A Field Test of Electret Ion Chambers for Environmental Remediation Verification at the SL-1 Burial Grounds

Luke R. Paulus, Health Physicist
Douglas W. Walker, Health Physicist
State of Idaho, INEEL Oversight Program

KC Thompson, Health Physicist
Bechtel BWXT Idaho, LLC

Idaho Falls Office	Boise Office	World Wide Web
900 N. Skyline Dr. Ste C Idaho Falls, ID 83402 Ph. (208) 528-2600 Fax: (208) 528-2605	1410 N. Hilton Boise, ID 83706 Ph. (208) 373-0498 Fax: (208) 373-0429	http://www.oversight.state.id.us Toll Free: 1-800-232-4635

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ABSTRACT

In 1999, the state of Idaho INEEL Oversight Program (INEEL OP) performed a field test to determine if electret ion chambers could be used as a replacement to soil sampling in field survey releases at a remediated, radioactively contaminated site. This study compared exposure rates measured using electret ion chambers with gamma spectroscopic analysis results of soil samples collected at the remediated site. Exposure rate measurements were made in 1999 using electret ion chambers at the same locations that INEEL OP sampled soil in 1998 following MARSSIM protocol. The waste site was divided into nine survey units based on site history including previous site surveys and physical boundaries. Exposure rate measurements at the remediation site compared well with exposure rate measurements made at reference background locations used for routine environmental monitoring by INEEL OP indicating that the remedial action met cleanup criteria. A poor correlation between exposure rate measurements and ^{137}Cs concentrations and other discrepancies were observed during this study with respect to measurements made during the 1998 final site survey.

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INTRODUCTION

In 1998, the state of Idaho INEEL Oversight Program (INEEL OP) employed the methodology described in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) to survey the status of a remediation and radioactive waste disposal site at the Idaho National Engineering and Environmental Laboratory (INEEL). INEEL OP conducted this survey to determine the usefulness of MARSSIM for verifying INEEL field measurements; evaluating whether remedial activities had reduced ^{137}Cs contamination levels to below a predetermined criterion.

The Record of Decision (ROD) for the Stationary Low-Power Reactor-1 (SL-1) Burial Grounds (INEL 1996) established risk-based, clean-up criteria for the burial grounds for the homogeneous distribution of radionuclides in 2,800 m^3 of soil. The primary risk drivers were ^{137}Cs and its gamma-emitting progeny ^{137m}Ba. Exposure rates were calculated assuming a homogeneous distribution of radionuclides in the top 10 centimeters of soil. Clean-up criteria were established assuming an individual could reside at the remediation site after 2099 and that the Department of Energy (DOE) would lose administrative control of the contaminated area at that time. The risk to an individual residing on the contaminated soil for a period of 30 years was estimated from exposure rates at a height of 0.8 meters above the ground. During that 30-year period, the individual was assumed to be present at the location for 250 days per year, 24 hours per day. Clean-up criteria were set such that the individual would receive no more than 150 μSv (15 mrem) per year from the contamination (Holdren et al. 1995).

The INEEL OP conducted a final site survey in 1998 to compare MARSSIM characterization with global positioning radiometric scanner analyses performed by Lockheed Martin Idaho Technologies Company (LMITCO). During the course of the 1998 survey, soil samples were collected at 128 accessible locations within the SL-1 burial ground. The trench and pits are mounded over with additional backfill to facilitate precipitation runoff and covered with a barrier of large rectangular rocks making these areas inaccessible for soil sampling. Soil samples were analyzed via gamma spectroscopy for ^{137}Cs and compared to gamma spectroscopic analysis results of reference background soil samples collected at offsite background locations.

Since the primary risk attributed to contamination at the SL-1 burial grounds is assumed to be due to external exposure from ^{137m}Ba (radioactive progeny of ^{137}Cs), passive radiation dosimeters were deployed to ascertain applicability of dosimeters for verifying remediation measurements. For routine environmental monitoring, thermoluminescent dosimeters (TLDs) are most commonly used to make integrated exposure measurements. Studies conducted by INEEL OP and others (Fjeld et al., 1994) indicate that the Electret Ion Chamber (EIC) is an acceptable alternative to TLD for integrated exposure measurements. In July 1999, INEEL OP deployed 128 E-PERM™ EICs at the INEEL SL-1 burial grounds.

Since ^{137}Cs is the primary risk driver, the average dose equivalent of 15 mrem (150 μSv) per year in 2099 corresponds to an average exposure rate of 17 μR h^{-1} (1.22 pC kg^{-1} s^{-1}) above typical background exposure rates in 1999. This considers the radioactive decay of ^{137}Cs and assumes an exposure of 1 Roentgen (1 R or 2.58 x 10^{-4} C kg^{-1} s^{-1}) corresponds to a tissue kerma of about 0.97-rad (9.7-mGy). The typical environmental exposure rates measured using EICs from routine environmental monitoring have ranged from 10 to 22 μR h^{-1} (0.72 to 1.58 pC kg^{-1} s^{-1}) with a median value of approximate 17 μR h^{-1} (1.22 pC kg^{-1} s^{-1}) when deployed for 60 to 90 days. Thus an additional 17 μR h^{-1} (1.22 pC kg^{-1} s^{-1}) above background should be readily measurable.

METHODS AND MATERIALS

A triangular sampling grid was established for the 1998 final site survey for collecting soil samples (Briggs et al., 1999, Schilk et al., 2000). The area was segregated into nine distinct units and 128 sampling locations were determined on the triangular sampling grid. These same grid locations were used to place the EICs. Measurement locations were described using a unique identification number consisting of the survey unit number and location number within that survey unit. Seventeen reference background measurements were collected during the same time period along the southern and eastern boundaries of the INEEL for a period of 90 days. The survey area (**Figure 1**) includes two pits and a burial trench encompassing an area approximately 90-m by 180-m (200 feet x 600 feet).

Electret Ion Chambers[1] (**Figure 2**) used for this study are comprised of an electrically charged disk (electret) placed inside an air-filled chamber. Ionization events within the air-filled chamber partially discharge the electret. The decrease in electret voltage is proportional to the exposure. The air-filled chambers of the EICs are composed of electrically conducting plastic (carbon-filled polypropylene), which offers a nearly air-equivalent response (Redmond et al., 1996).

EICs were used to measure total exposure over the deployment period. The actual exposure received as a result of the ^{137}Cs contamination present in the SL-1 burial ground soil can be estimated by subtracting exposure from the natural radionuclides in the soil and cosmic radiation from the total exposure.

