LabSOCS™ vs. SOURCE-BASED GAMMA-RAY DETECTOR EFFICIENCY COMPARISONS FOR NUCLEAR POWER PLANT GEOMETRIES

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ABSTRACT

This paper describes a comparison of two gamma-ray efficiency determination methods – Canberra's LabSOCS (Laboratory SOurceless Calibration Software) vs. source-based efficiency calibrations – for common nuclear power plant sample types. These included process, RadCon, radwaste and effluent sample types in a variety of sample container geometries. These included point sources, paper and charcoal filters, cylindrical gas and liquid containers and both gas and liquid Marinelli beakers.

LabSOCS geometry modeling which included sample fixtures, sample containers, sample matrices, sample-to-detector spacing and internal detector dimensions and materials have been developed using the Geometry Composer feature of Canberra's Genie™ 2000 Version 2.0 and Gamma Analysis Version 2.0A software packages for 48 common nuclear power plant sample types. A total of 16 different sample container types at five source-to-detector spacings were included in the LabSOCS analysis. Sample matrices were limited to simulated water (epoxy) and simulated air (polystyrene), as well as the point source, paper filter and charcoal cartridge filters. Customized templates were created to accurately define inner and outer wall contours, materials and density values of each container.

A coaxial Intrinsic Germanium (IGe) detector, which was characterized by Canberra and calibrated using commercially available sources, was used in this study. The Canberra Industries LabSOCS system Version 4.0 was used to generate source-based gamma-ray efficiency calibrations for this detector. The source-based detector efficiencies for the 898.02 and 1836.01 keV lines of ^{88}Y and the 1173.22 and 1332.49 keV lines of ^{60}Co were corrected for cascade summing by performing a Peak-to-Total Calibration (PTC) and applying the resultant cascade summing correction factors. The uncertainties were then calculated for each efficiency value for each standard.

The LabSOCS efficiencies were compared to the source-based efficiencies for each geometry by calculating the efficiency ratios and ratio uncertainties for each gamma-ray energy for each standard source. The results indicate agreement at the 95% confidence level for an energy range of 59.5 to 1838.01 keV for all geometries.

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INTRODUCTION

The sample geometry modeling and efficiency calibration file generation were performed using the Geometry Composer feature of the Genie 2000 Version 2.0 and Gamma Acquisition and Analysis (GAA) software packages. The resulting sample geometry files and Genie 2000 efficiency calibration files were delivered to Sequoyah NP for testing on a laboratory-based gamma spectroscopy system. This system includes the coaxial IGe detector (serial number 7386) which had been characterized by Canberra.

A total of 48 different sample counting geometries were specified for this LabSOCS modeling project. Each of these 48 geometries represents a unique combination of a particular sample container, a particular source matrix, and a specific source-to-detector end cap distance. A total of 16 different sample containers and fixtures were supplied by TVA. These components were inspected and measured by Canberra for accurate determination of container dimensions, absorber thickness values, and source-to-detector distance values needed as part of the modeling process. The critical assumptions and methods used to determine the dimensions and final parameter input required for the LabSOCS models are described in this report.

LabSOCS MODELING

The following sections detail the LabSOCS geometry modeling and efficiency file generation process for the 48 different sample geometries.

SAMPLE CONTAINERS AND MATERIALS

A total of 16 different sample containers and sample matrix materials were used in this study and are listed in Table 1:

Table 1.
Sample containers and materials.

Sample Container Description	Sample Matrix Description
50 mm diameter Falcon Petri disk	47 mm diameter paper filter
F & J “C” charcoal filter with plastic case	Charcoal (carbon and air)
F & J charcoal filter with tall metal case	Charcoal (carbon and air)
20 mL Packard liquid scintillation vial (LSC)	20 mL water
0.25 liter GA-MA liquid Marinelli beaker	250 mL water
0.50 liter GA-MA liquid Marinelli beaker	500 mL water
1.0 liter GA-MA liquid Marinelli beaker	800 mL water
4.0 liter GA-MA liquid Marinelli beaker	3500 mL water
0.12 liter Alpha wide-mouth Poly bottle	120 mL water
0.25 liter Nalgene wide-mouth Poly bottle	250 mL water
0.50 liter Nalgene wide-mouth Poly bottle	500 mL water
1.0 liter Nalgene wide-mouth Poly bottle	1000 mL water
25 cc GA-MA gas sampler	25 cc air
1.24 liter GA-MA gas Marinelli beaker	1240 cc air
14 cc glass serum vial	14 cc air
Aluminum ring with thin tape layer	Point source

A set of pre-fabricated acrylic plates and tubes intended to hold these samples at various reproducible positions relative to the detector end cap were provided. These sample positioning components and the six reference counting configurations used by TVA Sequoyah are summarized in Table 2:

LabSOCS MODEL DESCRIPTIONS

Each of the LabSOCS models was designated with a unique number, ranging from Model #01 to Model #48. Each model represents a specific combination of sample container, sample matrix and sample position.

Table 2.
Counting geometries used.

