FC-18-009
Revision 0
Use of In-Situ Gamma Spectroscopy for Characterization

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1.0 INTRODUCTION

The purpose of this document is to describe the use of *in situ* gamma spectroscopy for performing scoping, characterization, and final status surveys in support of characterization and License Termination. Use of *in situ* gamma spectroscopy for unrestricted release of materials and equipment is not addressed in this document. ISOCS have been used for characterization and Final Status Survey (FSS) measurements at Rancho Seco, Yankee Rowe and Maine Yankee. ISOCS has also been used for decommissioning characterization at Brookhaven National Laboratory. [5] This document uses information from these previously NRC approved technical basis documents and the Brookhaven experience. The source documents for the information presented are referenced throughout this document.

This document applies to use of a Canberra characterized HPGe detector coupled to an MCA using Canberra Genie software for performing gamma spectrum analyses of various media. Acquisition of a characterized detector allows the use of the geometry composer software to model actual survey unit conditions in order to obtain accurate gamma survey results. Use of the geometry composer also allows the determination of investigation criteria which will identify the possible presence of an elevated area of residual activity within the detector field of view exceeding the elevated measurement criteria value for the survey medium.

2.0 BACKGROUND

Technical guidance contained within NUREG-1575, "Multi-Agency Radiation and Site Investigation Manual" (MARSSIM) regarding the conduct of radiation surveys and site investigations has generic application, and has the potential for use in any situation involving radioactive contamination, whether or not a release criterion is to be applied. The Data Quality Objective (DQO) process is the basis for the performance-based guidance in planning MARSSIM surveys. Because the MARSSIM emphasizes the use of statistical planning and data analysis for demonstrating compliance with a final status survey, there are few examples of how to apply the DQO process for other types of surveys where such formal analyses are not necessary, or even appropriate. For example, data are collected during scoping surveys to confirm absence of licensed material in non-impacted areas or in characterization surveys in order to determine the extent, but not necessarily the amount, of contamination. This does not mean that the data do not meet the objectives of compliance demonstration, but it may mean that formal statistical tests would be of little or no value because the data have not been collected for that purpose. However, all analytical data should be of a quality, demonstrable through the DQO process, to support the determination or decision needed.

Large areas or volumes can be assayed using ISOCS with a large field of view to reduce errors arising from non-homogeneity, providing a more accurate estimate of average radionuclide concentrations. These advantages make *in situ* spectroscopy an attractive tool for many characterization applications. The battery operated, field deployable gamma spectrometer provides traditional spectra of counts as a function of gamma energy. The spectra are then converted to radionuclide concentration by applying innovative efficiency calculations using Monte Carlo statistical methods and pre-defined geometry templates in the analysis software.

In situ gamma spectroscopy has been effectively employed to perform final surveys at MDCs comparable to those typically achieved with hand-held instruments without the possibility of failing to detect an area of elevated activity greater than the elevated measurement criteria value. *In situ* gamma spectroscopy can be used for any situation in which the contaminant is a gamma emitter and the source geometry can be defined by the geometry composer.

Canberra has developed a HPGe detector which has been exposed to gamma sources at multiple points in space in order to determine the detector response to gamma photons which interact with the detector and which originate from any location about the detector. The software uses an iterative discrete ordinate attenuation computation routine to predict the detector response when particular geometry features such as source to detector distances, shielding materials, thickness of source or shield materials, source and shield densities, source to detector angles, and source configurations are entered into the geometry composer. These features allow the same spectrum to be analyzed using more than one geometry. It is this capability which makes possible the identification and evaluation of hot spots using the investigation criterion.

Validation of the ISOCS efficiency calibration software is beyond the scope of this report. Canberra Industries has performed extensive testing and validation on both the MCNP-based detector characterization process and the ISOCS calibration algorithms used by the software. The full MCNP method has been shown to be accurate to within 5% (typically). ISOCS results have been compared to both full MCNP and to 119 different radioactive calibration sources. In general, ISOCS is accurate to within 4-5% at high energies and 7-11% for low energies.

3.0 DEFINITIONS

3.1 **Investigation criterion**- An activity limit at which further evaluation of the survey data is required for a MARSSIM Class 1 survey area. The investigation criterion is typically set at a value that ensures that the Derived Concentration Guideline Level (DGCL) for the elevated measurement criteria ($DCGL_{EMC}$) will not be exceeded.

3.2 **ISOCS** – *In Situ* Object Counting System

3.3 **World-Wide Fallout** – The descent and deposition of radioactive material in the atmosphere onto the earth following a nuclear explosion, incident, or accident.

4.0 CALCULATIONS AND EVALUATIONS

4.1 ISOCS Scoping, Characterization, and Final Status Surveys of Soils and Concrete

The purpose of using ISOCS for soils and concrete characterization is to determine if the material is impacted (e.g., contaminated) and to evaluate the gamma emitting radionuclide concentrations. ISOCs may also be used for other purposes such as unrestricted release of components, materials, soils or concrete or for reuse of concrete or soil as "clean" fill in accordance with MARSAME. The gamma emitting radionuclides of concern for FCS Unit 1 have been identified in FCS FC-18-002. The current list of radionuclides of concern are shown in **Error! Reference source not found.**.

Table1 - Initial Suite of Potential Radionuclides for the Decommissioning of FCS

Radionuclide	Half Life (years)
H-3	12.3
Fe-55	2.73
Co-60	5.27
Ni-63	100.1
Sr-90	28.74
Cs-134	2.07
Cs-137	30.04
Pu-238	87.7
Pu-239/240	24,110
Pu-241	14.35
Am-241	432.2
Cm-243/244	29.1

Gamma emitting radionuclides such as Nb-94, Eu-152, Eu-154 and Am-241 do not make up significant percentages of the typical waste stream radionuclide mix and are likely to be limited in abundance. Cs-137 however has a long half-life, is readily detectable by gamma spectroscopy, and comprises a significant fraction of most waste streams. Eu-152 and Eu-154 are present in activated concrete. Identification of Cs-137 can be used to screen soils and concrete.

This technical position can only be met using a characterized detector with geometry composer software using approved procedures unless geometry-specific, NIST-traceable calibration sources equal to the size of the detector field of view for each media are obtained. The FCS ISOCS are HPGe detectors with a 50% relative efficiency. A description and documentation of the characterization of the Canberra FCS HPGe detector (Model GX5020) is documented in Reference 8.

It is anticipated that final surveys will typically be performed with the detector at a distance of 1, 2, and 3 meters from the source with the 90 degree collimator installed. These geometries have detector fields of view of 3 m^2, 12 m^2 and 28 m^2 respectively. Due to the critical relationship of the geometries to the analytical results, only approved geometries will be used for FSS surveys.

The gamma spectroscopy analysis report provides the total activity detected within the field of view of the detector and reports them in units of pCi/g, pCi/m^2 or dpm/m^2. For spectra collected using the 90 degree collimator, the field of view is the source to detector distance (which is equal to the radius of the field of view) squared and multiplied by pi (π).

For ISOCS Final Status Survey scoping and characterization surveys concrete source activity depths will typically be set at 2 cm to 5 cm. Location or Building specific concrete activity depths may be set at other depths based upon concrete core or other characterization data. Soil source activity depths will typically be set at 15 cm. These values are consistent with site characterization experience and NUREG-1575 assumptions. These source geometries allow for the collection of spectra with MDA values for the nuclides of interest (e.g., Cs- 137 and Co-60) at less than or equal to 0.3 pCi/g for soil and less than 500 to 1,500 dpm/100 cm^2 for concrete. The NUREG-1757 Appendix H screening DCGLs can be used in lieu of site specific DCGLs that may be developed for soils and structures. Since the 40% *relative efficient* ISOCS MDA values are three percent or less of the Cs-137 NUREG-1757 screening DCGLs for soils and structure surfaces, the chances of making a Type 1 error were less than 0.05 for reasonable count times of 20 to 60 minutes. The 50% *relative efficient* count times to reach similar MDAs are anticipated to be 10 to 20 minutes. The "count to MDA" feature of the Canberra software will be employed as necessary to ensure that the desired MDAs are achieved.

The following investigation criteria will be used for ISOCS scoping and characterization surveys of non-impacted soils and concrete.

- Detection of plant derived gamma emitting radionuclides of concern other than Cs-137 provide immediate indication that the material may be impacted by licensed radionuclides and should result in follow-up investigations and surveys in accordance with the characterization survey package.

- Detection of Cs-137 in concrete designated as non-impacted should also require additional investigative surveys and sampling in accordance with the characterization survey package.

- It is anticipated that some soils will contain readily detectable levels of Cs-137 from nuclear weapons testing fallout. Detection of Cs-137 in non-impacted soils that exceed the identified DGCLs for disturbed, undisturbed, drainage, and non-drainage soils should require additional investigative surveys and sampling in accordance with the characterization survey package.

For ISOCS surveys of MARSSIM Class 1 areas requiring a $DCGL_{EMC}$, the determination of the Investigation Criteria is based on taking a series of measurements using the detector in a standard geometry, such as a disk, located at a defined distance from the detector. The required geometry parameters are entered into the geometry composer and the acquired spectra are analyzed using the standard geometry. A new geometry is then developed which reduces the source to an area of 1 m^2 located at the periphery of the detector field of view. The original spectra are then re-analyzed using the new, small source area geometry. The ratio of the full field of view activity to the small source activity is determined and the ratio is multiplied by the $DCGL_{EMC}$ for a 1 m^2 area which becomes the Investigation Criterion. Any *in situ* measurement which equals or exceeds the Investigation Criterion, when analyzed using the full field of view geometry, requires further evaluation to rule out the possibility of a small elevated area of activity within the detector field of view. Evaluations of the $DCGL_{EMC}$ for ISOCS detectors have been performed at Rancho Seco [2], Yankee Rowe [3] and Maine Yankee. [4]. This information is presented in the following sections.

4.2 ISOCS Field of View and Detection Sensitivity and $DCGL_{EMC}$

4.2.1 Soils

Soils have been surveyed using *in situ* gamma spectroscopy with a geometry that evaluates soil activity to a depth of 15 cm over the detector field of view. With respect to Class 1 Survey Units, a surveillance for elevated activity is performed via scan surveys using hand-held field instruments. Acceptance criteria ($DCGL_{EMC}$) is derived by multiplying the $DCGL_W$ by the area factor associated with that area bounded by the grid used to locate samples for direct measurements. Class 2 or Class 3 area survey designs do not employ elevated measurement comparisons, associated investigation levels are based on positive indications of licensed radioactivity above the $DCGL_W$ or above background.

Occasionally, due to either background radioactivity or the size of the sample location grid, the detection sensitivity for these hand-held instruments exceeds the $DCGL_{EMC}$. In such instances, the survey grid is reduced so that area factors yielding higher $DCGL_{EMC}$ values can be used. This approach has a side effect of additional sampling, which impacts project schedules and costs. Additional sampling is further experienced to distinguish between natural radioactivity and plant-derived radioactivity to investigate elevated instrument responses.

When an investigation level is encountered an investigation is conducted, which may include the use of hand-held field instruments and soil sampling. Investigation Criteria are established to ensure the $DCGL_{EMC}$ will not go undetected in a small elevated area at the edge of the field of view. Because the detector's field-of-view is greater than one-square-meter, it is assumed that the (potential) one-square-meter of elevated radioactivity is situated at the edge of the area being evaluated. To compensate for reduced detection efficiencies associated with this assumption, an offset geometry adjustment factor is developed. Before the offset geometry adjustment factor can be developed, the detector's field-of-view must be determined based on the detector configuration (e.g. collimator, detector height above the surface to be evaluated, etc.). At Yankee Rowe, the detector was configured with a 90-degree collimator and the detector was positioned at 2 meters from the surface to be evaluated. This would normally have a 12 m^2 field of view based upon a circle radius of 2 meters.

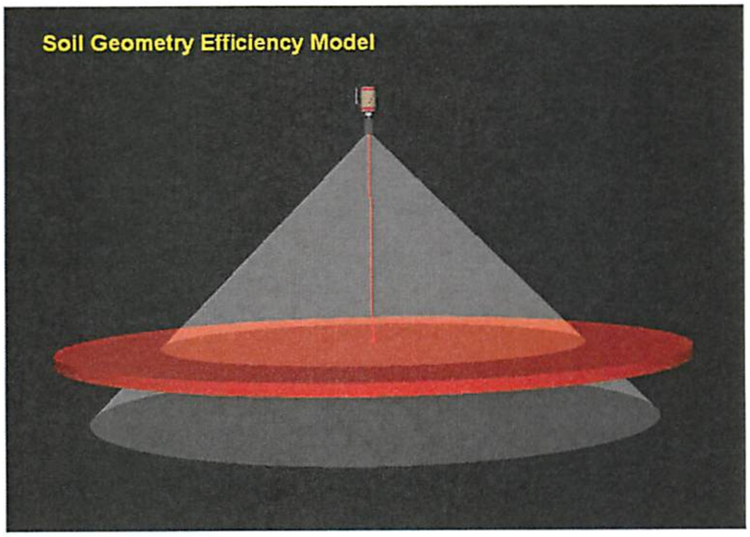


Figure 1 - 90 Degree Collimator Field of View

At Yankee Rowe [3], the detector's field of- view was empirically determined using a series of measurements made at various off-sets relative to the center of the reference plane. The source used for these measurements was a 1.2 µCi Co-60 point-source with a physical size of approximately 1 cm^3.

Each spectrum was analyzed as a point source both with and without background subtract. It was observed that the detector responded quite well to the point source. Figure 2 presents the results with background subtraction applied. Note that there was a good correlation with the expected nominal activity and that outside the 2-meter radius of the "working" field-of-view (e.g., at 90 inches, 2.286 meters) some detector response occurs. This validates that the correct attenuation factors are applied to the algorithms used to compute the efficiency calibration. It also demonstrated that the actual field of view is greater than the 2 meter radius assumed at a 2 meter stand-off distance.

Figure 2 - Yankee Rowe Point Source Test Background Subtracted

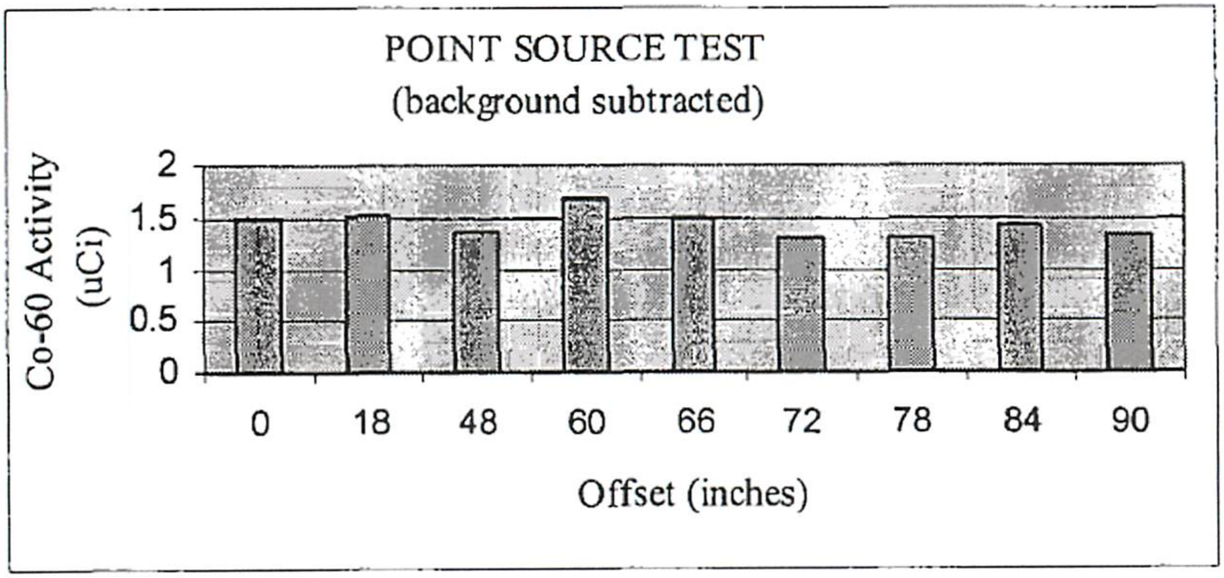
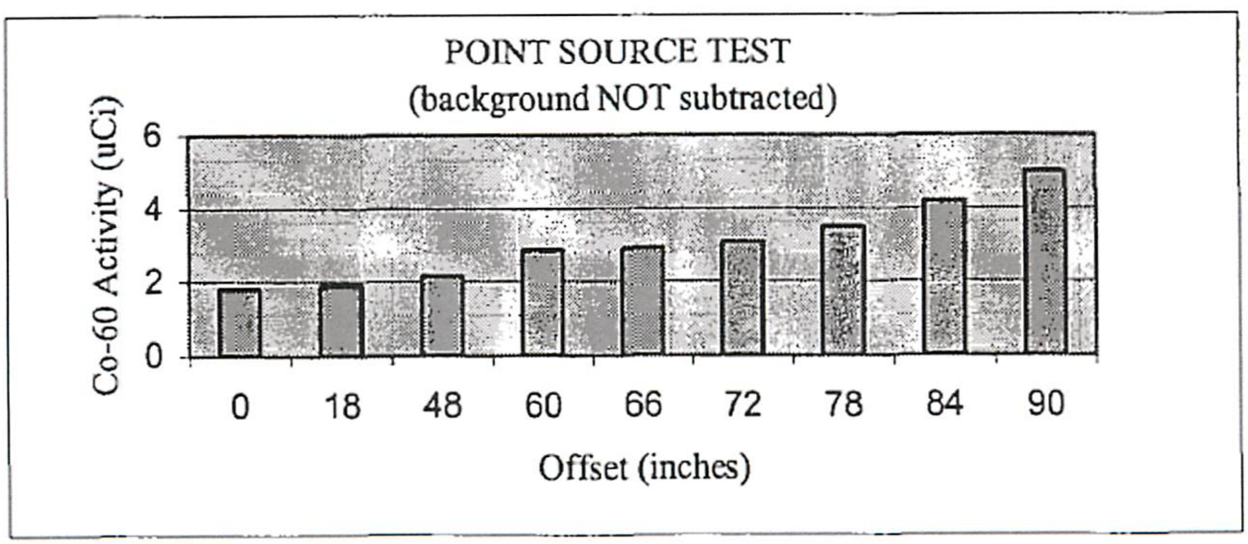


Figure 3 shows the effect of plant-derived materials present in the reference background, which indicates an increasing over-response the further the point source is moved off center. Detector response outside the assumed 2-meter field-of-view would yield conservative results. Normally, source term adjacent to the survey units should be reduced to eliminate background interference.

Figure 3 - Yankee Rowe Point Source Test Background Not Subtracted



The Yankee Rowe empirically determined field of view at 2 meters had a radius of at least 2.3 meters (16.6 m^2) which is larger than a calculated field of view with a radius of 2 meters and 12 m^2. Since all activity detected is attributed to the calculated field of view, this leads to conservative estimates of soil concentrations when a calculated field of view is used in the geometry efficiency file.

Alternately, the field-of-view may be determined by comparing efficiency values for various diameters. For instance, considering a detector positioned at one meter above a surface, a 200-meter diameter could be considered an infinite plane. Efficiencies for this "infinite" diameter would be determined. Subsequently, efficiencies would be determined for other, much smaller, diameters (e.g., 5.5 m, 6 m, 7 m, etc.) and then compared to the efficiencies associated with the infinite plane. The diameter that yields efficiency values at 95% that of the infinite plane would be considered the field-of-view for the detector configuration. As alternative collimator configurations are implemented specific evaluations should be conducted. The $DCGL_{EMC}$ is divided by the geometry adjustment factor to derive investigation levels.

Since the calculated field of views are smaller than the true fields of view of the detector, use of the calculated field of view and the algorithm corrected efficiencies are fairly flat. Use of calculated field of views is conservative and will slightly over estimate the concentrations (e.g., pCi/m^2 over 12m^2 as opposed to 16.6 m^2). The following calculated fields of view for the FCS ISOCS geometries are conservative.

Table 1 - Calculated Fields of View

Distance to Source	90 Degree Collimator field of view m^2
1	3.14
2	12.57
3	28.27

At Rancho Seco the HPGe had a 40% relative efficiency as opposed to the 50% relative efficiency for the FCS detectors. A calculated field of view of 28 m^2 was used for 3 meter detector to source geometry at Rancho Seco. Soil Investigation Criteria were determined by constructing an initial geometry for soils using a circular plane with a source depth of 15 cm, a radius of 3 m, and a source to detector distance of 3 m. A series of spectra were collected using this geometry with the 90 degree collimator attached to the detector.

Following the original analyses of the collected spectra using the 28 m^2 source geometry at Rancho Seco, the spectra were re-evaluated using a geometry having a 15 cm thick source of 1 m^2 placed at the periphery of the field of view. The analytical results for the small1 m^2 area sources were compared to the results for the large area sources (i.e., the 28 m^2). The ratio of the small source to large source activity is the geometry correction factor by which the $DCGL_{EMC}$ must be divided by to derive the Investigation Criterion as shown in the Table 3 below.

Table 2 - Rancho Seco Test Soil Results for 1m^2 Source in Periphery of 28 m^2 Field of View

Sample #	Nuclide	28 m^2 source in 28 m^2 field of view Geometry pCi/m^2	1 m^2 source in 28 m^2 field of view Geometry pCi/m^2	Ratio (Small to Large)
S3M005	Cs-137	0.376	9.517	25.31
	Co-60	<0.220	<5.71	25.95
S3M006	Cs-137	0.48	12.155	25.32
	Co-60	<0.152	<3.93	25.86
S3M007	Cs-137	0.31	7.842	25.3
	Co-60	<0.129	<3.35	25.97
S3M008	Cs-137	0.288	7.298	25.34
	Co-60	<0.143	<3.71	25.94
S3M009	Cs-137	0.319	8.072	25.3
	Co-60	<0.148	<3.84	25.95
S3MO10	Cs-137	<0.167	Obtained as a background count	
	Co-60	<0.138		
S3M011	Cs-137	<0.143	3.624	25.34
	Co-60	<0.142	<3.68	25.92
S3M012	Cs-137	0.431	10.923	25.34
	Co-60	<0.137	<3.55	25.91
S3M013	Cs-137	0.411	10.412	25.33
	Co-60	<0.153	<3.96	25.88
S3M014	Cs-137	0.273	6.91	25.31
	Co-60	<0.142	<3.68	25.92
S3M015	Cs-137	0.468	11.841	25.3
	Co-60	<0.135	<3.49	25.85
S3M017	Cs-137	0.554	14.018	25.3
	Co-60	<0.148	<3.84	25.95
S3M018	Cs-137	0.372	9.416	25.31
	Co-60	<0.161	<4.18	25.96
S3M019	Cs-137	0.376	9.527	25.34
	Co-60	<0.176	<4.55	25.85
S3M020	Cs-137	0.435	10.022	25.34
	Co-60	<0.147	<3.81	25.92
Mean	**Cs-1 37**			**25.3**
	Co-60			**25.9**

Using the above geometry correction factors, the Rancho Seco Investigation Criterion for Cs-137 was 23.6 pCi/g and for Co-60 is 5.7 pCi/g based on their site specific DCGLs and Area Factors.

A similar methodology using a 40% relative efficiency HPGe was used at Maine Yankee where a spectrum was collected at a 3 meter height using a 90 degree collimator. The spectrum was then analyzed using the 28 m^2 and the peripheral 1 m^2 geometries. The results are provided in Figure 4. The Cs-137 $DCGL_{EMC}$ of 22.63 and Co-60 $DCGL_{EMC}$ of 7.66 are in close agreement with the Rancho Seco test results.

