Appendix A

HQ Air Force Safety Center, Weapons Safety Division & USAF School of Aerospace Medicine Support to Non-Time Critical Removal Actions Uranium and Lead Contaminated Soil, 1958 B-47 Plane Crash Site, Abilene, TX

Final Site Status Summary

Final Version

1 November 2012

(This Page Intentionally Left Blank)

1. Purpose. In support of the Non-Time Critical Removal Actions (NTCRA) Uranium and Lead Contaminated Soil, 1958 B-47 Plane Crash Site, Abilene, TX, the Government in its solicitation planned to provide some support during the field activity and the documentation of final radiological status of the site. This Appendix documents field activities provided by the Government and the assessment of the post removal action radiological conditions of the site. Data in this Appendix was synthesized, in part, from data collected during the Site Evaluation (USACE et al. 2010), α-spectroscopy analyses results of Survey Unit 1 soils samples collected during the Site Evaluation but not completed prior to publication of the report, in-situ radiological measurements collected during field activities by USAF School of Aerospace Medicine and HQ Air Force Safety Center, and the radioanalyses of soil samples collected by EDI (sub-contracted to Sullivan-Arrowhead) and Texas Commission on Environmental Quality (TCEQ) with subsequent analyses by Test America.

2. Brief Summary of Surveillance and Conclusions from the Site Evaluation.

The Site Evaluation conducted in 2010 incorporated geophysical surveys targeted at identifying metallic parts in shallow surface soils or on the surface, in-situ radiological surveys to identify areas of radiological contamination in surface soils, and the collection of 146 soil samples. Samples were screened on-site for lead using a portable x-ray fluorescence device, with a fraction of them analyzed by laboratory mass spectrometry for confirmation. Laboratory high-resolution γ-spectroscopy analysis was accomplished on the samples, with a fraction having laboratory mass spectrometry for uranium isotopes. Survey measurements and soil sampling was conducted for Survey Unit designations as shown in Figure A-1 following Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance [NRC 2000]. Lead and uranium was identified in many of the samples, and over 100 metal parts related to the weapon or aircraft involved in the accident. None of the parts were radioactive, however. All lead impacted soils were below the Texas Risk Reduction Program (TRRP) protective concentration limit (PCL) of 150 milligrams per kilogram (mg/kg), i.e., parts per million (ppm). As such, under the NTCRA, the existence of low concentrations of lead in excavated soils was incident to the objective of uranium removal. Areas of elevated uranium contamination were identified based on corroborative information from in-situ radiological surveys and soil sample analyses. Uranium concentrations in surface soils were evaluated against generic soil screening levels (SSLs) recommended by the Environmental Protection Agency (EPA) for Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) sites at the 10^{-4} excess life-time cancer risk level, as summarized in Table A-1. The table displays SSLs for the isotopic mixtures of moderately- depleted uranium (DU) and 93.3 % highly-enriched uranium (HEU). Though the weapon contained both uranium types, 93.3 % HEU has a specific activity 172-fold higher than the DU, prompting use of the 200 pCi/g combined pathways SSL in the Site Evaluation phase of the project. Groundwater criteria are listed in the table, but under the CERCLA process for radiological materials, this pathway, in general, is evaluated separately from the other pathways. The Safe Drinking Water Act (SDWA) criterion listed in the table was based on a 1991 EPA proposal that was never promulgated. Acceptable concentrations for this criterion are listed for dilution-attenuation factors (DAF) of 20 and one, based on a conservative default soil-water partition coefficient of 0.4 mL/g. The current SDWA MCL under 40 CFR 161.66(e) is 30 μg/L, total uranium by mass, without a radioactivity criterion. Dose and risk modeling was also completed with Residual Radiation (ResRad), version 6.5, developed by Argonne National Laboratory (ANL), based on a 12 inch (30 cm) thick contamination zone to match the sampling depth of Site Evaluation phase samples. The criterion closely matched the EPA SSL.

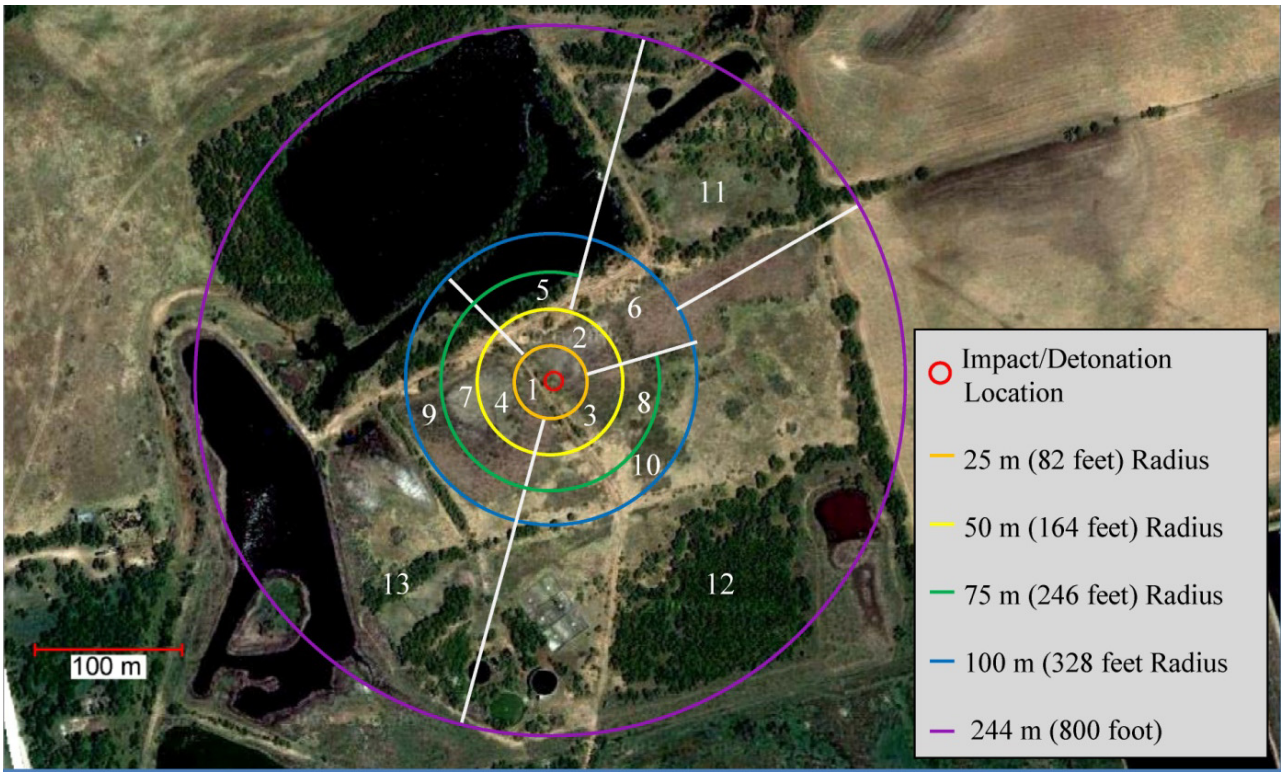

Figure A-1. Site Map with Survey Unit Designations.

TABLE A-1. Generic SSLs for Uranium in Residential-Use Soils (pCi/g) at the 10^{-4} Excess Risk Level [EPA-540-R-00-006-TBD (EPA 2000a)].

Radionuclide	Ingestion of Homegrown Produce	Direct Ingestion of Soil	Inhalation of Fugitive Dusts	External Radiation Exposure	Combined Pathways	Ground Water SDWA MCL 20 pCi/L*	
						20 DAF	1 DAF
^{234}U	590	502	160,000	440,000	270	0.24	0.012
^{235}U + progeny	580	4,870	180,000	21	20	0.24	0.012
^{238}U + progeny	470	380	194,000	98	67	0.24	0.012
Moderate DU	480	400	188,000	110	73	0.24	0.012
HEU 93.3 %	590	510	160,000	690	200	0.24	0.012

* This value was proposed by the EPA in 1991 as a uranium MCL. In another document (EPA 2000b), a proposed MCL of 30 pCi/L was listed for cancer risks, and a proposed MCL of 20 µg/L was listed for kidney toxicity.

Due to the unremarkable in-situ radiological scanning results for areas outside 75 meters from the impact/detonation location, biased and systematic soil samples were only collected for survey units 1 - 10. Among these, only three survey units had areas of elevated contamination and corresponding uranium activity concentrations greater than 200 pCi/g in associated sample(s). Figure A-2 shows

systematic and biased soil sampling locations, with colored-code ^{235}U activity concentrations in the samples based on γ-spectroscopy analysis. Due to the generally unremarkable uranium activity concentrations in soil samples collected outside of 164 feet (50 m) from the impact/detonation location, only the results for samples from Survey Units 1 - 5 and those with ^{235}U greater than or equal to 0.5 pCi/g were plotted. Three areas of interest (AOI) # 1, #2, and #7, as annotated on this plot, were targeted for this removal action. All three were in close proximity to the impact/ detonation location. Table A-2 and A-3 contain summary statistics for the all systematic and biased soil sampling results, respectively, from the Site Evaluation. Since α-spectroscopy results were not available for the Site Evaluation report, ^{234}U activity concentrations were based on a conservative assumption that all of the reported ^{235}U was from 93.3 % HEU, with a ^{234}U to ^{235}U activity

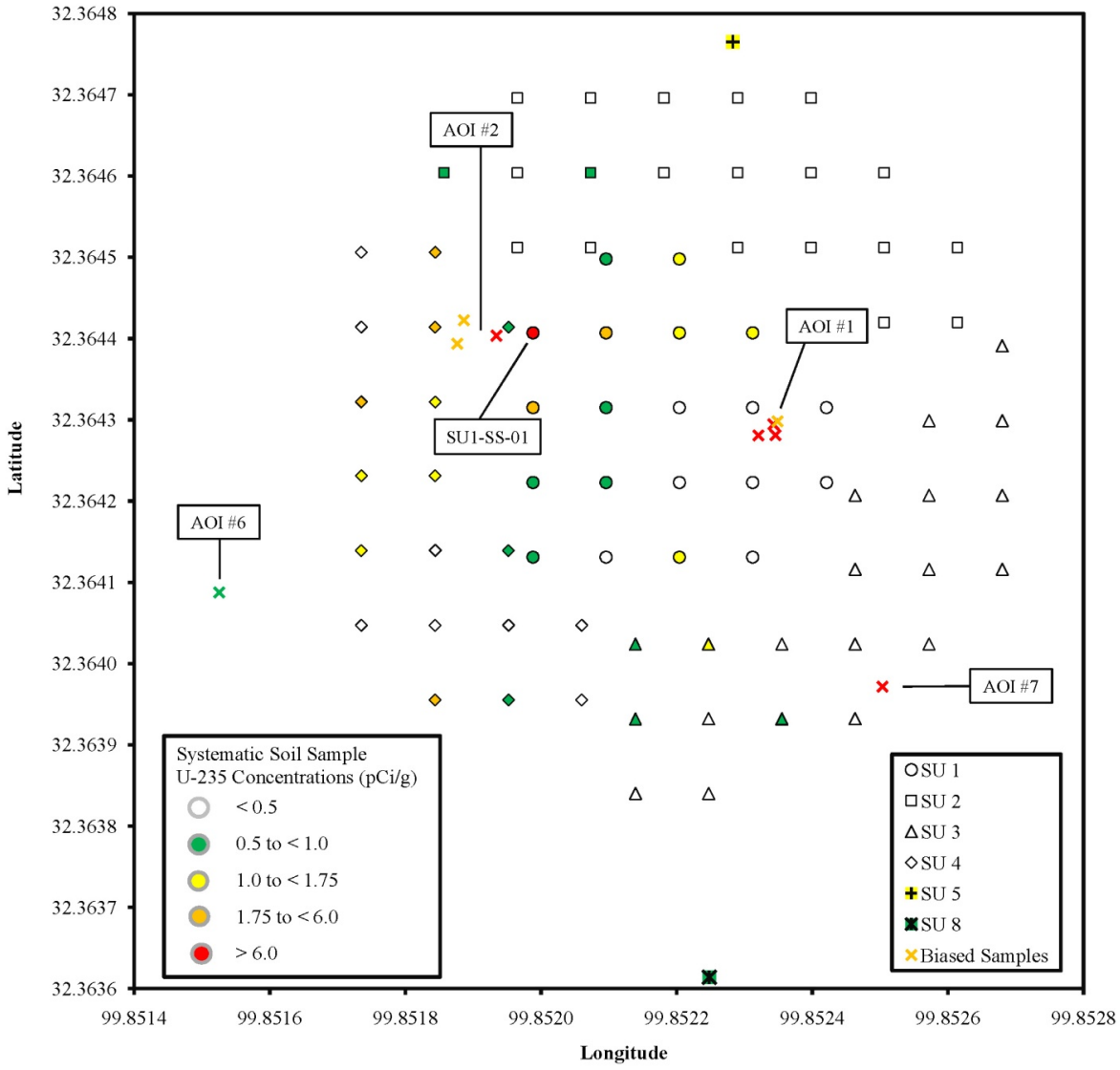

Figure A-2. Systematic and Biased Surface Soil Sample Results for ^{235}U from Site Evaluation Report, Figure 5-15 (USACE et al. 2010).

TABLE A-2. Summary Statistics for Systematic Soil Samples (γ-Spectroscopy from Site Evaluation, α-Spectroscopy Results Unavailable for Site Evaluation Report).

Survey Unit	Number of Samples	Method	Activity Concentration (pCi/g)										
			U-238			U-235			U-234			Total Uranium	
			Mean	Median	Max	Mean	Median	Max	Mean	Median	Max	Mean	Max
1	20	γ-Spec*	1.08	1.13	2.23	1.41	0.60	12.7	46.2	NR	418.8	48.7	433.7
		α-Spec	0.83	0.65	3.60	1.13**	0.43**	13.0	28.6	11.3	326.9	30.5	343.5
2	20	γ-Spec*	1.01	1.01	1.01	0.19	0.15	0.91	6.07	NR	29.74	7.26	32.0
3	20		0.78	0.78	1.23	0.34	0.23	1.81	10.85	NR	59.44	12.0	62.2
4	19		1.05	0.93	2.72	1.06	0.67	3.28	34.61	NR	108.0	36.7	112.5
5	20		0.60	0.60	1.57	0.12	0.05	1.36	3.62	NR	44.59	4.34	47.5
6	10		0.74	0.65	1.21	0.08	0.09	0.17	2.31	NR	5.15	3.13	5.9
7	6		0.61	0.57	1.12	0.17	0.21	0.27	5.31	NR	8.72	6.09	9.5
8	6		0.77	0.81	0.97	0.30	0.27	0.72	9.74	NR	23.53	10.81	25.0
9	6		0.73	0.78	1.04	0.11	0.08	0.20	3.45	NR	6.24	4.29	7.1
10	5		0.65	0.63	0.88	0.08	0.10	0.12	2.33	NR	3.73	3.06	4.5
	Above 200 pCi/g SSL action level												

* ^{234}U based on ^{234}U:^{235}U ratio of 33. ** Two reported ^{235}U results < minimum detectable concentration, set to < value in calculation. NR = Not Reported

TABLE A-3. Summary Statistics for Surface Soils in Biased Sampling Areas from Site Evaluation Report.

AOI (Survey Unit)	Number of Samples	Activity Concentration (pCi/g)									
		U-238			U-235			U-234* (Predicted)		Total Uranium	
		Mean	Median	Max	Mean	Median	Max	Mean	Max	Mean	Max
#1 (1)	4	2.54	2.51	2.99	23.1	18.2	52.5	763	1,732	788	1,787
#2 (4)	3	1.84	1.80	2.27	5.45	3.38	10.1	179	333	187	345
#6 (7)	1	1.10	NA	NA	0.85	NA	NA	27.7	NA	29.7	NA
#7 (3)	1	6.65	NA	NA	94.4	NA	NA	3,115	NA	3,216	NA
	Above 200 pCi/g SSL action level										

* ^{234}U based on ^{234}U:^{235}U ratio of 33.

concentration ratio of 33 for 93.3 % HEU. The α-spectroscopy summary results for systematic soil samples from Survey Unit 1 are provided in Table A-2, with Table Annex-1 containing the complete results. Apparent from comparison to the predicted ^{234}U activity concentrations listed in the Site Evaluation report, ^{234}U predictions were very conservative, having an actual ratio of 25.3 between the mean ^{234}U and ^{235}U concentrations for Survey Unit 1.

Table A-4 contains a comparison of the soil sampling results to the SSL and ResRad-calculated elevated comparison levels (EMCs) from the Site Evaluation report. None of the survey units had mean uranium activity concentrations among systematic samples greater than the SSL. However, two survey units had unity rule term sums in excess of one using the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) [NRC 2000] approach for evaluation of survey units containing EMC areas. The existence of elevated contamination in these areas formed the basis for the NTCRA. The Air Force documented its justification for the NTCRA in an Engineering Evaluation/Cost Analysis (EECA) [USACE and HQ AFSC 2010]. Elevated contamination areas within Survey Units 1 and 3 were estimated to contain approximately six cubic yards (yd^3). Because a typical roll-off container used for waste transportation can accept 15 yd^3, the targeting of additional contaminated soils until the container reached its capacity was planned for field removal actions.

TABLE A-4. Comparison of Soil Sampling Results to Soil Screening and ResRad-Calculated EMC Levels for Survey Units 1, 3, and 4, as Documented in the Site Evaluation report.

Area of Evaluation	Area (m^2)	Criterion Type	Area Factor	Criterion (pCi/g)	Concentration (pCi/g)	Unity Rule *
Survey Unit 1						
Entire survey unit (systematic sample mean concentration)	1,964	SSL	1	200	48.7	0.244
Biased sampling area (SU1-BS-01 thru 04, AOI #1)	13	EMC	3.6	720	788	1.027
Systematic sample (SU1-SS-01)	100	EMC	2.2	440	433.7	0.875
					Sum	2.15
Survey Unit 4						
Entire survey unit (systematic sample mean concentration)	1,964	SSL	1	200	36.7	0.184
Biased sampling area (SU4-BS-01 thru 03, AOI #2)	16	EMC	3.3	660	187	0.228
					Sum	0.41
Survey Unit 3						
Entire survey unit (systematic sample mean concentration)	1,964	SSL	1	200	12.0	0.060
Biased sampling location (SU1-BS-05, AOI #7)	1	EMC	13.3	2,660	3,216	1.205
* Application of MARSSIM unity rule for EMC areas, based on § 8.5.2 and Eq. 8-2 (subtraction of δ omitted for simplicity) [NRC 2000]					Sum	1.27

This approach effectively implements the ALARA (As Low As Reasonably Achievable) approach, with the total volume removed being limited by available waste container volume. The additional soil removal was planned for elevated areas in Survey Unit 4, where a broad area of elevated contamination existed. The contamination levels in this survey unit, however, did not exceed the MARSSIM unity rule.

2. Removal Action Activities.

a. The first field work involved clearing brush from the areas of interest (AOI) in the three survey units where surface soils with elevated concentrations of uranium were planned for excavation. Some of this work was accomplished by Arrowhead-Sullivan as part of their contract. Since the Texas Commission of Environmental Quality (TCEQ) requested an opportunity to conduct radiological scans of the general area during the removal action phase, the 7th Civil Engineering Squadron cleared a significant amount of brush from areas surrounding the AOI's. Due to the enduring drought conditions for west Texas, most of the brush that was cleared was very dry.

b. NaI(Tl) scintillators FIDLER instruments operated in a scanning mode of operation were used to evaluate areas planned for excavation. Table A-5 lists the instruments used by USAFSAM and HQ AFSC/SEW for field work. Calibration documents are in Annex 2. AOI #7 was an isolated area of elevated contamination that was identified with a single flag, while AOI's #1 and #2 were substantially larger areas. For these AOI's, rectangular areas were delineated with a post on each corner, with fine positioning to ensure the areas were right rectangles. Survey grids were established for each rectangular area, using a north and east coordinate system, though no effort was expended to orient the sides along true north-south and east-west bearings. For AOI #1, due the high degree of variability in contamination levels observed from the Site Evaluation, three foot grid spacing was used. Each measurement encompassed 1 yd^3 (~ 1 m^2), the minimum averaging area used in the ResRad dose modeling code. A Trimble™ global positioning system (GPS) was used to record coordinates for the corners of the gridded AOI survey areas. Interpolated coordinates were calculated for other surveys points in the grids. The Annex contains tabular lists of the coordinates for each AOI. Static FIDLER measurements were collected for each gridded AOI for a 30-second count period. For static measurements, the detector was mounted on a stand, maintaining a detector to ground separation distance of 4 inches (Figure A-3).

