Phase II Final Status Survey Report
Mallinckrodt Columbium-Tantalum Plant

St. Louis, Missouri

Chapter 11

Project No. 137131 **Revision 0**

Prepared by:
Energy*Solutions*, LLC
Commercial Projects
1009 Commerce Park Drive, Suite 100
Oak Ridge, TN 37830

Authored By:	Timothy J. Bauer, Health Physicist	10-22-2013 Date
Reviewed By:	Michael A. Carr, CHP, Radiological Engineer/Radiation Safety Officer	10-22-2013 Date
Reviewed By:	Mark Cambra, P.E., Project Manager	10-23-2013 Date
Approved By:	Arthur J. Palmer, CHP, PMP, Director, Health Physics & Radiological Engineering	10-24-2013 Date

[X] Non-Proprietary	[X] New
[ ] Proprietary	[ ] Title Change
[ ] Restricted Information	[ ] Revision
[ ] Safeguards Information	[ ] Rewrite
[ ] Sensitive Security Information	[ ] Cancellation

Effective Date 10-25-2013

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

%	percent
σ	sigma; standard deviation
AECOM	AECOM Technical Services
bgs	below grade surface
C-T	columbium-tantalum
CFR	Code of Federal Regulations
DCGL	derived concentration guideline level
DP	decommissioning plan
DQO	data quality objectives
EMC	elevated measurement comparison
F	exposure-weighted fraction of the $DCGL_W$
FSS	Final Status Survey
FSSR	Final Status Survey Report
ft	feet
GWS	gamma walk-over survey
m	meters
m^2	square meters
MARSSIM	Multi-Agency Radiation and Site Investigation Manual (NUREG-1575)
MDC	minimum detectable concentration
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
pCi/g	picoCuries per gram
Ra	radium
SOF	sum of fractions
Th	thorium
U	uranium
WRS	Wilcoxon Rank Sum

11.0 RESULTS SUMMARY FOR PLANT 5 SUBSURFACE SU05

This chapter of the Final Status Survey Report (FSSR) presents the results of the final status survey (FSS) and data assessment for Plant 5 subsurface survey unit SU05 in accordance with Columbium-Tantalum (C-T) Phase II Decommissioning Plan (DP) Section 14.5. The FSS for this Class 1 survey unit was completed by AECOM Technical Services (AECOM) in September 2011. The SU05 data assessment was performed based on the assumptions, methods, and performance criteria established to satisfy the data quality objectives (DQOs) in accordance with the C-T Phase II DP Section 14.4.3.8. The summary statistics provide numerical values for measures of central tendency (i.e., mean, median), variation (i.e., standard deviation), and spread (i.e., minimum, maximum). Data evaluation and statistical analyses were performed and a separate decision was made for each survey unit of the C-T Plant as to its suitability for release for unrestricted use based upon the industrial use scenario release criterion as established in C-T Phase II DP Chapter 5.

11.1 OVERVIEW

SU05 is a Class 1 survey unit in the western portion of C-T Plant 5. The survey unit is approximately 480 square meters (m^2) in size, which is less than the size limit of 3,000 m^2 for Class 1 survey units for subsurface material (per C-T Phase II DP, Table 14-4). Class 1 was the appropriate classification because the survey unit contained residual radioactivity that exceeded the derived concentration guideline value ($DCGL_W$) prior to remediation. Figure 11-1 shows the location of SU05 within the Plant 5 area.

Figure 11-2 is a photograph of SU05. In Figure 11-2, as viewed from west of the survey unit looking east, shows the east wall of Building 250 in the background. Evident in the figure is the sloped area next to Building 250. The soil adjacent to Building 250 was removed down to the Building 250 grade beam and then along a 1-to-1 slope down to the final remedial depth. Additional excavation threatened to undermine the building foundation and existing water line running along the building and was not performed. Excavated depth ranged from 4 to 13 feet (ft). The sloped area adjacent to Building 250 was addressed as part of the FSS.

