FC-18-003
Revision 1
Evaluation of Cs-137 Global Fallout in Soils at Fort Calhoun Station

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Date

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Date

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Date

1.0 INTRODUCTION

This technical document provides a review of information from published global fallout studies and Fort Calhoun Station soil sample data. The technical basis for anticipated soil concentrations attributable to fallout and establishes criteria for investigating soil Cs-137 concentrations that are higher than those anticipated due to world-wide fallout. The end result is the determination of a site-specific background value for Cs-137 that will be used as the release criteria.

2.0 DEFINITIONS

2.1 Data Quality Objectives (DQO): Seven Step DQO process is a component of the planning phase of the data life cycle for site release.

2.2 Multi-Agency Radiation Survey and Site Investigation (MARSSIM): Standardized approach to demonstrating compliance with a dose or risk based regulation. NUREG/CR-1575.

2.3 Background: means radiation from cosmic sources; naturally occurring radioactive material, including radon (except as a decay product of source or special nuclear material); and global fallout as it exists in the environment from the testing of nuclear explosive devices or from past nuclear accidents such as Chernobyl that contribute to background radiation and are not under the control of the licensee. "Background radiation" does not include radiation from source, byproduct, or special nuclear materials regulated by the NRC.

2.4 Residual Radioactive Material: Radioactive contamination that may be present at NRC licensed facilities that may be present in structures or impacted areas.

2.5 NORM: Naturally Occurring Radioactive Material, radioactive elements found in the environment, such as uranium, thorium and potassium and any of their decay products, such as radium and radon.

2.6 Fallout: Radioactive particles that are carried into the atmosphere after a nuclear explosion or accident and gradually fall back as dust or in precipitation.

3.0 BACKGROUND RADIATION SOURCES

Different sources of alpha, beta and gamma emitting radionuclides comes from naturally occurring radioactive material (NORM), nuclear weapons testing and previous nuclear accidents. Most of the testing and all of the accidents have occurred in the northern hemisphere and the highest concentrations of fallout have been found in the 40 – 50 degrees north latitude range. Fort Calhoun Station lies in this range of latitudes. Since there are various sources of radioactive material pre-existing in the soil, these radionuclides must be taken into account when analyzing soil samples to determine the activity that should be

attributed to Uranium fuel cycle activities and whether or not remediation of areas is required.

3.1 Nuclear Weapons Testing

The estimated total activity of Sr-90 admitted to the atmosphere from nuclear weapons testing has been calculated to be approximately 600 PBq (Ref. 7, UNSCEAR, 1982). The ratio of Cs-137 to Sr-90 from weapons testing has been shown to be fairly consistently 1.6:1 and thus the Cs-137 release could be calculated to be 960 PBq from weapons testing fallout.

Weapons testing peaked in the mid-1960's and though there have been several nuclear accidents since this time, the Cs-137 present from fallout is predominantly from weapons testing. Cs-137 has a half life of 30.17 years, where Sr-90 has a half-life of 28.8 years. The distribution of Cs-137 and Sr-90 in soil will vary slightly after deposition as Cs-137 is a group I metal. Group I metals are soluble and will dissociate to ions in water, thus will penetrate deeper into the soil.

The deposition of fallout from nuclear weapons testing is generally reported in activity per unit surface area (nCi/m^2) as the deposition is not affected by the density of the soils. However for our purposes in site release, the density plays a factor, as more dense soil will indicate a lower activity per unit mass (pCi/g). Thus for 2 different soil areas having a different density, the more dense soil will indicate a lower activity per unit mass than the less dense soil, even though both had the same deposition rate per unit area.