TABLE A-5. Survey Instruments Used by USAFSAM and HQ AFSC/SEW for Field Work

Instrument	Meter		Probe		Calibration	
	Model	Serial Number	Model	Serial Number	Date Completed	Renewal Date
FIDLER	Ludlum 2221	78154	Alpha Spectra 20DT063	031606C	23 Mar 11	23 Mar 12
FIDLER		169214		0310606H	28 Sep 10	28 Sep 11
Pancake Geiger-Müeller	Bicron Analyst	C433C	Bicron PGM	13873H	23 May 11	23 May 12
High-Purity Ge γ-Spectroscopy	OrtecR Trans-SPEC-DX-100 (Single Unit Contains Integrated Meter and Probe)				Calibrated in Field with ^{137}Cs Check Source	

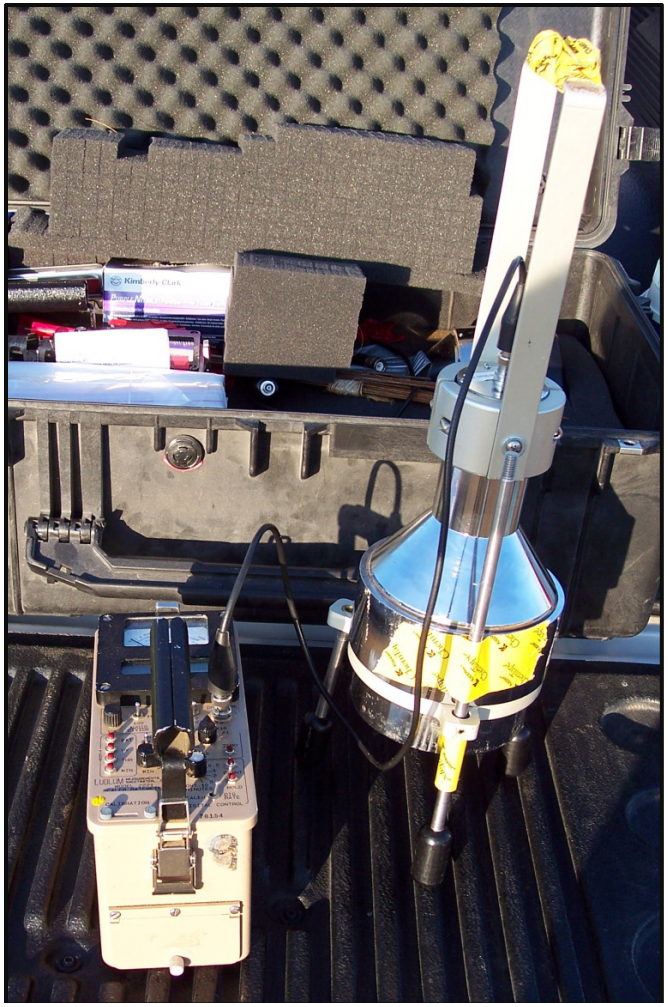

Figure A-3. Photograph of FIDLER with Stand.

Table A-6 contains the pre-excavation FIDLER measurements for AOI #1. The integrated counts ranged between 4286 and 17,561. The color-coding in the table, corresponding to integrated counts, clearly shows the highly localized nature of the contamination within this AOI. In-situ γ-spectroscopy measurements were collected at three locations in AOI #1 to evaluate specific radionuclides contributing to the response of the FIDLER system. Each measurement location had a spectrum collected for a five-minute data accumulation period, with the spectral results in Figure A-4. The results of these measurements clearly support the in-situ FIDLER measurements. The measurements at grid corner locations have no evidence of ^{235}U, while the measurement at the grid location with the highest in-situ FIDLER reading exhibits the four primary γ-emission lines for ^{235}U: 143.8 keV (10.5 %), 163.3 keV (4.7 %), 185.7 keV (54 %), and 205.3 keV (4.7 %).

Static FIDLER measurements for AOI #2 are contained in Table A-7. As noted earlier, this AOI had a more diffusely-distributed pattern of contamination than AOI #1, prompting the use of eight foot grid spacing for FIDLER measurements. The only exception was a small isolated area of contamination on the lower, middle section that had a count rate about 30 kilo counts per minute (kcpm). In-situ γ-spectroscopy spectra were collected at three locations, like that accomplished in AOI #1 (Figure A-5). The prominent spectrum was for grid location 24N - 56E, which had the highest FIDLER measurement on a fixed grid location. The measurement at 4N - 32E had a lower overall response, and was located in the vicinity of the isolated area of elevated contamination. The measurement at 0N - 0E, a grid corner, had a somewhat unremarkable spectrum compared to the spectra from the other two measurement locations; however, there is some minor elevated counts observable in the vicinity of the 143.8 and 185.7 keV energy regions. This is in minor contrast to the observed spectra for the grid corners for AOI #1, but is attributable to the more diffuse pattern of contamination in AOI #2.

TABLE A-6. Static FIDLER Integrated Count Measurements for AOI #1 (Pre-Excavation).

North-South Latitude (feet)	East-West Longitude (feet)													
	0	3	6	9	12	15	18	21	24	27	30	33	36	39
27			4532	4456	4801	4594	4439	4525						
24	4444	4535	4779	4949	4888	4672	4681	4523	4633	4555	4502	4556	4473	4442
21	4670	4869	5300	5396	5103	5571	5018	4638	4564	4706	4721	4572	4634	4435
18	4908	5301	6051	6282	6303	7081	6802	5012	4849	4870	4640	4611	4535	4440
15	4845	5645	7578	8360	9225	9143	8304	6612	5391	5155	4758	4399	4472	4402
12	4858	5097	7368	7293	8766	16823	17561	14023	7492	5734	4786	4423	4358	4457
9	4318	4421	4798	5588	8389	7869	12462	12774	9727	10072	5912	4756	4457	4449
6	4325	4498	4466	4653	5162	5788	6605	8573	17256	7214	5685	6217	4708	4504
3	4466	4411	4456	4436	4610	4764	5040	5665	5621	5022	4911	4915	5381	4803
0	4286	4490	4588	4503	4430	4502	4548	4688	4669	4548	4471	4554	4585	4439

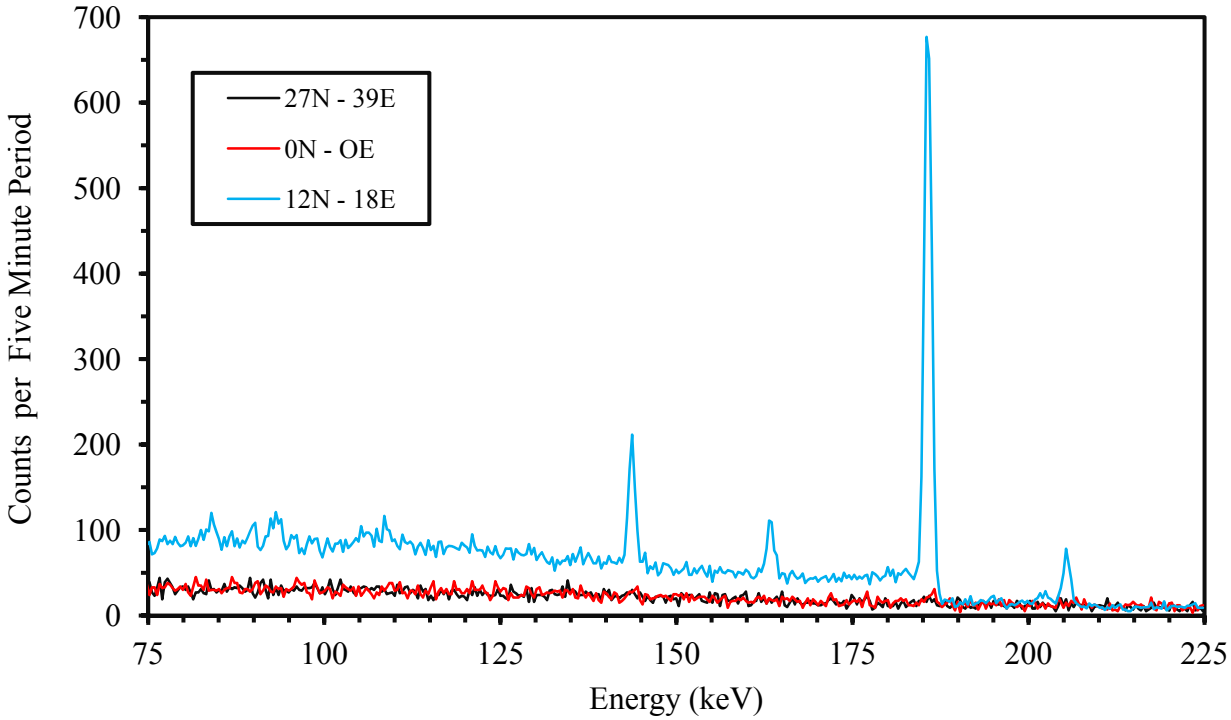

Figure A-4. OrtecR Pre-Excavation In-situ Spectra for Select Grid Location in AOI #1.

TABLE A-7. Static FIDLER Integrated Count Measurements for AOI#2 (Pre-Excavation).

North-South Latitude (feet)	East-West Longitude (feet)								
	0	8	16	24	32	40	48	56	64
56	4534	4697	4990	5009	4789	4647	4683	4474	3605
48	5733	4965	5305	5766	5937	5829	5397	5093	3611
40	5105	5351	5687	5973	5777	7170	6088	5971	4032
32	5315	5228	5554	6009	7320	8223	6847	7533	5041
24	5239	5199	5314	5670	6545	8324	6514	8685	5237
16	5186	7308	4867	5401	5401	5741	6506	6043	7013
8	4871	4658	4670	4902	5459	5345	5604	5963	4326
0	4508	4460	4571	4739	5191	5424	4841	5129	4209

Isolated Area with Elevated Contamination FIDLER Surface Count Rate ~ 30 kcpm

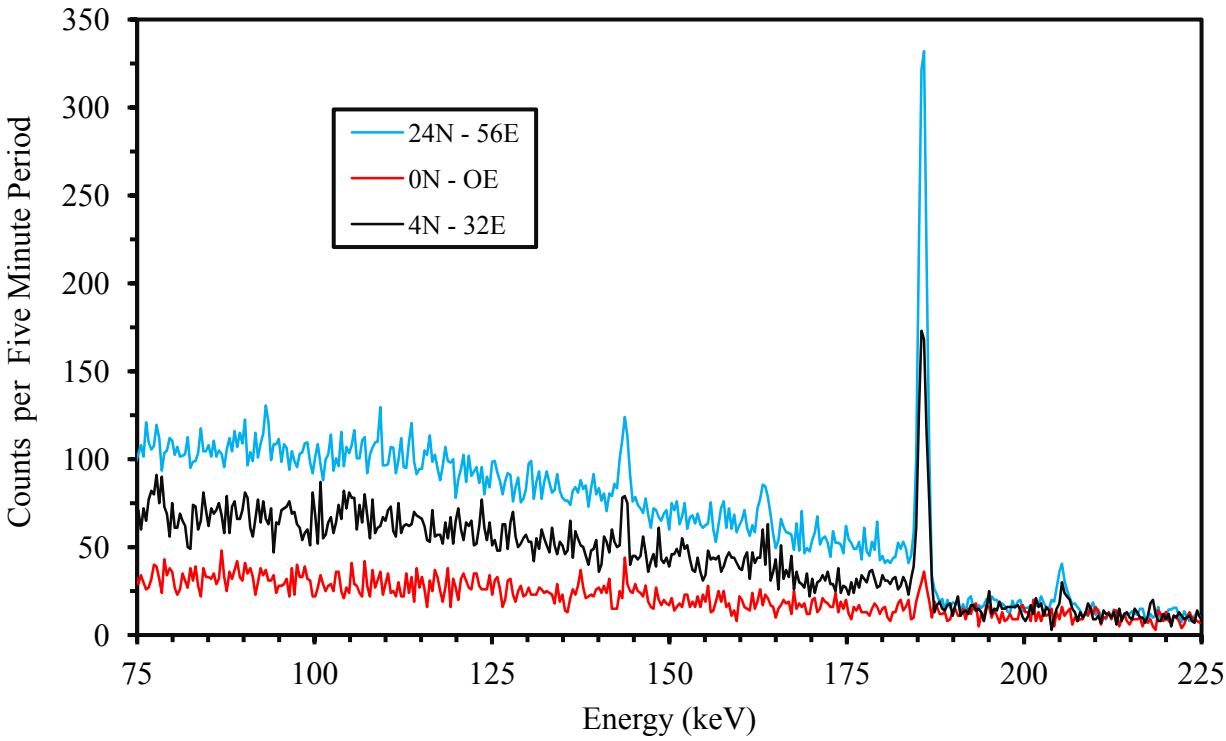

Figure A-5. OrtecR Pre-Excavation In-situ Spectra for Select Grid Location in AOI #2.

Survey Unit 1 partially encompassed the easternmost portion of AOI #2, including some areas on the berm that forms a natural barrier between AOIs #1 and #2. Because the highest systematic soil sample for Survey Unit 1, SU1-SS-01, was located on the berm and in the vicinity of AOI #2, there was plans to include parts of the berm in evaluation of AOI #2. However, careful scanning and a series of static in-situ measurements collected with a FIDLER in this area did not identify any remarkable findings. As such, this area was excluded from the rectangular AOI #2 region.

c. Based on the in-situ FIDLER measurements, the three AOIs were delineated for excavation activity. For AOIs #1 and #2, wire flags were used to delineate excavation areas, as shown in Figures A-6 and -7, respectively. Clear from Figure A-6 is the proximity of the AOI to the berm on the right section of the photograph. Because the contamination in AOIs #1 and #7 caused the survey

Figure A-6. Delineation of Excavation Areas for AOI #1 (View to North).

Figure A-7. Delineation of Excavation Areas for AOI #2 (View to Northwest).

units they were within to fail comparison against the criterion established for the site using EMC evaluation methods of MARSSIM, these areas were prioritized for excavation. Figure A-8 shows excavation in AOI #1 with a front loader. Surface soils were removed to a depth of about a foot. The volume of soil removed in AOI #1 was about 7 yd^3. Soil removal in AOI #7 was initiated by

Figure A-8. Excavation in AOI #1 (View to North).

Figure A-9. Soil Removal in AOI #7.

a shovel and bucket method initially, as shown in Figure A-9. This process was used to investigate the possibility of a discrete source of contamination, though no evidence of this was found. At a depth of about two feet in a small area in the center of the excavation site, additional soil removal was desired, but was difficult due to the hard packed clay. Due to this, the front loader was used for a final removal at depth. Because the bucket had a width of four feet, about 0.75 yd^3 of soil was removed from this area rather than the preliminary estimate of 0.25 yd^3. This would effectively have reduced the average concentration of uranium in the disposal waste stream compared to preliminary estimates. During and post excavation support surveys were conducted with FIDLERs in a scanning mode. Figure A-10 shows the scanning of AOI #1 by an EDI technician, though support surveys were conducted jointly by EDI, USAFSAM, and AFSC personnel. The FIDLERs used by EDI and the

Figure A-10. FIDLER Scanning of Excavated Area in AOI #1 (View to West).

USAFSAM/HQ AFSC team had similar calibration set-ups, making qualitative information from survey personnel interchangeable in directing any additional removal actions. Figure A-11 contains an image of a TECQ team member using a FIDLER to evaluate excavated areas in AOI #2. As pre-

Figure A-11. Excavated Areas in AOI #2 (View to South).

planned with HQ AFSC, TCEQ used FIDLERs provided by USAFSAM. AOI #2 had three separate excavation areas. The southern-most area was for the isolated area of elevated contamination. Similar to AOI #7, this area required excavation to a depth of about three feet. Due to the width of the bucket, a greater volume of soil (1.5 yd^3) was excavated than planned. Subsequently, a large portion of the excavated soils were of much lower uranium concentration than the isolated area of elevated contamination that was the target of removal. The other two areas were only excavated to one foot depths. The areal extent and depth of removal for these two areas were based on the goal of removing the most highly contaminated soils, within the limit of remaining available capacity of the disposal container. The driver estimated that the container had about 16 to 17 yd^3 of soil at the completion of excavations in AOI #2. This included about 0.25 yd^3 of soil samples, retained from the Site Evaluation phase and added to the container earlier in the day.

3. Post Removal Action Surveys.

a. AOIs #1 and #2 were re-evaluated with static in-situ FIDLER and high-resolution γ-spectroscopy to document the effectiveness of the removal action. To ensure comparability of the pre-excavation and post-excavation measurements, the same FIDLER was used for both sets of measurements, though both FIDLERs were purposely closely-paired in their calibrations at USAFSAM. Table A-8 contains post-excavation FIDLER readings for AOI #1. For most grid

TABLE A-8. Static FIDLER Integrated Count Measurements for AOI #1, Post-Excavation Readings* [Grid-Location 6N - 33E, Center Sampling Point for TCEQ Sampling of AOI].

North-South Latitude (feet)	East-West Longitude (feet)													
	0	3	6	9	12	15	18	21	24	27	30	33	36	39
27			4532	4456	4801	4594	4439	4525						
24	4444	4535	4779	4949	4888	4672	4681	4523	4633	4555	4502	4556	4473	4442
21	4670	4869	5300	5563	5103	5571	5107	4638	4564	4706	4721	4572	4634	4435
18	4908	5301	6088	6066	6045	5655	7373	5071	4849	4870	4640	4611	4535	4440
15	4845	5560	6023	5860	5725	5719	5389	5912	5692	5155	4758	4399	4472	4402
12	4858	5194	5945	6018	5659	5649	5986	5597	5041	5089	5030	4423	4358	4457
9	4318	4421	4689	6005	5303	5047	5497	5370	5560	5330	5885	4756	4457	4449
6	4325	4498	4537	4811	5023	6222	6227	5666	5530	6020	6623	5565	4708	4504
3	4466	4411	4456	4436	4716	4932	5048	5919	6073	5873	4911	4915	5381	4803
0	4286	4490	4588	4503	4430	4502	4548	4688	4686	4698	4471	4554	4585	4439

* Pre-Excavation Measurements in Unexcavated Grid Locations without a Post-Excavation Measurement

locations outside the excavated part of the AOI, a post-excavation measurement was not deemed necessary, with a pre-excavation measurement contained in this table. Table Annex-4 contains details on grid locations within the excavated portion of the AOI and measurement type (pre- or post-excavation). Comparison of the data in the table to that in Table A-6 clearly demonstrates the effectiveness of the removal action, with uranium concentrations in systematic samples collected in this AOI being below SSLs. This is evidenced by the comparison of pre- and post excavation in-situ γ-spectroscopy spectrum for location 12N - 18E shown in Figure A-12. The 185.7 keV channel peak count rate in the post-excavation spectrum is about one-fourth that of the pre-excavation spectrum.

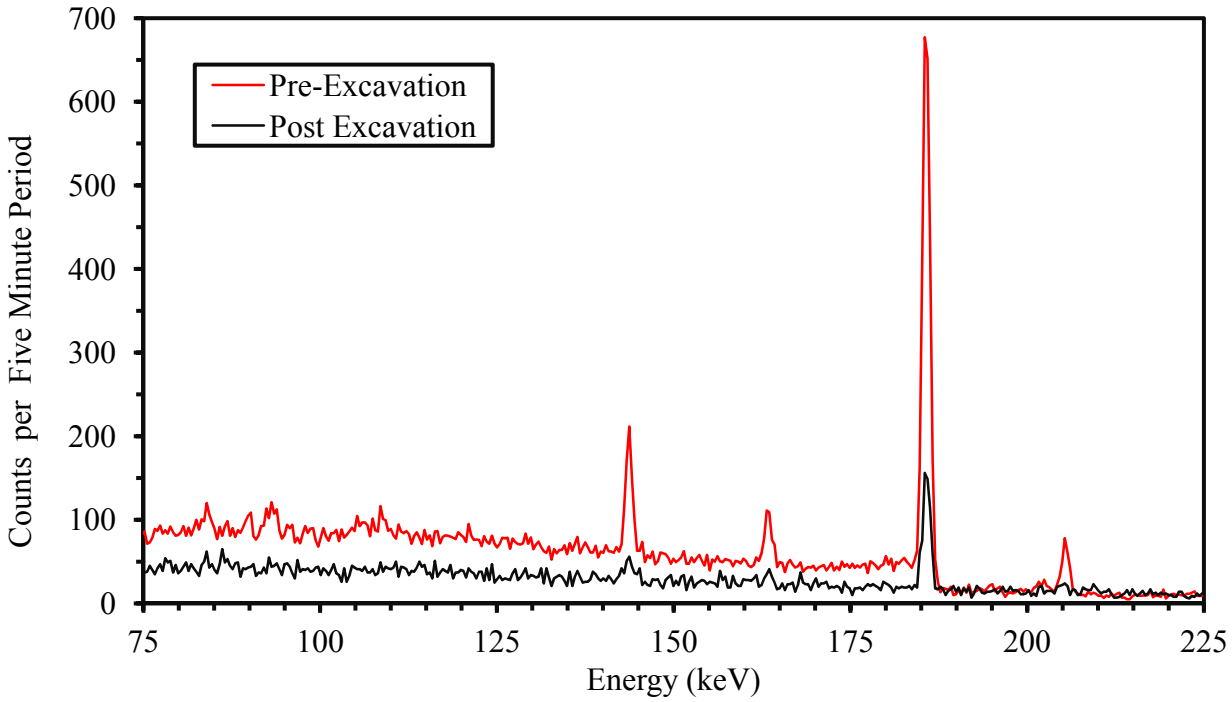

Figure A-12. OrtecR Pre- & Post-Excavation In-situ Spectra for Location 12N - 18E in AOI #1.

Table A-9 contains post-excavation FIDLER readings for AOI #2. For most grid locations outside the excavated parts of the AOI, a post-excavation measurement was not deemed necessary, with a pre-excavation measurement contained in this table. Table Annex-5 contains details on grid locations within the excavated portion of the AOI and measurement type (pre- or post-excavation). Pre- and post excavation in-situ γ-spectroscopy spectra for location 24N - 56E is shown in Figure A-13. The 185.7 keV channel peak count rate in the post-excavation spectrum is about one-half that of the pre-excavation spectrum. Like AOI #1, low-levels of residual contamination exist in the excavated area soils, though removal actions were effective in reducing the overall uranium concentrations in the AOI.

Figure A-14 contains a map of the excavation areas within each AOI, with the corresponding corner locations for micro survey grids established for AOIs #1 and #2.