Figure 4 - Maine Yankee 3 meter Investigation Level Equivalent $DCGL_{EMC}$ Test Results

Investigation Level Equivalent $DCGL_{EMC}$ Test

Att 8. Files	28-m^2 Area (3m height) Geometry Results		1-m^2 Edge Geometry Results		Investigation Level Eq DCGLemc / 28m^2 Result		Derived Activity in 1m^2 at the Investigation Level Eq DCGLemc	
	Co-60	Cs-137	Co-60	Cs-137	Co-60* (0.36 pCi/g)	Cs-137* (1.0 pCi/g)	Co-60** (pCi/g)	Cs-137** (pCi/g)
7607-EXC00135	0.25	0.11	5.26	2.49	1.46	9.10	7.67	22.64
7607-EXC00137	0.23	0.13	5.00	2.86	1.54	7.91	7.67	22.64
7607-EXC00138	0.21	0.20	4.51	4.63	1.69	4.89	7.64	22.64
7607-EXC00139	0.21	0.17	4.52	3.81	1.70	5.93	7.68	22.64
7607-EXC00141	0.14	0.35	3.01	7.99	2.54	2.83	7.65	22.64
7607-EXC00142	0.13	0.16	2.78	3.59	2.76	6.31	7.66	22.64
7607-EXC00147	0.12	0.15	2.62	3.33	2.95	6.80	7.74	22.64
7607-EXC00155	0.16	0.24	3.40	5.52	2.27	4.10	7.72	22.64
7607-EXC00159	0.14	0.14	2.96	3.11	2.57	7.29	7.61	22.64
7607-EXC00160	0.12	0.30	2.64	6.82	2.92	3.32	7.72	22.64
7607-EXC00177	0.12	0.34	2.44	7.72	3.13	2.93	7.64	22.64
7722-EXC00564	0.18	0.41	3.83	9.24	1.98	2.45	7.59	22.61
7722-EXC00567	0.15	0.18	3.19	4.06	2.39	5.57	7.61	22.61
7722-EXC00576	0.12	0.30	2.49	6.72	3.06	3.36	7.64	22.62
				Average	2.35	5.20	7.66	22.63
				Max	3.13	9.10	7.74	22.64
				Stdev	0.59	2.11	0.044	0.012

*Inv Level/28 m2 Result for Co-60 is (0.36 pCi/g Admin Value)/Col. 2 Results (0.36/0.25=1.46)

**Derived Act Inv Level for Co-60 is Col.4 value times Col.6 value (5.26x1.46=7.67)

Note that the Cs-137 values are calculated in a similar manner.

The Figure 4 data showing the 28 m^2 to 1 m^2 geometry correction factors is provided in Table 3.

Table 3 - Maine Yankee Figure 4 (3 meter) Data with Geometry Factors

Aft 8. Files	28-m² Area (3m Height) pCi/g		1-m² Area (3m Height) pCi/g		Geometry Factor		Investigation Level pCi/g		1 m² Activity at Investigation Level (DCGL$_{EMC}$) pCi/g	
	Co-60	Cs-137	Co-60	Cs-137	Co-60	Cs-137	Co-60	Cs-137	Co-60	Cs-137
7607-EXCO0135	0.25	0.11	5.26	2.49	21.04	22.64	1.46	9.10	7.67	22.64
7607-EXCO0137	0.23	0.13	5.00	2.86	21.74	22.00	1.54	7.91	7.67	22.64
7607-EXC00138	0.21	0.20	4.51	4.63	21.48	23.15	1.69	4.89	7.64	22.64
7607-EXCO0139	0.21	0.17	4.52	3.81	21.52	22.41	1.70	5.93	7.68	22.64
7607-EXCO0141	0.14	0.35	3.01	7.99	21.50	22.83	2.54	2.83	7.65	22.64
7607-EXC00142	0.13	0.16	2.78	3.59	21.38	22.44	2.76	6.31	7.66	22.64
7607-EXC00147	0.12	0.15	2.62	3.33	21.83	22.20	2.95	6.80	7.74	22.64
7607-EXCO0155	0.16	0.24	3.40	5.52	21.25	23.00	2.27	4.10	7.72	22.64
7607-EXCO0159	0.14	0.14	2.96	3.11	21.14	22.21	2.57	7.29	7.61	22.64
7607-EXCO0160	0.12	0.30	2.64	6.82	22.00	22.73	2.92	3.32	7.72	22.64
7607-EXCO0177	0.12	0.34	2.44	7.72	20.33	22.71	3.13	2.93	7.64	22.64
7722-EXC00564	0.18	0.41	3.83	9.24	21.28	22.54	1.98	2.45	7.59	22.61
7722-EXC00567	0.15	0.18	3.19	4.06	21.27	22.56	2.39	5.57	7.61	22.61
7722-EXC00576	0.12	0.30	2.49	6.72	20.75	22.40	3.06	3.36	7.64	22.62
				Average	**21.32**	**22.56**	2.35	5.20	7.66	22.63
				Max	22.00	23.15	3.13	9.10	7.74	22.64
				Min	20.33	22.00	1.46	2.45	7.59	22.61

The Maine Yankee geometry correction factors are lower than Rancho Seco's and would yield somewhat higher investigation levels.

At Yankee Rowe the geometry correction factor was developed using a spectrum free of plant-related radioactivity that was analyzed using two different efficiency calibrations (i.e. geometries). The first scenario assumed radioactivity was uniformly distributed over the detector's field-of-view at 2 meters from the source (4.6 meter source diameter). The second scenario assumed radioactivity localized within one-square-meter and was situated at the edge of the detector's field-of-view. A ratio of the resultant MDC values characterizes the difference in detection efficiencies between the two scenarios. This ratio is the offset geometry adjustment factor. The 2 meter area factors determined at Yankee Rowe for soils by this method are provided in Figure 5. The Cs-137 results were similar to the Maine Yankee and Rancho Seco test with a Cs-137 area factor of 22 and DCGL$_{EMC}$ of 22 pCi/g. The Co-60 results were a DCGL$_{EMC}$ of 15 pCi/g with an area factor of 11. This is why the investigation level was higher than the Maine Yankee 7.66 pCi/g and the Rancho Seco 5.77 pCi/g. There is a greater disparity between the Co-60 and Cs-137 geometry correction factors in the Yankee Rowe results than would be anticipated based upon the Maine Yankee and Rancho Seco results. This is probably due to using the ratio of MDCs from a spectrum free of plant nuclides as opposed to calculated concentrations based upon spectra containing the radionuclides. Since the Rancho Seco area factors are bounding and result in slightly lower investigation levels they can be used for establishing investigation levels at FCS. It should also be noted that the FCS detectors are 50% relative efficient as opposed to the Maine Yankee, Rancho Seco and Yankee Rowe 40% relative efficient detectors and are thus capable of greater sensitivities.

Figure 5 - Yankee Rowe Area Factors and DCGL$_{EMC}$ for Soils

SOIL DCGL$_{EMC}$ FOR ONE-SQUARE-METER

	Soil DCGL$_W$ (pCi/g) (NOTE 1)	Soil DCGL$_W$ (pCi/g) (NOTE 2)	1 m² Area Factor (NOTE 3)	DCGL$_{EMC}$ for 1 m² (pCi/g) (NOTE 4)
Co-60	3.8	1.4	11	15
Ag-108m	6.9	2.5	9.2	23
Cs-134	4.7	1.7	16	28
Cs-137	8.2	3.0	22	66

NOTE 1 – LTP Table 6-1
NOTE 2 – Adjusted to 8.73 mRem/yr
NOTE 3 – LTP Appendix 6Q
NOTE 4 – Soil DCGL$_W$ (adjusted to 8.73 mRem/yr) for a 1 m² area

The Yankee Rowe MDCs and soil investigation levels are provided in Figure 6.

Figure 6 - Yankee Rowe 2 meter Geometry MDCs and Soil Investigation Levels

SOIL INVESTIGATION LEVEL DERIVATION

	MDC pCi/g (NOTE 1)	MDC pCi/g (NOTE 2)	RATIO (NOTE 3)	DCGL$_{EMC}$ for 1 m² (NOTE 4)	INVESTIGATION LEVEL pCi/g (NOTE 5)
Co-60	0.121	1.86	0.0651	15	1.0
Ag-108m	0.184	2.82	0.0652	23	1.5
Cs-134	0.189	2.90	0.0652	28	1.8
Cs-137	0.182	2.78	0.0655	66	4.3

NOTE 1 – Assumed activity distributed over the detector's field-of-view.
NOTE 2 – Efficiency calibration modeled for a 1 m² area situated (off-set) at the edge of the detector's field-of-view. The model assumes that all activity is distributed within the 1 m².
NOTE 3 – Ratio = (field-of-view MDC ÷ 1 m² MDC).
NOTE 4 – DCGL$_{EMC}$ values for 1 m² (from Table 1)
NOTE 5 – Investigation levels derived by applying of the off-set geometry adjustment factor (e.g. 0.0653) to the DCGL$_{EMC}$ for a 1 m² area for each radionuclide.

The NUREG-1757 soil screening DCGL is 11 pCi/g. Using an Area Factor of 14 for Cs-137 in soils equals a DCGL$_{EMC}$ of 154 pCi/g. Dividing this by the Rancho Seco geometry factor of 25.3 for Cs-137 yields an investigation level of 6 pCi/g. The investigation level is well within the sensitivity capabilities of the 50% relative efficient ISOCS. Actual soil $DCGL_{EMC}$ values will be calculated using FCS Area Factors calculated for the License Termination Plan. Given the MDAs and Investigation Criteria for soil, final surveys of Class 1 MARSSIM areas can be performed on soil with a Type 1 error of 0.05 using *in situ* gamma spectroscopy for scans at FCS.

4.2.2 Structures

Current end state plans for FCS are to remove all structures associated with the FCS facilities to 3 feet below grade and backfill them. Therefore, the Industrial Use screening levels in NUREG-1757 and plant specific $DCGL_{WS}$ developed at other facilities such as Rancho Seco are not applicable at FCS since they assume occupancy within the structures. However, ISOCS surveys may be conducted to better quantify the source term in the remaining below grade structures. Under the source modeling scenario the assay of the overall remaining source term to demonstrate compliance with the release criteria for license termination is of more importance than the identification of areas with elevated levels since significant diffusion of any source term released from concrete with elevated contamination levels would occur in the down gradient plume to the resident scenario potable water well. However, in order to achieve compliance with the release criteria, and to implement ALARA measures, remediation of subsurface structure locations with elevated contamination levels may be the most effective way of reducing the overall source term. Remediation of areas with elevated levels reduces the overall source term with the least amount of effort. Although it is unlikely that DCGLs will be used or $DCGL_{EMCs}$ will be calculated at FCS, it is likely that action levels for ISOCS scans quantifying overall source terms will be established and that there may be action levels or investigation criterion targeting identification of small areas of elevated contamination for remediation. The following information on the calculation of $DCGL_{EMC}$ for ISOCS scans demonstrates that ISOCS scans will have adequate sensitivity to identify small 1 m^2 areas with elevated contamination levels on structures.

At Rancho Seco [2] an initial geometry was constructed for concrete structures using a circular plane with a source depth of 2 cm, a radius of 3 m and a source to detector distance of 3 m. A series of spectra were collected using this geometry with the 90 degree collimator attached to the detector. Source depth at FCS will be evaluated based upon concrete core data from the structures being evaluated (e.g. Reactor Buildings, Auxiliary Building and Turbine Building). The spectra at Rancho Seco were collected from a concrete wall with low, but detectable levels of Cs-137 and Co-60. Analytical results were presented in pCi per m^2 and Cs-137 data were converted to dpm/100 cm^2 in order to demonstrate the sensitivity of the analyses relative to site specific DCGLs (Co-60 was not converted due to higher ambient levels of cobalt in the survey area and background was not subtracted from any of the data).

Following the original 28 m^2 geometry analyses at Rancho Seco, the data was re-evaluated using a geometry having a 2 cm thick source of 1 m^2 placed at the periphery of the field of view. The analytical results for the small area sources were compared to the result for the large area sources (the 28 m^2 field of view). The ratio of the small source to large source activity is the geometry correction factor by which the $DCGL_{EMC}$ must be divided by to derive the Investigation Criterion as shown in the Table 4 below.

Table 4 - Rancho Seco Test Concrete Results for 1m² Source in Periphery of 28 m² Field of View

Sample #	Nuclide	28 m² source in 28 m² field of view Geometry		1 m² source in 28 m² field of view Geometry	Ratio (Small to Large)
		pCi/m²	dpm/100 cm²	pCi/m²	
CRC002	Cs-137	115,684	2,568	3,058,937	26.4
	Co-60	922,077	20,470	24,604,310	26.7
CRC003	Cs-137	30,368	674	803,012	26.4
	Co-60	1,182,335	26,248	31,550,640	26.7
CRC004	Cs-137	84,654	1,879	2,238,500	26.4
	Co-60	1,176,505	26,118	31,394,350	26.7
CRC005	Cs-137	646,634	14,355	17,099,200	26.4
	Co-60	653,756	14,513	17,444,690	26.7
CRC006	Cs-137	271,698	6,032	7,184,433	26.4
	Co-60	708,836	15,736	18,915,281	26.7
CRC007	Cs-137	54,494	1,210	1,441,027	26.4
	Co-60	835,538	18,549	22,298,770	26.7
CRC008	Cs-137	36,151	803	955,918	26.4
	Co-60	640,738	14,224	17,097,850	26.7
CRC009	Cs-137	26,204	582	692,930	26.4
	Co-60	417,889	9,277	11,151,050	26.7
CRC010	Cs-137	46,540	1,033	1,230,622	26.4
	Co-60	1,052,418	23,364	28,080,790	26.7
CRC011	Cs-137	98,584	2,189	2,606,865	26.4
	Co-60	965,999	21,445	25,775,990	26.7
CRC012	Cs-137	298,052	6,617	7,881,140	26.4
	Co-60	792,048	17,583	21,134,200	26.7
CRC013	Cs-137	434,564	9,647	11,491,151	26.4
	Co-60	1,065,999	23,665	28,444,600	26.7
CRC014	Cs-137	230,746	5,123	6,101,277	26.4
	Co-60	456,766	10,140	12,186,860	26.7
CRC015	Cs-137	607,692	13,491	16,068,710	26.4
	Co-60	393,634	8,739	105,04,530	26.7
CRC016	Cs-137	356,727	7,919	943,931	26.4
	Co-60	161,815	3,592	43,16,970	26.7
CRC017	Cs-137	309,195	6,864	8,175,661	26.4
	Co-60	313,478	6,959	836,4573	26.7
CRC018	Cs-137	156,929	3,484	4,149,533	26.4
	Co-60	770,318	17,101	20,555,180	26.7
CRC019	Cs-137	75,953	1,686	2,008,371	26.4
	Co-60	1,048,337	23,273	27,974,780	26.7
	Mean Cs-137 dpm/100 cm²		**4786**	**Mean Ratio**	**26.6**

The mean geometry correction factor for Cs-137 was in the same range as for the soil geometry at 26.6. This is primarily due to the difference in the density thickness of the 15 cm soil source and the 2 cm concrete source.

Table 5 - Soil and Concrete Source Density Thickness

Model	Thickness cm	Typical Density g/cc	Density Thickness g/cm²
Soil	15	1.6	24
Concrete	2	2.34	4.68
Concrete	5	2.34	11.7

The gross beta-gamma DCGL for structures based on the established nuclide fraction and conditions at Rancho Seco was 43,000 dpm/100 cm^2. Applying the Rancho Seco 14.9 area factor for a 1 m^2 area results in a $DCGL_{EMC}$ of 640,700 dpm/100 cm^2. The apparent geometry correction factor for a 1 m^2 elevated area at the edge of the detector field of view of 28 m^2 is 26.6 as shown above in Table 4. Dividing the $DCGL_{EMC}$ value by the geometry factor gives an Investigation Criterion of 24,000 dpm/100 cm^2 or 1.08E+6 pCi/m^2 or 3.04E+7 pCi in a 28 m^2 field of view circular plane geometry. This means that as long as the *in situ* gamma spectroscopy result does not exceed 24,000 dpm/100 cm^2, there cannot be an undetected elevated area within the field of view of 1 m^2 which exceeds the $DCGL_{EMC}$.

Similarly the NUREG-1757 $DCGL_W$ is 28,000 dpm/100 cm^2. Applying the Rancho Seco area factor for a 1 m^2 area of 14.9 results in a $DCGL_{EMC}$ of 417,200 dpm/100 cm^2. The apparent geometry correction factor for a 1 m^2 elevated area at the edge of the detector field of view of 28 m^2 is 26.6 as shown above in Table 4. Dividing the $DCGL_{EMC}$ value by the geometry factor gives an Investigation Criterion of 15,684 dpm/100 cm^2. It should be noted that this calculation can be adjusted to calculate the highest 1 m^2 area of elevated contamination that could go undetected for any scan by dividing the ISOCS 28 m^2 results by the 1 m^2 geometry correction factor. This could be used to target locations with the highest results for further investigation and potential remediation.

Given FCS plans to develop a site specific fate and transport model to evaluate end state doses from below grade structures it is likely that the investigation levels will be higher than those developed for Rancho Seco or those derived from the NUREG-1757 screening levels.

The Rancho Seco data in Table 6 also indicates that the typical concrete surface MDAs for a 1200 second count with a 40% relative efficient detector are 1318 dpm/100 cm^2 for Cs-1 37 and 562 dpm/100 cm^2 for Co-60. These were a small fraction of the Rancho Seco surface DCGL of 43,000 dpm/100 cm^2. Therefore structure characterizations at FCS using 50% relative efficient ISOCS detectors will have more than adequate sensitivity to detect elevated levels within the field of view.

Table 6 - Rancho Seco [2] Concrete Surface 28 m^2 field of view MDA Values for 1200 Second Count

Sample #	Cs MDA (pCi/m^2)	Co MDA (pCi/m^2)
CRC002	66,400	23,500
CRC003	64,900	30,300
CRC004	84,700	35,200
CRC005	60,900	26,800
CRC006	66,600	25,800
CRC007	50,600	27,900
CRC008	49,800	20,200
CRC009	47,900	25,000
CRC010	53,600	27,300
CRC011	56,300	26,200
CRC012	61,800	21,900
CRC013	74,800	32,900
CRC014	54,600	18,300
CRC015	50,900	18,100
CRC016	41,100	20,100
CRC017	52,900	17,900
CRC018	66,500	28,800
CRC019	64,300	29,500
Mean	**59,397**	**125,317**
dpm/100 cm^2	**1,318**	**1,562**

At Yankee Rowe the development of the investigation level for building surfaces was identical to that for soil surfaces. Using the same approach and a 5 cm thick concrete source, an offset geometry adjustment factor was developed. The MDC values for these two geometries were compared to characterize the difference in detection efficiencies. As expected, the condition with localized (one square- meter) radioactivity at the edge of the detector's field-of-view yielded higher MDC values. The ratio between the reported MDC values for the two scenarios was used as the offset geometry adjustment factor. The Yankee Rowe 2 meter geometry MDC values, the associated ratios, and the derived investigation level for building surfaces are presented in Figure 7.

Figure 7 - Yankee Rowe Field of View Correction Factors and $DCGL_{EMC}$ for Structures

TABLE 2,
BUILDING SURFACE $DCGL_{EMC}$ FOR ONE-SQUARE-METER

	Bldg $DCGL_W$ (dpm/100m²) (NOTE 1)	Bldg $DCGL_W$ (dpm/100cm²) (NOTE 2)	1 m² Area Factor (NOTE 3)	$DCGL_{EMC}$ For 1 m² (dpm/100cm²) (NOTE 4)
Co-60	18,000	6,300	7.3	46,000
Ag-108m	25,000	8,700	7.2	62,600
Cs-134	29,000	10,000	7.4	74,000
Cs-137	63,000	22,000	7.6	167,000

NOTE 1 – LTP Table 6-1
NOTE 2 – Adjusted to 8.73 mRem/yr
NOTE 3 – LTP Appendix 6S
NOTE 4 – Building $DCGL_W$ (adjusted to 8.73 mRem/yr) for a 1 m² area

The 5 cm thick Yankee Rowe model and the 2 meter standoff as opposed to the Rancho Seco 2 cm thick source and 3 meter standoff account for the lower Yankee Rowe geometry adjustment factors. The Rancho Seco geometry correction factors with a 3 meter standoff are conservative and appropriate for use at FCS.

4.3 Moisture Content of Soils

In situ gamma spectroscopy of open land areas is inherently subject to various environmental variables not present in laboratory analyses. Most notably is the impact that water saturation has on assay results. This impact has two components. First, the total activity result for the assay is assigned over a larger, possibly non-radioactive mass introduced by the presence of water. Secondly, water introduces a self-absorption factor. The increase in sample mass due to the presence of water is addressed by the application of a massimetric efficiency developed by Canberra Industries.

Massimetric efficiency units are defined as:
(counts per second)÷(gammas per second per gram of sample)

Mathematically, this is the product of traditional efficiency and the mass of the sample. When the efficiency is expressed this way, the efficiency asymptotically approaches a constant value as the sample becomes very large. Under these conditions changes in sample size, including mass variations from excess moisture, have little impact on the counting efficiency. However, the massimetric efficiency does not completely address attenuation characteristics associated with water in the soil matrix.

To evaluate the extent of self-absorption at Yankee Rowe, (traditional) counting efficiencies were compared for two densities. Based on empirical data associated with their monitoring wells, typical nominally dry *in situ* soil is assigned a density of 1.7 g/cc. They obtained a density of 2.08 g/cc, obtained from a technical reference publication by Thomas J. Glover, as representative of saturated soil. A density of 2.08 g/cc accounts for a possible water content of 20%. A summary of the Yankee Rowe comparison is presented in Figure 8.

Figure 8 Yankee Rowe Saturated and Unsaturated Soil Counting Efficiency Comparisons

	Efficiencies		Deviation due to density
keV	1.7 g/cc	2.08 g/cc	increase (excess moisture)
434	3.3 E-6	2.7 E-6	-18.7%
661.65	2.9 E-6	2.4 E-6	-17.5%
1173.22	2.5 E-6	2.1 E-6	-15.4%
1332.49	2.4 E-6	2.1 E-6	-14.8%

It should be noted that if a saturated soils geometry is created with the higher density and it is used rather than the dry soil geometry to analyze spectra in locations with wet soil conditions, the algorithm will correct for efficiency differences when it analyzes the spectra and convert it to pCi/m^2. This will essentially negate the efficiency differences between wet and dry soil conditions.

In cases when the soil is observed to contain more than "typical" amounts of water, potential under-reporting may occur if the dry soil geometry is used to analyze the collected spectrum. In general, the presence of standing water (or ice or snow) on the surface of the soil being assayed will be not be tolerated during Final Status Survey activities. In cases where minor surface water is present, notes will be made in field logs so that associated measurement results can be reviewed and reanalyzed if necessary using a wet soil geometry. Alternatively, a saturated soil geometry may be used to analyze the spectra in the field.

4.4 Discrete Particles in the Soil Matrix

An evaluation was performed at Yankee Rowe assuming all the activity in the detector's field-of-view, to a depth of 15 cm, was situated in a discrete point-source configuration. A concentration of 1.0 pCi/g (Co-60), corresponding to the investigation level correlates to a discrete point-source of approximately 3.2 µCi. This activity value is considered as the discrete particle of concern. Since the presence of any discrete particles will most likely be accompanied by distributed activity, the investigation level may provide an opportunity to detect discrete particles below 3.2 µCi of Co-60. Discrete particles exceeding this magnitude would readily be detected during characterization or investigation surveys. Cs-137 is highly soluble and is unlikely to remain as a hot particle in an outside area.