[1] E-PERM™ electret ion chambers used for this study were manufactured by Rad Elec, Inc., Frederick, MD.

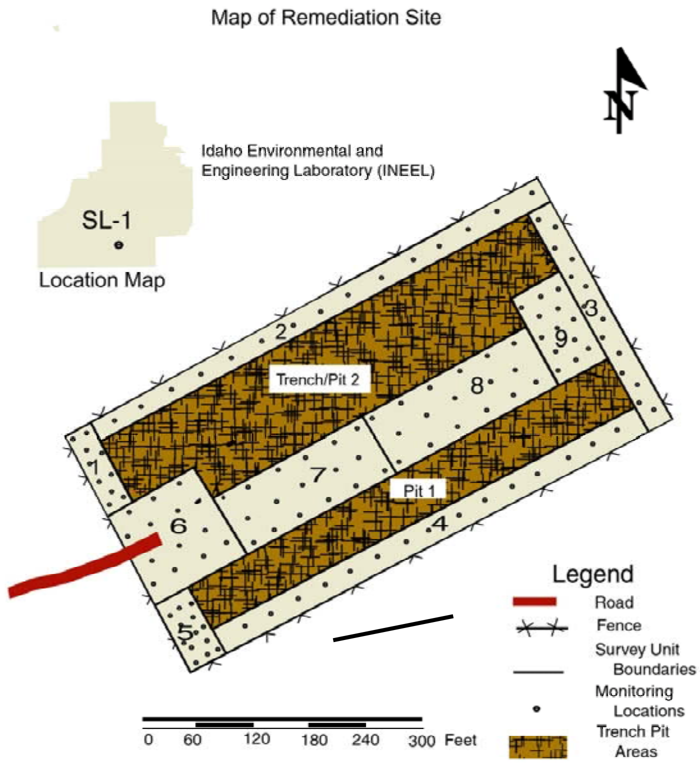

Figure 1. Map of SL-1 Burial Ground with corresponding survey unit and monitoring locations.

The EICs provide a cumulative exposure measured over the deployment period and an average exposure rate. This averages the effect of possible "hot spots" or discrete particles of radioactive contamination in the survey area and accounts for a larger field of view. The variability in ^{137}Cs concentrations observed in soil samples collected during the 1998 Final Site Survey suggests the presence of "hot spots" in the survey area (Briggs et al., 1999, Schilk et al., 2000). Each soil sample collected in the 1998 Final Site Survey covered a surface area of approximately 0.04 m^2. The EIC, however, should be capable of measuring the cumulative exposure from gamma and x-ray photon-emitting radionuclides averaged over a much larger surface area.

Initial electret voltage measurements were made at the INEEL OP office in Idaho Falls. Each assembled EIC (chamber and electret) was then sealed in a Mylar bag to minimize the effects of radon on the exposure measurements. The Mylar bags were subsequently sealed in labeled Tyvek envelopes to protect the EIC and the Mylar from weather. Immediately prior to deployment, 6.3-mm diameter steel posts 122-cm in length were placed in the ground at each monitoring location used during 1998 soil sampling. Posts were driven into the ground by hand with a fence post driver. The 92-cm length of the driver was used as a guide to ensure proper and consistent height of the steel post. Tyvek envelopes containing the EICs were attached to the steel posts such that each EIC was positioned 80-cm above the ground.

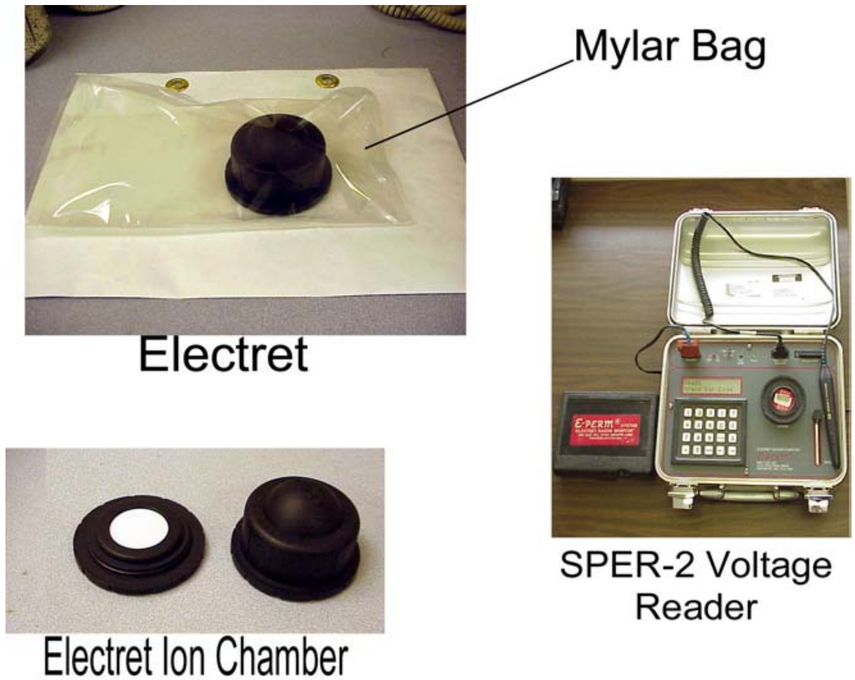

Figure 2. Electret Ion Chambers (EICs), electret, and electret voltage reader used for this study.

After 65-days, EICs were collected from the SL-1 Burial Grounds and electret voltages were measured at the INEEL OP office in Idaho Falls. Corresponding exposure rates were calculated and corrected to standard temperature and pressure and corrected for radon gas trapped in the chamber. Exposure rates measured in the survey area were compared to the reference background measurements.

Following MARSSIM guidance and the ROD, a Derived Concentration Guideline Level (DCGL) for the 1998 survey for ^{137}Cs concentrations in soil was set at 17 pCi g^{-1} (630 Bq kg^{-1}). A corresponding exposure rate correcting for the radioactive decay of ^{137}Cs is 34 μR h^{-1} (2.44 pC kg^{-1} s^{-1}). Assumptions used to verify cleanup measurements included α and β values of 0.05 (95% confidence interval to avoid Type I errors and Type II errors) and a Lower Bound to the Gray Region (LBGR) of half the DCGL or 17 μR h^{-1} (1.22 pC kg^{-1} s^{-1}). Using the MARSSIM guidance, specifically the Wilcoxon-Rank Sum test and accounting for measurement uncertainty of the EICs, the null hypothesis (H_N) statement and alternative hypothesis (H_A) statements were defined as follows:

> H_N: If the remedial action has not met cleanup criteria, the median EIC response for each survey unit will be greater than 34 μR h^{-1} (2.44 pC kg^{-1} s^{-1}) with a sample standard deviation greater than 3.9 μR h^{-1} (0.28 pC kg^{-1} s^{-1}).
>
> H_A: If the remedial action has met cleanup criteria, the median EIC response for each survey unit will be less than 34 μR h^{-1} (2.44 pC kg^{-1} s^{-1}) with a sample standard deviation less than 3.9 μR h^{-1} (0.28 pC kg^{-1} s^{-1}).