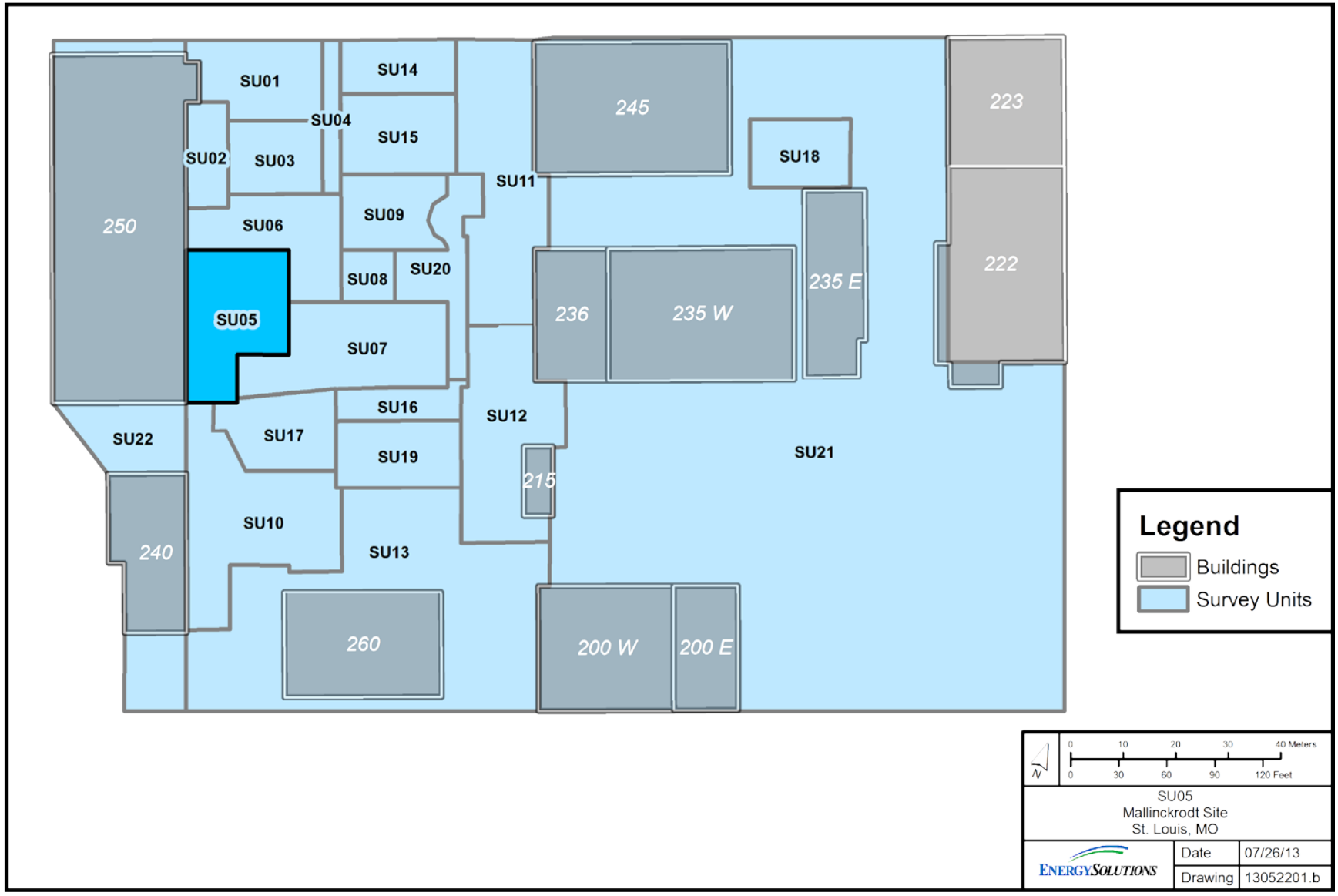


Figure 11-1 Location of SU05 in C-T Plant 5

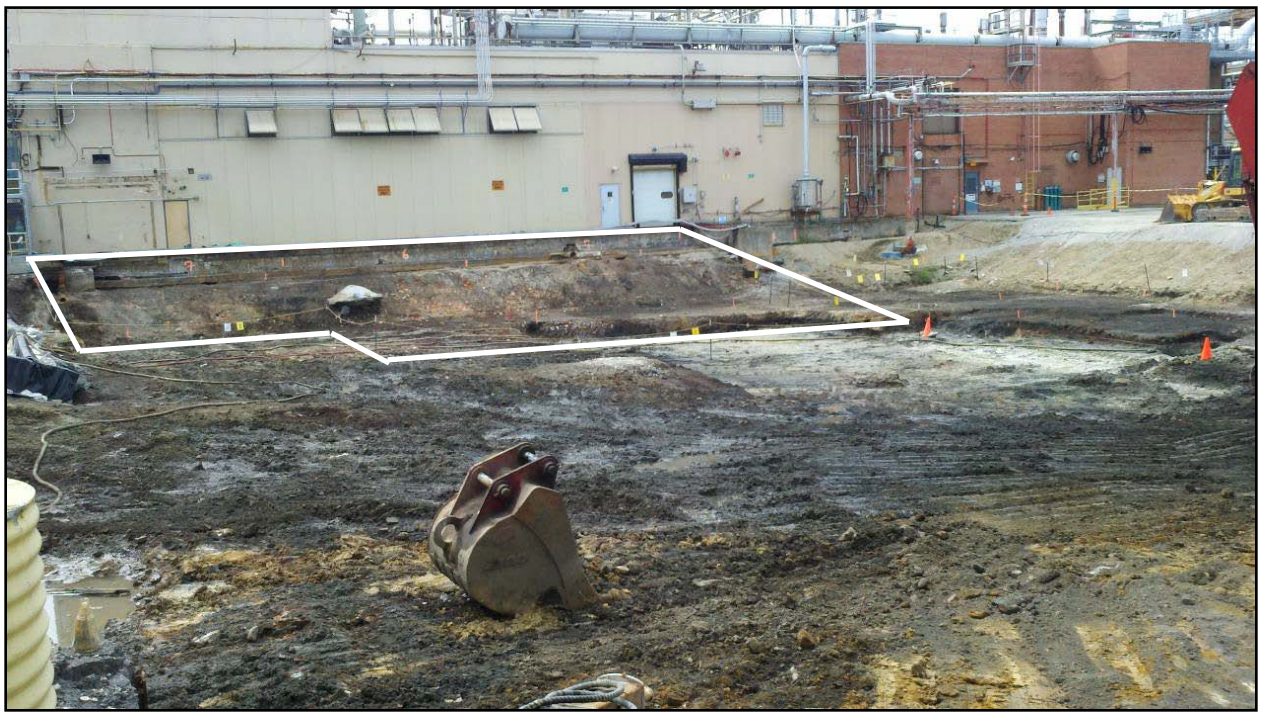


Figure 11-2 Photograph of SU05 Looking West at East Side of Building 250

11.2 REMEDIAL ACTION AND RADIOLOGICAL SAMPLING SUMMARY

Post-remediation soil sampling, shown in Figure 11-3, was performed by AECOM and included: 1) "Grid + Step-Out Sampling", 2) "Sloped Area Characterization" sampling, 3) "At-Depth (Auger) Sampling", and 4) miscellaneous characterization of sludge in a brick pipe. All post-remediation soil samples were analyzed at the on-site laboratory only. Table 11-1 provides the results for the 9 "Grid + Step-Out" samples, 11 "Sloped Area Characterization" samples, 8 "At-Depth (Auger)" samples, and 1 sludge sample.

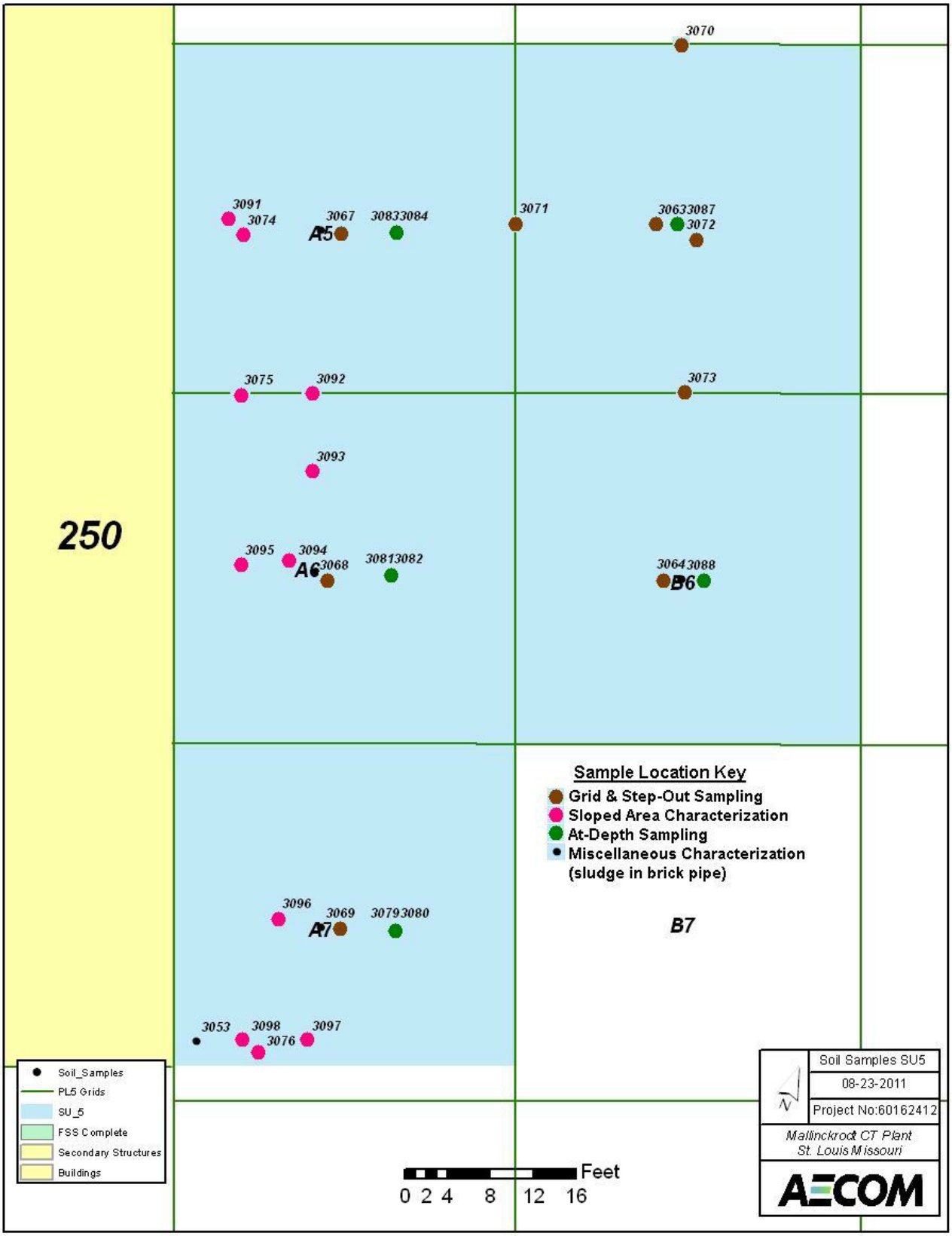


Figure 11-3 Post-Remediation Soil Sampling Locations

Table 11-1 Post-Remediation Sampling Analytical Results

Sample ID	Collection Date	On-Site Results			
		Concentration (pCi/g)			Gross SOF [a]
		^{232}Th	^{226}Ra	^{238}U	
"Grid + Step-Out"					
3063	8/10/2011	4.51	23.90	15.30	**1.03**
3064		2.39	8.49	13.90	0.41
3067		1.59	6.80	5.00	0.31
3068	8/11/2011	3.47	12.20	7.42	**0.57**
3069		2.86	5.40	5.87	0.31
3070		1.14	3.61	37.70	0.23
3071		1.42	1.66	9.07	0.13
3072		2.27	9.83	7.87	0.44
3073		1.23	2.68	12.50	0.16
"Sloped Area Characterization"					
3074	8/12/2011	50.20	81.50	70.80	**4.99**
3075		107.00	28.80	20.50	**5.48**
3076		1.35	4.66	10.40	0.23
3091	8/16/2011	1.12	2.76	5.59	0.15
3092		3.67	3.46	4.91	0.28
3093		22.80	8.00	9.82	**1.24**
3094		2.29	4.73	6.79	0.27
3095		1.88	4.74	7.81	0.25
3096		2.02	2.16	9.98	0.17
3097		36.10	5.49	8.96	**1.71**
3098		0.62	1.21	3.70	0.07
"At-Depth (Auger)"					
3079	8/15/2011	1.23	2.15	2.62	0.13
3080		1.36	2.36	3.24	0.14
3081		1.41	3.30	2.18	0.17
3082		1.52	2.48	2.28	0.15
3083	8/16/2011	0.76	2.51	4.04	0.12
3084		1.20	1.85	2.27	0.12
3087		1.38	1.99	5.45	0.13
3088		1.05	2.01	4.72	0.12
Miscellaneous Characterization (sludge in brick pipe)					
3053	8/4/2011	2.99	12.40	33.80	**0.60**

[a] **Bolded orange** SOF values indicate a result >0.5 but ≤1 and **bolded red** SOF values indicate a result >1.