The MDCs associated with hand-held field instruments used for scan surveys are capable of detecting very small areas of elevated radioactivity that could be present in the form of discrete point sources. The minimum detectable particle activity for these scanning instruments and methods correspond to a small fraction of the license termination 25 mrem/year TEDE limit provided in 10CFR20 subpart E. When the investigation level in a Class 1 area is encountered, subsequent investigation surveys will be performed to include the use of hand-held detectors. The detection sensitivities of instruments used for these surveys will be addressed in the License Termination Plan. Furthermore, discrete point sources do not contribute to the uniformly distributed activity of the survey unit. It is not expected that such sources at this magnitude would impact a survey unit's ability to satisfy the applicable acceptance criteria. Noting that Class 2 or Class 3 area survey designs do not employ elevated measurement comparisons, associated investigation levels are based on positive indications of licensed radioactivity above the $DCGL_W$ or above background. Based upon the decay of Co-60 post shutdown and the detection of only background levels of Cs-137 in site soils to date, detection of Co-60 in a soil scan will warrant further investigation in all non-impacted and MARSSIM Class 2 and Class 3 areas as well as Class 1 areas.

4.5 Environmental Backgrounds

If background subtraction is used, an appropriate background spectrum will be collected and saved. Count times for environmental backgrounds should exceed the count time associated with the assay. In areas where the background radioactivity is particularly problematic, the background will be characterized to the point of identifying gradient(s) such that background subtractions are either appropriate or conservative. Documentation regarding the collection and application of environmental backgrounds will be provided as a component of the final survey plan.

4.6 Quality Control

Quality Control (QC) activities for the ISOCS system ensure that the energy calibration is valid and detector resolution is within specifications. A QC file will be set up for each detector system to track response to a multiple-radionuclide check source. The parameters checked/tracked should include peak centroid position, FWHM, and decay-corrected activity (typically for Am-241, Cs-137, and Co-60). An additional QC file will be set up and maintained for a periodic background check. Quality Control counts will be performed on a per-shift basis when the system is in use. For field operations photopeaks relative to other radionuclides may be used for gain adjustments. These nuclides include, but are not limited to the 661.6 keV Cs-137 and 1460 keV K-40 energy peaks. If the energy calibration is found to be out of an acceptable tolerance (e.g., greater than ±6 channels), then the amplifier gain may be adjusted and a follow-up QC count performed. If the detector's resolution is found to be above the factory specification, then an evaluation will be performed to determine if the detector should be removed from service and/or if the data is impacted. Evaluations associated with QC counts shall be documented. Such documentation may be limited to a remark directly on the applicable QC report or in a logbook if the resolution does not render the system out of service. Otherwise the evaluation should be separately documented (e.g. Condition Report, etc.) so as to address the impact of any assay results obtained since the last acceptable QC surveillance.

Where it is determined that background subtraction is necessary, a baseline QC system background will be determined specific to that area or location. When background subtraction is required, a QC system background surveillance will be performed before a set of measurements are made to verify the applicability of the background to be subtracted. Due to the prevailing variability of the background levels across the site, the nature and extent of such surveillances will be on a case-by-case basis and should be addressed in the documentation associated with the applicable survey units.

In addition to the routine QC counts, each assay report is routinely reviewed with respect to K-40 to provide indications where amplifier drift impacts nuclide identification routines. This review precludes the necessity for specific after-shift QC surveillances. It also minimizes investigations of previously collected data should the system fail a before-use QC surveillance on the next day of use.

4.7 Data Collection

Data collection to support FSS activities will be administered by a specific Survey Package/Plan. Survey Packages/Plans may include an index of measurement locations with associated spectrum filenames to ensure that all the required measurements are made and results appropriately managed. Personnel specifically trained to operate the system will perform data collection activities.

Data collection activities will address environmental conditions that may impact soil moisture content. Logs will be maintained so as to provide a mechanism to annotate such conditions to ensure that efficiency calibration files address the *in situ* condition(s). In extreme cases (e.g. standing water, ice, snow etc.) specific conditions will be addressed to ensure that analysis results reflect the conditions. As previously discussed with respect to water, when unique environmental conditions exist that may impact analysis results, conservative compensatory factors will be applied to the analysis of the data.

4.8 Efficiency Calibration

The central feature of the portable ISOCS technology is to support *in situ* gamma spectroscopy via the application of mathematically derived efficiency calibrations. The intrinsic efficiency calibrations of the FCS ISOCS are provided in Reference 8. Due to the nature of the environment and surfaces being evaluated (assayed), input parameters for the ISOCS efficiency calibrations will be reviewed on a case-by-case basis to ensure the applicability of the resultant efficiency. Material densities applied to efficiency calibrations will be documented. In practice, a single efficiency calibration file may be applied to the majority of the measurements. The geometry most generally employed will be a circular plane assuming uniformly distributed activity. Efficiency calibrations will address a depth of 15 cm for soil and a depth based on site data such as core data for concrete surfaces. Other geometries (e.g., exponential circular plane, rectangular plane, etc.) will be applied if warranted by the physical attributes of the area or surface being evaluated. Efficiency calibrations are developed by radiological engineers or instrumentation specialists who have received training with respect to the ISOCS® software. Efficiency calibrations will be documented and reviewed and approved in accordance with FCS procedures.

4.9 Contaminant Depth Resolution

The ISOCS detectors utilized at FCS are "BeGe" Canberra detectors that utilize a thin carbon composite window over the end cap of the detector. The thin window contact region and doping of the crystal along with the composite window play a role in the ability of the detector to detect low energy x-ray and gamma energies down to 3.0 keV. This thin window feature can be used to examine the 32 and 661 keV energy lines associated with Cs-137. By examining the ratio of the 32 and 661 keV energy lines, determinations can be made regarding the depth of Cs-137 contamination in concrete. This approach will allow for determining if the observed activity is surface or volumetric in nature.

4.10 ISOCS Uncertainty Evaluator (IUE)

As appropriate, the ISOCS Uncertainty Evaluator will be used to evaluate conditions where parameters associated with the Geometry Composer are not well known. It may also be used to examine the uncertainty associated with known parameter changes due to density, soil moisture and similar conditions that may be encountered in a field environment.

The ISOCS Uncertainty Evaluator (IUE) is a tool associated with the Geometry Composer software that may be utilized to improve the quality of the gamma spectroscopy uncertainty estimate, improve the ease of generating these uncertainty estimates, and to document how they were generated. The ISOCS efficiency calibration software is performed in the normal manner to determine the normal reference efficiency for the sample being measured. The efficiency has encoded within it the uncertainty in the efficiency calibration method (as with most efficiency calibrations, this assumes the calibration model is a perfect representation of the sample).

The calibration process requires defining the sample with various parameters. Some are well known and do not vary appreciably. Others are not well known (soil composition, soil density, vertical radioactivity distribution, overburden, soil moisture, etc.) and could vary with each location assayed. Inputs are included to provide the IUE software an estimate as to how greatly the parameter(s) vary. Examples include soil density ranges, soil composition, distances and thickness of material.

For each unknown parameter the upper and lower limits are provided (input) and a distribution function that the parameter values within the limits are assumed to follow. This could include 1, 2 or 3 standard deviations or if the values are known as limits they can be assigned a uniform, triangular or other distribution function. The IUE software assigns a value for each of the unknown parameters following the probabilities defined by the assigned distribution functions. The efficiency for the detector and conditions is computed for the model and the process is repeated a large number of times until adding additional models does not change the results. The software then computes the model-to model uncertainty for each energy, which will be combined with the calibration uncertainty and the counting statistics uncertainty. If the activity within the object to be measured is distributed in a non-uniform manner the IUE can be used to examine various non-uniform distributions to estimate that portion of the Total Measurement Uncertainty

The IUE software also operates in a Sensitivity Mode, where only one parameter is varied at a time. This approach provides a method to determine which parameters are the major contributors to the total uncertainty and, concentrating the data collection resources on the parameters that are most important.

5.0 DATA MANAGEMENT

Data management will be implemented in various stages as follows:

- An index or log will be maintained to account for each location where evaluations for elevated activity are performed. Raw spectrum files will be written directly or copied to a central file server.

- Data Analysis - After the spectrum is collected and analyzed, a qualified Radiological Engineer will review the results. The data review process includes application of appropriate background, nuclide libraries, and efficiency calibrations. Data reviews also verify assay results with respect to the applicable investigation levels and the MDCs achieved. Data reviews may include monitoring system performance utilizing K-40, Cs-137, etc. peaks. When the data analysis is completed, the analyzed data file will be archived to a directory located on a central file server.

- Data Reporting - The results of data files whose reviews have been completed and are deemed to be acceptable may be uploaded to a central database for subsequent reporting and statistical analysis.

- Data Archiving - Routinely (daily) the centralized file server(s) where the raw and analyzed data files are maintained will be backed up.

6.0 CONCLUSION

As demonstrated above, *in situ* gamma spectroscopy can be employed for performing final surveys with adequate sensitivity of analysis for non-impacted and Class 1, 2, and 3 MARSSIM areas. $DCGL_{EMCs}$ can be calculated for Class 1 MARSSIM Area scans once area factors and the actual $DCGL_W$ are calculated for FCS. Initial evaluations based upon the Rancho Seco, Maine Yankee and Yankee Rowe geometry correction factor data indicate that a geometry correction factor of 26 for a 1 m^2 region at the edge of the field of view field of view is conservative for the 3 meter detector height geometry in soil. The Investigation Level for Cs-137 at the NUREG-1757 $DCGL_W$ of

11 pCi/g is in the range of 5.8 pCi/g for soils. Therefore ISOCS scans of FCS Class 1 area soils can readily discern areas requiring further investigation. Given that any source term containing significant Co-60 contamination has less than 80% of the activity deposited due to decay after shutdown. It is unlikely that a Co-60 hot particle of 4.6 µCi would be present in Class 1 soils. If it were, it would be readily detected by ISOCS. Given that the Area Factor for Co-60 and Cs-137 are predominantly due to external radiation it is also unlikely that particles below the 4.6 µCi source strength would have any significant dose consequences for future site residents. In addition, since Cs-137 is readily soluble, and it is unlikely that it would result in hot particles in soils and would rather be a distributed source bound to clay particles and organic material in the soil.

The Rancho Seco data indicates that a structures geometry correction factor of 27 is bounding for a 1 m^2 source at the edge of the field of view for an ISOCS at 3 meters. Using this value and an area factor of 14 indicates that the Investigation Level at the NUREG-1757 DCGLw screening level of 28,000 dpm/100 cm^2 would be approximately 15,000 dpm/100 cm^2 which is also readily discernible with an ISOCS. Since the source modeling method rather than DCGLs will be used for demonstration of the decommissioning release criteria, the NUREG-1757screening DCGLs for structures are likely very conservative and action levels for investigation and remediation of subsurface structures at FCS are likely to be higher given that the NUREG-1757 screening DCGLs are for occupied buildings. This demonstrates that the ISOCs has sufficient sensitivity for any future uses to quantify below grade source terms for end state structures at FCS.

7.0 ATTACHMENTS

None

8.0 REFERENCES

8.1 NUREG-1575, “Multi-Agency Radiation and Site Investigation Manual (MARSSIM),” Rev. 1, August 2000.

8.2 NUREG-1757, Volume 1, Revision 2, "Consolidated Decommissioning Guidance: Characterization, Survey and Determination of Radiological Criteria," U.S. Nuclear Regulatory Commission, September 2006.

8.3 NUREG-1757, Volume 2, Revision 1, "Consolidated Decommissioning Guidance: Characterization, Survey and Determination of Radiological Criteria," U.S. Nuclear Regulatory Commission, September 2006.

8.4 FC 18 002, “Potential Radionuclides of Concern During the Decommissioning of Fort Calhoun Station,” 2018

8.5 Maine Yankee Calculation EC-003-04 Rev. 1, “Use of Canberra In Situ Object Counting System (ISOCS) for FSS Surveys,” November 24, 2004

8.6 BNL-52607-01/04-Rev Formal Report, "Comparability of ISOCS Instrument In Radionuclide Characterization At Brookhaven National Laboratory," Paul Kalb et al, March 2001

8.7 "Optimum Methods to Determine Radioactivity in Large Tracts of Land – In-situ Gamma Spectroscopy or Sampling Followed by Laboratory Measurements" Frazier Bronson, CHP, Canberra Industries, 800 Research Parkway, Meriden, CT 06450, USA

8.8 ISOCS/LabSOCS Detector Calibration Report – Detector Model BE5030P, S/N 13218, Mirion Technologies (Canberra), December 2017

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ISOCS/LabSOCS
Detector Characterization Report

Canberra Sales Order # 75766
Detector Model BE5030P
S/N 13218
December 12, 2017

Laboratory Measurements Performed By: **Meriden**

MCNP/ISOCS Characterization By: **Gabriela Ilie**

Approved By: ______________________________

David Sullivan

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Printed in the United States of America.

For Technical Assistance, please call our Customer Service Hotline at 800-255-6370 or email techsupport@canberra.com

Table of Contents

1. Introduction

This document is a detailed report of the characterization of an HPGe detector for use with Canberra’s ISOCS/LabSOCS software packages. The characterization was performed at Mirion Technologies (Canberra), Inc. The main body of text discusses the validation measurements, characterization process, detector characterization grid creation, and total uncertainty of the process. Information and calibration results specific to your ISOCS/LabSOCS detector and software are given in the appendices. The comparison of the measured data to the characterization results are presented in Appendix A, the energy calibration and hardware settings used for the measurements are presented in Appendix B, and the calibration source certificates are presented in Appendix C. A description of the ISOCS check source measurements is presented in Appendix D, and recommended quality assurance and control guidelines are presented in Appendix E.

2. Monte Carlo Modeling

The MCNP Monte Carlo physics modeling code was used extensively in the development of the ISOCS characterization. The MCNP code is a direct descendant of the Monte Carlo simulation methods used at Los Alamos during the Manhattan Project for predicting criticality of various geometries [1]. The code simulates detector responses to gamma ray sources by mimicking the inherently random behavior of real physical events. For each simulation, the source/detector geometry is specified via mathematical descriptions of the surfaces and volumes that make up the objects in the "universe." A source region, which can be point-like or distributed, is defined and the code simulates the emission of gamma rays with a specified energy distribution. Each emitted gamma ray is tracked as it interacts with the atoms in the materials it encounters, accurately taking into account the double-differential cross sections for photo-atomic reactions. Tallies (i.e. histograms as functions of energy) of the energy deposited in the model detector are tabulated. The final tally distributions are then given as output from the program; these distributions represent the energy-response function of the detector and can thus be used to obtain the full-energy efficiency for the source/detector/universe geometry. Canberra Industries has had a vast amount of experience and success using MCNP in modeling gamma-ray detection systems and in accurately reproducing measured efficiencies [2].

3. Overview of the ISOCS Characterization Process

Development of an ISOCS characterization involves three steps. The first is the development and validation of a model for the particular detector to be characterized. The second step is the generation of a large number of efficiency datasets with the validated detector model in response to point-like sources at many locations about the detector. The final step is the generation and validation of the detector characterization file, which contains the relationship of the detector to this point-efficiency data. The end result of this process is a detector parameter file that is used by the ISOCS/LabSOCS Calibration Software. The three steps listed here are each discussed in detail below.

3.1 Mathematical Model of the Detector

A model of the HPGe detector is developed based on the physical dimensions of the detector. In order to determine the full-energy peak efficiency response of the detector, an MCNP model of the active bare-crystal and any internal structures, such as the well and internal contact pin, is created. The crystal itself is mounted in a holder cup, which is in turn surrounded by the detector endcap. The attenuation of the gamma rays passing through these external layers, as well as any crystal dead layers and other various support structures, is computed using ISOCS-based algorithms. Over 30 different dimensions, including the length and diameter of the Ge crystal, the thickness of the dead layer(s), the detector well, holder, and endcap dimensions, are used in developing the model. For Canberra detectors, this information is supplied by our detector production facility. For non-Canberra detectors, these dimensions are obtained from the detector user.

3.2 Validation of the Detector Model

In order to develop an accurate model (and hence characterization), it is necessary to determine many of these dimensions to higher degree of accuracy than is normally known in the detector manufacturing process. In addition, certain critical dimensions are not physically measurable at all. Ultimately, the most sensitive and accurate way to develop the complete model is by comparison with traceable source measurements.

To refine and validate the detector model, the computed efficiencies for five different source geometries are compared against the corresponding measured efficiency values determined from well defined point source standards of a mixed Am-241/Eu-152 source and a mixed Am-241/Cs-137 source. The certificate activities for the sources used in this validation process are presented in Appendix C. The per-decay yields for gamma and *X*-rays of interest in Eu-152 and Cs-137 are obtained from the Evaluated Nuclear Structure Data Files (ENSDF) database [3], while the decay yields for the low energy gamma and *X*-ray radiation in Am-241 are taken from Ref. [4].

The validation of the detector model to these measured reference data is an iterative process whereby the initial model dimensions are used as a starting point. The dimensions are adjusted slightly to provide optimum agreement between the computed efficiencies and the measured efficiencies.
The source geometries used in the validation process are the following:

1. Am-241/Eu-152 point source on the detector axis, nominally 30 cm from the endcap face (Figure 1),
2. Am-241/Eu-152 point source at 90°, 2 cm below the endcap face, nominally 32 cm from the axis of Ge crystal (Figure 2),
3. Am-241/Eu-152 point source at 135°, at a lateral distance of approximately 22 cm from the axis of Ge crystal (Figure 3),
4. Am-241/Cs-137 point source mounted on a 3 mm thick Plexiglas disk, positioned 10.4 cm from the detector endcap face (Figure 4),
5. Am-241/Cs-137 point source mounted on a 3 mm thick Plexiglas disk, positioned directly on the face of the detector endcap (Figure 5).

For measurements 1, 2, and 3, the source is mounted in a specially built jig which is attached to the detector endcap during the source measurements. This jig, depicted in Figures 1 through 3, provides very accurate and reproducible source positioning.

For the 90° and 135° point source geometries, three measurements are performed with the source positioned at three equi-spaced azimuthal positions (i.e. 0°, 120°, and 240°) about the detector axis. These are performed to verify that the germanium crystal is mounted symmetrically inside the endcap. The measured efficiencies from the three azimuthal positions are averaged at each gamma-ray energy; these average values are used as the measured 90° and 135° efficiencies. Table A1.1 gives the efficiencies for the three 90° measurements, their average, and the percent deviation from the average.

Two of the source geometries utilize the Am-241/Cs-137 point source mounted on a 3 mm thick Plexiglas disk. For one of the validation measurements, the source/Plexiglas assembly is placed directly on the detector endcap face. For the other disk measurement, the same source is used with a Plexiglas spacer cylinder, 10.17 cm tall, placed between it and the detector endcap to insure position reproducibility.

The Am-241/Eu-152 and the Am-241/Cs-137 point sources used in these characterization measurements are NIST-traceable sources manufactured by Eckert and Ziegler (Type C capsule). The active portion of the source is 3.3 mm in diameter, deposited into a cylindrical bore within a rectangular source capsule (measuring 23.5 mm x 10.9 mm x 1.9 mm). The active source is mixed in a 1.5 mm thick porous glass cylinder located 0.34 mm into the depth of the capsule. The certificates for these sources are included in Appendix C.

Tables A1.2a, A1.2b, and A1.2c give the comparisons of the optimized computed efficiencies with measured efficiencies for the 0°, 90°, and 135° point source geometries, respectively. The computed and measured efficiencies for the near and far disk mounted geometries are given in Tables A1.2d and A1.2e, respectively. In each of these tables the measurement and model uncertainties are presented based on the total uncertainty analysis discussed and presented on pages 12 and 13 of this document. The 1σ error columns are the propagation of the measured and model uncertainties and the Dev./σ columns indicate the deviation per sigma to which the model and measurements agree within these uncertainties.

3.3 Computed Efficiencies for Point Sources with Validated Model

Once the model of the detector is validated against measured efficiencies, the model is used to generate energy/efficiency/uncertainty triplets. The efficiencies are generated at a large number of point "source" locations, in vacuum, and at 20 energies between 10 keV and 7000 keV. The point source locations are chosen to fill a semicircular plane extending from 0 degrees (i.e. on the detector axis, in front of the detector) to 180 degrees (i.e. behind the detector), and extending from the center of the front face of the detector endcap out to a radius of 500 meters. The point locations are generated in Ln(R)-θ coordinates, R being the radius in centimeters, and θ being the angle in radians (Figure 7). The X axis represents the angle θ, and the Y-axis represents Ln(R). As seen from Figure 6, the points are in a grid pattern, spanning the entire semicircular plane. The number of point locations depends on the size of the crystal and the dimensions of the detector endcap. The density of points at the vicinity of the detector endcap is higher than in other regions.

3.4 Gridding Method to Create Detector Calibration Grid

The calculations described above yield efficiencies at each point location in the Ln(R)-θ grid, at 20 different energies. The first step in producing a Detector Calibration Grid (DCG) file is to sort the bare-crystal efficiencies at a given energy by the X coordinate (θ), and then by the Y coordinate [Ln(R)]. Next, using the cubic spline interpolation technique, the efficiencies at a large number of nodal points are generated by interpolating between the bare-crystal reference data. The DCG process thus creates a spatially dense grid of efficiencies in the Ln(R)-θ coordinates, at each of the 20 photon energies. Once the full grid of bare-crystal efficiencies is created, the attenuation due to the external crystal structures are computed point-by-point using the ISOCS-based computational algorithms. The properly attenuated efficiency grids at the 20 energies are then combined to produce the ISOCS detector characterization. The efficiency at any arbitrary spatial point between the grid nodes is obtained by linear interpolation along the Ln(R) and θ directions. At a given spatial location, the efficiency at any arbitrary energy between 10 keV and 7000 keV is obtained by parabolic interpolation between the energy grids.

Due to the geometry of the detector, its efficiency response is cylindrically symmetric about its axis. Therefore, the response characterization that is valid within a semicircular plane of a given radius is also valid within a hemispherical region about the symmetry axis of the detector. In other words, the ISOCS characterization represents the detector's response to a point source in vacuum, anywhere within a *sphere* of 500 meter radius, centered about the detector, and at any energy between 10 keV and 7 MeV. Given the DCG grids, the ISOCS/LabSOCS software can then calculate the efficiency for macroscopic sources by integrating the response over the active volume(s) of a given geometry, taking into account the attenuation through the materials in the geometry.

3.5 Statistical Tests to Validate the Quality of DCG Grids

<u>Statistical Report</u>:

A statistical test is performed to check the interpolation quality of the bare-crystal DCG grids. The test involves a bootstrapping method. First, a secondary set of point source locations is generated, intermediate to the primary set of points. Efficiencies at the secondary points are determined by linear interpolation, using the primary DCG grids. Using the efficiencies at the intermediate points, a secondary set of DCG grids (DCG2) are created. From the secondary DCG, the efficiencies at the primary point locations are determined and compared to the MCNP efficiencies at the primary points.

Within a specified spatial region, the relative deviation of the grid efficiencies with respect to the MCNP efficiencies is given as follows:

$$\%RD = 100 \bullet \frac{(DCG2eff - MCNPeff)}{MCNPeff}$$

The % Average Relative Deviation (%ARD) = Sum(%RD) / N, where N is the number of points in the specified region.

Standard Deviation of $\%RD = \sqrt{\sum\left(\%RD - \%ARD\right)^2 / N}$

For efficiency data points within a DCG region and at the various photon energies at which the DCG grids have been created, the following statistics are reported:

1. The % Average Relative Deviation of the DCG2 efficiencies with respect to the MCNP efficiencies,
2. The % Standard Deviation in these relative deviations,
3. The % Standard Deviation of the MCNP data, averaged over the number of points in the DCG region,
4. The number of efficiency data points that are within 1σ between 1σ and 2σ and between 2σ and 3σ confidence intervals, at the various DCG energies,
5. The number of data points that are outside the 3σ limit.