RESULTS AND DISCUSSION

Average exposure rate measurements from the reference background locations and the nine survey units including the sample standard deviation and median exposure rate measurements are shown in **Table 1**. Exposure rate measurements from the SL-1 Burial Grounds ranged from 11.1 to 38.1 μR h^{-1} (0.80 to 2.73 pC kg^{-1} s^{-1}). Reference background exposure rate measurements ranged from 14.9 to 29.2 μR h^{-1} (1.07 to 2.09 pC kg^{-1} s^{-1}). Median exposure rate measurements from the individual survey units ranged from 16.7 to 20.8 μR h^{-1} (1.20 to 1.49 pC kg^{-1} s^{-1}) and the median exposure rate measurement from the reference background was 18.8 μR h^{-1} (1.35 pC kg^{-1} s^{-1}). The 1998 Final Site Survey indicated ^{137}Cs concentrations in soil ranging from -0.1 to 61.4 pCi g^{-1} (–4 to 2273 Bq kg^{-1}) (Briggs et al., 1999, Schilk et al., 2000). Exposure rate measurements from the individual survey units and the corresponding ^{137}Cs concentrations measured in the soil samples collected in the individual survey units are listed in **Appendix A**.

Table 1. Average Exposure Rate Measurements from the Reference Background and Individual Survey Units. All measurements in μR h^{-1}.

	Mean	Sample Standard Deviation	Median
Reference Background	19.6	3.9	19.1
Survey Unit 1	20.3	3.2	20.0
Survey Unit 2	20.1	3.7	20.8
Survey Unit 3	19.4	2.2	19.1
Survey Unit 4	20.4	2.9	20.1
Survey Unit 5	16.8	1.2	16.7
Survey Unit 6	19.7	6.3	17.6
Survey Unit 7	19.2	3.3	18.2
Survey Unit 8	18.0	1.8	17.5
Survey Unit 9	20.1	4.0	18.9

According to the MARSSIM guidance, a survey unit meets the DCGL if sample population distribution of the measurements collected from that survey unit can be shown to be similar to those collected from the reference background area with the reference measurements adjusted by the DCGL. A quantile plot is used as a non-parametric, qualitative tool to compare the median values of two distinct data sets that may or may not be distributed normally. **Figure 3** is the quantile plot of ^{137}Cs concentration in the soil samples collected from the SL-1 Burial Grounds in 1998. The quantile plot demonstrates the distribution of ^{137}Cs concentrations as a function of their rank (or percentile) with respect to the sample distribution.

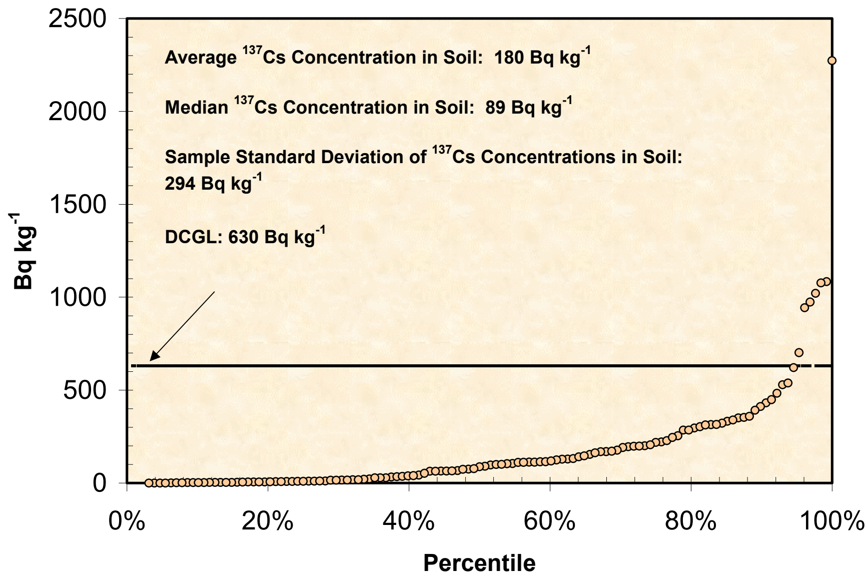

Figure 3. Quantile plot of ^{137}Cs concentrations in soil samples collected during the 1998 Final Site Survey by the State of Idaho INEEL Oversight Program. Eight sampling locations measured ^{137}Cs concentrations in soil exceeding the 17 pCi g^{-1} clean-up criterion.

The quantile plot for soil samples indicates that 94% of the samples have ^{137}Cs concentrations less than 17 pCi g^{-1} (630 Bq kg^{-1}). But, there are several soil samples with ^{137}Cs concentrations in excess of 17 pCi g^{-1} (630 Bq kg^{-1}). As indicated in the 1998 Final Site Survey, the ^{137}Cs contamination distribution is not homogeneous throughout the SL-1 Burial Grounds.

The ROD also assumed that the primary risk driver is external radiation exposure (i.e., the gamma-emitting progeny of ^{137}Cs, ^{137m}Ba). With ^{137}Cs as the primary risk driver, there should be a correlation between ^{137}Cs concentrations and gross exposure rates. **Figure 4** shows a plot of exposure rates as a function of ^{137}Cs concentrations in soil samples collected from the same locations. The trend line of this plot indicates "background" exposure rates ranging from 19 to 22 μR h^{-1} (1.36 to 1.59 pC kg^{-1} s^{-1}). The correlation coefficient (R^2 = 0.0158) indicates essentially no relationship between ^{137}Cs concentrations and exposure rates within the SL-1 Burial Grounds. This suggests that ^{137}Cs concentrations in soil provide a minor, if any, contribution to total exposure measured or that ^{137}Cs concentrations in the soil are not homogeneously distributed, but rather is present as discrete particles.

