0.19 U	217
H+I	Strontium-90	0.18	pCi/g	19/19	0.182 U	6	0.713 U	89	0.208 U	143
J	Strontium-90	0.18	pCi/g	10/10	0.247 U	157.7	4.01	0.5	0.735 U	173.3
L1+L2	Strontium-90	0.18	pCi/g	19/19	0.117	6	4.01 J	0.5	0.64 U	222
P	Strontium-90	0.18	pCi/g	25/25	1.44 U	20.5	141	11	3.53 U	133.3
R	Strontium-90	0.18	pCi/g	7/7	0.26 U	133	1.19 U	0.5	0.26 U	133
U	Strontium-90	0.18	pCi/g	8/8	0.201 U	39	4.2	0.5	0.271 U	158
C	Strontium-90	0.18	pCi/g	8/9	0.169 U	87.8	3	0.5	0.208 U	75.5
A+B	Strontium-90	0.18	pCi/g	15/19	0.14 U	81.4	24 J	0.5	0.537 U	169.7
H+I	Sulfate	237000	ug/kg	1/19	2590 B	0.5	458000	11	458000	11
A+B	Sulfate	237000	ug/kg	2/19	620 U	0.5	592000	14.2	366000	36.0
P	Technetium-99	no background	pCi/g	8/30	2.14 Y	169	45.5 Y	20.5	6.07 Y	169
U	Technetium-99	no background	pCi/g	2/8	2.55 U	0.5	53.5 Y	129	53.5 Y	129
L1+L2	Technetium-99	no background	pCi/g	3/19	5.25 U	12	76 BYUJ	115	28.4 Y	222
R	Technetium-99	no background	pCi/g	1/9	5.1 U	81	30.1 U	12	6.45 B	40
F+G	Technetium-99	no background	pCi/g	2/21	5.27 U	0.5	54.6 Y	126	50.1 Y	136
A+B	Technetium-99	no background	pCi/g	1/19	0.0171 U	0.5	16.2	36.0	3.1	137.0
U	Thorium-230	no background	pCi/g	6/8	0.571 BU	0.5	1.36 B	158	1.36 B	158
H+I	Thorium-230	no background	pCi/g	7/19	0.573 U	18	1.85 B	0.5	0.984 B	123
L1+L2	Thorium-230	no background	pCi/g	5/19	0.511 U	15	1.01 U	6	0.703	134
E	Thorium-230	no background	pCi/g	2/9	0.567 U	0.5	0.767	11	0.635	15
P	Thorium-230	no background	pCi/g	4/24	0.532 U	7	1.46 U	15	1.18	20.5
A+B	Thorium-230	no background	pCi/g	3/19	0.625 U	0.5	1.17	0.5	0.72	118.7
F+G	Thorium-230	no background	pCi/g	2/21	0.493 U	130	1.32 J	6	0.495	159
F+G	Uranium	3210	ug/kg	10/10	18100 U	126	19700 U	0.5	18300 U	136
L1+L2	Uranium	3210	ug/kg	10/10	17200 U	44.5	19800 U	0.5	18300 U	134
P	Uranium	3210	ug/kg	24/24	17000 U	55.5	101000 U	15	18600 U	133.3
P	Vanadium	85100	ug/kg	2/30	27300 0	133.3	110000 M	15	95100 M	19

Summary by Analyte

shading	**= highest frequency of exceedance/detection**
shading	**= maximum reported concentration for analyte at WMA C**
shading	**= location has both highest frequency of exceedence/detection AND max concentration for analyte**

Table V-2. Summary of Extent of Contamination for Select Constituents by Investigation Site/Group

IG	Analyte	Background Value	Units	Frequency greater than background	Minimum Concentration	Minimum Concentration Depth (ft bgs)	Maximum Concentration	Maximum Concentration Depth (ft bgs)	Extent Concentration	Extent Depth (ft bgs)
A+B	Calcium	17200000	ug/kg	1/19	6620000	169.7	32200000	36.0	32200000	36.0
A+B	Cesium-137	1.1	pCi/g	4/19	-0.036 U	11.1	27.7	0.5	27.7	0.5
A+B	Chromium	18500	ug/kg	5/19	5970 B	14.1	27700	81.4	26400	137.0
A+B	Cobalt-60	0.0084	pCi/g	16/19	-0.017 U	5.1	0.157 U	118.7	0.0712 U	169.7
A+B	Europium-154	0.033	pCi/g	14/19	-0.064 U	36.0	0.305 U	0.5	0.0775 U	169.7
A+B	Potassium-40	17	pCi/g	6/19	6.63 X	0.5	31	81.4	12.6	169.7
A+B	Strontium-90	0.18	pCi/g	15/19	0.14 U	81.4	24 J	0.5	0.537 U	169.7
A+B	Technetium-99	no background	pCi/g	1/19	0.0171 U	0.5	16.2	36.0	3.1	137.0
A+B	Thorium-230	no background	pCi/g	3/19	0.625 U	0.5	1.17	0.5	0.72	118.7
A+B	Sulfate	237000	ug/kg	2/19	620 U	0.5	592000	14.2	366000	36.0
C	Calcium	17200000	ug/kg	1/9	7520000	45.6	17500000	6.5	17500000	6.5
C	Cesium-137	1.1	pCi/g	2/9	0.104 U	11.5	7.09	0.5	7.09	0.5
C	Chromium	18500	ug/kg	3/9	8700	0.5	22200	16.5	21400	87.8
C	Cobalt-60	0.0084	pCi/g	9/9	0.0614 U	16.5	0.134 U	57.3	0.13 U	87.8
C	Europium-154	0.033	pCi/g	9/9	0.235 U	11.5	0.411 U	57.3	0.363 U	87.8
C	Potassium-40	17	pCi/g	9/9	9.95	11.5	15.8	87.8	15.8	87.8
C	Strontium-90	0.18	pCi/g	8/9	0.169 U	87.8	3	0.5	0.208 U	75.5
E	Cesium-137	1.1	pCi/g	2/9	0.374 U	38	5.13	0.5	5.13	0.5
E	Chromium	18500	ug/kg	3/9	7440	0.5	29800	38	20300	123
E	Cobalt-60	0.0084	pCi/g	9/9	0.304 U	38	0.384 U	6	0.305 U	123
E	Europium-154	0.033	pCi/g	9/9	0.95 U	123	1.24 U	6	0.95 U	123
E	Nickel	19100	ug/kg	2/9	7820 B	6	25300	74	25300	74
E	Potassium-40	17	pCi/g	1/7	7.62	38	17.6	84	17.6	84
E	Sodium	690000	ug/kg	1/9	185000	74	972000	38	972000	38
E	Strontium-90	0.18	pCi/g	9/9	0.183 U	38	2.5	0.5	0.647 U	123
E	Thorium-230	no background	pCi/g	2/9	0.567 U	0.5	0.767	11	0.635	15
F+G	Calcium	17200000	ug/kg	1/21	4800000	217	19600000	6	19600000	6
F+G	Cesium-137	1.1	pCi/g	5/21	0.235 U	126	4.75	0.5	0.555	44.5
F+G	Chromium	18500	ug/kg	3/21	4740	15	22100	217	22100	217
F+G	Cobalt-60	0.0084	pCi/g	21/21	0.206 U	126	0.411 U	98	0.261 U	217
F+G	Europium-154	0.033	pCi/g	21/21	0.641 U	126	1.09 U	98	0.806 U	217
F+G	Nitrate	52000	ug/kg	2/21	1940 B	93	192000	126	173000	136
F+G	Potassium-40	17	pCi/g	1/21	8.72	15	19.1	126	19.1	126
F+G	Strontium-90	0.18	pCi/g	21/21	0.182 U	130	4.06 UJ	6	0.19 U	217
F+G	Technetium-99	no background	pCi/g	2/21	5.27 U	0.5	54.6 Y	126	50.1 Y	136
F+G	Thorium-230	no background	pCi/g	2/21	0.493 U	130	1.32 J	6	0.495	159
F+G	Uranium	3210	ug/kg	10/10	18100 U	126	19700 U	0.5	18300 U	136
H+I	Chromium	18500	ug/kg	5/19	5340 M	11	28700 M	93	28700 M	93
H+I	Cobalt-60	0.0084	pCi/g	19/19	0.277 U	0.5	0.446 U	0.5	0.304 U	143
H+I	Europium-154	0.033	pCi/g	19/19	0.884 U	143	1.46 U	6	0.884 U	143
H+I	Nitrate	52000	ug/kg	2/19	2750	11	54600	0.5	53000	0.5

Table V-2. Summary of Extent of Contamination for Select Constituents by Investigation Site/Group

IG	Analyte	Background Value	Units	Frequency greater than background	Minimum Concentration	Minimum Concentration Depth (ft bgs)	Maximum Concentration	Maximum Concentration Depth (ft bgs)	Extent Concentration	Extent Depth (ft bgs)
H+I	Potassium-40	17	pCi/g	3/15	8.09	11	20	0.5	17	93
H+I	Strontium-90	0.18	pCi/g	19/19	0.182 U	6	0.713 U	89	0.208 U	143
H+I	Sulfate	237000	ug/kg	1/19	2590 B	0.5	458000	11	458000	11
H+I	Thorium-230	no background	pCi/g	7/19	0.573 U	18	1.85 B	0.5	0.984 B	123
J	Cesium-137	1.1	pCi/g	2/10	0.066 U	173.3	5.71	0.5	5.71	0.5
J	Chromium	18500	ug/kg	1/10	8490	0.5	27400	173.3	27400	173.3
J	Cobalt-60	0.0084	pCi/g	10/10	0.0795 U	131.8	0.101 U	0.5	0.0858 U	173.3
J	Europium-154	0.033	pCi/g	10/10	0.122 U	131.8	0.165 U	38.8	0.131 U	173.3
J	Potassium-40	17	pCi/g	1/10	9.26	0.5	17.4	90.1	13.4	173.3
J	Strontium-90	0.18	pCi/g	10/10	0.247 U	157.7	4.01	0.5	0.735 U	173.3
L1+L2	Cesium-137	1.1	pCi/g	4/19	0.181 U	0.5	7.52	0.5	0.444	6
L1+L2	Chromium	18500	ug/kg	3/19	6960 MJ	0.5	32200	222	32200	222
L1+L2	Cobalt-60	0.0084	pCi/g	19/19	0.162 U	0.5	0.497 U	110.5	0.274 U	222
L1+L2	Europium-154	0.033	pCi/g	19/19	0.539 U	0.5	1.48 U	115	0.896 U	222
L1+L2	Nickel	19100	ug/kg	1/19	7330	11	20200 MJ	40	20200 MJ	40
L1+L2	Nitrate	52000	ug/kg	2/19	1920 B	15	90300	115	90300	115
L1+L2	Strontium-90	0.18	pCi/g	19/19	0.117	6	4.01 J	0.5	0.64 U	222
L1+L2	Technetium-99	no background	pCi/g	3/19	5.25 U	12	76 BYUJ	115	28.4 Y	222
L1+L2	Thorium-230	no background	pCi/g	5/19	0.511 U	15	1.01 U	6	0.703	134
L1+L2	Uranium	3210	ug/kg	10/10	17200 U	44.5	19800 U	0.5	18300 U	134
P	Cesium-137	1.1	pCi/g	13/30	0.292 U	133.3	73.1	15	1.64	43
P	Chromium	18500	ug/kg	5/30	4470 0	11	32700	169	32700	169
P	Cobalt-60	0.0084	pCi/g	30/30	0.2 U	11	3.13 U	7	0.309 U	169
P	Europium-154	0.033	pCi/g	30/30	0.631 U	11	9.45 U	11	1.05 U	169
P	Iodine-129	no background	pCi/g	1/25	0.114 U	11	0.808 B	6	0.808 B	6.0
P	Nickel	19100	ug/kg	5/30	6710 0	7	30600 J	26	22400 B	169
P	Nitrate	52000	ug/kg	1/31	3060 0	60	143000 M	43	143000 M	43.0
P	Potassium-40	17	pCi/g	3/19	7.9	32	19.4	57	17	169
P	Sodium	690000	ug/kg	8/30	140000 B	58	1930000	15	888000	43
P	Strontium-90	0.18	pCi/g	25/25	1.44 U	20.5	141	11	3.53 U	133.3
P	Technetium-99	no background	pCi/g	8/30	2.14 Y	169	45.5 Y	20.5	6.07 Y	169
P	Thorium-230	no background	pCi/g	4/24	0.532 U	7	1.46 U	15	1.18	20.5
P	Uranium	3210	ug/kg	24/24	17000 U	55.5	101000 U	15	18600 U	133.3
P	Vanadium	85100	ug/kg	2/30	27300 0	133.3	110000 M	15	95100 M	19
R	Cobalt-60	0.0084	pCi/g	7/7	0.27 U	81	0.337 U	0.5	0.297 U	133
R	Europium-154	0.033	pCi/g	7/7	0.847 U	16	1.03 U	40	0.939 U	133
R	Potassium-40	17	pCi/g	1/7	8.93	28	18.1	81	18.1	81
R	Strontium-90	0.18	pCi/g	7/7	0.26 U	133	1.19 U	0.5	0.26 U	133
R	Technetium-99	no background	pCi/g	1/9	5.1 U	81	30.1 U	12	6.45 B	40
U	Cesium-137	1.1	pCi/g	2/8	0.486 U	158	2.06	0.5	2.06	0.5
U	Chromium	18500	ug/kg	1/8	7260	0.5	44500	158	44500	158

Table V-2. Summary of Extent of Contamination for Select Constituents by Investigation Site/Group

IG	Analyte	Background Value	Units	Frequency greater than background	Minimum Concentration	Minimum Concentration Depth (ft bgs)	Maximum Concentration	Maximum Concentration Depth (ft bgs)	Extent Concentration	Extent Depth (ft bgs)
U	**Cobalt-60**	0.0084	pCi/g	8/8	0.338 U	0.5	0.463 U	129	0.346 U	158
U	**Europium-154**	0.033	pCi/g	8/8	1.04 U	16	1.49 U	129	1.17 U	158
U	**Nickel**	19100	ug/kg	1/8	6680 B	11	29400	158	29400	158
U	**Nitrate**	52000	ug/kg	1/8	4490	158	71600	129	71600	129
U	**Potassium-40**	17	pCi/g	1/6	8.84	0.5	21.7	158	21.7	158
U	**Strontium-90**	0.18	pCi/g	8/8	0.201 U	39	4.2	0.5	0.271 U	158
U	**Technetium-99**	no background	pCi/g	2/8	2.55 U	0.5	53.5 Y	129	53.5 Y	129
U	**Thorium-230**	no background	pCi/g	6/8	0.571 BU	0.5	1.36 B	158	1.36 B	158

Summary by Investigation Group

shading	**= highest frequency of exceedance/detection**
shading	**= maximum reported concentration for analyte at WMA C**
shading	**= location has both highest frequency of exceedence/detection AND max concentration for analyte**

APPENDIX W

SUMMARY OF CESIUM-137, COBALT-60, AND EUROPIUM-154 VADOSE ZONE LOGGING AND ANALYTICAL RESULTS AT WMA C

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APPENDIX W
SUMMARY OF CESIUM-137, COBALT-60, AND EUROPIUM-154 VADOSE ZONE LOGGING AND ANALYTICAL RESULTS AT WMA C

This appendix presents geophysical logging and analytical sampling results from the various phases of field investigation supporting the WMA C RFI along with logging results from surrounding groundwater wells. Figures W-1 through W-9 present the logging and analytical results for the three constituents with comparable results: cesium-137, cobalt-60, and europium-154. For each constituent, figures show maximum concentrations for shallow and deep soil and additionally show the vertical extent. Figures W-1 through W-6 present results for shallow and deep soil. Figures W-7 through W-9 present the extent of contamination by cesium-137, cobalt-60, and europium-154 based on both logging and analytical results.