TABLE A-9. Static FIDLER Integrated Count Measurements
for AOI #2, Post-Excavation Readings*

North-South Latitude (feet)	East-West Longitude (feet)								
56	4534	4697	4990	5009	4789	4647	4683	4474	3605
48	5733	4965	5305	5766	5863	5907	5318	5093	3611
40	5105	5351	5687	5973	6925	6949	6145	6026	3901
32	5315	5228	5554	6009	7128	8388	6548	7331	4688
24	5239	5199	5314	5670	6050	7155	6432	6272	5085
16	5186	7308	4867	5262	5673	6599	5754	7154	3884
8	4871	4658	4670	4809	5442	4905	5274	5880	4326
0	4508	4460	4571	4717	4908	5085	4841	5129	4209
	0	8	16	24	32	40	48	56	64

*Pre-Excavation Measurements in Unexcavated Grid Locations without a Post-Excavation Measurement

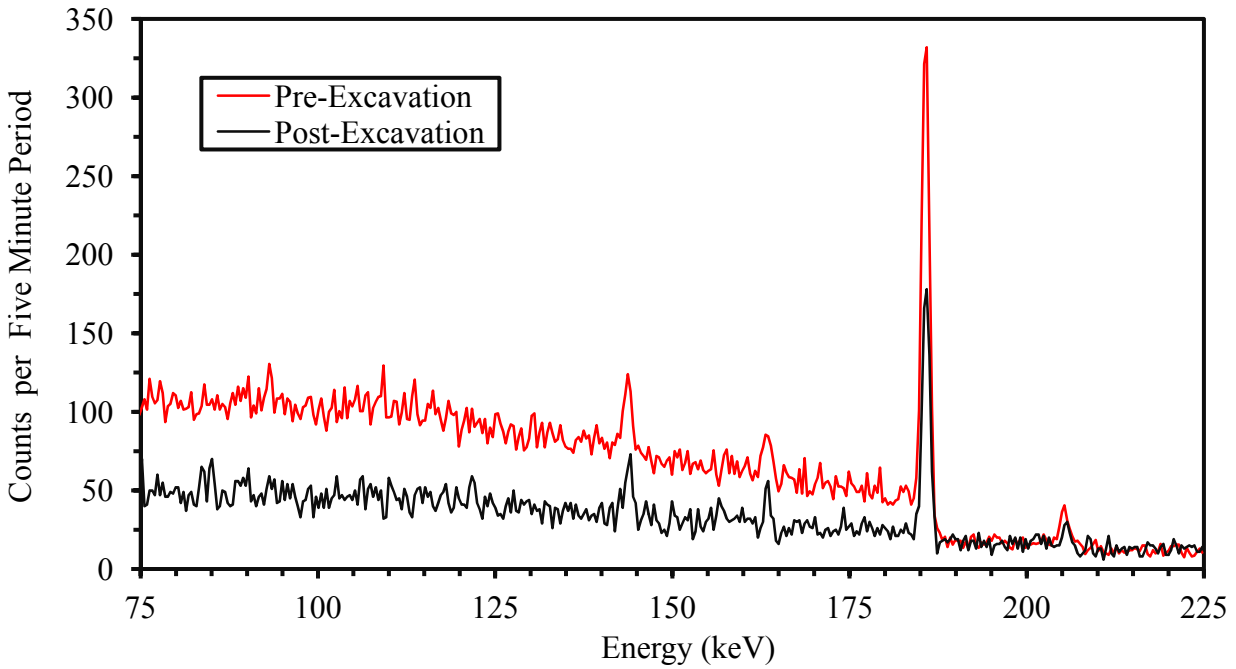

Figure A-13. OrtecR Pre- & Post-Excavation In-situ Spectra for Location 24N - 56E in AOI #2.

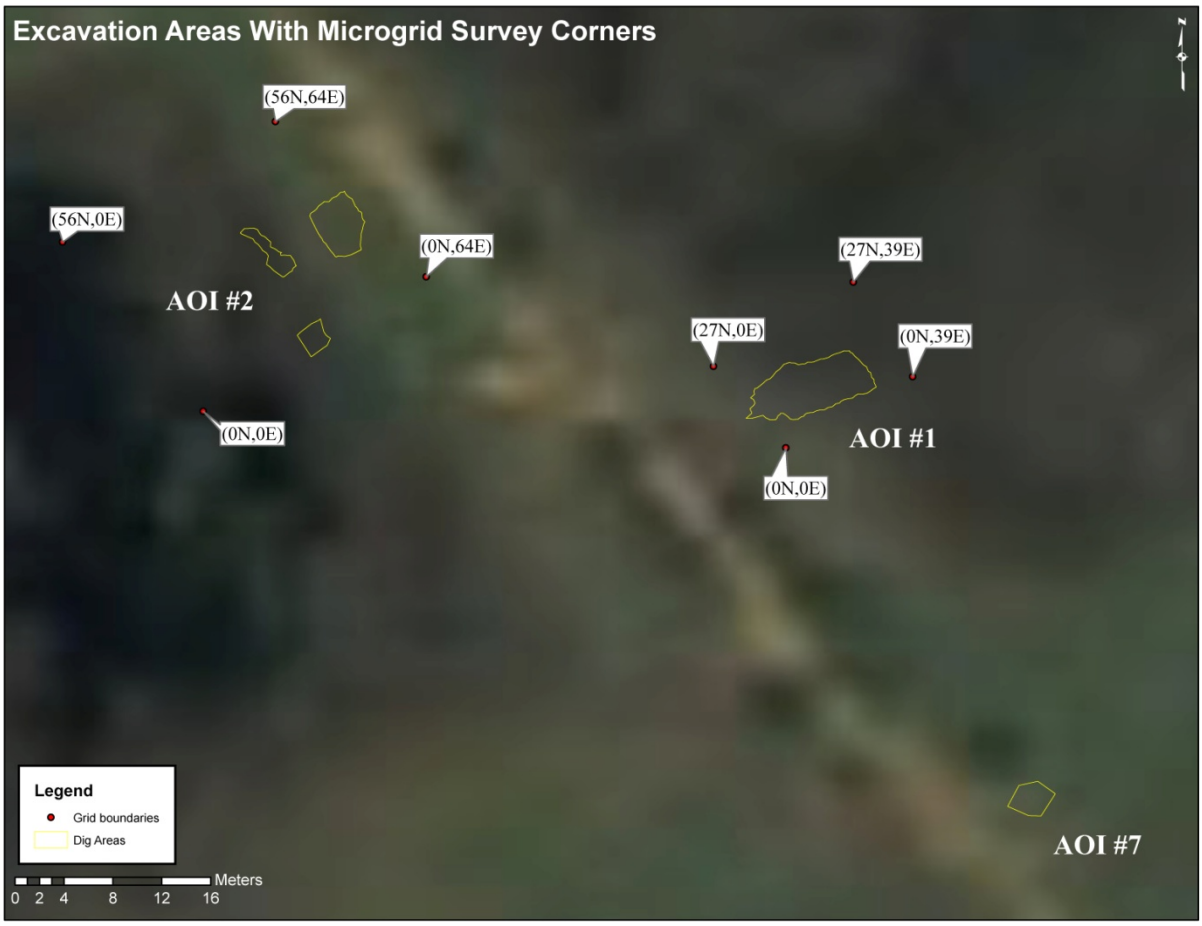

Figure A-14. Excavation Areas with Annotation of Survey Corner Locations for AOIs.

b. Due to severe drought conditions in West Texas during the NTCRA, a portion of the pond located north of the impact/detonation location was dry. This small portion of the pond was filled during the Site Evaluation and during the accident, based on historical photographs. Though this portion of the pond was not believed to be impacted to any significant degree, the drought conditions afforded an opportunity to scan the pond basin sediment with a FIDLER, thereby adding greater completeness to Site Evaluation data. Figures A-15 and A-16, respectfully, have photographs of the ponds during the Site Evaluation and Removal Action phases. Figure A-17 delineates the area scanned by USAFSAM and HQ ASFC with FIDLERs enclosed by the yellow-bounded polygons. The scanning surveys were unremarkable. As well, there was no evidence of metal parts on the surface of the pond basin. The blue dot on the plot corresponds to a soil sampling location chosen as one of 20 planned for post excavation action sampling. This sample was not collected to support the excavation activity part of the removal actions conducted; it was opportune to sample while the pond was dry. The results of this sample provide additional site data that was not possible for collection during the Site Evaluation phase.

Figure A-15. Pond during Site Evaluation.

Figure A-16. Pond during Removal Action.

Figure A-17. Areas Scanned by USAFSAM and AFSC
with FIDLERs [Inside Yellow Polygons].

4. Post Removal Action Soil Sampling.

a. Fifteen post excavation soil samples were collected by EDI in AOIs #1, #2, and #7. Figure A-18 shows the eight soil sampling locations selected for AOI #1 with white flags and sample containers at each location. These samples were distributed on the micro survey grid established for the AOI in a systematic manner. Six of the eight samples were located in excavated locations, while two were near the edge of the excavated area, but in locations undisturbed by the excavation. The samples were collected by EDI to a depth of one foot (30 cm) prior to placement of clean fill. AOI #2 had five soil samples placed systematically on the micro survey grid, with four samples located in excavated areas and one in an undisturbed area near an excavated area. A single biased soil sample was collected from within the excavation pit of the isolated area of elevated contamination on the southern part of the AOI. Similarly, a biased sample was collected from the AOI #7 excavation pit.

Figure A-18. Post Removal Action Soil Sampling Locations and Preparation for AOI #1. [Red Wire Flags Correspond to Post-Excavation FIDLER Measurement Locations & White Flags and White Sample Containers are at Soil Sampling Locations].

b. One sample was collected by EDI in the top foot of the pond basin at a randomly selected area in the middle of the basin, as discussed above. Four samples among the twenty samples planned for analysis in this removal action were reserved for split analysis from independently-collected samples by TCEQ. TCEQ collected five-point composite samples from the three AOIs subjected to removal action, and an additional sample from another general area on the site. TCEQ collected the composites at two surface soil depths: 0 - 6 inches (0 - 15 cm) and 6 - 12 inches (15 - 30 cm). EDI composited the two samples into one for analysis. Table Annex-6 contains summary details on the sampling locations to include GPS coordinates.

c. Air Force samples were sent to Test America, Earth City, MO for α- and γ-spectroscopy analysis. The systematic grid soil sample at 32N - 40E in AOI #2, was subjected to the solid, synthetic precipitation leachate procedure (SPLP) extraction to evaluate partitioning of uranium between the solid and liquid phases. This sampling location was chosen for the procedure because it had the highest predicted residual uranium concentration in surface soils based on the post-excavation static FIDLER measurements. Table Annex-7 contains radiological results for the samples. While the γ-spectroscopy analyses identified a number of radionuclides, natural to the environment and from fallout from nuclear weapons testing, only ^{235}U and ^{40}K results were listed in the table. The ^{235}U was listed because it is related to uranium contamination from the accident, while ^{40}K is typically identified in all soil samples and is useful in evaluating variability factors.

d. Table A-10 contains summary statistics for radioanalysis of soil samples collected within each AOI compared to biased samples collected in each AOI during the Site Evaluation phase. For both AOI's, the systematic samples are more representative of contamination that existed at the time of sampling in the general area than the biased samples due to the process of sample location selection and the greater number of samples collected for each area post excavation. The residual mean ^{235}U, post-excavation in AOI #1 as analyzed by either α-spectroscopy or γ-spectroscopy, was considerably lower than the mean in the four biased samples collected during the Site Evaluation. For AOI #2, the post-excavation mean ^{235}U α-spectroscopy results were a little lower than the mean for the biased samples collected during Site Evaluation. For this AOI, however, there was not an expectation for a drastic reduction in uranium activity concentration in surface soils from the Removal Action, as was the case for AOI #1.

TABLE A-10. Summary Statistics for Selected Soil Samples in AOIs #1, #2, and #7 Post- Excavation Compared to Soil Sample Results from the Site Evaluation Phase.

AOI	Sample Types (Number)	Project Phase	Analytical Method	Mean Activity Concentration (pCi/g)			
				U-234	U-235	U-238	Total U
#1	Systematic (8)	Removal Action	α-Spec	46.3	1.7	1.2	49.1
			γ-Spec	-	2.1	-	-
#2	Systematic (5)	Removal Action	α-Spec	126.4	4.5	1.7	132.5
			γ-Spec	-	5.9	-	-
#7	Biased (1)	Removal Action	α-Spec	142	5.5	1.9	149.4
			γ-Spec	-	4.8	-	-
#1	Biased (4)	Site Evaluation	γ-Spec	763*	23.5	2.5	788*
#2	Biased (3)	Site Evaluation	γ-Spec	179*	5.5	1.8	187*
#7	Biased (1)	Site Evaluation	γ-Spec	3115*	94.4	6.7	3216

* Estimated, based on ^{234}U to ^{235}U Activity Ratio of 33:1

The biased soil sample collected at the bottom of the excavation pit in AOI #7 had a ^{235}U activity concentrations about 18-fold lower than the biased sample collected at this location during the site evaluation. The total uranium activity concentration in this sample, 149.4 pCi/g, is below the SSL of 200 pCi/g for HEU.

e. A regression analysis was performed for ^{235}U activity concentrations in the post excavation samples by the α- and γ-spectroscopy methods, as shown in Figure A-19. The relationship in reported values between the two methods was consistent for low activity concentration samples, but had a much greater degree of variability among samples with higher activity concentrations. Overall, based on the regression analysis, the γ-spectroscopy results appear biased low compared to the α-spectroscopy results. The variability observed for samples of higher activity concentration is suspected to be a result of heterogeneity of the contaminant in samples. The γ-spectroscopy analyses are typically accomplished on sample masses on the order of 500 - 1,000 g, whereas aliquots drawn for chemical separations and subsequent α-spectroscopy analyses are typically about 2 g. Figure Annex-1 contains the same regression of Survey Unit 1 samples from the Site Evaluation phase. The regression analysis for the data in the large plot appears to have better agreement than the data set displayed below. However, as shown in the inset plot, containing all data points but the highest two, a greater degree of variability between reported results from each method is apparent, as well as

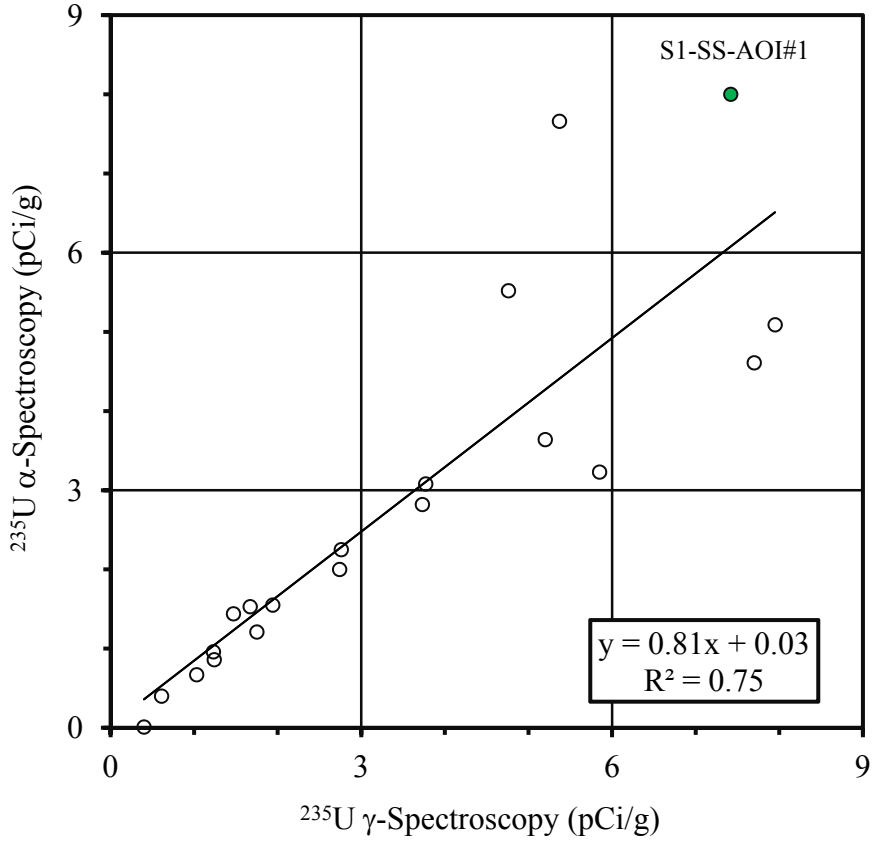

Figure A-19. Regression of α-Spectroscopy vs. γ-Spectroscopy Analyses for ^{235}U in Removal Action Soil Samples.

bias. While subject to the effects of heterogeneity, the α-spectroscopy method produces more useful data for the uranium contaminants at this site than the γ-spectroscopy analyses alone, as the latter cannot be used to quantify the ^{234}U isotope and assess the isotopic mixtures. Similar effects of heterogeneity have been observed in by α-spectroscopy analyses of environmental surveillance samples of uranium dispersed in other conventional explosives dispersal events. Figure Annex-2 contains comparisons of results from multiple aliquot analyses of samples from the Medina Annex to Lackland AFB, TX site (Rademacher et al. 2002). Figure A-20 is a plot of the ^{238}U to ^{234}U ratio vs. total uranium for samples analyzed by α-spectroscopy. Data from Site Evaluation and post excavation soil samples are plotted, with a line for a theoretical mixture of 93.3 % HEU, moderately-depleted uranium (DU), and a natural background of 1.3 pCi/g. It is apparent from the plot good agreement in both data sets with the

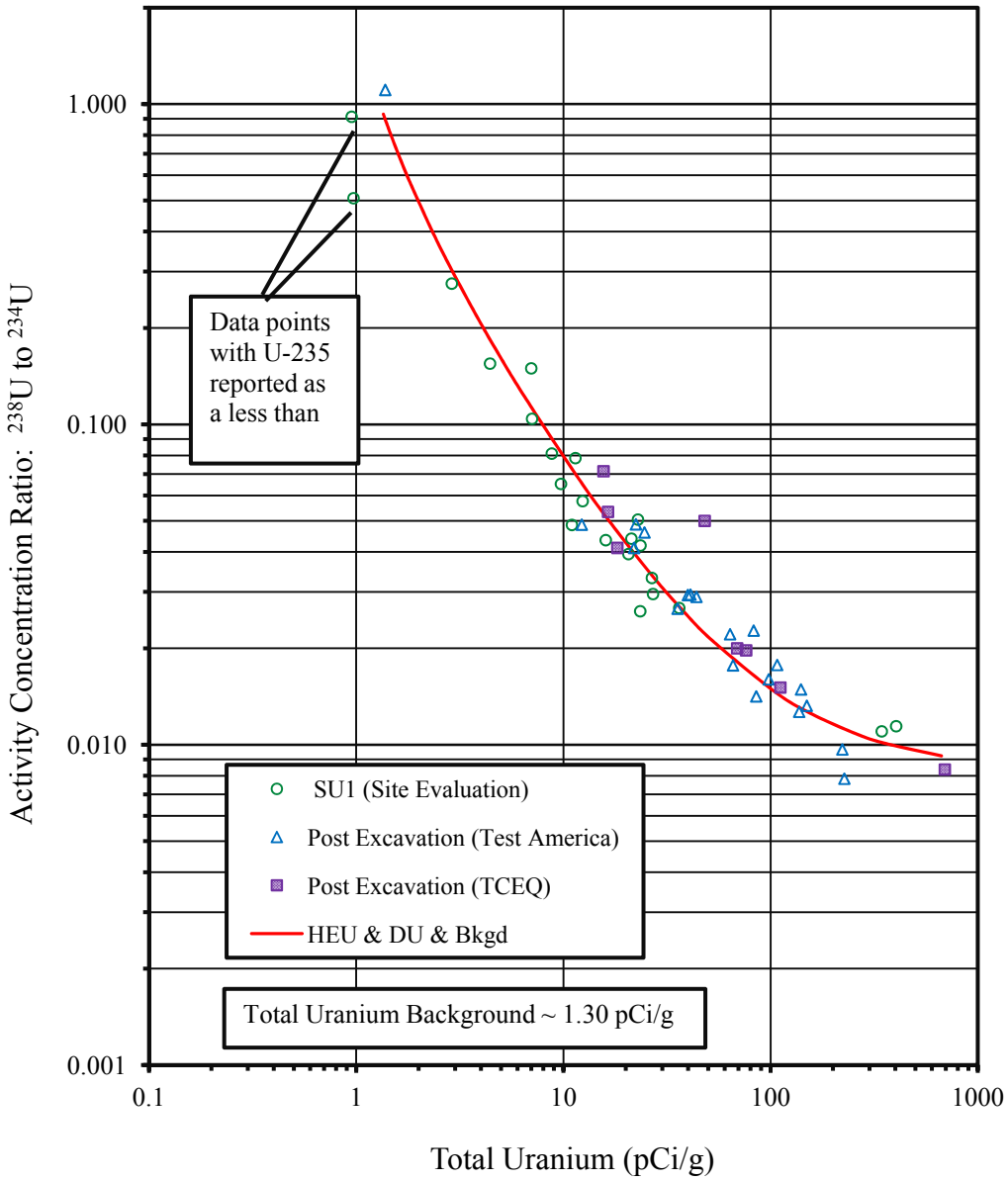

Figure A-20. ^{238}U to ^{234}U Activity Concentration Ratio vs. Total Uranium.

theoretical relationship. This is evidence that the HEU and DU dispersed by the explosives action and present in surface soils for 50 years is visibly uniform in its isotopic mix. The mechanism responsible for the evidenced uniformity is unknown - the mixing by the conventional explosive detonation, the intervening 50 years of environmental actions, or perhaps both.

f. Table A-11 contains the SPLP results, radiological results for soil, and projected doses for consumption of uranium in leachate, using Federal Guidance Report 11 (EPA 1988) dose conversion factors (DCFs) and a consumption rate of 2 L/d. Uranium is reported in terms of activity, based on reported results from the laboratory, with listed mass concentrations based on specific activity multiplied by the activity concentration for each radionuclide. For each isotope, the Freundlich soil/water partition coefficient, K_d, is calculated as the quotient of the concentration sorbed on soil to the soil leachate concentration, under the assumption that adsorption is linear with respect to concentration (EPA 2000). The partition coefficient is an important parameter in the modeling of contaminant transport by water in the environment. The parameter is a predictor of uranium contamination in groundwater, and is important for sites where groundwater is a potential source of drinking water. The calculated coefficient from SPLP and soil results for total uranium was 2,450 mL/g, about 50-fold higher than the default value, 50 mL/g, used in the ResRad computer-based dose modeling code, and about 6,000-fold higher than EPA default value, 0.4 mL/g, used for generic groundwater SSLs (EPA 2000). Higher K_d values result in a greater retardation of uranium leaching from the soil to groundwater, typically resulting in lower calculated doses for use of ground water as a source of drinking water and a greater elapsed period of time to reach peak concentrations in a hypothetical groundwater well head. The isotopic mixture of uranium in the leachate corresponds well to that in the soil sample from which it was derived. The calculated total uranium mass concentration in the leachate was 2.77 μg/L, 9.2 % of the SDWA MCL of 30 μg/L. It's important to note that the uranium mass concentration in this sample was 7.11 μg/g (see Table A-11). This value is only three-fold higher than the estimated uranium background concentrations, based on a

TABLE A-11. Synthetic Precipitation Leachate Procedure (SPLP) Results for Soil Sample S4-SS-32N40E, Associated Radiological Analysis Results, Calculated Uranium Mass Concentrations, and Projected Ingestion Committed Effective Dose Equivalent (CEDE).

