Westinghouse

Hematite Decommissioning Project

HDP-RPT-FSS-301

OFF-SITE BORROW SOIL ANALYSIS

2112 HORINE ROAD, FESTUS, MISSOURI

November 2014

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Purpose

Borrow soils have been utilized from an off-site source located at 2112 Horine Road in Festus, Missouri, at the Hematite Decommissioning Project (HDP). HDP staff prepared HEM-14-31, *Hematite Decommissioning Project: Radiological Testing of Backfill Soil from an Off-site Borrow Location*, to inform the U.S. Nuclear Regulatory Commission (NRC) of the measures that HDP was using for radiological testing of backfill soil brought to HDP from off-site borrow locations. The NRC questioned the methodology and conclusions of HEM-14-31. HDP made the decision to collect additional samples and perform statistical analyses on the results of the borrow materials to demonstrate radiological compliance of the soils originating from the 2112 Horine Road location. The intent was also to develop a statistically acceptable methodology for use in assessing soil at other potential offsite borrow locations. This document presents the results of the analyses that were performed.

Sample Collection

The radiological data that was used in HEM-14-31 was based on samples collected over a period of years for varying purposes and utilizing differing counting methodologies. To normalize analytical methods and laboratories HDP made the decision to collect an entirely new set of data for these analyses.

The Westinghouse HDP collected and analyzed soil samples from three off-site locations. The first location which is located 3.7 miles northeast of the site at 2112 Horine Road, Festus (identified in Figure 1 as Offsite Deep Backfill) contains borrow soil for use as deep backfill. The second and third locations are approximately a mile from the HDP site (as identified in Figure 2), and were sites used to establish background soil concentrations for the Hematite Radiological Characterization Report (HRCR) in support of the Hematite Decommissioning Project's Final Status Survey Program. HDP collected new soil samples at 8 sample points at each of the two locations previously specified in the HRCR, as well as at sixteen random locations within the Offsite Deep Backfill area as identified in Figure 3 to better characterize the borrow soils.

Each sample location was sampled in 3 foot intervals to a depth of at least 6 feet, or until refusal was met. Refusal was encountered at one sample location at the deep backfill site, resulting in a total of 31 samples taken from the borrow site. A total of 32 samples were taken from the two reference areas, for a total of 63 samples from all three locations.

All the samples were analyzed for Tc-99 by ICP-MS, isotopic uranium by alpha spectroscopy, and gamma spectroscopy both with and without radium ingrowth.

Sample Results

Sample results are presented in Tables 1 and 2 for the reference areas and borrow location, respectively. Alpha spectroscopy results are presented for uranium. Gamma spectroscopy results from the final counting (after 21 day ingrowth) are presented for thorium and radium. Technetium results are from ICP-MS analysis. The following summarizes the analytical results of the soil sample analyses:

Tc-99		Ra-226 21 Day Ingrowth		Th-232 Final Count		U-234 Alpha Spec		U-235 Alpha Spec		U-238 Alpha Spec	
Borrow	Reference	Borrow	Reference	Borrow	Reference	Borrow	Reference	Borrow	Reference	Borrow	Reference
Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
0.021	0.044	1.051	1.071	1.176	1.017	0.611	0.707	0.028	0.035	0.656	0.738
St Dev	St Dev	St Dev	St Dev	St Dev	St Dev	St Dev	St Dev	St Dev	St Dev	St Dev	St Dev
0.013	0.058	0.121	0.168	0.131	0.219	0.206	0.235	0.020	0.025	0.251	0.180
Min	Min	Min	Min	Min	Min	Min	Min	Min	Min	Min	Min
-0.005	-0.014	0.721	0.618	0.788	0.225	0.389	0.345	-0.002	-0.003	0.354	0.379
Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max
0.045	0.205	1.270	1.340	1.340	1.390	1.520	1.160	0.092	0.099	1.800	0.997

Statistical Analysis

ProUCL was used to compare the laboratory data for Ra-226, Th-232, U-234, and U-238 from the samples obtained from the offsite borrow location to the data for background reference area soil. ProUCL is a statistical analytical tool to determine if the concentrations of uranium, radium, and thorium were statistically distinguishable from background. This process is consistent with the statistical process described in HEM-10-80 (Chapter 14, Question #4, ML102140158), which included two-sample hypothesis testing performed using the Quantile and Mann-Whitney U tests (referred to as Wilcoxon-Mann-Whitney in ProUCL). A statistical analysis was not performed on the Tc-99 as all sample results were non-detects.

Outlier Determination

ProUCL v4.1.01 was used on each data set to determine if potential outliers were present at a 1% significance level using the Rosner's Outlier Test. Samples that exceed the 1% significance level may be dropped from the data set when performing statistical analyses. Sample 9574-SS-140910-01-34 from one of the reference areas was determined to be an outlier for Th-232 with a value of 0.225 pCi/g. Sample 9498-RU-140903-71-01 from the borrow area was determined to be a outlier for U-234 and U-238 with concentrations of 1.52 and 1.80, respectively. Quantile-quantile (Q-Q) plots of the data sets were produced. The distributions for Th-232, U-234, and U-238 are mostly linear, but the outliers deviate.

Based upon the Rosner's test and a review of the Q-Q plots, the Th-232 data for sample 9574-SS-140910-01-34 and the uranium values for sample 9498-RU-140903-71-01 were removed from the data set. The resulting data set was utilized for the statistical analyses that follow. The following summarizes the results after the outliers were removed:

Th-232 Final Count		U-234 Alpha Spec		U-238 Alpha Spec	
Borrow	Reference	Borrow	Reference	Borrow	Reference
Average	Average	Average	Average	Average	Average
1.176	1.043	0.580	0.707	0.618	0.738
St Dev	St Dev	St Dev	St Dev	St Dev	St Dev
0.131	0.168	0.120	0.235	0.137	0.180
Min	Min	Min	Min	Min	Min
0.788	0.749	0.389	0.345	0.354	0.379
Max	Max	Max	Max	Max	Max
1.340	1.390	0.820	1.160	0.922	0.997

Background Distinguishability

The Kruskal-Wallis test was performed on the reference area data set to determine variability in background. The results of the tests indicate that all four isotopes have significant differences among the means at a 95% confidence level.

The concentration level that is indistinguishable from background was then calculated utilizing the methodology presented in Section 13.3 of NUREG-1505. The Th-232 sample result for sample 9574-SS-140910-01-34 was replaced in the test with the average of the remaining data to allow an equal number of values in each data set. The default value of 3ω was calculated and used for the Wilcoxon-Mann-Whitney tests. The concentrations relating to the value of 3ω for each of the radionuclides follow:

Ra-226 – 0.18 pCi/g

Th-232 – 0.30 pCi/g

U-234 – 0.59 pCi/g

U-238 – 0.37 pCi/g

Box Plots

Box plots for each radionuclide were prepared to graphically display the data. The comparison is presented in box plot format (Figures 1 to 4). The box plots depict the background reference area soil data and off-site borrow location data through five-number summaries: lower quartile (25th percentile of the data), median (50th percentile of the data), and upper quartile (75th percentile of the data). The boxes illustrate data that range from the lower quartile to the upper quartile. The box plots display differences between the two data populations without assuming an underlying statistical distribution. The offsite borrow location data is reflected on the left side of Figures 4 to 7; the background reference area data is on the right side.

Wilcoxon-Mann-Whitney Tests

Wilcoxon-Mann Whitney tests were performed for each radionuclide to determine if the median of the concentrations from the borrow area differ from the reference areas. Form 2 of the test was used, with a null hypothesis of the borrow materials and a mean greater than the reference area. The value of 3ω was used for each radionuclide as a substantial difference. A 95% confidence level was utilized for each test.

The Wilcoxon-Mann-Whitney tests concluded that Ra-226, U-235, U-234 and U-238 from offsite fill locations were determined to be indistinguishable from the background reference area soil data plus the concentration level that is indistinguishable from background (substantial difference). Appendix A contains the output from ProUCL for the Wilcoxon-Mann-Whitney tests. Table 3 presents the data sets utilized for the ProUCL statistical tests.

Quantile Tests

Quantile tests were performed for each radionuclide to compare the upper tails of the borrow and reference area data sets. ProUCL was used to perform the Quantile test for each of the radionuclides. All four radionuclides passed the Quantile test at a 95% confidence level. Appendix B contains the output from ProUCL for the Quantile tests.

Retrospective Power

Retrospective power curves were created for each Wilcoxon-Mann-Whitney test. The derived concentration guideline level was set as the mean plus the 3ω value. The standard deviation was input and the lower bound of the gray region was set at the median. A 0.05 alpha error and 0.1 beta error was utilized. The resulting sample sizes follow:

Ra-226 – 17 samples

Th-232 – 10 samples

U-234 – 7 samples

U-238 – 8 samples

Appendix C presents the retrospective power curves for each radionuclide's Wilcoxon-Mann-Whitney test.

Laboratory Intercomparison

Field duplicate samples were obtained at a rate of 1 per 20 samples. The field duplicate was analyzed by GEL Laboratories, whereas the main sample set was analyzed at Test America Laboratories. The duplicate results were evaluated per HDP-PR-HP-425, Sample Analysis Quality Control, which includes evaluation per Section 7.4.1.1 of the Multi-Agency Radiological

Laboratory Analytical Protocols (MARLAP) Manual. All detected radionuclides were evaluated and none exceeded either the warning or control limit.