Position Designation	Acrylic Absorber Thickness	Source-to-Detector Distance
No Shelf	No absorber present	0.00 mm (1)
Shelf 0	5.44 mm (2)	5.44 mm (2)
Shelf 1	8.01 mm (2)	29.5 mm (2)
Shelf 2	8.01 mm (2)	97.0 mm (3)
Shelf 3	1.20 mm (2)	50.1 cm (4)
Shelf 4	1.20 mm (2)	100.1 cm (4)

Notes:
1 - Used for Marinelli beakers
2 - Dimensions measured with a micrometer (smallest units = 0.001 inches)
3 - Dimensions measured with a metal ruler (smallest units = 0.5 mm)
4 - Dimensions measured with a flexible tape (smallest units = 0.063 inches)

The applicable dimensions listed above were used as part of the parameter input for the 48 different LabSOCS models, with each model representing a specific combination of sample container, sample matrix and sample position. For some models, the total source-detector distance was increased beyond the "default" values listed above, due to additional spacing contributed by the designated acrylic centering plate or a portion of the sample container itself. The acrylic centering plates also contributed some additional photon attenuation near the base of the 20 mL LSC vial, 14 cc glass serum vial and the 0.12 liter Alpha Poly bottle containers. These factors have been included, when appropriate, in the final LabSOCS models described in the project documentation provided to TVA.

All of the sample configurations involving a water matrix were modeled twice with LabSOCS, once with an actual water matrix (as appropriate for actual samples) and again with a "water equivalent" solid epoxy matrix (used by Analytics to prepare "water-equivalent" radioactive standards). All of the sample configurations involving an air matrix were modeled twice with LabSOCS, once with actual air as the material (as appropriate for actual samples), and again with an "air-equivalent" polystyrene bead matrix (used by Analytics to prepare "air-equivalent" radioactive standards). This comparative modeling was done to evaluate the expected magnitude of variation in efficiency for the water vs. "water-equivalent" and air vs. "air-equivalent" sample configurations.

The Geometry Composer option of the Canberra Industries Genie 2000 Version 2.0 and Gamma Analysis Version 2.0A software packages was used to create the 48 specific models for this project. Two special materials were defined and added to the Materials Library file: "Charcoal" as 100% carbon (mass percentage) with a default density = 0.59 g/cc, and "smltdair" as 93.6% polystyrene and 6.4% air (mass percentages) with a default density of 0.03 g/cc.

LabSOCS SAMPLE MODELS

A summary list of all models created for this project is provided in Table 3.

Table 3.
Geometry models that were created.

Model Number	Sample Container Description	Shelf	Geom Code	Sample Matrix Description
01	Polystyrene Falcon Petri dish	0	MPF0	47 mm paper filter
02	Polystyrene Falcon Petri dish	1	MPF1	47 mm paper filter
03	Polystyrene Falcon Petri dish	2	MPF2	47 mm paper filter
04	F&J “C” (plastic) charcoal filter	0	CHF0	“Face-loaded” charcoal
05	F&J “C” (plastic) charcoal filter	1	CHF1	“Face-loaded” charcoal
06	F&J “C” (plastic) charcoal filter	2	CHF2	“Face-loaded” charcoal
07	F&J (metal case) charcoal filter	0	WCF0	“Face-loaded” charcoal
08	F&J (metal case) charcoal filter	1	WCF1	“Face-loaded” charcoal
09	F&J (metal case) charcoal filter	2	WCF2	“Face-loaded” charcoal
10	20 mL Packard LSC vial	0	D200	20 mL water
11	20 mL Packard LSC vial	0	D200	20 mL epoxy
12	20 mL Packard LSC vial	1	D201	20 mL water
13	20 mL Packard LSC vial	1	D201	20 mL epoxy
14	20 mL Packard LSC vial	2	D202	20 mL water
15	20 mL Packard LSC vial	2	D202	20 mL epoxy
16	0.25 mL GA-MA Marinelli beaker	0	L250	250 mL water
17	0.25 mL GA-MA Marinelli beaker	0	L250	250 mL epoxy
18	0.50 mL GA-MA Marinelli beaker	0	L500	500 mL water
19	0.50 mL GA-MA Marinelli beaker	0	L500	500 mL epoxy
20	1.0 liter GA-MA Marinelli beaker	0	LM10	1000 mL water
21	1.0 liter GA-MA Marinelli beaker	0	LM10	1000 mL epoxy
22	4.0 liter GA-MA Marinelli beaker	0	LM40	3500 mL water
23	4.0 liter GA-MA Marinelli beaker	0	LM40	3500 mL epoxy
24	0.12 liter Alpha poly bottle	1	P121	120 mL water
25	0.12 liter Alpha poly bottle	1	P121	120 mL epoxy
26	0.25 liter Alpha poly bottle	1	P251	250 mL water
27	0.25 liter Alpha poly bottle	1	P251	250 mL epoxy
28	0.50 liter Alpha poly bottle	1	P501	500 mL water
29	0.50 liter Alpha poly bottle	1	P501	500 mL water
30	1.0 liter Alpha poly bottle	1	PLB1	1000 mL water
31	1.0 liter Alpha poly bottle	1	PLB1	1000 mL water
32	25 cc GA-MA gas sampler	0	G250	25 cc air
33	25 cc GA-MA gas sampler	0	G250	25 cc simulated air
34	25 cc GA-MA gas sampler	1	G251	25 cc air
35	25 cc GA-MA gas sampler	1	G251	25 cc simulated air
36	25 cc GA-MA gas sampler	2	G252	25 cc air
37	25 cc GA-MA gas sampler	2	G252	25 cc simulated air
38	1.24 liter GA-MA gas Marinelli	0	GM10	1240 cc air
39	1.24 liter GA-MA gas Marinelli	0	GM10	1240 cc simulated air
40	14 cc glass serum vial	0	S140	14 cc air
41	14 cc glass serum vial	0	S140	14 cc simulated air
42	14 cc glass serum vial	2	S142	14 cc air
43	14 cc glass serum vial	2	S142	14 cc simulated air
44	Aluminum ring with thin tape layer	0	PSG0	Point Source
45	Aluminum ring with thin tape layer	1	PSG1	Point Source
46	Aluminum ring with thin tape layer	2	PSG2	Point Source
47	Aluminum ring with thin tape layer	3	PSG3	Point Source
48	Aluminum ring with thin tape layer	4	PSG4	Point Source