Isotope	Uranium Concentrations				Method	Partition Coefficient K_d (mL/g)	Federal Guidance Report 11 DCFs (Sv/Bq)	CEDE** (mrem/y)	
	Leachate (SPLP)		Soil					DAF	
	Activity (pCi/L)	Mass (μg/L)	Activity (pCi/g)	Mass (μg/g)				1	20
^{234}U	53.4	0.0086	131	0.021	α-Spec	2,450	7.66E-08	11.1	0.55
^{235}U	-	-	7.7*	3.56*	γ-Spec	-	7.19E-08	-	-
	1.97	0.91	4.61	2.13	α-Spec	2,340		0.38	0.02
^{238}U	0.62	1.85	1.66	4.96	α-Spec	2,680	7.66E-08	0.12	0.01
$^{Total}U$	56.0	2.77	137.3	7.11	α-Spec	2,450	-	11.5	0.58

* Not included in $^{Total}U$ calculation. ** Consumption assumed to be 2 L/d.

regression of mass spectrometry analyses of soil samples from the Site Evaluation phase. The regression analysis is in Figure A-21 with data listed in Table Annex-8. With negligible ^{235}U mass compared to ^{238}U in un-impacted soils, the y-intercept of the regression analysis is a good estimate of the background, 2.04 $\pm$ 0.23 μg/g.

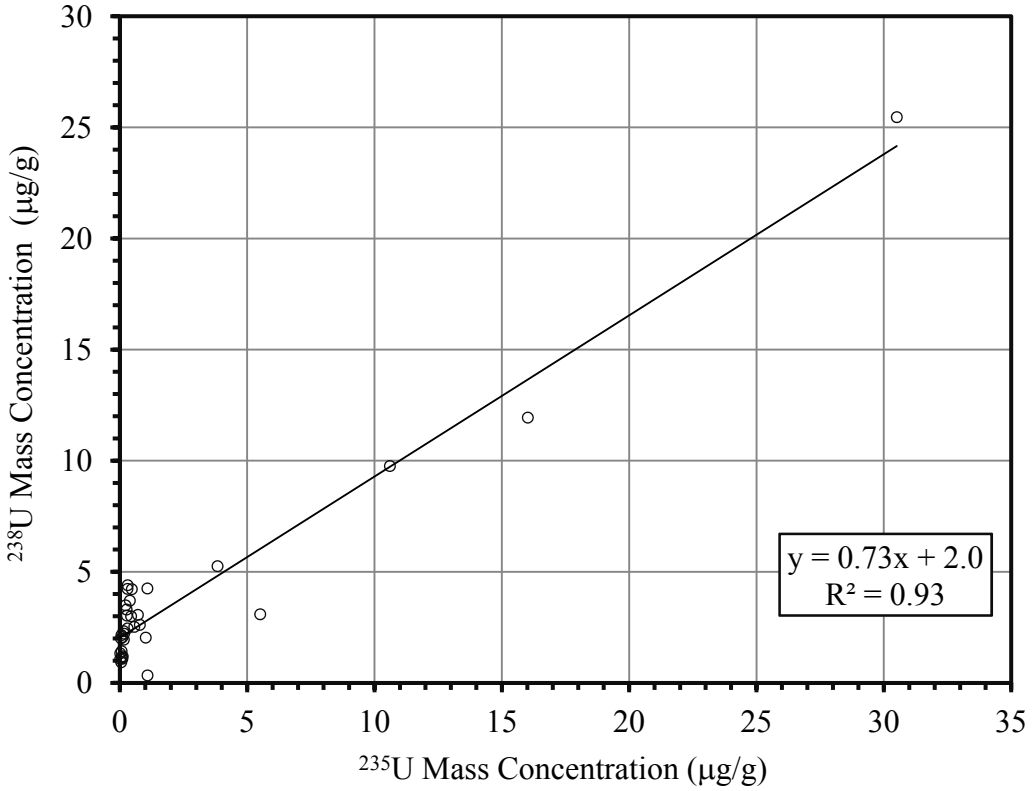

Figure A-21. Regression of ^{238}U to ^{235}U from Mass Spectrometry on Site Evaluation Samples.

5. Evaluation of Final Site Status.

a. Comparison to Soil Screening Levels and ResRad-Calculated EMC Levels for Survey Unit 1. Table A-12 contains a comparison of Survey Unit 1 residual soil concentrations to the SSLs. The table is an update to Table 6-2 of the Site Evaluation report (USACE et al. 2010), supplemented with post excavation sample results. Updated values from the Site Evaluation are shown in red. For evaluation of the mean concentration of uranium in the entire survey unit, there has been no change in soil samples used for this evaluation, except that α-spectroscopy results have been used for the calculation instead of γ-spectroscopy, and an estimate of the ^{234}U activity concentration. The update for this row, dropped the unity rule term to 63 % of the previous estimate (see Table A-4). Three updates were made for evaluation of AOI #1: the estimated area, area factor, and average concentration in the AOI. The area encompassed by this AOI was set to size of the excavated area, with the area factor from Figure 6-4 of the Site Evaluation report (Figure Annex-3). Due to the excavation, the unity rule term for AOI #1 is much lower than prior to excavation: 0.082 compared to 1.027. Selection of the AOI size for evaluation could have been accomplished in differently. For

TABLE A-12. Survey Unit 1 Comparison to Soil Screening and ResRad-Calculated EMC Levels for Uranium (Updated from TABLE 6-2 of Site Evaluation Report, in Red).

Area of Evaluation	Area (m^2)	Criterion Type	Area Factor	Uranium Criterion (pCi/g)	Uranium Concentration (pCi/g)	Unity Rule ǂ
Entire survey unit (systematic sample mean concentration) α-Spectroscopy (n = 20)	1,964	SSL	1	200	30.5*	0.153
Elevated area (AOI #1) Post removal action sampling α-Spectroscopy (n = 8)	27.5	EMC	3	600	49.1	0.031
Systematic sample Site Evaluation Report (SU1-SS-01) – α-Spectroscopy	1	EMC	13.3	2660	343.5*	0.118
* Value lower than that in Site Evaluation report due to actual ^{234}U concentration rather than estimate. ǂ MARSSIM § 8.5.2 and Equation 8-2.					Sum	0.30

example, the AOI could have included all of the excavation area, plus some surrounding area - perhaps delineated by an additional three feet, or the entire area with in-situ measurements could have been considered. In either case, the area considered under the EMC would have been larger, subsequently providing a lower mean residual uranium concentration, but also a lower area factor, which would essentially be self-compensating in the overall evaluation of the EMC area. If either of these cases were considered, the soil samples would no longer be representative of the area under evaluation, in which case, FIDLER measurements could be used as a surrogate, based on the relationship established by the paired soil sample/FIDLER measurements.

The last row of data in Table A-12 with an update from the Site Evaluation was the area encompassed by the systematic soil sampling location SU1-SS-01. The uranium concentration for this sample was replaced with the α-spectroscopy results, which were lower than the previously reported results that relied on an estimate of the ^{234}U. Also, due to the unremarkable FIDLER scanning results surrounding this soil sampling location in the vicinity of AOI #2, it was deemed appropriate to set the area encompassed by this sampling location to 1 m^2. In the Site Evaluation, the area was arbitrarily set at 100 m^2, the area equivalent to the total area of the survey unit divided by the number of systematic soil samples. This was overly conservative, but was done in the Site Evaluation phase because detailed FIDLER measurements had not been conducted in the area surrounding this sample in that phase of the project. Overall, the updated unity rule sum is 0.36, less than one. As such, due the removal action, this survey unit meets the SSLs selected for this site with ResRad-calculated EMC levels under the MARSSIM approach. Only one soil sample among the 20 systematic soil samples was above the SSL for a survey unit as a whole, with the mean well below the SSL criterion. The survey unit passes the Sign test (MARSSIM Table I.3), which allows four samples to exceed the remediation criterion at the most restrictive α-value, 0.005. It is important to note that the estimated final site status data summarized in Table A-12 is based on a number of conservative assumptions. First, background uranium concentrations were not subtracted from the

reported results. Second, the top soil layer AOI subjected to soil sampling (post excavation) was eventually covered in clean soil, eliminating contributions to dose from the residual uranium in this AOI. Third, FIDLER scanning measurements do not support significant residual contamination in the vicinity of SU1-SS-01 to the degree existing in the sample collected during the Site Evaluation. The concentration of uranium in this sample contributes over 50 % to the mean uranium among the systematic soil samples, and a separate EMC evaluation area. However, because resampling and a subsequently lower sampled soil concentration (an assumption based on FIDLER screening results) for this location would not have changed the conclusion, this measure was not taken. Overall, the latter two conservative assumptions overestimate the unity rule sum by a factor of two.

TCEQ, in consultation with USACE and HQ AFSC/SEW on results documented in the Site Evaluation (USACE et al. 2010) and the EE/CA (USACE and HQ AFSC 2010), requested that final site status be evaluated, based on an individual isotope basis, rather than a 93.3 % HEU isotopic mixture. Table A-13 contains an evaluation using soil sampling data and isotopic-specific SSLs. The results of the evaluation is an overall unity rules sum about 13 % higher than that in Table A-12. However, a background subtraction provides a lower sum, 0.33, only 10 % higher than the 0.30.

TABLE A-13. Survey Unit 1 Comparison to Soil Screening and ResRad-Calculated EMC Levels using Isotopic-Specific SSLs for Uranium.

Area of Evaluation	Isotope	Area (m^2)	Criterion Type	Area Factor	Criterion (pCi/g)	Concentration (pCi/g)		Unity Rules Term ǂ	
						Gross	Net*	Gross	Net
Entire survey unit (system. sample mean concentration)	^{234}U	1,964	SSL	1	270	28.6	28.0	0.106	0.104
	^{235}U				20	1.13	1.10	0.057	0.055
	^{238}U				67	0.83	0.20	0.012	0.003
	$^{Total}U$				-	-	-	0.175	0.162
Elevated area (AOI #1) Post removal action (n = 8)	^{234}U	27.5	EMC	3	810	46.3	45.7	0.022	0.022
	^{235}U				60	1.71	1.68	0.010	0.010
	^{238}U				201	1.16	0.52	0.002	0.002
	$^{Total}U$				-	-	-	0.033	0.033
Systematic sample (SU1-SS-01)	^{234}U	1	EMC	13.3	3591	326.9	326.3	0.083	0.083
	^{235}U				266	13.0	13.0	0.045	0.045
	^{238}U				891	3.6	2.96	0.003	0.003
	$^{Total}U$				-	-	-	0.131	0.131
All						Sum		0.34	0.33

* $^{Total}U$ Background ~ 1.3 pCi/g, $^{234\ or\ 238}U$ = 0.635, ^{235}U = 0.029. ǂ MARSSIM multiple radionuclide unity rule, § 4.3.3 and Equation 4-3, and EMC unity rule, § 8.5.2 and Equation 8-2 (NRC 2000).

b. Comparison to Soil Screening Levels and ResRad-Calculated EMC Levels for Survey Unit 4. Table A-14 contains a comparison of Survey Unit 4 residual soil concentrations to the SSLs. The table is an update to Table 6-3 of the Site Evaluation report (USACE et al. 2010). AOI #2 has an area much larger than noted in the Site Evaluation report, which impacted the area factor and

criterion for this EMC area. The mean uranium concentrations estimate for AOI #2 was lower than the pre-excavation estimate, but provided a higher unity rule term due to the lower area factor incurred with a larger EMC area. A separate EMC area was included for the one isolated area of elevated contamination, though the concentration of uranium in the post excavation sample in the pit was well below the SSL for large areas. Nevertheless, the sum of the unity rules terms was well below one, similar to the pre-excavation estimate. As in the case of Survey Unit 1, some conservatism exists in this estimate. First, the mean uranium soil concentration in the survey unit based on systematic soil samples is biased high, due to the high-sided estimate of ^{234}U. For Survey Unit 1, ^{234}U estimates were about 30 % higher than actual based on α-spectroscopy results. Second, excavated areas were covered with clean fill. Subtraction of background provides a 5 % reduction in the unity rules term for this survey unit based on the displayed difference in the gross and net terms. Because none of the systematic soil samples were above the SSL for the survey unit as a whole, statistical evaluations using either the Sign Test (ignoring background uranium) or the Wilcoxon Rank Sum Test (considering background uranium) were not accomplished as described in MARSSIM, as a survey unit will pass the statistical test if all measurements are below the criterion.

TABLE A-14. Survey Unit 4 Comparison to Soil Screening and ResRad-Calculated EMC Levels for Uranium (Updated from Table 6-3 of Site Evaluation Report).

Area of Evaluation	Isotope	Area (m^2)	Criterion Type	Area Factor	Criterion (pCi/g)	Concentration (pCi/g)		Unity Rules Term ǂ	
						Gross	Net*	Gross	Net
Entire survey unit (system. sample mean concentration)	^{234}U**	1,964	SSL	1	270	34.6	34.0	0.128	0.126
	^{235}U				20	1.06	1.03	0.053	0.052
	^{238}U				67	1.05	0.42	0.016	0.006
	$^{Total}U$				-	-	-	0.197	0.184
Elevated area (AOI #2) Post removal action (n = 5)	^{234}U	36	EMC	2.8	756	126.4	125.8	0.121	0.121
	^{235}U				56	4.52	3.89	0.062	0.051
	^{238}U				188	1.66	1.03	0.003	0.003
	$^{Total}U$				-	-	-	0.186	0.176
Biased sampling location (S4-SS-8N32E)	^{234}U	1	EMC	13.3	3591	33.1	32.5	-4E-4	-4E-4
	^{235}U				266	1.55	0.92	0.002	-4E-4
	^{238}U				891	0.88	0.25	-2E-4	-2E-4
	$^{Total}U$				-	-	-	0.001	-1E-3
All						Sum		0.38	0.36

* $^{Total}U$ Background ~ 1.3 pCi/g, $^{234 \text{ or } 238}U$ = 0.635, ^{235}U = 0.029. ** Estimated. ǂ MARSSIM multiple radionuclide unity rule, § 4.3.3 and Equation 4-3, and EMC unity rule, § 8.5.2 and Equation 8-2 (NRC 2000).

c. Comparison to Soil Screening Levels and ResRad-Calculated EMC Levels for Survey Unit 3. Table A-15 contains a comparison of Survey Unit 3 residual soil concentrations to the SSLs. As expected, due to the drastic reduction in uranium activity concentration effected by the excavation, the sum of the unity rule terms is only about 0.12. As was the case for other survey units, this evaluation has some built-in conservatism. ^{234}U is biased-high in the case the mean uranium

concentration for the survey unit, AOI #7 was filled with clean cover, and an EMC area was considered in the unity rule calculation, though the residual uranium concentrations in AOI #7 was below the SSL for a large area. Because none of the systematic soil samples were above the SSL for a survey unit as a whole, statistical evaluations using either the Sign Test (ignoring background uranium) or the Wilcoxon Rank Sum Test (considering background uranium) were not accomplished as described in MARSSIM.

TABLE A-15. Survey Unit 3 Comparison to Soil Screening and ResRad-Calculated EMC Levels for Uranium. (Updated from Table 6-4 of Site Evaluation Report).

Area of Evaluation	Isotope	Area (m^2)	Criterion Type	Area Factor	Criterion (pCi/g)	Concentration (pCi/g)		Unity Rules Term ǂ	
						Gross	Net*	Gross	Net
Entire survey unit (system. sample mean concentration)	^{234}U**	1,964	SSL	1	270	10.9	10.3	0.040	0.038
	^{235}U				20	0.34	0.31	0.017	0.016
	^{238}U				67	0.78	0.15	0.011	0.002
	$^{Total}U$				-	-	-	0.068	0.056
Biased sampling location (S8-SS-AOI#7)	^{234}U	1	EMC	13.3	3591	142	141	0.037	0.036
	^{235}U				266	5.52	5.49	0.020	0.020
	^{238}U				891	1.88	1.25	0.001	0.001
	$^{Total}U$				-	-	-	0.057	0.057
All						Sum		0.13	0.12

* $^{Total}U$ Background ~ 1.3 pCi/g, $^{234\ or\ 238}U$ = 0.635, ^{235}U = 0.029. ** Estimated. ǂ MARSSIM multiple radionuclide unity rule, § 4.3.3 and Equation 4-3, and EMC unity rule, § 8.5.2 and Equation 8-2 (NRC 2000).

6. Groundwater Discussion.

a. Site Conditions. The Site Investigation workplan (HQ AFSC et al. 2009) contained detailed descriptions of the geological setting of the site, surface waters in Taylor County where the site is located, sub-surface waters, and soil conditions at the site. [Note: efforts conducted under this workplan were later described as a "site evaluation," as the AF chose to follow a NTCRA process]. There are neither major surface water flows in the vicinity of the site nor major sub-surface aquifers beneath the site. As well, Taylor County does not contain any minor aquifers according to the Texas Water Development Board (TWDB). Because of the vital issue of water resources to the State, 96 groundwater conservation districts exist, but none currently in Taylor County. Most of the productive aquifers in Taylor County are derived from alluvial depositions that encompass about 20% of the total area of the county (Taylor 1978). The Vale Formation, which comprises the geology underlying the accident site, has little utilization of groundwater because it is believed to occur only in small, thin sandstone lenses of low permeability (Taylor 1978). Groundwater in this area is generally encountered at about 13 feet below ground level, but is not generally used as a source of potable water due to its high salinity. The City of Abilene derives most of its water from surface sources - some from outside Taylor County. The TWDB has record of a small number of wells in Taylor County Vale Formation; of two in current use, water is derived from depths of about

40 feet, under low flow rates, and used for livestock (TWDB 2009). Because uranium is generally an insoluble contaminant under common soil conditions it has limited mobility. Depth distribution profiling of the uranium contaminant was accomplished at a number of the biased soil sampling locations during the Site Evaluation. Samples collected at depth of 1 to 2 feet had total estimated uranium concentration between 9 and 46 % of the concentrations in samples from the upper foot of soil. As such, due to these factors groundwater contamination was not believed to a concern for this site. In the workplan, the site was assessed to be a Class 3 groundwater source.

b. SPLP Results. The SPLP results accomplished at a biased sampling location in AOI #2, Survey Unit 4, demonstrated the low portioning of uranium in leachate compared to soil. As discussed above, the estimated K_d of 2,450 ml/g is well below default values used in ResRad and by the EPA in soil screening guidance for radionuclides (EPA 2000). The SPLP test leachate uranium mass concentrations were 9.2 % of the SDWA MCL of 30 μg/L. While the SDWA does not have an MCL for uranium developed on a radiation dose basis (i.e., activity concentration vice mass concentration), one was proposed by the EPA in 1991. A dose-based criterion would provide a basis for protection against cancer risks. Table A-11 contains committed effective dose equivalent (CEDE) values for consumption of water at a rate of 2 L/d using dose conversion factors of Federal Guidance Report (FGR) 11 [EPA 1988]. CEDE values are contained in the table for DAFs of one and 20. The EPA recommended a DAF of 20 using a "weight of evidence" approach, noting that it was protective for sources up to 0.5 acre (2,023.5 m^2) in size (EPA 2000). This area is slightly larger than the individual area of Survey Units 1 - 5, 1964 m^2. The soil sample used in the SPLP analysis represented one of the highest among the 20 post-excavation soil samples, with a total activity concentration of 137.3 pCi/g. However, the activity concentration in the soil sample was significantly higher than mean activity concentration of surface soils in Survey Unit 4, and other survey units, as listed in Table A-16. Therefore, while the uranium leachate concentration is applicable to the small area encompassed by AOI #2, it is inappropriate to broadly apply the results to a single survey unit or the site as a whole due to the significantly lower mean uranium activity concentrations in soils for these entities.

TABLE A-16. Fraction of Mean $^{Total}U$ in Survey Units to $^{Total}U$ in S4-SS-32N40E.

Survey Unit	Method	Mean $^{Total}U$ Activity Concentration (pCi/g) [Table A-2]	Fraction of Mean $^{Total}U$ Activity Concentration in Survey Units to $^{Total}U$ in S4-SS-32N40E
1	α-Spec	30.5	0.222
2	γ-Spec	7.26	0.053
3	γ-Spec	12.0	0.087
4	γ-Spec	36.7	0.267
5	γ-Spec	4.34	0.032
6	γ-Spec	3.13	0.023
7	γ-Spec	6.09	0.044
8	γ-Spec	10.81	0.079

CEDEs for consumption of water with uranium concentrations one-twentieth (DAF = 20) of the leachate concentrations are well below 4 mrem, which is similar, but not equivalent, to the current SDWA dose-based criterion for β–particle and photon emitters. This provides a reasonable basis for evaluation of the leachate concentrations to human consumption from a radiation dose-based approach and could be considered a relevant and appropriate requirement under the National Contingency Plan (NCP) [40 CFR 300.430(d)(3)] for groundwater in lieu of an existing MCL in the SDWA. However, it is important to note that:

1) the current SDWA does not have a radiological dose-based MCL for uranium, and
2) the evaluation method recognized for β–particle and photon emitters uses NBS Handbook 69, which for this purpose is essentially equivalent to International Commission on Radiological Protection (ICRP) Publication 2, *Permissible Dose for Internal Radiation,* published in 1959.