Figure W-1. Cesium-137 Maximum Shallow Results for Logging and Analytical Sampling

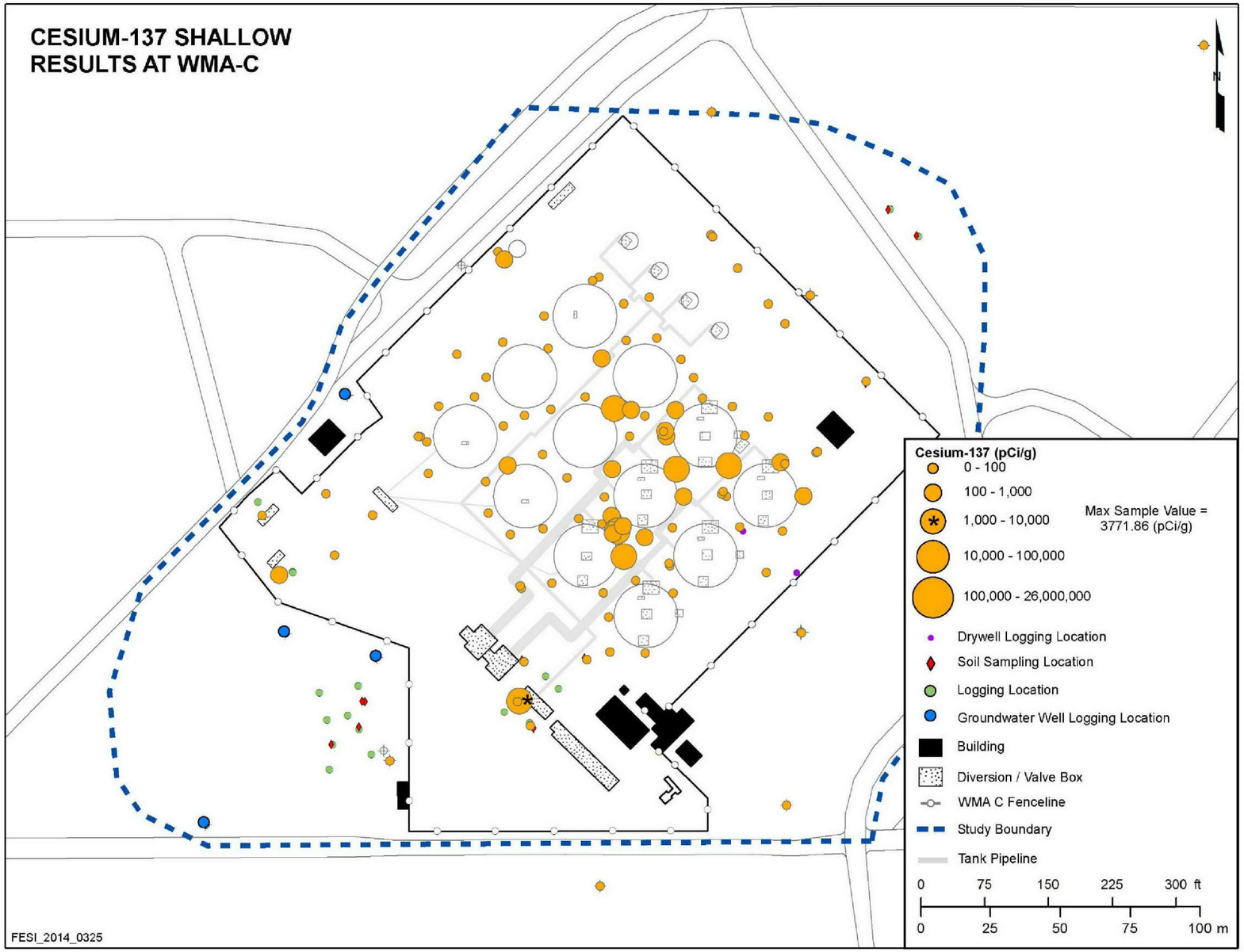


Figure W-2. Cesium-137 Maximum Deep Results for Logging and Analytical Sampling

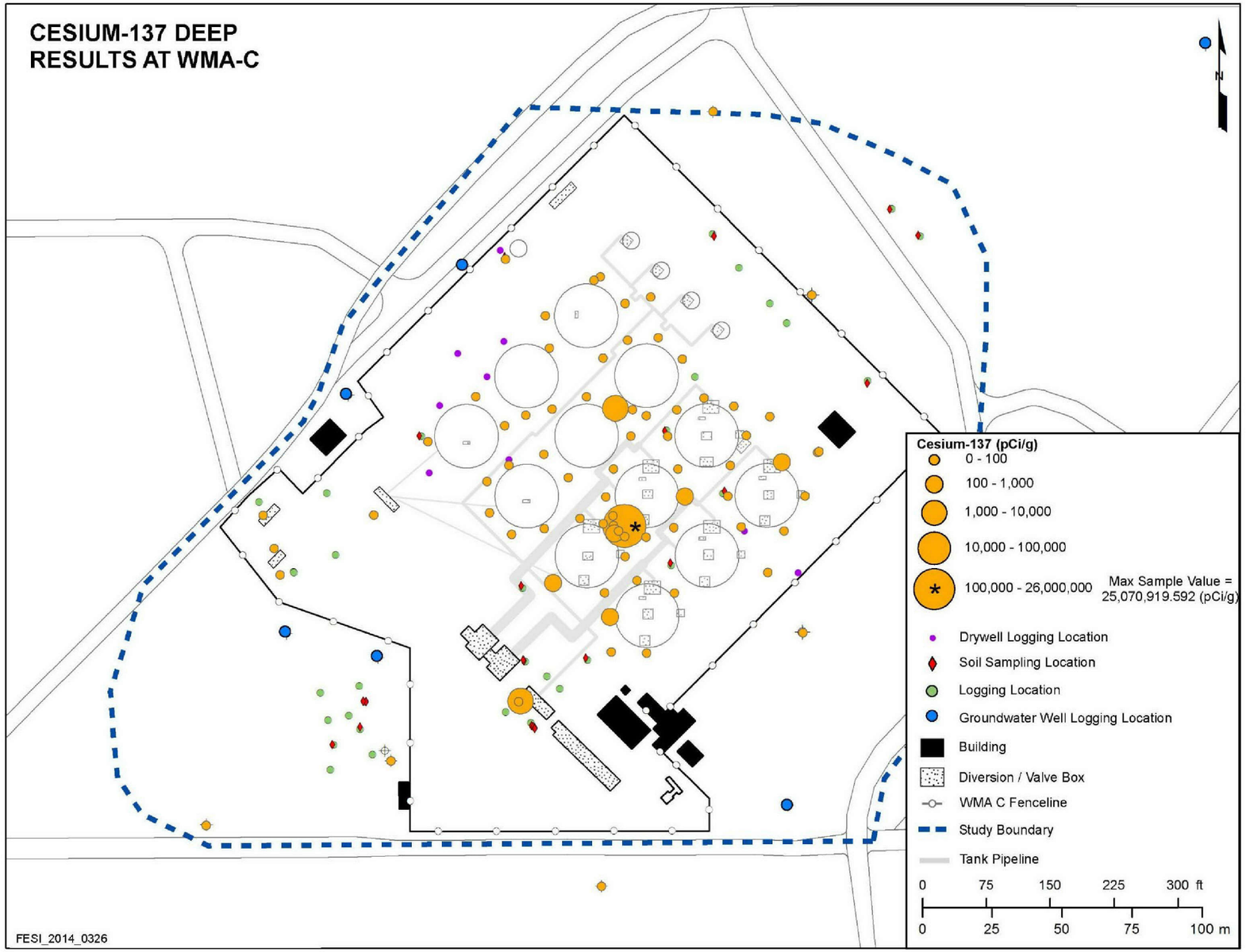


Figure W-3. Cobalt-60 Maximum Shallow Results for Logging and Analytical Sampling

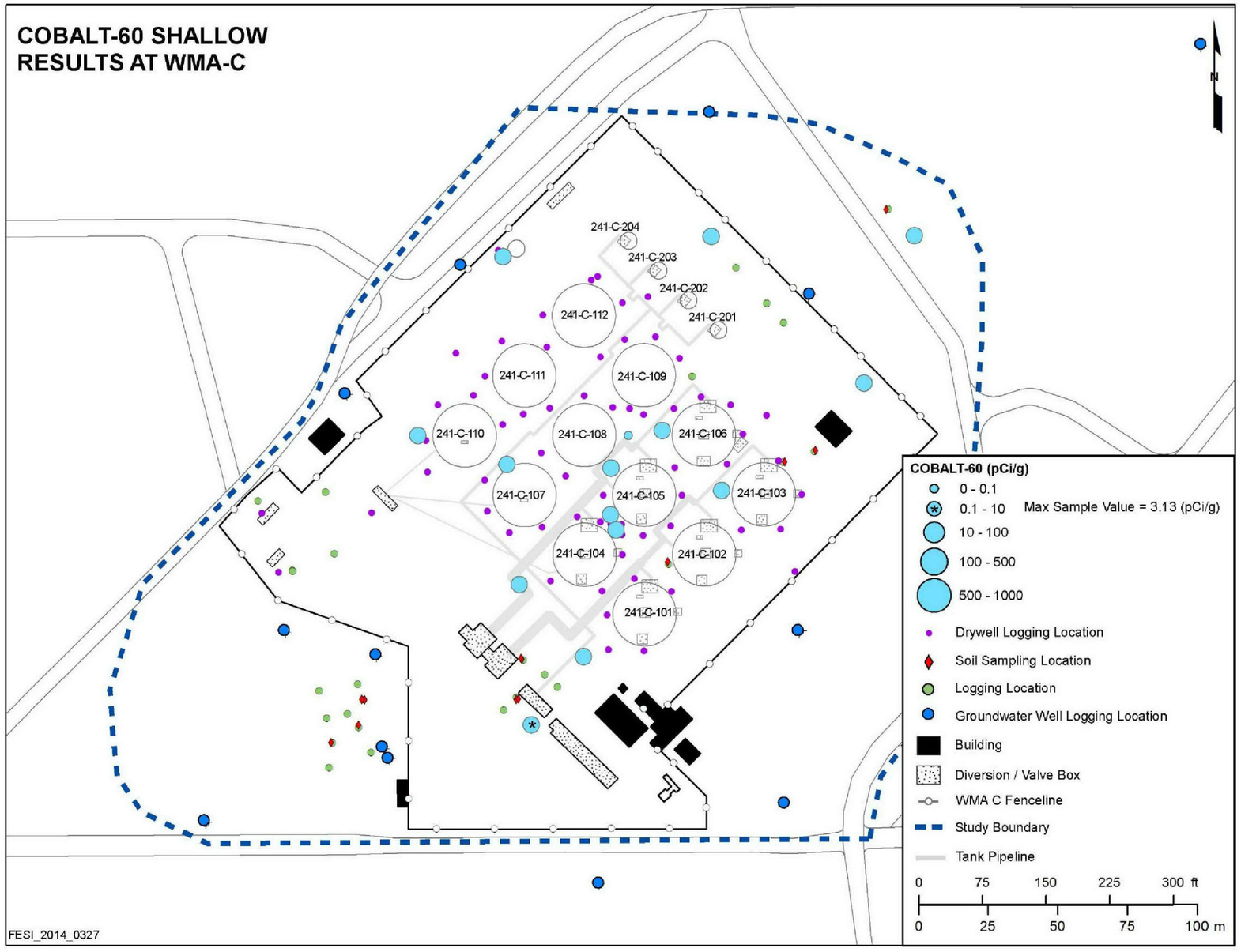


Figure W-4. Cobalt-60 Maximum Deep Results for Logging and Analytical Sampling

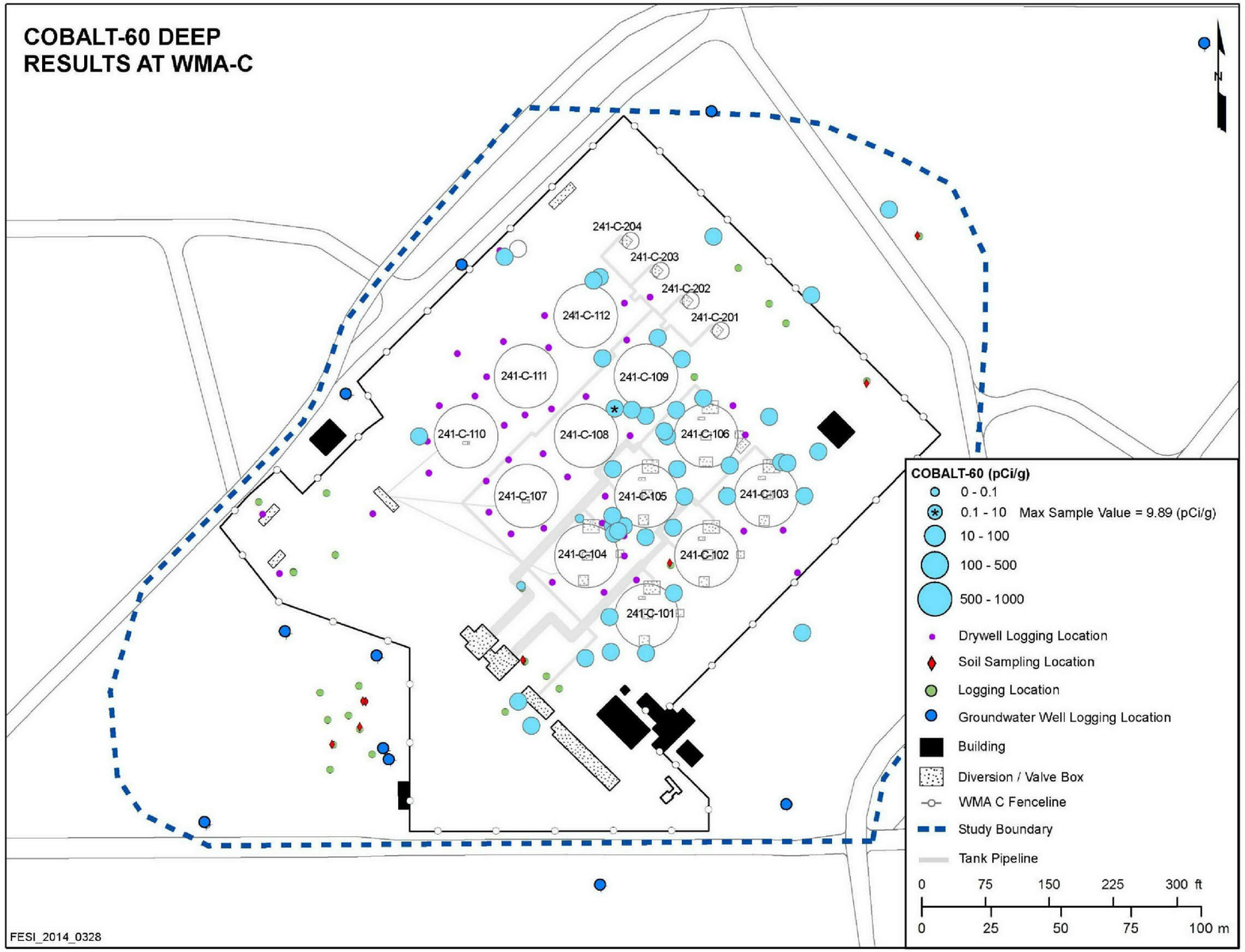


Figure W-5. Europium-154 Maximum Shallow Results for Logging and Analytical Sampling

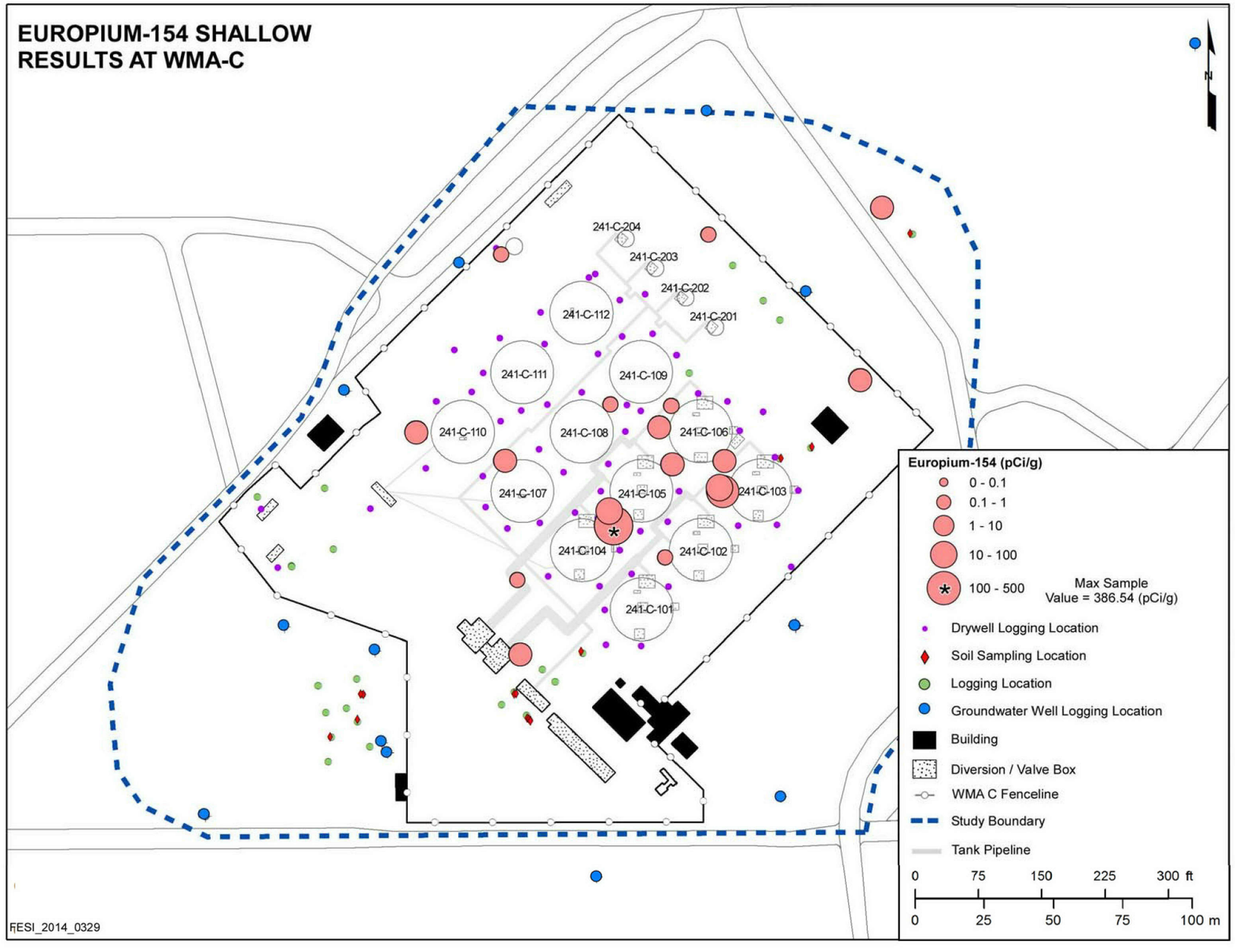


Figure W-6. Europium-154 Maximum Deep Results for Logging and Analytical Sampling