Conclusion

To demonstrate the suitability of using borrow material from 2112 Horine Road, Festus, MO for deep backfill at the Hematite site, HDP staff prepared and provided to the NRC HEM-14-31, Hematite Decommissioning Project: Radiological Testing of Backfill Soil from an Off-site Borrow Location. Because the NRC questioned the methodology and conclusions of HEM-14-31, HDP collected additional soil samples and modified the statistical analyses to provide a more rigorous basis for concluding the borrow material was acceptable. The subsequent statistical analysis showed that the number of samples collected was more than sufficient to support the statistical methodology, and that based upon the non-detects of T-99 and the analysis of Ra-226, Th-232, U-234 and U-238, the borrow material from 2112 Horine Road is suitable for use as deep backfill at the Hematite Decommissioning Project.

Figure 1 – Top Soil and Deep Backfill Locations

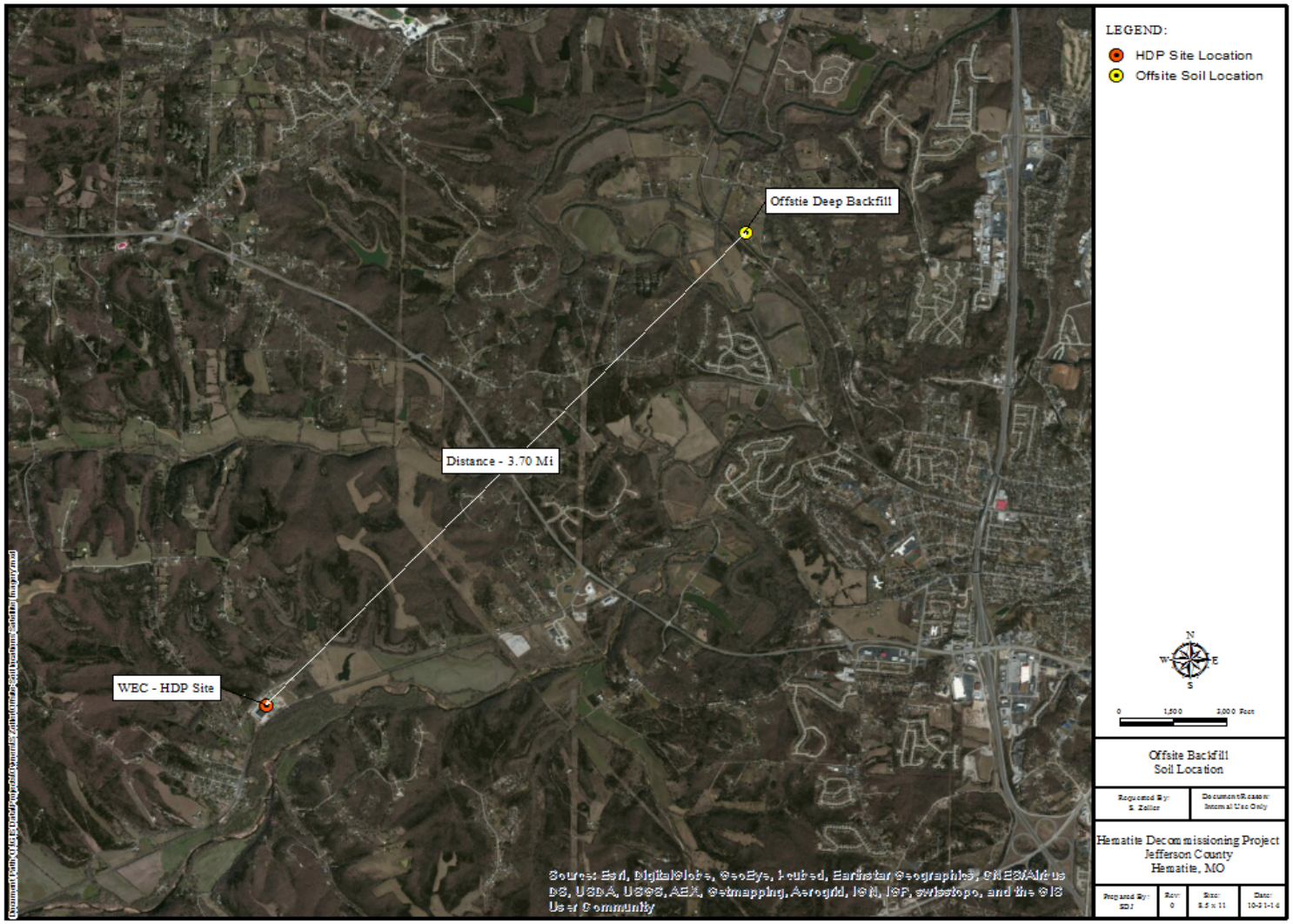

Figure 2 – Hematite Site Background Sample Locations

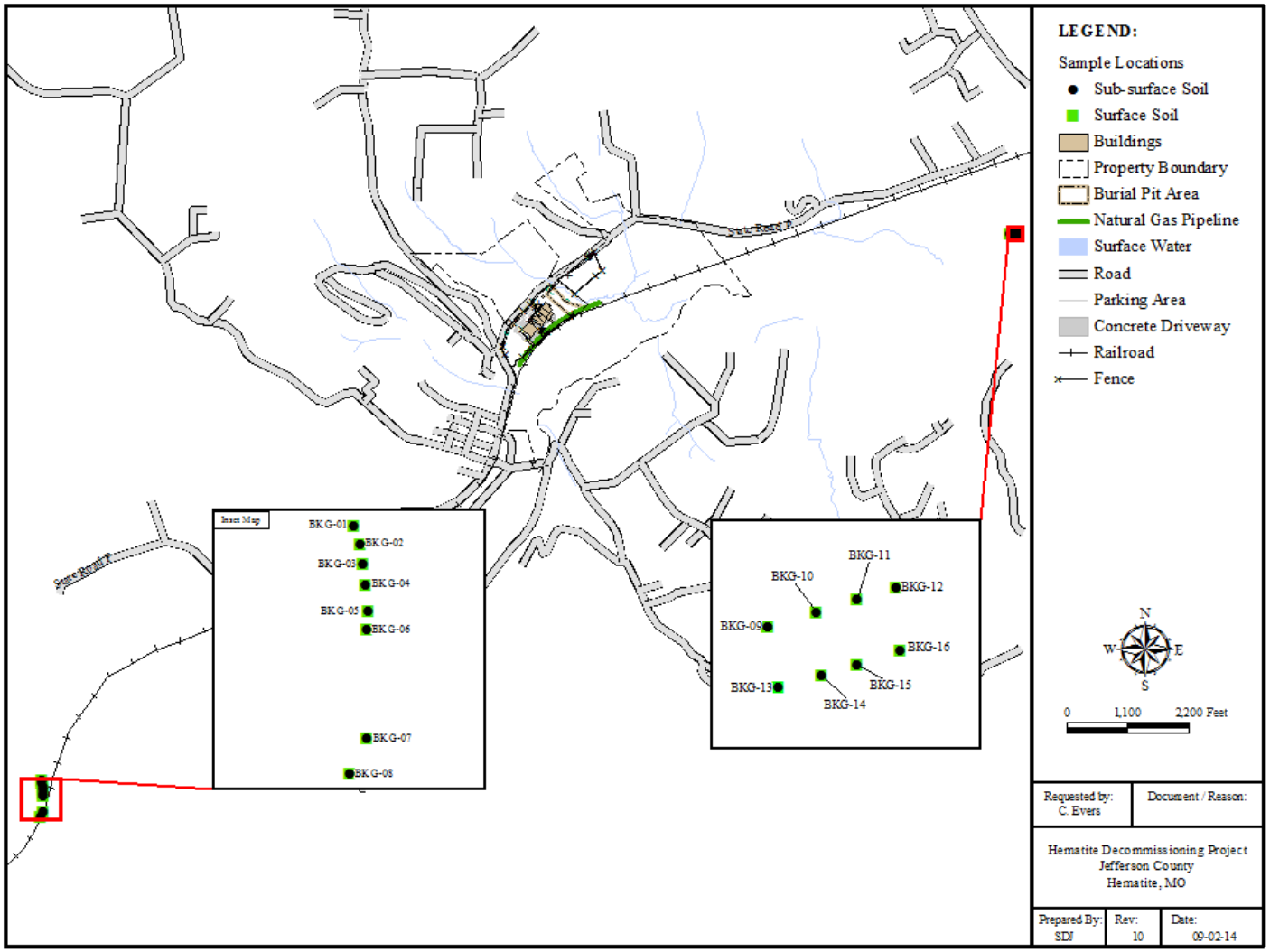

Figure 3 – Deep Backfill Sample Locations

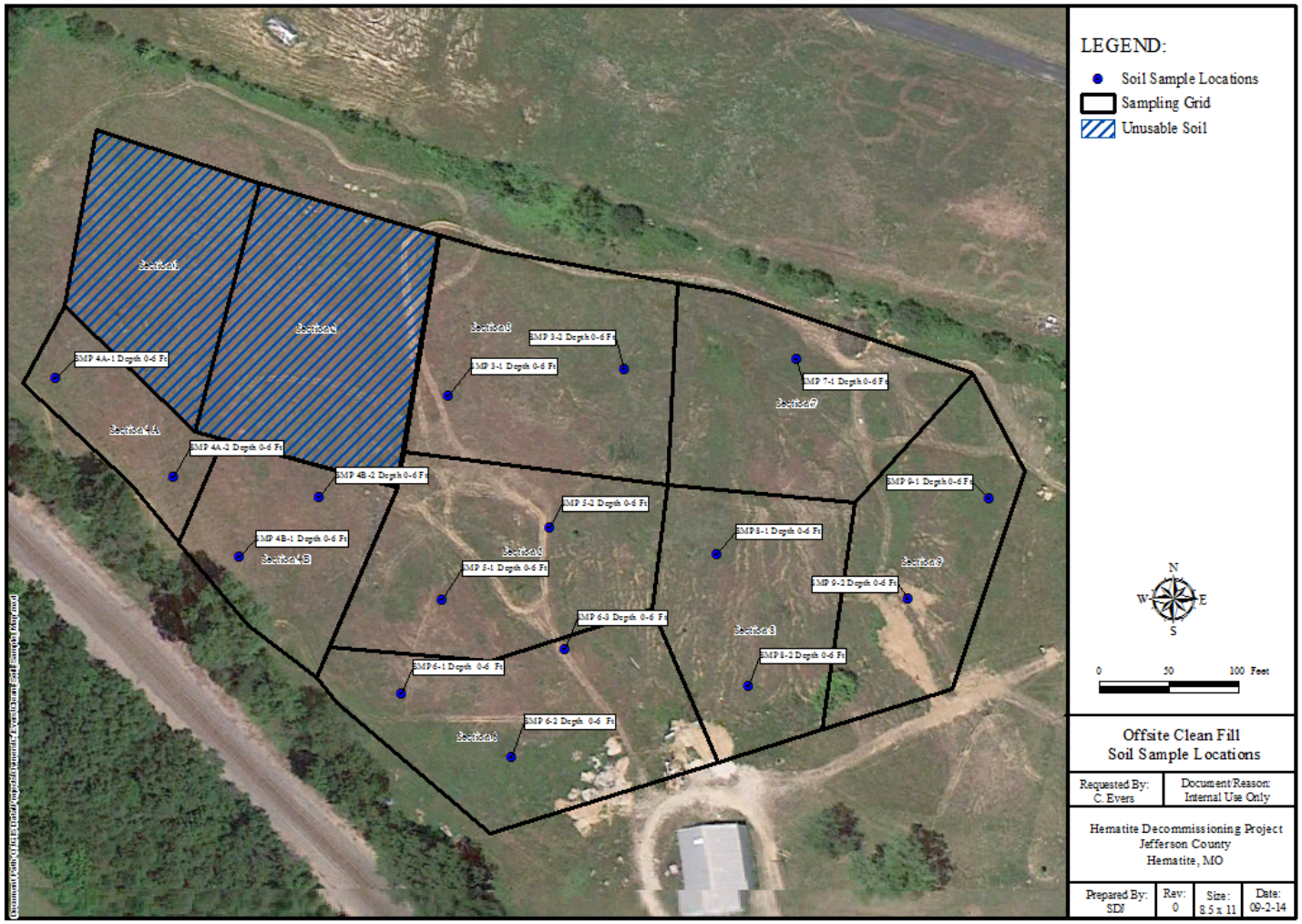

Figure 4 - Radium-226 Box Plot

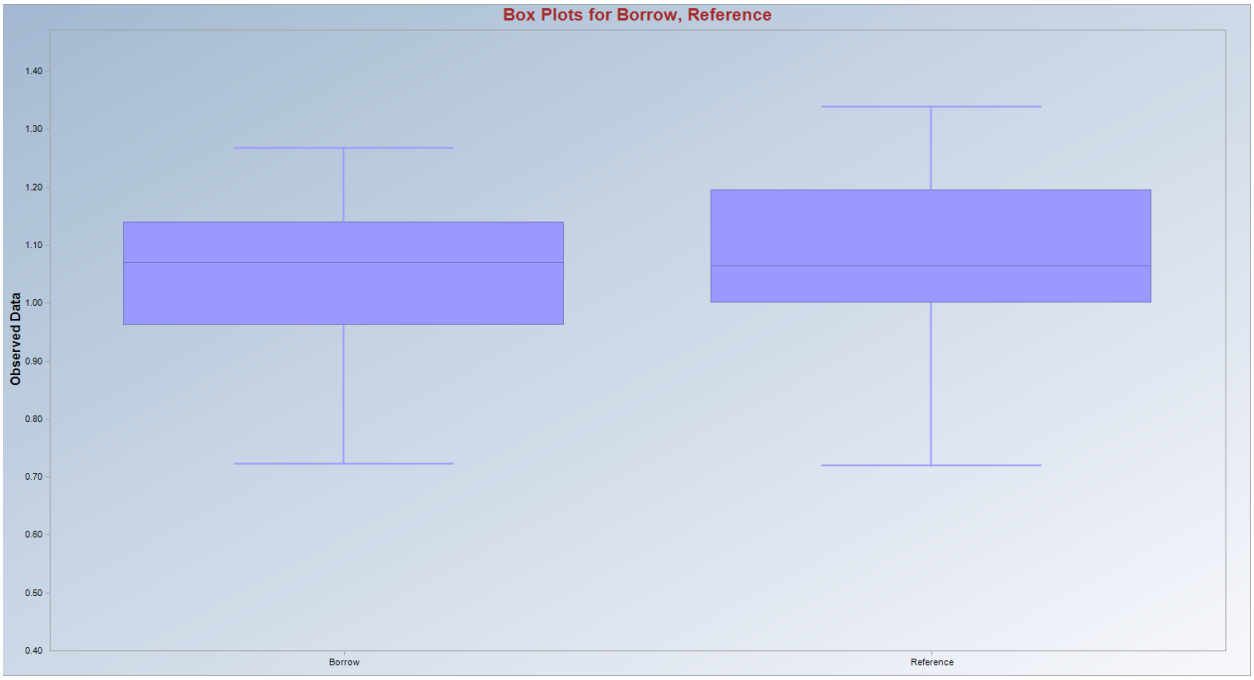

Figure 5 - Thorium-232 Box Plot

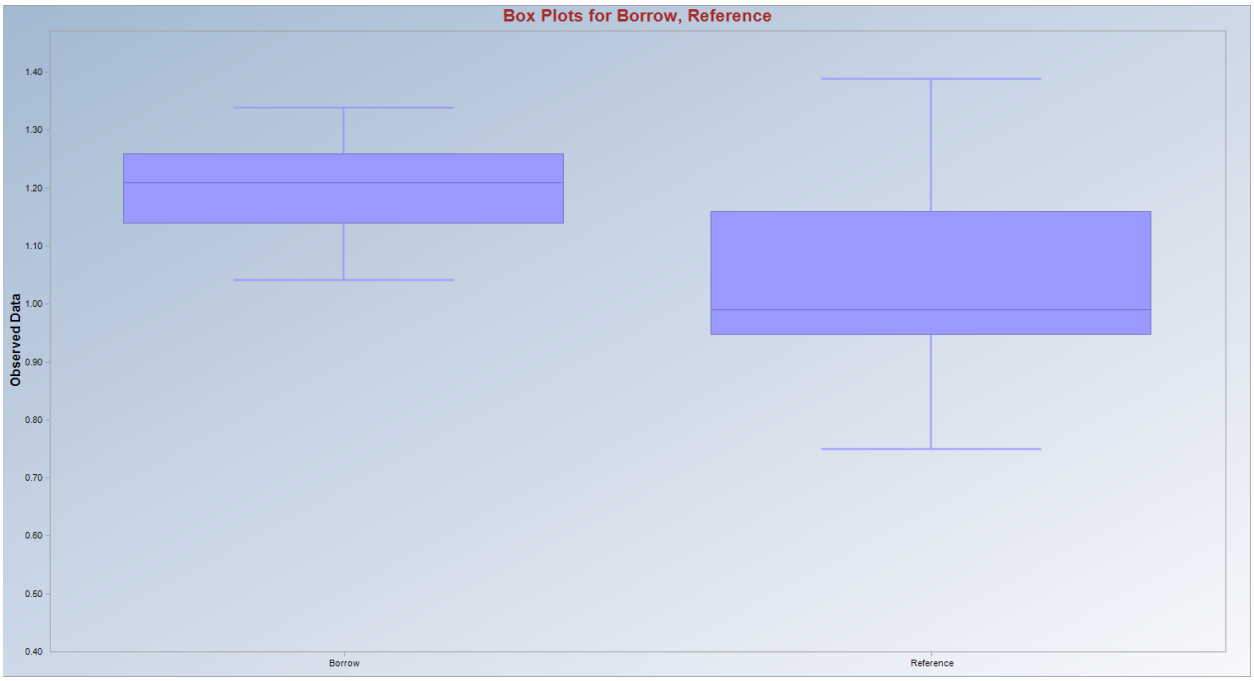

Figure 6 - U-234 Box Plot

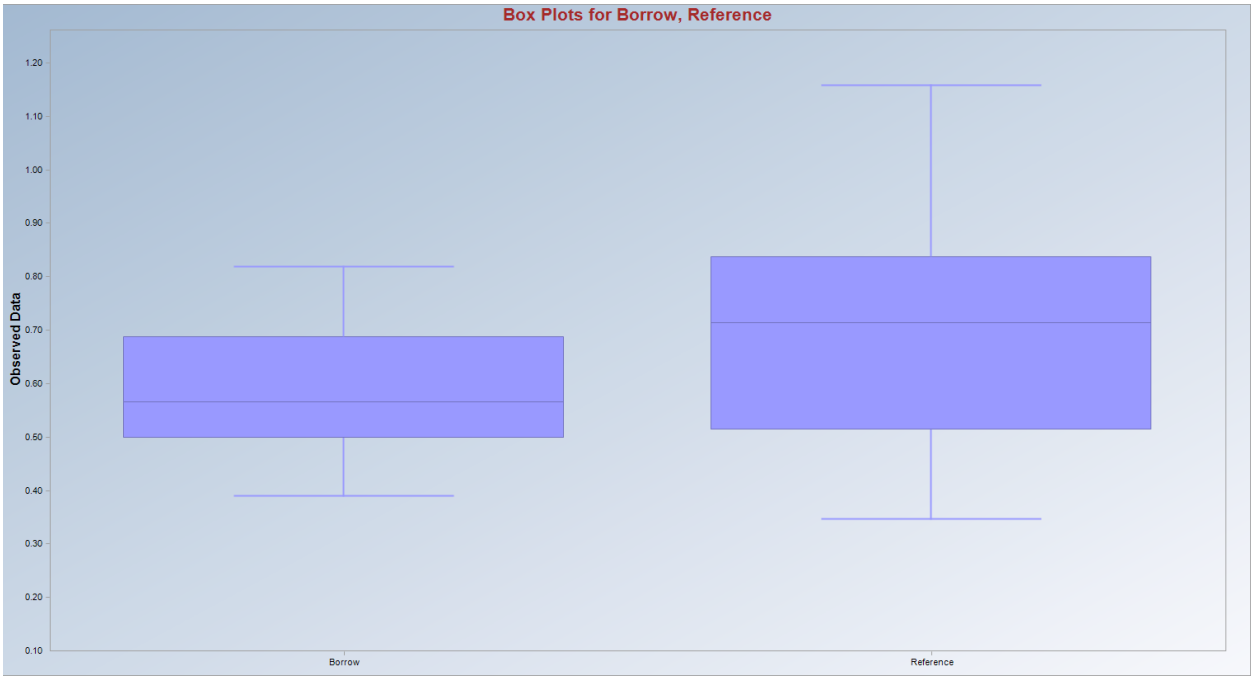

Figure 7 - U-238 Box Plot

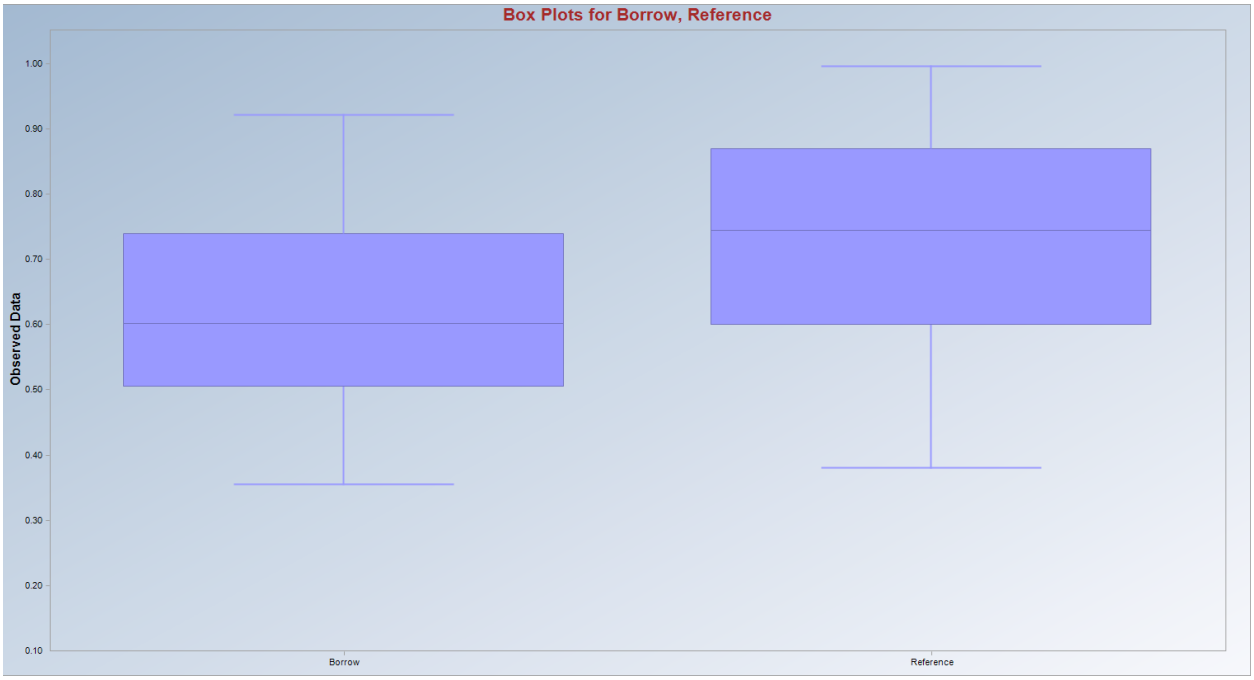

Table 1 – Reference Area Analytical Results

Reference Area Results																				
		Technetium-99 (pCi/g)			Radium-226 (pCi/g) 21 Day Ingrowth			Thorium-232 (pCi/g) (Ac-228) Final Count			Uranium-234 (pCi/g) Alpha Spec			Uranium-235 (pCi/g) Alpha Spec			Uranium-238 (pCi/g) Alpha Spec		
Sample ID	Sample Date	Result	Error	MDC	Result	Error	MDC	Result	Error	MDC	Result	Error	MDC	Result	Error	MDC	Result	Error	MDC
9574-SS-140910-01-01	9/10/2014	0.06	0.0254	0.228	1.15	0.164	0.0678	1.15	0.178	0.133	0.671	0.181	0.0502	0.0223	0.0395	0.0713	0.724	0.189	0.0501
9574-SS-140910-01-02	9/10/2014	0.0451	0.143	0.212	0.719	0.103	0.0447	0.749	0.12	0.0896	0.353	0.129	0.0505	0.0112	0.0281	0.0629	0.379	0.135	0.0676
9574-SS-140910-01-03	9/10/2014	0.0272	0.116	0.214	1.04	0.166	0.0772	0.936	0.183	0.145	0.518	0.164	0.0617	0.0148	0.0296	0.0444	0.723	0.195	0.0356
9574-SS-140910-01-04	9/10/2014	0.00489	0.161	0.222	1.01	0.138	0.0513	0.962	0.171	0.0901	0.39	0.138	0.0344	0.0143	0.0286	0.0428	0.591	0.172	0.0595
9574-SS-140910-01-05	9/10/2014	0.000801	0.00339	0.2	0.995	0.16	0.0848	0.948	0.178	0.0908	0.345	0.163	0.0834	0	0.00855	0.0684	0.421	0.179	0.0549
9574-SS-140910-01-07	9/10/2014	0.0923	0.17	0.209	0.858	0.133	0.0642	0.831	0.15	0.11	0.512	0.16	0.0349	0.038	0.0508	0.0752	0.453	0.15	0.0348
9574-SS-140910-01-08	9/10/2014	0.205	0.439	0.213	1.03	0.143	0.064	0.979	0.139	0.0868	0.832	0.21	0.0748	0	0.00539	0.0431	0.632	0.179	0.0525
9574-SS-140910-01-09	9/10/2014	0.186	0.235	0.226	1.08	0.169	0.0702	0.768	0.188	0.184	0.484	0.159	0.0554	0.0426	0.0529	0.0689	0.493	0.161	0.0631