The recommendations in Publication 2 were replaced by those in Publication 30, initially released in part in 1979. FGR 11 uses ICRP 30 annual limits on intakes (ALIs), with a few exceptions.

c. EPA Consultation Triggers. While the radiological contaminants at this site are not regulated by the Nuclear Regulatory Commission (NRC), the EPA and NRC developed a Memorandum of Understanding (MOU) for Atomic Energy Act (AEA) sites under the jurisdiction of both the NRC and EPA under its CERCLA authority. While the contaminants at this site are AEA radioactive materials, but outside NRC regulatory authority, the MOU (Cook 2002) provides some useful information on application of CERCLA to radioactively contaminated sites that are not on the National Priorities List (NPL) or under Resource Conservation Recovery Act (RCRA) Corrective Action. The MOU contained the following consultation triggers:

1) NRC determines residual levels in groundwater will exceed SDWA MCLs, or
2) residual levels in soils will exceed the soil concentrations in "MOU Table 1: Consultation Triggers for Residential and Commercial/Industrial Soil Contamination," or
3) NRC contemplates that future use of the site will be restricted by conditions contained in the license termination (as specified in 10 CFR 20.1403), or
4) NRC contemplates the use of alternative criteria for license termination (i.e., a site-specific dose greater than the NRC's primary dose limit of 25 mrem/yr).

Consultation triggers for uranium isotopes are listed in Table Annex-9. Mean concentrations of residual uranium in survey units at this site are well below these consultation triggers.

7. TCEQ Soils Sample Analyses.

a. General. TCEQ collected soils samples in four separate locations: around AOI#1, around AOI#2, around AOI#7, and a general area of elevated contamination southwest of AOI#2. The latter area was in Survey Unit 7 (see Figure A-1). In addition, a vegetation sample was collected in same general area as that for soil samples collection in Survey Unit 7. The results of the analyses are contained in Table Annex-10. The State's laboratory analyzed the samples by γ-spectroscopy and α-spectroscopy for isotopic uranium. For each soil sampling location, the sample was comprised of five sub-aliquots: one center aliquot and four equidistant from the center, forming a square with 10 meter spacing per side.

b. Comparison to Air Force Sample Results. As noted earlier in the appendix, TCEQ chose to sample at depths of 0 to 6 and 6 to 12 inches, with separate analyses for each sample. A split of each TCEQ sample was provided to the Air Force. The Air Force had EDI composite the two samples for analysis, or essentially an average over the top 12 inches. This process made the samples comparable to those collected by the Air Force, which were averaged over the top 12 inches. Table A-17 contains a comparison of TCEQ α-spectroscopy analyses to AF composited sample results. The TCEQ results contain some important characteristics worth noting. The uranium isotopic mixture was similar to that obtained by the Site Evaluation phase sample analyzed by USAFSAM and post remedial action samples analyzed by Test America, as displayed in Figure A-20. The only exception to close agreement was sample S0-01-A, which appears to be a slight outlier in comparison to other results plotted. The ratio of ^{234}U in the upper layer of soil compared to the lower is highly varied among the samples, with the ratios being 1.5, 0.88, 10, and 3.1 in order from top to bottom in Table A-17. Figure A-22 contains a scatterplot of the ^{234}U, ^{235}U, and total uranium activity concentrations based on the α-spectroscopy results as analyzed by the Air Force, listed in Table A-17, to the mean of the two sampling depths, as analyzed by TCEQ. Among the four samples, S4-SS-AOI#2 had the closest agreement in all three parameters compared, while S1-SS-AOI#1 had the greatest discrepancy, with the TCEQ results about 1.7-fold higher for the ^{234}U and total uranium, and two-fold higher for the ^{235}U than the samples analyzed for the Air Force by Test America. The discrepancy between the results from the two labs on this sample is outside normal variability expected from the random nature of radioactive decay (e.g., counting uncertainties). As discussed earlier, heterogeneity in the contaminant was obvious based on comparison of ^{235}U, as reported by α-spectroscopy and γ-spectroscopy analyses on post removal action samples (Figure A-19). As discussed earlier in this Appendix, multiple aliquot analyses by α-spectroscopy from the same samples from another historical explosives dispersion of uranium to the environment exhibited similar characteristics. This is clearly displayed in Figure Annex-2 (top plot), where there is a two-fold ratio between the total uranium in the two aliquots. The differences between the ^{235}U evaluated by α-spectroscopy and γ-spectroscopy for S1-SS-AOI#1, as analyzed by both laboratories was explored. The mean ^{235}U in the 0 - 6 and 6 - 12 inch depth samples was 16.3 and 12.7 pCi/g,

TABLE A-17. TCEQ Composite Soil Sample Results Compared to Air Force Composite Analyses.

USAF Sample Identification	Depth (inches)	TCEQ α-Spectroscopy (pCi/g)			Air Force α-Spectroscopy (pCi/g)		
		^{234}U	^{235}U	^{238}U	^{234}U	^{235}U	^{238}U
S4-SS-AOI#2 (Split)	0 - 6	106 ± 12	3.8 ± 0.8	1.6 ± 0.4	102 ± 12	3.6 ± 0.5	1.8 ± 0.3
	6 - 12	71 ± 8	3.7 ± 0.7	1.4 ± 0.3			
S8-SS-AOI#7 (Split)	0 - 6	15 ± 2	0.6 ± 0.2	0.8 ± 0.2	20 ± 2	0.7 ± 0.2	0.8 ± 0.2
	6 - 12	17 ± 2	0.5 ± 0.2	0.7 ± 0.2			
S1-SS-AOI#1 (Split)	0 - 6	657 ± 79	30 ± 5	5.5 ± 0.9	217 ± 18	8.0 ± 0.9	1.7 ± 0.3
	6 - 12	65 ± 8	2.6 ± 0.6	1.3 ± 0.7			
S4/7-SS-General (Split)	0 - 6	44 ± 5	1.8 ± 0.5	2.2 ± 0.5	20 ± 2	0.9 ± 0.2	1.0 ± 0.2
	6 - 12	14 ± 2	0.6 ± 0.2	1.0 ± 0.3			

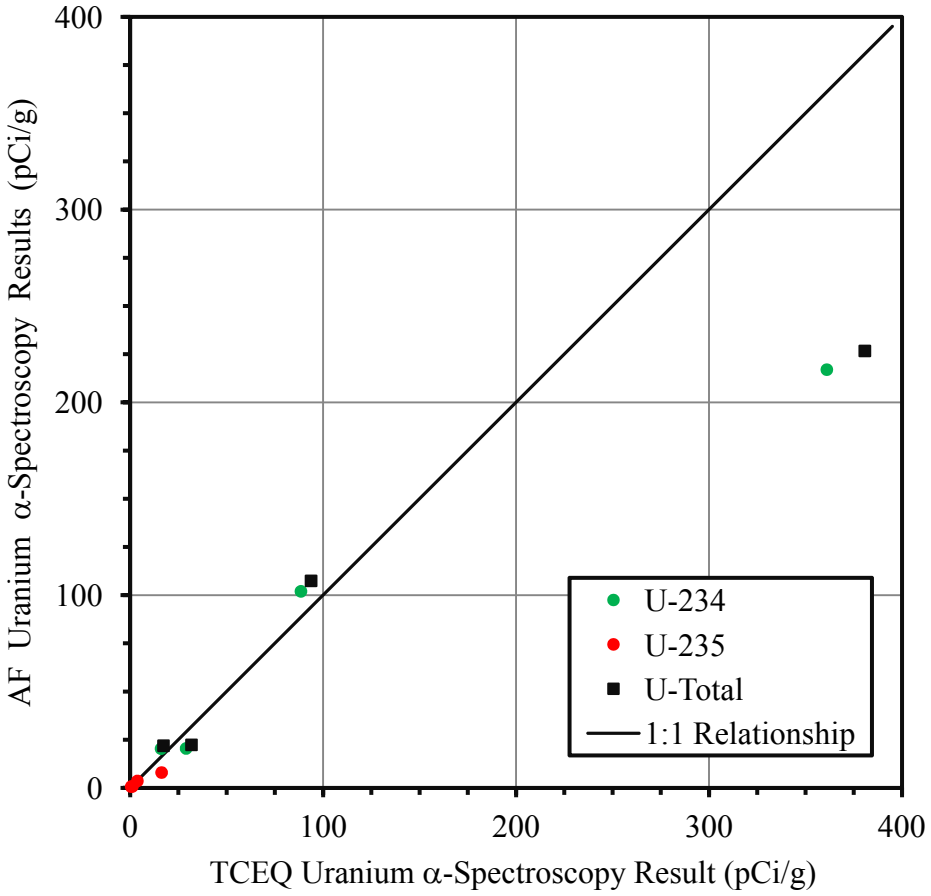

Figure A-22. Scatterplot of α-Spectroscopy Results for Split Samples Analyzed by Air Force and Texas Commission on Environmental Quality.

respectively, for α- and γ-spectroscopy analyses by the State laboratory. For the Test America analyses, the results were 7.4 and 8.0 pCi/g, respectively, for α- and γ-spectroscopy methods. The α-spectroscopy result was 28.3 % higher than the γ-spectroscopy result for the TCEQ analysis, while for the Test America analyses, it was 7.5 % lower. This result could be indicative of the effects of heterogeneity. A regression analysis was performed for ^{235}U activity concentrations in the TCEQ samples by the α- and γ-spectroscopy methods, as shown in Figure A-23. With the exception of one data point, seven samples had good agreement with the fitted line of the linear regression, though the regression suggests a factor of 1.3 bias between the two methods. The discrepancy was a little greater than that of an identical comparison of Test America data (Figure A-19), which had a ratio of 1.25. For this data set, the bias is opposite, with the α-spectroscopy results lower on average compared to the γ-spectroscopy results. The S1-SS-AOI#1 analyses results are annotated in both plots (data markers green-filled). This sample had the highest ratio in uranium activity concentrations (total and individual isotopes) between the 0 - 6 and 6 - 12 inch samples, which also supports the contention that this sampling area had heterogeneously-distributed contaminant.

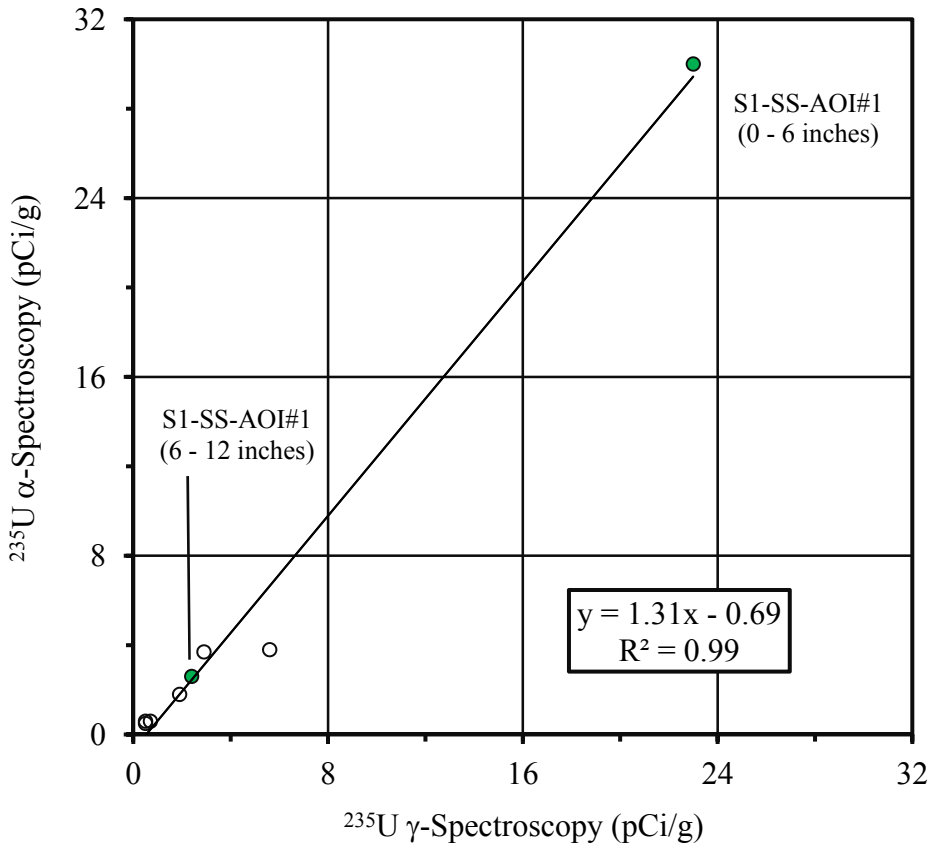

Figure A-23. Regression of α-Spectroscopy vs. γ-Spectroscopy Analyses for ^{235}U in Texas Commission on Environmental Quality Analyzed Soil Samples.

b. Vegetation Sample Results. The analytical results for the one vegetation sample is contained in Table Annex-10. Due to the low activity concentration in the sample, the γ-spectroscopy analysis did not identify emission lines for ^{235}U and ^{238}U isotopes. As well, due to the low activity concentrations, the α-spectroscopy analysis had high fractional uncertainties for ^{234}U, ^{235}U, and ^{238}U, though ^{234}U comprised about 80 % of the total uranium activity concentration. The dominance of ^{234}U among the other uranium isotopes is expected, as this isotope was also dominant in the soils in this area. The ratio of ^{234}U in the vegetation sample to the average ^{234}U in the TCEQ soil sample collected by TCEQ in this area was 0.0017. The ResRad default plant to soil concentration ratio is 0.001 for uranium. In light of the high degree of uncertainties in the estimated ratio from this sample, continued use of the ResRad default parameter for soil to plant transfer of uranium is deemed appropriate.

c. Conclusions from TCEQ Sample Analyses.

1) General. The comparison of results between TCEQ and Test America analyses of split samples were reasonable for this type of environmental contaminant. The isotopic mixture for the samples as a whole were comparative the theoretical expectations and the results from two other laboratories. One sampling location had a 1.7-fold difference between the total uranium activity

concentration quantified by the two laboratories, however, there was an expectation for impacts of heterogeneity on field measurements and sample analyses for contaminants released to the environment from this type of accident circumstance. Both laboratories had bias between α- and γ-spectroscopy results for ^{235}U analyses. The magnitude of the bias observed is not uncommon for evaluation of environmental samples, where photon interaction characteristics in soil matrices are unlikely to match that of the instrument calibration standards in density and/or elemental composition.

2) Impact on Conclusions Drawn by AF. The five-point sampling method used by TCEQ to evaluate activity concentrations in AOI's followed a different approach than that used by the AF for evaluation of the survey units as a whole and elevated measurement comparison areas. All four TCEQ sampling locations used this method, which by TCEQ design encompass 100 m^2. For each location sampled, the comparative value of the composite sampling results to the AF assessment of the AOI was varied. Further, the ResRad modeling used by the AF to established area factors for this contaminant and support the SSL developed under EPA-540-R-00-006-TBD (EPA 2000a), used a 12 inch (0.3 m) contaminant thickness, while TCEQ collected samples from 0 to 6 and 6 to 12 inch depths. Based on discussions with Robert Beleckis, Radioactive Materials Division, Office of Waste, TCEQ, this sampling method is commonly used by their division in evaluation of residual contaminants at radium and uranium mining sites in the State. Table A-18 provides a comparison of soil sampling results for each of the AOIs evaluated by TCEQ. For AOIs #2 and #6, the contamination was more diffusely-distributed based on the site evaluation as compared that in AOIs #1 and #7 that had more localized contamination, justifying the use of EMC evaluations. For AOIs #2 and #6, the analytical results for the TCEQ composite samples were in good agreement with the analytical results from AF sampling in the respective AOIs. For AOI#6, the average uranium activity concentration between TCEQ and AF analyses of the TCEQ split sample was 27.1 pCi/g,

TABLE A-18. Comparison of Texas Commission on Environmental Quality Composite Sampling Results to AF Sampling Results in Areas of Interest (AOI).

AOI	Description	Area (m^2) [Source]	^{Total}Uranium Activity Concentration (pCi/g) [α-Spectroscopy]			
			TCEQ Composite*		AF Sampling	
			TCEQ	AF	Value	Number
#1	Localized area of contamination in Survey Unit 1	27.5 [TABLE A-12]	381	226.7	49.1	8
#2	Diffusely contaminated area in Survey Unit 4	36 [TABLE A-14]	93.8	107.5	132.5	5
#7	Highly localized area of contamination in Survey Unit 8	1 [TABLE A-15]	17.3	21.9	149.4	1
#6***	Diffusely contaminated area in Survey Unit 7 chosen by TCEQ for sampling [S4/7-SS-General]	Not assigned (further evaluation not recommended by Site Evaluation)	31.8	22.4	29.7**	1

* Averaged over top 12 inches (30 cm) ** γ-Spectroscopy result with estimated ^{234}U, based on ^{234}U:^{235}U ratio of 33:1
*** Location identified in Figures 5-6 & 5-15, with data from TABLE 5-3 of Site Evaluation (USACE et al. 2010)

while the result for a sample collected by the AF in this AOI during the site evaluation was 29.7 pCi/g. The latter is biased high due an estimate of the ^{234}U activity concentration rather than a measurement by α-spectroscopy. For AOI #2, the average uranium activity concentration between TCEQ and AF analyses of the TCEQ split sample was 101 pCi/g, while the average activity concentration among the five AF samples collected in the AOI was 132.5 pCi/g. The latter average activity concentration is deemed to be higher than the former due to sampling completely with the AOI, while the four outer sub-aliquots of the TCEQ sample would have been on the outside of this area, where activity concentrations of the contaminant would have been lower.

For AOI #7, the AF collected a soil sample with the excavation pit to evaluate residual contamination in this EMC area, while only one of the sub-aliquots of the TCEQ sample was collected from the excavation. Four sub-aliquots of the TCEQ composite sample for this AOI would have contributed negligible activity to the composite due to the highly localized nature of this contaminated location. This is clear from examination of the results, the AF sample had an activity concentration about 7-fold higher than the average activity concentration reported between the AF and TCEQ analyses of the TCEQ composite sample. For this AOI, the sampling method implemented by TCEQ was destined to underestimate the residual activity in this AOI.

For AOI #1, a significant disparity existed between the AF's estimate of residual activity concentration in the AOI compared to that of the TCEQ composite sample, regardless of whether the TCEQ or Air Force split sample analytical result was compared. Like AOI#2, due to the fact that the AOI is smaller than the 100 m^2 area encompassed by the TCEQ sub-aliquot sample spacing, it would be possible that a composite sample could have an average activity concentration lower than the average of the eight samples collected by the AF in the AOI. However, due to the highly localized nature of the contaminant distribution in this area, the results of the sampling using the TCEQ approach is highly dependent on the selection of the central sub-aliquot sampling point. For this AOI, the point was chosen by a careful scanning of the AOI by TCEQ with a FIDLER, and selection of the location that provided the highest instrument response. The response was not significantly higher that readings recorded in Table A-8 according to Mr. Robert Beleckis. In fact, the 9 ft^2 (~ 1 m^2) area encompassing this sampling point had a systematic grid location FIDLER reading of 5,565 counts (Table A-8), below many of the other post-excavation systematic grid readings in this AOI. It is our best judgment that the central sub-aliquot sampling location chosen by TCEQ had highly localized contamination, with substantially lower uranium activity concentrations is adjacent soils. This position is supported by the many field measurements collected at the site.

a) The sample for AOI #1 was collected in an area not subject to excavation, and therefore would have had a contaminant deposition pattern dictated by accident conditions, which for this AOI was highly heterogeneous, as illustrated by the distribution of pre-excavation FIDLER readings displayed in Table A-6. In contrast, contamination found below the top 6 inches of the surface would have been more uniformly distributed if it had been mixed by some plowing of the site that was accomplished a few times post accident, and/or chemical dissolution and re-distribution of the contaminant to soils at greater depth. As noted earlier in the Appendix and referenced in the Site Investigation workplan (HQ AFSC et al. 2009), other projects with similar circumstances exhibited this characteristic. The 1957 nuclear weapon accident in Albuquerque, NM, involved the detonation of high explosives and dispersal of DU. At this accident site, a few locations in close proximity to the impact/detonation location contained highly-isolated uranium contamination in the

top inch of soil that had a yellow color, presumed to be U_3O_8. It was believed that the material had slowly oxidized over the interceding years, yet due to inactivity at this site and low rainfall observed in Albuquerque, the material did not disperse to a significant degree in adjacent soils. The Abilene site receives greater rainfall and subsequently an expectation for greater contaminant migration to adjacent soils. Nevertheless, the fact that the soil sample from the 6 to 12 inch depth layer (directly below the sample from the top 6 inches) had a total uranium activity concentration one tenth that of the upper layer, makes it entirely plausible that lateral migration would have been limited - creating a small area with contamination much greater in concentration than that in adjacent soils.

b) Pre-excavation contaminant concentrations in biased soil sampling locations within AOI #1 had very high activity concentrations. Table A-19 contains analytical results for biased soil samples collected within this AOI during the Site Evaluation phase. The depth of these samples was 12 inches. Two of the four biased samples had activity concentrations considerable higher than the average for the TCEQ composited sample for this AOI. In the case of the two biased samples with the highest total predicted uranium activity concentration, they had associated high FIDLER readings, indicative that the sampling locations had some reasonably high adjacent contamination.