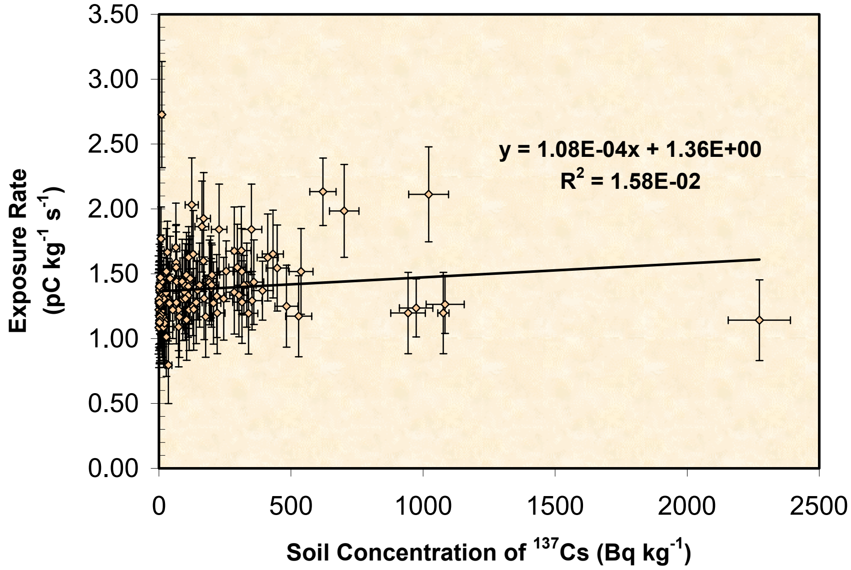

Figure 4. Comparison of ^{137}Cs concentrations in soil samples and exposure rate measurements performed at the same locations using electret ion chambers. Error bars represent 2-sigma measurement uncertainty for the exposure rate and 2-sigma counting uncertainty for ^{137}Cs soil concentrations.

Quantile plots for the exposure rate measurements made using EICs deployed in the SL-1 Burial Grounds and the exposure rate measurements from the reference background locations are shown in **Figure 5**. The quantile plot demonstrates the distribution of exposure rates as a function of their rank (or percentile) with respect to the sample distributions for the reference background and the survey unit. Based upon this plot, it is difficult to distinguish between the exposure rates measured within the SL-1 Burial Grounds and exposure rates measured at reference background locations. The Burial Grounds had an average exposure rate of 19.3 μR h^{-1} (1.38 pC kg^{-1} s^{-1}), median of 18.6 μR h^{-1} (1.33 pC kg^{-1} s^{-1}), and a standard deviation of 3.5 μR h^{-1} (0.25 pC kg^{-1} s^{-1}). The Reference Background had an average exposure rate of 19.6 μR h^{-1} (1.40 pC $kg^{-1}s^{-1}$), median of 19.1 μR h^{-1} (1.37 pC kg^{-1} s^{-1}), and a sample standard deviation of 3.9 μR h^{-1} (0.28 C kg^{-1} s^{-1}). Treating the entire SL-1 Burial Ground as a single survey unit meets the alternative hypothesis or the acceptance criteria and voids the null hypothesis.

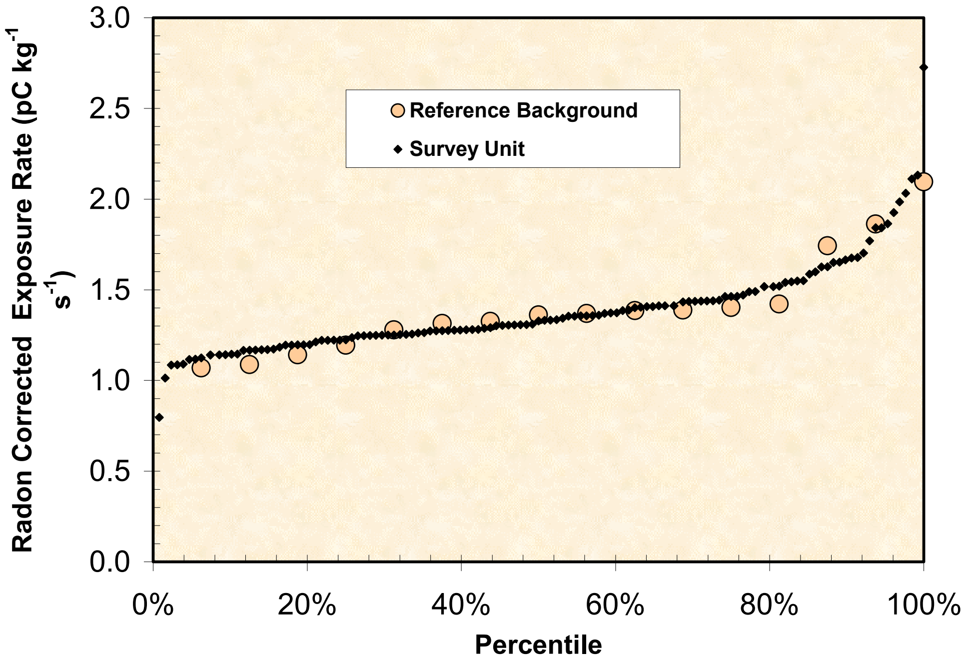

Figure 5. Quantile plot of gross exposure rate measurements (μR h^{-1}) made at the SL-1 Burial Grounds in 1999 and the Reference Background using electret ion chambers.

Comparison between EIC survey data and soil sampling results show relatively good agreement with respect to MARSSIM criteria. The 1998 survey indicated that the null hypothesis could not be rejected in survey units 1 and 6. The EIC measurements indicated that the null hypothesis could not be rejected in survey unit 6 due to a relatively large standard deviation of measurements. The 1998 survey indicated that several of the samples collected in unit 6 had ^{137}Cs concentrations that exceeded the DCGL suggesting a need for further site characterization. But when the entire SL-1 Burial Ground is treated as a single survey unit, the alternate hypothesis statement holds true and the null hypothesis can be rejected.

CONCLUSION

In terms of implementing EICs for Final Status Surveys following MARSSIM guidance, the EICs may provide opportunity for a complete coverage surface scan that allows for a accurate measurement of average exposure rates within the survey area. This in turn, provides a more realistic assessment of the extent of exposure due to ^{137}Cs contamination than do soil samples with their limited geographic coverage. EICs may also be appropriate for such surveys involving contamination from other radionuclides where external radiation is the principal risk driver. In situations where the primary risk to contamination is attributed to external exposure, *in-situ* screening techniques (e.g, *in-situ* gamma spectroscopy or environmental dosimetry) may be appropriate in lieu of collecting soil samples.

There was no distinct correlation between exposure rate measurements and concentrations of ^{137}Cs in soil samples. Variations were expected since the EIC has a much larger field of view due to its positioning above the soil surface than the soil sampling method used, and since ^{137}Cs contamination is likely found in the form of discrete radioactive particles (Briggs et al., 1999, Schilk et al., 2000).