11.3 DATA COLLECTION

Data collection was performed based on the assumptions, methods, and performance criteria established to satisfy the DQOs in accordance with the C-T Phase II DP, Sections 14.4.1 and 14.4.3. Details regarding FSS design and quality assurance and quality control applicable to all survey units were discussed in Chapters 4 and 5, respectively, of this FSSR.

11.3.1 Gamma Scans

A gamma walk-over survey (GWS) was performed over 100% of the excavated area to locate radiation anomalies that might indicate areas with elevated residual radioactivity where further data collection (i.e., biased soil sampling) was warranted.

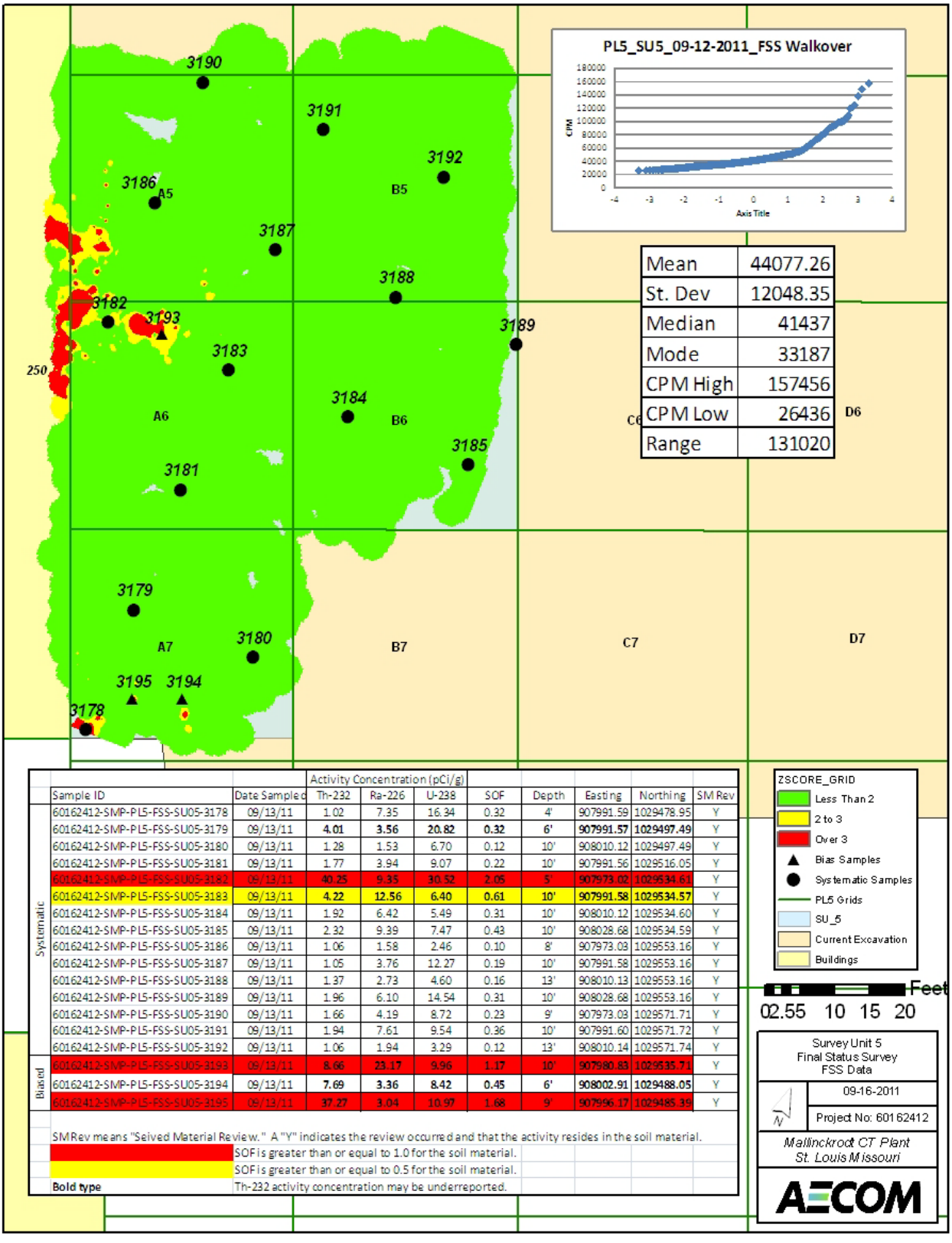
11.3.2 Soil Sampling

Soil samples to be used for the statistical test were collected at a frequency and at representative locations throughout SU05 such that a statistically sound conclusion regarding the radiological condition of the survey unit could be developed. Biased soil samples were collected at locations of elevated residual radioactivity identified by GWS as well as along the sloped excavation along Building 250. Figure 11-4 provides the GWS results and soil sampling locations and Figure 11-5 shows the sloped excavation samples. A total of 35 soil samples were collected throughout SU05, 18 over the areal footprint of SU05 (15 systematic and 3 GWS biased) and 17 biased for elevated area bounding of the sloped excavation along Building 250. Further excavation threatened to undermine the building foundation and therefore additional sampling was performed in order to evaluate the residual contamination.

Figure 11-6 illustrates two elevated areas defined by AECOM using both post-remedial and FSS GWS and soil sampling:

- Elevated Area #1: The larger area in the center of the west edge of the survey unit along Building 250 is no larger than 50 m^2 in size.
- Elevated Area #2: The smaller area in the southeast corner of the survey unit along Building 250 is no larger than 20 m^2.

The combined elevated area was 70 m^2.



	Sample ID	Date Sampled	Activity Concentration (pCi/g) Th-232	Ra-226	U-238	SOF	Depth	Easting	Northing	SM Rev
Systematic	60162412-SMP-PL5-FSS-SU05-3178	09/13/11	1.02	7.35	16.34	0.32	4'	907991.59	1029478.95	Y
	60162412-SMP-PL5-FSS-SU05-3179	09/13/11	**4.01**	**3.56**	**20.82**	**0.32**	**6'**	**907991.57**	**1029497.49**	Y
	60162412-SMP-PL5-FSS-SU05-3180	09/13/11	1.28	1.53	6.70	0.12	10'	908010.12	1029497.49	Y
	60162412-SMP-PL5-FSS-SU05-3181	09/13/11	1.77	3.94	9.07	0.22	10'	907991.56	1029516.05	Y
	60162412-SMP-PL5-FSS-SU05-3182	09/13/11	**40.25**	**9.35**	**30.52**	**2.05**	**5'**	**907973.02**	**1029534.61**	Y
	60162412-SMP-PL5-FSS-SU05-3183	09/13/11	**4.22**	**12.56**	**6.40**	**0.61**	**10'**	**907991.58**	**1029534.57**	Y
	60162412-SMP-PL5-FSS-SU05-3184	09/13/11	1.92	6.42	5.49	0.31	10'	908010.12	1029534.60	Y
	60162412-SMP-PL5-FSS-SU05-3185	09/13/11	2.32	9.39	7.47	0.43	10'	908028.68	1029534.59	Y
	60162412-SMP-PL5-FSS-SU05-3186	09/13/11	1.06	1.58	2.46	0.10	8'	907973.03	1029553.16	Y
	60162412-SMP-PL5-FSS-SU05-3187	09/13/11	1.05	3.76	12.27	0.19	10'	907991.58	1029553.16	Y
	60162412-SMP-PL5-FSS-SU05-3188	09/13/11	1.37	2.73	4.60	0.16	13'	908010.13	1029553.16	Y
	60162412-SMP-PL5-FSS-SU05-3189	09/13/11	1.96	6.10	14.54	0.31	10'	908028.68	1029553.16	Y
	60162412-SMP-PL5-FSS-SU05-3190	09/13/11	1.66	4.19	8.72	0.23	9'	907973.03	1029571.71	Y
	60162412-SMP-PL5-FSS-SU05-3191	09/13/11	1.94	7.61	9.54	0.36	10'	907991.60	1029571.72	Y
	60162412-SMP-PL5-FSS-SU05-3192	09/13/11	1.06	1.94	3.29	0.12	13'	908010.14	1029571.74	Y
Biased	60162412-SMP-PL5-FSS-SU05-3193	09/13/11	**8.66**	**23.17**	**9.96**	**1.17**	**10'**	**907980.83**	**1029535.71**	Y
	60162412-SMP-PL5-FSS-SU05-3194	09/13/11	**7.69**	**3.36**	**8.42**	**0.45**	**6'**	**908002.91**	**1029488.05**	Y
	60162412-SMP-PL5-FSS-SU05-3195	09/13/11	**37.27**	**3.04**	**10.97**	**1.68**	**9'**	**907996.17**	**1029485.39**	Y