The above mentioned statistics are printed out for 6 different pre-defined spatial regions where the laboratory or the in-situ users are most likely to locate their samples. The relative deviations and the standard deviations are calculated for those data points that are within these spatial regions only. This data is meant to provide the user with information regarding the quality of the response characterization within these regions. The pre-defined regions are as follows.

Region1: This region represents a laboratory source that is 2.5 cm in radius and 6 cm in height (e.g. a liquid scintillation vial), located directly on the detector endcap face.

Region 2: This region represents a disk source with a radius of 5 cm and a thickness of 0.5 cm (e.g. a filter paper or evaporated liquid), located directly on the detector endcap face.

Region 3: It represents a Marinelli Beaker, with a well diameter of 10 cm, a well depth of 10 cm (a volume of 1 liter approximately), and bottom thickness of 4 cm.

Region 4: This is a region in space de-limited by a minimum radius of 20 cm and a maximum radius of 1 meter. This region may be of interest to both laboratory and in-situ users.

Region 5: This is a spatial region with a minimum radius of 1 meter and a maximum radius of 2 meters. This region is of interest primarily to an in-situ user.

Region 6: This region extends in space from a minimum radius of 2 meters to a maximum radius of 500 meters. This region is of interest primarily to in-situ users.

In the statistical report, the target values of average relative deviation and the percent standard deviation are indicated for each of the 6 regions, at all DCG energies. For the average relative deviation of DCG2 efficiencies, the target value is 1% at all DCG energies. For the standard deviation of the relative deviations, the target value is $\pm$ 2% at all DCG energies.

Three different statistical summaries are provided in the report. The 'Statistical Bias Summary' verifies whether the average relative deviations are within the % standard deviation limits that have been obtained. Average relative deviation values that exceed 1σ standard deviation are indicated by an asterisk(*) at the appropriate energy, and ARDs that exceed 2σ are indicated by (**). Large ARD values that exceed the 1σ limit may indicate of a bias in the data. The second summary titled 'Absolute Bias Summary' compares the average relative deviations of DCG2 efficiencies, with the target relative deviation (TRD) of 1%. Once again, if the average relative deviations exceed the TRD or 2•TRD, such an occurrence is indicated by an * or **, respectively, at the appropriate DCG energies. This would quantify the absolute bias in the group of efficiency data at a given DCG energy. The third and final summary titled 'Standard Deviation Summary' compares the standard deviation of the relative deviations of DCG2 efficiencies against the target standard deviations (TSD). If the observed standard deviation values exceed the TSD limits, the occurrence is indicated at the corresponding DCG energies. Large standard deviations are indicative of poor data quality.

3.6 Validation of DCG Efficiencies using Measurements

Finally, to come full circle and to compare once again with measurements, the file containing DCG grid is loaded into LabSOCS/ISOCS user-interface software, and efficiencies are generated for the 0°, 90°, and 135° point source geometries, as well as the Plexiglas-mounted source geometries. Figure A1.1 and Tables A1.3a- A1.3e present the results of comparison of LabSOCS/ISOCS efficiencies with measured efficiencies, for the five source geometries. The measurement uncertainties in these tables are presented for each data set. The uncertainties on the ISOCS efficiencies are based on the standard deviation of these efficiencies compared to the measured efficiencies for a large number of germanium detectors of various model types. Since this uncertainty effectively includes the measurement uncertainties, the 1σ error columns are simply a reproduction of these uncertainties. The Dev./σ columns indicate the deviation per sigma to which the model and measurement efficiencies agree within these uncertainties.

4. Estimated Uncertainties of the Characterization Process

There are several contributing factors to the final uncertainty of the characterization process. The sources of uncertainty for the validation measurements and source modeling are summarized in the following tables as one standard deviation uncertainties in percent (%). It should be noted that measurements less than 39 keV from the front and side of the detector and less than 60 keV from the back of the detector are not possible at the factory; therefore the uncertainties for these locations are not estimated.

The independent contributors to the total measurement uncertainties listed in Tables 1a through 1d are the following:

- **Source Activity** – This is the uncertainty in the source activity as provided in the source certificate and verified by independent measurements.
- **Decay Yield –** Accepted per decay yield uncertainties for the specific gamma or *X*-ray. Yields for Eu-152 and Cs-137 lines are from Ref. 3 and Am-241 transition yields are from Ref. 4.
- **Statistical Accuracy –** The typical Poisson uncertainty from the peak area. For the specific measurement uncertainties please refer to the tables in Appendix A.
- **Peak Analysis –** The estimated uncertainty due to peak area analysis. This includes uncertainties due to the modeling of the background and differences due to equivalently valid choices of initial conditions.
- **Geometrical –** Uncertainty inherent in the source positioning reproducibility.
- **Electronic –** Estimated uncertainties in the system data acquisition, including dead time and pulse pile-up correction effects.

The independent contributors to the total model uncertainties are the following:

- **Simulation Precision –** Maximum uncertainty in the Monte-Carlo simulation tallies. These uncertainties are typically less than this uncertainty. For the specific simulation uncertainties for this characterization please refer to the tables in Appendix A.
- **Model Approximation –** Estimated uncertainty inherent in the physical modeling of the detector.

The overall characterization uncertainty is a propagation of all the above factors.

Table 1a. One standard deviation uncertainties (%) for $^{241}Am^{152}Eu$ point source on axis at 29 cm

	13.9	17.8	26.3	39.9	59.5	122	245	344	779	1112	1408
Source Activity	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Decay Yield	3.0	3.1	4.2	2.3	0.3	0.5	0.5	1.9	1.1	0.5	0.5
Statistical Accuracy	0.4	0.3	0.7	0.1	0.1	0.1	0.4	0.1	0.3	0.2	0.2
Peak Analysis	7.0	7.0	7.0	3.5	0.5	0.5	1.4	0.5	0.5	0.75	0.5
Geometrical	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Electronic	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Simulation Precision	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Model Approx.	4.0	4.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total Uncertainty	**8.9**	**8.9**	**9.4**	**4.9**	**2.9**	**2.8**	**3.1**	**3.3**	**2.9**	**2.8**	**2.7**

Table 1b. One standard deviation uncertainties (%) for $^{241}Am^{152}Eu$ point source at 90 degrees

	13.9	17.8	26.3	39.9	59.5	122	245	344	779	1112	1408
Source Activity	--	--	--	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Decay Yield	--	--	--	2.3	0.3	0.5	0.5	1.9	1.1	0.5	0.5
Statistical Accuracy	--	--	--	0.5	0.2	0.1	0.4	0.1	0.3	0.2	0.2
Peak Analysis	--	--	--	3.5	0.5	0.5	1.4	0.5	0.5	0.75	0.5
Geometrical	--	--	--	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Electronic	--	--	--	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Simulation Precision	--	--	--	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Model Approx.	--	--	--	20.0	10.0	7.0	5.0	4.0	4.0	4.0	4.0
Total Uncertainty	**--**	**--**	**--**	**20.5**	**10.2**	**7.3**	**5.5**	**4.8**	**4.5**	**4.5**	**4.4**

Table 1c. One standard deviation uncertainties (%) for $^{241}Am^{152}Eu$ point source at 135 degrees

	13.9	17.8	26.3	39.9	59.5	122	245	344	779	1112	1408
Source Activity	--	--	--	--	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Decay Yield	--	--	--	--	0.3	0.5	0.5	1.9	1.1	0.5	0.5
Statistical Accuracy	--	--	--	--	1.0	0.3	0.1	0.4	0.1	0.3	0.2
Peak Analysis	--	--	--	--	3.5	0.5	0.5	1.4	0.5	0.5	0.75
Geometrical	--	--	--	--	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Electronic	--	--	--	--	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Simulation Precision	--	--	--	--	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Model Approx.	--	--	--	--	25.0	15.0	10.0	10.0	10.0	7.0	7.0
Total Uncertainty	**--**	**--**	**--**	**--**	**25.4**	**15.2**	**10.2**	**10.3**	**10.3**	**7.3**	**7.3**

Table 1d. One standard deviation uncertainties (%) for $^{241}Am^{137}Cs$ source geometries

	$^{241}Am^{137}Cs$ on end cap						$^{241}Am^{137}Cs$ on axis at 10 cm				
	13.9	17.8	26.3	59.5	662		13.9	17.8	26.3	59.5	662
Source Activity	1.0	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0
Decay Yield	3.0	3.1	4.2	0.3	0.3		3.0	3.1	4.2	0.3	0.3
Statistical Accuracy	0.4	0.3	0.7	0.1	0.1		0.4	0.3	0.7	0.1	0.1
Peak Analysis	7.0	7.0	7.0	0.5	0.5		7.0	7.0	7.0	0.5	0.5
Geometrical	0.75	0.75	0.75	0.75	0.75		0.5	0.5	0.5	0.5	0.5
Electronic	3.0	3.0	3.0	3.0	3.0		1.0	1.0	1.0	1.0	1.0
Simulation Precision	1.0	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0
Model Approx.	4.5	4.5	3.0	2.5	2.5		4.0	4.0	3.0	2.0	2.0
Total Uncertainty	**9.6**	**9.6**	**9.9**	**4.4**	**4.3**		**8.9**	**9.0**	**9.5**	**3.0**	**2.7**

5. ISOXSRCE Measurements & QA Recommendations

The ISOCS/LabSOCS characterization is based on the properties and dimensions of the HPGe detector at the time that it is characterized. Therefore, any changes in the Ge crystal properties could potentially induce a bias in the ISOCS/LabSOCS efficiency calculations. For example, in coaxial HPGe detectors, the thickness of the lithium dead layer(s) is known to increase over a period of several years if the detector is not kept cooled. A thicker dead layer would mean a higher attenuation of gamma rays, especially at low energies, and consequently a lower response to the measured radiation. Additionally, as a dead layer increases, it reduces the total active Ge volume, which causes a decrease in efficiency at all energies. These changes over time will result in a gradually increasing discrepancy between the actual detector efficiency and the efficiency response as reflected by the characterization. This will cause measured sample activities to be biased low.

If included in the ISOCS/LabSOCS characterization, the ISOXSRCE Detector Characterization Check Source can have two primary uses:

1) Primarily, it is intended to track the relative changes in detector efficiency for general Quality Assurance purposes. It is imperative that users institute a QA procedure to verify that the ISOCS characterization and the rest of the electronics/software chain continue to be valid. While there is a great degree of flexibility in terms of which source and measurement geometry to use for a QA procedure, it is recommended that *at minimum*, the ISOXSRCE Check Source be used as described in Appendix D of this document. Further recommendations regarding QA procedures are given in Appendix E of this document. Note also that the ISOXSRCE Check Source Fixture User's Manual has detailed discussions on the use of the ISOXSRCE Check Source as well as on implementation of QA procedures.

2) If it is believed that a change in detector efficiency has occurred *solely* due to an increase in dead layer thickness, data collected in the field with this source can be used at the Canberra production facility to estimate the change in dead layer thickness and to generate a new characterization. This alleviates the need to send the detector back to Canberra's production facility for a full recharacterization. This is described in Appendix D of this document.

Prior to shipment, if the ISOXSRCE was included in the ISOCS/LabSOCS characterization, a baseline dataset was collected at Canberra's production facility using the detector and its associated ISOXSRCE Check Source. The details of these ISOXSRCE measurements are discussed in Appendix D of this document as well as in the ISOXSRCE Check Source Fixture User's Manual. Tables A1.5a and A1.5b present the baseline dataset from the ISOXSRCE measurements performed at the factory, as well as the serial number of the source used for these measurements. The certificate describing this source is in Appendix C.

A key aspect of a good QA program is the establishment of a baseline set of measurements. Consequently, as soon as possible after the ISOCS characterized detector and the check source are received from the factory, users are strongly advised to set up the system with their own electronics and generate their own base line results for the various QC parameters. An example of this using the ISOXSRCE Check Source is presented in Appendix D of this document. The results of these baseline measurements should not be appreciably different from those obtained at Canberra's production facility. Furthermore, if other check sources are to be used as part of the QA program, these should also be measured at this time to establish a baseline as well as a cross-reference to the ISOXSRCE source.

6. List of References

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[3] Evaluated Nuclear Structure Data File (ENSDF), National Nuclear Data Center, Brookhaven National Laboratory. http://www.nndc.bnl.gov/ensdf/.

[4] Lepy, M.C., Plagnard, J., and Ferreux L., *Measurement of ^{241}Am L X-ray emission probabilities*, Applied Radiation and Isotopes. **66** (2008) 715.

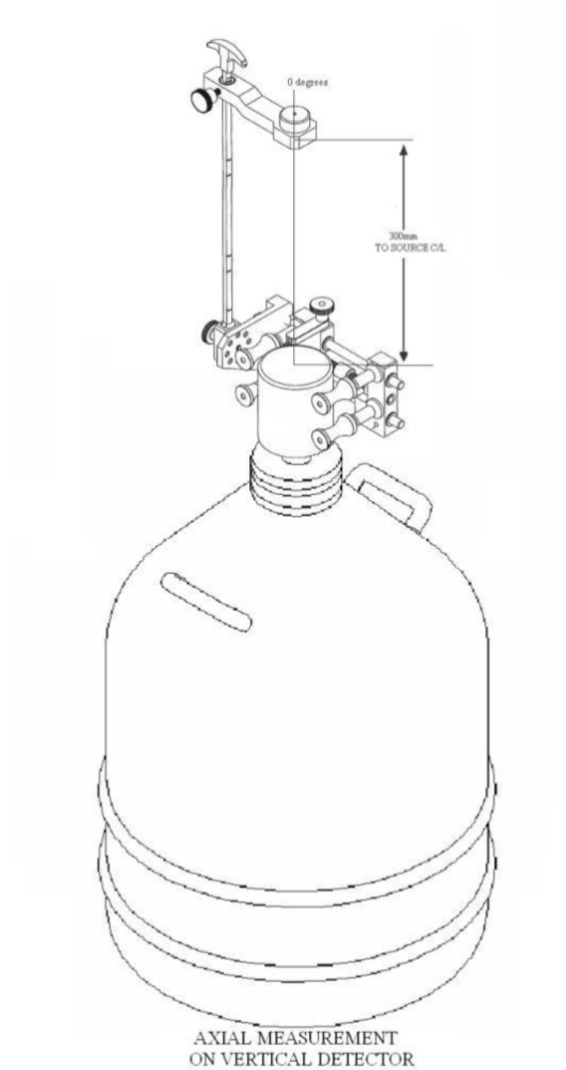


Figure 1. Am-241/Eu-152 point source On-Axis.

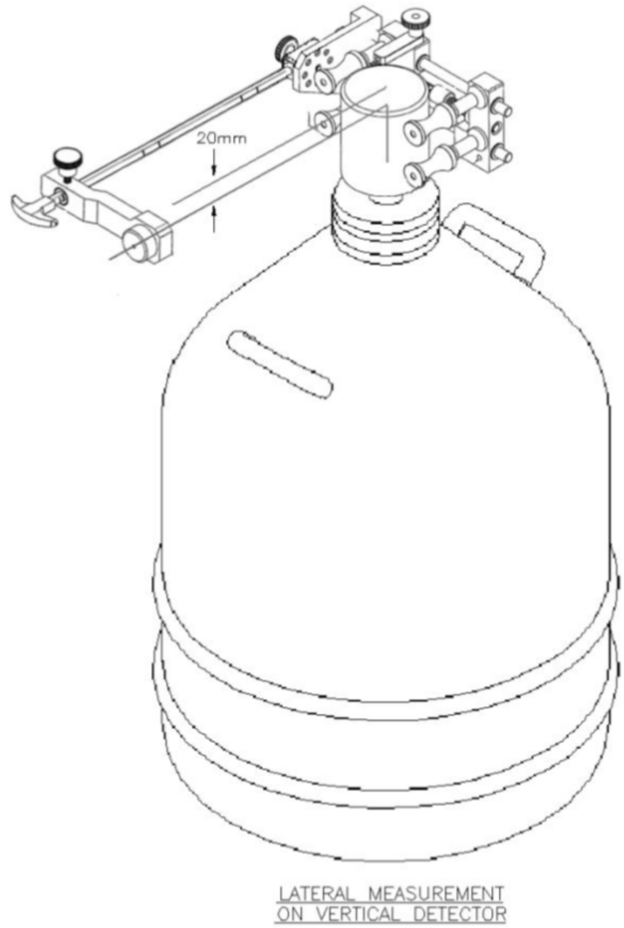


Figure 2. Am-241/Eu-152 point source at 90°.

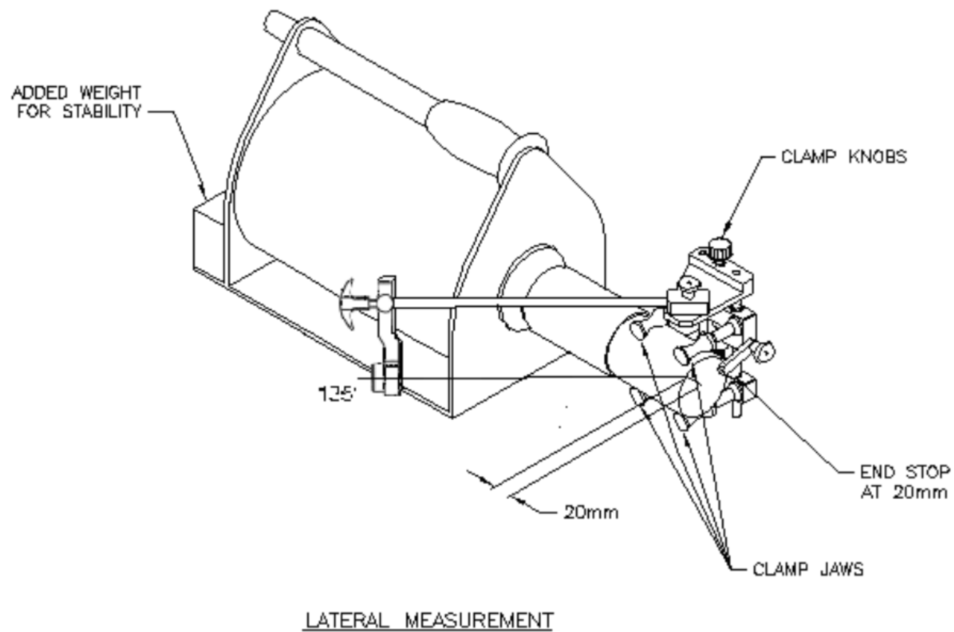


Figure 3. Am-241/Eu-152 point source at 135°.

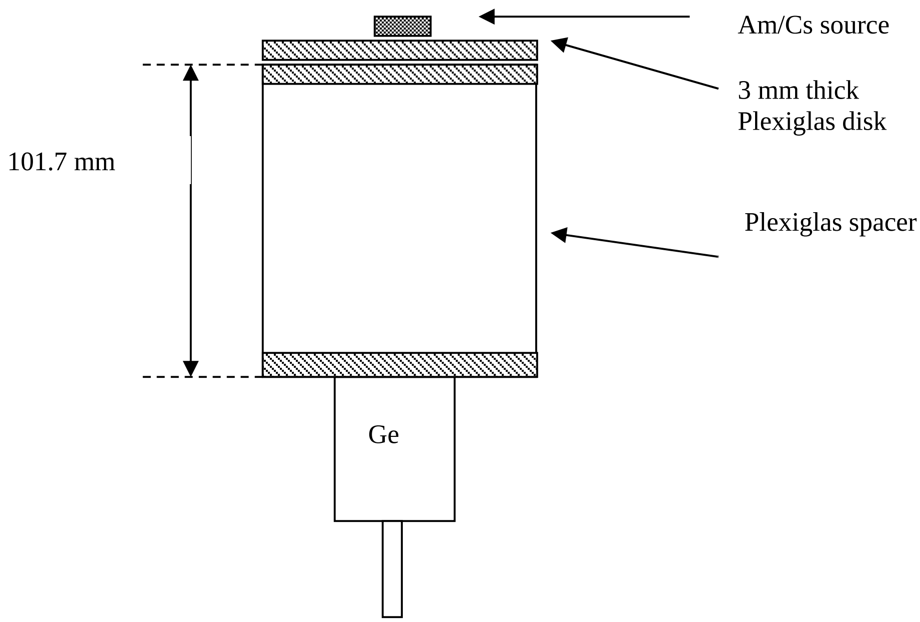


Figure 4. Am-241/Cs-137 point source 104 mm from endcap.

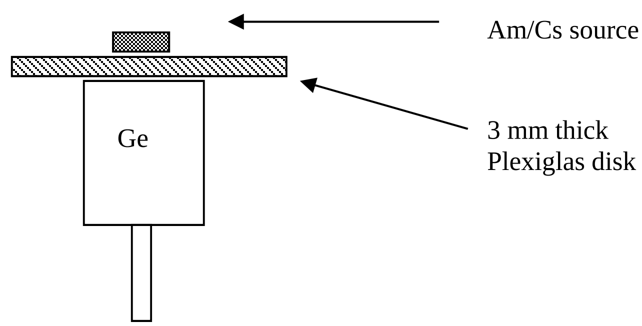


Figure 5. Am-241/Cs-137 point source on endcap.

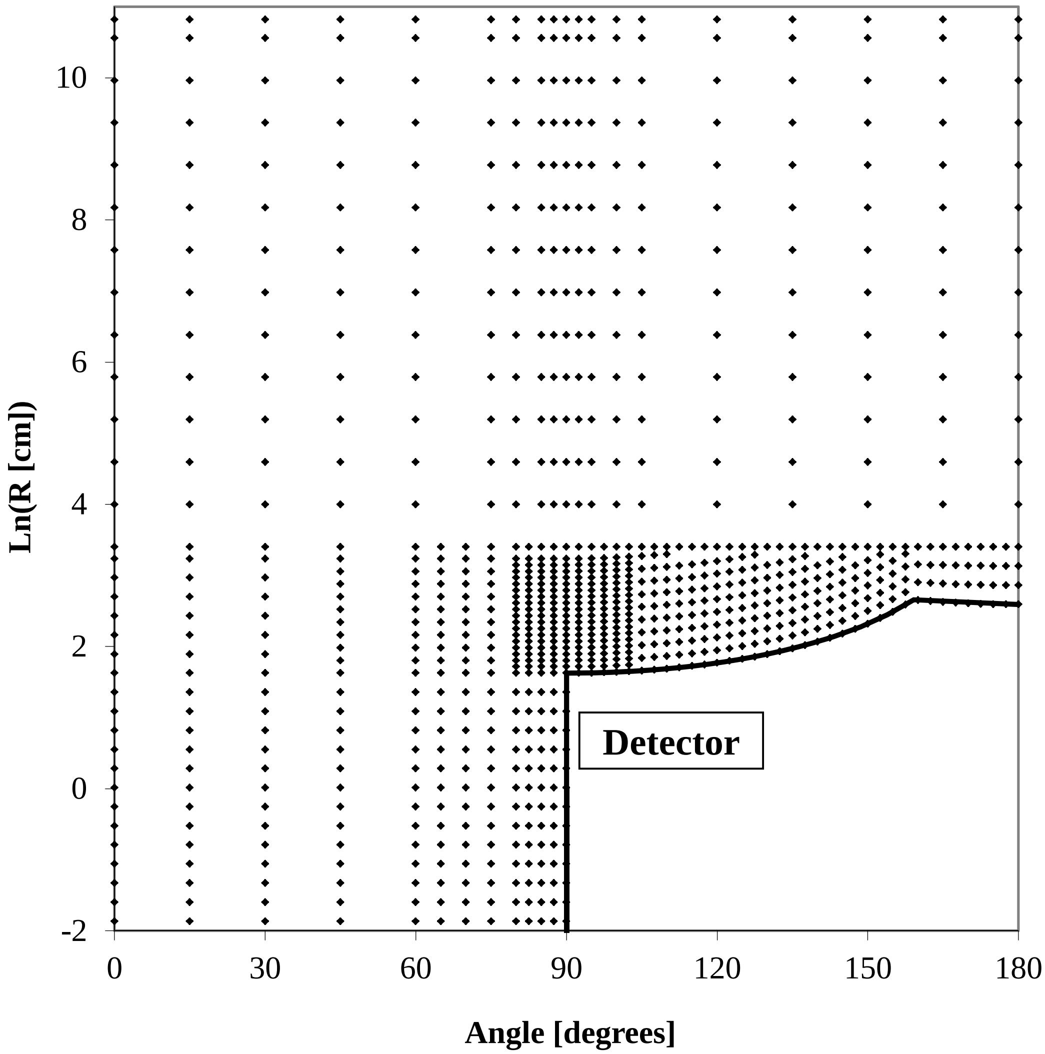


Figure 6. MCNP point locations.