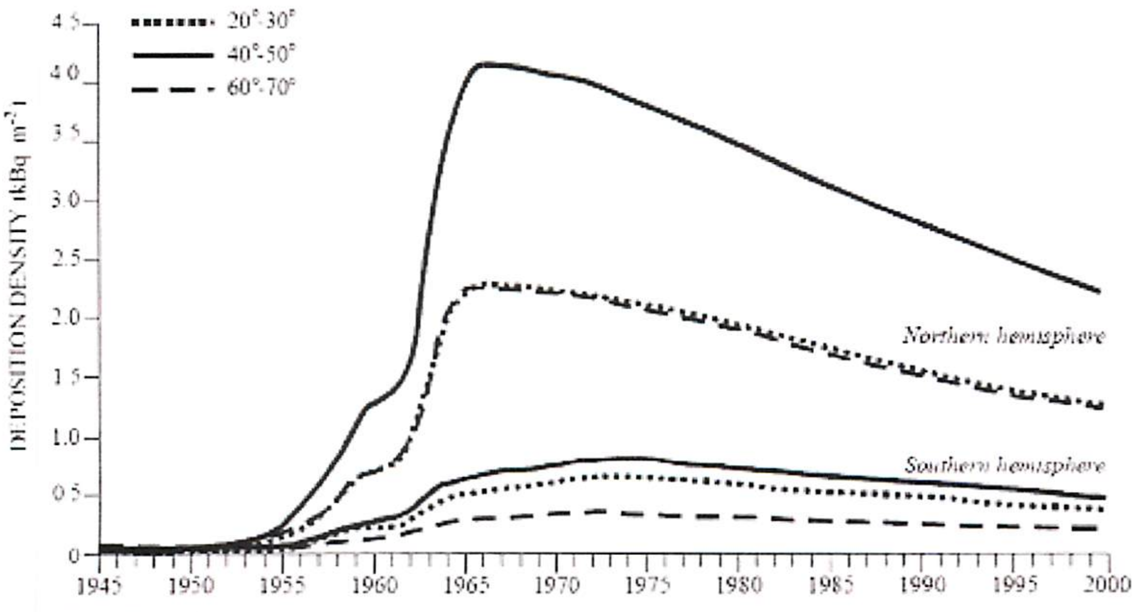

Figure 1 – Cs-137 deposition density in the northern and southern hemispheres (ref 7)

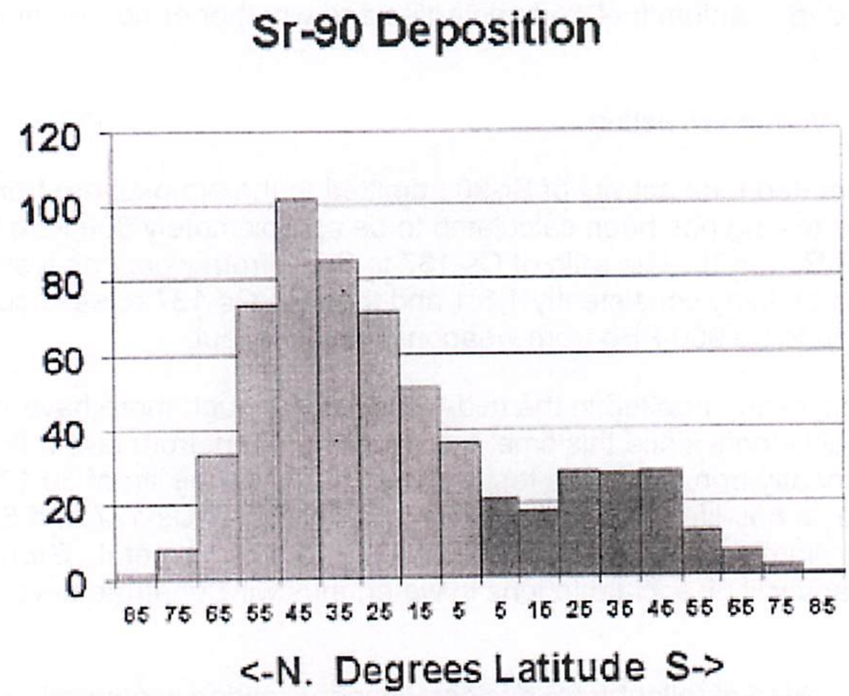

Figure 2 – Variation of total Sr-90 deposition with latitude. (ref 11)

As Fort Calhoun lies in the latitude range of the highest deposition from fallout testing, the activity present in the soil must be statistically accounted for such that weapons testing fallout is not attributed to licensed operation of Fort Calhoun Station. The following figure presents an estimate of the Cs-137 deposition in Washington County in which Fort Calhoun Station is located.