The lack of correlation between EIC exposure rate measurements and ^{137}Cs concentrations in soil samples collected during the previous final site survey suggests the likely presence of "hot spots" within the survey area. This also indicates that ^{137}Cs soil concentrations at the Burial Grounds are a minor contributor to total exposure.

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Appendix A

Table A-1. Reference Background measurements. Measurements given in both SI units (pico Coulombs per kilogram per second) and traditional exposure rate units (micro Roentgen per hour).

Reference Background Location	**Reference Background ($pC\ kg^{-1}\ s^{-1}$)**	**Reference Background ($\mu R\ h^{-1}$)**
Rover Tower	1.09 ± 0.22 [a]	15.2 ± 3.0 [a]
Rover Tower	1.39 ± 0.23	19.4 ± 3.2
Rover Tower	1.38 ± 0.23	19.3 ± 3.2
Rover Rd 4.9 mi.	1.28 ± 0.23	17.9 ± 3.2
Rover Rd 6.3 mi.	1.33 ± 0.23	18.5 ± 3.2
Rover Rd 6.8 mi.	1.74 ± 0.26	24.3 ± 3.6
Rover Rd 8.8 mi.	1.36 ± 0.23	19.0 ± 3.2
Rover Rd 10.8 mi.	2.09 ± 0.28	29.2 ± 3.9
Rover Rd 15.4 mi.	1.86 ± 0.26	26.0 ± 3.7
Hwy 20 MP264	1.31 ± 0.23	18.3 ± 3.1
Hwy 20 MP266	1.14 ± 0.22	15.9 ± 3.0
Hwy 20 MP268	1.42 ± 0.23	19.8 ± 3.2
Hwy 20 MP270	1.40 ± 0.23	19.6 ± 3.2
Hwy 20 MP272	1.19 ± 0.22	16.7 ± 3.0
Hwy 20 MP274	1.07 ± 0.21	14.9 ± 3.0
Hwy 20 MP276	1.37 ± 0.23	19.1 ± 3.2
Average Value ± Standard Deviation:	**1.40 ± 0.28** [b]	**19.6 ± 3.9** [b]
Median Value:	**1.37**	**19.1**

[a] 2-sigma measurement uncertainty
[b] sample standard deviation

Table A-2. Reference Background ^{137}Cs concentrations in Soil used in the 1998 Survey

Location		**^{137}Cs in soil (pCi g^{-1})**
Main Gate		0.378 ± 0.017 [a]
Rover		0.581 ± 0.018
Sand Dunes		0.381 ± 0.027
Atomic City		0.177 ± 0.018
Big Southern Butte		0.987 ± 0.041
Idaho Falls		0.160 ± 0.016
Big Lost River Rest Area		0.137 ± 0.015
Base of Howe Peak		0.495 ± 0.031
Howe		0.227 ± 0.019
Mud Lake		0.505 ± 0.022
Monteview		0.220 ± 0.019
	Average:	**0.386 ± 0.252** [b]
	Median:	**0.378**

[a] 2-sigma counting uncertainty
[b] sample standard deviation

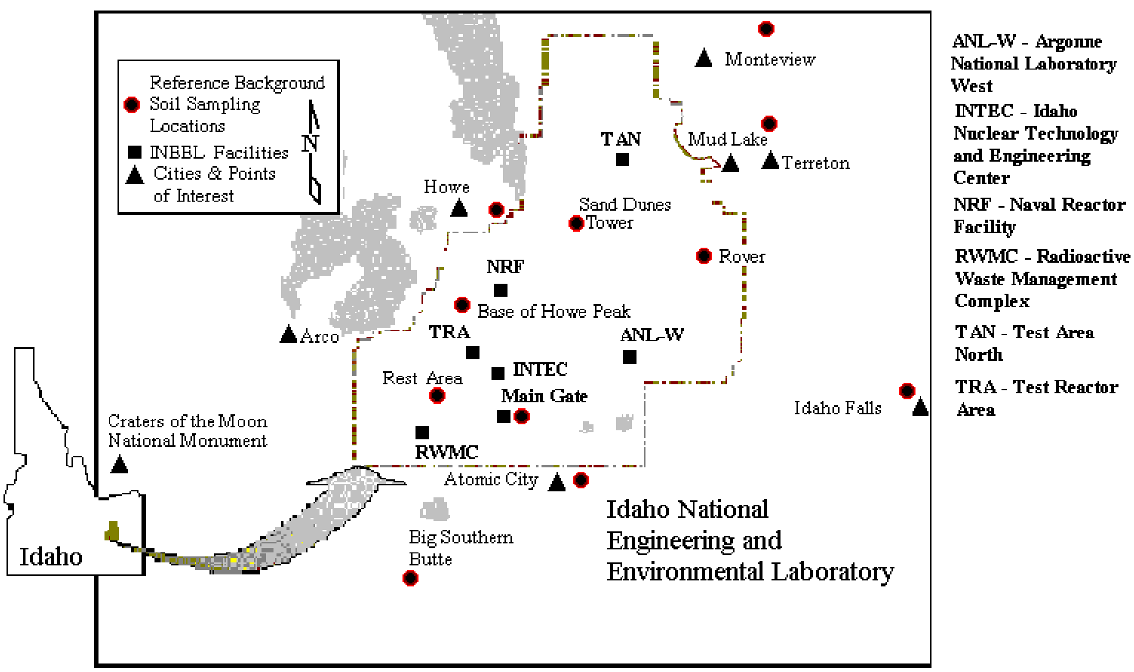

Figure 6. Approximate locations of reference background soil samples collected for the 1998 Final Status Survey at SL-1.

Table A-3.1. ^{137}Cs in soil samples from the individual sampling locations in survey units 1, 2, and 3 collected in 1998 and the corresponding exposure rate measurement made using EICs in 1999.