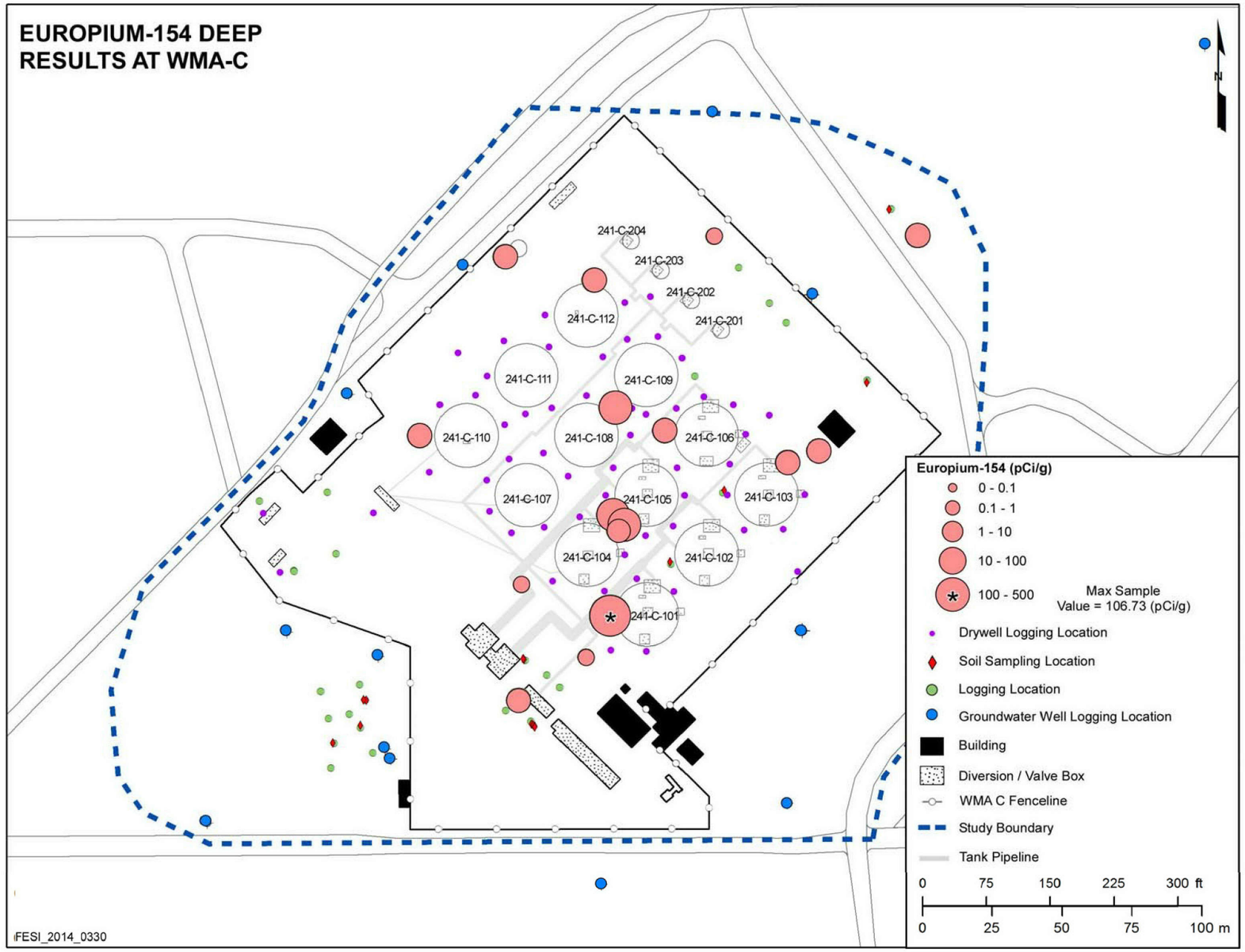


Figure W-7. Cesium-137 Extent for Logging and Analytical Sampling

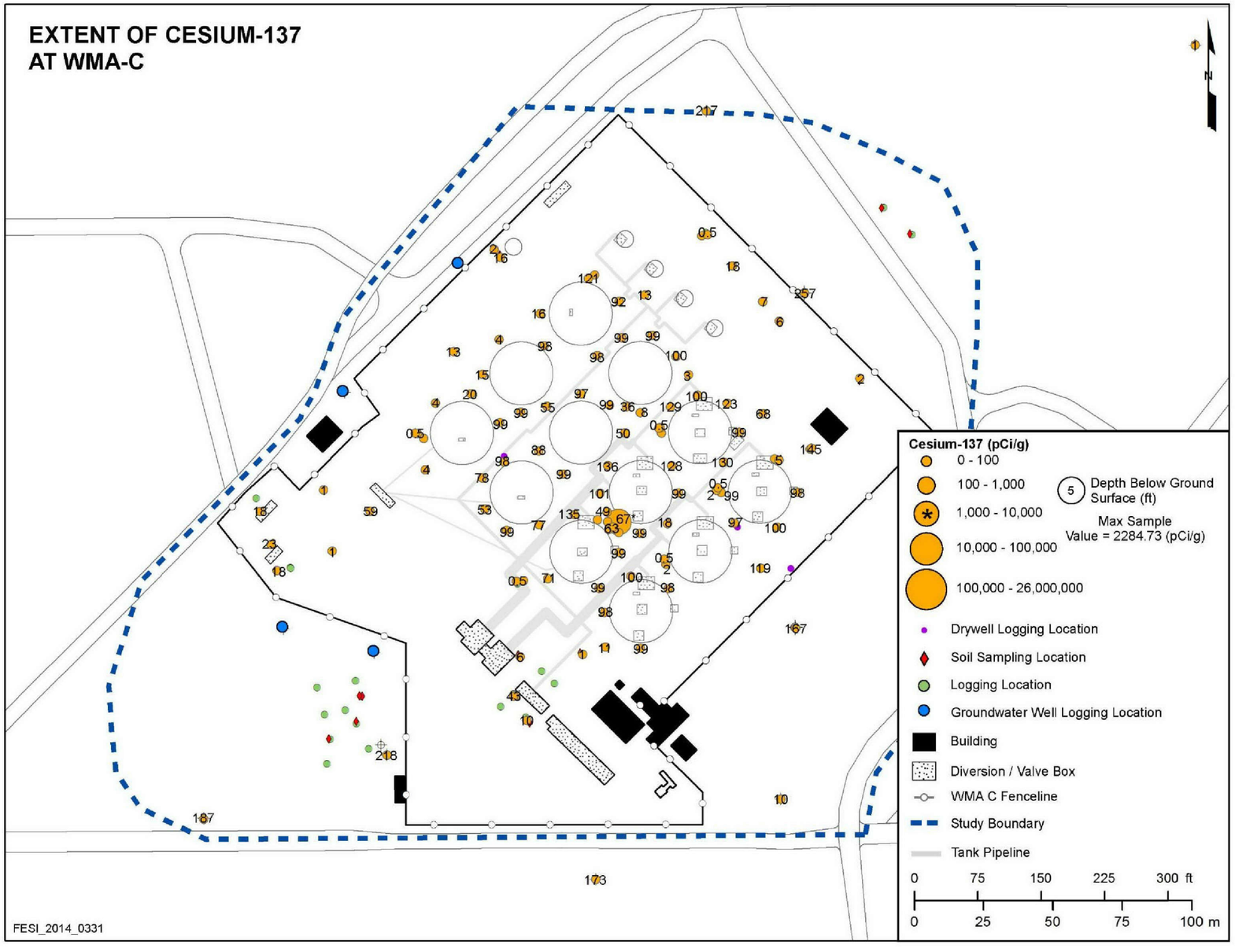


Figure W-8. Cobalt-60 Extent for Logging and Analytical Sampling

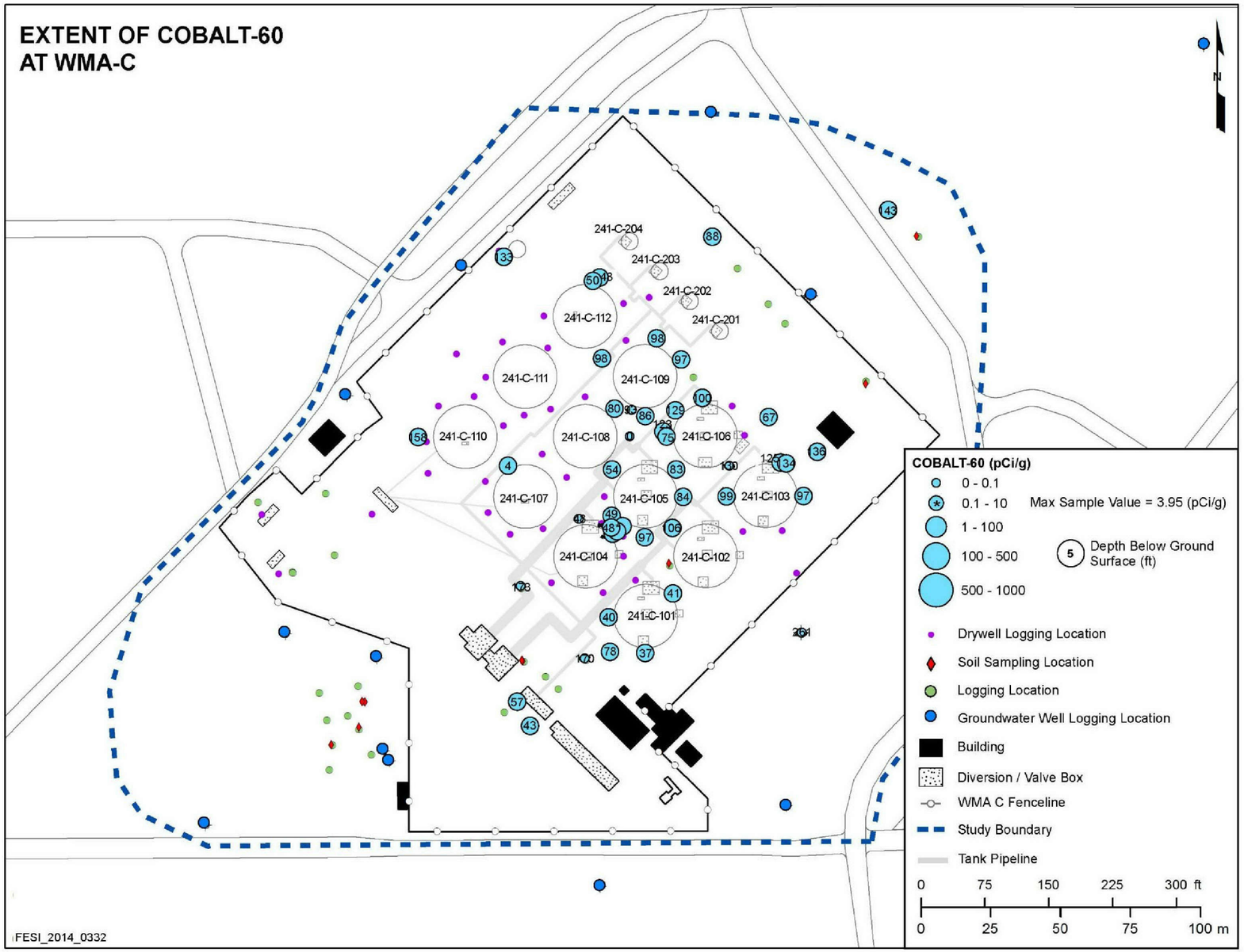
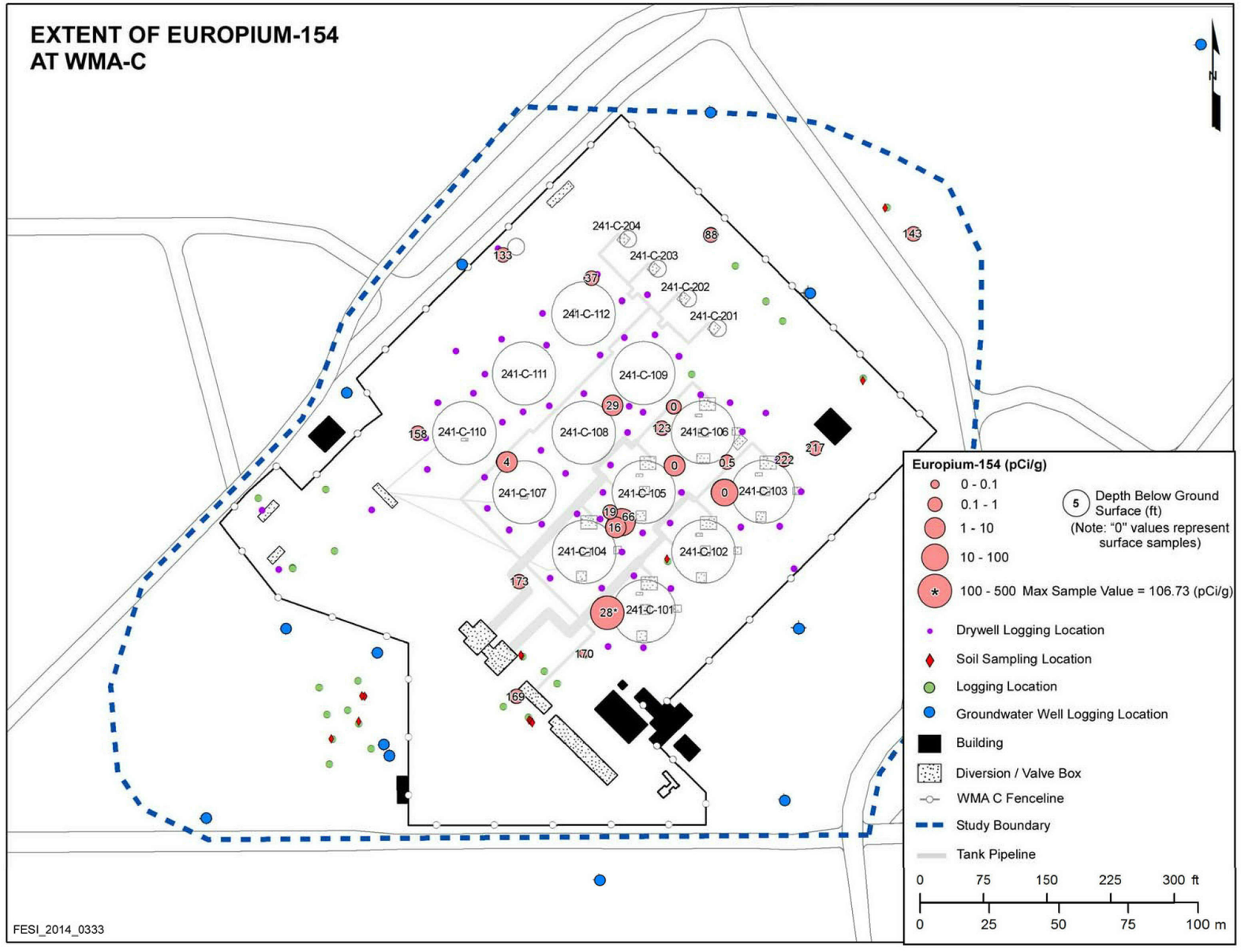


Figure W-9. Europium-154 Extent for Logging and Analytical Sampling



APPENDIX X

WMA C SOIL CONTAMINATION INVENTORY ESTIMATES

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APPENDIX X
WMA C SOIL CONTAMINATION INVENTORY ESTIMATES

This appendix presents the estimate of soil contamination inventories for the various waste releases in WMA C. These inventories are from Appendix C of RPP-RPT-42294, Rev. 1, *Hanford Waste Management Area C Soil Contamination Inventory Estimates*.

The soil contamination inventories are presented in Figures X-1 through X-6. The figures visually present the waste released in a spatial manner.

The soil contamination inventories are presented in tabular format by individual analytes (for both chemical and radiochemical components) by waste release areas.