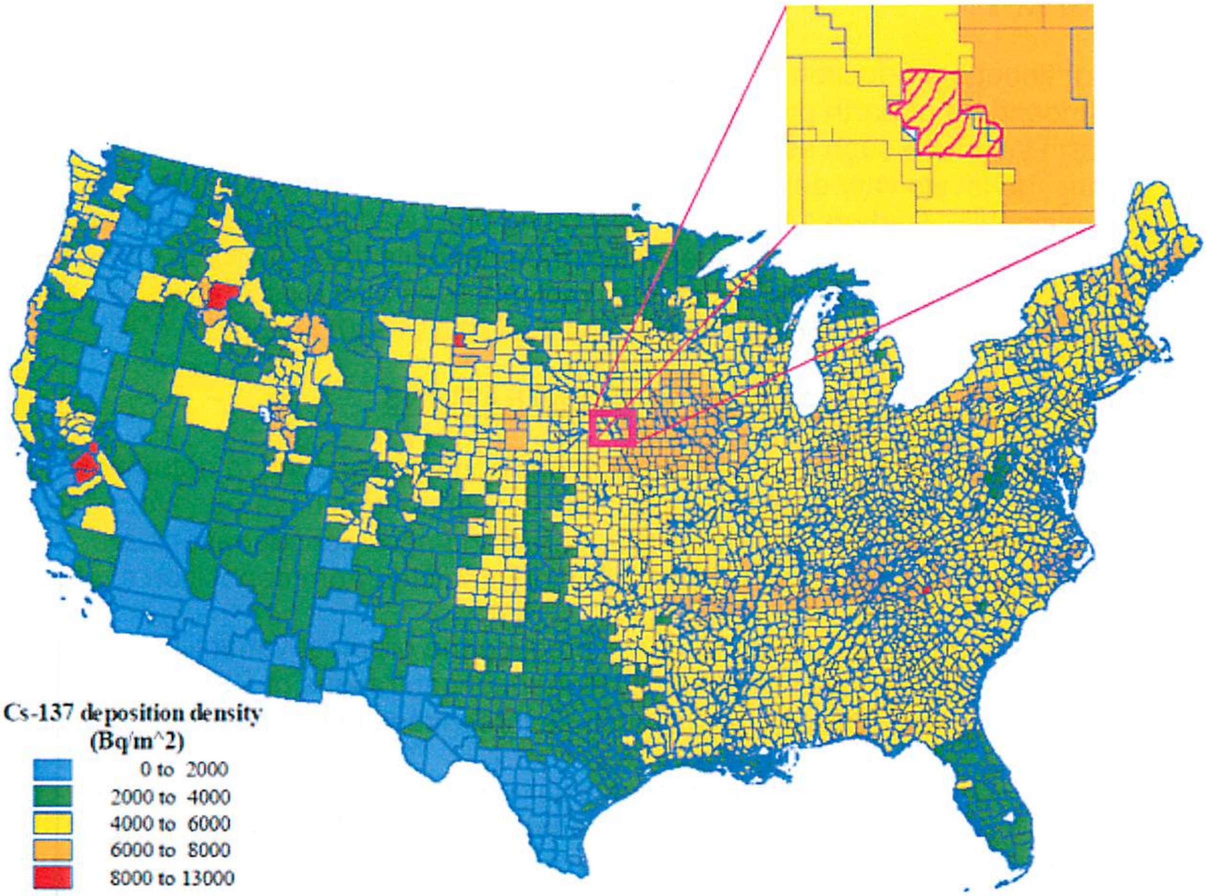

Figure 3- Cs-137 deposition from fallout and Nuclear Weapons Testing (Ref. 1, CDC-NCI, 2013)

3.2 Chernobyl

In 1986, the accident at the former Soviet Union's Chernobyl Nuclear Power Plant was the world's worst nuclear accident and released significant amounts of radionuclides into the local and global environment. Chernobyl was a light water cooled, graphite moderated reactor. Sr-90 release into the atmosphere is estimated to have been 10 PBq and Cs-137 released is estimated to be 85 PBq (Ref. 8, UNSCEAR, 2008).

3.3 Fukushima Daiichi

In March of 2011 the Great East-Japan Tohoku earthquake and tsunami struck the six nuclear power plants in Fukushima prefecture in Japan causing nuclear accidents and subsequent radioactive releases at three of the six boiling water reactors at Fukushima Daiichi. The estimated atmospheric release of Cs-137 was on the order of 20 PBq (Ref. 9, UNSCEAR, 2013).