LabSOCS CUSTOMIZED BEAKER FILES

For some of the models listed in the previous table, customized beaker files were created to accurately define the inner and outer wall contours, the material(s), and density value(s) of the container. These files were created using a standard text editor and stored with a *.bkr file extension to allow selection as one of the "complex beaker" templates in the Geometry Composer window. The template file names, corresponding container types, and models using each of these beaker shapes for parameter input are summarized in Table 4:

Table 4.
Sample container files.

File Name	Container Description
TVA20cc.bkr	20 mL Packard Polypropylene LSC (including acrylic plate). [Model #10 - 15]
TVA120mL.bkr	0.12 liter Alpha Polystyrene bottle (including acrylic plate). [Model #24 - 25]
TVA250mL.bkr	0.25 liter Nalgene wide-mouth bottle (LDPE). [Model #26 - 27]
TVA500mL.bkr	0.50 liter Nalgene wide-mouth bottle (LDPE). [Model #28 - 29]
TVA1l.bkr	1.0 liter Nalgene wide-mouth bottle (HDPE). [Model #30 - 31]
G-130G.bkr	1.24 liter GA-MA gas Marinelli beaker (Polystyrene). [Model #38 - 39]
14ccvial.bkr	14 cc glass serum vial (including acrylic plate). [Model #40 - 41]

Copies of these text files and the additional complex beaker files named 130G.bkr and 430G.bkr distributed with the standard Canberra software were provided in the final project documentation. The 130G.bkr file represents a 1.0 liter GA-MA Marinelli beaker with Polypropylene walls, used for Models #20 and #21. The 430G.bkr file represents a 4.0 liter GA-MA Marinelli beaker with Polypropylene, used for Models #22 and 23.

For each of the 48 models listed previously, a detailed description of the parameter values used to define the dimensions and material composition of the container, sample matrix, acrylic shelf absorber layer (if present), and source-to-detector distance is provided in the final project documentation. A written description of each model is provided, followed by the Geometry Composer report and printed copy of the *.GIS text file for that model. The naming convention for the Geometry Composer *.GEO files and corresponding *.GIS files used throughout this project is as follows:

Model #	*.GEO File Name	*.GIS File Name
nn	TVA_nn.GEO	TVA_nn.GIS

LabSOCS EFFICIENCY CALIBRATION PROCESS

For each of the sample models described in the previous section, the LabSOCS Version 4.0 software was used to generate a set of mathematically calculated efficiency values for a specified set of energy values. The energy range specified by TVA for all routine gamma spectroscopy measurements at Sequoyah NP was 45 keV to 2000 keV. A customized energy list was created and stored as a text file named TVA1.txt for use in all LabSOCS efficiency calculations for this project. This energy list included 16 energy values ranging from 45 keV to 2000 keV, with appropriate corresponding percent uncertainty values ranging from 10% at low energies to 4% at high energies.

Prior to perform in the final LabSOCS modeling using the Geometry Composer, the detector characterization file named 7386.par (created by Canberra for TVA's serial number 7386 coaxial germanium detector) was copied to the Genie2k\isocs\data\Dcg folder on the Canberra personal computer used to run the software. This detector characterization file was then used for all LabSOCS modeling and efficiency calculations performed during this project.

With the desired *.GEO file opened in the Geometry Composer window, the **Efficiency|Generate efficiency data points** option was selected from the menu bar. This action generated the required set of energy/efficiency/uncertainty data triplets to be used for the final efficiency calibration file. These data triplets were stored in a file named TVA_nn.ECC for each model, where nn is the same two-digit number present in the TVA_nn.GEO file used in Geometry Composer.

For each model, the following steps were then performed:

1. The appropriate *.ECC file was used to generate the final efficiency calibration results, as follows. A Gamma Acquisition and Analysis (GAA) window was launched, and a pre-existing CAM file datasource opened in the GAA window.

   The **Calibrate|Efficiency|By ISOCS|LabSOCS** option was selected from the GAA window menu bar. The desired *.ECC file was then selected as the data input file.

2. The traditional "Efficiency" option (counts per gamma) was selected as the appropriate LabSOCS efficiency calculation factor for all models.

3. When the "Calibrate by ISOCS/LabSOCS:Efficiency Results" dialog box was displayed, the **Show** action button was used to display the Dual, Empirical and Linear efficiency curves. The order of the polynomial for the efficiency curve type was modified as necessary to achieve the best curve fit.

4. From the "Calibrate by ISOCS/LabSOCS:Efficiency Results" dialog box, the **Report** action button was used to generate a one-page report of the LabSOCS efficiency results. The "Geometry Description" field for each of these reports has the format TVA_nn, where nn is the model number. Each of these reports was included in the final project report.