Figures

Figure X-1. Volume of Waste Released at WMA C
Figure X-2. Cations Released at WMA C
Figure X-3. Anions Released at WMA C
Figure X-4. Metals Released at WMA C
Figure X-5. Radiochemical (Co-60, Cs-137, Eu-154, Tc-99) Released at WMA C
Figure X-6. Radiochemical (I-129, Sr-90) Released at WMA C

Tables

Table X-1. Soil Contamination Inventory Associated With Tank C-101
Table X-2. Soil Contamination Inventory Associated With Tank C-105
Table X-3. Soil Contamination Inventory Associated With Tank C-110
Table X-4. Soil Contamination Inventory Associated With Tank C-111
Table X-5. Soil Contamination Inventory Associated With 200-Series Tanks
Table X-6. Soil Contamination Inventory Associated With UPR-81
Table X-7. Soil Contamination Inventory Associated With UPR-82
Table X-8. Soil Contamination Inventory Associated With UPR-86

Figure X-1. Volume of Waste Released at WMA C

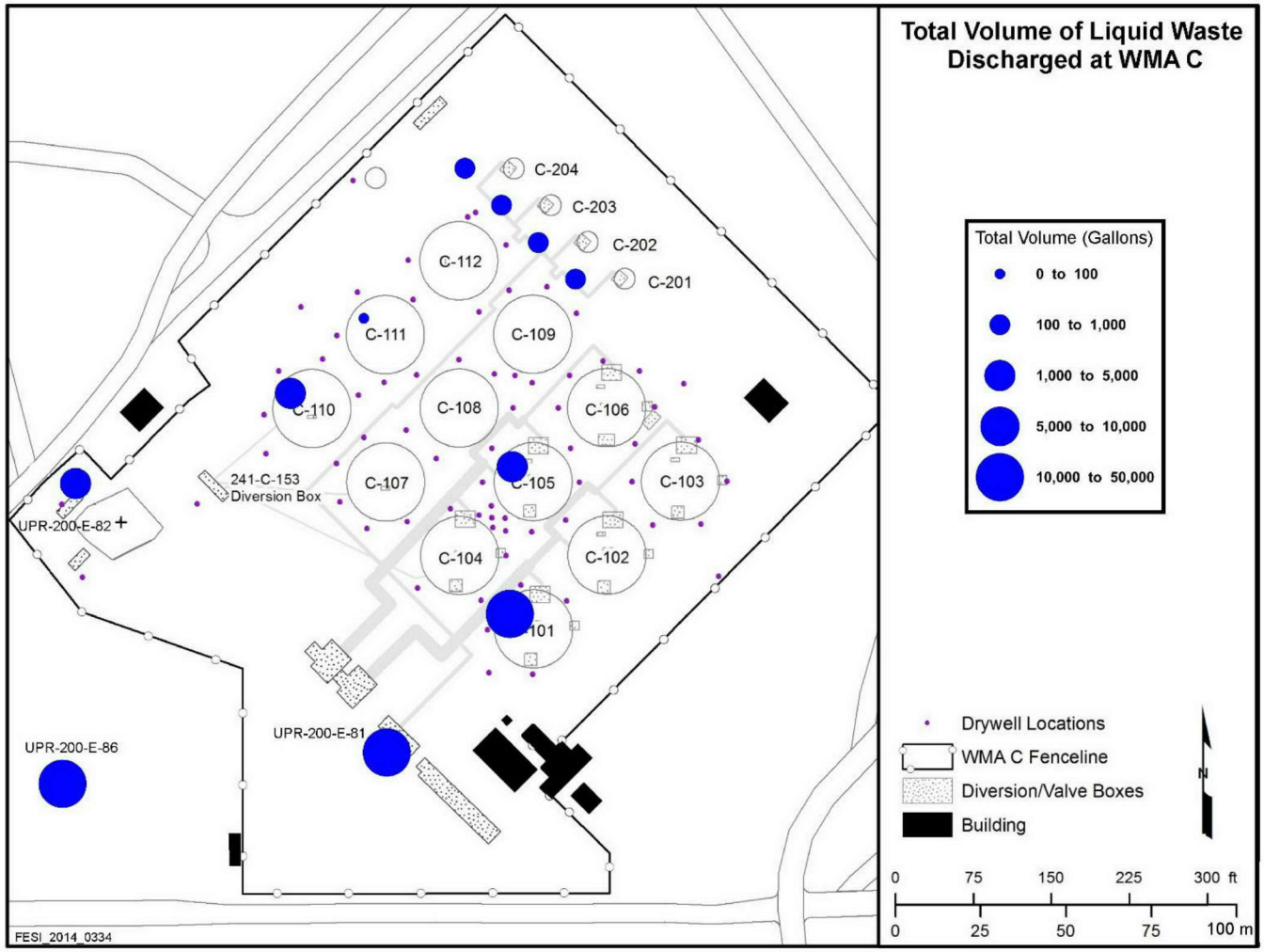

Figure X-2. Cations Released at WMA C

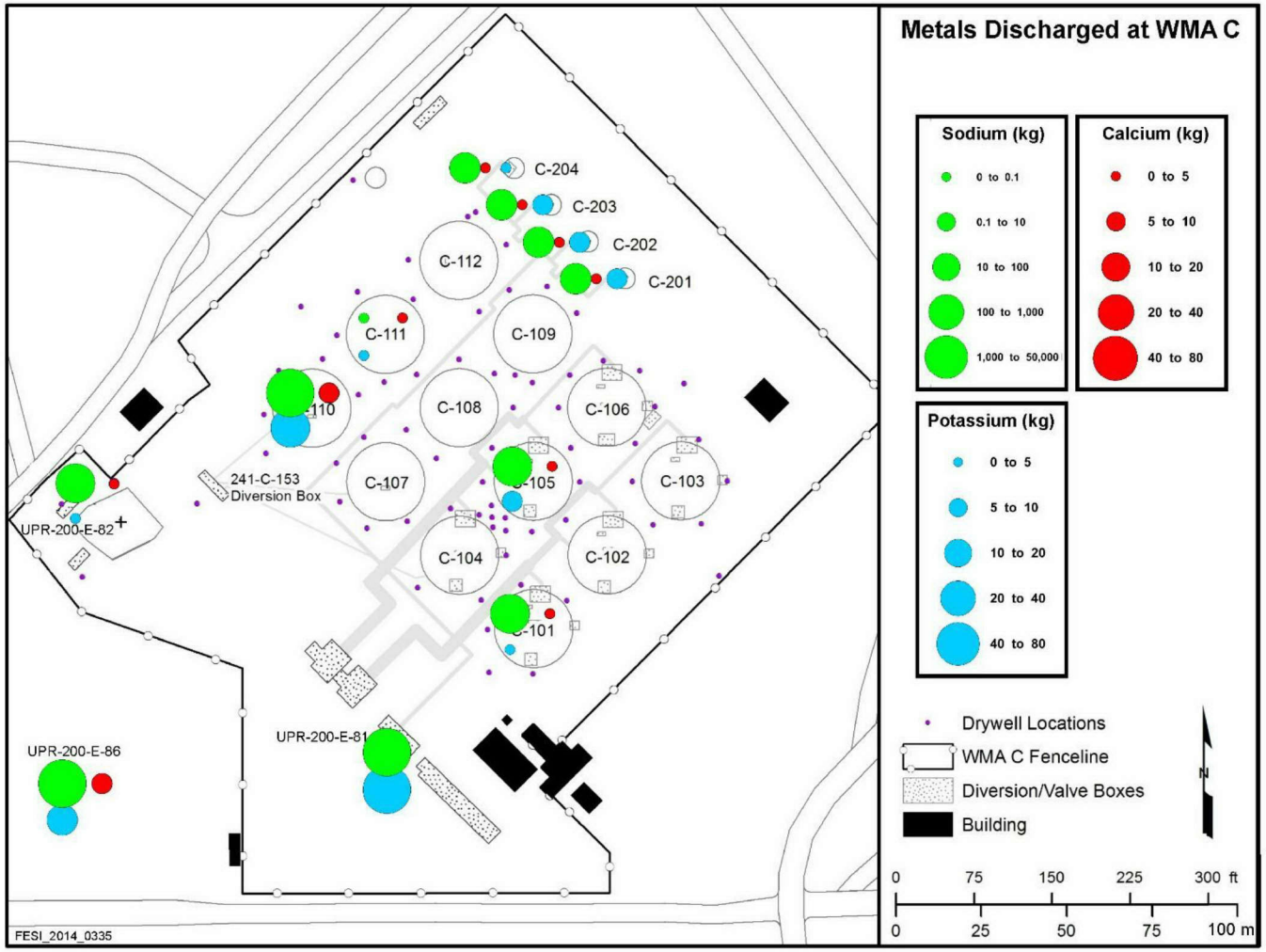

Figure X-3. Anions Released at WMA C

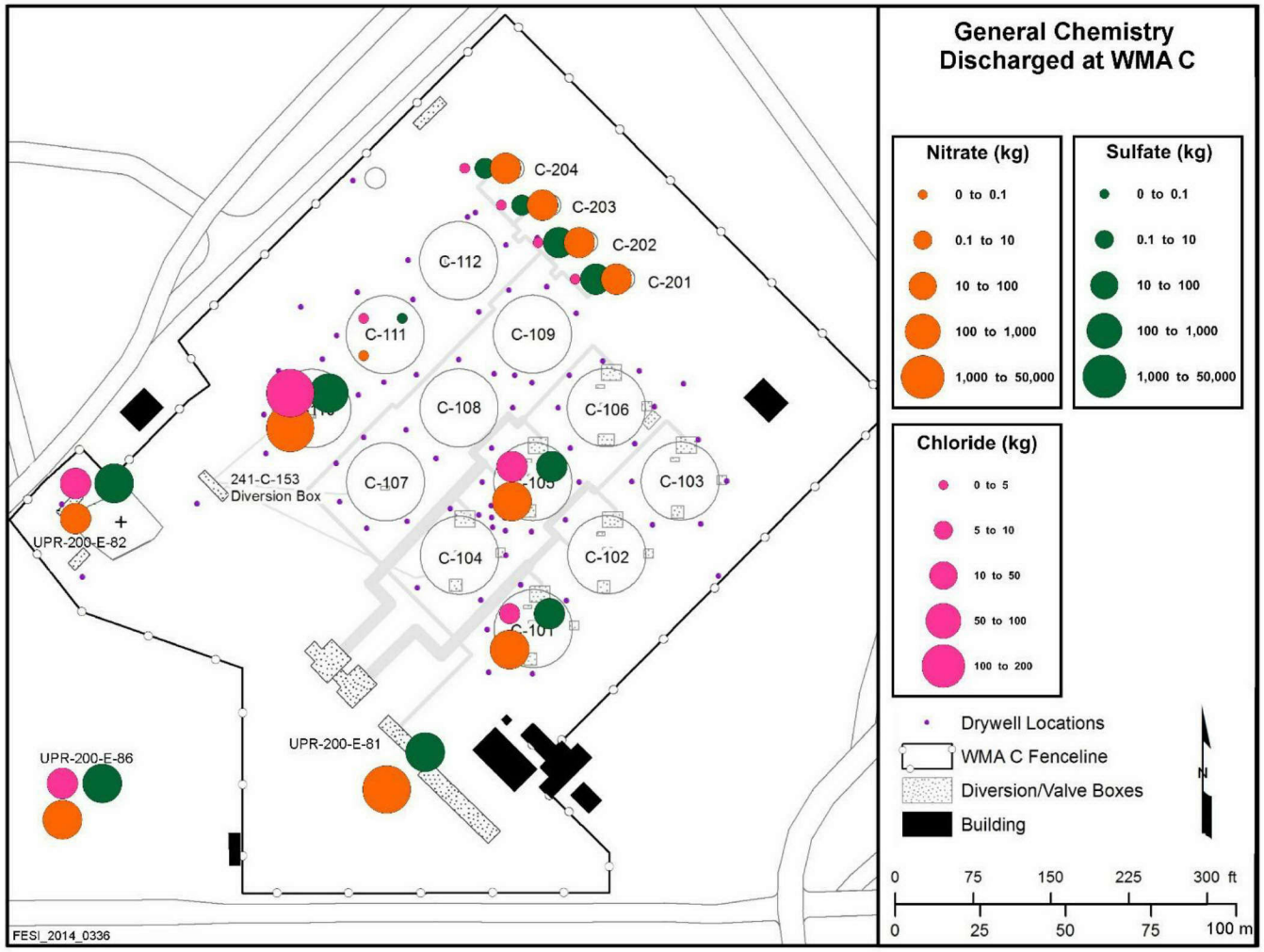

Figure X-4. Metals Released at WMA C

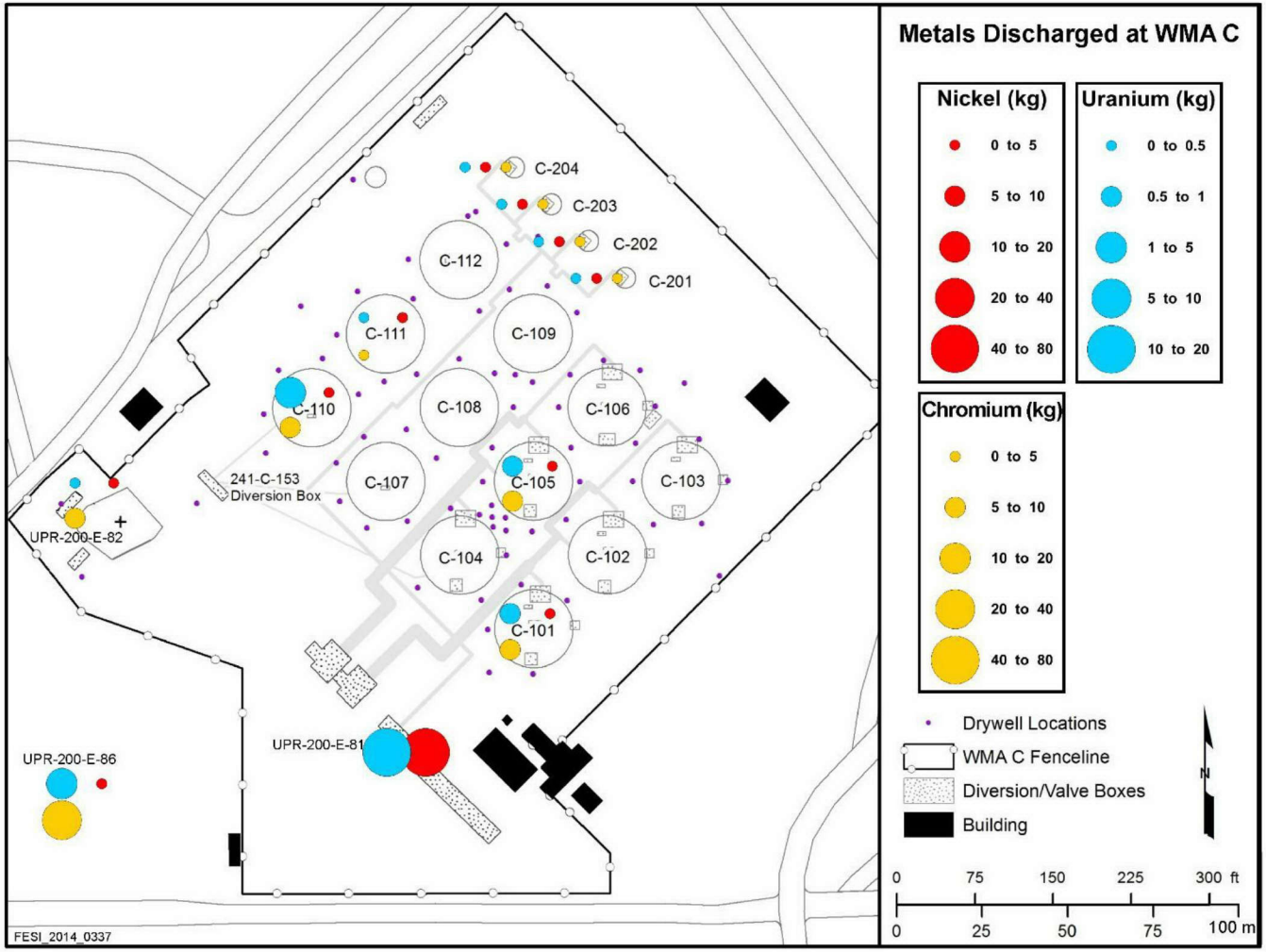

Figure X-5. Radiochemical (Co-60, Cs-137, Eu-154, Tc-99) Released at WMA C

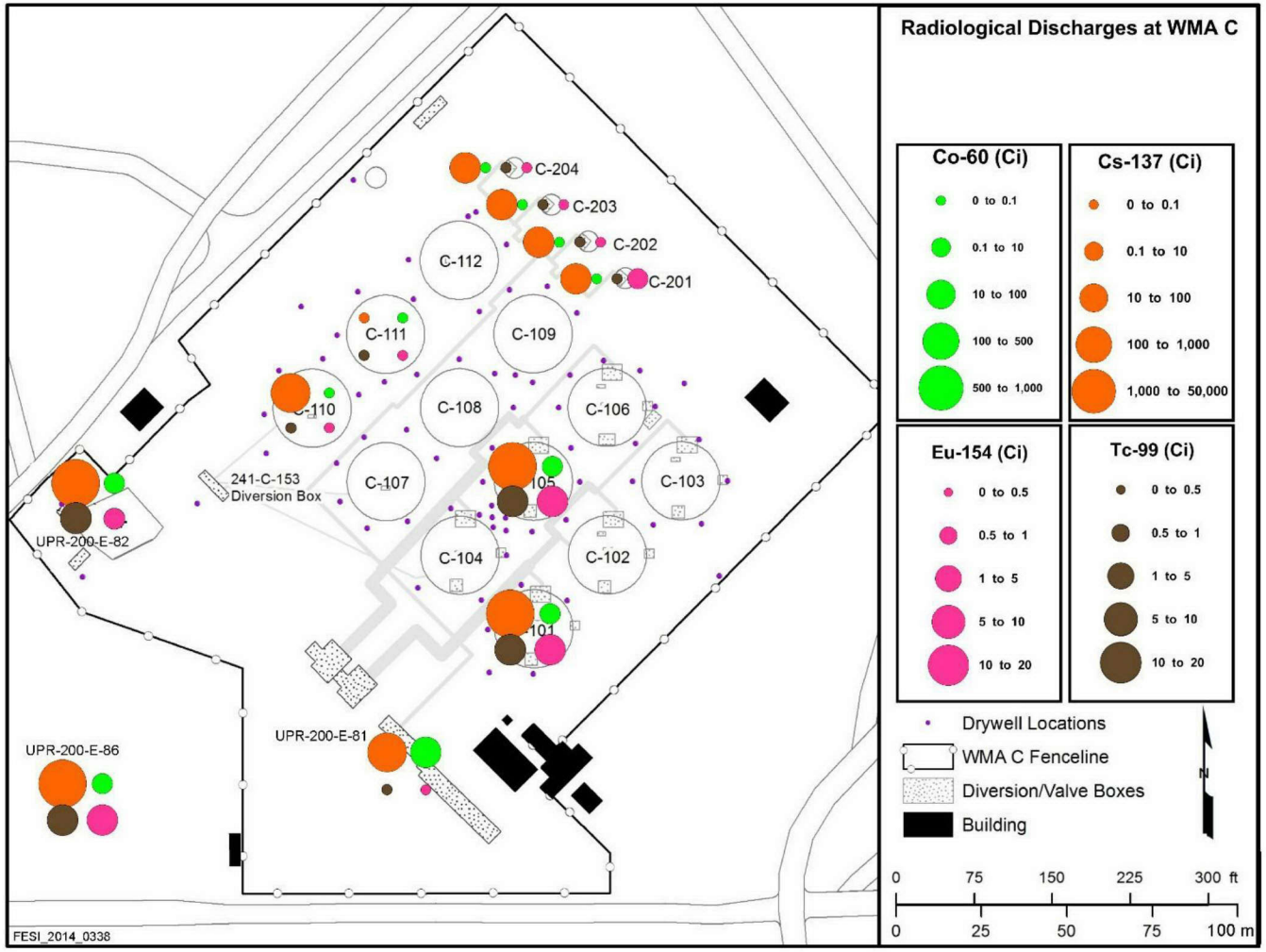

Figure X-6. Radiochemical (I-129, Sr-90) Released at WMA C

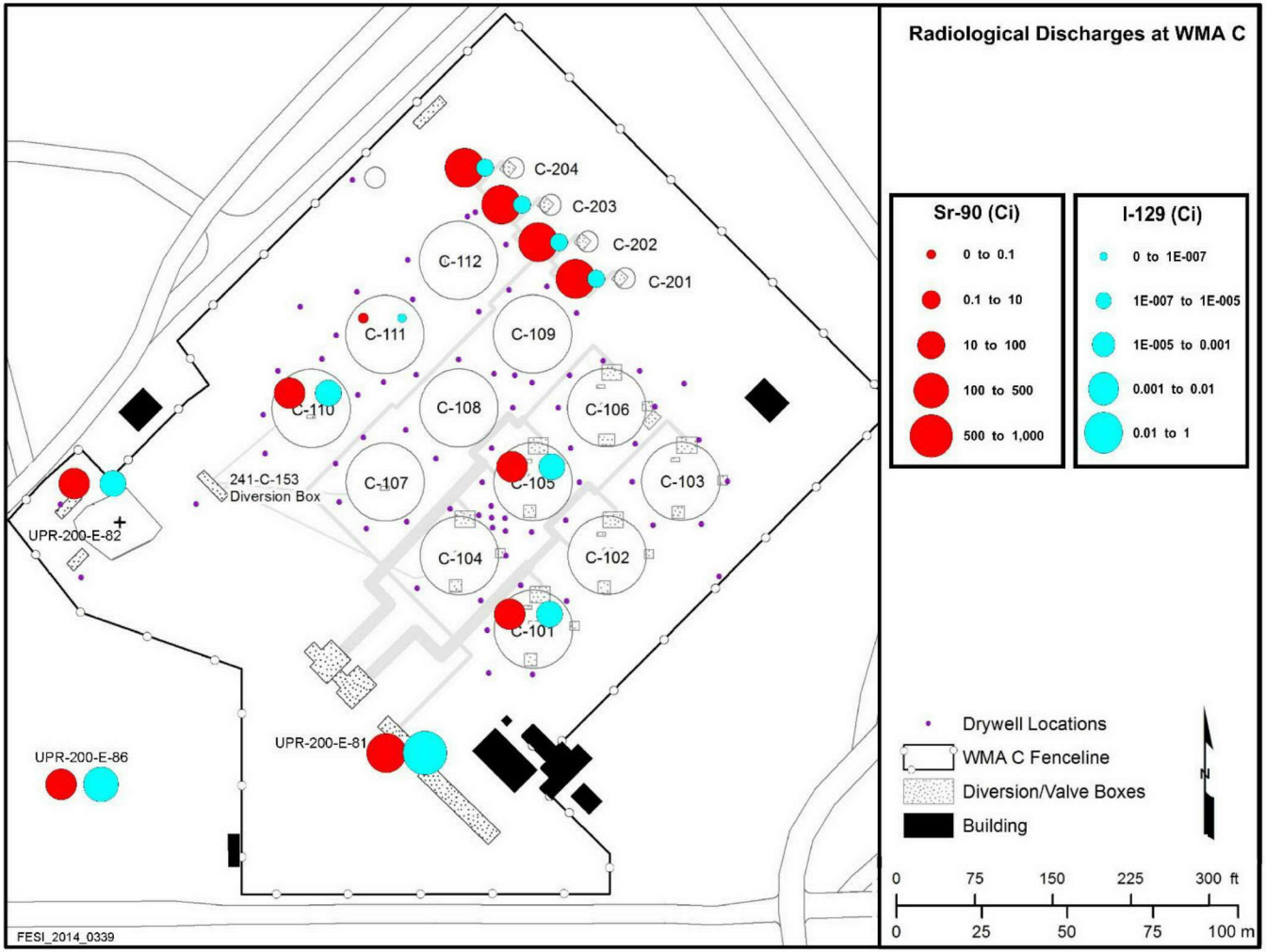

Table X-1. Soil Contamination Inventory Associated With Tank C-101

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-101	Cs-137	Ci	3.79E-03	4.26E+03	5.03E+01
241-C-101	Ba-137m	Ci	3.79E-03	4.02E+03	4.74E+01
241-C-101	Na	kg	3.79E-03	3.33E+02	3.50E+01
241-C-101	NO3	kg	3.79E-03	2.51E+02	2.64E+01
241-C-101	NO2	kg	3.79E-03	2.04E+02	2.14E+01
241-C-101	Sm-151	Ci	3.79E-03	1.09E+02	1.29E+00
241-C-101	SO4	kg	3.79E-03	6.55E+01	6.88E+00
241-C-101	CO3	kg	3.79E-03	4.44E+01	4.67E+00
241-C-101	Sr-90	Ci	3.79E-03	3.87E+01	4.57E-01
241-C-101	Y-90	Ci	3.79E-03	3.87E+01	4.57E-01
241-C-101	Al	kg	3.79E-03	1.47E+01	1.54E+00
241-C-101	Cl	kg	3.79E-03	8.70E+00	9.14E-01
241-C-101	Cr	kg	3.79E-03	7.57E+00	7.96E-01
241-C-101	Butanol	kg	3.79E-03	5.53E+00	5.81E-01
241-C-101	Si	kg	3.79E-03	4.41E+00	4.63E-01
241-C-101	Ca	kg	3.79E-03	2.81E+00	2.95E-01
241-C-101	K	kg	3.79E-03	2.28E+00	2.40E-01
241-C-101	NH3	kg	3.79E-03	2.20E+00	2.31E-01
241-C-101	Ni	kg	3.79E-03	1.98E+00	2.08E-01
241-C-101	Fe	kg	3.79E-03	1.95E+00	2.05E-01
241-C-101	Ni-63	Ci	3.79E-03	1.50E+00	1.77E-02
241-C-101	Eu-154	Ci	3.79E-03	1.21E+00	1.43E-02
241-C-101	Tc-99	Ci	3.79E-03	1.12E+00	1.32E-02
241-C-101	U-Total	kg	3.79E-03	5.79E-01	6.09E-02
241-C-101	Eu-155	Ci	3.79E-03	5.55E-01	6.55E-03
241-C-101	Pb	kg	3.79E-03	4.84E-01	5.09E-02
241-C-101	PO4	kg	3.79E-03	2.84E-01	2.98E-02
241-C-101	Zr-93	Ci	3.79E-03	2.13E-01	2.51E-03
241-C-101	H-3	Ci	3.79E-03	2.04E-01	2.41E-03
241-C-101	Co-60	Ci	3.79E-03	2.02E-01	2.38E-03
241-C-101	Cd-113m	Ci	3.79E-03	1.91E-01	2.25E-03
241-C-101	Nb-93m	Ci	3.79E-03	1.77E-01	2.09E-03
241-C-101	Am-241	Ci	3.79E-03	1.05E-01	1.24E-03
241-C-101	Pu-239	Ci	3.79E-03	9.50E-02	1.12E-03
241-C-101	F	kg	3.79E-03	9.09E-02	9.55E-03
241-C-101	Pu-241	Ci	3.79E-03	9.04E-02	1.07E-03
241-C-101	C-14	Ci	3.79E-03	3.84E-02	4.53E-04
241-C-101	Sb-125	Ci	3.79E-03	2.83E-02	3.34E-04
241-C-101	Pu-240	Ci	3.79E-03	1.93E-02	2.28E-04
241-C-101	Eu-152	Ci	3.79E-03	1.63E-02	1.92E-04
241-C-101	Ni-59	Ci	3.79E-03	1.59E-02	1.88E-04
241-C-101	Sn-126	Ci	3.79E-03	1.48E-02	1.75E-04
241-C-101	Mn	kg	3.79E-03	1.30E-02	1.37E-03
241-C-101	Np-237	Ci	3.79E-03	6.10E-03	7.20E-05

Table X-1. Soil Contamination Inventory Associated With Tank C-101

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-101	Hg	kg	3.79E-03	4.83E-03	5.08E-04
241-C-101	Se-79	Ci	3.79E-03	3.58E-03	4.23E-05
241-C-101	Bi	kg	3.79E-03	3.02E-03	3.17E-04
241-C-101	Pu-238	Ci	3.79E-03	2.40E-03	2.83E-05
241-C-101	Cs-134	Ci	3.79E-03	1.13E-03	1.33E-05
241-C-101	Ag	kg	3.79E-03	7.01E-04	7.37E-05
241-C-101	I-129	Ci	3.79E-03	6.04E-04	7.13E-06
241-C-101	Cm-242	Ci	3.79E-03	5.49E-04	6.48E-06
241-C-101	Zr	kg	3.79E-03	5.47E-04	5.75E-05
241-C-101	Cm-244	Ci	3.79E-03	2.86E-04	3.38E-06
241-C-101	U-238	Ci	3.79E-03	1.93E-04	2.28E-06
241-C-101	U-234	Ci	3.79E-03	1.90E-04	2.24E-06
241-C-101	U-233	Ci	3.79E-03	1.00E-04	1.18E-06
241-C-101	Am-243	Ci	3.79E-03	4.63E-05	5.46E-07
241-C-101	Ra-228	Ci	3.79E-03	1.51E-05	1.78E-07
241-C-101	Cm-243	Ci	3.79E-03	1.08E-05	1.27E-07
241-C-101	U-235	Ci	3.79E-03	8.08E-06	9.54E-08