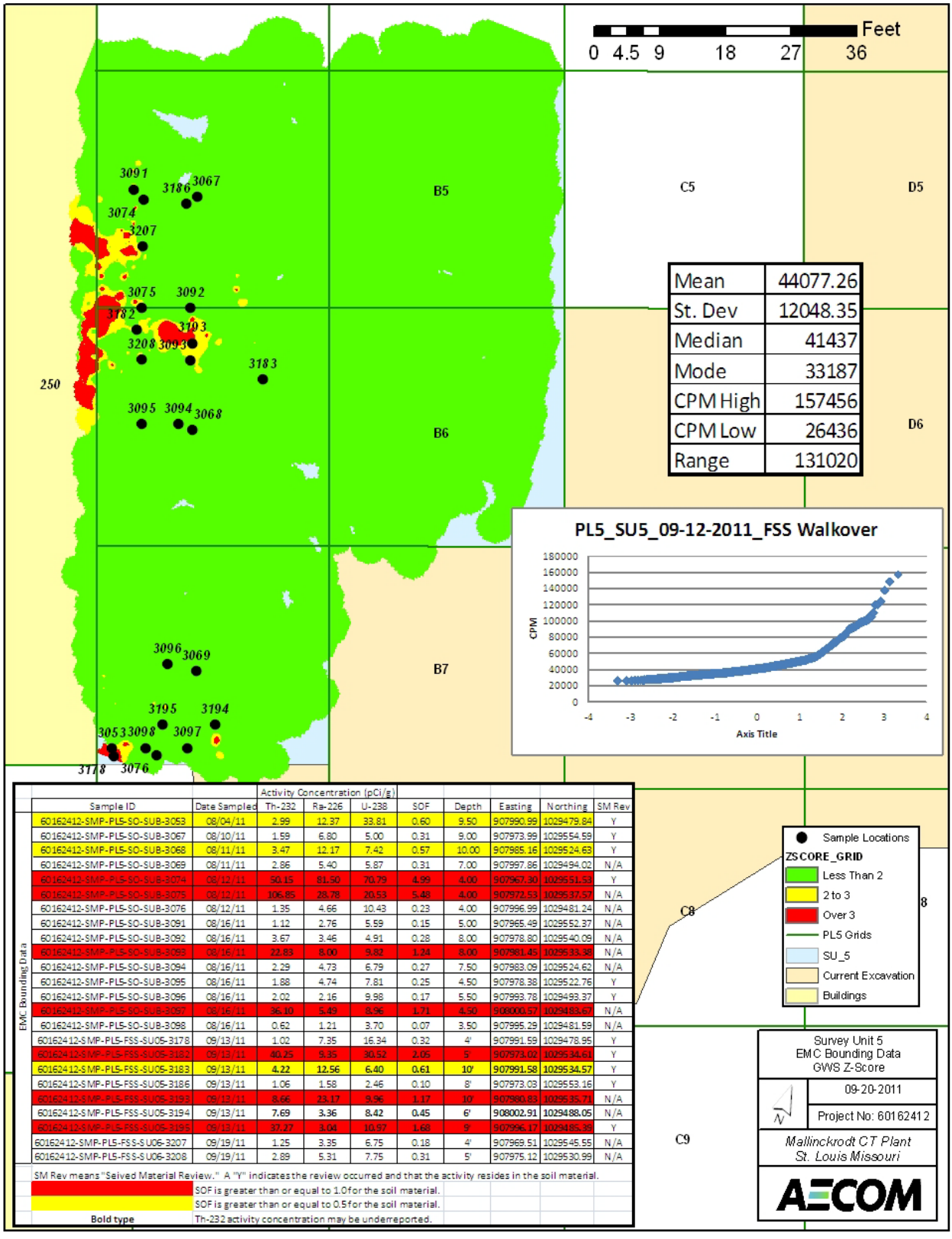
SM Rev means "Seived Material Review." A "Y" indicates the review occurred and that the activity resides in the soil material.

SOF is greater than or equal to 1.0 for the soil material.

SOF is greater than or equal to 0.5 for the soil material.

Bold type Th-232 activity concentration may be underreported.

Figure 11-4 GWS and Soil Sampling Locations



EMC Bounding Data

Sample ID	Date Sampled	Activity Concentration (pCi/g) Th-232	Ra-226	U-238	SOF	Depth	Easting	Northing	SM Rev
60162412-SMP-PL5-SO-SUB-3053	08/04/11	2.99	12.37	33.81	0.60	9.50	907990.99	1029479.84	Y
60162412-SMP-PL5-SO-SUB-3067	08/10/11	1.59	6.80	5.00	0.31	9.00	907973.99	1029554.59	Y
60162412-SMP-PL5-SO-SUB-3068	08/11/11	3.47	12.17	7.42	0.57	10.00	907985.16	1029524.63	Y
60162412-SMP-PL5-SO-SUB-3069	08/11/11	2.86	5.40	5.87	0.31	7.00	907997.86	1029494.02	N/A
60162412-SMP-PL5-SO-SUB-3074	08/12/11	50.15	81.50	70.79	4.99	4.00	907967.30	1029551.53	Y
60162412-SMP-PL5-SO-SUB-3075	08/12/11	106.85	28.78	20.53	5.48	4.00	907972.53	1029537.57	N/A
60162412-SMP-PL5-SO-SUB-3076	08/12/11	1.35	4.66	10.43	0.23	4.00	907996.99	1029481.24	N/A
60162412-SMP-PL5-SO-SUB-3091	08/16/11	1.12	2.76	5.59	0.15	5.00	907965.49	1029552.37	N/A
60162412-SMP-PL5-SO-SUB-3092	08/16/11	3.67	3.46	4.91	0.28	8.00	907978.80	1029540.09	N/A
60162412-SMP-PL5-SO-SUB-3093	08/16/11	22.83	8.00	9.82	1.24	8.00	907981.45	1029533.38	N/A
60162412-SMP-PL5-SO-SUB-3094	08/16/11	2.29	4.73	6.79	0.27	7.50	907983.09	1029524.62	N/A
60162412-SMP-PL5-SO-SUB-3095	08/16/11	1.88	4.74	7.81	0.25	4.50	907978.38	1029522.76	Y
60162412-SMP-PL5-SO-SUB-3096	08/16/11	2.02	2.16	9.98	0.17	5.50	907993.78	1029493.37	Y
60162412-SMP-PL5-SO-SUB-3097	08/16/11	36.10	5.49	8.96	1.71	4.50	908000.57	1029483.67	N/A
60162412-SMP-PL5-SO-SUB-3098	08/16/11	0.62	1.21	3.70	0.07	3.50	907995.29	1029481.59	N/A
60162412-SMP-PL5-FSS-SU05-3178	09/13/11	1.02	7.35	16.34	0.32	4'	907991.59	1029478.95	Y
60162412-SMP-PL5-FSS-SU05-3182	09/13/11	40.25	9.35	30.52	2.05	5'	907973.02	1029534.61	Y
60162412-SMP-PL5-FSS-SU05-3183	09/13/11	4.22	12.56	6.40	0.61	10'	907991.58	1029534.57	Y
60162412-SMP-PL5-FSS-SU05-3186	09/13/11	1.06	1.58	2.46	0.10	8'	907973.03	1029553.16	Y
60162412-SMP-PL5-FSS-SU05-3193	09/13/11	8.66	23.17	9.96	1.17	10'	907980.83	1029535.71	N/A
60162412-SMP-PL5-FSS-SU05-3194	09/13/11	7.69	3.36	8.42	0.45	6'	908002.91	1029488.05	N/A
60162412-SMP-PL5-FSS-SU05-3195	09/13/11	37.27	3.04	10.97	1.68	9'	907996.17	1029485.38	Y
60162412-SMP-PL5-FSS-SU06-3207	09/19/11	1.25	3.35	6.75	0.18	4'	907969.51	1029545.55	N/A
60162412-SMP-PL5-FSS-SU06-3208	09/19/11	2.89	5.31	7.75	0.31	5'	907975.12	1029530.99	N/A

SM Rev means "Seived Material Review." A "Y" indicates the review occurred and that the activity resides in the soil material.