5. From the "Calibrate by ISOCS/LabSOCS:Efficiency Results" dialog box, the **Store** action button was used to save the results as a standard Genie 2000 efficiency calibration file in the Genie2k\Calfiles folder. The naming convention used to store these files is TVA_nn.CAL, where nn is the same two-digit model number in the corresponding *.GEO, *.GIS and *.ECC file names. The "Eff.Geom.ID" field for each *.CAL file is identical to the "Geometry Description" field in the report of LabSOCS efficiency results, i.e., TVA_nn, where nn is the two-digit model number.

6. From the "Calibrate by ISOCS/LabSOCS:Efficiency Results" dialog box, the **Finish** action button was used to close the dialog box and return to the GAA window.

7. The *.CAL file created in Step 5 was then opened as a CAM file datasource in the GAA window. The **Calibrate|Efficiency show** option was selected from the menu bar, and the **Print** action button used to generate printed plots of the appropriate efficiency curve type. These plots were included in the final report.

   Note: These curve plots were printed from the GAA window with the TVA_nn.CAL datasource opened to insure that the datasource file name included on the plot would match the actual TVA_nn.CAL file name to avoid possible confusion when reviewing these plots at a later time.

SOURCE-BASED EFFICIENCY CALIBRATION PROCESS

Equipment Utilized

The detector utilized in these source-based measurements was the same Canberra coaxial IGe detector used in the LabSOCS efficiency calculations, serial number 7386. The Peak-to-Total calibrations were performed using a Canberra Model S-PTC Peak-to-Total Calibration source set. A set of mixed gamma efficiency calibration sources were purchased from Analytics, Inc. and were fabricated from the late 2001 NIST source batch.

Software Utilized

The detailed isotopic information from the Certificates of Calibration for the mixed gamma efficiency calibration standards from Analytics was entered using the Genie 2000 Certificate Editor Version 2.1. The Genie 2000 GAA was used to acquire the spectra and perform the efficiency calibration calculations. Finally, the LabSOCS and source-based efficiency results were compared using a custom Visual Basic program written by Greg Landry of Canberra Industries. This program, the Canberra Empirical Efficiency Point Calculator Program Version 2.0, was modified to calculate the LabSOCS/Source-based efficiency ratios for each of the mixed gamma energies.

Peak-to-Total Calibration

The Peak-to-Total calibration (PTC) was performed per the Peak-to-Total section of the Genie 2000 Operations Manual (March 2001) using the Canberra Model S-PTC Peak-to-Total Calibration Source Set. The CSC factors were calculated using the Cascade Summing Correction section of the Genie 2000 Operations Manual.

Source-based Efficiency Calibration

Each mixed-gamma standard was counted on the appropriate fixture shelf using the 20,000 net counts in each certificate peak criteria. Then, the efficiency calibration calculations were performed using the GAA **Calibrate|Efficiency|By Certificate File** option from the GAA menu bar and the report printed.

Efficiency Comparison Method

The efficiency data set to be analyzed was limited to those geometries with identical matrices which assured comparison consistency. The worksheet – example contained in Appendix I – methodology was used to organize and process the data as follows:

1. The LabSOCS efficiencies and efficiency uncertainty values were entered on the worksheet.
2. The source-based efficiencies and efficiency uncertainty values were entered on the worksheet.
3. The CSC factors were entered for the appropriate energies of ^{88}Y and ^{60}Co and those efficiencies divided by the CSC factor.
4. The uncertainty associated with the CSC correction process was calculated using 5% of the CSC corrected efficiency value for the ^{88}Y and ^{60}Co values only.
5. The total source-based efficiency uncertainty was calculated by summing the source-based efficiency uncertainty and the CSC uncertainty value for the ^{88}Y and ^{60}Co values only.
6. The ratio of the total source-based efficiency uncertainty and the source-based efficiency was calculated for each mixed gamma energy.
7. The ratio of the LabSOCS efficiency value to the source-based CSC corrected efficiency value was calculated for each mixed gamma energy.
8. The total uncertainty associated with each ratio calculation was calculated using the equation in Table 2-Uncertainties of ANSI N42.14 for the ratio of two quantities and associated uncertainties.
9. The ratio value ±1.96 times the calculated ratio total uncertainty from Step 8 was then compared to unity (ratio = 1) using an agreement plot generated from an Excel spreadsheet for each mixed gamma energy.

The above steps were repeated for each geometry comparison.

COMPARISON RESULTS

The agreement plots for several representative geometries included in this study are contained in Appendix II. An examination of each agreement plot demonstrates that all of the 95% confidence intervals (ratio value ±1.96 times the calculated ratio total uncertainty) contain the agreement value of unity. An alternative method of stating this agreement is that the hypothesis that the 95% confidence intervals did not contain the agreement value was rejected in every case.

SUMMARY

This study has demonstrated that the LabSOCS efficiency calibration technique will produce efficiency values which, when corrected for cascade summing effects, will agree with source-based efficiency calibrations for a wide variety of sample and container types which support power plant process, radcon, radwaste and effluent operations. Using the LabSOCS efficiency calibration method will reduce costs associated with purchase, maintenance and disposal of physical sources. In addition, the LabSOCS technique, using the Geometry Composer, will enable count room personnel to produce assay-grade measurements of unique sample/matrix/container samples such as oil, soil, gravel and certain biological samples presented to the count room for analysis.