241-C-101	U-236	Ci	3.79E-03	4.23E-06	4.99E-08
241-C-101	Pa-231	Ci	3.79E-03	2.46E-06	2.90E-08
241-C-101	U-232	Ci	3.79E-03	1.65E-06	1.95E-08
241-C-101	Ac-227	Ci	3.79E-03	9.50E-07	1.12E-08
241-C-101	Pu-242	Ci	3.79E-03	6.50E-07	7.67E-09
241-C-101	Th-232	Ci	3.79E-03	1.90E-07	2.24E-09
241-C-101	Ra-226	Ci	3.79E-03	1.45E-07	1.71E-09
241-C-101	Ru-106	Ci	3.79E-03	6.04E-08	7.13E-10
241-C-101	Th-229	Ci	3.79E-03	4.51E-08	5.32E-10
241-C-101	La	kg	3.79E-03	0.00E+00	0.00E+00
241-C-101	CCl4	kg	3.79E-03	0.00E+00	0.00E+00
241-C-101	TBP	kg	3.79E-03	0.00E+00	0.00E+00
241-C-101	NPH	kg	3.79E-03	0.00E+00	0.00E+00
241-C-101	Fe(CN)6	kg	3.79E-03	0.00E+00	0.00E+00
			Total Mass	9.51E+02	
			Total Activity	8.47E+03	

Table X-2. Soil Contamination Inventory Associated With Tank C-105

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-105	Cs-137	Ci	3.79E-03	4.15E+03	5.03E+01
241-C-105	Ba-137m	Ci	3.79E-03	3.91E+03	4.74E+01
241-C-105	NO3	kg	3.79E-03	7.64E+02	3.75E+01
241-C-105	Na	kg	3.79E-03	7.02E+02	3.44E+01
241-C-105	NO2	kg	3.79E-03	2.52E+02	1.24E+01
241-C-105	CO3	kg	3.79E-03	1.09E+02	5.35E+00
241-C-105	SO4	kg	3.79E-03	9.65E+01	4.73E+00
241-C-105	Sm-151	Ci	3.79E-03	6.75E+01	8.18E-01
241-C-105	Sr-90	Ci	3.79E-03	6.01E+01	7.28E-01
241-C-105	Y-90	Ci	3.79E-03	6.01E+01	7.28E-01
241-C-105	Al	kg	3.79E-03	4.36E+01	2.14E+00
241-C-105	Cl	kg	3.79E-03	1.91E+01	9.37E-01
241-C-105	PO4	kg	3.79E-03	1.34E+01	6.57E-01
241-C-105	Cr	kg	3.79E-03	9.48E+00	4.65E-01
241-C-105	K	kg	3.79E-03	6.17E+00	3.03E-01
241-C-105	Si	kg	3.79E-03	4.39E+00	2.15E-01
241-C-105	Butanol	kg	3.79E-03	4.32E+00	2.12E-01
241-C-105	Ca	kg	3.79E-03	3.43E+00	1.68E-01
241-C-105	NH3	kg	3.79E-03	3.36E+00	1.65E-01
241-C-105	Fe	kg	3.79E-03	2.50E+00	1.23E-01
241-C-105	Ni	kg	3.79E-03	2.44E+00	1.20E-01
241-C-105	Ni-63	Ci	3.79E-03	1.73E+00	2.10E-02
241-C-105	Pb	kg	3.79E-03	1.57E+00	7.70E-02
241-C-105	Tc-99	Ci	3.79E-03	1.51E+00	1.83E-02
241-C-105	Eu-154	Ci	3.79E-03	1.20E+00	1.45E-02
241-C-105	U-Total	kg	3.79E-03	6.59E-01	3.23E-02
241-C-105	F	kg	3.79E-03	5.56E-01	2.73E-02
241-C-105	Eu-155	Ci	3.79E-03	5.44E-01	6.59E-03
241-C-105	Pu-241	Ci	3.79E-03	3.50E-01	4.24E-03
241-C-105	Cd-113m	Ci	3.79E-03	3.34E-01	4.05E-03
241-C-105	Co-60	Ci	3.79E-03	3.06E-01	3.71E-03
241-C-105	Zr-93	Ci	3.79E-03	2.88E-01	3.49E-03
241-C-105	H-3	Ci	3.79E-03	2.80E-01	3.39E-03
241-C-105	Nb-93m	Ci	3.79E-03	2.28E-01	2.76E-03
241-C-105	Mn	kg	3.79E-03	1.33E-01	6.52E-03
241-C-105	Am-241	Ci	3.79E-03	1.25E-01	1.51E-03
241-C-105	Pu-239	Ci	3.79E-03	1.07E-01	1.30E-03
241-C-105	Sb-125	Ci	3.79E-03	9.21E-02	1.12E-03
241-C-105	C-14	Ci	3.79E-03	3.34E-02	4.05E-04
241-C-105	Pu-240	Ci	3.79E-03	2.84E-02	3.44E-04
241-C-105	Sn-126	Ci	3.79E-03	2.03E-02	2.46E-04
241-C-105	Ni-59	Ci	3.79E-03	1.80E-02	2.18E-04
241-C-105	Eu-152	Ci	3.79E-03	1.61E-02	1.95E-04
241-C-105	Bi	kg	3.79E-03	1.48E-02	7.26E-04

Table X-2. Soil Contamination Inventory Associated With Tank C-105

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-105	Pu-238	Ci	3.79E-03	6.67E-03	8.08E-05
241-C-105	Np-237	Ci	3.79E-03	5.23E-03	6.34E-05
241-C-105	Hg	kg	3.79E-03	4.84E-03	2.37E-04
241-C-105	Se-79	Ci	3.79E-03	4.84E-03	5.86E-05
241-C-105	Cs-134	Ci	3.79E-03	4.84E-03	5.86E-05
241-C-105	Zr	kg	3.79E-03	1.81E-03	8.88E-05
241-C-105	U-233	Ci	3.79E-03	7.53E-04	9.12E-06
241-C-105	Ag	kg	3.79E-03	6.43E-04	3.15E-05
241-C-105	I-129	Ci	3.79E-03	5.91E-04	7.16E-06
241-C-105	Cm-242	Ci	3.79E-03	2.94E-04	3.56E-06
241-C-105	Cm-244	Ci	3.79E-03	2.94E-04	3.56E-06
241-C-105	U-234	Ci	3.79E-03	2.52E-04	3.05E-06
241-C-105	U-238	Ci	3.79E-03	2.20E-04	2.67E-06
241-C-105	Am-243	Ci	3.79E-03	8.22E-05	9.96E-07
241-C-105	U-232	Ci	3.79E-03	1.25E-05	1.51E-07
241-C-105	Cm-243	Ci	3.79E-03	1.19E-05	1.44E-07
241-C-105	Ra-228	Ci	3.79E-03	1.16E-05	1.41E-07
241-C-105	U-235	Ci	3.79E-03	1.05E-05	1.27E-07
241-C-105	Pa-231	Ci	3.79E-03	9.42E-06	1.14E-07
241-C-105	U-236	Ci	3.79E-03	8.47E-06	1.03E-07
241-C-105	Pu-242	Ci	3.79E-03	3.02E-06	3.66E-08
241-C-105	Ac-227	Ci	3.79E-03	1.64E-06	1.99E-08
241-C-105	Ru-106	Ci	3.79E-03	5.33E-07	6.46E-09
241-C-105	Th-232	Ci	3.79E-03	2.35E-07	2.85E-09
241-C-105	Ra-226	Ci	3.79E-03	2.34E-07	2.83E-09
241-C-105	Th-229	Ci	3.79E-03	1.17E-07	1.42E-09
241-C-105	La	kg	3.79E-03	6.17E-09	3.03E-10
241-C-105	CCl4	kg	3.79E-03	0.00E+00	0.00E+00
241-C-105	TBP	kg	3.79E-03	0.00E+00	0.00E+00
241-C-105	NPH	kg	3.79E-03	0.00E+00	0.00E+00
241-C-105	Fe(CN)6	kg	3.79E-03	0.00E+00	0.00E+00
			Total Mass	2.04E+03	
			Total Activity	8.25E+03	