SOF is greater than or equal to 1.0 for the soil material.

SOF is greater than or equal to 0.5 for the soil material.

Bold type — Th-232 activity concentration may be underreported.

Figure 11-5 Additional Biased Soil Sampling Locations

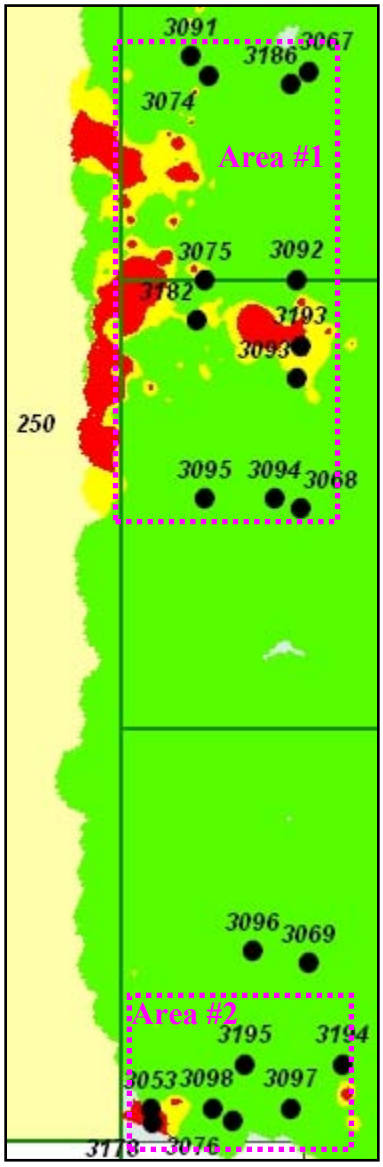


Figure 11-6 Elevated Areas Defined by AECOM

All soil samples were analyzed on site via gamma spectroscopy analysis. Table 11-2 provides the sample results and summary statistics for the 15 systematic samples. Table 11-3 provides the sample results for the 3 GWS biased samples and the 17 biased samples for elevated area bounding of the sloped excavation along Building 250.

Any remaining sieved material from each sample was analyzed separately to verify residual radioactivity was consistent with sample results. The radiological screening process did not identify any significant levels of radioactivity in the sieved materials removed from samples.

The C-T Phase II DP, Table 4-17, provided mean background activity levels of 1.3, 2.5, and 4.4 picoCuries per gram (pCi/g) for thorium-232 (^{232}Th), radium-226 (^{226}Ra), and uranium-238 (^{238}U), respectively. These values were used to calculate net SOF values—note that when measured activity concentration levels were less than the background mean resulting in a negative value, the net activity concentration was set equal to zero for the net SOF calculation.

To mitigate the risk of backfilling, the on-site laboratory analytical results were reviewed to determine the likelihood of the survey unit failing to meet the criteria for radiological release. The on-site laboratory, by design, reported conservative sample results.

Table 11-2 Gamma Spectroscopy Systematic Sample Analytical Results

Sample ID	Depth (ft bgs)	On-Site Results											Off-Site Results [a]										On-Site/ Off-Site Gross SOF Ratio
		Activity Concentration (pCi/g)									SOF [b]		Activity Concentration (pCi/g)									SOF [b]	
		^{232}Th			^{226}Ra			^{238}U					^{232}Th			^{226}Ra			^{238}U				
		Result	Uncert. (2σ)	MDC	Result	Uncert. (2σ)	MDC	Result	Uncert. (2σ)	MDC	Gross	Net [c]	Result	Uncert. (2σ)	MDC	Result	Uncert. (2σ)	MDC	Result	Uncert. (2σ)	MDC	Gross	Net [c]	
3178	4	1.02	0.25	0.09	7.35	1.99	1.46	16.34	1.66	0.86	0.32	0.18	1.20	0.63	0.46	4.94	0.69	0.12	5.04	0.69	0.15	0.23	0.08	1.40
3179	6	4.01	0.53	0.14	3.56	2.15	1.69	20.82	2.25	1.14	0.32	0.17	4.86	0.87	0.53	1.87	0.32	0.17	2.03	0.33	0.16	0.27	0.15	1.18
3180	10	1.28	0.26	0.05	1.53	1.30	1.02	6.70	1.42	0.77	0.12	0.00	1.35	0.37	0.38	1.72	0.32	0.11	2.00	0.30	0.12	0.12	0.00	0.98
3181	10	1.77	0.30	0.05	3.94	1.51	1.12	9.07	1.49	0.86	0.22	0.08	2.10	0.56	0.44	1.73	0.29	0.12	2.02	0.31	0.12	0.15	0.03	1.48
3182	5	40.25	2.35	0.43	9.35	3.90	3.04	30.52	5.15	3.05	**2.04**	**1.90**	40.00	5.40	1.49	44.00	5.40	0.73	7.30	1.10	0.42	**3.18**	**3.03**	0.64
3183	10	4.22	0.54	0.13	12.56	2.03	1.32	6.40	1.55	1.11	**0.61**	0.47	3.58	0.86	0.68	8.93	1.20	0.16	9.69	1.20	0.20	0.47	0.32	1.31
3184	10	1.92	0.36	0.11	6.42	1.42	0.97	5.49	1.47	0.88	0.31	0.16	2.02	0.58	0.49	5.14	0.73	0.13	5.29	0.68	0.15	0.27	0.12	1.15
3185	10	2.32	0.44	0.14	9.39	1.90	1.27	7.47	1.54	1.04	0.43	0.28	2.88	0.81	0.64	7.49	1.00	0.16	7.91	1.05	0.19	0.39	0.24	1.11
3186	8	1.06	0.29	0.10	1.58	0.98	0.72	2.46	0.88	0.60	0.10	0.00	0.94	0.47	0.36	1.21	0.22	0.12	1.21	0.24	0.11	0.08	0.00	1.24
3187	10	1.05	0.20	0.08	3.76	1.61	1.22	12.27	1.70	0.86	0.19	0.05	0.92	0.38	0.36	2.39	0.37	0.11	2.69	0.37	0.11	0.12	0.00	1.53
3188	13	1.37	0.30	0.08	2.73	1.26	0.93	4.60	1.36	0.77	0.16	0.01	1.56	0.50	0.41	1.93	0.31	0.12	1.86	0.29	0.12	0.13	0.01	1.17
3189	10	1.96	0.33	0.11	6.10	1.89	1.41	14.54	1.58	0.85	0.31	0.16	1.62	0.53	0.50	3.85	0.57	0.13	4.17	0.56	0.14	0.20	0.06	1.51
3190	9	1.66	0.37	0.13	4.19	1.71	1.28	8.72	2.04	1.16	0.22	0.08	2.60	0.61	0.52	5.00	0.72	0.16	5.46	0.74	0.15	0.29	0.14	0.78
3191	10	1.94	0.37	0.13	7.61	1.79	1.27	9.54	1.82	1.07	0.35	0.21	2.26	0.62	0.54	5.96	0.84	0.16	6.52	0.84	0.17	0.31	0.16	1.15
3192	13	1.06	0.23	0.05	1.94	1.04	0.78	3.29	0.89	0.59	0.12	0.00	1.06	0.39	0.39	1.17	0.24	0.11	1.31	0.22	0.11	0.09	0.00	1.34
Summary Statistics																								
Count:		15			15			15			15	15	15			15			15			15	15	15
Average:		4.46			5.47			10.55			0.39	0.25	4.60			6.49			4.30			0.42	0.29	1.20
Median:		1.77			4.19			8.72			0.31	0.16	2.02			3.85			4.17			0.23	0.08	1.18
Standard Dev.:		9.95			3.29			7.48			0.48	0.47	9.85			10.65			2.69			0.77	0.77	0.25
Minimum:		1.02			1.53			2.46			0.10	0.00	0.92			1.17			1.21			0.08	0.00	0.64
Maximum:		40.25			12.56			30.52			**2.04**	**1.90**	40.00			44.00			9.69			**3.18**	**3.03**	1.53
Range:		39.23			11.03			28.06			1.94	1.90	39.08			42.83			8.48			3.10	3.03	0.89

[a] Off-site laboratory results as reported by TestAmerica after sufficient in-growth time to reach ^{226}Ra progeny equilibrium.
[b] **Bolded orange** SOF values indicate a result >0.5 but ≤1 and **bolded red** SOF values indicate a result >1.
[c] Calculated as discussed in Section 11.3.2.