3.4 NORM

Continuous production of radiation from cosmic rays interacting with the upper atmosphere of earth produces a constant source of radiation that falls to the earth's surface such as Be-7. This radiation varies based on solar effects and thus the levels vary depending on atmospheric and solar conditions. Additionally, Carbon 14 is continually being produced in the atmosphere and then being absorbed by plant matter which then deposits the C-14 back into the soil after the vegetation dies. Primordial radionuclides also exist in the soil such as Uranium, Radium, Thorium, and Potassium (e.g., K-40) isotopes.

4.0 CESIUM-137 TYPICAL SOIL CONCENTRATIONS

There have been numerous investigations and studies done to determine typical Cesium 137 concentrations in soil. The concentrations have been found to vary by orders of magnitude within a given area and peak concentrations are expected to be 10 times the concentration predicted from deposition studies.

4.1 Surface samples of undisturbed soil produce the greatest variability. Areas that collect rain water have significantly higher concentrations of Cs-137 in soil than open areas and can vary by as much as three times non-drainage areas.

4.2 The concentration in soil decreases significantly with depth. In undisturbed soil, most of the Cs-137 is contained in the top 15 cm. Surface samples from within the top 5 cm in undisturbed soil had significantly higher concentrations than those taken at the same depth in disturbed soil. Samples taken from surface to 10 cm or surface to 15 cm were less sensitive to soil disturbance.

4.3 Soil density from national studies is typically assumed to be 1.6 g/cm^3 and a greater or lesser density will affect the average background Cs-137 concentration. The soil densities in the sampled areas under active cultivation were approximately 1.3 g/cm^3.

5.0 FORT CALHOUN STATION SPECIFIC CS-137 BACKGROUND CONCENTRATIONS

5.1 Given the potential variability in Cs-137 concentrations between the local site soil properties and the national average, empirical data was taken to determine the background levels of radionuclides in soil at the site that is a result of fallout and global nuclear accidents. The tables in Attachment 1 list the sample locations and activity concentrations found in soils around Fort Calhoun Station. The samples were taken in areas similar in soil composition but in locations distant enough that they would not be impacted by releases of licensed material. Figure 4 shows the locations of soil samples obtained for this background assessment relative to the site. The table in Attachment 1 shows the data from soil samples and direct scans using a NaI detector at various background locations, along with their GPS coordinates.