TABLE A-19. Analytical Results for Biased Soil Samples Collected During Site Evaluation in AOI#1. Laboratory Data from TABLE C-1 of Site Evaluation Report (USACE et al. 2010).

Base Sample Number	AFIOH/ SDRR ID	Sample Number	FIDLER Reading (cpm)	γ-Spectroscopy (pCi/gm) [95 % CI - 1.96σ]							Total Predicted Uranium (pCi/g)
				Th-234			U-235			U-234*	
				Value	Uncertainty	MDC	Value	Uncertainty	MDC	Predicted	
GS100134	11000133	SU1-BS-1A	11636	2.48	0.26	0.56	6.28	0.15	0.034	207.2	216
GS100137	11000136	SU1-BS-2A	43524	2.99	0.23	0.99	30.2	0.52	0.042	996.6	1030
GS100139	11000138	SU1-BS-3A	11705	2.54	0.25	0.46	3.50	0.09	0.029	115.5	122
GS100141	11000140	SU1-BS-4A	126000	2.13	0.25	1.29	52.5	0.87	0.053	1732.5	1787

* ^{234}U based on ^{234}U:^{235}U ratio of 33:1

c) FIDLER readings paired to post excavation soil sampling results provides an important insight into the areal extent of the contamination surrounding the central sub-aliquot sampling location of TCEQ's sample in this AOI. Figures Annex-4 and -5 contain regression plots of ^{235}U activity concentrations in soils samples to paired FIDLER measurements, respectively, for α- and γ-spectroscopy methods. As anticipated, due to the effects of heterogeneity and variations in contaminant depth distribution characteristics, the regression analysis with the γ-spectroscopy method provided better correlation than that by the α-spectroscopy method. Using the slope and intercept from these regression analyses, predicted FIDLER readings for these areas is provided, under the assumption that contaminant concentrations are relatively consistent in the measurement area. All of the predicted FIDLER readings are much higher than FIDLER measurements on the systematic grid (listed in Table A-8), and are contradictory to the conclusion that this sample is representative of contamination in this AOI or the 9 ft^2 grid cell where the sample was collected. The predicted FIDLER reading for the TCEQ split is consistent with a few pre-excavation FIDLER measurements that contained reasonably high FIDLER measurements in adjacent 9ft^2 grid cells.

TABLE A-20. Predicted FIDLER Response for Various ^{235}U Activity Concentration in Surface Soils Averaged Over to 12 inches for TCEQ Samples for AOI #1.

^{235}U Activity Concentration (pCi/g)	Analytical Method	Split Sample	Linear Regression Parameters		Predicted FIDLER Reading (counts in 30 seconds)
			Slope (pCi/g/counts)	Intercept (pCi/g)	
16.3	α-Spec	TCEQ	0.0013	- 5.4	16,692
8	α-Spec	AF	0.0013	- 5.4	10,308
7.42	γ-Spec	AF	0.0019	- 8.3	8,274

In summary, while the analytical results for the TCEQ composite sample for AOI #1 are reasonable based on heterogeneity observed in field measurements and laboratory analyses, the results for this sample are not as representative of residual contamination in AOI#1 as the mutually-supporting measurements conducted by the AF, comprised of:

i eight systematic grid samples collected in the AOI,
ii FIDLER screening conducted by the AF, and
iii FIDLER measurements on the systematic grid.

As such, the contamination concentration observed in this sample is unlikely to encompass an area in proportion to a square meter, which is the smallest modeling area considered in ResRad for outdoor areas. The only significant exposure pathways for contamination in 1 m^2 areas in the ResRad modeling for the uranium contamination at this site were inhalation and external radiation (called "ground" in ResRad). However, it clear that the external radiation dose rates expected for an area contaminated to the extent sample of the TCEQ composite sample for AOI #1 are directly contradicted by the FIDLER measurement for this grid cell. It is important to note that this sample had a mass of 322.4 g, and with an assumed density of 1.6 g/cm^3, only represents 0.13 % of the soil in a 1 m^2 area, while an in-situ FIDLER measurement is much more representative of residual contamination levels in an area of this size.

d) Table A-21 contains an evaluation of the Survey Unit 1 using the MARSSIM unity rule with the TCEQ analytical result for AOI #1. As the ResRad dose modeling was accomplished for residual contamination averaged over the top 12 inches (30 cm), the average results from the two TCEQ samples was used in the calculation. The unity rule summation for either gross or net uranium contamination was below the unity rule of 1.

8. ResRad Calculations. At the request of TCEQ, Annex 3 contains ResRad modeling data from the Site Evaluation Report (USACE et al. 2010). ResRad modeling was performed primarily to augment EPA SSLs in the calculation of area factors for assessment of EMC areas. ResRad summary tables are from Appendix G of the Site Evaluation Report. Table G-1 contains modeling results for a 93.3 % HEU contaminant. Water-dependent pathways were not predicted to produce significant dose to a site residents. At the 1000 year modeling point, the dose-equivalent was only 0.204 mrem in a year, and completely from water-dependent pathways (i.e., groundwater). For consistency with risk-based EPA SSLs, Table G-4 provides a tabular summary of cancer morbidity

TABLE A-21. Survey Unit 1 Comparison to Soil Screening and ResRad-Calculated EMC Levels for Uranium (Modified from Table A-13 - AOI #1 Evaluated with TCEQ Sample S0-02-A&B [0 - 12 in]).

Area of Evaluation	Isotope	Area (m^2)	Criterion Type	Area Factor	Criterion (pCi/g)	Concentration (pCi/g)		Unity Rules Term ǂ	
						Gross	Net*	Gross	Net
Entire survey unit (system. sample mean concentration)	^{234}U	1,964	SSL	1	270	28.6	28.0	0.106	0.104
	^{235}U				20	1.13	1.10	0.057	0.055
	^{238}U				67	0.83	0.20	0.012	0.003
	$^{Total}U$				-	-	-	0.175	0.162
Elevated area (AOI #1) Post removal action	^{234}U	27.5	EMC	3	810	361	360	0.410	0.411
	^{235}U				60	16.3	16.3	0.252	0.253
	^{238}U				201	3.4	2.77	0.013	0.013
	$^{Total}U$				-	-	-	0.675	0.677
Systematic sample (SU1-SS-01)	^{234}U	1	EMC	13.3	3591	326.9	326.3	0.083	0.083
	^{235}U				266	13.0	13.0	0.045	0.045
	^{238}U				891	3.6	2.96	0.003	0.003
	$^{Total}U$				-	-	-	0.131	0.131
All						Sum		0.98	0.97

* $^{Total}U$ Background ~ 1.3 pCi/g, $^{234\ or\ 238}U$ = 0.635, ^{235}U = 0.029. ǂ MARSSIM multiple radionuclide unity rule, § 4.3.3 and Equation 4-3, and EMC unity rule, § 8.5.2 and Equation 8-2 (NRC 2000).

risk values that were used to calculate the area factors that are plotted in Figure Annex-3. Table G-3 provides a tabular summary of dose modeling values for various contaminated area sizes. Table G-2 lists the key parameters used in the ResRad modeling. For all of the modeling documented in the Site Evaluation report, the uranium soil/water partition coefficient, K_d, was set at 50 mL/g, the ResRad default for this parameter. A new modeling run was completed with a K_d of 2,450 ml/g, based on the estimate provided by the SPLP analysis on soil sample S4-SS-32N40E. Figure Annex 6 contains a plot of the total dose-equivalent for a 10,000 m^2 contaminated area for the two partitioning coefficients over time. As expected, the predicted dose-equivalent levels for the higher partitioning coefficient do not decrease as rapidly over time compared to predicted levels for the lower coefficient due to higher predicted retention in the soil matrix. As well, due to the higher predicted retention, water-dependent pathways had a very small dose-equivalent level for soil with the higher predicted partitioning coefficient compared to the lower default value used. A copy of the ResRad summary report for the new modeling run is provided in Annex-3.

References:

Cook, Michael B., "Distribution of Memorandum of Understanding between EPA and the Nuclear Regulatory Commission," Office of Solid Waste and Emergency Response, OSWER No. 9295.8-06a, Environmental Protection Agency, Washington D.C., 09 October 2002.

EPA, "Soil Screening Guidance for Radionuclides: Technical Background Document," Report No. 540-R-00-006, Office of Indoor Air, Office of Solid Waste and Emergency Response, Environmental Protection Agency, Washington, D.C., October 2000.

EPA, "Radionuclides Notice of Data Availability Technical Support Document," Office of Ground Water and Drinking Water in collaboration with Office of Indoor Air and Radiation, and US Geological Survey, Environmental Protection Agency, Washington, D.C., March 2000.

EPA, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," Report No. 520/1-88-020, Office of Radiation Programs, Environmental Protection Agency, Washington, D.C., September 1988.

HQ Air Force Safety Center, USAF School of Aerospace Medicine, HQ ACC, 7th Civil Engineering Squadron, US Army Corp of Engineers (Omaha District), "Workplan, Site Investigation, B-47 Crash Site, Dyess AFB, TX," December 2009.

NRC, "Multi-Agency Radiation Survey and Site Investigation Manual," Nuclear Regulatory Commission, NUREG-1575, Revision 1, August 2000.

Rademacher, S.E., "Technical Guidebook to Permitting, Investigations, and Remedial Actions on Air Force Section 91b Radiological Sites," 2nd Ed., Report, IOH-SD-BR-SR-2007-0002, Air Force Institute for Operational Health, Brooks AFB TX, 28 March 2008.

Rademacher, S.E., Shaw, D.A., and Renaghan, B., "Interim Radiological Scoping and Characterization Survey Report, 1963 Igloo 572 Accident, Lackland Training Annex, Lackland AFB, Texas, Air Force Institute for Environment, Safety and Occupational Health Risk Analysis, Special Report, IERA-SD-BR-SR-2002-0001, Brooks AFB TX, March 2002.

Taylor, H.D., "Occurrence, Quantity, and Quality of Ground Water in Taylor County, Texas," Texas Department of Water Resources, Report 224, October 1978.

US Army Corp of Engineers (Omaha District) and HQ Air Force Safety Center, "Engineering Evaluation/Cost Analysis, B-47 Crash Site, Dyess AFB, TX," 3 November 2010.

US Army Corp of Engineers (Omaha District), HQ Air Force Safety Center, USAF School of Aerospace Medicine, HQ ACC, 7th Civil Engineering Squadron, "Site Evaluation Report, B-47 Crash Site, Dyess AFB, TX," 1 November 2010.

Annex 1
To
Appendix A

Data Files Tables and Figures

(This Page Intentionally Left Blank)

TABLE Annex-1. Alpha and γ-Spectroscopy Results for Survey Unit 1 Soil Samples from Site Evaluation Phase [γ-Spectroscopy Results Previously Reported in Site Evaluation Report (USACE et al. 2010)].

AFIOH/ SDRR ID	Sample Number	γ-Spectroscopy (pCi/gm) [95 % CI - 1.96σ]								α-Spectroscopy (pCi/gm) [95 % CI - 1.96σ]							
		Th-234			U-235			U-234 Predicted*	Total Uranium	U-234		U-235		U-238		Chemical Recovery	Total Uranium
		Value	Uncertainty	MDC	Value	Uncertainty	MDC			Value	Uncertainty	Value	Uncertainty	Value	Uncertainty		
11000001	SU1-SS-01	2.23	0.29	0.67	12.7	0.26	0.03	419.1	434.0	326.9	28.92	12.97	1.47	3.6	0.54	1.07	343.5
11000001	SU1-SS-01 (DUP)	2.23	0.31	0.68	13.2	0.3	0.04	435.6	451.0	383.3	33.81	15.49	1.7	4.38	0.62	1.02	403.2
11000002	SU1-SS-02	1.5	0.2	0.37	2.27	0.08	0.028	74.9	78.7	34.05	3.3	1.22	0.31	0.91	0.24	1.03	36.2
11000003	SU1-SS-03	1.21	0.21	0.32	0.60	0.060	0.027	19.8	21.6	10.09	1.07	0.4	0.15	0.49	0.16	1.21	11.0
11000004	SU1-SS-04	0.81	0.16	0.31	0.48	0.03	0.024	15.8	17.1	14.93	1.47	0.41	0.18	0.65	0.18	1.18	16.0
11000005	SU1-SS-05	1.37	0.18	0.38	0.597	0.056	0.023	19.7	21.7	19.54	1.88	0.87	0.23	0.86	0.21	1.13	21.3
11000006	SU1-SS-06	0.72	0.2	0.39	1.73	0.088	0.022	57.1	59.5	22.21	2.13	0.67	0.21	0.58	0.17	1.16	23.5
11000007	SU1-SS-07	0.295	0.25	0.35	0.521	0.054	0.031	17.2	18.0	8.74	1.02	0.41	0.17	0.57	0.18	1.1	9.7
11000008	SU1-SS-08	1.05	0.18	0.37	0.971	0.063	0.021	32.0	34.1	11.28	1.2	0.44	0.16	0.65	0.18	1.05	12.4
11000009	SU1-SS-09	0.75	0.44	0.36	0.492	0.059	0.02	16.2	17.5	7.89	1.1	0.25	0.15	0.64	0.22	0.75	8.8
11000010	SU1-SS-10	1.26	0.20	0.39	1.24	0.051	0.023	40.9	43.4	21.48	2.19	1.15	0.29	0.9	0.23	0.97	23.5
11000011	SU1-SS-11 (DUP)	1.66	0.35	0.42	1.74	0.093	0.023	57.4	60.8	25.02	2.37	0.85	0.23	0.83	0.21	1.1	26.7
11000011	SU1-SS-11	1.2	0.20	0.41	1.44	0.088	0.023	47.5	50.2	25.04	3.33	1.26	0.41	0.74	0.28	0.56	27.0
11000012	SU1-SS-12	0.66	0.17	0.38	1.15	0.049	0.021	38.0	39.8	19.04	1.9	0.79	0.23	0.75	0.2	1.1	20.6
11000013	SU1-SS-13	0.42	0.12	0.30	0.0435	0.062	0.020	1.4	1.9	0.46	0.15	< 0.07		0.42	0.15	1.34	1.0
11000014	SU1-SS-14	0.95	0.17	0.36	0.439	0.027	0.020	14.5	15.9	6.05	0.75	0.37	0.15	0.63	0.19	1.06	7.1
11000015	SU1-SS-15	1.50	0.26	0.34	1.36	0.054	0.026	44.9	47.7	5.88	0.73	0.23	0.12	0.88	0.22	1.09	7.0
11000016	SU1-SS-16	1.72	0.18	0.35	1.02	0.043	0.026	33.7	36.4	21.4	2.18	0.39	0.17	1.08	0.26	1.05	22.9
11000017	SU1-SS-17	1.23	0.15	0.31	0.475	0.055	0.025	15.7	17.4	10.19	1.12	0.42	0.16	0.8	0.21	1.13	11.4
11000018	SU1-SS-18	1.34	0.23	0.34	0.454	0.028	0.029	15.0	16.8	0.59	0.19	< 0.08		0.3	0.14	0.99	1.0
11000019	SU1-SS-19	0.556	0.093	0.23	0.0326	0.073	0.104	1.1	1.7	3.68	0.52	0.17	0.1	0.57	0.17	1.15	4.4
11000020	SU1-SS-20	0.79	0.17	0.28	0.176	0.017	0.023	5.8	6.8	2.18	0.41	0.11	0.09	0.6	0.19	0.92	2.9
	**Mean =	1.1	NA	NA	1.4	NA	NA	46.5	49.0	28.6	NA	1.13	NA	0.83	NA	NA	30.5

* Based on a ^{234}U to ^{235}U Ratio of 33:1

** Duplicate Analyses Values Omitted from Calculation

TABLE Annex-2. Coordinates for AOI #1 Survey Grid.

(Latitude-Coordinates)

North-South (feet)	0	3	6	9	12	15	18	21	24	27	30	33	36	39
27	32.3642784	32.3642731	32.3642678	32.3642625	32.3642572	32.3642519	32.3642466	32.3642413	32.3642360	32.3642307	32.3642254	32.3642200	32.3642147	32.3642094
24	32.3642713	32.3642661	32.3642608	32.3642556	32.3642504	32.3642451	32.3642399	32.3642346	32.3642294	32.3642242	32.3642189	32.3642137	32.3642085	32.3642032
21	32.3642642	32.3642590	32.3642538	32.3642487	32.3642435	32.3642383	32.3642332	32.3642280	32.3642228	32.3642177	32.3642125	32.3642073	32.3642022	32.3641970
18	32.3642571	32.3642520	32.3642469	32.3642418	32.3642367	32.3642316	32.3642265	32.3642214	32.3642163	32.3642112	32.3642061	32.3642010	32.3641959	32.3641908
15	32.3642499	32.3642449	32.3642399	32.3642349	32.3642298	32.3642248	32.3642198	32.3642147	32.3642097	32.3642047	32.3641997	32.3641946	32.3641896	32.3641846
12	32.3642428	32.3642379	32.3642329	32.3642279	32.3642230	32.3642180	32.3642131	32.3642081	32.3642031	32.3641982	32.3641932	32.3641883	32.3641833	32.3641784
9	32.3642357	32.3642308	32.3642259	32.3642210	32.3642161	32.3642112	32.3642064	32.3642015	32.3641966	32.3641917	32.3641868	32.3641819	32.3641770	32.3641721
6	32.3642286	32.3642237	32.3642189	32.3642141	32.3642093	32.3642045	32.3641997	32.3641948	32.3641900	32.3641852	32.3641804	32.3641756	32.3641707	32.3641659
3	32.3642214	32.3642167	32.3642119	32.3642072	32.3642024	32.3641977	32.3641930	32.3641882	32.3641835	32.3641787	32.3641740	32.3641692	32.3641645	32.3641597
0	32.3642143	32.3642096	32.3642050	32.3642003	32.3641956	32.3641909	32.3641862	32.3641816	32.3641769	32.3641722	32.3641675	32.3641629	32.3641582	32.3641535

East-West (feet)

(Longitude-Coordinates)

North-South (feet)	0	3	6	9	12	15	18	21	24	27	30	33	36	39
27	99.8520753	99.8520718	99.8520684	99.8520649	99.8520614	99.8520579	99.8520545	99.8520510	99.8520475	99.8520440	99.8520406	99.8520371	99.8520336	99.8520302
24	99.8520870	99.8520835	99.8520800	99.8520764	99.8520729	99.8520694	99.8520659	99.8520624	99.8520589	99.8520553	99.8520518	99.8520483	99.8520448	99.8520413
21	99.8520986	99.8520951	99.8520915	99.8520880	99.8520844	99.8520809	99.8520773	99.8520737	99.8520702	99.8520666	99.8520631	99.8520595	99.8520560	99.8520524
18	99.8521103	99.8521067	99.8521031	99.8520995	99.8520959	99.8520923	99.8520887	99.8520851	99.8520815	99.8520779	99.8520743	99.8520707	99.8520671	99.8520635
15	99.8521220	99.8521183	99.8521147	99.8521111	99.8521074	99.8521038	99.8521001	99.8520965	99.8520928	99.8520892	99.8520856	99.8520819	99.8520783	99.8520746
12	99.8521336	99.8521300	99.8521263	99.8521226	99.8521189	99.8521152	99.8521115	99.8521079	99.8521042	99.8521005	99.8520968	99.8520931	99.8520894	99.8520858
9	99.8521453	99.8521416	99.8521379	99.8521341	99.8521304	99.8521267	99.8521230	99.8521192	99.8521155	99.8521118	99.8521081	99.8521043	99.8521006	99.8520969
6	99.8521570	99.8521532	99.8521494	99.8521457	99.8521419	99.8521381	99.8521344	99.8521306	99.8521268	99.8521231	99.8521193	99.8521155	99.8521118	99.8521080
3	99.8521686	99.8521648	99.8521610	99.8521572	99.8521534	99.8521496	99.8521458	99.8521420	99.8521382	99.8521344	99.8521305	99.8521267	99.8521229	99.8521191
0	99.8521803	99.8521764	99.8521726	99.8521687	99.8521649	99.8521610	99.8521572	99.8521533	99.8521495	99.8521456	99.8521418	99.8521379	99.8521341	99.8521302

East-West (feet)

TABLE Annex-3. Coordinates for AOI #1 Survey Grid.

AOI #2 (Latitude-Coordinates)										
North-South Latitude (feet)	56	32.36430874	32.36432030	32.36433185	32.36434341	32.36435496	32.36436652	32.36437807	32.36438963	32.36440118
	48	32.36429116	32.36430284	32.36431453	32.36432622	32.36433791	32.36434959	32.36436128	32.36437297	32.36438465
	40	32.36427357	32.36428539	32.36429721	32.36430903	32.36432085	32.36433267	32.36434449	32.36435631	32.36436813
	32	32.36425599	32.36426794	32.36427989	32.36429184	32.3643038	32.36431575	32.3643277	32.36433965	32.3643516
	24	32.3642384	32.36425049	32.36426257	32.36427466	32.36428674	32.36429882	32.36431091	32.36432299	32.36433508
	16	32.36422082	32.36423304	32.36424525	32.36425747	32.36426969	32.3642819	32.36429412	32.36430633	32.36431855
	8	32.36420323	32.36421558	32.36422793	32.36424028	32.36425263	32.36426498	32.36427733	32.36428968	32.36430203
	0	32.36418565	32.36419813	32.36421061	32.36422309	32.36423558	32.36424806	32.36426054	32.36427302	32.3642855
		0	8	16	24	32	40	48	56	64
		East-West Longitude (feet)								

AOI #2 (Longitude-Coordinates)										
North-South Latitude (feet)	56	99.85265655	99.85263530	99.85261404	99.85259279	99.85257154	99.85255028	99.85252903	99.85250777	99.85248652
	48	99.85264203	99.85262087	99.85259971	99.85257855	99.85255739	99.85253623	99.85251507	99.85249391	99.85247274
	40	99.85262752	99.85260645	99.85258538	99.85256431	99.85254324	99.85252217	99.85250111	99.85248004	99.85245897
	32	99.852613	99.85259203	99.85257105	99.85255007	99.8525291	99.85250812	99.85248715	99.85246617	99.85244519
	24	99.85259849	99.8525776	99.85255672	99.85253584	99.85251495	99.85249407	99.85247318	99.8524523	99.85243142
	16	99.85258397	99.85256318	99.85254239	99.8525216	99.85250081	99.85248002	99.85245922	99.85243843	99.85241764
	8	99.85256946	99.85254876	99.85252806	99.85250736	99.85248666	99.85246596	99.85244526	99.85242456	99.85240387
	0	99.85255494	99.85253433	99.85251373	99.85249312	99.85247252	99.85245191	99.85243130	99.85241070	99.85239009
		0	8	16	24	32	40	48	56	64
		East-West Longitude (feet)								

TABLE Annex-4. Post-Excavation FIDLER Reading in AOI #1 with Pre-Excavation Readings on Grid Locations without a Post-Excavation Reading.