Unit	^{137}Cs in soil ($pCi\ g^{-1}$)	Exposure ($\mu R\ h^{-1}$)	Unit	^{137}Cs in soil ($pCi\ g^{-1}$)	Exposure ($\mu R\ h^{-1}$)	Unit	^{137}Cs in soil ($pCi\ g^{-1}$)	Exposure ($\mu R\ h^{-1}$)
1-1	3.0 ± 0.6 [a]	22.7 ± 3.3 [b]	2-1	1.8 ± 0.4 [a]	22.1 ± 3.3 [b]	3-1	10.6 ± 1.1 [a]	19.1 ± 3.2 [b]
1-2	4.6 ± 0.7	26.9 ± 4.9	2-2	8.0 ± 0.8	21.6 ± 4.6	3-2	2.4 ± 0.5	18.2 ± 4.4
1-3	2.8 ± 0.5	16.0 ± 4.3	2-3	9.5 ± 1.0	25.7 ± 4.9	3-3	0.1 ± 0.2	18.9 ± 4.5
1-4	0.0 ± 0.2	15.1 ± 4.3	2-4	11.7 ± 1.1	23.1 ± 4.7	3-4	6.0 ± 0.8	16.7 ± 4.4
1-5	0.2 ± 0.2	19.3 ± 4.5	2-5	3.0 ± 0.6	20.0 ± 4.5	3-5	14.3 ± 1.3	16.4 ± 4.4
1-6	4.6 ± 0.7	22.3 ± 3.3	2-6	5.4 ± 0.8	20.8 ± 3.2	3-6	9.5 ± 1.0	18.0 ± 3.1
1-7	5.3 ± 0.7	20.4 ± 4.6	2-7	7.7 ± 0.9	18.9 ± 4.5	3-7	3.1 ± 0.6	17.0 ± 4.4
1-8	9.0 ± 1.0	19.7 ± 4.5	2-8	4.2 ± 0.7	19.7 ± 4.5	3-8	0.3 ± 0.2	20.1 ± 4.5
1-9	8.5 ± 0.9	21.2 ± 4.6	2-9	12.1 ± 1.1	21.5 ± 4.6	3-9	14.5 ± 1.2	21.2 ± 4.6
1-10	5.2 ± 0.7	20.0 ± 4.5	2-10	11.1 ± 1.1	22.7 ± 4.7	3-10	7.7 ± 0.9	23.4 ± 4.7
1-11	5.4 ± 0.7	19.4 ± 3.2	2-11	0.9 ± 0.3	23.2 ± 3.3	3-11	8.7 ± 1.0	19.7 ± 3.2
Mean:	**4.4 ± 2.9** [c]	**20.3 ± 3.2** [c]	2-12	0.9 ± 0.3	18.2 ± 4.4	3-12	3.5 ± 0.6	23.0 ± 4.7
Median:	**4.6**	**20.0**	2-13	2.6 ± 0.6	19.0 ± 4.5	3-13	2.8 ± 0.5	20.8 ± 4.6
			2-14	0.8 ± 0.3	14.1 ± 4.3	**Mean:**	**6.4 ± 4.9** [c]	**19.4 ± 2.2** [c]
			2-15	1.0 ± 0.4	11.1 ± 4.1	**Median:**	**6.0**	**19.1**
			Mean:	**5.4 ± 4.3** [c]	**20.1 ± 3.7** [c]			
			Median:	**4.2**	**20.8**			

[a] 2-sigma counting uncertainty.
[b] 2-sigma measurement uncertainty.
[c] sample standard deviation.

Table A-3.2. ^{137}Cs in soil samples from the individual sampling locations in survey units 4, 5, and 6 collected in 1998 and the corresponding exposure rate measurement made using EICs in 1999.

Unit	^{137}Cs in soil (pCi g^{-1})	Exposure (μR h^{-1})	Unit	^{137}Cs in soil (pCi g^{-1})	Exposure (μR h^{-1})	Unit	^{137}Cs in soil (pCi g^{-1})	Exposure (μR h^{-1})
4-1	0.2 ± 0.2 [a]	24.7 ± 3.4 [b]	6-1	0.3 ± 0.2 [a]	16.9 ± 3.1 [b]	5-1	0.0 ± 0.2 [a]	18.0 ± 3.1 [b]
4-2	0.8 ± 0.3	21.2 ± 4.6	6-2	0.2 ± 0.2	18.9 ± 4.5	5-2	0.3 ± 0.2	16.3 ± 4.4
4-3	1.7 ± 0.4	23.8 ± 4.8	6-3	3.0 ± 0.5	18.6 ± 4.5	5-3	-0.1 ± 0.2	16.7 ± 4.4
4-4	1.7 ± 0.5	21.5 ± 4.6	6-4	1.0 ± 0.4	17.8 ± 4.4	5-4	0.5 ± 0.3	15.2 ± 4.3
4-5	1.8 ± 0.4	21.6 ± 4.6	6-5	0.4 ± 0.2	17.5 ± 4.4	5-5	0.4 ± 0.2	16.0 ± 4.3
4-6	1.8 ± 0.4	20.1 ± 3.2	6-6	26.3 ± 1.7	17.3 ± 3.1	5-6	0.1 ± 0.2	15.9 ± 3.1
4-7	1.8 ± 0.4	17.8 ± 4.4	6-7	25.5 ± 1.8	16.7 ± 4.4	5-7	0.4 ± 0.3	17.5 ± 4.4
4-8	2.0 ± 0.5	15.2 ± 4.3	6-8	0.3 ± 0.2	38.1 ± 5.7	5-8	0.6 ± 0.3	15.9 ± 4.3
4-9	2.4 ± 0.5	20.1 ± 4.5	6-9	27.6 ± 2.0	29.5 ± 5.1	5-9	4.8 ± 0.7	16.3 ± 4.4
4-10	6.2 ± 0.8	25.7 ± 4.9	6-9	61.4 ± 3.2	15.9 ± 4.3	5-10	0.0 ± 0.1	17.1 ± 4.4
4-11	6.9 ± 0.8	21.2 ± 3.3	6-11	29.3 ± 1.9	17.6 ± 3.1	5-11	-0.1 ± 0.2	19.6 ± 3.2
4-12	5.4 ± 0.8	19.7 ± 4.5	6-12	29.1 ± 0.6	16.7 ± 4.4	5-12	0.1 ± 0.2	17.9 ± 4.4
4-13	13.1 ± 1.2	17.4 ± 4.4	6-13	0.6 ± 0.3	15.6 ± 4.3	5-13	9.2 ± 1.0	16.7 ± 4.4
4-14	8.2 ± 0.9	18.6 ± 4.5	6-14	0.2 ± 0.2	18.6 ± 4.5	**Mean:**	**1.2 ± 2.7** [c]	**16.8 ± 1.2** [c]
4-15	8.5 ± 1.0	17.9 ± 4.4	**Mean:**	**14.7 ± 18.8** [c]	**19.7 ± 6.3** [c]	**Median:**	**0.3**	**16.7**
Mean:	**4.2 ± 3.7** [c]	**20.4 ± 2.9** [c]	**Median:**	**2.0**	**17.6**			
Median:	**2.0**	**20.1**						

[a] 2-sigma counting uncertainty.
[b] 2-sigma measurement uncertainty.
[c] sample standard deviation.