REFERENCES

1. F. Bronson & R. Venkataraman, "Validation of the Accuracy of the LabSOCS Mathematical Efficiency Calibration for Typical Laboratory Samples". 46th Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, November 11-17, 2000, Seattle, WA.

2. "ANSI Standard for Calibration and Use of Germanium Spectrometers for the Measurement of Gamma-Ray Emission Rates of Radionuclides", ANSI N42.14-1999, Table 2, Page 22.

3. D. Groff, "LabSOCS Geometry Modeling and Efficiency Calibration File Generation for TVA Sample Fixtures", December 6, 2001.

APPENDIX I

Example LabSOCS vs. Source-based Efficiency Comparison Worksheet

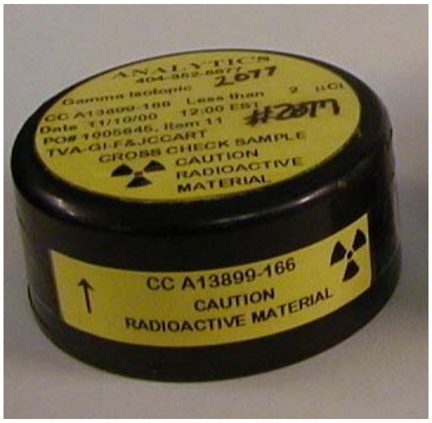
LabSOCS VS. SOURCE-BASED EFFICIENCY RATIO UNCERTAINTY CALCULATION
LabSOCS CASE: TVA_25_ae – P121 – 125 mL POLY BOTTLE – EPOXY MATRIX – SHELF 1
SOURCE CASE: P121 – 125 mL POLY BOTTLE – EPOXY MATRIX – SHELF 1

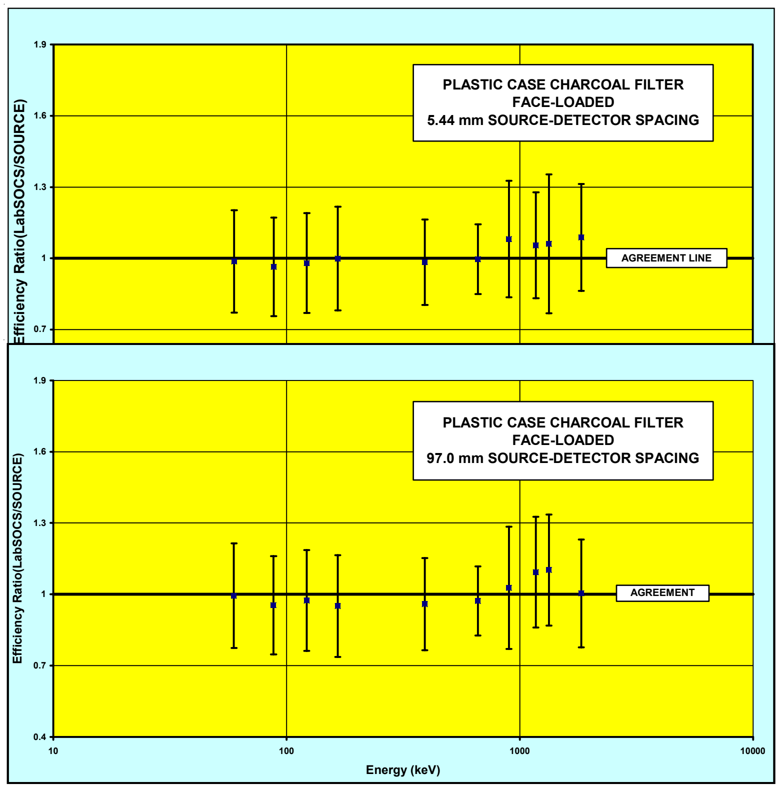
ENERGY (keV)	LABSOCS EFFIC. (E_L)	LABSOCS (EFFIC UNCERT/ EFFIC) RATIO (S_L/ E_L)	SOURCE BASED EFFIC (E_S)	CSC FACTOR	CSC SOURCE BASED EFFIC (E_C) (SEE NOTE 1)	SOURCE EFFIC UNCERT (S_S)	SOURCE CSC UNCERT (S_C) (SEE NOTE 2)	SOURCE TOTAL EFFIC UNCERT (S_T) (SEE NOTE 3)	SOURCE (EFFIC UNCERT /EFFIC) RATIO (S_S / E_S) OR (S_T / E_C)	LABSOCS/ SOURCE EFFIC RATIO (R) (SEE NOTE 4)	RATIO UNCERT (S_R) (SEE NOTE 5)	IS RATIO SIGNIF @95% CL?
59.5	5.83E-3	±0.1	6.27E-3			±3.18E-4			±0.051	0.930	±0.104	NO
88.03	1.06E-2	±0.1	1.12E-2			±5.25E-4			±0.047	0.946	±0.105	NO
122.06	1.19E-2	±0.1	1.19E-2			±5.48E-4			±0.046	1.000	±0.110	NO
165.85	1.12E-2	±0.1	1.13E-2			±6.07E-4			±0.054	0.991	±0.113	NO
391.69	6.14E-3	±0.08	6.89E-3			±1.99E-4			±0.029	0.891	±0.076	NO
661.65	4.10E-3	±0.06	4.25E-3			±4.30E-4			±0.101	0.965	±0.113	NO
898.02	3.43E-3	±0.06	3.23E-3	0.982	3.29E-3	±1.87E-4	±1.62E-4	±3.49E-4	±0.108	1.043	±0.129	NO
1173.22	2.90E-3	±0.04	2.71E-3	0.978	2.77E-3	±1.37E-4	±1.36E-4	±2.73E-4	±0.101	1.047	±0.114	NO
1332.49	2.64E-3	±0.04	2.50E-3	0.977	2.56E-3	±1.22E-4	±1.25E-4	±2.47E-4	±0.099	1.031	±0.110	NO
1836.01	2.08E-3	±0.04	1.87E-3	0.977	1.91E-3	±9.94E-5	±9.35E-5	±1.93E-4	±0.103	1.089	±0.120	NO