A. Detector and System Specific Information

The In Situ Object Counting System (ISOCS) is designed to count a wide variety of source geometries and to report activities of gamma-ray emitting radioisotopes which may be present in the source. ISOCS is ideally suited for assaying large samples in an uncollimated or a collimated counting geometry.

The Laboratory Sourceless Calibration Software (LabSOCS) is ideal for performing efficiency calibration of laboratory counting geometries such as filter papers, vials, bottles, and Marinelli Beakers. Using LabSOCS, containers of any shape may be custom defined, as long as the shape is rotationally symmetric. Using LabSOCS with Canberra's Genie 2000 software, gamma ray spectra from a variety of source geometries may be analyzed and nuclide activities reported.

The sales number for this order is 75766. The system assembled for this order consists of one 50 cm2 BE5030P germanium detector (serial number 13218).

For a typical ISOCS system, gamma-ray spectra from the detector are accumulated and processed using a Lynx MCA. The data is stored on a Laptop PC. The system is controlled and spectra analyzed by the Genie2000 software. Efficiencies may be generated using ISOCS software.

For a system using LabSOCS, users may employ their own set of electronics to acquire gamma ray spectra in their laboratory. Efficiencies may be generated using LabSOCS software and used with Genie2000.

Data Distributed on Disk

The end result of the characterization process described in this report is a set of 20 efficiency grids, corresponding to the 20 energies between 10 keV – 7000 keV; all the energy grids having been compressed into a single binary file. The LabSOCS/ISOCS software generates efficiencies for sources of nearly any shape or size, based on this detector characterization file. The name of this binary file is the same as the detector serial number with an extension of PAR. The detector will be referenced in the user-interface menu structure using this same label.

In addition to this report and the characterization file, five other files are included on the disk:

DETECTOR.TXT -- contains additional detector information required by the ISOCS/LabSOCS software.

README.TXT-- contains detailed instructions on how to install the characterization and DETECTOR.TXT files on the computer. This can be done manually, or automatically. Both methods are described in README.TXT.

9231598B_ISOXSRCE_USERS_MANUAL.PDF -- This is the user’s manual for the ISOXSRCE check source. It contains a detailed description of the source, along with instructions on how to properly use the source to track any relative changes in the detector’s efficiency and to determine any dead layer growth. (This is included only if the ISOCS characterization ordered included an ISOXSRCE check source with the measurements)

Table A1.1. Point source at 90 degrees: Efficiency at different azimuthal angles.

Source located at 90 degrees		Efficiency at different Azimuthal angles							
		0 degrees		120 degrees		240 degrees		Average	
Nuclide	E (keV)	Efficiency	Uncertainty	Efficiency	Uncertainty	Efficiency	Uncertainty	Efficiency	Uncertainty
Eu-152	39.9	1.70E-05	7.53%	1.46E-05	10.86%	1.46E-05	11.89%	1.54E-05	5.86%
Am-241	59.5	1.66E-04	2.13%	1.65E-04	2.12%	1.66E-04	2.12%	1.66E-04	1.09%
Eu-152	121.8	9.79E-04	1.78%	9.64E-04	1.78%	9.63E-04	1.78%	9.68E-04	0.82%
	244.7	9.22E-04	2.32%	9.08E-04	2.32%	9.28E-04	2.31%	9.19E-04	1.19%
	344.3	7.47E-04	2.53%	7.51E-04	2.53%	7.49E-04	2.53%	7.49E-04	1.03%
	778.9	4.19E-04	2.27%	4.28E-04	2.24%	4.24E-04	2.25%	4.24E-04	1.06%
	1112.1	3.35E-04	2.04%	3.27E-04	2.04%	3.29E-04	2.04%	3.31E-04	1.01%
	1408.0	2.84E-04	1.91%	2.78E-04	1.92%	2.84E-04	1.92%	2.82E-04	0.92%

Nuclide	E (keV)	Average Efficiency	% deviation from Average		
			0 deg	120 deg	240 deg
Eu-152	39.9	1.54E-05	10.48%	-5.11%	-5.38%
Am-241	59.5	1.66E-04	0.27%	-0.33%	0.06%
Eu-152	121.8	9.68E-04	1.07%	-0.48%	-0.59%
	244.6	9.19E-04	0.32%	-1.28%	0.96%
	344.3	7.49E-04	-0.28%	0.30%	-0.02%
	778.9	4.24E-04	-1.01%	0.91%	0.10%
	1112.0	3.31E-04	1.38%	-0.94%	-0.44%
	1408.0	2.82E-04	0.84%	-1.42%	0.58%

Table A1.2a. ^{241}Am-^{152}Eu point source on axis:
Comparison of Modeled vs. Measured Efficiencies.

Source located at 0 degrees		Measured Efficiency		Model Efficiency		Ratio of Model eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Am-241	13.9	1.77E-03	7.24%	1.66E-03	4.07%	0.936	0.078	-0.8
	17.8	2.49E-03	7.22%	2.46E-03	4.06%	0.987	0.082	-0.2
	26.3	3.05E-03	7.35%	3.24E-03	3.06%	1.062	0.085	0.7
Eu-152	39.9	3.47E-03	4.12%	3.57E-03	2.09%	1.029	0.048	0.6
Am-241	59.5	3.63E-03	1.66%	3.66E-03	2.09%	1.008	0.027	0.3
Eu-152	121.8	3.50E-03	1.74%	3.45E-03	2.09%	0.986	0.027	-0.5
	244.7	2.18E-03	2.21%	2.18E-03	2.14%	0.999	0.031	0.0
	344.3	1.56E-03	2.49%	1.54E-03	2.20%	0.988	0.033	-0.4
	778.9	7.06E-04	2.07%	6.97E-04	2.23%	0.986	0.030	-0.5
	1112.1	5.07E-04	1.92%	5.10E-04	2.22%	1.006	0.030	0.2
	1408.0	4.08E-04	1.82%	4.18E-04	2.22%	1.025	0.029	0.9
				Weighted Average		1.001	0.011	

Table A1.2b. ^{241}Am-^{152}Eu point source at 90 degrees:
Comparison of Modeled vs. Measured Efficiencies.

Source located at 90 degrees		Measured Efficiency		Model Efficiency		Ratio of Model eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Eu-152	39.9	1.54E-05	5.86%	1.32E-05	20.02%	0.855	0.178	-0.8
Am-241	59.5	1.66E-04	1.09%	1.74E-04	10.04%	1.047	0.106	0.4
Eu-152	121.8	9.68E-04	0.82%	9.39E-04	7.06%	0.970	0.069	-0.4
	244.7	9.19E-04	1.19%	8.94E-04	5.10%	0.972	0.051	-0.5
	344.3	7.49E-04	1.03%	7.24E-04	4.12%	0.966	0.041	-0.8
	778.9	4.24E-04	1.06%	4.15E-04	4.12%	0.980	0.042	-0.5
	1112.1	3.31E-04	1.01%	3.25E-04	4.12%	0.983	0.042	-0.4
	1408.0	2.82E-04	0.92%	2.78E-04	4.12%	0.987	0.042	-0.3
				Weighted Average		0.978	0.018	

Table A1.2c. ^{241}Am-^{152}Eu point source at 135 degrees:
Comparison of Modeled vs. Measured Efficiencies.

Source located at 135 degrees		Measured Efficiency		Model Efficiency		Ratio of Model eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Am-241	59.5	6.11E-05	5.75%	6.13E-05	15.01%	1.004	0.161	0.0
Eu-152	121.8	1.11E-03	2.46%	1.08E-03	10.02%	0.971	0.100	-0.3
	244.7	1.14E-03	3.51%	1.13E-03	10.04%	0.990	0.105	-0.1
	344.3	9.08E-04	3.07%	8.88E-04	10.05%	0.978	0.103	-0.2
	778.9	4.89E-04	3.08%	4.87E-04	7.07%	0.995	0.077	-0.1
	1112.1	3.74E-04	2.97%	3.80E-04	7.07%	1.017	0.078	0.2
	1408.0	3.16E-04	2.73%	3.20E-04	7.07%	1.013	0.077	0.2
				Weighted Average		0.998	0.035	

Table A1.2d. ^{241}Am-^{137}Cs point source on end cap:
Comparison of Modeled vs. Measured Efficiencies.

Source located at 0 degrees		Measured Efficiency		Model Efficiency		Ratio of Model eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Am-241	13.9	6.30E-02	7.80%	6.22E-02	15.03%	0.987	0.167	-0.1
	17.8	1.29E-01	7.78%	1.31E-01	15.02%	1.016	0.172	0.1
	26.3	2.09E-01	7.87%	2.23E-01	10.02%	1.064	0.136	0.5
	59.5	2.79E-01	3.35%	2.81E-01	2.58%	1.009	0.043	0.2
Cs-137	661.7	6.88E-02	3.52%	6.85E-02	2.69%	0.995	0.044	-0.1
				Weighted Average		1.005	0.029	

Table A1.2e. ^{241}Am-^{137}Cs point source at 10.4 cm from end cap:
Comparison of Modeled vs. Measured Efficiencies.

Source located at 0 degrees		Measured Efficiency		Model Efficiency		Ratio of Model eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Am-241	13.9	4.04E-03	7.30%	3.83E-03	15.03%	0.948	0.158	-0.3
	17.8	9.93E-03	7.25%	9.05E-03	15.03%	0.911	0.152	-0.6
	26.3	1.67E-02	7.46%	1.61E-02	10.03%	0.964	0.120	-0.3
	59.5	2.07E-02	1.73%	2.06E-02	2.11%	0.993	0.027	-0.2
Cs-137	661.7	4.69E-03	2.04%	4.80E-03	2.23%	1.025	0.031	0.8
				Weighted Average		1.003	0.020	

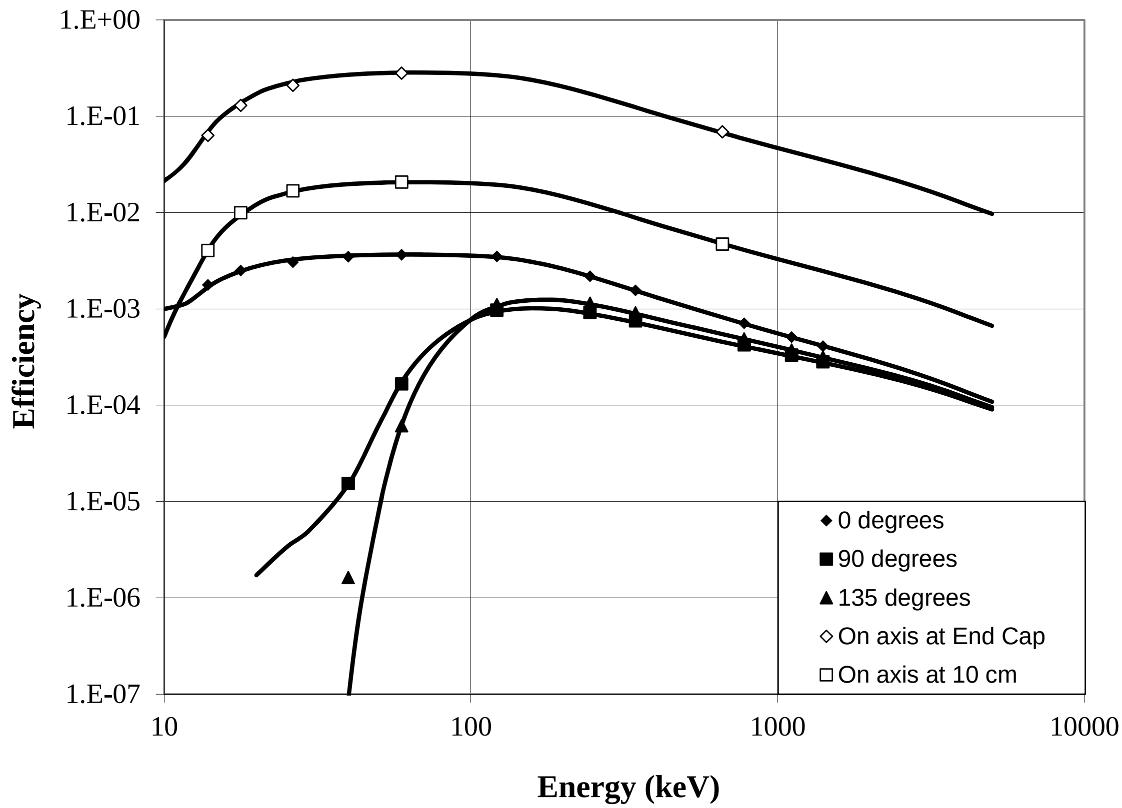


Figure A1.1. ISOCS efficiencies (solid lines) compared to experimental measurements (points) for validation geometries.

Table A1.3a. ^{241}Am-^{152}Eu point source on axis:
Comparison of ISOCS vs. Measured Efficiencies.

Source located at 0 degrees		Measured Efficiency		ISOCS Efficiency		Ratio of ISOCS eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Am-241	13.9	1.77E-03	7.24%	1.69E-03	10.00%	0.955	0.118	-0.4
	17.8	2.49E-03	7.22%	2.49E-03	10.00%	1.000	0.123	0.0
	26.3	3.05E-03	7.35%	3.24E-03	10.00%	1.064	0.132	0.5
Eu-152	39.9	3.47E-03	4.12%	3.57E-03	6.00%	1.028	0.075	0.4
Am-241	59.5	3.63E-03	1.66%	3.66E-03	3.00%	1.008	0.035	0.2
Eu-152	121.8	3.50E-03	1.74%	3.44E-03	3.00%	0.983	0.034	-0.5
	244.7	2.18E-03	2.21%	2.15E-03	3.00%	0.988	0.037	-0.3
	344.3	1.56E-03	2.49%	1.54E-03	3.00%	0.988	0.039	-0.3
	778.9	7.06E-04	2.07%	6.99E-04	3.00%	0.990	0.036	-0.3
	1112.1	5.07E-04	1.92%	5.06E-04	3.00%	0.999	0.036	0.0
	1408.0	4.08E-04	1.82%	4.10E-04	3.00%	1.004	0.035	0.1
				Weighted Average		0.996	0.013	

Table A1.3b. ^{241}Am-^{152}Eu point source at 90 degrees:
Comparison of ISOCS vs. Measured Efficiencies.

Source located at 90 degrees		Measured Efficiency		ISOCS Efficiency		Ratio of ISOCS eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Eu-152	39.9	1.54E-05	5.86%	1.51E-05	25.00%	0.983	0.252	-0.1
Am-241	59.5	1.66E-04	1.09%	1.73E-04	12.00%	1.045	0.126	0.4
Eu-152	121.8	9.68E-04	0.82%	9.39E-04	8.00%	0.970	0.078	-0.4
	244.7	9.19E-04	1.19%	8.89E-04	8.00%	0.966	0.078	-0.4
	344.3	7.49E-04	1.03%	7.19E-04	5.00%	0.960	0.049	-0.8
	778.9	4.24E-04	1.06%	4.07E-04	5.00%	0.962	0.049	-0.8
	1112.1	3.31E-04	1.01%	3.23E-04	5.00%	0.978	0.050	-0.4
	1408.0	2.82E-04	0.92%	2.76E-04	5.00%	0.980	0.050	-0.4
				Weighted Average		0.972	0.022	

Table A1.3c. ^{241}Am-^{152}Eu point source at 135 degrees:
Comparison of ISOCS vs. Measured Efficiencies.

Source located at 135 degrees		Measured Efficiency		ISOCS Efficiency		Ratio of ISOCS eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Am-241	59.5	6.11E-05	5.75%	6.10E-05	18.00%	1.000	0.189	0.0
Eu-152	121.8	1.11E-03	2.46%	1.07E-03	12.00%	0.965	0.118	-0.3
	244.7	1.14E-03	3.51%	1.11E-03	12.00%	0.968	0.121	-0.3
	344.3	9.08E-04	3.07%	8.87E-04	12.00%	0.976	0.121	-0.2
	778.9	4.89E-04	3.08%	4.85E-04	8.00%	0.991	0.085	-0.1
	1112.1	3.74E-04	2.97%	3.74E-04	8.00%	1.002	0.086	0.0
	1408.0	3.16E-04	2.73%	3.14E-04	8.00%	0.994	0.084	-0.1
				Weighted Average		0.988	0.039	

Table A1.3d. ^{241}Am-^{137}Cs point source on end cap:
Comparison of ISOCS vs. Measured Efficiencies.

Source located at 0 degrees		Measured Efficiency		ISOCS Efficiency		Ratio of ISOCS eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Am-241	13.9	6.30E-02	7.80%	7.00E-02	20.00%	1.111	0.239	0.5
	17.8	1.29E-01	7.78%	1.40E-01	20.00%	1.085	0.217	0.4
	26.3	2.09E-01	7.87%	2.27E-01	20.00%	1.083	0.217	0.4
	59.5	2.79E-01	3.35%	2.83E-01	5.00%	1.016	0.051	0.3
Cs-137	661.7	6.88E-02	3.52%	6.75E-02	5.00%	0.981	0.049	-0.4
				Weighted Average		1.004	0.034	

Table A1.3e. ^{241}Am-^{137}Cs point source at 10.4cm from end cap:
Comparison of ISOCS vs. Measured Efficiencies.

Source located at 0 degrees		Measured Efficiency		ISOCS Efficiency		Ratio of ISOCS eff. over Measured eff.		
Nuclide	E (keV)	Efficiency	1 sd %	Efficiency	1 sd %	Ratio	1 σ error	Dev./ σ
Am-241	13.9	4.04E-03	7.30%	4.14E-03	20.00%	1.025	0.218	0.1
	17.8	9.93E-03	7.25%	9.66E-03	20.00%	0.972	0.207	-0.1
	26.3	1.67E-02	7.46%	1.65E-02	20.00%	0.988	0.211	-0.1
	59.5	2.07E-02	1.73%	2.06E-02	4.00%	0.994	0.043	-0.1
Cs-137	661.7	4.69E-03	2.04%	4.77E-03	4.00%	1.017	0.046	0.4
				Weighted Average		1.004	0.030	

The relative efficiency (1332 keV from ^{60}Co at 25 cm) was calculated using the ISOCS characterization for the detector S/N 13218 and compared against the value measured during the characterization measurements. The relative efficiency measurement is not use directly in the characterization procedure. Therefore, this measurement is intended to serve as an independent verification of the ISOCS characterization of the detector. It should be noted that the relative efficiency on the detector specification sheet is meant to be a guaranteed minimum value for the specific detector. Therefore, the ISOCS calculated relative efficiency is typically higher than the guaranteed minimum value. The ISOCS efficiency, taken with a 1σ uncertainty estimate of 4%, can be construed to be a more representative efficiency value for the detector.

Table A1.4. The relative efficiency: Comparison of ISOCS vs. the nominal value.

Efficiency	
Nominal	50.79%
ISOCS	50.88%
Ratio	1.002

The baseline ISOXSRCE Detector Characterization Check Source measurements are presented in the following two tables, if the ISOXSRCE was included as part of the ISOCS/LabSOCS characterization. Please note that the ISOXSRCE check source is included by default, unless specifically requested to be excluded from the characterization at the time of order. Details on the check source measurements and their usage are presented in Appendix E.

Table A1.5a. ISOXSRCE base line measurement data (on end).

Measurement date	Energy (keV)	FWHM (keV)	Centroid (channel)	Peak count rate (cps)	% 1σ uncertainty
12/02/2017	42.8	0.75	478.06	181.33	2.89%
	60.0	0.73	669.47	11.59	2.10%
	86.5	0.80	964.18	312.30	1.51%
	105.3	0.80	1172.51	208.86	1.51%
	511.0	2.42	5677.65	463.26	3.32%
	1274.5	1.66	14156.60	105.08	1.52%

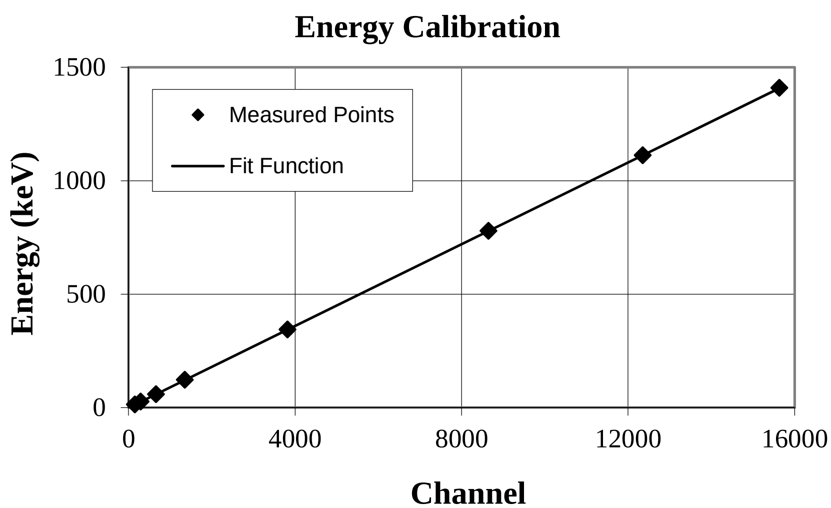
Table A1.5b. ISOXSRCE base line measurement data (on side).

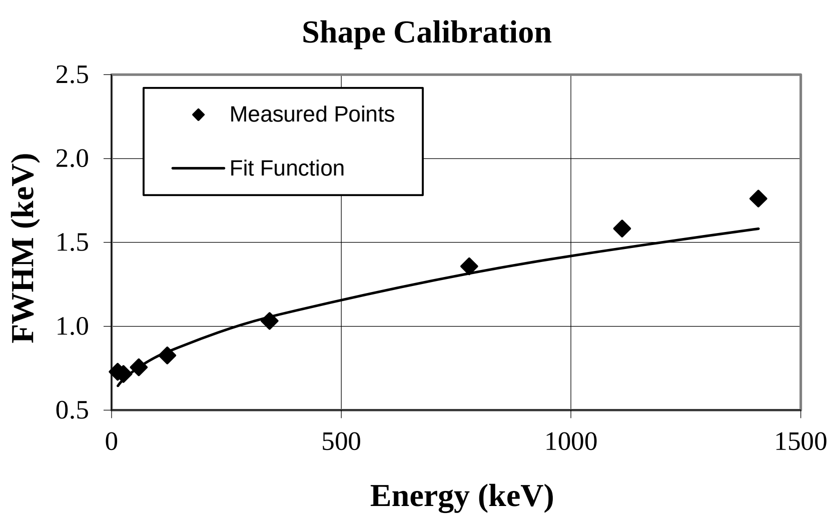
Measurement date	Energy (keV)	Peak count rates in azimuthal directions					
		Count rate @ 0 deg		Count rate @ 120 deg		Count rate @ 240 deg	
12/02/2017		cps	% 1σ Unc	cps	% 1σ Unc	cps	% 1σ Unc
	42.8	0.90	6.31%	0.64	9.19%	0.83	15.76%
	60.0	0.53	21.69%	0.45	18.70%	0.55	16.96%
	86.5	38.81	1.59%	38.55	1.60%	38.97	1.58%
	105.3	36.55	1.59%	36.36	1.59%	36.83	1.59%
	511.0	185.11	3.32%	187.72	3.32%	187.63	3.32%
	1274.5	52.52	1.54%	53.29	1.54%	53.29	1.54%

ISOXSRCE serial number:82217-8

B. Energy/Shape Calibrations and Hardware Settings

Energy and Shape calibrations were performed by acquiring a gamma ray spectrum using a NIST traceable mixed gamma point source containing ^{241}Am and ^{152}Eu. The pole-zero setting was adjusted to yield an optimum pulse shape. The gain and the zero of the spectrum were adjusted to give, approximately, a slope of 0.09 keV/channel and an intercept of 0.0. The energy and Full Width Half Maximum calibrations were performed. The details of these and all hardware settings are presented in this appendix.