Table A-3.3. ^{137}Cs in soil samples from the individual sampling locations in survey units 7, 8, and 9 collected in 1998 and the corresponding exposure rate measurement made using EICs in 1999.

Unit	^{137}Cs in soil (pCi g^{-1})	Exposure (μR h^{-1})	Unit	^{137}Cs in soil (pCi g^{-1})	Exposure (μR h^{-1})	Unit	^{137}Cs in soil (pCi g^{-1})	Exposure (μR h^{-1})
7-1	3.5 ± 0.7 [a]	17.4 ± 3.1 [b]	8-1	0.0 ± 0.2 [a]	18.2 ± 3.1 [b]	9-1	0.1 ± 0.2 [a]	17.6 ± 3.1 [b]
7-2	2.7 ± 0.5	18.2 ± 4.5	8-2	0.1 ± 0.2	16.3 ± 4.4	9-2	0.0 ± 0.1	17.5 ± 4.4
7-3	0.4 ± 0.2	16.3 ± 4.4	8-3	0.2 ± 0.2	17.4 ± 4.4	9-3	0.2 ± 0.2	18.9 ± 4.5
7-4	0.0 ± 0.1	15.6 ± 4.3	8-4	0.0 ± 0.2	17.8 ± 4.4	9-4	0.8 ± 0.3	18.9 ± 4.5
7-5	0.5 ± 0.3	18.2 ± 4.5	8-5	0.3 ± 0.2	17.5 ± 4.4	9-5	0.1 ± 0.2	17.8 ± 4.4
7-6	0.2 ± 0.3	16.5 ± 3.1	8-6	0.2 ±0.2	17.4 ± 3.1	9-6	0.1 ± 0.2	19.2 ± 3.2
7-7	6.6 ± 0.9	18.2 ± 4.5	8-7	0.1 ± 0.2	15.9 ± 4.3	9-7	0.1 ± 0.1	19.6 ± 4.5
7-8	3.1 ± 0.6	20.1 ± 4.5	8-8	0.1 ± 0.2	17.5 ± 4.4	9-8	4.6 ± 0.7	18.3 ± 4.5
7-9	0.1 ± 0.2	17.4 ± 4.4	8-9	5.9 ± 0.8	18.5 ± 4.5	9-9	3.0 ± 0.5	19.6 ± 4.5
7-10	3.6 ± 0.6	17.1 ± 4.4	8-10	8.4 ± 1.0	23.4 ± 4.7	9-10	19.0 ± 1.5	27.7 ± 5.0
7-11	0.2 ± 0.2	18.7 ± 3.2	8-11	5.6 ± 0.8	17.8 ± 4.4	9-11	16.8 ± 1.3	29.7 ± 3.6
7-12	3.4 ± 0.7	28.4 ± 5.0	8-12	1.1 ± 0.4	17.8 ± 3.1	9-12	0.1 ± 0.2	20.5 ± 4.6
7-13	4.4 ± 0.7	26.0 ± 4.9	8-13	2.0 ± 0.4	17.0 ± 4.4	9-13	0.1 ± 0.2	15.7 ± 4.3
7-14	3.8 ± 0.6	17.8 ± 4.4	8-14	9.7 ± 1.0	20.0 ± 4.5	**Mean:**	**3.4 ± 6.6** [c]	**20.1 ± 4.0** [c]
7-15	3.2 ± 0.6	20.4 ± 4.6	8-15	2.1 ± 0.5	16.3 ± 4.4	**Median:**	**0.1**	**18.9**
7-16	4.0 ± 0.7	19.1 ± 3.2	8-16	1.4 ± 0.4	17.0 ± 3.1			
7-17	1.2 ± 0.4	20.4 ± 4.6	8-17	2.7 ± 0.5	19.6 ± 4.5			
Mean:	**2.4 ± 1.9** [c]	**19.2 ± 3.3** [c]	**Mean:**	**2.3 ± 3.1** [c]	**18.0 ± 1.8** [c]			
Median:	**3.1**	**18.2**	**Median:**	**1.1**	**17.5**			

[a] 2-sigma counting uncertainty.
[b] 2-sigma measurement uncertainty.
[c] sample standard deviation.

Appendix B - Quality Assurance

Of the 128 survey units, 29 (or 22.7%) of the survey units were monitored using duplicate EICs. Of the 29 duplicate measurements, 28 (or 96.6%) of the measurements agreed within 10% relative difference with respect to the mean of the two measurements. All of the duplicate measurements agreed with 20% relative difference and within 3-sigma measurement uncertainty. Results of the duplicate analyses are shown in **Table B-1**.

Table B-1. Duplicate exposure rate measurements collected during 1999 survey using EICs.

Unit	First Measurement μR h^{-1})	Duplicate Measurement (μR h^{-1})	Relative Difference [b]
1-1	24.5 ± 4.8 [a]	20.8 ± 4.6 [a]	8.2%
1-6	22.7 ± 4.7	22.0 ± 4.7	1.5%
1-11	20.9 ± 4.6	18.0 ± 4.4	7.8%
2-1	22.7 ± 4.7	21.6 ± 4.6	2.4%
2-6	20.8 ± 4.6	20.8 ± 4.6	0.0%
2-11	22.7 ± 4.7	23.8 ± 4.8	2.5%
3-1	19.7 ± 4.5	18.5 ± 4.5	3.1%
3-6	17.9 ± 4.4	18.2 ± 4.5	1.0%
3-11	19.3 ± 4.5	20.1 ± 4.6	1.9%
4-1	28.3 ± 5.0	21.1 ± 4.6	14.4%
4-6	20.8 ± 4.6	19.4 ± 4.5	3.6%
4-11	20.1 ± 4.6	22.3 ± 4.7	5.3%
5-1	17.4 ± 4.4	18.5 ± 4.5	3.1%
5-6	15.9 ± 4.3	15.9 ± 4.3	0.1%
5-11	19.6 ± 4.5	19.6 ± 4.5	0.0%
6-1	17.8 ± 4.4	16.0 ± 4.3	5.4%
6-6	16.3 ± 4.4	18.2 ± 4.5	5.5%
6-11	18.2 ± 4.5	17.1 ± 4.4	3.1%
7-1	16.7 ± 4.4	18.1 ± 4.5	4.2%
7-6	16.4 ± 4.4	16.7 ± 4.4	0.9%
7-11	18.5 ± 4.5	18.9 ± 4.5	1.1%
7-16	19.0 ± 4.5	19.3 ± 4.5	0.7%
8-1	16.7 ± 4.4	19.7 ± 4.5	8.2%
8-6	17.4 ± 4.4	17.4 ± 4.4	0.1%
8-11	17.8 ± 4.4	16.6 ± 4.4	3.4%
8-16	18.1 ± 4.5	16.7 ± 4.4	4.2%
9-1	18.2 ± 4.5	17.0 ± 4.4	3.2%
9-6	18.6 ± 4.5	19.7 ± 4.5	2.8%
9-11	28.8 ± 5.1	30.7 ± 5.2	3.1%
		Average:	**3.5%**