9574-SS-140910-01-10	9/10/2014	0.0546	0.129	0.22	1.17	0.174	0.0772	1.16	0.191	0.143	0.571	0.169	0.0644	0.0343	0.0497	0.0801	0.757	0.196	0.0339
9574-SS-140910-01-11	9/10/2014	0.0506	0.165	0.22	0.972	0.136	0.0838	0.977	0.142	0.0792	0.606	0.174	0.0587	0.0281	0.0398	0.0422	0.575	0.168	0.0338
9574-SS-140910-01-12	9/10/2014	0.0186	0.0775	0.221	1.22	0.184	0.0858	1.14	0.21	0.139	0.747	0.199	0.0541	0.0564	0.0596	0.0673	0.997	0.233	0.0356
9574-SS-140910-01-13	9/10/2014	0.196	0.214	0.228	1.02	0.14	0.0759	0.978	0.157	0.0959	0.724	0.198	0.0368	0.0458	0.053	0.0458	0.744	0.201	0.0557
9574-SS-140910-01-14	9/10/2014	0.0705	0.0929	0.214	1.05	0.146	0.0605	0.889	0.156	0.0802	0.705	0.193	0.0614	0.0294	0.0417	0.0441	0.607	0.178	0.0671
9574-SS-140910-01-15	9/10/2014	0.0174	0.0329	0.226	0.805	0.121	0.0579	0.871	0.14	0.11	0.434	0.145	0.0583	-0.00262	0.00524	0.0636	0.594	0.171	0.0336
9574-SS-140910-01-16	9/10/2014	0.000929	0.0403	0.232	1.32	0.201	0.0904	1.07	0.189	0.153	0.513	0.152	0.0537	0.049	0.0518	0.0585	0.835	0.198	0.0309
9574-SS-140910-01-17	9/10/2014	0.00743	0.045	0.225	1.19	0.165	0.0698	1.1	0.179	0.129	0.639	0.183	0.0619	0.0241	0.0427	0.077	0.844	0.213	0.0357
9574-SS-140910-01-18	9/10/2014	-0.00742	0.0464	0.212	1.34	0.193	0.0845	1.19	0.2	0.117	0.808	0.2	0.0618	0.038	0.0472	0.0615	0.745	0.191	0.0493
9574-SS-140910-01-20	9/11/2014	-0.0141	0.0477	0.205	1.26	0.206	0.109	1.01	0.197	0.176	1.12	0.241	0.0571	0.0683	0.0614	0.041	0.71	0.187	0.0499
9574-SS-140910-01-21	9/11/2014	0.0192	0.0727	0.234	1.07	0.156	0.0738	0.982	0.153	0.124	1.04	0.232	0.0504	0.0276	0.039	0.0413	0.705	0.187	0.0503
9574-SS-140910-01-22	9/11/2014	0.0451	0.0593	0.229	0.922	0.131	0.0573	1.21	0.17	0.106	0.829	0.215	0.0646	0.0126	0.0315	0.0705	0.981	0.236	0.0372
9574-SS-140910-01-23	9/11/2014	0.0064	0.0542	0.229	1.13	0.17	0.0835	1.37	0.229	0.115	1.14	0.254	0.0553	0.0728	0.0681	0.0688	0.994	0.235	0.0364
9574-SS-140910-01-24	9/11/2014	0.112	0.132	0.231	1.2	0.165	0.0649	1.39	0.221	0.131	1.09	0.247	0.0546	0.0243	0.043	0.0776	0.992	0.234	0.0545
9574-SS-140910-01-25	9/11/2014	0.0568	0.11	0.242	1.23	0.164	0.0653	0.99	0.156	0.126	0.887	0.216	0.0526	0.0691	0.0647	0.0654	0.959	0.226	0.0703
9574-SS-140910-01-26	9/11/2014	0.0376	0.147	0.228	1.08	0.159	0.079	1.21	0.179	0.106	0.73	0.219	0.078	0.0187	0.0374	0.056	0.764	0.223	0.0449
9574-SS-140910-01-27	9/11/2014	0.00356	0.0663	0.237	1.31	0.185	0.0818	1.05	0.163	0.11	1.16	0.255	0.0357	0.0592	0.0594	0.0444	0.956	0.228	0.0616
9574-SS-140910-01-28	9/11/2014	0.00967	0.0958	0.23	1.28	0.188	0.089	1.39	0.201	0.131	0.871	0.217	0.0545	0.0595	0.0597	0.0447	0.895	0.22	0.0358
9574-SS-140910-01-29	9/11/2014	0.0735	0.0242	0.245	1.08	0.154	0.0808	0.955	0.16	0.146	0.842	0.208	0.0587	0.0114	0.0286	0.064	0.708	0.189	0.0513
9574-SS-140910-01-30	9/11/2014	0.0154	0.0133	0.23	0.96	0.161	0.0864	0.851	0.166	0.156	0.744	0.196	0.0349	0.0723	0.065	0.0434	0.787	0.203	0.0528
9574-SS-140910-01-31	9/11/2014	-0.00068	0.0573	0.225	1.06	0.146	0.0498	1.1	0.159	0.089	0.572	0.17	0.0695	0.0992	0.0754	0.0425	0.986	0.228	0.0517