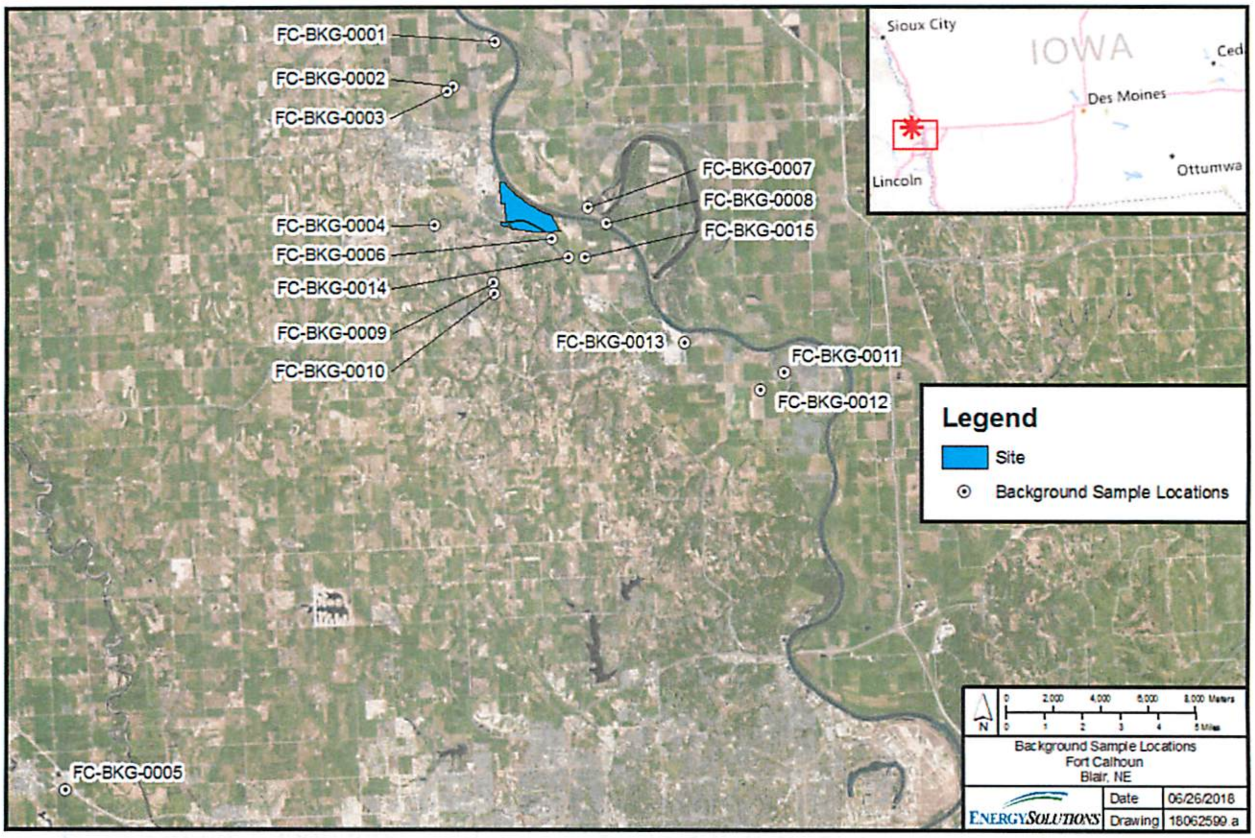

Figure 4 - Background Sample Locations

5.2 After global fallout has settled on top of the soil, rains tend to cause the activity to migrate to a deeper level within the first 10-15 cm of soil. Disturbing the soil such as farming activities tends to bring the activity up from these lower layers and more uniformly distribute the activity within this depth. Areas of the site around Fort Calhoun Station, along with background sample locations have been disturbed by farming activity from the same type of crops that have been grown on site at Fort Calhoun Station (corn and soybean) thus the distribution of fallout within the top layer of soil on site should be similar to background soil locations.

6.0 DATA ANALYSIS

Fifteen background samples were taken in areas around Fort Calhoun at locations listed in Attachment 1. Of these background samples, eight showed positive Cs-137 activity levels detectable by gamma spectroscopy. For the three samples that did not have an identifiable Cs-137 peak, the Cs-137 activity was calculated by the spectroscopy software (Apex Gamma) was conservatively used. Two of the gamma spectroscopy results had an identified Cs-137 peak and were less than the minimum detectable activity (MDA). These five values were included as part of the statistical analysis. The three samples analyzed off-site which had no identified Cs-137 were not used in the statistical analysis.