****
***** E N E R G Y C A L I B R A T I O N R E P O R T *****
****

Detector Name: 5524
Sample Title: SN13218_0D

************* ENERGY CALIBRATION COEFFICIENTS *************

Energy Calibrate Performed on: 12/1/2017 7:56:07 AM
by:
Energy Calibrate Type: POLY

Energy(keV) = -0.278 + 0.090*ch + 0.00E+000*ch^2 + 0.00E+000*ch^3

************* SHAPE CALIBRATION COEFFICIENTS *************

Shape Calibrate Performed on: 12/1/2017 7:56:07 AM
by:

FWHM = 0.542 + 0.028*E^1/2

LOW TAIL = 9.6E-001 + 3.9E-004*E

************* ENERGY CALIBRATION RESULTS TABLE *************

Centroid Channel	Centroid error	Energy (keV)
156.27	0.03	13.90
295.36	0.03	26.34
664.39	0.01	59.54
1355.54	0.04	121.78
3825.53	0.01	344.28
8653.64	0.05	778.90
12354.14	0.08	1112.07
15640.12	0.08	1408.01

************* SHAPE CALIBRATION RESULTS TABLE *************

Energy (keV)	FWHM channels	FWHM error	TAIL channels	TAIL error
13.90	8.08	0.06	10.84	1.00
26.34	7.93	0.06	7.72	1.51
59.54	8.37	0.01	12.39	1.00
121.78	9.17	0.07	11.24	1.00
344.28	11.45	0.03	12.22	0.59
778.90	15.07	0.10	17.04	4.01
1112.07	17.55	0.16	14.04	0.92
1408.01	19.55	0.14	19.19	1.48

```
*************************************************************************
** F R O N T   E N D   H A R D W A R E   S E T T I N G S   R E P O R T **
*************************************************************************

Report Generated On             : 12/12/2017  2:00:48 PM

Sample Title                    : SN13218_0D
Sample Identification           : 11-31
Sample Type                     :
Sample Geometry                 :


Sample Taken On                 :
Acquisition Started             : 12/1/2017   9:44:05 AM

Live Time                       :     3600.0 seconds
Real Time                       :     3777.9 seconds

==============================================================

MCA:         Type: Lynx         Serial No: 13000005
    ---------------------------------------------------------


Amplifier:   Type: LYNX         Serial No:
    ---------------------------------------------------------
    Composite Gain:    10.00   Shaping Mode:
    Coarse Gain:        5.66   BLR Mode:           Auto
    Fine Gain:          1.08   LTC Mode:           On
    Super-fine Gain:    1.00   Input Mode:         Normal
    Pole Zero Value:    2174   Input Polarity:     Neg
    Shaping Time:       0.00   Inhibit Polarity:   Pos
                               Pileup Rejection:   Off


HVPS:        Type: Internal     Serial No: 13000005
    ---------------------------------------------------------
    Voltage:         3101.00   Overload Latch:     Disable
    Voltage Limit:   5000.00   Inhibit Latch:      Disable
                               Inhibit Signal:     5V
    Voltage Range:   5000.00   Output Polarity:    Pos


Dig.Stabliz  Type: Internal     Serial No: 13000005
    ---------------------------------------------------
                           Window 1    Window 2
    Analog Range:             0.00        0.00
    Analog Mode:              Off         Off
    Stabilizer Centroid:      200           10
    Stabilizer Range:           5            4
    Stabilizer Spacing:         4           10
    Stabilizer Rate:          0.00        0.00
    Correction Factor:     2048.00        0.00
    Event Multiplier:           1            1
    Use NaI Range:            No          No

    Zero Overrange:    No       Gain Overrange:   No


DSP Gain     Type: Internal     Serial No: 13000005
```

```
    ---------------------------------------------------
    Coarse gain                       5.6600E+000
    Fine gain                         1.0814E+000
    S-fine gain                       1.0000E+000
    Amp gain                          1.0000E+001
    Conv. gain                                  0
    Range                                   32768
    Offset                                     -5
    LLD                               1.0000E-001
    Zero                              0.0000E+000
    FDisc Mode                       Auto
    FDisc Setting                     1.0000E+000
    Inp. Polarity                     1
    Inh. polarity                     0
    LTC mode                         On
    Coinc. mode                       0
    PUR Guard                         1.1000E+000
    Inhibit Mode                      0
    LT Trim                                   500
    ICR                               3.3950E+003


DSP Filter   Type: Internal     Serial No: 13000005
    ---------------------------------------------------
    Rise Time                         1.0400E+001
    Flat Top                          1.2000E+000
    BLR mode                         Auto
    Preamp type                      RC
    Pole zero                                2174


=============================================================
```

C. Calibration Source Certificates

Eckert & Ziegler
Isotope Products

24937 Avenue Tibbitts
Valencia, California 91355

Tel 661·309·1010
Fax 661·257·8303

CELEBRATING 50 YEARS Eckert & Ziegler Isotope Products 1967 - 2017

CERTIFICATE OF CALIBRATION
MIXED GAMMA STANDARD SOURCE

Radionuclide:	Am-241	**Customer:**	CANBERRA INDUSTRIES (CONNECTICUT)
Radionuclide:	Eu-152	**P.O. No.:**	4037486
Half-life (Am-241):	432.17 ± 0.66 years	**Catalog No.:**	GF-CUSTOM
Half-life (Eu-152):	4933 ± 11 days	**Reference Date:**	1-Nov-11 12:00 PST
		Source No.:	I4-621

Contained Radioactivity:

Am-241:	3.958	μCi,	146.4	kBq	Total Activity:	8.071	μCi,	298.6	kBq
Eu-152:	4.113	μCi,	152.2	kBq					

Physical Description:

A. Capsule type: C (11 mm x 23.5 mm)
B. Nature of active deposit: Evaporated metallic salts
C. Active diameter/volume: 3 mm
D. Backing: Epoxy
E. Cover: Plastic

Radioimpurities: Am-241: None detected
Eu-152: Gd-153 = 1.40% on 1-Nov-11

Method of Calibration:

This source was assayed using gamma ray spectrometry.

Am-241:	59.5 keV	0.360 gammas per decay
Eu-152:	344.3 keV	0.266 gammas per decay

Uncertainty of Measurement:	Am-241	Eu-152
A. Type A (random) uncertainty:	± 0.6 %	± 0.8 %
B. Type B (systematic) uncertainty:	± 3.0 %	± 3.0 %
C. Uncertainty in aliquot weighing:	± 0.0 %	± 0.0 %
D. Total uncertainty at the 99% confidence level:	± 3.1 %	± 3.1 %

Notes:

- See reverse side for leak test(s) performed on this source.
- EZIP participates in a NIST measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NIST certification) of Standard Reference Materials (as in NRC Regulatory Guide 4.15).
- Nuclear data was taken from IAEA-TECDOC-619, 1991.

Daniel James Van Dalsem
Quality Control

17-Apr-17
Reissued

EZIP Ref. No.: 1531-79

ISO 9001 CERTIFIED

Medical Imaging Laboratory
24937 Avenue Tibbitts Valencia, California 91355

Industrial Gauging Laboratory
1800 North Keystone Street Burbank, California 91504

Eckert & Ziegler
Isotope Products

24937 Avenue Tibbitts
Valencia, California 91355

Tel 661·309·1010
Fax 661·257·8303

CELEBRATING 50 YEARS Eckert & Ziegler Isotope Products 1967 - 2017

CERTIFICATE OF CALIBRATION
MIXED GAMMA STANDARD SOURCE

Radionuclide:	Am-241	**Customer:**	CANBERRA INDUSTRIES (CONNECTICUT)
Radionuclide:	Cs-137	**P.O. No.:**	4037486
Half-life (Am-241):	432.17 ± 0.66 years	**Catalog No.:**	GF-CUSTOM
Half-life (Cs-137):	30.17 ± 0.16 years	**Reference Date:**	1-Nov-11 12:00 PST
		Source No.:	I4-614

Contained Radioactivity:

Am-241:	0.5346	**μCi,**	19.78	**kBq**	Total Activity:	1.065	**μCi,**	39.41	**kBq**
Cs-137:	0.5307	**μCi,**	19.64	**kBq**					

Physical Description:

A. Capsule type:	C (11 mm x 23.5 mm)
B. Nature of active deposit:	Evaporated metallic salts
C. Active diameter/volume:	3 mm
D. Backing:	Epoxy
E. Cover:	Plastic

Radioimpurities: None detected

Method of Calibration:

This source was assayed using gamma ray spectrometry.

Am-241:	59.5 keV	0.360 gammas per decay
Cs-137:	661.7 keV	0.851 gammas per decay

Uncertainty of Measurement:	Am-241	Cs-137
A. Type A (random) uncertainty:	± 0.6 %	± 0.7 %
B. Type B (systematic) uncertainty:	± 3.0 %	± 3.0 %
C. Uncertainty in aliquot weighing:	± 0.0 %	± 0.0 %
D. Total uncertainty at the 99% confidence level:	± 3.1 %	± 3.1 %

Notes:

- See reverse side for leak test(s) performed on this source.
- EZIP participates in a NIST measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NIST certification) of Standard Reference Materials (as in NRC Regulatory Guide 4.15).
- Nuclear data was taken from IAEA-TECDOC-619, 1991.

Daniel James Van Dalsem
Quality Control

17-Apr-17
Reissued

EZIP Ref. No.: 1531-79

ISO 9001 CERTIFIED

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Industrial Gauging Laboratory
1800 North Keystone Street Burbank, California 91504

Certificate of Compliance

This is to certify that the enlcosed check source(s) conforms to the conditions and limitations specified in the regulations listed below.

- **U.S. NRC – 10 CFR Part 30.18 "Exempt Quantities"**
  NOTE: The source(s) in this package does not exceed the activity limit set forth in Section 30.71 Schedule B of the U.S. NRC Regulations (the source may be transferred to any individual in the U.S. free of specific licensing requirements); however, it may be licensable material in countries other than the U.S.
- **U.S. DOT – 49 CFR Part 173.421 "Excepted Packages for Limited Quantities of Class 7 (Radioactive) Materials"**
- **USPS – Postal Publication No. 52 "Hazardous, Restricted, and Perishable Mail"**
- **IAEA – No. TS-R-1 "Regulations for the Safe Transport of Radioactive Matierals"**
- **IATA – Section 4.2 "Identification" (UN2910 Radioactive Material, Excepted Package, Limited Limited Quantity of Material N.O.S., Class 7)**
- **IATA – Section 10.3.11.1.2. "Radioactive Material in Limited Quantities"**

All sealed sources are wipe tested for surface contamination prior to shipping.

NOTE: Unsealed sources (e.g. needle sources, Po-210 disk sources), which have an active area that is uncovered or protected by a very thin coat, are not designed to pass a standard leak test even though the deposit is adherent. The inactive portions of the source have been checked using a standard wipe test.

Product Description:

Model No.	Nuclide	Nominal Activity	Half-life	Wipe Test Results
EU155/NA22	Eu-155	1.0 µCi (0.037 MBq)	4.76 years	Clean
(Mixed Source)	Na-22	1.0 µCi (0.037 MBq)	2.60 years	

All sources have an uncertainty of ±20%

Date Code: 082217

Serial Number: 8

Assay Date: August 22, 2017

Authorized by: Andrew Cordell

Andrew Cordell, Radioisotope Manager

Date: August 22, 2017

Manufactured by:

SPECTRUM TECHNIQUES, LLC.
106 Union Valley Road, Oak Ridge, TN 37830
Phone: 865.482.9937 Fax: 865.483.0473 Email: sales@spectrumtechniques.com
www.spectrumtechniques.com

4/2016

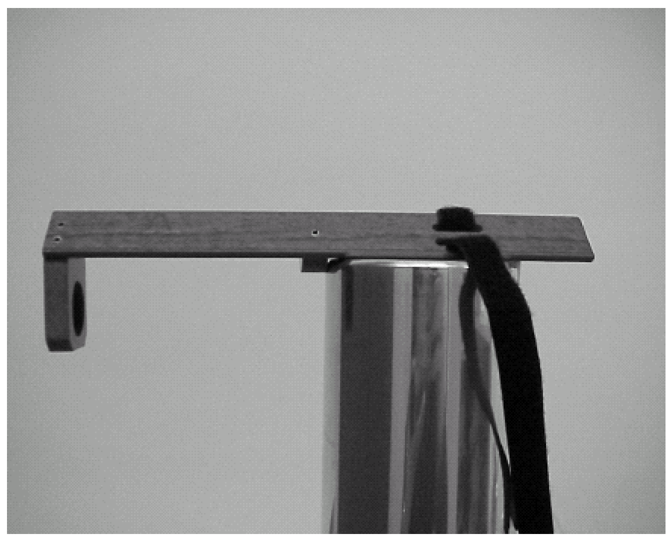
D. ISOXSRCE Measurements

The model ISOXSRCE Detector Characterization Check Source is used to track the relative changes in detector efficiency for quality assurance purposes. The data from measurements with this source can also be used by Canberra to determine the current dead layer thickness of the detector crystal as well as for updating the detector characterization parameters. Please note that the ISOXSRCE check source is included by default with an ISOCS/LabSOCS characterization, unless specifically requested to be excluded from the characterization at the time of order.

The check source is uncalibrated, and contains the isotopes ^{155}Eu (86.5 keV and 105.3 keV) and ^{22}Na (511 keV and 1275 keV) at approximately 1 μCi each. The source is permanently attached to a holder jig, and includes a Velcro strap to mount the source/jig onto the detector endcap. The ISOXSRCE Check Source Fixture User's Manual presents full documentation of the source, jig, and its intended uses.

Figure A6.1a End Measurement

Figure A6.1b. Side Measurement



Prior to shipment, the ISOXSRCE source was counted at Canberra's production facility according to the instructions in the ISOXSRCE Check Source Fixture User's Manual. One measurement was made with the source on-axis (Figure A6.1a) and three measurements were made on the sides (Figure A6.1b). The side measurements were performed with the jig fixed at presented in Tables A1.5a and A1.5b in this document. As soon as possible after the ISOCS characterized detector and the check source are received from the factory, users are strongly advised to set up the system with their own electronics and generate their own base line results for the various QC parameters. This should be done *at minimum* with the ISOXSRCE Check Source as described above.

The results of these baseline measurements should not be appreciably different from those presented in Tables A1.5a and A1.5b in this document. Further details and recommendations regarding implementation of a QA program are given in Appendix E of this document.

Detector Re-Characterization:

If the quality control process indicates that the detector efficiency has changed beyond the claimed accuracy for the ISOCS/LabSOCS software, corrective action is necessary. The ISOXSRCE Check Source Fixture User's Manual recommends that corrective action should be considered if the low-energy efficiency changes by more than 7-10%, or if the high energy efficiency changes by more than 4-5%. The user has three options for corrective action to address the change in efficiency. They all involve a trade-off, and the user must decide, based on their application requirements and available resources (e.g. time and backup detectors), which is the most appropriate action.

1) The simplest action is to increase the uncertainty values used in the ISOCS/LabSOCS software. Clearly this does not truly address the change in efficiency, it simply increases the overall uncertainty parameters used by the software calculations to reflect the change. This action may be acceptable if this additional uncertainty is relatively small in comparison with other uncertainties in the sample measurement process (e.g. uncertainties due to non-uniform source distribution in large containers, uncertainties in sample composition or density). This situation is more likely to be applicable to users in a large-scale decommissioning or decontamination environment than in a laboratory environment.

2) The most complete and accurate response is to send the detector back to Canberra's production facility for a full recharacterization (Canberra model ISOXCALU). A full recharacterization ensures that all aspects of the detector's efficiency response are incorporated into a new characterization, hence this is the recommended action if the maximum accuracy is required. However, it does entail being without the use of the detector for approximately 4 weeks in typical cases.

3) An intermediate action is appropriate if the change in efficiencies is primarily at lower energies. Such a change indicates an increase in the detector dead layer. In this case, users can perform the ISOXSRCE measurements according to the instructions in the ISOXSRCE Check Source Fixture User's Manual, and send the data to Canberra. This data can be used at Canberra's production facility to estimate the change in dead layer thickness and to generate a new characterization (Canberra model ISOXCALL). Note that this does not require that the detector itself be sent in, thus there is no interruption in the user's sample measurement program.

E. Quality Assurance and Quality Control Recommendations

It is imperative that users institute and maintain a QA program to monitor all of the significant performance parameters of their detector and signal chain, and to verify that these parameters have not changed to a degree that would significantly affect the quality of the intended sample measurements. One of the most important parameters to monitor for stability is the detector efficiency. In practice, this can be monitored by tracking the net peak count rates of the ISOXSRCE source, or any suitable, user supplied check source, if the ISOXSRCE was not requested. This same source can also be used to monitor the stability of the peak shape (i.e. FWHM) and peak location (i.e. centroid channel). Canberra recommends that the following parameters be tracked via the check source measurements.

- Net peak count rates at gamma ray energies of 86.5 keV, 511 keV (optional) and 1275 keV; this will monitor the detector efficiency.
- FWHM at the above gamma ray energies; this will monitor the stability of peak shape and detector resolution
- Centroid channel location at the above gamma ray energies; this will monitor gain stability.

Prior to shipment, the ISOXSRCE source was counted at Canberra's production facility according to the instructions in the ISOXSRCE Check Source Fixture User's Manual. The values for these measurements are presented in Tables A1.5a and A1.5b in this document.

A key aspect of a good QA program is the establishment of a baseline set of measurements. Consequently, as soon as possible after the ISOCS characterized detector and the check source are received from the factory, users are strongly advised to set up the system with their own electronics and generate their own baseline results for the various QC parameters. This should be done *at minimum* with the ISOXSRCE Check Source as described in Appendix E of this document. The results of these baseline measurements should not be appreciably different from those presented in Tables A1.5a and A1.5b in this document. Furthermore, if other check sources are to be used as part of the QA program, these should also be measured at this time to establish a baseline as well as a cross-reference to the ISOXSRCE source, or to be used in the case where the ISOXSRCE was not included.

For reference, the following Quality Control Recommendations are presented below, adapted from the ISOXSRCE Check Source Fixture User's Manual.

A good Quality Control (QC) program is essential for validating the system's proper performance to auditors. It is also a good source of data to help identify problems. The

Model S505 Genie 2000's Quality Assurance Software is an excellent tool to simplify and automate the collection of this data and present it in useful formats. Below are some generic guidelines to consider in setting up a program.

Quality Control Guidelines

1. Understand the system, and possible failure mechanisms. Develop a QC program that alerts the operator in the event of a failure, and creates a record for later review, which will help direct corrective action.
2. Determine the important parameters to monitor, which will generate an alarm if the parameter values exceed an Action Level. Select some additional parameters to record for periodic review, which will help diagnose the Action Level alarm. Do not set Action Levels on any of these additional parameters, although setting some of them as Investigation Levels is recommended.
3. A balanced approach should be used when setting alarm levels so as to reduce the number of false negative and false positive indications. Consider the overall uncertainty of the measurement and technique including background and environmental variability and the requirements of the application when setting Investigation or Action Levels. Setting these parameters based solely on two or three standard deviations will cause frivolous alarms.
4. Periodically review all QC data, and then revise the number of monitored parameters, and adjust the Investigation or Action Levels, as appropriate.

Check Source Counting

A properly designed QC program will alert the user to problems concerning noise, resolution, gain, zero, non-linearity, efficiency, etc. The ISOXSRCE check source, when counted according to the procedures given in the ISOXSRCE Check Source Fixture User's Manual, provides a good stream of QC data. As discussed in this Appendix, Canberra recommends that the user monitor the net peak count rates, the FWHM, and the centroid channel location.

Collection of QC data should start immediately after the efficiency calibration of the detector or immediately after the detector has been characterized for ISOCS/LabSOCS. There should be minimal time delay between the calibration/characterization and the establishment of baseline check source data.

In day-to-day practice, the check source should be counted at the beginning of each sequence of operations in a given day, and at the end of the sequence of operations on that day. In the case of continuous operations, count once every 8 hours.

Set Action Levels on Activity only. If the source peak activity is normal, it would indicate that the other parameters are also adequate. Investigation Levels may be set on other parameters. Set the Investigation Level just below the point at which changes in peak full width half maximum (FWHM) or changes in the peak energy (or centroid) could adversely change the activity.

Background Counting

A properly performed background count will alert the user to extraneous or unusual activity that might affect the normal sample counts. The detector should be located in an area where the background is expected to be constant (e.g. inside a shielded room). In other situations like *in situ* counting with unshielded or partially shielded detectors, frequent background counts are not practical. However, even for *in situ* counting, the detector should occasionally be placed in a low and stable background environment for these background checks. The 50 mm (1.97 in.) ISOCS shield with the back shield and zero-degree collimator can produce a stable background environment suitable for this check measurement.

As with check source data, collection of background data should start immediately after the efficiency calibration of the detector or immediately after the detector has been characterized for ISOCS/LabSOCS. There should be minimal time delay between the calibration/characterization and the establishment of the background.

The following parameters should be recorded:

- (i) Background Count Rate for a low energy band (e.g. up to 100 keV); this will help find unusual noise that might be coming into the system.
- (ii) Background Count Rate for most of the spectrum (e.g. 100 - 3000 keV); this will help prove that contamination is not present; visual examination of the spectrum provides an even more sensitive check.
- (iii) Activity of key or important nuclides that are likely sources of contamination; this will establish that the detector and/or shield are not contaminated with those particular nuclides.

In day-to-day practice, the background should be counted at the beginning of each sequence of operations in a given day, and at the end of the sequence of operations on that day. In the case of continuous operations, count once every 8 hours.

Choose Action Levels for background nuclide contamination based upon counting statistics of 2 or 3 standard deviations. This assumption is valid for background counts only. Choose Investigation Levels on background count-rate carefully, since the peak search algorithms can handle rather wide ranges of non-peaked backgrounds.

The Final Investigation and Action Level Settings

Examine the data obtained from at least one month of normal operations prior to establishing the final Investigation and Action Levels. The data should include at least 20–30 measurements that reflect the normal and full range of variable conditions. Perform a weekly review of all the data collected in order to spot trends before problems develop. Although most if not all of the data points will be at levels below alarm levels, the weekly review is recommended to help avert problems during real counts. Review the settings of all Investigation and Action Levels on a quarterly basis and adjust accordingly.