9574-SS-140910-01-32	9/11/2014	0.000231	0.0252	0.231	1.06	0.157	0.0709	1.17	0.177	0.0776	0.598	0.174	0.0602	0.0576	0.0578	0.0432	0.758	0.198	0.06
9574-SS-140910-01-33	9/11/2014	0.007	0.0391	0.233	1.03	0.147	0.0689	0.954	0.153	0.119	0.772	0.196	0.0504	0.0138	0.0276	0.0413	0.828	0.203	0.0331
9574-SS-140910-01-34	9/11/2014	0.00142	0.0793	0.202	0.618	0.0993	0.04	0.225	0.0848	0.0991	0.389	0.138	0.0524	0.0143	0.0287	0.043	0.494	0.156	0.0345
		Average			Average			Average			Average			Average			Average		
		0.044			1.071			1.017			0.707			0.035			0.738		
		St Dev			St Dev			St Dev			St Dev			St Dev			St Dev		
		0.058			0.168			0.219			0.235			0.025			0.180		
		Min			Min			Min			Min			Min			Min		
		-0.014			0.618			0.225			0.345			-0.003			0.379		
		Max			Max			Max			Max			Max			Max		
		0.205			1.340			1.390			1.160			0.099			0.997		

Table 2 – Borrow Area Analytical Results

Borrow Area Results																			
		Technetium-99 (pCi/g)			Radium-226 (pCi/g) 21 Day Ingrowth			Thorium-232 (pCi/g) (Ac-228) Final Count			Uranium-234 (pCi/g) Alpha Spec			Uranium-235 (pCi/g) Alpha Spec			Uranium-238 (pCi/g) Alpha Spec		
Sample ID	Sample Date	Result	Error	MDC	Result	Error	MDC	Result	Error	MDC	Result	Error	MDC	Result	Error	MDC	Result	Error	MDC
9498-RU-140903-31-01	9/5/2014	0.0204	0.0317	0.208	1.1	0.163	0.0784	1.09	0.166	0.0909	0.498	0.163	0.0784	0.0273	0.0431	0.0687	0.518	0.165	0.0551
9498-RU-140903-31-02	9/5/2014	0.0429	0.0695	0.201	1.15	0.171	0.0796	1.31	0.201	0.0655	0.539	0.157	0.0585	0.0256	0.0363	0.0384	0.573	0.161	0.0467
9498-RU-140903-32-01	9/3/2014	0.0283	0.0258	0.213	1.23	0.202	0.102	0.932	0.201	0.256	0.746	0.19	0.0611	0.0401	0.0464	0.0401	0.739	0.189	0.0321
9498-RU-140903-32-02	9/3/2014	0.0309	0.0799	0.216	1.14	0.16	0.0691	1.12	0.166	0.108	0.82	0.214	0.0567	0.0126	0.0316	0.0706	0.796	0.21	0.0373
9498-RU-140903-41-01	9/4/2014	0.033	0.0371	0.207	1.22	0.189	0.078	1.31	0.211	0.126	0.59	0.169	0.0571	0	0.00513	0.0411	0.446	0.146	0.057
9498-RU-140903-41-02	9/4/2014	0.0141	0.0107	0.199	0.721	0.111	0.058	0.788	0.144	0.0969	0.408	0.14	0.0579	0.0139	0.0278	0.0416	0.61	0.173	0.0507
9498-RU-140903-42-01	9/4/2014	0.0214	0.0448	0.214	1.03	0.16	0.0737	1.31	0.244	0.118	0.504	0.157	0.0512	0.028	0.0396	0.042	0.557	0.166	0.0583
9498-RU-140903-42-02	9/4/2014	0.00993	0.0444	0.211	0.862	0.127	0.0642	1.04	0.15	0.102	0.508	0.154	0.0685	0.0263	0.0373	0.0395	0.505	0.152	0.0481
9498-RU-140903-43-01	9/4/2014	0.0295	0.0201	0.219	0.99	0.168	0.0906	1.26	0.199	0.0729	0.481	0.152	0.063	0.0525	0.0555	0.0627	0.561	0.165	0.0503
9498-RU-140903-43-02	9/4/2014	-0.00493	0.0175	0.224	0.948	0.136	0.0619	1.22	0.189	0.105	0.577	0.17	0.0687	0.0254	0.04	0.0637	0.703	0.188	0.0583
9498-RU-140903-44-01	9/4/2014	0.00535	0.0606	0.214	0.931	0.172	0.113	1.22	0.206	0.156	0.432	0.141	0.0552	0.0265	0.0375	0.0397	0.601	0.168	0.0551
9498-RU-140903-44-02	9/4/2014	-0.00295	0.0407	0.211	0.946	0.137	0.064	1.14	0.173	0.113	0.596	0.175	0.0534	0.0146	0.0292	0.0438	0.48	0.155	0.0351
9498-RU-140903-51-01	9/4/2014	0.018	0.0835	0.206	1.08	0.171	0.0784	0.812	0.183	0.188	0.585	0.161	0.0303	0.0251	0.0356	0.0377	0.796	0.191	0.0302