Post-Excavation Readings in Areas Subject to Excavation (Yellow Highlighted). Excavation Area Approximately 33 yd^2 (27.5 $m^{2)}$. Post-Excavation Readings in Areas not Disturbed by Excavation (Green Highlighted). Pre-Excavation Readings in Undisturbed Areas (Unhighlighted). [30-second integrated counting period]

North-South Latitude (feet)															
	27			4532	4456	4801	4594	4439	4525						
	24	4444	4535	4779	4949	4888	4672	4681	4523	4633	4555	4502	4556	4473	4442
	21	4670	4869	5300	5563	5103	5571	5107	4638	4564	4706	4721	4572	4634	4435
	18	4908	5301	6088	6066	6045	5655	7373	5071	4849	4870	4640	4611	4535	4440
	15	4845	5560	6023	5860	5725	5719	5389	5912	5692	5155	4758	4399	4472	4402
	12	4858	5194	5945	6018	5659	5649	5986	5597	5041	5089	5030	4423	4358	4457
	9	4318	4421	4689	6005	5303	5047	5497	5370	5560	5330	5885	4756	4457	4449
	6	4325	4498	4537	4811	5023	6222	6227	5666	5530	6020	6623	5565	4708	4504
	3	4466	4411	4456	4436	4716	4932	5048	5919	6073	5873	4911	4915	5381	4803
	0	4286	4490	4588	4503	4430	4502	4548	4688	4686	4698	4471	4554	4585	4439
		0	3	6	9	12	15	18	21	24	27	30	33	36	39
		East-West Longitude (feet)													

Grid location, N6 - E33, outline-bolded, was the center point for the TCEQ composite sampling for this survey unit. A split, composited sample was shared with the Air Force, S1-SS-AOI#1.

TABLE Annex-5. Post-Excavation FIDLER Reading in AOI #2 with Pre-Excavation Readings on Grid Locations without a Post-Excavation Reading.

Post-Excavation Readings in Areas Subject to Excavation (Yellow Highlighted). Large Excavation Area Approximately 43 yd^2 (36 m^2). Post-Excavation Readings in Areas not Disturbed by Excavation (Green Highlighted). Pre-Excavation Readings in Undisturbed Areas (Unhighlighted). [30-second integrated counting period].

North-South Latitude (feet)										
	56	4534	4697	4990	5009	4789	4647	4683	4474	3605
	48	5733	4965	5305	5766	5863	5907	5318	5093	3611
	40	5105	5351	5687	5973	6925	6949	6145	6026	3901
	32	5315	5228	5554	6009	7128	8388	6548	7331	4688
	24	5239	5199	5314	5670	6050	7155	6432	6272	5085
	16	5186	7308	4867	5262	5673	6599	5754	7154	3884
	8	4871	4658	4670	4809	5442	4905	5274	5880	4326
	0	4508	4460	4571	4717	4908	5085	4841	5129	4209
		0	8	16	24	32	40	48	56	64
		East-West Longitude (feet)								

TABLE Annex-6. Soil Sampling Log.

No.	Identification No.	Sample Type	Coordinates		Sampling Notes
			Latitude	Longitude	
1	S1-SS-6N9E	Systematic Grid in AOI#1	32.36421411	99.85214567	Sample locations on systematic grid used to collect in-situ FIDLER measurements of AOI#1. Spacing established to generate 8 samples. Samples were collected by EDI to a depth of 30 cm.*
2	S1-SS-6N27E	Systematic Grid in AOI#1	32.3641852	99.85212307	
3	S1-SS-12N27E	Systematic Grid in AOI#1	32.36419819	99.85210049	
4	S1-SS-12N21E	Systematic Grid in AOI#1	32.36420811	99.85210786	
5	S1-SS-12N15E	Systematic Grid in AOI#1	32.36421802	99.85211522	
6	S1-SS-12N9E	Systematic Grid in AOI#1	32.36422794	99.85212259	
7	S1-SS-18N9E	Systematic Grid in AOI#1	32.36424177	99.85209951	
8	S1-SS-18N18E	Systematic Grid in AOI#1	32.36422647	99.85208871	
9	S5-SS-POND	Random Location, Pond Basin	32.36493677	99.85260871	EDI-collection to depth of 30 cm.
10	S4-SS-8N32E	Biased in ROI#2, Hot-Spot	32.36425263	99.85248666	
11	S4-SS-16N40E	Systematic Grid in AOI#2	32.3642819	99.85248002	Sample locations on systematic grid used to collect in-situ FIDLER measurements of AOI#2. Spacing established to generate 5 samples. Samples were collected by EDI to a depth of 30 cm.* Sample #12 chosen for SPLP analysis in addition to alpha spectroscopy planned for all samples, based on recommendation by Mr. Gary Beyer, TCEQ, to select a sample in the area of greatest residual contamination for analysis.
12	S4-SS-32N40E	Systematic Grid in AOI#2	32.36431575	99.85250812	
13	S4-SS-40N40E	Systematic Grid in AOI#2	32.36433267	99.85252217	
14	S4-SS-32N56E	Systematic Grid in AOI#2	32.36433965	99.85246617	
15	S4-SS-24N56E	Systematic Grid in AOI#2	32.36432299	99.8524523	
16	S8-SS-AOI#7	Biased in AOI#7, Hot-Spot	32.363972	99.852503	EDI-collection to depth of 30 cm.*
17	S4-SS-AOI#2	5-Point Composite	32.3642819	99.85248002	Composite sampling locations established by TCEQ around excavations areas. Sub-sampling locations on corners of a 10 m x 10m square, with the center sub-sampling location at the area of highest in-situ detector response. TCEQ composited 0 - 15 cm and 15 - 30 cm samples, and prepared splits for Air Force analysis. EDI composited the separate samples into a single split, averaged over a depth of 30 cm.*
18	S8-SS-AOI#7SPLIT	5-Point Composite	32.363972	99.852503	
19	S1-SS-AOI#1	5-Point Composite	32.36417557	99.85211553	
20	S4/7-SS-General	5-Point Composite	32.36413101	99.85263905	Similar method to sample numbers 17, 18, and 19, but in an un-excavated area with higher in-situ measurements within vicinity of the impact/detonation location. Area selected by TCEQ for sampling.

SPLP Sampling Location

* Samples collected in excavated area were collected prior to placement of clean fill.

TABLE Annex-7. Radioanalysis Results for Removal Action Soil Samples.

No.	Identification Number	α–Spectroscopy (pCi/g)								γ–Spectroscopy (pCi/g)			
		U-234		U-235		U-238		Total		K-40		U-235	
		Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty
1	S1-SS-6N9E	22.6	2.1	0.96	0.23	1.04	0.22	24.6	2.1	11.3	1.7	1.23	0.38
2	S1-SS-6N27E	81.2	7.1	2.82	0.44	1.15	0.24	85.2	7.1	13.7	1.9	3.73	0.65
3	S1-SS-12N27E	11.3	1.2	0.4	0.15	0.55	0.16	12.3	1.2	11.1	2.2	0.61	0.32
4	S1-SS-12N21E	41.1	3.7	1.53	0.32	1.19	0.25	43.8	3.7	10.6	1.7	1.67	0.51
5	S1-SS-12N15E	38.4	3.5	1.44	0.3	1.13	0.23	41.0	3.5	9.8	1.5	1.47	0.36
6	S1-SS-12N9E	37.5	3.4	1.21	0.26	1.1	0.23	39.8	3.4	12.2	1.9	1.75	0.45
7	S1-SS-18N9E	77.9	6.8	3.08	0.48	1.77	0.31	82.8	6.8	10.8	2.1	3.77	0.64
8	S1-SS-18N18E	60.1	5.3	2.25	0.39	1.33	0.26	63.7	5.3	14.6	2.1	2.76	0.57
9	S5-SS-POND	0.65	0.17	0.01	0.026	0.72	0.18	1.38	0.2	18.6	2.4	0.4	0.11
10	S4-SS-8N32E	33.1	3.0	1.55	0.3	0.88	0.19	35.5	3.0	11.8	1.6	1.94	0.41
11	S4-SS-16N40E	133	11	5.09	0.66	1.98	0.33	140.1	11.0	12.1	1.9	7.95	0.85
12	S4-SS-32N40E	131	11	4.61	0.64	1.66	0.31	137.3	11.0	10.5	1.7	7.7	1
13	S4-SS-40N40E	212	18	7.66	0.91	2.05	0.34	221.7	18.0	10.9	2.1	5.37	0.73
14	S4-SS-32N56E	93.1	8	3.23	0.48	1.49	0.27	97.8	8.0	11.4	1.7	5.85	0.81
15	S4-SS-24N56E	62.7	5.5	2.0	0.36	1.11	0.22	65.8	5.5	13.6	2.0	2.74	0.62
16	S8-SS-AOI#7	142	12	5.52	0.56	1.88	0.29	149.4	12.0	12.1	1.8	4.76	0.67
17	S4-SS-AOI#2	102	8.8	3.64	0.53	1.81	0.31	107.5	8.8	13.3	2.0	5.2	0.74
18	S8-SS-AOI#7SPLIT	20.4	1.9	0.67	0.19	0.84	0.2	21.9	1.9	10.5	1.7	1.03	0.42
19	S1-SS-AOI#1	217	18	8	0.92	1.7	0.29	226.7	18.0	14.9	2	7.42	0.92
20	S4/7-SS-General	20.5	1.9	0.86	0.22	1.0	0.22	22.4	1.9	8.6	1.5	1.24	0.38

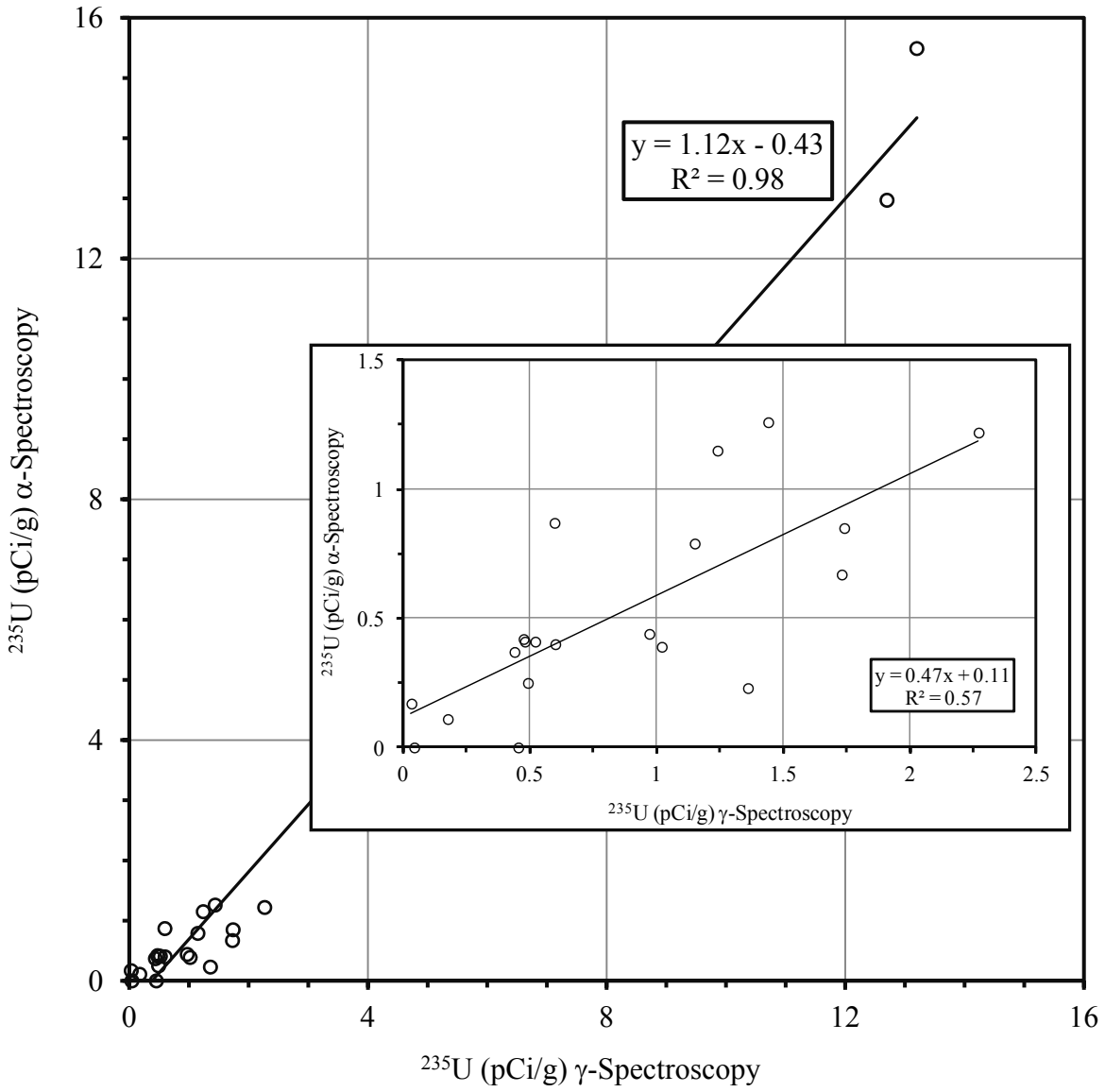

Figure Annex-1. Regression of α-Spectroscopy vs. γ-Spectroscopy Analyses for ^{235}U in Site Evaluation Soil Samples [Inset Contains Plot and Separate Regression for Low Values].

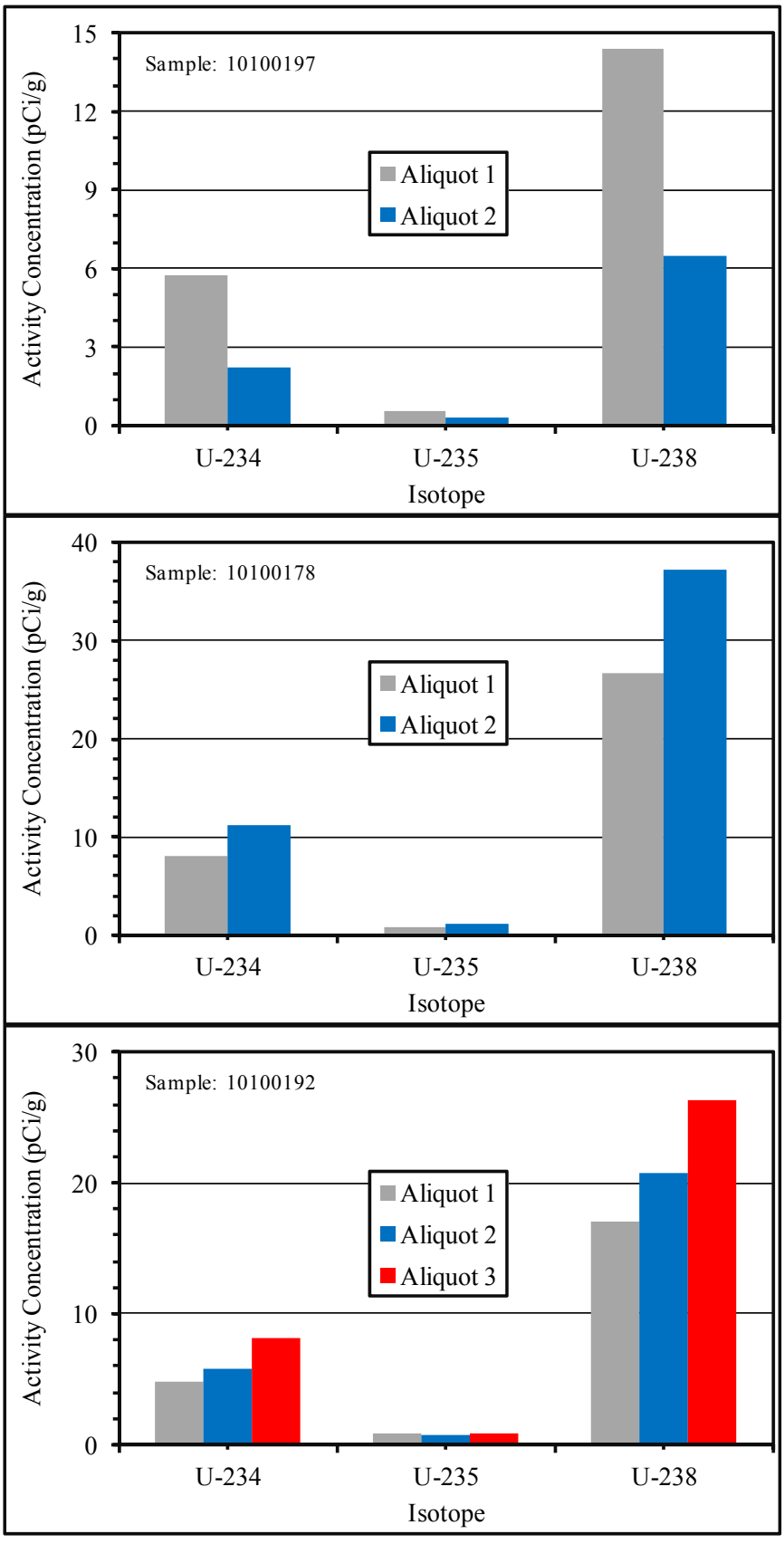

Figure Annex-2. Isotopic Mixtures of Uranium in Three Soil Samples Collected at Medina Annex Site Impacted By Depleted and Natural Uranium Dispersed by Conventional Explosives Detonation in 1963, as Analyzed by α-Spectroscopy, Data from Rademacher et al. (2002).

TABLE Annex-8. Mass Spectrometry Analysis Results from Site Evaluation.

Base Sample Number	AFIOH/ SDRR ID	Survey Unit	Sample Number	Mass Spectrometry ppm	
				U-235	U-238
GS100001	11000001	1	SU1-SS-01	3.83	5.25
GS100002	11000002	1	SU1-SS-02	0.564	2.52
GS100003	11000003	1	SU1-SS-03	0.263	3.30
GS100004	11000004	1	SU1-SS-04	0.073	1.13
GS100005	11000005	1	SU1-SS-05	0.303	4.40
GS100006	11000006	1	SU1-SS-06	0.782	2.61
GS100007	11000007	1	SU1-SS-07	0.155	1.95
GS100008	11000008	1	SU1-SS-08	0.271	3.03
GS100009	11000009	1	SU1-SS-09	0.298	4.23
GS100010	11000010	1	SU1-SS-10	0.467	4.22
GS100011	11000011	1	SU1-SS-11	0.438	3.00
GS100012	11000012	1	SU1-SS-12	0.705	3.06
GS100013	11000013	1	SU1-SS-13	0.013	1.33
GS100014	11000014	1	SU1-SS-14	0.104	2.06
GS100015	11000015	1	SU1-SS-15	0.220	3.49
GS100016	11000016	1	SU1-SS-16	0.389	3.70
GS100017	11000017	1	SU1-SS-17	0.144	2.33
GS100018	11000018	1	SU1-SS-18	0.013	1.08
GS100019	11000019	1	SU1-SS-19	0.060	2.15
GS100020	11000020	1	SU1-SS-20	0.040	2.01
GS100061	11000061	4	SU4-SS-01	0.066	1.43
GS100062	11000062	4	SU4-SS-02	0.071	1.16
GS100067	11000067	4	SU4-SS-07	0.301	2.45
GS100069	11000069	4	SU4-SS-09	1.08	0.338
GS100074	11000074	4	SU4-SS-14	0.107	1.20
GS100135	11000134	1	SU1-BS-1B	0.162	2.21
GS100136	11000135	1	SU1-BS-1C	0.050	0.931
GS100137	11000136	1	SU1-BS-2A	10.6	9.76
GS100138	11000137	1	SU1-BS-2B	1.01	2.04
GS100139	11000138	1	SU1-BS-3A	1.08	4.25
GS100140	11000139	1	SU1-BS-3B	0.097	1.090
GS100141	11000140	1	SU1-BS-4A	16.0	11.9
GS100142	11000141	1	SU1-BS-4B	5.51	3.09
GS100143	11000142	1	SU1-BS-05	30.5	25.5

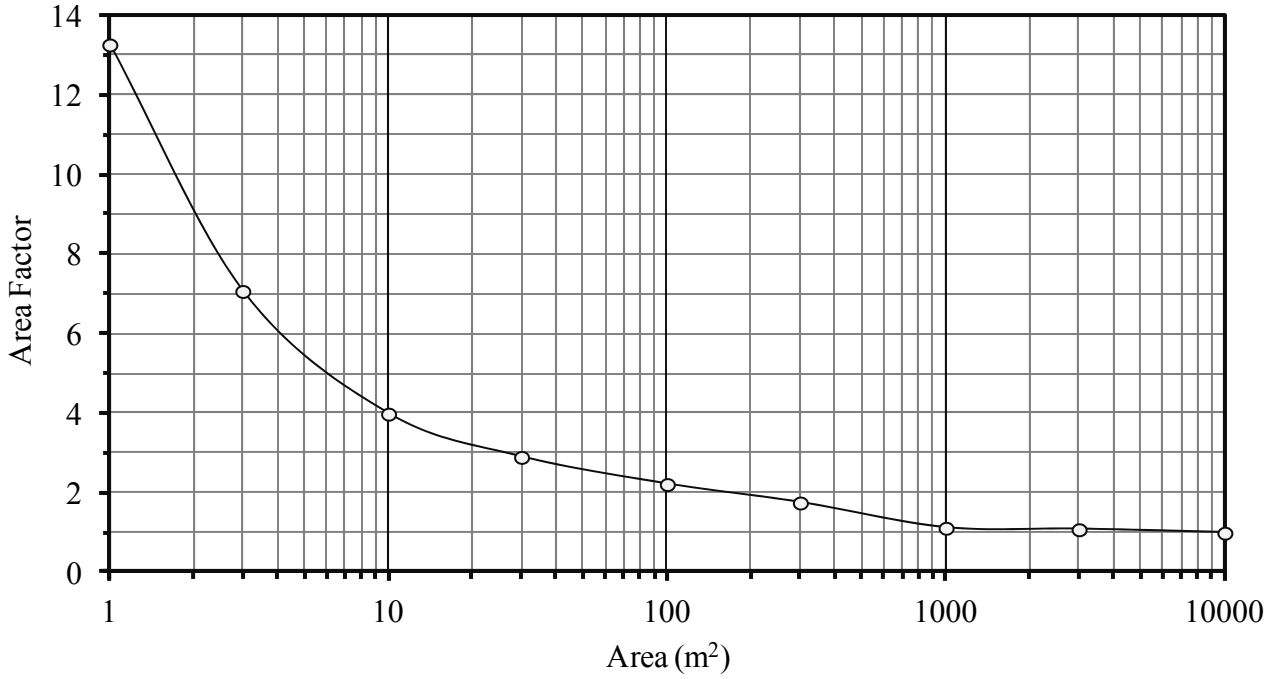

Figure Annex-3. Plot of Area Factors from Site Evaluation Report (USACE et al. 2010).