Table 11-3 Gamma Spectroscopy Biased Sample Analytical Results

Sample ID	Depth (ft bgs)	On-Site Results											Off-Site Results [a, b]										On-Site/ Off-Site Gross SOF Ratio
		Activity Concentration (pCi/g)									SOF [c]		Activity Concentration (pCi/g)									SOF [c]	
		^{232}Th			^{226}Ra			^{238}U					^{232}Th			^{226}Ra			^{238}U				
		Result	Uncert. (2σ)	MDC	Result	Uncert. (2σ)	MDC	Result	Uncert. (2σ)	MDC	Gross	Net [d]	Result	Uncert. (2σ)	MDC	Result	Uncert. (2σ)	MDC	Result	Uncert. (2σ)	MDC	Gross	Net [d]	
GWS Biased Samples																							
3193	10	8.66	0.85	0.26	23.17	2.80	1.73	9.96	2.80	1.85	**1.16**	**1.02**	8.85	1.60	0.94	17.80	2.40	0.26	18.70	2.30	0.30	**1.00**	**0.86**	1.16
3194	6	7.69	0.72	0.09	3.36	1.78	1.38	8.42	2.24	1.37	0.45	0.30	8.44	1.40	0.65	2.79	0.46	0.20	2.71	0.48	0.19	0.45	0.31	0.99
3195	9	37.27	2.02	0.30	3.04	2.59	2.08	10.97	3.56	2.44	**1.68**	**1.53**	39.30	5.20	1.28	2.69	0.56	0.36	2.40	0.50	0.35	**1.74**	**1.60**	0.96
Sloped Excavation Biased Samples																							
3053	9	2.99	0.67	0.18	12.37	4.49	3.30	33.81	3.78	1.66	**0.59**	0.45	9.41	2.98	1.90	25.50	3.80	1.04	114.00	23.10	20.20	**1.42**	**1.27**	0.42
3067	9	1.59	0.29	0.09	6.80	1.48	1.00	5.00	1.11	0.74	0.30	0.16	1.86	0.42	0.31	5.42	0.70	0.21	4.45	1.25	3.39	0.27	0.12	1.14
3068	10	3.47	0.50	0.13	12.17	2.04	1.32	7.42	1.58	1.09	**0.57**	0.42	4.04	0.67	0.45	9.92	1.19	0.33	5.16	1.45	4.32	**0.51**	0.37	1.11
3069	7	2.86	0.40	0.15	5.40	1.61	1.14	5.87	1.50	0.93	0.31	0.17	2.84	0.43	0.29	4.40	0.59	0.18	6.45	2.64	3.17	0.28	0.13	1.12
3074	4	50.15	2.84	0.63	81.50	6.39	3.88	70.79	6.18	3.45	**4.97**	**4.82**	61.50	7.80	1.65	71.30	9.20	0.43	73.80	9.00	0.48	**5.10**	**4.96**	0.97
3075	4	106.85	4.59	0.61	28.78	4.62	3.40	20.53	5.65	3.85	**5.48**	**5.33**	131.00	16.00	1.56	26.40	3.30	0.41	29.20	3.50	0.47	**6.42**	**6.27**	0.85
3076	4	1.35	0.18	0.55	4.66	1.63	1.22	10.43	1.46	0.90	0.23	0.08	5.01	0.78	0.17	1.99	0.45	0.34	16.00	4.94	4.93	0.30	0.17	0.77
3091	5	1.12	0.22	0.02	2.76	1.15	0.86	5.59	1.17	0.67	0.15	0.01	0.91	0.25	0.23	1.38	0.20	0.06	1.51	0.22	0.07	0.09	0.00	1.71
3092	8	3.67	0.48	0.14	3.46	1.26	0.92	4.91	1.18	0.83	0.28	0.13	4.14	0.60	0.27	2.76	0.36	0.07	3.10	0.40	0.08	0.27	0.13	1.02
3093	8	22.83	1.46	0.28	8.00	2.31	1.74	9.82	2.34	1.76	**1.24**	**1.10**	22.60	2.51	0.65	6.25	0.88	0.45	12.10	5.44	6.83	**1.17**	**1.03**	1.06
3094	7.5	2.29	0.36	0.12	4.73	1.31	0.93	6.79	1.13	0.71	0.27	0.12	2.36	0.39	0.30	3.64	0.51	0.21	8.08	3.30	3.66	0.23	0.09	1.14
3095	4.5	1.88	0.29	0.12	4.74	1.60	1.15	7.81	1.82	0.98	0.25	0.11	1.94	0.41	0.31	4.51	0.61	0.20	5.75	1.38	3.07	0.24	0.10	1.03
3096	5.5	2.02	0.34	0.07	2.16	1.45	1.13	9.98	1.27	0.69	0.17	0.04	2.48	0.49	0.36	1.54	0.25	0.11	1.71	0.26	0.10	0.16	0.05	1.08
3097	4.5	36.10	1.81	0.33	5.49	2.43	1.92	8.96	3.20	2.19	**1.71**	**1.56**	37.80	4.20	0.88	3.07	0.94	0.85	16.00	7.27	9.60	**1.71**	**1.56**	1.00
3098	3.5	0.62	0.20	0.07	1.21	0.96	0.75	3.70	1.02	0.57	0.07	0.00	*0.30*	0.14	0.31	0.85	0.19	0.12	2.83	0.78	1.91	0.05	0.00	1.60
3207	6	1.25	0.20	0.08	3.35	1.38	1.04	6.75	1.49	0.85	0.18	0.03	1.84	0.53	0.38	2.43	0.37	0.10	2.45	0.36	0.12	0.16	0.02	1.08
3208	6	2.89	0.43	0.10	5.31	1.64	1.19	7.75	1.39	0.89	0.31	0.17	2.83	0.64	0.52	3.69	0.55	0.14	4.05	0.55	0.14	0.25	0.10	1.25

[a] Off-site laboratory results as reported by TestAmerica after sufficient in-growth time to reach ^{226}Ra progeny equilibrium.
[b] Italicized results indicate < MDC.
[c] **Bolded orange** SOF values indicate a result >0.5 but ≤1 and **bolded red** SOF values indicate a result >1.
[d] Calculated as discussed in Section 11.3.2.

11.3.3 Core Boring

C-T Phase II DP Table 4-7 provided characterization borehole results. Of the locations provided in the table, four were collected within the extent of SU05: BH-010, BH-010A, BH-027, and BH-028. Table 11-4 provides the data for these locations. The results indicate that beyond the excavation extent, additional subsurface contamination is not reasonably expected where FSS results indicate acceptable levels of contamination. Therefore, in accordance with Page 14-22 of the C-T Phase II DP, FSS core sampling or measurements were not performed.

Table 11-4 Characterization Borehole Results

Location ID	Sample Depth (ft)	Activity Concentration (pCi/g) [a]			SOF [b]	
		^{232}Th	^{226}Ra	^{238}U	Gross	Net [c]
BH-010	2 - 3	51.10	239.30	21.50	**10.31**	**10.16**
	4 - 5	2.90	31.80	20.00	**1.23**	**1.09**
	5 - 6	0.45	2.84	15.00	0.14	0.03
BH-010A	6 - 7	10.80	22.50	7.10	**1.23**	**1.08**
	9 - 10	3.10	2.81	*3.98*	0.23	0.09
	13 - 14	1.00	1.30	1.30	0.09	0.00
BH-027	2.5 - 3.5	0.97	2.16	*4.76*	0.12	0.00
	4 - 5	0.99	1.44	*4.77*	0.10	0.00
	5 - 6	2.10	1.50	3.60	0.14	0.03
	8 - 9	2.90	4.60	7.10	0.29	0.14
	11 - 12	1.90	1.40	2.50	0.13	0.03
	22.5 - 23.5	1.30	1.10	1.10	0.09	0.00
BH-028	0.7 - 2	1.42	4.34	27.90	0.25	0.10
	2 - 3	1.10	5.10	23.50	0.25	0.11
	3 - 4	1.35	3.63	13.80	0.20	0.05
	10 - 11	1.00	1.70	3.00	0.10	0.00
	13 - 14	1.70	3.30	4.10	0.19	0.04

[a] Italicized results indicate < MDC.
[b] **Bolded red** SOF values indicate a result >1.
[c] Calculated as discussed in Section 11.3.2.