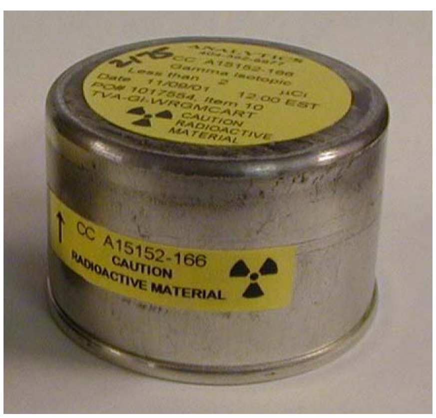
NOTE 1: CASCADE SUMMING CORRECTED SOURCE BASED EFFICIENCIES ARE: $\mathbf{E_C = E_S / CSC}$
NOTE 2: SOURCE CASCADE SUMMING CORRECTION (CSC) EFFIC UNCERT IS: $\mathbf{S_C = 0.05 * E_C}$ AND APPLIES ONLY TO ^{60}Co AND ^{88}Y.
NOTE 3: SOURCE TOTAL EFFICIENCY UNCERTAINTY IS: $\mathbf{S_T = S_S + S_C}$ AND APPLIES ONLY TO ^{60}Co AND ^{88}Y.
NOTE 4: The LabSOCS:SOURCE EFFICIENCY RATIO IS: $\mathbf{R = E_L / E_S}$ OR $\mathbf{R = E_L / E_C}$
NOTE 5: The LabSOCS:SOURCE EFFICIENCY RATIO UNCERTAINTY IS: $\mathbf{S_R = R * ((S_L / E_L)^2 + (S_S / E_S)^2)^{1/2}}$