9498-RU-140903-51-02	9/4/2014	0.0258	0.0575	0.219	0.929	0.14	0.0735	1.18	0.192	0.107	0.434	0.144	0.0626	0.0137	0.0274	0.0411	0.472	0.149	0.0329
9498-RU-140903-52-01	9/3/2014	-0.00488	0.0198	0.212	1.08	0.178	0.0973	1.27	0.21	0.11	0.554	0.166	0.0517	0.0539	0.0569	0.0643	0.601	0.173	0.034
9498-RU-140903-52-02	9/3/2014	0.0276	0.0883	0.204	1.09	0.167	0.0792	1.19	0.199	0.104	0.606	0.173	0.0713	0.0111	0.0279	0.0624	0.646	0.177	0.05
9498-RU-140903-61-01	9/4/2014	0.0229	0.0273	0.214	1.18	0.171	0.0782	1.21	0.185	0.12	0.538	0.158	0.0595	0.0391	0.0452	0.0391	0.583	0.164	0.0476
9498-RU-140903-61-02	9/4/2014	0.0151	0.0181	0.21	0.846	0.12	0.0741	1.26	0.182	0.101	0.547	0.167	0.0657	0.0144	0.0287	0.0431	0.47	0.153	0.0524
9498-RU-140903-62-01	9/5/2014	0.022	0.0632	0.209	1.27	0.18	0.0801	1.19	0.178	0.117	0.577	0.186	0.0721	0.0658	0.0696	0.0786	0.731	0.211	0.063
9498-RU-140903-62-02	9/5/2014	0.0171	0.044	0.204	1.08	0.152	0.0646	1.14	0.177	0.119	0.773	0.201	0.0702	0	0.00536	0.0429	0.757	0.197	0.0344
9498-RU-140903-63-01	9/3/2014	0.0448	0.0815	0.216	1.17	0.185	0.0886	1.26	0.221	0.113	0.788	0.197	0.0619	0.0381	0.0473	0.0616	0.76	0.193	0.0326
9498-RU-140903-63-02	9/3/2014	0.0254	0.0635	0.215	1.13	0.162	0.0706	1.13	0.195	0.137	0.69	0.188	0.0649	0.0426	0.0493	0.0426	0.922	0.219	0.0342
9498-RU-140903-71-01	9/3/2014	0.0262	0.0231	0.213	1.07	0.176	0.103	1.2	0.233	0.12	1.52	0.423	0.178	0.0917	0.114	0.148	1.8	0.46	0.0785
9498-RU-140903-71-02	9/3/2014	0.0223	0.0957	0.21	0.964	0.141	0.0939	1.23	0.183	0.1	0.508	0.152	0.0629	0.0361	0.0448	0.0584	0.605	0.166	0.0468
9498-RU-140903-81-01	9/4/2014	0.0217	0.0251	0.222	1.02	0.153	0.0754	1.26	0.194	0.108	0.426	0.136	0.0304	-0.00236	0.00473	0.0574	0.354	0.123	0.0303
9498-RU-140903-82-01	9/5/2014	0.0265	0.0256	0.209	1.05	0.163	0.0753	1.17	0.183	0.137	0.687	0.179	0.0312	0.0235	0.037	0.059	0.499	0.15	0.0312
9498-RU-140903-82-02	9/5/2014	0.00615	0.0365	0.212	0.988	0.147	0.0706	1.21	0.181	0.109	0.5	0.151	0.0587	0	0.00481	0.0385	0.472	0.145	0.0469
9498-RU-140903-91-01	9/4/2014	0.0172	0.0316	0.208	1.15	0.175	0.0796	1.34	0.21	0.114	0.754	0.195	0.0717	0.0388	0.0482	0.0628	0.619	0.174	0.0332
9498-RU-140903-91-02	9/4/2014	0.0426	0.0227	0.213	1.05	0.172	0.0888	1.23	0.211	0.0863	0.643	0.178	0.0742	0.0221	0.0391	0.0706	0.776	0.196	0.0665
9498-RU-140903-92-01	9/5/2014	0.0127	0.0946	0.223	1.14	0.162	0.0692	1.23	0.186	0.115	0.713	0.21	0.0732	0.0142	0.0357	0.0798	0.844	0.229	0.0422
9498-RU-140903-92-02	9/5/2014	0.0224	0.0233	0.208	1.04	0.155	0.0724	1.21	0.175	0.0821	0.389	0.134	0.0552	0.0397	0.046	0.0397	0.55	0.16	0.0483
		Average			Average			Average			Average			Average			Average		
		0.021			1.051			1.176			0.611			0.028			0.656		
		St Dev			St Dev			St Dev			St Dev			St Dev			St Dev		
		0.013			0.121			0.131			0.206			0.020			0.251		
		Min			Min			Min			Min			Min			Min		
		-0.005			0.721			0.788			0.389			-0.002			0.354		
		Max			Max			Max			Max			Max			Max		
		0.045			1.270			1.340			1.520			0.092			1.800		