11.4 DATA ANALYSIS

Data analysis was performed based on the assumptions, methods, and performance criteria established to satisfy the DQOs in accordance with the C-T Phase II DP, Sections 14.4.1 and 14.4.3. Details regarding FSS design and quality assurance and quality control applicable to all survey units were discussed in Chapters 4 and 5, respectively, of this FSSR.

11.4.1 Elevated Area Evaluation

AECOM provided a preliminary evaluation of the elevated areas. For a combined area of 70 m^2, the area factor from C-T Phase II DP Figure 5-3 was 1.4. The combined data set's average measured concentration SOF value was 1.2. AECOM concluded that the "application of the $DCGL_{EMC}$ to the two identified areas in the sloped area along Bldg 250 is warranted based on ALARA considerations" and that further "excavation threatens to undermine Bldg 250 foundation."

Using the elevated area extents defined by AECOM, Table 11-5 presents a summary of the sample results for the two elevated areas. The average gross SOF for Elevated Area #1 and Elevated Area #2 were 1.55 and 0.84, respectively. Because the average gross SOF for Elevated Area #2 was less than one, no further assessment was performed for this elevated area.

Table 11-5 Elevated Areas Results Summary

Sample ID	Activity Concentration (pCi/g)			SOF [a]	
	^{232}Th	^{226}Ra	^{238}U	Gross	Net [b]
Elevated Area #1					
3067	1.86	5.42	4.45	0.27	0.12
3068	4.04	9.92	5.16	**0.51**	0.37
3074	61.50	71.30	73.80	**5.10**	**4.96**
3075	131.00	26.40	29.20	**6.42**	**6.27**
3091	0.91	1.38	1.51	0.09	0.00
3092	4.14	2.76	3.10	0.27	0.13
3093	22.60	6.25	12.10	**1.17**	**1.03**
3094	2.36	3.64	8.08	0.23	0.09
3095	1.94	4.51	5.75	0.24	0.10
3182	40.00	44.00	7.30	**3.18**	**3.03**
3186	0.94	1.21	1.21	0.08	0.00
3193	8.85	17.80	18.70	**1.00**	**0.86**
Average	23.34	16.22	14.20	**1.55**	**1.40**
Elevated Area #2					
3053	9.41	25.50	114.00	**1.42**	**1.27**
3076	5.01	1.99	16.00	0.30	0.17
3097	37.80	3.07	16.00	**1.71**	**1.56**
3098	0.30	0.85	2.83	0.05	0.00
3178	1.20	4.94	5.04	0.23	0.08
3194	8.44	2.79	2.71	0.45	0.31
3195	39.30	2.69	2.40	**1.74**	**1.60**
Average	14.49	5.98	22.71	**0.84**	**0.70**

[a] **Bolded orange** SOF values indicate a result >0.5 but ≤1 and **bolded red** SOF values indicate a result >1.
[b] Calculated as discussed in Section 11.3.2.

Equation 9 from C-T Phase II DP, Section 5.8.7 provides for the calculation of an *Index* value that represents the fraction or multiple of the $DCGL_{EMC}$. If the *Index* value is greater than one, then the $DCGL_{EMC}$ is exceeded. Using the elevated area extents determined by AECOM, parameters necessary to calculate the *Index* value for Elevated Area #1 were:

- The average elevated area activity levels were 23.34, 16.22, and 14.20 pCi/g for ^{232}Th, ^{226}Ra, and ^{238}U, respectively (from Table 11-5 above);
- Mean background activity levels were 1.3, 2.5, and 4.4 pCi/g for ^{232}Th, ^{226}Ra, and ^{238}U, respectively (from C-T Phase II DP Table 4-17);
- The size of the elevated area was approximately 50 m^2; and,
- The area factors from C-T Phase II DP Figure 5-3 for the elevated area were 1.4, 1.5, and 2.1 for ^{232}Th, ^{226}Ra, and ^{238}U, respectively.

The calculation of the *Index* value for Elevated Area #1 is shown below. Because the *Index* value as calculated in accordance with the DP was less than one, this elevated area is compliant with the C-T Phase II DP for elevated measurements in soil.

$$Index = \frac{(23.34 - 1.3)\ pCi/g}{(1.4 \times 23.9\ pCi/g)_{Th\ series}} + \frac{(16.22 - 2.5)\ pCi/g}{(1.5 \times 29.4\ pCi/g)_{Ra226}} + \frac{(14.20 - 4.4)\ pCi/g}{(2.1 \times 721\ pCi/g)_{U}} = 0.98$$

11.4.2 Data Set Screening Analysis

Table 11-6 summarizes the results of the screening tests performed in accordance with Pages 14-27 through 14-29 of the C-T Phase II DP. All applicable tests demonstrating compliance passed.

Table 11-6 Screening Tests Results

Screening Test	Test Value	Conclusion
Min/Max	3.16	FAIL; conduct DCGL test
Low Level	N/A	Not applicable; Class 1 survey unit
DCGL	0.27	PASS; conduct WRS test
EMC Limit	0.32	PASS

11.4.2.1 Min/Max

In accordance with Page 14-27 of the C-T Phase II DP, the Min/Max screening test value was calculated by subtracting the minimum reference area result from the maximum survey unit systematic result. Sample 3182 with a gross SOF of 3.18 (from Table 11-2) was the maximum survey unit systematic result. Sample BH-Z-08 with a calculated gross SOF of 0.02 (from C-T Phase II DP Table B-1) was the minimum reference area result. The Min/Max screening test value was calculated to be 3.16. Because the test value was greater than one, further computations are required, i.e., $DCGL_W$ screening and Wilcoxon Rank Sum (WRS) tests.

11.4.2.2 Low Level

In accordance with Page 14-27 of the C-T Phase II DP, the Low Level screening test is not applicable to Class 1 survey units.

11.4.2.3 $DCGL_W$

In accordance with Page 14-28 of the C-T Phase II DP and because the Min/Max test value was greater than one, the $DCGL_W$ screening test value was calculated by subtracting the reference area average gross SOF from the survey unit average gross SOF. The survey unit average gross SOF was 0.42 (from Table 11-2). The reference area average gross SOF was calculated to be 0.15 using average activity concentrations from C-T Phase II DP Table 4-17. The $DCGL_W$ screening test value was calculated to be 0.27. Because the test value was less than one, the WRS test is required per C-T Phase II DP Table 14-6.

11.4.2.4 EMC Limit

In accordance with Page 14-28 of the C-T Phase II DP, the EMC limit screening test was applied to the AECOM-defined Elevated Area #1. Parameters necessary to calculate the exposure-weighted fraction of the $DCGL_W$, *F*, were:

- The size of Elevated Area #1 was determined to be approximately 50 m^2, as discussed in Section 11.3.2;
- The area factor from C-T Phase II DP Figure 5-3 for Elevated Area #1 was conservatively set to 1.4 (based on thorium series only);
- The average elevated area activity level was a gross SOF = 1.55, as discussed in Section 11.4.1; and,
- The survey unit average was a gross SOF = 0.22 (from Table 11-2, excluding sample 3182).

The calculation of the EMC screening test result is shown below, using C-T Phase II DP Equation 14-7.

$$F = \left[\frac{50\ m^2}{480\ m^2} \times \frac{1.55}{1.4 \times 1}\right] + \left[\frac{(480 - 50)\ m^2}{480\ m^2} \times \frac{0.22}{1}\right] = 0.31$$

In accordance with the C-T Phase II DP and because the result was less than one, the total radioactivity concentration in the survey unit is within the release criterion.

11.4.3 WRS Test

In accordance with Page 14-29 of the C-T Phase II DP, because the Min/Max test value was greater than one and the $DCGL_W$ test was less than one, the WRS Test was required to demonstrate compliance. The test was completed in accordance with Pages 14-29 and 14-30 of the C-T Phase II DP. The result was that the survey unit passed, with the calculation details provided in Table 11-7.