[a] 2-sigma propagated measurement uceratinty

[b] Absolute value of the relative difference with respect to mean of the two measurements

The Idaho State University Environmental Monitoring Laboratory conducts Quality Assurance irradiations of EICs for INEEL OP. During the 1999 calendar year, 28 QA irradiations were performed (**Table B-2**). The average relative difference between the measured value and the actual exposure received was –2.5%. All but one measurement had a relative difference within 10% of the actual exposure received. All of the measurements met the 20% relative difference criteria and also agreed within 2-sigma measurement uncertainty.

Linear regression analysis comparing known exposure and measured exposure is shown in **Figure 7.**

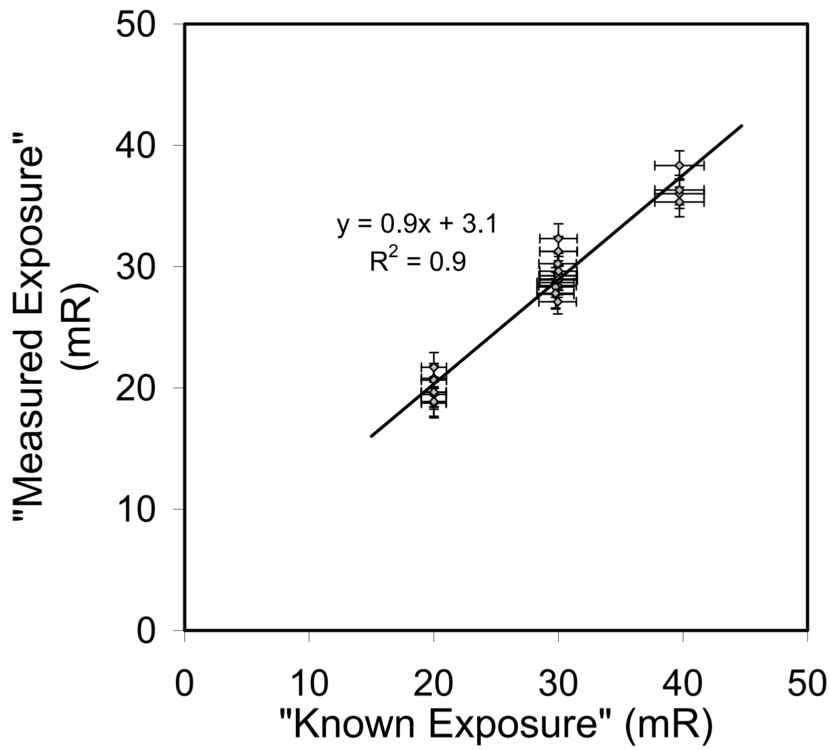

Figure 7. Regression analysis results comparing "known exposure" and "measured exposure". X-axis error bars represent source assay certificate uncertainty propagated with systematic operator uncertainty quoted by ISU EML. Y-axis error bars represent 1-sigma measurement uncertainty.

Table B-2. Quarterly EIC QA irradiation results from 1999. Approximately half of the EICs are irradiated to a "blind" exposure. "Blind" in the context that INEEL OP does not know or decide upon the exposure received prior to determining exposure measurement.

Electret #	Net Measured Exposure (mR)	Exposure Received (mR)	Relative Difference [c]
SS7325	29.2 ± 1.0 [a]	29.9 ± 1.5 [b]	-2.4%
SQ9725	30.2 ± 1.0	29.9 ± 1.5	1.0%
SQ5392	28.4 ± 1.0	29.9 ± 1.5	-5.0%
SU4000	27.1 ± 1.0	29.9 ± 1.5	-9.5%
SQ9606	31.2 ± 1.2	30.0 ± 1.5	4.1%
SU8194	31.3 ± 1.2	30.0 ± 1.5	4.2%
SU8212	29.2 ± 1.2	30.0 ± 1.5	-2.5%
SU8195	32.3 ± 1.2	30.0 ± 1.5	7.7%
SU8398	20.8 ± 1.2	20.0 ± 1.0	3.9%
ST5820	19.5 ± 1.2	20.0 ± 1.0	-2.7%
SU8275	21.7 ± 1.2	20.0 ± 1.0	8.4%
SU0413	20.6 ± 1.2	20.0 ± 1.0	3.2%
SU3918	27.7 ± 1.2	29.8 ± 1.5	-6.9%
SV0188	28.7 ± 1.2	29.8 ± 1.5	-3.6%
SV0341	28.3 ± 1.2	29.8 ± 1.5	-4.9%
SV0268	27.8 ± 1.2	29.8 ± 1.5	-6.6%
ST5780	36.0 ± 1.2	39.7 ± 2.0	-9.3%
SV0347	36.3 ± 1.2	39.7 ± 2.0	-8.6%
SV0266	35.3 ± 1.2	39.7 ± 2.0	-11.0%
SV0331	38.3 ± 1.2	39.7 ± 2.0	-3.5%
SS7314	28.9 ± 1.2	30.0 ± 1.5	-3.7%
SU0503	28.9 ± 1.2	30.0 ± 1.5	-3.6%
ST5866	29.0 ± 1.2	30.0 ± 1.5	-3.5%
ST5820	29.6 ± 1.2	30.0 ± 1.5	-1.3%
SU4052	19.6 ± 1.2	20.0 ± 1.0	-1.8%
SU8259	18.7 ± 1.2	20.0 ± 1.0	-6.3%
SU3879	19.7 ± 1.2	20.0 ± 1.0	-1.7%
SV0188	18.9 ± 1.2	20.0 ± 1.0	-5.6%
		Average:	**-2.5%**
		Within 10% Relative Difference:	**96%**
		Within 2-sigma:	**100%**

[a] 1-sigma propagated measurement uncertainty.

[b] 1-sigma propagated uncertainty estimated from source certificate of calibration as systematic operator error as quoted by ISU EML.

[c] Relative percent difference of measured value with respect to exposure received per source certificate as quoted by ISU EML.