Table X-3. Soil Contamination Inventory Associated With Tank C-110

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-110	NO3	kg	7.57E-03	6.09E+03	5.77E+01
241-C-110	Na	kg	7.57E-03	3.07E+03	2.91E+01
241-C-110	SO4	kg	7.57E-03	3.92E+02	3.72E+00
241-C-110	Cs-137	Ci	7.57E-03	3.50E+02	4.13E+01
241-C-110	CO3	kg	7.57E-03	3.39E+02	3.21E+00
241-C-110	Ba-137m	Ci	7.57E-03	3.31E+02	3.90E+01
241-C-110	NO2	kg	7.57E-03	2.39E+02	2.27E+00
241-C-110	PO4	kg	7.57E-03	2.35E+02	2.23E+00
241-C-110	Cl	kg	7.57E-03	1.11E+02	1.05E+00
241-C-110	Sr-90	Ci	7.57E-03	7.68E+01	9.05E+00
241-C-110	Y-90	Ci	7.57E-03	7.68E+01	9.05E+00
241-C-110	K	kg	7.57E-03	2.07E+01	1.96E-01
241-C-110	F	kg	7.57E-03	1.94E+01	1.84E-01
241-C-110	Sm-151	Ci	7.57E-03	1.30E+01	1.53E+00
241-C-110	NH3	kg	7.57E-03	1.05E+01	9.95E-02
241-C-110	Cr	kg	7.57E-03	6.90E+00	6.54E-02
241-C-110	Ca	kg	7.57E-03	5.27E+00	5.00E-02
241-C-110	Fe	kg	7.57E-03	3.67E+00	3.48E-02
241-C-110	Ni	kg	7.57E-03	3.37E+00	3.19E-02
241-C-110	Bi	kg	7.57E-03	1.63E+00	1.54E-02
241-C-110	Si	kg	7.57E-03	1.53E+00	1.45E-02
241-C-110	U-Total	kg	7.57E-03	1.10E+00	1.04E-02
241-C-110	H-3	Ci	7.57E-03	2.01E-01	2.37E-02
241-C-110	Ni-63	Ci	7.57E-03	1.79E-01	2.11E-02
241-C-110	Zr	kg	7.57E-03	1.39E-01	1.32E-03
241-C-110	Pu-239	Ci	7.57E-03	1.17E-01	1.38E-02
241-C-110	Tc-99	Ci	7.57E-03	1.14E-01	1.34E-02
241-C-110	Am-241	Ci	7.57E-03	5.03E-02	5.93E-03
241-C-110	Eu-154	Ci	7.57E-03	3.46E-02	4.08E-03
241-C-110	Butanol	kg	7.57E-03	2.07E-02	1.96E-04
241-C-110	Pu-241	Ci	7.57E-03	2.07E-02	2.44E-03
241-C-110	Eu-155	Ci	7.57E-03	2.05E-02	2.42E-03
241-C-110	Pu-240	Ci	7.57E-03	1.16E-02	1.37E-03
241-C-110	Ag	kg	7.57E-03	1.04E-02	9.86E-05
241-C-110	Cd-113m	Ci	7.57E-03	1.02E-02	1.20E-03
241-C-110	Hg	kg	7.57E-03	9.69E-03	9.18E-05
241-C-110	C-14	Ci	7.57E-03	7.71E-03	9.09E-04
241-C-110	Co-60	Ci	7.57E-03	6.19E-03	7.30E-04
241-C-110	Zr-93	Ci	7.57E-03	5.04E-03	5.94E-04
241-C-110	Nb-93m	Ci	7.57E-03	4.53E-03	5.34E-04
241-C-110	Ni-59	Ci	7.57E-03	1.99E-03	2.35E-04
241-C-110	Sn-126	Ci	7.57E-03	1.27E-03	1.50E-04
241-C-110	Np-237	Ci	7.57E-03	9.19E-04	1.08E-04
241-C-110	Pu-238	Ci	7.57E-03	7.37E-04	8.69E-05

Table X-3. Soil Contamination Inventory Associated With Tank C-110

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-110	Eu-152	Ci	7.57E-03	4.52E-04	5.33E-05
241-C-110	U-238	Ci	7.57E-03	3.68E-04	4.34E-05
241-C-110	U-234	Ci	7.57E-03	3.61E-04	4.26E-05
241-C-110	Se-79	Ci	7.57E-03	3.36E-04	3.96E-05
241-C-110	Sb-125	Ci	7.57E-03	2.98E-04	3.51E-05
241-C-110	I-129	Ci	7.57E-03	1.46E-04	1.72E-05
241-C-110	U-235	Ci	7.57E-03	1.62E-05	1.91E-06
241-C-110	Cm-242	Ci	7.57E-03	1.21E-05	1.43E-06
241-C-110	Ac-227	Ci	7.57E-03	7.76E-06	9.15E-07
241-C-110	Am-243	Ci	7.57E-03	7.05E-06	8.31E-07
241-C-110	Pa-231	Ci	7.57E-03	4.86E-06	5.73E-07
241-C-110	U-236	Ci	7.57E-03	3.98E-06	4.69E-07
241-C-110	Cm-244	Ci	7.57E-03	3.38E-06	3.98E-07
241-C-110	Cs-134	Ci	7.57E-03	3.10E-06	3.65E-07
241-C-110	Ra-226	Ci	7.57E-03	1.63E-06	1.92E-07
241-C-110	Cm-243	Ci	7.57E-03	1.44E-07	1.70E-08
241-C-110	Pu-242	Ci	7.57E-03	1.41E-07	1.66E-08
241-C-110	U-232	Ci	7.57E-03	4.33E-09	5.10E-10
241-C-110	Th-229	Ci	7.57E-03	5.25E-10	6.19E-11
241-C-110	U-233	Ci	7.57E-03	3.56E-10	4.20E-11
241-C-110	Ra-228	Ci	7.57E-03	7.53E-12	8.88E-13
241-C-110	Th-232	Ci	7.57E-03	4.43E-12	5.22E-13
241-C-110	Ru-106	Ci	7.57E-03	3.20E-13	3.77E-14
241-C-110	Al	kg	7.57E-03	0.00E+00	0.00E+00
241-C-110	La	kg	7.57E-03	0.00E+00	0.00E+00
241-C-110	Pb	kg	7.57E-03	0.00E+00	0.00E+00
241-C-110	Mn	kg	7.57E-03	0.00E+00	0.00E+00
241-C-110	CCl4	kg	7.57E-03	0.00E+00	0.00E+00
241-C-110	TBP	kg	7.57E-03	0.00E+00	0.00E+00
241-C-110	NPH	kg	7.57E-03	0.00E+00	0.00E+00
241-C-110	Fe(CN)6	kg	7.57E-03	0.00E+00	0.00E+00
			Total Mass	1.06E+04	
			Total Activity	8.48E+02	

Table X-4. Soil Contamination Inventory Associated With Tank C-111

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-111	Na	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Al	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Fe	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Cr	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Bi	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	La	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Hg	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Zr	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Pb	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ni	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ag	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Mn	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ca	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	K	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	NO3	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	NO2	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	CO3	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	PO4	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	SO4	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Si	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	F	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Cl	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	CCl4	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Butanol	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	TBP	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	NPH	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	NH3	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Fe(CN)6	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	H-3	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	C-14	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ni-59	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ni-63	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Co-60	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Se-79	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Sr-90	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Y-90	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Zr-93	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Nb-93m	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Tc-99	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ru-106	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Cd-113m	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Sb-125	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Sn-126	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	I-129	Ci	2.08E-02	0.00E+00	0.00E+00

Table X-4. Soil Contamination Inventory Associated With Tank C-111

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-111	Cs-134	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Cs-137	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ba-137m	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Sm-151	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Eu-152	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Eu-154	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Eu-155	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ra-226	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ra-228	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Ac-227	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Pa-231	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Th-229	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Th-232	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	U-232	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	U-233	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	U-234	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	U-235	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	U-236	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	U-238	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	U-Total	kg	2.08E-02	0.00E+00	0.00E+00
241-C-111	Np-237	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Pu-238	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Pu-239	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Pu-240	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Pu-241	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Pu-242	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Am-241	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Am-243	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Cm-242	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Cm-243	Ci	2.08E-02	0.00E+00	0.00E+00
241-C-111	Cm-244	Ci	2.08E-02	0.00E+00	0.00E+00
			Total Mass	0.00E+00	
			Total Activity	0.00E+00	

Table X-5. Soil Contamination Inventory Associated With 200 Series Tanks

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-201	Ac-227	Ci	2.08E-03	6.46E-09	
241-C-202	Ac-227	Ci	1.70E-03	5.28E-09	
241-C-203	Ac-227	Ci	1.51E-03	4.99E-09	
241-C-204	Ac-227	Ci	1.32E-03	4.24E-09	1.27E-09
241-C-201	Ag	kg	2.08E-03	0.00E+00	
241-C-202	Ag	kg	1.70E-03	0.00E+00	
241-C-203	Ag	kg	1.51E-03	0.00E+00	
241-C-204	Ag	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	Al	kg	2.08E-03	0.00E+00	
241-C-202	Al	kg	1.70E-03	0.00E+00	
241-C-203	Al	kg	1.51E-03	0.00E+00	
241-C-204	Al	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	Am-241	Ci	2.08E-03	5.56E-01	
241-C-202	Am-241	Ci	1.70E-03	4.55E-01	
241-C-203	Am-241	Ci	1.51E-03	4.30E-01	
241-C-204	Am-241	Ci	1.32E-03	3.65E-01	1.10E-01
241-C-201	Am-243	Ci	2.08E-03	2.78E-04	
241-C-202	Am-243	Ci	1.70E-03	2.27E-04	
241-C-203	Am-243	Ci	1.51E-03	2.15E-04	
241-C-204	Am-243	Ci	1.32E-03	1.82E-04	5.47E-05
241-C-201	Ba-137m	Ci	2.08E-03	4.06E+01	
241-C-202	Ba-137m	Ci	1.70E-03	3.32E+01	
241-C-203	Ba-137m	Ci	1.51E-03	3.14E+01	
241-C-204	Ba-137m	Ci	1.32E-03	2.67E+01	8.01E+00
241-C-201	Bi	kg	2.08E-03	0.00E+00	
241-C-202	Bi	kg	1.70E-03	0.00E+00	
241-C-203	Bi	kg	1.51E-03	0.00E+00	
241-C-204	Bi	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	Butanol	kg	2.08E-03	0.00E+00	
241-C-202	Butanol	kg	1.70E-03	0.00E+00	
241-C-203	Butanol	kg	1.51E-03	0.00E+00	
241-C-204	Butanol	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	C-14	Ci	2.08E-03	2.78E-04	
241-C-202	C-14	Ci	1.70E-03	2.27E-04	
241-C-203	C-14	Ci	1.51E-03	2.14E-04	
241-C-204	C-14	Ci	1.32E-03	1.82E-04	5.47E-05
241-C-201	Ca	kg	2.08E-03	3.86E-01	
241-C-202	Ca	kg	1.70E-03	3.16E-01	
241-C-203	Ca	kg	1.51E-03	2.98E-01	
241-C-204	Ca	kg	1.32E-03	2.53E-01	1.52E-01
241-C-201	CCl4	kg	2.08E-03	0.00E+00	
241-C-202	CCl4	kg	1.70E-03	0.00E+00	
241-C-203	CCl4	kg	1.51E-03	0.00E+00	
241-C-204	CCl4	kg	1.32E-03	0.00E+00	0.00E+00

Table X-5. Soil Contamination Inventory Associated With 200 Series Tanks

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-201	Cd-113m	Ci	2.08E-03	2.05E-03	
241-C-202	Cd-113m	Ci	1.70E-03	1.68E-03	
241-C-203	Cd-113m	Ci	1.51E-03	1.59E-03	
241-C-204	Cd-113m	Ci	1.32E-03	1.35E-03	4.05E-04
241-C-201	Cl	kg	2.08E-03	3.42E+00	
241-C-202	Cl	kg	1.70E-03	2.79E+00	
241-C-203	Cl	kg	1.51E-03	2.64E+00	
241-C-204	Cl	kg	1.32E-03	2.24E+00	1.34E+00
241-C-201	Cm-242	Ci	2.08E-03	2.98E-05	
241-C-202	Cm-242	Ci	1.70E-03	2.43E-05	
241-C-203	Cm-242	Ci	1.51E-03	2.30E-05	
241-C-204	Cm-242	Ci	1.32E-03	1.95E-05	5.86E-06
241-C-201	Cm-243	Ci	2.08E-03	1.59E-06	
241-C-202	Cm-243	Ci	1.70E-03	1.30E-06	
241-C-203	Cm-243	Ci	1.51E-03	1.23E-06	
241-C-204	Cm-243	Ci	1.32E-03	1.05E-06	3.14E-07
241-C-201	Cm-244	Ci	2.08E-03	3.76E-05	
241-C-202	Cm-244	Ci	1.70E-03	3.07E-05	
241-C-203	Cm-244	Ci	1.51E-03	2.91E-05	
241-C-204	Cm-244	Ci	1.32E-03	2.47E-05	7.41E-06
241-C-201	CO3	kg	2.08E-03	5.86E-01	
241-C-202	CO3	kg	1.70E-03	4.79E-01	
241-C-203	CO3	kg	1.51E-03	4.46E-01	
241-C-204	CO3	kg	1.32E-03	3.81E-01	2.29E-01
241-C-201	Co-60	Ci	2.08E-03	4.05E-02	
241-C-202	Co-60	Ci	1.70E-03	3.31E-02	
241-C-203	Co-60	Ci	1.51E-03	3.13E-02	
241-C-204	Co-60	Ci	1.32E-03	2.66E-02	7.98E-03
241-C-201	Cr	kg	2.08E-03	7.80E-01	
241-C-202	Cr	kg	1.70E-03	6.37E-01	
241-C-203	Cr	kg	1.51E-03	6.03E-01	
241-C-204	Cr	kg	1.32E-03	5.12E-01	3.06E-01
241-C-201	Cs-134	Ci	2.08E-03	3.40E-05	
241-C-202	Cs-134	Ci	1.70E-03	2.78E-05	
241-C-203	Cs-134	Ci	1.51E-03	2.63E-05	
241-C-204	Cs-134	Ci	1.32E-03	2.23E-05	6.70E-06
241-C-201	Cs-137	Ci	2.08E-03	4.30E+01	
241-C-202	Cs-137	Ci	1.70E-03	3.52E+01	
241-C-203	Cs-137	Ci	1.51E-03	3.32E+01	
241-C-204	Cs-137	Ci	1.32E-03	2.82E+01	8.47E+00
241-C-201	Eu-152	Ci	2.08E-03	7.78E-03	
241-C-202	Eu-152	Ci	1.70E-03	6.36E-03	
241-C-203	Eu-152	Ci	1.51E-03	6.01E-03	
241-C-204	Eu-152	Ci	1.32E-03	5.10E-03	1.53E-03

Table X-5. Soil Contamination Inventory Associated With 200 Series Tanks

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-201	Eu-154	Ci	2.08E-03	6.11E-01	
241-C-202	Eu-154	Ci	1.70E-03	4.99E-01	
241-C-203	Eu-154	Ci	1.51E-03	4.72E-01	
241-C-204	Eu-154	Ci	1.32E-03	4.01E-01	1.20E-01
241-C-201	Eu-155	Ci	2.08E-03	3.24E-01	
241-C-202	Eu-155	Ci	1.70E-03	2.64E-01	
241-C-203	Eu-155	Ci	1.51E-03	2.50E-01	
241-C-204	Eu-155	Ci	1.32E-03	2.12E-01	6.37E-02
241-C-201	F	kg	2.08E-03	1.67E-05	
241-C-202	F	kg	1.70E-03	1.39E-05	
241-C-203	F	kg	1.51E-03	0.00E+00	
241-C-204	F	kg	1.32E-03	5.31E-06	4.35E-06
241-C-201	Fe	kg	2.08E-03	5.28E+00	
241-C-202	Fe	kg	1.70E-03	4.31E+00	
241-C-203	Fe	kg	1.51E-03	4.08E+00	
241-C-204	Fe	kg	1.32E-03	3.46E+00	2.07E+00
241-C-201	Fe(CN)6	kg	2.08E-03	0.00E+00	
241-C-202	Fe(CN)6	kg	1.70E-03	0.00E+00	
241-C-203	Fe(CN)6	kg	1.51E-03	0.00E+00	
241-C-204	Fe(CN)6	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	H-3	Ci	2.08E-03	6.41E-04	
241-C-202	H-3	Ci	1.70E-03	5.24E-04	
241-C-203	H-3	Ci	1.51E-03	4.96E-04	
241-C-204	H-3	Ci	1.32E-03	4.21E-04	1.26E-04
241-C-201	Hg	kg	2.08E-03	6.35E-04	
241-C-202	Hg	kg	1.70E-03	5.19E-04	
241-C-203	Hg	kg	1.51E-03	4.91E-04	
241-C-204	Hg	kg	1.32E-03	4.17E-04	2.50E-04
241-C-201	I-129	Ci	2.08E-03	6.42E-07	
241-C-202	I-129	Ci	1.70E-03	5.24E-07	
241-C-203	I-129	Ci	1.51E-03	4.96E-07	
241-C-204	I-129	Ci	1.32E-03	4.21E-07	1.26E-07
241-C-201	K	kg	2.08E-03	6.80E+00	
241-C-202	K	kg	1.70E-03	5.56E+00	
241-C-203	K	kg	1.51E-03	5.25E+00	
241-C-204	K	kg	1.32E-03	4.46E+00	2.67E+00
241-C-201	La	kg	2.08E-03	0.00E+00	
241-C-202	La	kg	1.70E-03	0.00E+00	
241-C-203	La	kg	1.51E-03	0.00E+00	
241-C-204	La	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	Mn	kg	2.08E-03	7.63E-07	
241-C-202	Mn	kg	1.70E-03	6.35E-07	
241-C-203	Mn	kg	1.51E-03	0.00E+00	
241-C-204	Mn	kg	1.32E-03	2.43E-07	1.99E-07