Table 11-7 WRS Test Results

Sample ID	Area	On-Site Results				Off-Site Results			
		Data (SOF)	Adjusted Data (SOF)	Ranks	RA Ranks	Data (SOF)	Adjusted Data (SOF)	Ranks	RA Ranks
BH-013	RA	0.11	1.11	22	22	0.11	1.11	22	22
BH-016	RA	0.42	1.42	29	29	0.42	1.42	29	29
BH-028	RA	0.10	1.10	21	21	0.10	1.10	21	21
BH-031	RA	0.09	1.09	18	18	0.09	1.09	18	18
BH-034	RA	0.29	1.29	28	28	0.29	1.29	28	28
BH-037	RA	0.22	1.22	25	25	0.22	1.22	25	25
BH-045	RA	0.10	1.10	20	20	0.10	1.10	20	20
BH-053	RA	0.16	1.16	23	23	0.16	1.16	23	23
BH-065	RA	0.23	1.23	26	26	0.23	1.23	26	26
BH-083	RA	0.07	1.07	17	17	0.07	1.07	17	17
BH-091	RA	0.24	1.24	27	27	0.24	1.24	27	27
BH-093	RA	0.10	1.10	19	19	0.10	1.10	19	19
BH-099	RA	0.22	1.22	24	24	0.22	1.22	24	24
BH-Z-02	RA	0.07	1.07	16	16	0.07	1.07	16	16
BH-Z-09	RA	0.05	1.05	15	15	0.05	1.05	15	15
3178	SU	0.32	0.32	10	0	0.23	0.23	8	0
3179	SU	0.32	0.32	11	0	0.27	0.27	10	0
3180	SU	0.12	0.12	2	0	0.12	0.12	3	0
3181	SU	0.22	0.22	6	0	0.15	0.15	6	0
3182	SU	2.04	2.04	30	0	3.18	3.18	30	0
3183	SU	0.61	0.61	14	0	0.47	0.47	14	0
3184	SU	0.31	0.31	8	0	0.27	0.27	9	0
3185	SU	0.43	0.43	13	0	0.39	0.39	13	0
3186	SU	0.10	0.10	1	0	0.08	0.08	1	0
3187	SU	0.19	0.19	5	0	0.12	0.12	4	0
3188	SU	0.16	0.16	4	0	0.13	0.13	5	0
3189	SU	0.31	0.31	9	0	0.20	0.20	7	0
3190	SU	0.22	0.22	7	0	0.29	0.29	11	0
3191	SU	0.35	0.35	12	0	0.31	0.31	12	0
3192	SU	0.12	0.12	3	0	0.09	0.09	2	0
			Sum:	465	330		Sum:	465	330
			Critical Value:	272			Critical Value:	272	
			Conclusion:	**PASS**			**Conclusion:**	**PASS**	

11.4.4 Retrospective Analysis

A retrospective analysis was performed of the FSS results to determine whether the results met the survey design objectives, in accordance with Page 14-30 of the C-T Phase II DP. Sample 3182 was the maximum systematic result (Table 11-2) with a gross SOF of 3.18. This result was greater than one and systematic sample 3182 was evaluated as part of the elevated area evaluation (Section 11.4.1). Also, the next largest systematic result was sample 3183 (Table 11-2) with a gross SOF of 0.47. Because systematic sample 3182 was over 6½ times greater than the next highest systematic result, it was considered an outlier that would not allow for a meaningful assessment of the survey unit average and was therefore excluded from the

analysis of the survey unit statistics. Table 11-8 provides the results of the retrospective analysis, with systematic sample 3182 excluded. Because the actual sample size exceeded the retrospective value sample size, the conclusion is that the survey design objectives were met.

Table 11-8 Retrospective Analysis

Parameter	*A Priori* Value	Retrospective Value Based on FSS Results (Gross SOF)
Upper Bound of Gray Region	DCGL = 1	1
Lower Bound of Gray Region	0.5 x DCGL = 0.5	0.22
Spatial Variability (standard deviation)	1/6 x DCGL = 0.17	0.12
Type I Error (false positive)	0.05	0.05
Type II Error (false negative)	0.05	0.05
Relative Shift	3	6.5
Calculated N/2 Sample Size	15 [a]	9
Actual N/2 Sample Size	--	14

[a] The *a priori* value of 15 for the N/2 sample size was determined to be a conservative value that would allow application of either the Sign or WRS test. The *a priori* value for N/2 is 10 based on MARSSIM Table 5.3.

11.5 DEVIATIONS

In accordance with the second bullet in Section 14.5 of the C-T Phase II DP, the FSSR is required to list changes made in the FSS from what was proposed in the DP. Two deviations were noted.

1. Page 14-22 of the C-T Phase II DP indicated where "subsoil contamination is reasonably suspected, final status survey design will be expected to include subsoil radioactivity measurement, either by soil core sampling and gamma spectrometry or in-ground, down-hole gamma spectrometry to measure key radionuclides." The elevated areas discussed in Section 11.4.1 were included in the areas that were excavated to a 1-to-1 slope because additional excavation threatened to undermine the building foundation and existing water line running along the building. Therefore additional contamination subsurface to the excavated slope and the 30 cm layer of sampled soil is reasonably suspected and additional sampling should have been performed. However, even if the sampling would have confirmed that the elevated area was thicker than 30 cm, the dose consequence would have not been significant as shown in Figure 5-1 and as discussed in Section 5.7.1.2 of the C-T Phase II DP. Figure 5-1 shows that as the thickness of the contaminated zone increases past 30 cm, the maximum annual dose does not significantly increase, or conversely the DCGL would not significantly decrease. Therefore, this deviation does not have significant dose consequences and does not affect the assessment.
2. Page 14-27 of the C-T Phase II DP indicated that the "data set for the survey unit will be processed within a database using screening software developed and verified for the project." This database was not developed; instead, a combination of Microsoft® Excel® spreadsheets and hand calculations was utilized. This deviation is not significant and does not affect the data collection or assessment.

11.6 NRC INSPECTIONS

A summary of NRC inspections applicable to the FSS are provided in Section 5.8 of this FSSR. The scope of the inspections included, but was not limited to: review of project plans, interviewing of project personnel, evaluation of the on-site laboratory, and independent confirmatory surveys conducted by the NRC after backfilling. Inspection Report 040-06563/11-003 noted that the NRC reviewed the FSS data package for SU05 to ensure the licensee conducted the surveys in accordance with the NRC-approved DP and work plans. No violations were identified. No findings of significance were identified.

11.7 CONCLUSION

FSS data were verified to be reliable, appropriately documented, and technically defensible. Specifically, the following conclusions are made:

- The instruments used to collect the data were capable of detecting the radiation type (i.e., gamma) at or below the release criteria (described in Sections 4.4 and 4.5 of this FSSR).
- The calibration of the instruments used to collect the data was current and radioactive sources used for calibration were National Institute of Standards and Technology (NIST) traceable (described in Section 5.4 of this FSSR). Specific records available upon request.
- Instrument response was checked before instrument use each day, at minimum (described in Section 5.4 of this FSSR). Specific records available upon request.
- The survey methods used to collect the data were appropriate for the media and type of radiation being measured (described in Sections 4.4, 4.5, and 4.6 of this FSSR).
- The custody of samples collected for laboratory analysis was tracked from the point of collection until final results were obtained (described in Section 5.5.2 of this FSSR). Specific records available upon request.
- The survey data consist of qualified measurement results that are representative of the area of interest.
- Areas identified with elevated residual radioactivity (i.e. SOF > 1.0) were appropriately investigated and the $DCGL_{EMC}$ properly applied.

All the applicable screening tests passed and the retrospective analysis found that the survey design objectives were met; however, as discussed in Section 11.5, additional subsurface contamination within the 1-to-1 sloped excavation adjacent to Building 250 was reasonably suspected but AECOM did not perform additional subsoil radioactivity measurements per the requirements of the C-T Phase II DP. Section 11.5 discusses the deviation and it was presented that if the contaminated soil was thicker than 30 cm, the dose consequence would not be significant. SU05 meets the industrial use scenario release criterion as established in the C-T Phase II DP Chapter 5; and therefore, satisfies the unrestricted release provisions of Title 10, Code of Federal Regulations (CFR), Part 20, Subpart E.

11.8 REFERENCES

Mallinckrodt, *Mallinckrodt Columbium-Tantalum Phase II Decommissioning Plan*, Revision 2, August 2008.