TABLE Annex-9. Consultation Triggers for Residential and Commercial/Industrial Soil Contamination with Uranium Isotopes (Cook 2002).

Radionuclide	Soil Concentration (pCi/g)	
	Residential	Industrial/Commercial
^{234}U	401	3,310
^{235}U + daughters	20	39
^{238}U + daughters	74	179
Total uranium	47 mg/kg	1,230 mg/kg
Moderately-depleted uranium*	19 (47 mg/kg)	200 (500 mg/kg)
Highly-enriched uranium (93.3 %)*	257 (3.7 mg/kg)	953 (14 mg/kg)

* For isotopic mixtures from Rademacher (2008).

TABLE Annex-10. Radioanalysis Results for Samples Collected by Texas Commission on Environmental Quality.

					α-Spectroscopy (pCi/g)										γ-Spectroscopy (pCi/g)					
No.	Identification Number	Sample Type (USAF Sample Identification)	Coordinates		U-234		U-235		U-238		Total		Uranium (μg/g)		K-40		U-235		U-238	
			Latitude	Longitude	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty
1	S0-01-A (0 - 6 in)	5-Point Composite (S4/7-SS-General Area)	Not Recorded by AF Team	Not Recorded by AF Team	44	5	1.8	0.5	2.2	0.5	48	5.0	7.5	1.5	9.6	1.3	1.9	0.5	2.8	0.8
2	S0-01-B (6 - 12 in)				14	2	0.6	0.2	1	0.3	15.6	2.0	3.4	0.9	10	1	0.7	0.2	< 2.0	
1/2	S0-01-A&B (0 - 12 in)				29	5.4	1.2	0.5	1.6	0.6	31.8	5.4	5.5	1.7	9.8	1.6	1.3	0.5	NA	NA
3	S0-02-A (0 - 6 in)	5-Point Composite (S1-SS-AOI#1)	32.36417557	99.85211553	657	79	30	5	5.5	0.9	692.5	79.2	30	5	12	2	23	2	< 3.3	
4	S0-02-B (6 - 12 in)				65	8	2.6	0.6	1.3	0.7	68.9	8.1	5.1	1.3	14	2	2.4	0.2	< 2.6	
3/4	S0-02-A&B (0 - 12 in)				361	79.4	16.3	5.0	3.4	1.1	380.7	79.6	17.6	5.2	13	2.8	12.7	2.0	NA	NA
5	S0-03-A (0 - 6 in)	5-Point Composite (S4-SS-AOI#2)	32.36430633	99.85243843	106	12	3.8	0.8	1.6	0.4	111.4	12.0	6.6	1.4	12	2	5.6	0.2	< 2.4	
6	S0-03-B (6 - 12 in)				71	8	3.7	0.7	1.4	0.3	76.1	8.0	6.0	1.3	10	1	2.9	0.5	< 2.8	
5/6	S0-03-A&B (0 - 12 in)				88.5	14.4	3.75	1.1	1.5	0.5	93.75	14.5	6.3	1.9	11	2.2	4.25	0.5	NA	NA
7	S0-04-A (0 - 6 in)	5-Point Composite (S8-SS-AOI#7)	32.363972	99.852503	15	2	0.6	0.2	0.8	0.2	16.4	2.0	2.8	0.8	9.1	1.3	0.5	0.2	< 1.5	
8	S0-04-B (6 - 12 in)				17	2	0.5	0.2	0.7	0.2	18.2	2.0	2.4	0.7	11	1	0.5	0.2	< 2.0	
7/8	S0-04-A&B (0 - 12 in)				16	2.8	0.55	0.3	0.75	0.3	17.3	2.9	2.6	1.1	10.05	1.6	0.5	0.3	NA	NA
9	S0-01	Vegetation (S4/7-SS-General Area)	Not Recorded by AF Team	Not Recorded by AF Team	0.05	0.04	0.007	0.007	0.007	0.007	0.064	0.04	0.02	0.02	54					

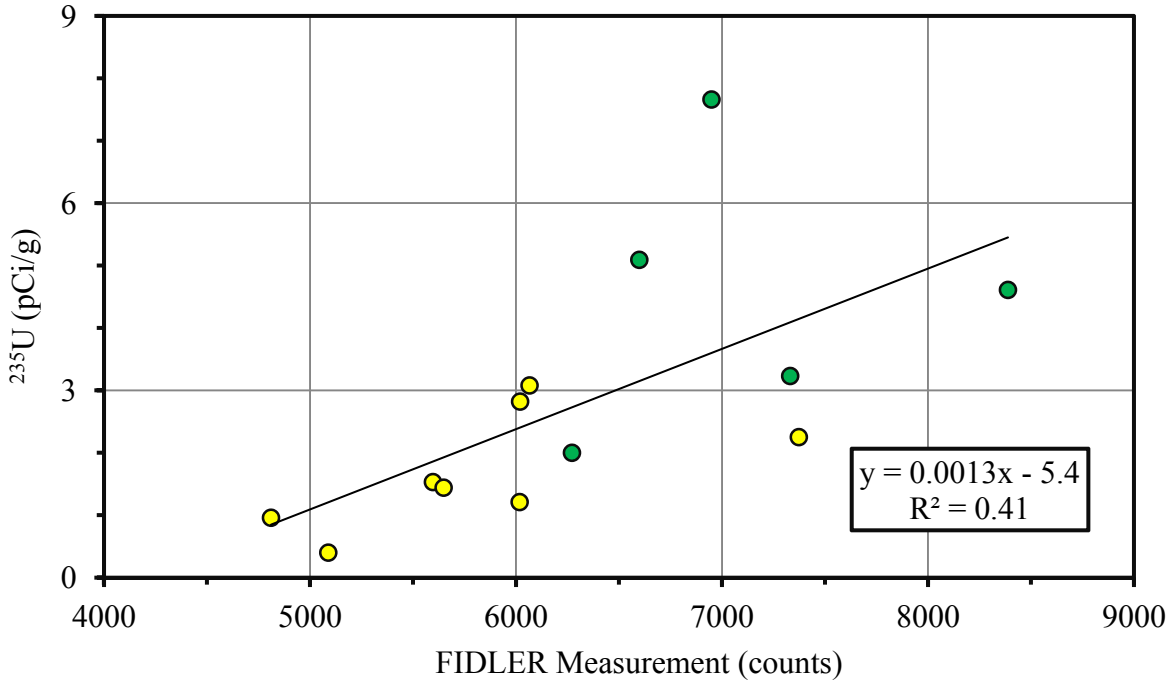

Figure Annex-4. Regression of ^{235}U in Soil (α-Spectroscopy) vs. FIDLER Measurement (AOI #1 Samples in Yellow, AOI #2 Samples in Green).

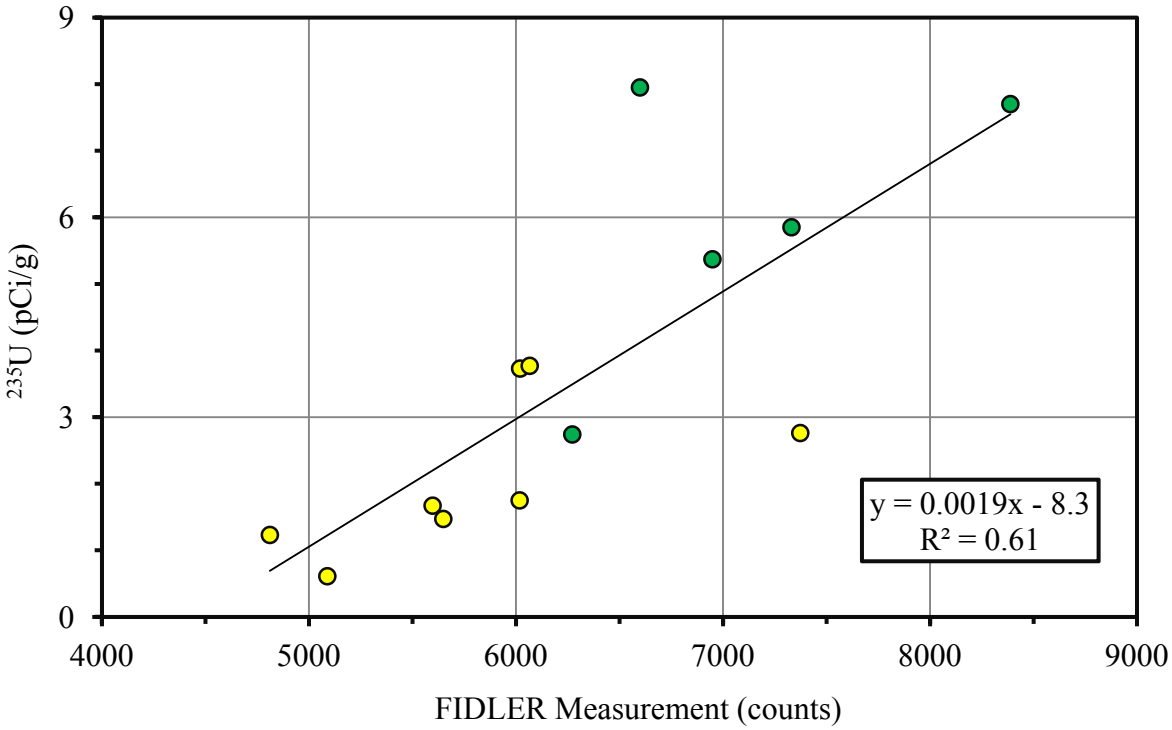

Figure Annex-5. Regression of ^{235}U in Soil (γ-Spectroscopy) vs. FIDLER Measurement (AOI #1 Samples in Yellow, AOI #2 Samples in Green).

(This Page Intentionally Left Blank)

Annex 2
To
Appendix A

Instrument Calibration Documents

(This Page Intentionally Left Blank)

(This Page Intentionally Left Blank)

Annex 3
To
Appendix A

ResRad Modelling

[Tables from Site Evaluation Report, Appendix G]
(USACE et al. 2010)

(This Page Intentionally Left Blank)

TABLE G-1. ResRad Version 6 Dose Modeling Results for 100 pCi/g ^{Tot}U Contaminant, Resident Rancher Scenario (Uranium Isotopic Composition of 93.3 % HEU, Table 2-1).

Time (years)	Exposure Pathways [Dose-Equivalent (mrem/yr)]						
	Ground	Inhalation	Plant	Meat	Milk	Soil	Total
0	1.298	0.835	2.026	0.167	0.421	0.765	5.511
1	1.27	0.815	1.976	0.1633	0.411	0.748	5.384
3	1.215	0.78	1.878	0.152	0.394	0.716	5.139
10	1.041	0.668	1.572	0.134	0.337	0.613	4.365
30	0.67	0.43	0.943	0.086	0.215	0.394	2.738
50	0.432	0.276	0.562	0.137	0.137	0.254	1.717
100	0.145	0.921	0.151	0.018	0.045	0.085	0.536
300	0	0	0	0	0	0	0
1000	0	0	0.015	0.00004	0.00009	0	0.204*
* Drinking water pathway dominant source of dose							

TABLE G-4. ResRad Version 6 Risk Modeling Results for 100 pCi/g ^{Tot}U Contaminant, Resident Rancher Scenario (Uranium Isotopic Composition of 93.3 % HEU, Table 2-1) for Various Contaminated Area Sizes at Time = 0.

Contaminated Area (m^2)	Exposure Pathways (30-Year Cancer Morbidity Risk)							Area Factor
	Ground	Inhalation	Plant	Meat	Milk	Soil	Total	
10000	2.1E-05	3.9E-06	1.5E-05	1.3E-06	3.2E-06	5.7E-06	4.9E-05	1
3000	2.0E-05	3.4E-06	1.5E-05	3.7E-07	9.4E-07	5.7E-06	4.5E-05	1.09
1000	2.0E-05	3.1E-06	15E-05	1.3E-07	3.2E-07	5.7E-06	4.4E-05	1.12
300	1.9E-05	2.7E-06	4.4E-06	3.7E-08	9.4E-08	1.7E-06	2.8E-05	1.8
100	1.8E-05	2.4E-06	1.5E-06	1.3E-08	3.2E-08	5.7E-07	2.2E-05	2.2
30	1.4E-05	2.1E-06	4.4E-07	3.7E-09	9.4E-09	1.7E-07	1.7E-05	2.9
10	1.0E-05	1.9E-06	1.5E-07	1.3E-09	3.2E-09	5.7E-08	1.2E-05	4.0
3	4.8E-06	1.6E-06	4.3E-08	3.7E-10	9.2E-10	1.7E-08	6.9E-06	7.1
1	2.2E-06	1.5E-06	1.5E-08	1.3E-10	3.2E-10	5.7E-09	3.7E-06	13.3
Total Uranium (93.3% HEU) = 204 pCi/g (10,000 m^2) [10^{-4} Cancer Morbidity Risk]								

TABLE G-3. ResRad Version 6 Dose Modeling Results for 100 pCi/g ^{Tot}U Contaminant, Resident Rancher Scenario (Uranium Isotopic Composition of 93.3 % HEU) for Various Contaminated Area Sizes at Time = 0.

Contaminated Area (m^2)	Exposure Pathways, Dose-Equivalent (mrem/yr)						
	Ground	Inhalation	Plant	Meat	Milk	Soil	Total
10000	1.298	0.835	2.026	0.167	0.421	0.765	5.511
3000	1.274	0.736	2.026	0.05	0.126	0.765	4.978
1000	1.257	0.657	2.026	0.0167	0.0421	0.765	4.763
300	1.2	0.578	0.607	0.005	0.013	0.229	2.633
100	1.11	0.5144	0.203	0.00167	0.0042	0.077	1.91
30	0.898	0.452	0.061	0.0005	0.0013	0.023	1.44
10	0.647	0.402	0.0203	0.00017	0.0004	0.0077	1.077
3	0.313	0.352	0.0061	0.00005	0.00013	0.0023	0.6733
1	0.141	0.312	0.00203	0.000017	0.00004	0.00077	0.456

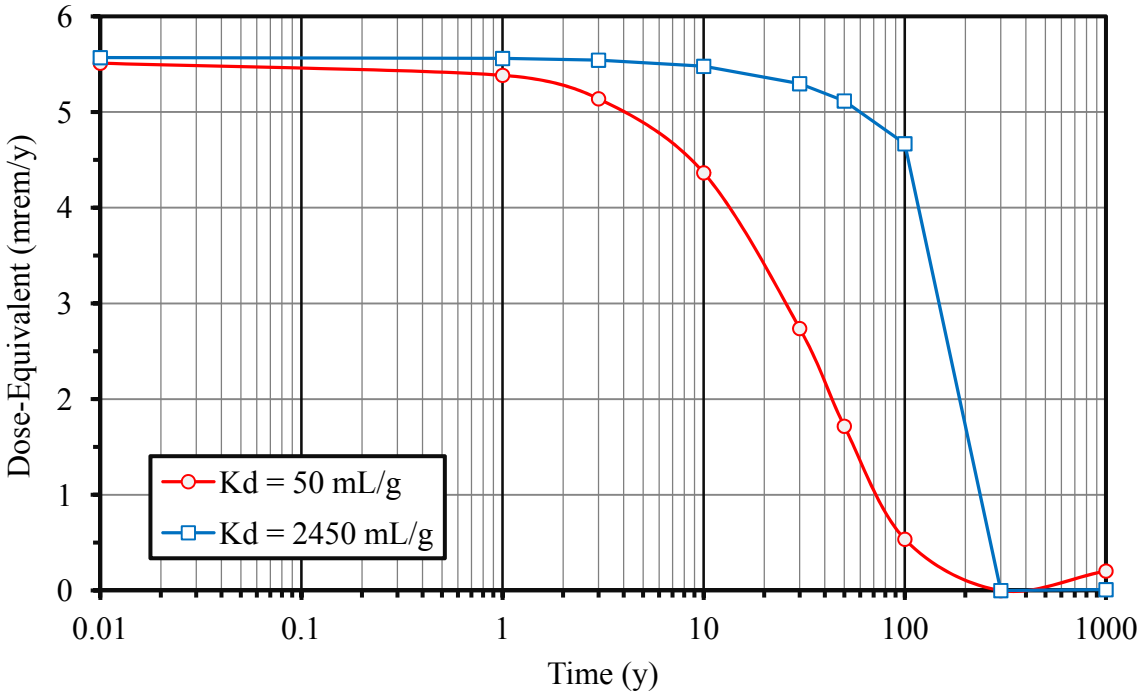

Figure Annex-6. Total Dose-Equivalent Modeling Results for 100 pCi/g ^{Tot}U Contaminant (93.3 % HEU) with Contaminated Area of 10,000 m^2 and Different Soil/Water Partitioning Coefficients. [Modeling for "0" time was set to 0.01 y to accommodate logarithmic x-axis]

TABLE G-2. Key RESRAD Parameters for ResRad
Calculated Dose-Equivalent Rates in TABLE G-1.

Parameter (units)	Value	Parameter (units)	Value
Area of contaminated zone (m^2)	10,000	Thickness of contaminated zone (m)	0.3
Length parallel to aquifer (m)	100	Basic radiation dose limit (mrem/yr)	25
Principal radionuclides	$^{234+235+238}U$	Percent: ^{235}U, ^{238}U (balance ^{234}U)	2.94, 0.0275
Cover depth (m)	0	Density of contaminated zone (g/cm^3)	1.5
Contaminated zone erosion rate (m/yr)	0.001	Contaminated zone total porosity	0.4
Contaminated zone effective porosity	0.4	Contaminated zone hydraulic conductivity (m/yr)	10
Contaminated zone b parameter	5.3		
Evapotranspiration coefficient	0.5	Precipitation (m/yr)	1
Runoff coefficient	0.2	Watershed area for nearby stream pond (m^2)	1×10^6
Density of saturated zone (g/cm^3)	1.5		
Contaminated zone total porosity	0.4	Contaminated zone field capacity	0.2
Contaminated zone hydraulic conductivity (m/yr)	10	Saturated zone hydraulic gradient	0.02
		Contaminated zone b parameter	5.3
Water table drop rate (m/yr)	0.001	Well pump intake depth (meters below water table)	10
Drinking water intake (L/yr)	510		
Unsaturated zone thickness (m)	13	Unsaturated zone soil density (g/cm^3)	1.5
Unsaturated zone total porosity	0.4	Unsaturated zone effective porosity	0.4
Unsaturated zone specific b parameter	5.3	Unsaturated zone hydraulic conductivity (m/yr)	10
U distribution coefficients (cm^3/g) [contaminated, unsaturated, saturated]	50	Inhalation rate (m^3/yr)	8,400
Fraction of time spent indoors	0.5	Mass loading for inhalation (g/m^3)	0.0001
		Fruits, vegetables, and grain consumption (kg/yr)	160
Fraction of time spent outdoors	0.25		
Exposure duration (yr)	30	Uranium leach rate (/yr)	0.0
Indoor dust filtration factor (inhalation)	0.4	Milk consumption (L/yr)	920
Shielding factor, external gamma	0.7	Soil ingestion rate (g/yr)	36.5
Leafy vegetable consumption (kg/yr)	14	Irrigation fraction from groundwater	1
Meat and poultry consumption (kg/yr)	63	Livestock soil intake (kg/day)	0.5
Fraction of drinking water from site	1	Livestock fodder intake for meat (kg/d)	68
Livestock fodder intake for milk (kg/d)	55	Livestock water intake for meat (L/d)	55
Livestock water intake for milk (L/d)	160	Mass loading for foliar deposition (g/m^3)	0.0001
Drinking, livestock, irrigation water fraction from ground water	1	Depth of roots (m)	0.9
		Depth of soil mixing layer (m)	0.15