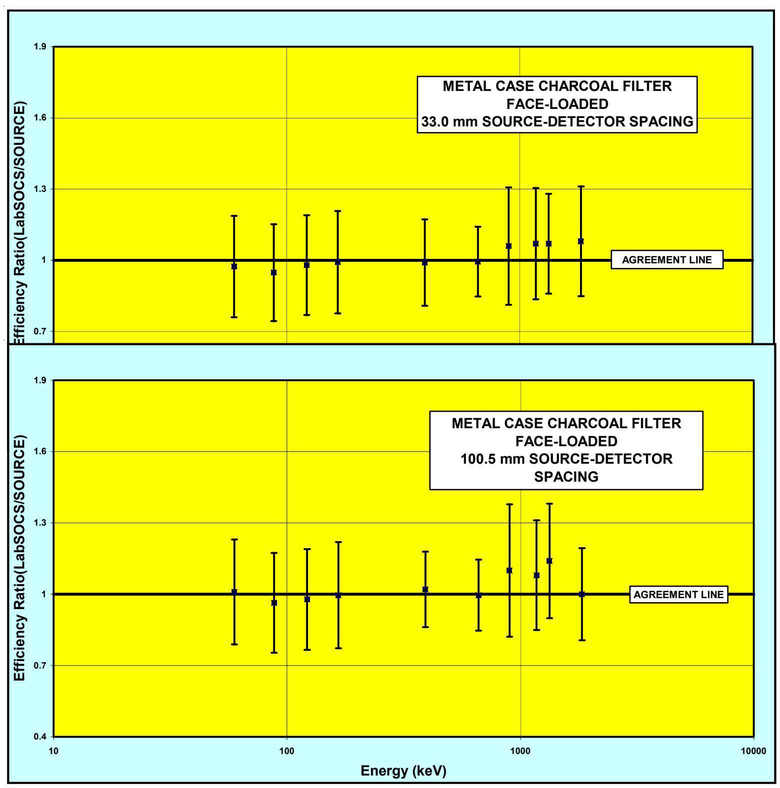
APPENDIX II

LabSOCS vs. Source-based Efficiency Ratio Agreement Plots

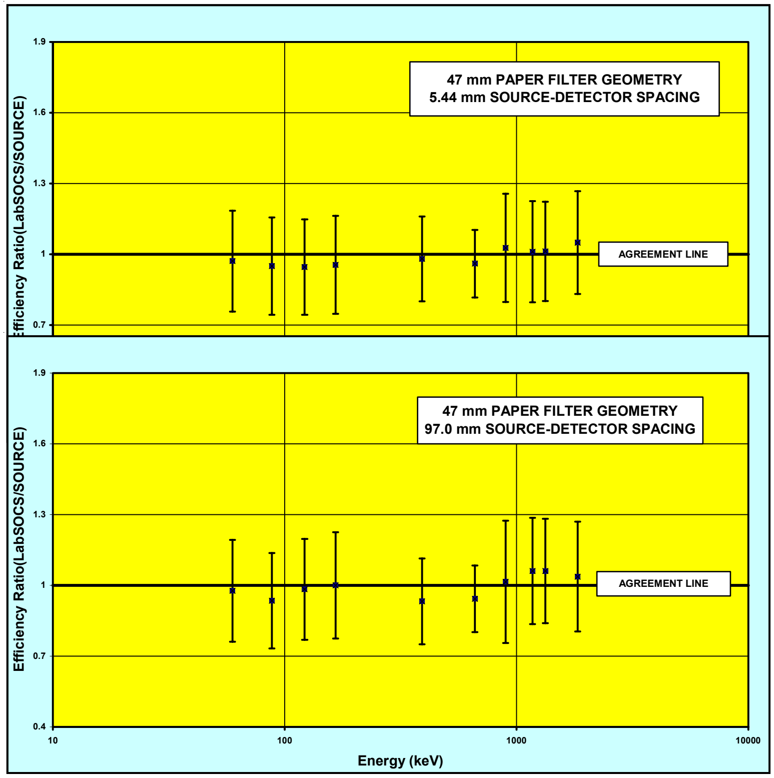

ANALYTICS
Gamma Isotopic
CROSS CHECK SAMPLE
CAUTION
RADIOACTIVE
MATERIAL
CC A13899-166
CAUTION
RADIOACTIVE MATERIAL

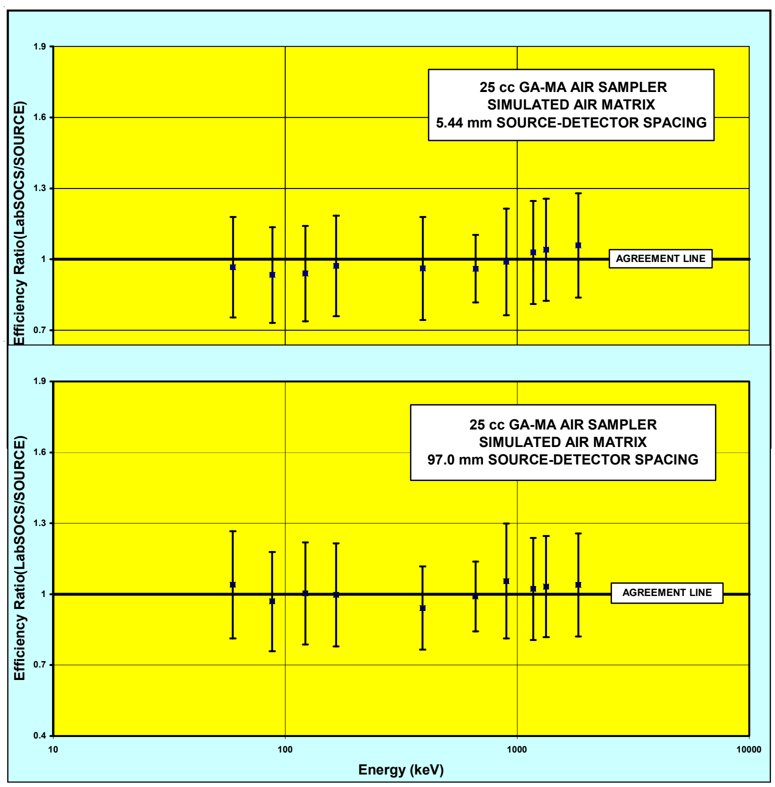

PLASTIC CASE CHARCOAL FILTER
FACE-LOADED
5.44 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
PLASTIC CASE CHARCOAL FILTER
FACE-LOADED
97.0 mm SOURCE-DETECTOR SPACING
AGREEMENT
Efficiency Ratio(LabSOCS/SOURCE)
Energy (keV)