Table 3 – ProUCL Data Sets

Ra-226		Th-232		U-234		U-238	
Borrow	Reference	Borrow	Reference	Borrow	Reference	Borrow	Reference
1.1	1.15	1.09	1.15	0.498	0.671	0.518	0.724
1.15	0.719	1.31	0.749	0.539	0.353	0.573	0.379
1.23	1.04	0.932	0.936	0.746	0.518	0.739	0.723
1.14	1.01	1.12	0.962	0.82	0.39	0.796	0.591
1.22	0.995	1.31	0.948	0.59	0.345	0.446	0.421
0.721	0.858	0.788	0.831	0.408	0.512	0.61	0.453
1.03	1.03	1.31	0.979	0.504	0.832	0.557	0.632
0.862	1.08	1.04	0.768	0.508	0.484	0.505	0.493
0.99	1.17	1.26	1.16	0.481	0.571	0.561	0.757
0.948	0.972	1.22	0.977	0.577	0.606	0.703	0.575
0.931	1.22	1.22	1.14	0.432	0.747	0.601	0.997
0.946	1.02	1.14	0.978	0.596	0.724	0.48	0.744
1.08	1.05	0.812	0.889	0.585	0.705	0.796	0.607
0.929	0.805	1.18	0.871	0.434	0.434	0.472	0.594
1.08	1.32	1.27	1.07	0.554	0.513	0.601	0.835
1.09	1.19	1.19	1.1	0.606	0.639	0.646	0.844
1.18	1.34	1.21	1.19	0.538	0.808	0.583	0.745
0.846	1.26	1.26	1.01	0.547	1.12	0.47	0.71
1.27	1.07	1.19	0.982	0.577	1.04	0.731	0.705
1.08	0.922	1.14	1.21	0.773	0.829	0.757	0.981
1.17	1.13	1.26	1.37	0.788	1.14	0.76	0.994
1.13	1.2	1.13	1.39	0.69	1.09	0.922	0.992
1.07	1.23	1.2	0.99		0.887		0.959
0.964	1.08	1.23	1.21	0.508	0.73	0.605	0.764
1.02	1.31	1.26	1.05	0.426	1.16	0.354	0.956
1.05	1.28	1.17	1.39	0.687	0.871	0.499	0.895
0.988	1.08	1.21	0.955	0.5	0.842	0.472	0.708
1.15	0.96	1.34	0.851	0.754	0.744	0.619	0.787
1.05	1.06	1.23	1.1	0.643	0.572	0.776	0.986
1.14	1.06	1.23	1.17	0.713	0.598	0.844	0.758
1.04	1.03	1.21	0.954	0.389	0.772	0.55	0.828
	0.618				0.389		0.494

Appendix A

ProUCL Output – Wilcoxson-Mann-Whitney Tests

(4 Pages)

Appendix A

ProUCL Output – Wilcoxson-Mann-Whitney Tests

Page 1 of 4

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Users\zollersg\Desktop\Ra226IngrowthProUCL.xls.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0.180
Selected Null Hypothesis	Site or AOC Mean/Median >= Background Mean/Median Plus Substantial Difference, S (Form 2)
Alternative Hypothesis	Site or AOC Mean/Median Less Than Background Mean/Median Plus Substantial Difference, S

Area of Concern Data: Borrow
Background Data: Reference

Raw Statistics

	Site	Background
Number of Valid Observations	31	32
Number of Distinct Observations	26	28
Minimum	0.721	0.618
Maximum	1.27	1.34
Mean	1.051	1.071
Median	1.07	1.065
SD	0.121	0.168
SE of Mean	0.0218	0.0297

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC >= Mean/Median of Background + 0.18

Site Rank Sum W-Stat	645
WMW Test U-Stat	-4.764
WMW Critical Value (0.050)	-1.645
P-Value	9.5019E-7

Conclusion with Alpha = 0.05
Reject H0, Conclude Site < Background + 0.18
P-Value < alpha (0.05)

Appendix A

ProUCL Output – Wilcoxson-Mann-Whitney Tests

Page 2 of 4

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Users\zollersg\Desktop\Borrow\Th232FinalProUCLwoOutlier.xls.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0.300
Selected Null Hypothesis	Site or AOC Mean/Median >= Background Mean/Median Plus Substantial Difference, S (Form 2)
Alternative Hypothesis	Site or AOC Mean/Median Less Than Background Mean/Median Plus Substantial Difference, S

Area of Concern Data: Borrow

Background Data: Reference

Raw Statistics

	Site	Background
Number of Valid Observations	31	31
Number of Distinct Observations	19	28
Minimum	0.788	0.749
Maximum	1.34	1.39
Mean	1.176	1.043
Median	1.21	0.99
SD	0.131	0.168
SE of Mean	0.0234	0.0301

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC >= Mean/Median of Background + 0.3

Site Rank Sum W-Stat	700.5
WMW Test U-Stat	-3.879
WMW Critical Value (0.050)	-1.645
P-Value	5.2520E-5

Conclusion with Alpha = 0.05

Reject H0, Conclude Site < Background + 0.30

P-Value < alpha (0.05)

Appendix A

ProUCL Output – Wilcoxson-Mann-Whitney Tests

Page 3 of 4

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options	
From File	C:\Users\zollersg\Desktop\Borrow\U234ProUCLwoOutlier.xls.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0.590
Selected Null Hypothesis	Site or AOC Mean/Median >= Background Mean/Median Plus Substantial Difference, S (Form 2)
Alternative Hypothesis	Site or AOC Mean/Median Less Than Background Mean/Median Plus Substantial Difference, S