Mirion Technologies (Canberra), Inc.
800 Research Parkway
Meriden, CT 06450
Phone:203-238-2351
Fax: 203-639-2060

Verification of the ISOCS Characterization of the Canberra LabSOCS System

Canberra Sales Order # 75766
S/N 13218
December 12, 2017

ISOXVRFY Measurements Performed By: **Meriden**

ISOCS Data Analysis Performed By: **Gabriela Ilie**

Approved By: ______________________________

David Sullivan

Mirion Technologies (Canberra), Inc., 800 Research Parkway, Meriden, CT 06450 Tel: 203-238-2351 FAX: 203-235-1347 http://www.canberra.com/.

Printed in the United States of America.

For Technical Assistance, please call our Customer Service Hotline at 800-255-6370 or email techsupport@canberra.com

Table of Contents

1. Verification of ISOCS Characterization (ISOXVRFY)

1.1 Verification Tests

In the Factory Integration and Test report supplied with the ISOCS characterization, validation results were provided for five geometries, namely, (i) an Am-241/Eu-152 point source 29 cm away on-axis with respect to the detector, (ii) the Am-241/Eu-152 point source 31 cm away and at 90° from the axis of the detector, (iii) the Am-241/Eu-152 point source laterally 21 cm away and at 135º from the axis of the detector, (iv) an Am-241/Cs-137 point source on the endcap, and (v) the Am-241/Cs-137 point source placed a distance of 10.4 cm away from the endcap.

In this section, test results based on measurement of several additional standard source geometries are presented. The measurements were performed using the ISOCS characterized HPGe detector S/N 13218. The measurement geometries are as follows.

1. A glass fiber filter paper mounted on a Plexiglas centering plate, placed on the detector endcap (same as in the characterization measurement).
2. A 20cc acrylic cylinder with a solid resin matrix, resting on the Plexiglas centering plate, which is placed on the detector endcap.
3. A 400ml polypropylene container with a solid resin matrix, resting on the Plexiglas centering plate, which is placed on the detector endcap.
4. A 2.8-liter Marinelli beaker with a solid resin matrix, centered on the detector endcap.
5. The glass fiber filter paper at a distance of 10.17cm from the detector endcap (same as in the characterization measurement).
6. The 20cc acrylic cylinder at a distance of 10.17cm from the detector end cap.
7. The 400ml polypropylene container at a distance of 10.17cm from the detector endcap.

Refer to the attached schematic diagrams of the measurement geometries.

Each source is a multi-nuclide gamma ray standard, emitting gamma rays in the energy range from 59.5 keV (Am-241) to 1836 keV (Y-88). The measurements are performed in a shielded area, not influenced by other sources. Dedicated electronics and computer are used in acquiring data.

1.2 Verification Test Results

The results for each of the seven verification tests are given in Tables 1 through 7 that are attached to this report. In each case, a brief description of the source-detector geometry is given at the top. Columns 1 and 2 of each table give the name of the nuclide and the energy of the gamma ray peak being measured. Column 3 gives the measured activity in units of gammas/sec, obtained using the measured peak area and the LabSOCS efficiency at the given energy. Column 4 gives the relative uncertainty (1σ) due to counting statistics and LabSOCS uncertainties. Columns 5 gives the true activity of the nuclides in units of gammas/sec at the source calibration date given in the certificate. Column 6 gives the true activity of the nuclides, decay corrected until the measurement date. Column 7 of each table gives the uncertainty (1σ) in the source activity. Column 8 gives the ratio of measured to true activity for each nuclide, and column 9 gives uncertainty in the measured/true ratio. Column 8 in Tables 1 through 7 specifies the expected uncertainty in the LabSOCS efficiencies. The expected uncertainty values for the LabSOCS efficiencies have been derived based on the results of approximately 50 validation tests performed by Canberra Industries using similar laboratory sources on a variety of detectors. For details on these validation tests, refer to the document titled "Validation and Internal Consistency Testing of ISOCS Efficiency Calibration" published by Canberra. The final column (COI value) shows the computed cascade summing correction values. These values are used to produce the sum-loss corrected activities in Column 3. The cascade summing effects are described in more detail below.

In addition to the tables, Figures 1-7 present the measured/true activity ratio versus energy for each verification test. The plots have been appended to this report.

It should be noted that for close-in geometries, the measured activities of Co-60, Y-88, and in some cases, Ce-139 and Co-57, are lower than their true activities. This is because of gamma ray cascade summing (or true coincidence summing) losses in these nuclide measurements. The severity of cascade summing losses is dependent upon the decay scheme of a given nuclide and the total efficiency of the measurement geometry. The higher the total efficiency, the greater is the loss due to cascade summing. In other words, cascade summing losses will be more severe at smaller source-detector distances and with larger detectors.

The standard sources used in the verification tests contain Ce-139, a nuclide whose gamma rays exhibit true coincidence summing. The energy of the principal gamma ray emitted from the decay of Ce-139 is 165 keV. This gamma ray undergoes true coincidence summing with low energy X-rays emitted from Ce-139. Therefore, true coincidence summing losses for Ce-139 are observable primarily in the case of measurements with BEGe, LEGe, REGe, and Xtra detectors, owing to the absence of dead germanium layer in the front. The 122 keV line from Co-57 is emitted about 10% of the time in cascade with a 14 keV gamma-ray. This causes a typically minor summing loss to the 122 keV line. The two lines listed in the tables for Co-60 (1173 and 1332 keV) emitted simultaneously per decay nearly 100% of the time. The similar is true for the two lines of Y-88 (898 and 1896 keV) at about 94% of the time. Consequently, in the lines from Co-60 and Y-88 will shows typically significant losses in close geometries for all detector types.

With the release of Genie2k version 3.2 software, it is possible to automatically perform cascade summing corrections for ISOCS characterized detectors. Previous versions of Genie2k required a peak-to-total calibration using additional sources. With the current release of Genie2k total efficiencies are computed based on the ISOCS characterization efficiency. In this report we have utilized the cascade summing correction algorithm to perform corrections for measured activities in the different source geometries (Note: only Co-57, Ce-139, Co-60, and Y-88 require corrections). The measured activities are corrected by dividing by the cascade summing correction (COI) value.

1.3 Results Summary

A summary of the verification test results is presented in the following table. The results for each geometry are grouped into three energy regimes; (i) less than 150 keV, (ii) 150-400 keV and (iii) greater than 400 keV. For each energy regime, the following results are presented.

1. For nuclides within a given energy range, the weighted average value of the measured to true activity ratio is calculated. The ratios are weighted by the inverse of their squared uncertainties ($1/\sigma^2$). For close-in geometries, nuclides exhibiting true coincidence losses are not included in the weighted average calculations.
2. The bias in the ISOCS efficiency of this detector is obtained by calculating the deviation of the average value of the ratio from its true mean, the true mean being unity. For close-in geometries, nuclides exhibiting cascade summing are not included.
3. The estimated uncertainty in LabSOCS efficiencies, derived from Canberra's validation test database, for a group of detectors.
4. The weighted average value of the measured to true activity ratio for a given energy range, computed by pooling together the ratios from all seven geometries.
5. The standard deviation of the ratios for a given energy range, computed by pooling together the ratios from all seven geometries.
6. The average uncertainty in LabSOCS efficiencies for this specific detector, computed as the difference between the standard deviation of the ratios and the measurement uncertainties.
7. The LabSOCS uncertainty for this detector is calculated in the same manner as described in the Validation and Internal Consistency document

For a given source geometry, if the observed bias is less than twice the assigned 1σ uncertainty for LabSOCS, then the characterization for the detector is within the tolerance limits at the 95% confidence level. If the observed bias is larger than twice the assigned 1σ LabSOCS uncertainty for a given geometry, the ISOXVRFY data forewarns the user that the results of their sample measurements in the given geometry may have a bias for those energies and geometries.

ISOXVRFY Geometry	Data < 150 keV			Data 150 – 400 keV			Data > 400 keV		
	Meas/True Ratio (avg)	Bias	LabSOCS Unc (1σ)	Meas/True Ratio (avg)	Bias	LabSOCS Unc (1σ)	Meas/True Ratio (avg)	Bias	LabSOCS Unc (1σ)
Filter Paper (close)	1.01	0.82%	7.0%	1.01	0.53%	6.0%	1.02	2.17%	4.3%
Filter Paper (far)	1.04	3.63%	7.0%	1.00	-0.47%	6.0%	1.00	0.39%	4.3%
20 ml Cyl. (close)	1.02	2.04%	7.0%	1.00	0.05%	6.0%	1.00	0.43%	4.3%
20 ml Cyl. (far)	1.03	2.78%	7.0%	1.01	1.36%	6.0%	1.00	0.32%	4.3%
400 ml Cyl. (close)	1.03	2.65%	7.0%	0.99	-0.88%	6.0%	1.01	0.99%	4.3%
400 ml Cyl. (far)	1.01	1.20%	7.0%	1.02	1.91%	6.0%	0.99	-0.60%	4.3%
Marinelli	1.05	4.65%	7.0%	1.06	6.04%	6.0%	1.05	5.05%	4.3%
Average (all)	1.03			1.01			1.01		
% Std. Dev.	1.56%			2.59%			2.22%		
Average bias		2.54%			1.61%			1.42%	
LabSOCS Unc.			8.85%			9.93%			4.04%

2. ISOXVRFY Measurement Results

Table 1. Glass Fiber Filter (48 mm diameter) in contact with Detector Endcap

Description:

This is a Glass Fiber Filter resting on the endcap of the detector.
The pre-defined beaker file used in the LabSOCS calculations is FILTER.BKR.
The diameter of the source matrix used in LabSOCS calculations is 48 mm.

Nuclide	Energy (keV)	Meas. Activity (LabSOCS eff) gammas/s	Statistical uncertainty (1σ)	True Activity 7/1/2017 gammas/s	True Activity 12/4/2017 gammas/s	Source uncertainty (1σ)	Meas./True	Rel. uncert. (1σ)	Specified LabSOCS Uncert.	COI value
Am-241	59.5	1251.4	9.06%	1251.0	1250.1	1.80%	1.00	9.06%	7.00%	1.00
Cd-109	88	690.8	9.45%	857.1	678.2	2.05%	1.02	9.45%	7.00%	1.00
Co-57	122	309.1	9.06%	457.3	307.3	1.70%	1.01	9.06%	7.00%	0.98
Ce-139	166	294.7	14.67%	637.0	290.6	1.80%	1.01	14.67%	6.00%	0.79
Sn-113	392	351.4	7.50%	895.3	350.3	1.95%	1.00	7.50%	6.00%	1.00
Cs-137	662	557.7	4.61%	562.6	557.1	2.05%	1.00	4.61%	4.30%	1.00
Mn-54	835	1776.6	4.59%	2483.0	1756.7	1.65%	1.01	4.59%	4.30%	1.00
Y-88	898	822.3	4.63%	2150.0	780.7	1.85%	1.05	4.63%	4.30%	0.74
Zn-65	1115	1634.0	4.61%	2477.0	1590.9	1.75%	1.03	4.61%	4.30%	1.00
Co-60	1173	1046.7	4.59%	1089.0	1029.6	1.95%	1.02	4.59%	4.30%	0.81
Co-60	1332	1050.2	4.59%	1090.0	1030.5	1.95%	1.02	4.59%	4.30%	0.80
Y-88	1836	845.9	4.63%	2276.0	826.4	1.85%	1.02	4.63%	4.30%	0.73

Table 2. Glass Fiber Filter (48 mm diameter) 10.17 cm away from the Detector Endcap

Description:

This is a Glass Fiber Filter resting at a height 10.17 cm above the detector endcap.
The pre-defined beaker file used in the LabSOCS calculations is FILTER.BKR.
The diameter of the source matrix used in LabSOCS calculations is 48 mm.

Nuclide	Energy (keV)	Meas. Activity (LabSOCS eff) gammas/s	Statistical uncertainty (1σ)	True Activity 7/1/2017 gammas/s	True Activity 12/4/2017 gammas/s	Source uncertainty (1σ)	Meas./True	Rel. uncert. (1σ)	Specified LabSOCS Uncert.	COI value
Am-241	59.5	1282.5	9.07%	1251.0	1250.1	1.80%	1.03	9.07%	7.00%	1.00
Cd-109	88	707.3	9.48%	857.1	678.2	2.05%	1.04	9.48%	7.00%	1.00
Co-57	122	319.7	9.19%	457.3	307.3	1.70%	1.04	9.19%	7.00%	1.00
Ce-139	166	295.7	12.74%	637.0	290.5	1.80%	1.02	12.74%	6.00%	0.98
Sn-113	392	345.6	7.76%	895.3	350.2	1.95%	0.99	7.76%	6.00%	1.00
Cs-137	662	557.4	4.91%	562.6	557.1	2.05%	1.00	4.91%	4.30%	1.00
Mn-54	835	1765.5	4.66%	2483.0	1756.4	1.65%	1.01	4.66%	4.30%	1.00
Y-88	898	789.8	4.89%	2150.0	780.3	1.85%	1.01	4.89%	4.30%	0.98
Zn-65	1115	1630.4	4.66%	2477.0	1590.5	1.75%	1.03	4.66%	4.30%	1.00
Co-60	1173	1022.9	4.77%	1089.0	1029.6	1.95%	0.99	4.77%	4.30%	0.98
Co-60	1332	1034.5	4.79%	1090.0	1030.5	1.95%	1.00	4.79%	4.30%	0.98
Y-88	1836	814.2	4.83%	2276.0	826.0	1.85%	0.99	4.83%	4.30%	0.98

Table 3. 20 ml Acrylic Cylinder (1.17 g/cc) on the Detector Endcap

Description:

This is a 20 ml acrylic cylinder with 1.17 g/cc active matrix resting on a 0.3175 cm thick plexiglass centering plate. The plexiglass plate is on top of the detector endcap.

Nuclide	Energy (keV)	Meas. Activity (LabSOCS eff) gammas/s	Statistical uncertainty (1σ)	True Activity 7/1/2017 gammas/s	True Activity 12/4/2017 gammas/s	Source uncertainty (1σ)	Meas./True	Rel. uncert. (1σ)	Specified LabSOCS Uncert.	COI value
Am-241	59.5	2646.0	9.06%	2594.0	2592.2	1.80%	1.02	9.06%	7.00%	1.00
Cd-109	88	1448.1	9.45%	1777.0	1405.6	2.05%	1.03	9.45%	7.00%	1.00
Co-57	122	643.6	9.06%	947.9	636.6	1.70%	1.01	9.06%	7.00%	1.00
Ce-139	166	591.8	13.49%	1320.0	601.4	1.80%	0.98	13.49%	6.00%	0.89
Sn-113	392	729.2	7.50%	1856.0	725.2	1.95%	1.01	7.50%	6.00%	1.00
Cs-137	662	1141.6	4.61%	1166.0	1154.6	2.05%	0.99	4.61%	4.30%	1.00
Mn-54	835	3663.6	4.59%	5145.0	3638.0	1.65%	1.01	4.59%	4.30%	1.00
Y-88	898	1634.2	4.62%	4456.0	1615.3	1.85%	1.01	4.62%	4.30%	0.88
Zn-65	1115	3390.1	4.61%	5134.0	3294.9	1.75%	1.03	4.61%	4.30%	1.00
Co-60	1173	2146.8	4.60%	2257.0	2133.7	1.95%	1.01	4.60%	4.30%	0.89
Co-60	1332	2136.0	4.60%	2260.0	2136.5	1.95%	1.00	4.60%	4.30%	0.88
Y-88	1836	1689.4	4.62%	4717.0	1709.9	1.85%	0.99	4.62%	4.30%	0.87

Table 4. 20 ml Acrylic Cylinder (1.17 g/cc) 10.17 cm from the Detector Endcap

Description:

This is a 20 ml acrylic cylinder with 1.17 g/cc active matrix resting on a 10.17 cm tall cylindrical plexiglass spacer. The plexiglass plate is on top of the detector endcap and centered.

Nuclide	Energy (keV)	Meas. Activity (LabSOCS eff) gammas/s	Statistical uncertainty (1σ)	True Activity 7/1/2017 gammas/s	True Activity 12/4/2017 gammas/s	Source uncertainty (1σ)	Meas./True	Rel. uncert. (1σ)	Specified LabSOCS Uncert.	COI value
Am-241	59.5	2640.9	9.07%	2594.0	2592.2	1.80%	1.02	9.07%	7.00%	1.00
Cd-109	88	1462.8	9.48%	1777.0	1405.5	2.05%	1.04	9.48%	7.00%	1.00
Co-57	122	652.3	9.16%	947.9	636.5	1.70%	1.02	9.16%	7.00%	1.00
Ce-139	166	613.8	12.66%	1320.0	601.2	1.80%	1.02	12.66%	6.00%	0.99
Sn-113	392	732.9	7.67%	1856.0	724.9	1.95%	1.01	7.67%	6.00%	1.00
Cs-137	662	1126.7	4.82%	1166.0	1154.6	2.05%	0.98	4.82%	4.30%	1.00
Mn-54	835	3703.1	4.63%	5145.0	3637.6	1.65%	1.02	4.63%	4.30%	1.00
Y-88	898	1640.0	4.80%	4456.0	1614.7	1.85%	1.02	4.80%	4.30%	0.99
Zn-65	1115	3374.9	4.64%	5134.0	3294.4	1.75%	1.02	4.64%	4.30%	1.00
Co-60	1173	2121.6	4.72%	2257.0	2133.6	1.95%	0.99	4.72%	4.30%	0.99
Co-60	1332	2148.3	4.69%	2260.0	2136.5	1.95%	1.01	4.69%	4.30%	0.99
Y-88	1836	1685.6	4.76%	4717.0	1709.3	1.85%	0.99	4.76%	4.30%	0.99

Table 5. 400 ml Acrylic Cylinder (1.17 g/cc) on the Detector Endcap

Description:

This is a 400 ml acrylic cylinder with 1.17 g/cc active matrix resting on a 0.3175 cm thick plexiglass centering plate. The plexiglass plate is on top of the detector endcap.

Nuclide	Energy (keV)	Meas. Activity (LabSOCS eff) gammas/s	Statistical uncertainty (1σ)	True Activity 7/1/2017 gammas/s	True Activity 12/4/2017 gammas/s	Source uncertainty (1σ)	Meas./True	Rel. uncert. (1σ)	Specified LabSOCS Uncert.	COI value
Am-241	59.5	5212.4	9.06%	5040.0	5036.5	1.80%	1.03	9.06%	7.00%	1.00
Cd-109	88	2826.4	9.45%	3452.0	2730.2	2.05%	1.04	9.45%	7.00%	1.00
Co-57	122	1249.2	9.07%	1842.0	1236.7	1.70%	1.01	9.07%	7.00%	1.00
Ce-139	166	1183.2	13.38%	2565.0	1168.1	1.80%	1.01	13.38%	6.00%	0.90
Sn-113	392	1386.1	7.51%	3606.0	1408.1	1.95%	0.98	7.51%	6.00%	1.00
Cs-137	662	2215.7	4.61%	2266.0	2243.8	2.05%	0.99	4.61%	4.30%	1.00
Mn-54	835	7125.5	4.59%	9997.0	7067.3	1.65%	1.01	4.59%	4.30%	1.00
Y-88	898	3196.7	4.62%	8657.0	3136.2	1.85%	1.02	4.62%	4.30%	0.90
Zn-65	1115	6538.7	4.61%	9976.0	6400.7	1.75%	1.02	4.61%	4.30%	1.00
Co-60	1173	4206.5	4.59%	4385.0	4145.2	1.95%	1.01	4.59%	4.30%	0.91
Co-60	1332	4207.5	4.59%	4391.0	4150.9	1.95%	1.01	4.59%	4.30%	0.90
Y-88	1836	3334.8	4.61%	9165.0	3320.2	1.85%	1.00	4.61%	4.30%	0.89

Table 6. 400 ml Acrylic Cylinder (1.17 g/cc) 10.17 cm from the Detector Endcap

Description:

This is a 400 ml acrylic cylinder with 1.17 g/cc active matrix resting on a 10.17 cm tall cylindrical plexiglass spacer. The plexiglass plate is on top of the detector endcap and centered.

Nuclide	Energy (keV)	Meas. Activity (LabSOCS eff) gammas/s	Statistical uncertainty (1σ)	True Activity 7/1/2017 gammas/s	True Activity 12/4/2017 gammas/s	Source uncertainty (1σ)	Meas./True	Rel. uncert. (1σ)	Specified LabSOCS Uncert.	COI value
Am-241	59.5	5087.7	9.07%	5040.0	5036.5	1.80%	1.01	9.07%	7.00%	1.00
Cd-109	88	2799.2	9.47%	3452.0	2729.9	2.05%	1.03	9.47%	7.00%	1.00
Co-57	122	1238.2	9.14%	1842.0	1236.5	1.70%	1.00	9.14%	7.00%	1.00
Ce-139	166	1161.7	12.65%	2565.0	1167.7	1.80%	0.99	12.65%	6.00%	0.99
Sn-113	392	1446.8	7.62%	3606.0	1407.5	1.95%	1.03	7.62%	6.00%	1.00
Cs-137	662	2202.7	4.75%	2266.0	2243.8	2.05%	0.98	4.75%	4.30%	1.00
Mn-54	835	7100.7	4.62%	9997.0	7066.3	1.65%	1.00	4.62%	4.30%	1.00
Y-88	898	3132.4	4.75%	8657.0	3134.9	1.85%	1.00	4.75%	4.30%	0.99
Zn-65	1115	6430.3	4.65%	9976.0	6399.5	1.75%	1.00	4.65%	4.30%	1.00
Co-60	1173	4106.4	4.66%	4385.0	4145.2	1.95%	0.99	4.66%	4.30%	0.99
Co-60	1332	4172.3	4.66%	4391.0	4150.8	1.95%	1.01	4.66%	4.30%	0.99
Y-88	1836	3222.0	4.72%	9165.0	3318.9	1.85%	0.97	4.72%	4.30%	0.99

Table 7. 2.8 l Marinelli Beaker (1.17 g/cc) on the Detector Endcap

Description:

This is a 2.8 l Marinelli beaker with 1.17 g/cc active matrix resting on the endcap of the detector.