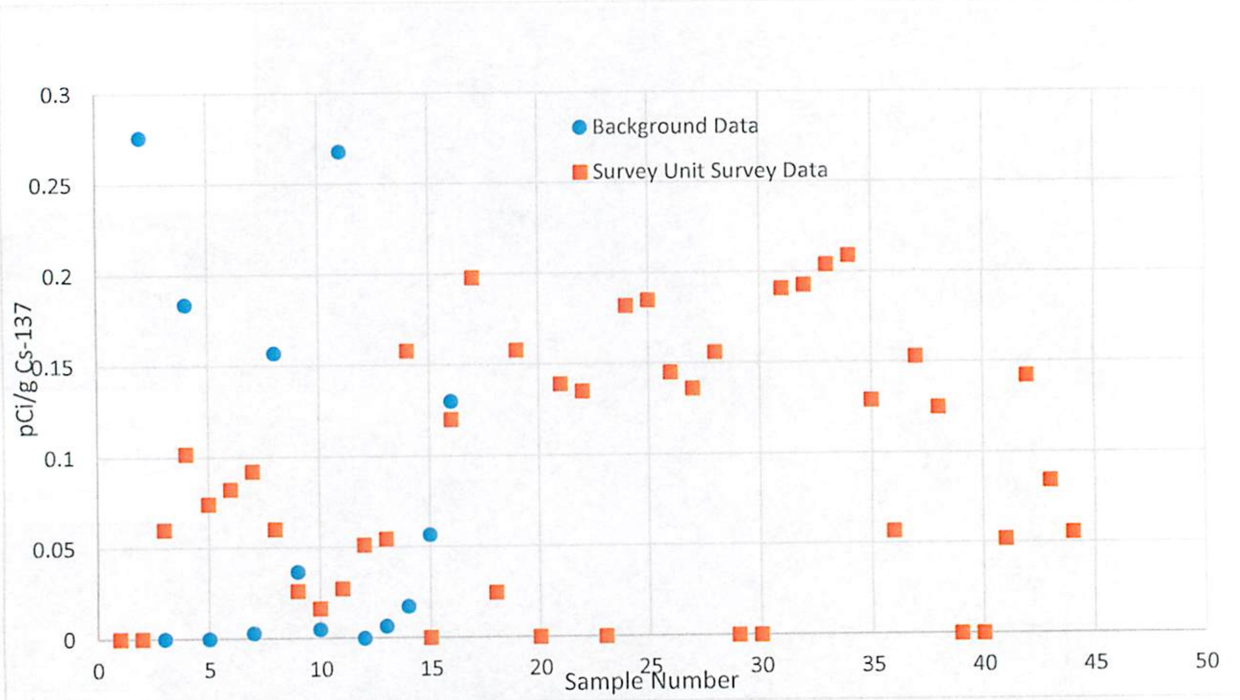

Figure 5 – Cs-137 Activity Scatter Plot

6.1 Interpretation of the data: The mean of the data used is 0.104 pCi/g and the standard deviation (σ) is 0.105 pCi/g. At the 95% confidence interval or two standard deviations (2σ), the activity of Cs-137 is 0.314 pCi/g.

7.0 CONCLUSION

The soil sample data obtained from empirical samples falls within the range of expected values from 40 – 50 N Latitude within which Fort Calhoun Station lies. The expected range of Cs-137 is 0.3 to 3.0 pCi/g from historic averages. Fort Calhoun Station, from empirical data from samples is at 0.314 pCi/g with 95% confidence interval.

8.0 REFERENCES

8.1 CDC-NCI, 2003, A Feasibility Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations Volume 1 Technical Report, Prepared for the U.S. Congress by the Department of Health and Human Services Centers ofr Disease Control & Prevention and the National Cancer Institute.

8.2 NUREG -1757, 2006, Consolidated Decommissioning guidance – Characterization, Survey, and Determination of Radiological Criteria Vol.2 Rev. 1, U.S. NRC

8.3 NUREG-1505, 1998, A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys, Rev. 1. U.S. NRC.

8.4 NUREG 1575, 2000, Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), U.S. NRC.

8.5 10CFR 20.1402, Radiological Criteria for Unrestricted Use, U.S. NRC

8.6 10CFR 20.1403, Criteria for License Termination Under Restricted Conditions.

8.7 UNSCEAR, 1982, Ionizing Radiation: Sources and Biological Effects, United Nations Scientific Committee on the Effects of Atomic Radiation 1982 Report to the General Assembly, with Annexes. Annex E, Exposures Resulting from Nuclear Explosions.

8.8 UNSCEAR, 2008, Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation 2008 Report to the General Assembly, with Scientific Annexes. Volume II, Scientific Annexes C,D and E.

8.9 UNSCEAR, 2013, Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation Volume I, 2013 Report to the General Assembly Scientific Annex A: Levels and Effects of Radiation Exposure Due to the Nuclear Accident After the 2011 Great East-Japan Earthquake and Tsunami.

8.10 Wallo III, Moscovitch, M., Rodgers, J., Duffery, D., Soares, C., 1994, Investigations of Natural Variations of Cesium-137 Concentrations in Residential Soils.

8.11 Beck, H., Bennett, B., (2002), “Historical Overview of Atmospheric Nuclear Weapons Testing and Estimates of Fallout in the Continental United States”, Health Physics, Vol. 82(5), 2002.

9.0 ATTACHMENTS

9.1 FCS Background Soil Sample Analysis Data

Attachment 1 – FCS Background Soil Sample Analysis Data

FCS Background Soil Sample Analysis											
Sample ID	Lab ID	Descriptive Location	GPS coordinates		Type	Isotope	Activity conc. (pCi/g)	Uncertainty 2σ	MDA (pCi/g)	Mean NaI (cpm)	Std. Dev NaI (cpm)
			Lat. (N)	Long. (W)							
FC-BKG-0001	L76343-1	Boat Ramp (riverview)	41.5852680	96.0916373	dist.	Cs-137			4.24E-02	9.16E+03	5.87E+02
						K-40	1.64E+01	1.21			
						Ra-226	2.12E+00	1.09			
						Th-232	1.03E+00	0.166			
						U-233/234	7.23E-01	0.244			
						U-238	8.54E-01	0.263			
FC-BKG-0002	L76343-2	Sorensen East Drainage	41.5689314	96.1142161	dist.	Cs-137	2.76E-01	8.34E-02			
						K-40	2.23E+01	2.08E+00			
						Ra-226	3.25E+00	1.59E+00			
						Th-232	1.34E+00	2.83E-01			
						U-233/234	1.04E+00	4.18E-01			
						U-238	7.23E-01	3.40E-01			