Area of Concern Data: Borrow
Background Data: Reference

Raw Statistics

	Site	Background
Number of Valid Observations	30	32
Number of Missing Values	1	0
Number of Distinct Observations	28	32
Minimum	0.389	0.345
Maximum	0.82	1.16
Mean	0.58	0.707
Median	0.566	0.715
SD	0.12	0.235
SE of Mean	0.022	0.0415

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC >= Mean/Median of Background + 0.59

Site Rank Sum W-Stat	465
WMW Test U-Stat	-6.754
WMW Critical Value (0.050)	-1.645
P-Value	7.182E-12

Conclusion with Alpha = 0.05
Reject H0, Conclude Site < Background + 0.59
P-Value < alpha (0.05)

Appendix A

ProUCL Output – Wilcoxson-Mann-Whitney Tests

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Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options	
From File	C:\Users\zollersg\Desktop\Borrow\U238ProUCLwoOutlier.xls.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0.370
Selected Null Hypothesis	Site or AOC Mean/Median >= Background Mean/Median Plus Substantial Difference, S (Form 2)
Alternative Hypothesis	Site or AOC Mean/Median Less Than Background Mean/Median Plus Substantial Difference, S

Area of Concern Data: Borrow
Background Data: Reference

Raw Statistics

	Site	Background
Number of Valid Observations	30	32
Number of Missing Values	1	0
Number of Distinct Observations	27	32
Minimum	0.354	0.379
Maximum	0.922	0.997
Mean	0.618	0.738
Median	0.601	0.745
SD	0.137	0.18
SE of Mean	0.025	0.0318

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC >= Mean/Median of Background + 0.37

Site Rank Sum W-Stat	480
WMW Test U-Stat	-6.543
WMW Critical Value (0.050)	-1.645
P-Value	3.017E-11

Conclusion with Alpha = 0.05
Reject H0, Conclude Site < Background + 0.37
P-Value < alpha (0.05)

Appendix B

ProUCL Output – Quantile Tests

(4 Pages)

Appendix B

ProUCL Output – Quantile Tests

Page 1 of 4

Non-parametric Quantile Hypothosis Test for Full Dataset (No NDs)

User Selected Options

From File	C:\Users\zollersg\Desktop\Borrow\Ra226IngrowthProUCL.xls.wst
Full Precision	OFF
Confidence Coefficient	95%
Null Hypothesis	Site or AOC Concentration Less Than or Equal to Background Concentration (Form 1)
Alternative Hypothesis	Site or AOC Concentration Greater Than Background Concentration

Area of Concern Data: Borrow

Background Data: Reference

Raw Statistics

	Site	Background
Number of Valid Observations	31	32
Number of Distinct Observations	26	28
Minimum	0.721	0.618
Maximum	1.27	1.34
Mean	1.051	1.071
Median	1.07	1.065
SD	0.121	0.168
SE of Mean	0.0218	0.0297

Quantile Test

H0: Site Concentration <= Background Concentration (Form 1)

Approximate R Value (0.056)	4
Approximate K Value (0.056)	4
Number of Site Observations in 'R' Largest	0
Calculated Alpha	0.0528

Conclusion with Alpha = 0.056

Do Not Reject H0, Perform Wilcoxon-Mann-Whitney Ranked Sum Test

Appendix B

ProUCL Output – Quantile Tests

Page 2 of 4

Non-parametric Quantile Hypothosis Test for Full Dataset (No NDs)

User Selected Options

From File	C:\Users\zollersg\Desktop\Borrow\Th232FinalProUCLwoOutlier.xls.wst
Full Precision	OFF
Confidence Coefficient	95%
Null Hypothesis	Site or AOC Concentration Less Than or Equal to Background Concentration (Form 1)
Alternative Hypothesis	Site or AOC Concentration Greater Than Background Concentration

Area of Concern Data: Borrow

Background Data: Reference

Raw Statistics

	Site	Background
Number of Valid Observations	31	31
Number of Distinct Observations	19	28
Minimum	0.788	0.749
Maximum	1.34	1.39
Mean	1.176	1.043
Median	1.21	0.99
SD	0.131	0.168
SE of Mean	0.0234	0.0301

Quantile Test

H0: Site Concentration <= Background Concentration (Form 1)

Approximate R Value (0.056)	4
Approximate K Value (0.056)	4
Number of Site Observations in 'R' Largest	1
Calculated Alpha	0.0564

Conclusion with Alpha = 0.056

Do Not Reject H0, Perform Wilcoxon-Mann-Whitney Ranked Sum Test

Appendix B

ProUCL Output – Quantile Tests

Page 3 of 4

Non-parametric Quantile Hypothosis Test for Full Dataset (No NDs)

User Selected Options	
From File	C:\Users\zollersg\Desktop\Borrow\U234ProUCLwoOutlier.xls.wst
Full Precision	OFF
Confidence Coefficient	95%
Null Hypothesis	Site or AOC Concentration Less Than or Equal to Background Concentration (Form 1)
Alternative Hypothesis	Site or AOC Concentration Greater Than Background Concentration

Area of Concern Data: Borrow

Background Data: Reference

Raw Statistics

	Site	Background
Number of Valid Observations	30	32
Number of Missing Values	1	0
Number of Distinct Observations	28	32
Minimum	0.389	0.345
Maximum	0.82	1.16
Mean	0.58	0.707
Median	0.566	0.715
SD	0.12	0.235
SE of Mean	0.022	0.0415

Quantile Test

H0: Site Concentration <= Background Concentration (Form 1)

Approximate R Value (0.056)	4
Approximate K Value (0.056)	4
Number of Site Observations in 'R' Largest	0
Calculated Alpha	0.0491

Conclusion with Alpha = 0.056

Do Not Reject H0, Perform Wilcoxon-Mann-Whitney Ranked Sum Test

Appendix B

ProUCL Output – Quantile Tests

Page 4 of 4

Non-parametric Quantile Hypothosis Test for Full Dataset (No NDs)

User Selected Options	
From File	C:\Users\zollersg\Desktop\Borrow\U238ProUCLwoOutlier.xls.wst
Full Precision	OFF
Confidence Coefficient	95%
Null Hypothesis	Site or AOC Concentration Less Than or Equal to Background Concentration (Form 1)
Alternative Hypothesis	Site or AOC Concentration Greater Than Background Concentration

Area of Concern Data: Borrow

Background Data: Reference

Raw Statistics

	Site	Background
Number of Valid Observations	30	32
Number of Missing Values	1	0
Number of Distinct Observations	27	32
Minimum	0.354	0.379
Maximum	0.922	0.997
Mean	0.618	0.738
Median	0.601	0.745
SD	0.137	0.18
SE of Mean	0.025	0.0318

Quantile Test

H0: Site Concentration <= Background Concentration (Form 1)

Approximate R Value (0.056)	4
Approximate K Value (0.056)	4
Number of Site Observations in 'R' Largest	0
Calculated Alpha	0.0491

Conclusion with Alpha = 0.056

Do Not Reject H0, Perform Wilcoxon-Mann-Whitney Ranked Sum Test

Appendix C

Retrospective Power Curves

(4 Pages)

Appendix C

Retrospective Power Curves

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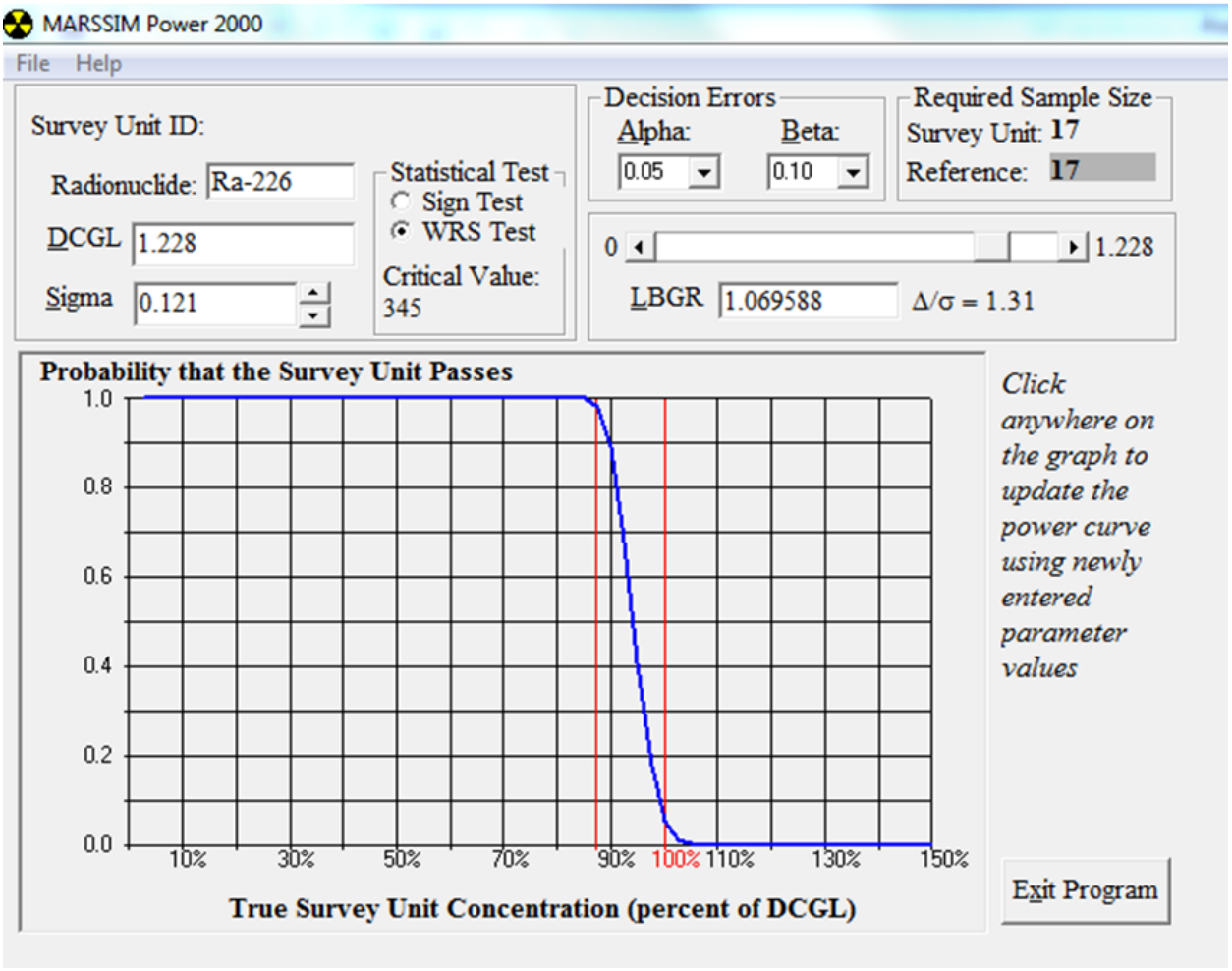
Ra-226 Retrospective Power Curve