Table X-5. Soil Contamination Inventory Associated With 200 Series Tanks

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-201	Na	kg	2.08E-03	9.99E+01	
241-C-202	Na	kg	1.70E-03	8.16E+01	
241-C-203	Na	kg	1.51E-03	7.72E+01	
241-C-204	Na	kg	1.32E-03	6.55E+01	3.92E+01
241-C-201	Nb-93m	Ci	2.08E-03	1.66E-03	
241-C-202	Nb-93m	Ci	1.70E-03	1.35E-03	
241-C-203	Nb-93m	Ci	1.51E-03	1.28E-03	
241-C-204	Nb-93m	Ci	1.32E-03	1.09E-03	3.27E-04
241-C-201	NH3	kg	2.08E-03	1.20E-01	
241-C-202	NH3	kg	1.70E-03	9.83E-02	
241-C-203	NH3	kg	1.51E-03	9.30E-02	
241-C-204	NH3	kg	1.32E-03	7.90E-02	4.72E-02
241-C-201	Ni	kg	2.08E-03	4.60E-01	
241-C-202	Ni	kg	1.70E-03	3.76E-01	
241-C-203	Ni	kg	1.51E-03	3.56E-01	
241-C-204	Ni	kg	1.32E-03	3.02E-01	1.81E-01
241-C-201	Ni-59	Ci	2.08E-03	5.72E-03	
241-C-202	Ni-59	Ci	1.70E-03	4.67E-03	
241-C-203	Ni-59	Ci	1.51E-03	4.42E-03	
241-C-204	Ni-59	Ci	1.32E-03	3.75E-03	1.13E-03
241-C-201	Ni-63	Ci	2.08E-03	5.39E-01	
241-C-202	Ni-63	Ci	1.70E-03	4.41E-01	
241-C-203	Ni-63	Ci	1.51E-03	4.17E-01	
241-C-204	Ni-63	Ci	1.32E-03	3.54E-01	1.06E-01
241-C-201	NO2	kg	2.08E-03	2.63E+01	
241-C-202	NO2	kg	1.70E-03	2.15E+01	
241-C-203	NO2	kg	1.51E-03	2.03E+01	
241-C-204	NO2	kg	1.32E-03	1.72E+01	1.03E+01
241-C-201	NO3	kg	2.08E-03	9.69E+01	
241-C-202	NO3	kg	1.70E-03	7.92E+01	
241-C-203	NO3	kg	1.51E-03	7.49E+01	
241-C-204	NO3	kg	1.32E-03	6.36E+01	3.81E+01
241-C-201	Np-237	Ci	2.08E-03	4.53E-05	
241-C-202	Np-237	Ci	1.70E-03	3.71E-05	
241-C-203	Np-237	Ci	1.51E-03	3.50E-05	
241-C-204	Np-237	Ci	1.32E-03	2.98E-05	8.93E-06
241-C-201	NPH	kg	2.08E-03	0.00E+00	
241-C-202	NPH	kg	1.70E-03	0.00E+00	
241-C-203	NPH	kg	1.51E-03	0.00E+00	
241-C-204	NPH	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	Pa-231	Ci	2.08E-03	9.52E-09	
241-C-202	Pa-231	Ci	1.70E-03	7.78E-09	
241-C-203	Pa-231	Ci	1.51E-03	7.36E-09	
241-C-204	Pa-231	Ci	1.32E-03	6.25E-09	1.88E-09

Table X-5. Soil Contamination Inventory Associated With 200 Series Tanks

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-201	Pb	kg	2.08E-03	8.90E-01	
241-C-202	Pb	kg	1.70E-03	7.28E-01	
241-C-203	Pb	kg	1.51E-03	6.88E-01	
241-C-204	Pb	kg	1.32E-03	5.84E-01	3.50E-01
241-C-201	PO4	kg	2.08E-03	0.00E+00	
241-C-202	PO4	kg	1.70E-03	0.00E+00	
241-C-203	PO4	kg	1.51E-03	0.00E+00	
241-C-204	PO4	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	Pu-238	Ci	2.08E-03	3.82E-04	
241-C-202	Pu-238	Ci	1.70E-03	3.12E-04	
241-C-203	Pu-238	Ci	1.51E-03	2.95E-04	
241-C-204	Pu-238	Ci	1.32E-03	2.50E-04	7.52E-05
241-C-201	Pu-239	Ci	2.08E-03	1.17E-02	
241-C-202	Pu-239	Ci	1.70E-03	9.56E-03	
241-C-203	Pu-239	Ci	1.51E-03	9.04E-03	
241-C-204	Pu-239	Ci	1.32E-03	7.68E-03	2.31E-03
241-C-201	Pu-240	Ci	2.08E-03	2.53E-03	
241-C-202	Pu-240	Ci	1.70E-03	2.06E-03	
241-C-203	Pu-240	Ci	1.51E-03	1.95E-03	
241-C-204	Pu-240	Ci	1.32E-03	1.66E-03	4.98E-04
241-C-201	Pu-241	Ci	2.08E-03	1.55E-02	
241-C-202	Pu-241	Ci	1.70E-03	1.26E-02	
241-C-203	Pu-241	Ci	1.51E-03	1.19E-02	
241-C-204	Pu-241	Ci	1.32E-03	1.01E-02	3.04E-03
241-C-201	Pu-242	Ci	2.08E-03	1.19E-07	
241-C-202	Pu-242	Ci	1.70E-03	9.70E-08	
241-C-203	Pu-242	Ci	1.51E-03	9.18E-08	
241-C-204	Pu-242	Ci	1.32E-03	7.79E-08	2.34E-08
241-C-201	Ra-226	Ci	2.08E-03	1.42E-09	
241-C-202	Ra-226	Ci	1.70E-03	1.16E-09	
241-C-203	Ra-226	Ci	1.51E-03	1.10E-09	
241-C-204	Ra-226	Ci	1.32E-03	9.34E-10	2.80E-10
241-C-201	Ra-228	Ci	2.08E-03	1.01E-14	
241-C-202	Ra-228	Ci	1.70E-03	8.28E-15	
241-C-203	Ra-228	Ci	1.51E-03	7.83E-15	
241-C-204	Ra-228	Ci	1.32E-03	6.65E-15	1.99E-15
241-C-201	Ru-106	Ci	2.08E-03	7.96E-08	
241-C-202	Ru-106	Ci	1.70E-03	6.51E-08	
241-C-203	Ru-106	Ci	1.51E-03	6.15E-08	
241-C-204	Ru-106	Ci	1.32E-03	5.22E-08	1.57E-08
241-C-201	Sb-125	Ci	2.08E-03	8.96E-03	
241-C-202	Sb-125	Ci	1.70E-03	7.32E-03	
241-C-203	Sb-125	Ci	1.51E-03	6.93E-03	
241-C-204	Sb-125	Ci	1.32E-03	5.88E-03	1.77E-03

Table X-5. Soil Contamination Inventory Associated With 200 Series Tanks

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-201	Se-79	Ci	2.08E-03	3.43E-05	
241-C-202	Se-79	Ci	1.70E-03	2.80E-05	
241-C-203	Se-79	Ci	1.51E-03	2.65E-05	
241-C-204	Se-79	Ci	1.32E-03	2.25E-05	6.76E-06
241-C-201	Si	kg	2.08E-03	3.08E-04	
241-C-202	Si	kg	1.70E-03	2.56E-04	
241-C-203	Si	kg	1.51E-03	0.00E+00	
241-C-204	Si	kg	1.32E-03	9.80E-05	8.01E-05
241-C-201	Sm-151	Ci	2.08E-03	3.86E+01	
241-C-202	Sm-151	Ci	1.70E-03	3.15E+01	
241-C-203	Sm-151	Ci	1.51E-03	2.98E+01	
241-C-204	Sm-151	Ci	1.32E-03	2.53E+01	7.60E+00
241-C-201	Sn-126	Ci	2.08E-03	1.42E-04	
241-C-202	Sn-126	Ci	1.70E-03	1.16E-04	
241-C-203	Sn-126	Ci	1.51E-03	1.10E-04	
241-C-204	Sn-126	Ci	1.32E-03	9.33E-05	2.80E-05
241-C-201	SO4	kg	2.08E-03	1.27E+01	
241-C-202	SO4	kg	1.70E-03	1.04E+01	
241-C-203	SO4	kg	1.51E-03	9.81E+00	
241-C-204	SO4	kg	1.32E-03	8.33E+00	4.99E+00
241-C-201	Sr-90	Ci	2.08E-03	1.91E+02	
241-C-202	Sr-90	Ci	1.70E-03	1.56E+02	
241-C-203	Sr-90	Ci	1.51E-03	1.48E+02	
241-C-204	Sr-90	Ci	1.32E-03	1.26E+02	3.77E+01
241-C-201	TBP	kg	2.08E-03	0.00E+00	
241-C-202	TBP	kg	1.70E-03	0.00E+00	
241-C-203	TBP	kg	1.51E-03	0.00E+00	
241-C-204	TBP	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	Tc-99	Ci	2.08E-03	1.07E-02	
241-C-202	Tc-99	Ci	1.70E-03	8.77E-03	
241-C-203	Tc-99	Ci	1.51E-03	8.29E-03	
241-C-204	Tc-99	Ci	1.32E-03	7.04E-03	2.11E-03
241-C-201	Th-229	Ci	2.08E-03	1.65E-11	
241-C-202	Th-229	Ci	1.70E-03	1.35E-11	
241-C-203	Th-229	Ci	1.51E-03	1.28E-11	
241-C-204	Th-229	Ci	1.32E-03	1.08E-11	3.25E-12
241-C-201	Th-232	Ci	2.08E-03	1.05E-14	
241-C-202	Th-232	Ci	1.70E-03	8.58E-15	
241-C-203	Th-232	Ci	1.51E-03	8.11E-15	
241-C-204	Th-232	Ci	1.32E-03	6.88E-15	2.07E-15
241-C-201	U-232	Ci	2.08E-03	1.49E-09	
241-C-202	U-232	Ci	1.70E-03	1.21E-09	
241-C-203	U-232	Ci	1.51E-03	1.15E-09	
241-C-204	U-232	Ci	1.32E-03	9.75E-10	2.93E-10

Table X-5. Soil Contamination Inventory Associated With 200 Series Tanks

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
241-C-201	U-233	Ci	2.08E-03	6.27E-09	
241-C-202	U-233	Ci	1.70E-03	5.12E-09	
241-C-203	U-233	Ci	1.51E-03	4.84E-09	
241-C-204	U-233	Ci	1.32E-03	4.11E-09	1.23E-09
241-C-201	U-234	Ci	2.08E-03	2.03E-05	
241-C-202	U-234	Ci	1.70E-03	1.66E-05	
241-C-203	U-234	Ci	1.51E-03	1.57E-05	
241-C-204	U-234	Ci	1.32E-03	1.33E-05	4.00E-06
241-C-201	U-235	Ci	2.08E-03	8.56E-07	
241-C-202	U-235	Ci	1.70E-03	7.00E-07	
241-C-203	U-235	Ci	1.51E-03	6.62E-07	
241-C-204	U-235	Ci	1.32E-03	5.62E-07	1.69E-07
241-C-201	U-236	Ci	2.08E-03	4.84E-07	
241-C-202	U-236	Ci	1.70E-03	3.96E-07	
241-C-203	U-236	Ci	1.51E-03	3.74E-07	
241-C-204	U-236	Ci	1.32E-03	3.18E-07	9.54E-08
241-C-201	U-238	Ci	2.08E-03	2.03E-05	
241-C-202	U-238	Ci	1.70E-03	1.66E-05	
241-C-203	U-238	Ci	1.51E-03	1.57E-05	
241-C-204	U-238	Ci	1.32E-03	1.33E-05	4.00E-06
241-C-201	U-Total	kg	2.08E-03	6.08E-02	
241-C-202	U-Total	kg	1.70E-03	4.97E-02	
241-C-203	U-Total	kg	1.51E-03	4.70E-02	
241-C-204	U-Total	kg	1.32E-03	3.99E-02	2.39E-02
241-C-201	Y-90	Ci	2.08E-03	1.92E+02	
241-C-202	Y-90	Ci	1.70E-03	1.57E+02	
241-C-203	Y-90	Ci	1.51E-03	1.48E+02	
241-C-204	Y-90	Ci	1.32E-03	1.26E+02	3.78E+01
241-C-201	Zr	kg	2.08E-03	0.00E+00	
241-C-202	Zr	kg	1.70E-03	0.00E+00	
241-C-203	Zr	kg	1.51E-03	0.00E+00	
241-C-204	Zr	kg	1.32E-03	0.00E+00	0.00E+00
241-C-201	Zr-93	Ci	2.08E-03	2.04E-03	
241-C-202	Zr-93	Ci	1.70E-03	1.67E-03	
241-C-203	Zr-93	Ci	1.51E-03	1.58E-03	
241-C-204	Zr-93	Ci	1.32E-03	1.34E-03	4.02E-04
			Total Mass	8.26E+02	
			Total Activity	1.65E+03	

Table X-6. Soil Contamination Inventory Associated With UPR-81

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
UPR-200-E-81	NO3	kg	1.36E-01	2.36E+04	3.80E+01
UPR-200-E-81	Na	kg	1.36E-01	2.07E+04	3.33E+01
UPR-200-E-81	Al	kg	1.36E-01	9.40E+03	1.51E+01
UPR-200-E-81	NO2	kg	1.36E-01	7.24E+03	1.17E+01
UPR-200-E-81	Ni-63	Ci	1.36E-01	4.20E+02	2.29E+01
UPR-200-E-81	SO4	kg	1.36E-01	3.59E+02	5.78E-01
UPR-200-E-81	Cs-137	Ci	1.36E-01	3.50E+02	1.91E+01
UPR-200-E-81	Ba-137m	Ci	1.36E-01	3.31E+02	1.81E+01
UPR-200-E-81	Sr-90	Ci	1.36E-01	2.99E+02	1.63E+01
UPR-200-E-81	Y-90	Ci	1.36E-01	2.99E+02	1.63E+01
UPR-200-E-81	Cl	kg	1.36E-01	2.27E+02	3.66E-01
UPR-200-E-81	CO3	kg	1.36E-01	1.25E+02	2.01E-01
UPR-200-E-81	H-3	Ci	1.36E-01	9.32E+01	5.09E+00
UPR-200-E-81	Cr	kg	1.36E-01	8.83E+01	1.42E-01
UPR-200-E-81	Ca	kg	1.36E-01	8.33E+01	1.34E-01
UPR-200-E-81	Pb	kg	1.36E-01	8.27E+01	1.33E-01
UPR-200-E-81	Fe	kg	1.36E-01	5.81E+01	9.36E-02
UPR-200-E-81	K	kg	1.36E-01	5.45E+01	8.78E-02
UPR-200-E-81	Ni	kg	1.36E-01	4.99E+01	8.04E-02
UPR-200-E-81	U-Total	kg	1.36E-01	1.72E+01	2.77E-02
UPR-200-E-81	Co-60	Ci	1.36E-01	1.15E+01	6.27E-01
UPR-200-E-81	Sm-151	Ci	1.36E-01	1.10E+01	6.00E-01
UPR-200-E-81	Pu-241	Ci	1.36E-01	4.78E+00	2.61E-01
UPR-200-E-81	Ni-59	Ci	1.36E-01	4.35E+00	2.37E-01
UPR-200-E-81	Am-241	Ci	1.36E-01	3.09E+00	1.69E-01
UPR-200-E-81	Pu-239	Ci	1.36E-01	2.80E+00	1.53E-01
UPR-200-E-81	Cd-113m	Ci	1.36E-01	1.12E+00	6.11E-02
UPR-200-E-81	Pu-240	Ci	1.36E-01	6.61E-01	3.61E-02
UPR-200-E-81	C-14	Ci	1.36E-01	5.94E-01	3.24E-02
UPR-200-E-81	Eu-154	Ci	1.36E-01	2.19E-01	1.19E-02
UPR-200-E-81	NH3	kg	1.36E-01	1.75E-01	2.82E-04
UPR-200-E-81	Eu-155	Ci	1.36E-01	1.21E-01	6.60E-03
UPR-200-E-81	Tc-99	Ci	1.36E-01	1.12E-01	6.11E-03
UPR-200-E-81	I-129	Ci	1.36E-01	9.70E-02	5.29E-03
UPR-200-E-81	Pu-238	Ci	1.36E-01	6.77E-02	3.69E-03
UPR-200-E-81	U-233	Ci	1.36E-01	4.60E-02	2.51E-03
UPR-200-E-81	Ag	kg	1.36E-01	2.15E-02	3.46E-05
UPR-200-E-81	Zr-93	Ci	1.36E-01	1.55E-02	8.46E-04
UPR-200-E-81	Nb-93m	Ci	1.36E-01	1.21E-02	6.60E-04
UPR-200-E-81	Sb-125	Ci	1.36E-01	1.17E-02	6.38E-04
UPR-200-E-81	Ra-228	Ci	1.36E-01	9.87E-03	5.39E-04
UPR-200-E-81	U-234	Ci	1.36E-01	6.39E-03	3.49E-04
UPR-200-E-81	U-238	Ci	1.36E-01	5.74E-03	3.13E-04
UPR-200-E-81	Eu-152	Ci	1.36E-01	2.85E-03	1.55E-04