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			Lat. (N)	Long. (W)							
FC-BKG-0003	L76343-3	Sorensen Cultivated Field	41.5671474	96.1170117	dist.	Cs-137			8.28E-02	8.77E+03	9.11E+02
						K-40	1.91E+01	1.54E+00			
						Ra-226	3.17E+00	1.49E+00			
						Th-232	1.07E+00	2.28E-01			
						U-233/234	1.02E+00	3.59E-01			
						U-238	1.08E+00	3.74E-01			
FC-BKG-0004	L76343-4	Row Loess Hills	41.5160900	96.1266056	dist.	Cs-137	1.84E-01	6.97E-02			
						K-40	1.62E+01	1.63E+00			
						Ra-226	2.86E+00	1.17E+00			
						Th-232	9.36E-01	2.37E-01			
						U-233/234	1.33E+00	3.93E-01			
						U-238	1.18E+00	3.62E-01			

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			Lat. (N)	Long. (W)							
FC-BKG-0005	L76343-5	Valley Substation	41.3062700	96.3247820	dist.	Cs-137			1.07E-01		
						K-40	1.92E+01	1.81E+00			
						Ra-226			1.49E+00		
						Th-232	9.35E-01	2.27E-01			
						U-233/234	6.43E-01	2.54E-01			
						U-238	8.36E-01	2.98E-01			
L4-BKG-0006s	HPGe ISOCS		41.5091668	96.0673679		Cs-137	2.88E-03	9.81E-03		9743	1280
						K-40	1.23E+01	5.05E-01			
						Ra-226	2.11E+00	2.21E-01			
L4-BKG-0007s	HPGe ISOCS		41.5204040	96.0480132		Cs-137	1.57E-01	1.53E-02			
						K-40	1.54E+01	6.23E-01			
						Ra-226	2.52E+00	2.65E-01			

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			Lat. (N)	Long. (W)							
						U-235	1.53E-01	1.63E-02			
L4-BKG-0008s	HPGe ISOCS		41.5140565	96.0388763		Cs-137	3.66E-02	1.11E-02			
						K-40	1.36E+01	5.58E-01			
						U-235	9.93E-02	1.29E-02			
L4-BKG-0009s	HPGe ISOCS		41.4930132	96.0981551		Cs-137	4.88E-03		5.62E-02		
						K-40	14.3	0.589			
						U-235	0.138	1.59E-02			
L4-BKG-0010s	HPGe ISOCS		41.4891150	96.0980097		Cs-137	2.68E-01	2.01E-02			
						K-40	1.49E+01	5.99E-01			
						Mn-54	1.04E-02	7.96E-03			
						U-235	1.38E-01	1.60E-02			
L4-BKG-0011s	HPGe ISOCS		41.4537819	95.9522425		Cs-137			4.26E-02		

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			Lat. (N)	Long. (W)							
						K-40	12.5	0.498			
						Ra-226	1.2	0.163			
						U-235	7.32E-02	9.96E-03			
L4-BKG-0012s	HPGe ISOCS		41.4475814	95.9645488		Cs-137	6.43E-03		3.55E-02		
						K-40	1.15E+01	4.62E-01			
						U-235	4.45E-02	8.85E-03			
L4-BKG-0013s	HPGe ISOCS		41.4671317	96.0017925		Cs-137			4.15E-02		
						K-40	10.8	0.438			
						Ra-226	1.24	0.159			
						U-235	7.55E-02	9.73E-03			
L4-BKG-0014s	HPGe ISOCS		41.5016617	96.0589678		Cs-137	5.67E-02	1.28E-02			
						K-40	1.56E+01	6.28E-01			

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			Lat. (N)	Long. (W)							
						Mn-54	7.97E-03	8.56E-03			
						U-235	1.96E-01	1.77E-02			
L4-BKG-0015s	HPGe ISOCS		41.5014825	96.0504468		Cs-137	1.30E-01	1.62E-02			
						K-40	1.64E+01	6.64E-01			
						U-235	1.60E-01	1.70E-02			
					mean	Cs-137	1.24E-01				
					std. dev		1.06E-01				