Appendix C

Retrospective Power Curves

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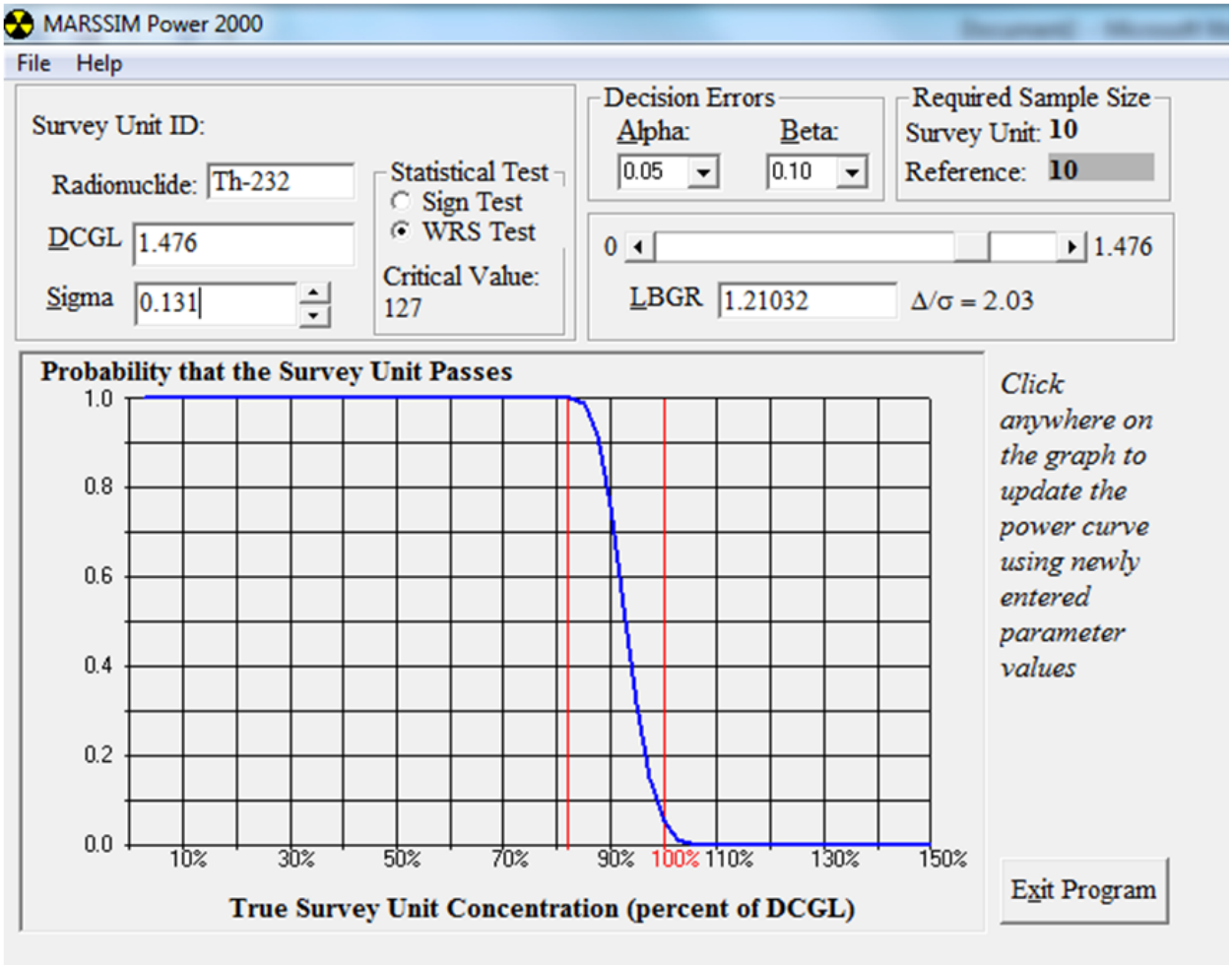
Th-232 Retrospective Power Curve



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Retrospective Power Curves

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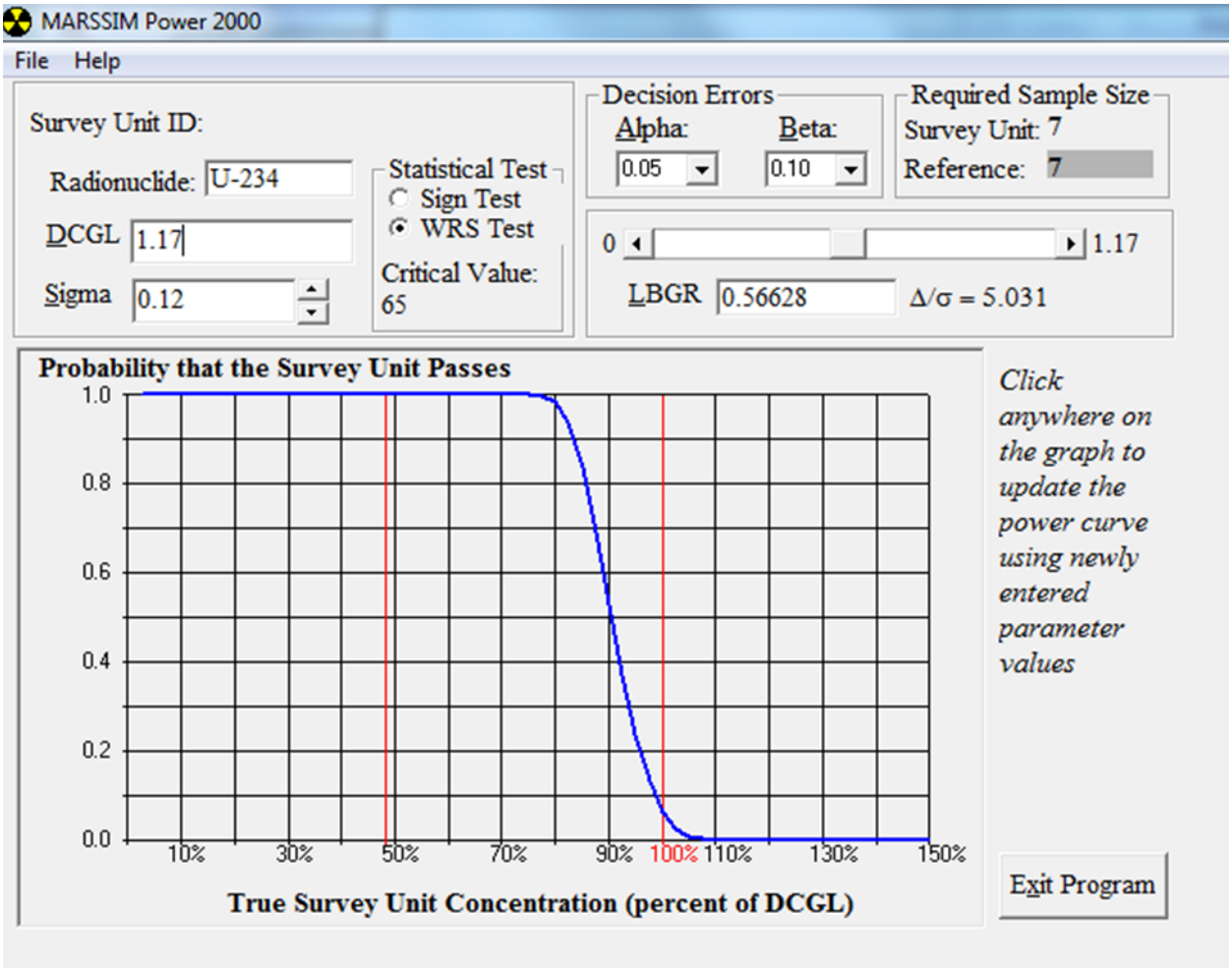
U-234 Retrospective Power Curve



Appendix C

Retrospective Power Curves

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U-238 Retrospective Power Curve