Nuclide	Energy (keV)	Meas. Activity (LabSOCS eff) gammas/s	Statistical uncertainty (1σ)	True Activity 7/1/2017 gammas/s	True Activity 12/4/2017 gammas/s	Source uncertainty (1σ)	Meas./True	Rel. uncert. (1σ)	Specified LabSOCS Uncert.	COI value
Am-241	59.5	5503.5	9.06%	5310.0	5306.4	1.80%	1.04	9.06%	7.00%	1.00
Cd-109	88	3008.3	9.46%	3636.0	2875.2	2.05%	1.05	9.46%	7.00%	1.00
Co-57	122	1375.3	9.08%	1940.0	1302.1	1.70%	1.06	9.08%	7.00%	1.00
Ce-139	166	1320.4	12.96%	2702.0	1229.7	1.80%	1.07	12.96%	6.00%	0.95
Sn-113	392	1565.0	7.52%	3798.0	1482.0	1.95%	1.06	7.52%	6.00%	1.00
Cs-137	662	2474.3	4.63%	2387.0	2363.6	2.05%	1.05	4.63%	4.30%	1.00
Mn-54	835	7892.5	4.59%	10530.0	7442.2	1.70%	1.06	4.59%	4.30%	1.00
Y-88	898	3518.8	4.63%	9119.0	3301.0	1.85%	1.07	4.63%	4.30%	0.94
Zn-65	1115	7168.1	4.61%	10510.0	6741.0	1.75%	1.06	4.61%	4.30%	1.00
Co-60	1173	4581.1	4.60%	4619.0	4366.3	1.95%	1.05	4.60%	4.30%	0.94
Co-60	1332	4547.3	4.60%	4625.0	4371.9	1.95%	1.04	4.60%	4.30%	0.94
Y-88	1836	3590.8	4.62%	9654.0	3494.7	1.85%	1.03	4.62%	4.30%	0.93

Figure 1. Glass Fiber Filter Paper on Endcap

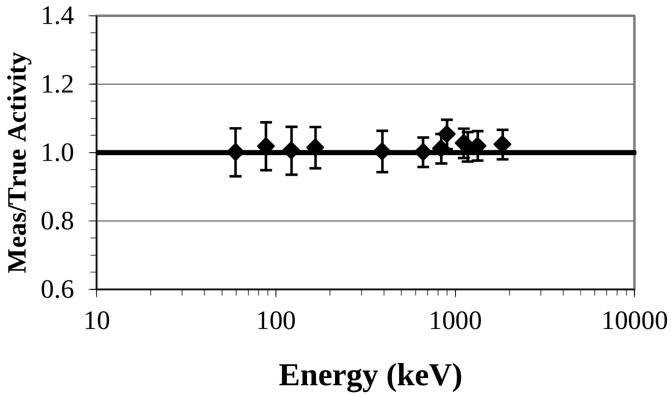


Figure 2. Glass Fiber Filter Paper at 10.17 cm

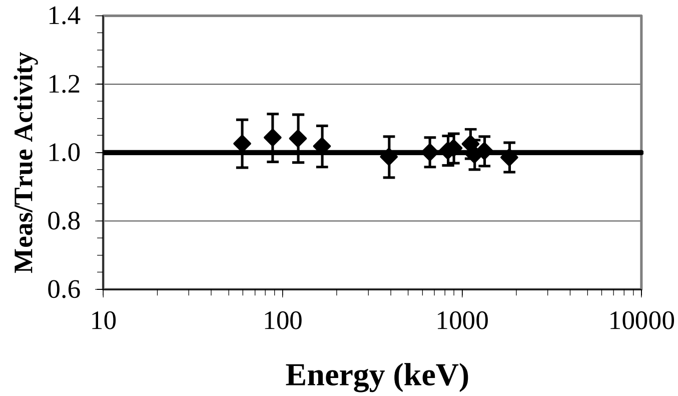


Figure 3. 20 ml Acrylic Cylinder on Endcap

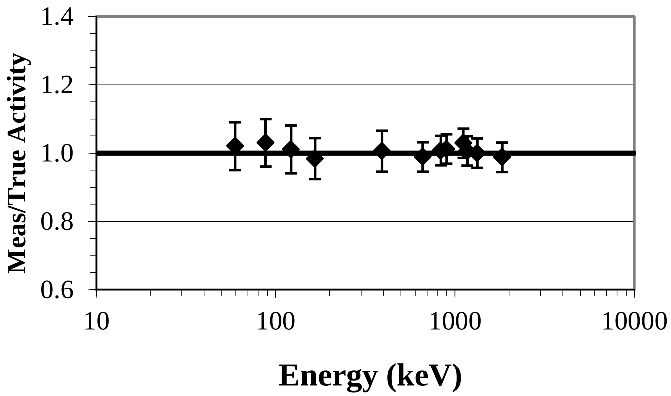


Figure 4. 20 ml Acrylic Cylinder at 10.17 cm

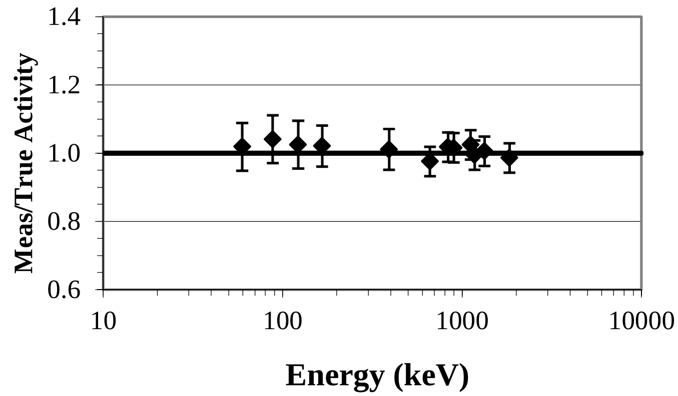


Figure 5. 400 ml Acrylic Cylinder on Endcap

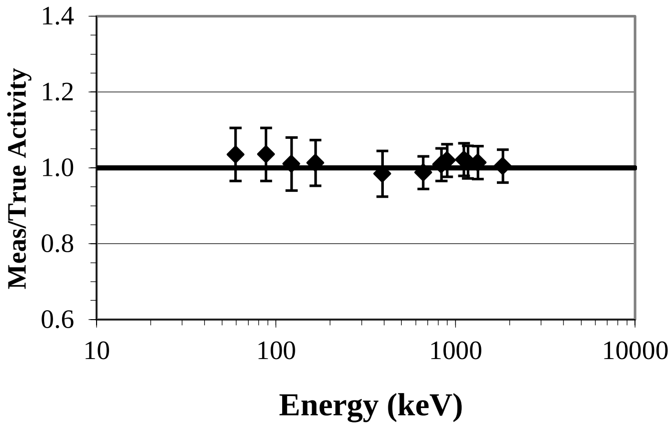


Figure 6. 400 ml Acrylic Cylinder at 10.17 cm

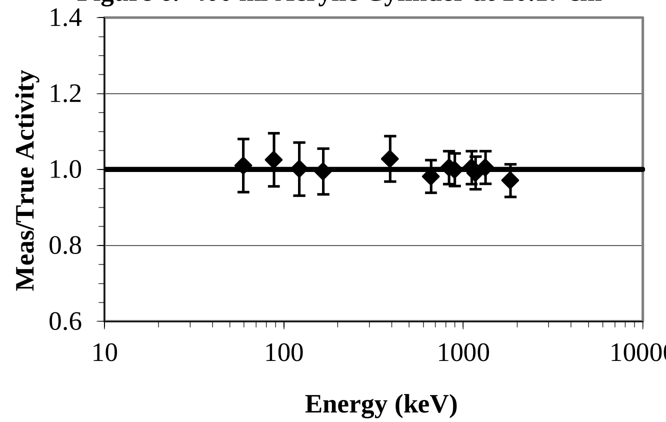
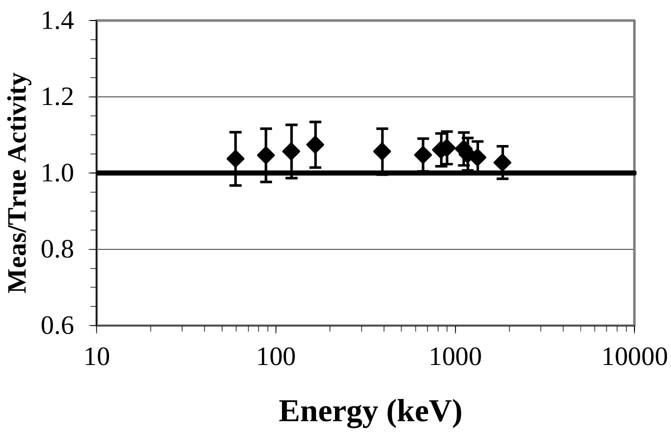


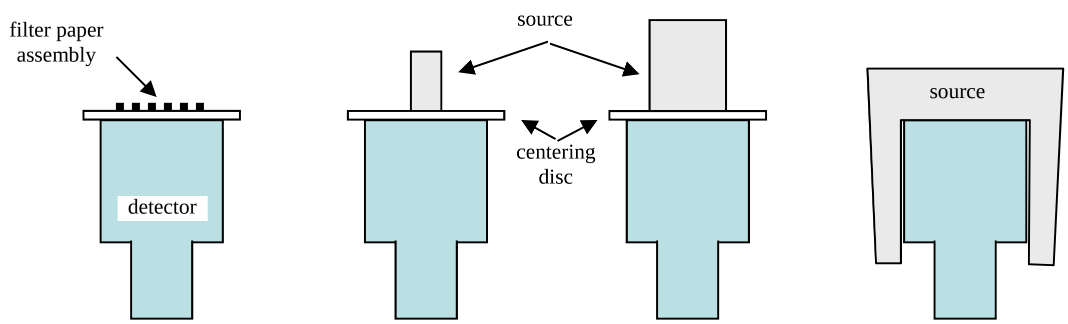
Figure 7. 2.8 l Marinelli Beaker



3. Schematic Drawings of ISOXVRFY Geometries

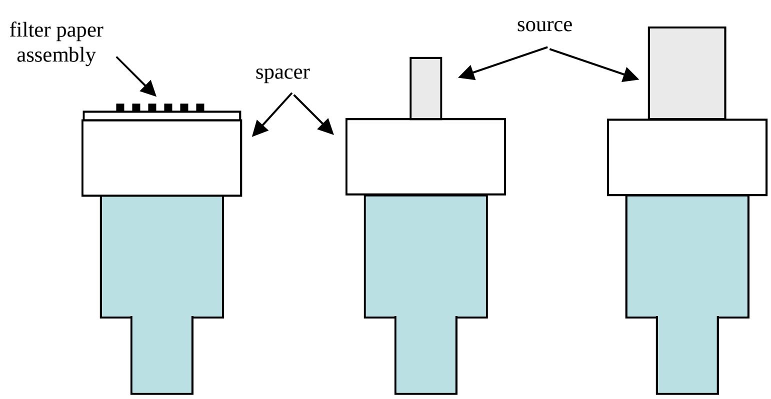
Position 1

Filter Paper **20 ml Cylinder** **400 ml Cylinder** **Marinelli Beaker**



Position 2

Filter Paper **20 ml Cylinder** **400 ml Cylinder**



A. ISOXVRFY Source Certificates

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404·352·8677
Fax 404·352·2837
www.ezag.com

CERTIFICATE OF CALIBRATION

Standard Reference Source

17-29

SRS Number: 106860
Source Description: 2 Inch Diameter Glass Fiber Filter in Tape
Product Code: MIX-8600-GF-FP
Customer: Mirion Technologies (Canberra), Inc.
P.O. Number: 4104707, Item 4

This standard radionuclide source was prepared from an aliquot measured gravimetrically from a master radionuclide solution calibrated with a germanium gamma-ray spectrometer system. Additional radionuclides were added gravimetrically from solutions calibrated by gamma-ray spectrometry, ionization chamber, or liquid scintillation counting. Calibration and purity were checked using germanium gamma-ray spectrometry. At the time of calibration no interfering gamma-ray emitting impurities were detected. The gamma-ray emission rates for the most intense gamma-ray lines are given. Eckert & Ziegler Analytics (EZA) maintains traceability to the National Institute of Standards and Technology (NIST) through a Measurements Assurance Program as described in USNRC Regulatory Guide 4.15, Revision 2, July 2007, and compliance with ANSI N42.22-1995, "Traceability of Radioactive Sources to NIST."

Reference Date: 01-July-2017 12:00 PM EST

GRS Mixture

Isotope	Gamma-Ray Energy, keV	Half-Life, d	Activity, Bq	Flux, s^{-1}	Uncertainty u_A, %	u_B, %	U, %*	Calibration Method**
Am-241	59.5	1.580E+05	3.486E+03	1.251E+03	0.1	1.8	3.6	4π LS
Cd-109	88.0	4.614E+02	2.317E+04	8.571E+02	0.5	2.0	4.1	HPGe
Co-57	122.1	2.717E+02	5.342E+02	4.573E+02	0.4	1.7	3.4	HPGe
Ce-139	165.9	1.376E+02	7.962E+02	6.370E+02	0.4	1.7	3.6	HPGe
Cr-51	320.1	2.770E+01	2.332E+04	2.311E+03	0.1	1.7	3.5	IC
Sn-113	391.7	1.151E+02	1.378E+03	8.953E+02	0.4	1.9	3.9	HPGe
Sr-85	514.0	6.485E+01	1.808E+03	1.781E+03	0.1	1.7	3.5	IC
Cs-137	661.7	1.099E+04	6.611E+02	5.626E+02	0.7	1.9	4.1	HPGe
Mn-54	834.8	3.121E+02	2.483E+03	2.483E+03	0.1	1.7	3.3	IC
Y-88	898.0	1.066E+02	2.294E+03	2.150E+03	0.7	1.7	3.7	HPGe
Y-88	1836.1	———	———	2.276E+03	0.7	1.7	3.7	———
Zn-65	1115.5	2.439E+02	4.950E+03	2.477E+03	0.1	1.7	3.5	IC
Co-60	1173.2	1.925E+03	1.090E+03	1.089E+03	0.7	1.8	3.9	HPGe
Co-60	1332.5	———	———	1.090E+03	0.7	1.8	3.9	———

Gamma-Ray (GRS) master solution is EZA's mixture that consists of Cd-109, Co-57, Ce-139, Sn-113, Cs-137, Y-88, and Co-60 (calibrated quarterly) with the addition of Cr-51 and Sr-85.
***Uncertainty:** U - Relative expanded uncertainty, k = 2. See NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results." ****Calibration Methods:** 4π LS - 4π Liquid Scintillation Counting, HPGe - High Purity Germanium Gamma-Ray Spectrometer, IC - Ionization Chamber.

(Certificate continued on reverse side)

F-CR-32, Rev. 0, 01 Nov. 14

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17-28

CERTIFICATE OF CALIBRATION
Standard Reference Source

SRS Number: 106858C
Source Description: 20 mL Solid in Custom Acrylic Cylinder
Product Code: MIX-8600-EG-SD
Customer: Mirion Technologies (Canberra), Inc.
P.O. Number: 4104707, Item 3

This standard radionuclide source was prepared from an aliquot measured gravimetrically from a master radionuclide solution calibrated with a germanium gamma-ray spectrometer system. Additional radionuclides were added gravimetrically from solutions calibrated by gamma-ray spectrometry, ionization chamber, or liquid scintillation counting. Calibration and purity were checked using germanium gamma-ray spectrometry. At the time of calibration no interfering gamma-ray emitting impurities were detected. The gamma-ray emission rates for the most intense gamma-ray lines are given. Eckert & Ziegler Analytics (EZA) maintains traceability to the National Institute of Standards and Technology (NIST) through a Measurements Assurance Program as described in USNRC Regulatory Guide 4.15, Revision 2, July 2007, and compliance with ANSI N42.22-1995, "Traceability of Radioactive Sources to NIST."

Density of solid matrix: 1.17 g/cm³ ± 3 %.

Reference Date: 01-July-2017 12:00 PM EST
GRS Mixture

Isotope	Gamma-Ray Energy, keV	Half-Life, d	Activity, Bq	Flux, s^{-1}	Uncertainty u_A, %	u_B, %	U, %*	Calibration Method**
Am-241	59.5	1.580E+05	7.226E+03	2.594E+03	0.1	1.8	3.6	4π LS
Cd-109	88.0	4.614E+02	4.802E+04	1.777E+03	0.5	2.0	4.1	HPGe
Co-57	122.1	2.717E+02	1.107E+03	9.479E+02	0.4	1.7	3.4	HPGe
Ce-139	165.9	1.376E+02	1.650E+03	1.320E+03	0.4	1.7	3.6	HPGe
Cr-51	320.1	2.770E+01	4.833E+04	4.790E+03	0.1	1.7	3.5	IC
Sn-113	391.7	1.151E+02	2.857E+03	1.856E+03	0.4	1.9	3.9	HPGe
Sr-85	514.0	6.485E+01	3.747E+03	3.691E+03	0.1	1.7	3.5	IC
Cs-137	661.7	1.099E+04	1.370E+03	1.166E+03	0.7	1.9	4.1	HPGe
Mn-54	834.8	3.121E+02	5.146E+03	5.145E+03	0.1	1.7	3.3	IC
Y-88	898.0	1.066E+02	4.755E+03	4.456E+03	0.7	1.7	3.7	HPGe
Y-88	1836.1	———	———	4.717E+03	0.7	1.7	3.7	———
Zn-65	1115.5	2.439E+02	1.026E+04	5.134E+03	0.1	1.7	3.5	IC
Co-60	1173.2	1.925E+03	2.260E+03	2.257E+03	0.7	1.8	3.9	HPGe
Co-60	1332.5	———	———	2.260E+03	0.7	1.8	3.9	———

Gamma-Ray (GRS) master solution is EZA's mixture that consists of Cd-109, Co-57, Ce-139, Sn-113, Cs-137, Y-88, and Co-60 (calibrated quarterly) with the addition of Cr-51 and Sr-85.

***Uncertainty:** U - Relative expanded uncertainty, k = 2. See NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results." ****Calibration Methods:** 4π LS - 4π Liquid Scintillation Counting, HPGe - High Purity Germanium Gamma-Ray Spectrometer, IC - Ionization Chamber.

(Certificate continued on reverse side)

F-CR-32, Rev. 0, 01 Nov 14

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Tel 404·352·8677
Fax 404·352·2837
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CERTIFICATE OF CALIBRATION
Standard Reference Source

17-27

SRS Number: 106856A
Source Description: 400 mL Solid in 16 Ounce MRP PP Plastic Jar
Product Code: MIX-8600-EG-SD
Customer: Mirion Technologies (Canberra), Inc.
P.O. Number: 4104707, Item 2

This standard radionuclide source was prepared from an aliquot measured gravimetrically from a master radionuclide solution calibrated with a germanium gamma-ray spectrometer system. Additional radionuclides were added gravimetrically from solutions calibrated by gamma-ray spectrometry, ionization chamber, or liquid scintillation counting. Calibration and purity were checked using germanium gamma-ray spectrometry. At the time of calibration no interfering gamma-ray emitting impurities were detected. The gamma-ray emission rates for the most intense gamma-ray lines are given. Eckert & Ziegler Analytics (EZA) maintains traceability to the National Institute of Standards and Technology (NIST) through a Measurements Assurance Program as described in USNRC Regulatory Guide 4.15, Revision 2, July 2007, and compliance with ANSI N42.22-1995, "Traceability of Radioactive Sources to NIST."

Density of solid matrix: 1.17 g/cm³ ± 3 %.

Reference Date: 01-July-2017 12:00 PM EST
GRS Mixture

Isotope	Gamma-Ray Energy, keV	Half-Life, d	Activity, Bq	Flux, s^{-1}	Uncertainty u_A, %	u_B, %	U, %*	Calibration Method**
Am-241	59.5	1.580E+05	1.404E+04	5.040E+03	0.1	1.8	3.6	4π LS
Cd-109	88.0	4.614E+02	9.330E+04	3.452E+03	0.5	2.0	4.1	HPGe
Co-57	122.1	2.717E+02	2.152E+03	1.842E+03	0.4	1.7	3.4	HPGe
Ce-139	165.9	1.376E+02	3.207E+03	2.565E+03	0.4	1.7	3.6	HPGe
Cr-51	320.1	2.770E+01	9.391E+04	9.306E+03	0.1	1.7	3.5	IC
Sn-113	391.7	1.151E+02	5.550E+03	3.606E+03	0.4	1.9	3.9	HPGe
Sr-85	514.0	6.485E+01	7.281E+03	7.172E+03	0.1	1.7	3.5	IC
Cs-137	661.7	1.099E+04	2.663E+03	2.266E+03	0.7	1.9	4.1	HPGe
Mn-54	834.8	3.121E+02	9.999E+03	9.997E+03	0.1	1.7	3.3	IC
Y-88	898.0	1.066E+02	9.239E+03	8.657E+03	0.7	1.7	3.7	HPGe
Y-88	1836.1	———	———	9.165E+03	0.7	1.7	3.7	———
Zn-65	1115.5	2.439E+02	1.994E+04	9.976E+03	0.1	1.7	3.5	IC
Co-60	1173.2	1.925E+03	4.392E+03	4.385E+03	0.7	1.8	3.9	HPGe
Co-60	1332.5	———	———	4.391E+03	0.7	1.8	3.9	———

Gamma-Ray (GRS) master solution is EZA's mixture that consists of Cd-109, Co-57, Ce-139, Sn-113, Cs-137, Y-88, and Co-60 (calibrated quarterly) with the addition of Cr-51 and Sr-85.
***Uncertainty:** U - Relative expanded uncertainty, k = 2. See NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results." ****Calibration Methods:** 4π LS - 4π Liquid Scintillation Counting, HPGe - High Purity Germanium Gamma-Ray Spectrometer, IC - Ionization Chamber.

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www.ezag.com

CERTIFICATE OF CALIBRATION

Standard Reference Source

17-26

SRS Number: 106854
Source Description: 2.8 Liter Solid in 445N GA-MA Beaker
Product Code: MIX-8600-EG-SD
Customer: Mirion Technologies (Canberra), Inc.
P.O. Number: 4104707, Item 1

This standard radionuclide source was prepared from an aliquot measured gravimetrically from a master radionuclide solution calibrated with a germanium gamma-ray spectrometer system. Additional radionuclides were added gravimetrically from solutions calibrated by gamma-ray spectrometry, ionization chamber, or liquid scintillation counting. Calibration and purity were checked using germanium gamma-ray spectrometry. At the time of calibration no interfering gamma-ray emitting impurities were detected. The gamma-ray emission rates for the most intense gamma-ray lines are given. Eckert & Ziegler Analytics (EZA) maintains traceability to the National Institute of Standards and Technology (NIST) through a Measurements Assurance Program as described in USNRC Regulatory Guide 4.15, Revision 2, July 2007, and compliance with ANSI N42.22-1995, "Traceability of Radioactive Sources to NIST."

Density of solid matrix: 1.17 g/cm³ ± 3 %.

Reference Date: 01-July-2017 12:00 PM EST

GRS Mixture

Isotope	Gamma-Ray Energy, keV	Half-Life, d	Activity, Bq	Flux, s^{-1}	Uncertainty u_A, %	u_B, %	U, %*	Calibration Method**
Am-241	59.5	1.580E+05	1.479E+04	5.310E+03	0.1	1.8	3.6	4π LS
Cd-109	88.0	4.614E+02	9.828E+04	3.636E+03	0.5	2.0	4.1	HPGe
Co-57	122.1	2.717E+02	2.266E+03	1.940E+03	0.4	1.7	3.4	HPGe
Ce-139	165.9	1.376E+02	3.378E+03	2.702E+03	0.4	1.7	3.6	HPGe
Cr-51	320.1	2.770E+01	9.892E+04	9.803E+03	0.1	1.7	3.5	IC
Sn-113	391.7	1.151E+02	5.846E+03	3.798E+03	0.4	1.9	3.9	HPGe
Sr-85	514.0	6.485E+01	7.669E+03	7.554E+03	0.1	1.7	3.5	IC
Cs-137	661.7	1.099E+04	2.805E+03	2.387E+03	0.7	1.9	4.1	HPGe
Mn-54	834.8	3.121E+02	1.053E+04	1.053E+04	0.1	1.7	3.3	IC
Y-88	898.0	1.066E+02	9.732E+03	9.119E+03	0.7	1.7	3.7	HPGe
Y-88	1836.1	———	———	9.654E+03	0.7	1.7	3.7	———
Zn-65	1115.5	2.439E+02	2.100E+04	1.051E+04	0.1	1.7	3.5	IC
Co-60	1173.2	1.925E+03	4.626E+03	4.619E+03	0.7	1.8	3.9	HPGe
Co-60	1332.5	———	———	4.625E+03	0.7	1.8	3.9	———

Gamma-Ray (GRS) master solution is EZA's mixture that consists of Cd-109, Co-57, Ce-139, Sn-113, Cs-137, Y-88, and Co-60 (calibrated quarterly) with the addition of Cr-51 and Sr-85.
***Uncertainty:** U - Relative expanded uncertainty, k = 2. See NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results." ****Calibration Methods:** 4π LS - 4π Liquid Scintillation Counting, HPGe - High Purity Germanium Gamma-Ray Spectrometer, IC - Ionization Chamber.

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