Table X-6. Soil Contamination Inventory Associated With UPR-81

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
UPR-200-E-81	Sn-126	Ci	1.36E-01	1.11E-03	6.06E-05
UPR-200-E-81	Pa-231	Ci	1.36E-01	1.00E-03	5.46E-05
UPR-200-E-81	U-232	Ci	1.36E-01	7.69E-04	4.20E-05
UPR-200-E-81	Cs-134	Ci	1.36E-01	7.55E-04	4.12E-05
UPR-200-E-81	Np-237	Ci	1.36E-01	7.42E-04	4.05E-05
UPR-200-E-81	Se-79	Ci	1.36E-01	2.68E-04	1.46E-05
UPR-200-E-81	U-235	Ci	1.36E-01	2.49E-04	1.36E-05
UPR-200-E-81	Cm-244	Ci	1.36E-01	2.08E-04	1.13E-05
UPR-200-E-81	Ac-227	Ci	1.36E-01	1.99E-04	1.09E-05
UPR-200-E-81	U-236	Ci	1.36E-01	1.57E-04	8.57E-06
UPR-200-E-81	Cm-242	Ci	1.36E-01	1.28E-04	6.98E-06
UPR-200-E-81	Th-232	Ci	1.36E-01	1.24E-04	6.77E-06
UPR-200-E-81	Am-243	Ci	1.36E-01	8.22E-05	4.48E-06
UPR-200-E-81	Pu-242	Ci	1.36E-01	3.35E-05	1.83E-06
UPR-200-E-81	Th-229	Ci	1.36E-01	2.71E-05	1.48E-06
UPR-200-E-81	Cm-243	Ci	1.36E-01	6.77E-06	3.69E-07
UPR-200-E-81	Ra-226	Ci	1.36E-01	1.28E-06	6.98E-08
UPR-200-E-81	Ru-106	Ci	1.36E-01	3.93E-07	2.14E-08
UPR-200-E-81	Bi	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	La	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	Hg	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	Zr	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	Mn	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	PO4	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	Si	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	F	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	CCl4	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	Butanol	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	TBP	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	NPH	kg	1.36E-01	0.00E+00	0.00E+00
UPR-200-E-81	Fe(CN)6	kg	1.36E-01	0.00E+00	0.00E+00
			Total Mass	6.21E+04	
			Total Activity	1.83E+03	

Table X-7. Soil Contamination Inventory Associated With UPR-82

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
UPR-200-E-82	Cs-137	Ci	9.84E-03	4.40E+03	5.07E+01
UPR-200-E-82	Ba-137m	Ci	9.84E-03	4.15E+03	4.79E+01
UPR-200-E-82	NO2	kg	9.84E-03	3.46E+02	3.49E+01
UPR-200-E-82	Na	kg	9.84E-03	3.30E+02	3.33E+01
UPR-200-E-82	SO4	kg	9.84E-03	1.46E+02	1.47E+01
UPR-200-E-82	NO3	kg	9.84E-03	9.10E+01	9.19E+00
UPR-200-E-82	Sm-151	Ci	9.84E-03	5.40E+01	6.23E-01
UPR-200-E-82	OH	kg	9.84E-03	3.84E+01	3.88E+00
UPR-200-E-82	Sr-90	Ci	9.84E-03	3.03E+01	3.49E-01
UPR-200-E-82	Y-90	Ci	9.84E-03	3.03E+01	3.49E-01
UPR-200-E-82	Cl	kg	9.84E-03	1.14E+01	1.15E+00
UPR-200-E-82	NH3	kg	9.84E-03	6.39E+00	6.45E-01
UPR-200-E-82	Cr	kg	9.84E-03	5.18E+00	5.23E-01
UPR-200-E-82	Si	kg	9.84E-03	3.62E+00	3.66E-01
UPR-200-E-82	CO3	kg	9.84E-03	2.75E+00	2.78E-01
UPR-200-E-82	K	kg	9.84E-03	2.74E+00	2.77E-01
UPR-200-E-82	Tc-99	Ci	9.84E-03	2.07E+00	2.39E-02
UPR-200-E-82	Ca	kg	9.84E-03	1.84E+00	1.86E-01
UPR-200-E-82	Pb	kg	9.84E-03	1.82E+00	1.84E-01
UPR-200-E-82	Ni-63	Ci	9.84E-03	1.58E+00	1.82E-02
UPR-200-E-82	Ni	kg	9.84E-03	1.31E+00	1.32E-01
UPR-200-E-82	Fe	kg	9.84E-03	1.28E+00	1.29E-01
UPR-200-E-82	Eu-154	Ci	9.84E-03	9.97E-01	1.15E-02
UPR-200-E-82	Eu-155	Ci	9.84E-03	5.52E-01	6.37E-03
UPR-200-E-82	Cd-113m	Ci	9.84E-03	4.56E-01	5.26E-03
UPR-200-E-82	Zr-93	Ci	9.84E-03	3.95E-01	4.55E-03
UPR-200-E-82	U-Total	kg	9.84E-03	3.79E-01	3.83E-02
UPR-200-E-82	Nb-93m	Ci	9.84E-03	3.11E-01	3.59E-03
UPR-200-E-82	Co-60	Ci	9.84E-03	2.93E-01	3.38E-03
UPR-200-E-82	H-3	Ci	9.84E-03	1.44E-01	1.66E-03
UPR-200-E-82	Pu-241	Ci	9.84E-03	1.34E-01	1.55E-03
UPR-200-E-82	Sb-125	Ci	9.84E-03	1.07E-01	1.23E-03
UPR-200-E-82	Am-241	Ci	9.84E-03	8.22E-02	9.48E-04
UPR-200-E-82	Pu-239	Ci	9.84E-03	6.15E-02	7.09E-04
UPR-200-E-82	C-14	Ci	9.84E-03	3.64E-02	4.20E-04
UPR-200-E-82	Sn-126	Ci	9.84E-03	2.77E-02	3.19E-04
UPR-200-E-82	Ni-59	Ci	9.84E-03	1.64E-02	1.89E-04
UPR-200-E-82	Pu-240	Ci	9.84E-03	1.51E-02	1.74E-04
UPR-200-E-82	Eu-152	Ci	9.84E-03	1.25E-02	1.44E-04
UPR-200-E-82	Cs-134	Ci	9.84E-03	1.23E-02	1.42E-04
UPR-200-E-82	Se-79	Ci	9.84E-03	6.63E-03	7.65E-05
UPR-200-E-82	Np-237	Ci	9.84E-03	5.58E-03	6.43E-05
UPR-200-E-82	Hg	kg	9.84E-03	3.96E-03	4.00E-04
UPR-200-E-82	Pu-238	Ci	9.84E-03	2.96E-03	3.41E-05

Table X-7. Soil Contamination Inventory Associated With UPR-82

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
UPR-200-E-82	Sr	kg	9.84E-03	5.56E-04	5.62E-05
UPR-200-E-82	Cm-244	Ci	9.84E-03	2.35E-04	2.71E-06
UPR-200-E-82	Cm-242	Ci	9.84E-03	1.67E-04	1.93E-06
UPR-200-E-82	U-234	Ci	9.84E-03	1.29E-04	1.49E-06
UPR-200-E-82	U-238	Ci	9.84E-03	1.26E-04	1.45E-06
UPR-200-E-82	I-129	Ci	9.84E-03	1.24E-04	1.43E-06
UPR-200-E-82	Am-243	Ci	9.84E-03	4.38E-05	5.05E-07
UPR-200-E-82	Cm-243	Ci	9.84E-03	1.00E-05	1.15E-07
UPR-200-E-82	U-235	Ci	9.84E-03	5.41E-06	6.24E-08
UPR-200-E-82	U-236	Ci	9.84E-03	3.32E-06	3.83E-08
UPR-200-E-82	Pa-231	Ci	9.84E-03	2.07E-06	2.39E-08
UPR-200-E-82	Ac-227	Ci	9.84E-03	1.35E-06	1.56E-08
UPR-200-E-82	Pu-242	Ci	9.84E-03	1.09E-06	1.26E-08
UPR-200-E-82	Ru-106	Ci	9.84E-03	6.24E-07	7.20E-09
UPR-200-E-82	Ra-226	Ci	9.84E-03	2.93E-07	3.38E-09
UPR-200-E-82	U-233	Ci	9.84E-03	1.83E-08	2.11E-10
UPR-200-E-82	U-232	Ci	9.84E-03	1.01E-08	1.16E-10
UPR-200-E-82	Th-229	Ci	9.84E-03	1.77E-09	2.04E-11
UPR-200-E-82	Th-232	Ci	9.84E-03	2.49E-12	2.87E-14
UPR-200-E-82	Ra-228	Ci	9.84E-03	2.40E-12	2.77E-14
UPR-200-E-82	Al	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	Bi	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	La	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	Zr	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	Mn	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	PO4	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	F	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	Butanol	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	Fe(CN)6	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	Ag	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	CCl4	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	TBP	kg	9.84E-03	0.00E+00	0.00E+00
UPR-200-E-82	NPH	kg	9.84E-03	0.00E+00	0.00E+00
			Total Mass	9.90E+02	
			Total Activity	8.67E+03	

Table X-8. Soil Contamination Inventory Associated With UPR-86

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
UPR-200-E-86	Cs-137	Ci	7.00E-02	1.15E+04	5.06E+01
UPR-200-E-86	Ba-137m	Ci	7.00E-02	1.08E+04	4.75E+01
UPR-200-E-86	Na	kg	7.00E-02	1.22E+03	3.34E+01
UPR-200-E-86	NO2	kg	7.00E-02	8.66E+02	2.37E+01
UPR-200-E-86	NO3	kg	7.00E-02	7.34E+02	2.01E+01
UPR-200-E-86	CO3	kg	7.00E-02	3.33E+02	9.11E+00
UPR-200-E-86	SO4	kg	7.00E-02	2.81E+02	7.68E+00
UPR-200-E-86	Sm-151	Ci	7.00E-02	2.21E+02	9.72E-01
UPR-200-E-86	Sr-90	Ci	7.00E-02	9.78E+01	4.30E-01
UPR-200-E-86	Y-90	Ci	7.00E-02	9.78E+01	4.30E-01
UPR-200-E-86	PO4	kg	7.00E-02	8.38E+01	2.29E+00
UPR-200-E-86	Cr	kg	7.00E-02	3.51E+01	9.60E-01
UPR-200-E-86	Cl	kg	7.00E-02	2.67E+01	7.30E-01
UPR-200-E-86	Al	kg	7.00E-02	2.33E+01	6.37E-01
UPR-200-E-86	NH3	kg	7.00E-02	1.19E+01	3.25E-01
UPR-200-E-86	K	kg	7.00E-02	1.18E+01	3.23E-01
UPR-200-E-86	Si	kg	7.00E-02	1.17E+01	3.20E-01
UPR-200-E-86	Ca	kg	7.00E-02	5.93E+00	1.62E-01
UPR-200-E-86	Ni	kg	7.00E-02	4.21E+00	1.15E-01
UPR-200-E-86	Fe	kg	7.00E-02	4.12E+00	1.13E-01
UPR-200-E-86	Eu-154	Ci	7.00E-02	3.22E+00	1.42E-02
UPR-200-E-86	Tc-99	Ci	7.00E-02	2.85E+00	1.25E-02
UPR-200-E-86	Ni-63	Ci	7.00E-02	2.06E+00	9.06E-03
UPR-200-E-86	Pb	kg	7.00E-02	1.84E+00	5.03E-02
UPR-200-E-86	Eu-155	Ci	7.00E-02	1.65E+00	7.26E-03
UPR-200-E-86	U-Total	kg	7.00E-02	1.22E+00	3.34E-02
UPR-200-E-86	Co-60	Ci	7.00E-02	7.33E-01	3.22E-03
UPR-200-E-86	Cd-113m	Ci	7.00E-02	5.54E-01	2.44E-03
UPR-200-E-86	Zr-93	Ci	7.00E-02	5.42E-01	2.38E-03
UPR-200-E-86	F	kg	7.00E-02	4.89E-01	1.34E-02
UPR-200-E-86	Nb-93m	Ci	7.00E-02	4.39E-01	1.93E-03
UPR-200-E-86	H-3	Ci	7.00E-02	4.18E-01	1.84E-03
UPR-200-E-86	Mn	kg	7.00E-02	3.85E-01	1.05E-02
UPR-200-E-86	Pu-241	Ci	7.00E-02	2.75E-01	1.21E-03
UPR-200-E-86	Am-241	Ci	7.00E-02	2.65E-01	1.17E-03
UPR-200-E-86	Pu-239	Ci	7.00E-02	2.00E-01	8.80E-04
UPR-200-E-86	Sb-125	Ci	7.00E-02	1.67E-01	7.35E-04
UPR-200-E-86	C-14	Ci	7.00E-02	7.59E-02	3.34E-04
UPR-200-E-86	Pu-240	Ci	7.00E-02	4.35E-02	1.91E-04
UPR-200-E-86	Eu-152	Ci	7.00E-02	4.14E-02	1.82E-04
UPR-200-E-86	Sn-126	Ci	7.00E-02	3.78E-02	1.66E-04
UPR-200-E-86	Ni-59	Ci	7.00E-02	2.17E-02	9.55E-05
UPR-200-E-86	Bi	kg	7.00E-02	1.68E-02	4.59E-04
UPR-200-E-86	Hg	kg	7.00E-02	1.28E-02	3.50E-04

Table X-8. Soil Contamination Inventory Associated With UPR-86

Site	Analyte	Units	Vol (ML)	Corrected Mean	%Mass or %Activity
UPR-200-E-86	Np-237	Ci	7.00E-02	1.17E-02	5.15E-05
UPR-200-E-86	Cs-134	Ci	7.00E-02	9.59E-03	4.22E-05
UPR-200-E-86	Se-79	Ci	7.00E-02	9.11E-03	4.01E-05
UPR-200-E-86	Pu-238	Ci	7.00E-02	6.69E-03	2.94E-05
UPR-200-E-86	I-129	Ci	7.00E-02	1.51E-03	6.64E-06
UPR-200-E-86	Cm-244	Ci	7.00E-02	7.57E-04	3.33E-06
UPR-200-E-86	Cm-242	Ci	7.00E-02	6.89E-04	3.03E-06
UPR-200-E-86	U-234	Ci	7.00E-02	4.09E-04	1.80E-06
UPR-200-E-86	U-238	Ci	7.00E-02	4.08E-04	1.79E-06
UPR-200-E-86	U-233	Ci	7.00E-02	1.58E-04	6.95E-07
UPR-200-E-86	Zr	kg	7.00E-02	1.47E-04	4.02E-06
UPR-200-E-86	Am-243	Ci	7.00E-02	1.32E-04	5.81E-07
UPR-200-E-86	Cm-243	Ci	7.00E-02	3.17E-05	1.39E-07
UPR-200-E-86	Ra-228	Ci	7.00E-02	2.32E-05	1.02E-07
UPR-200-E-86	U-235	Ci	7.00E-02	1.73E-05	7.61E-08
UPR-200-E-86	U-236	Ci	7.00E-02	9.83E-06	4.32E-08
UPR-200-E-86	Pa-231	Ci	7.00E-02	5.46E-06	2.40E-08
UPR-200-E-86	Ac-227	Ci	7.00E-02	2.59E-06	1.14E-08
UPR-200-E-86	U-232	Ci	7.00E-02	2.57E-06	1.13E-08
UPR-200-E-86	Pu-242	Ci	7.00E-02	2.13E-06	9.37E-09
UPR-200-E-86	Ru-106	Ci	7.00E-02	2.01E-06	8.84E-09
UPR-200-E-86	Ra-226	Ci	7.00E-02	3.93E-07	1.73E-09
UPR-200-E-86	Th-232	Ci	7.00E-02	3.91E-07	1.72E-09
UPR-200-E-86	Th-229	Ci	7.00E-02	1.53E-07	6.73E-10
UPR-200-E-86	La	kg	7.00E-02	0.00E+00	0.00E+00
UPR-200-E-86	Ag	kg	7.00E-02	0.00E+00	0.00E+00
UPR-200-E-86	CCl4	kg	7.00E-02	0.00E+00	0.00E+00
UPR-200-E-86	Butanol	kg	7.00E-02	0.00E+00	0.00E+00
UPR-200-E-86	TBP	kg	7.00E-02	0.00E+00	0.00E+00
UPR-200-E-86	NPH	kg	7.00E-02	0.00E+00	0.00E+00
UPR-200-E-86	Fe(CN)6	kg	7.00E-02	0.00E+00	0.00E+00
			Total Mass	3.66E+03	
			Total Activity	2.27E+04	