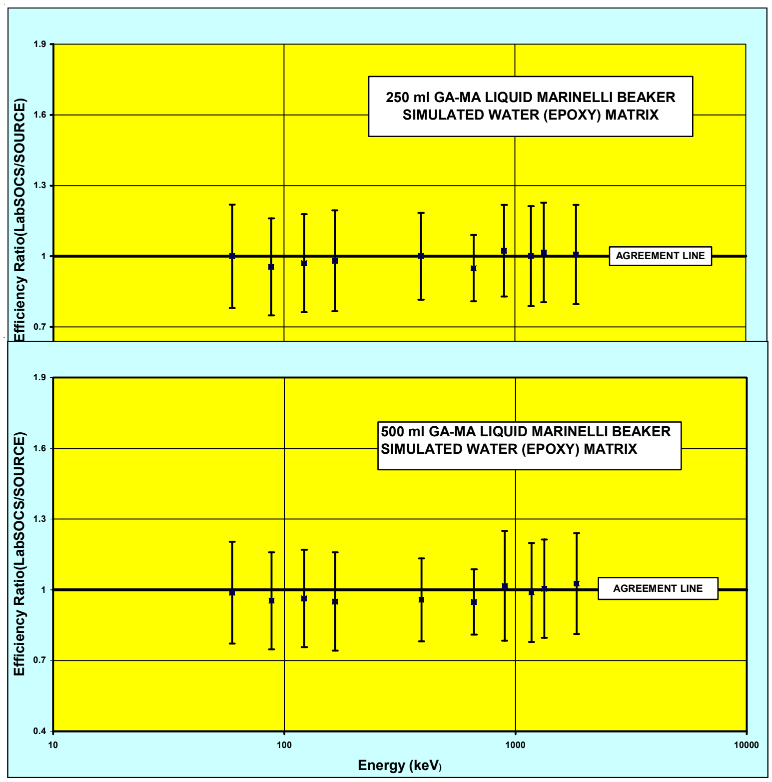

CC A15152-166
CAUTION
RADIOACTIVE MATERIAL

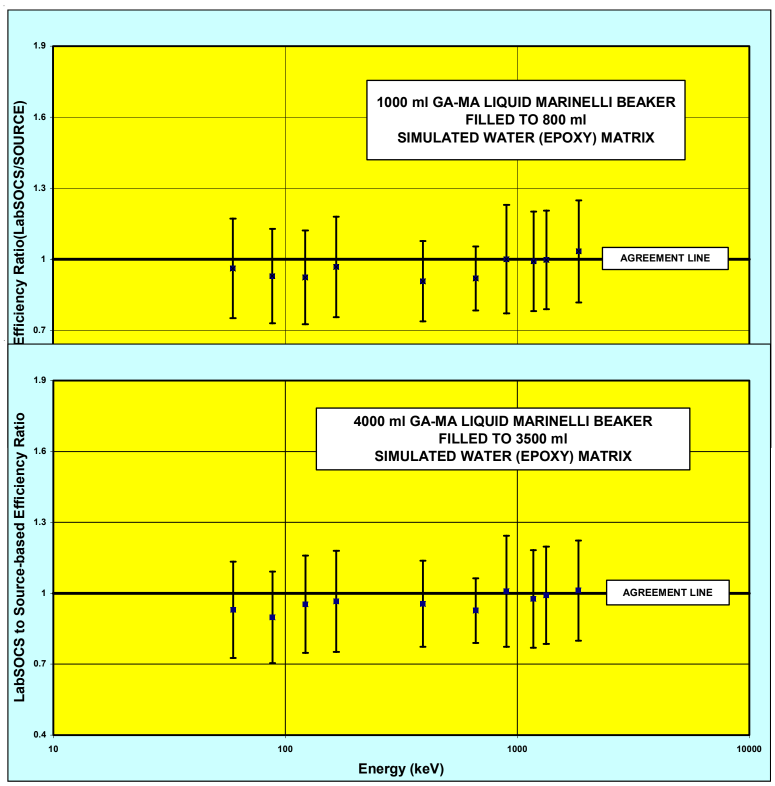

METAL CASE CHARCOAL FILTER
FACE-LOADED
33.0 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
METAL CASE CHARCOAL FILTER
FACE-LOADED
100.5 mm SOURCE-DETECTOR
SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
Energy (keV)

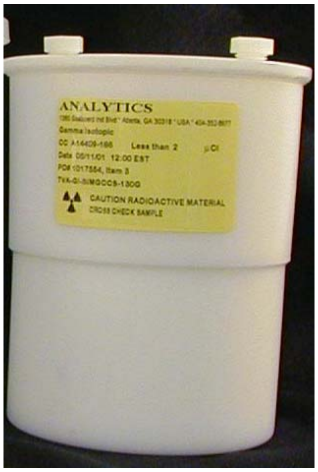

Type Mixed
Am-241
Date 1/1/00 12:00
SRS 58988-166
Amount 2.781 µCi
PO# 91MMA-45253B-002.C/031
CAUTION
RADIOACTIVE
MATERIAL

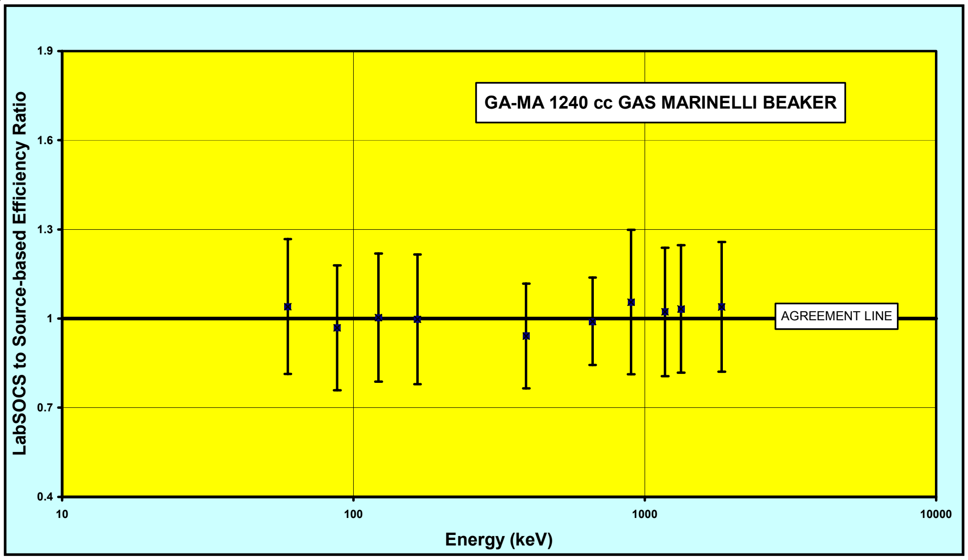

47 mm PAPER FILTER GEOMETRY
5.44 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
47 mm PAPER FILTER GEOMETRY
97.0 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
0.4
0.7
1
1.3
1.6
1.9
10
100
1000
10000
Energy (keV)

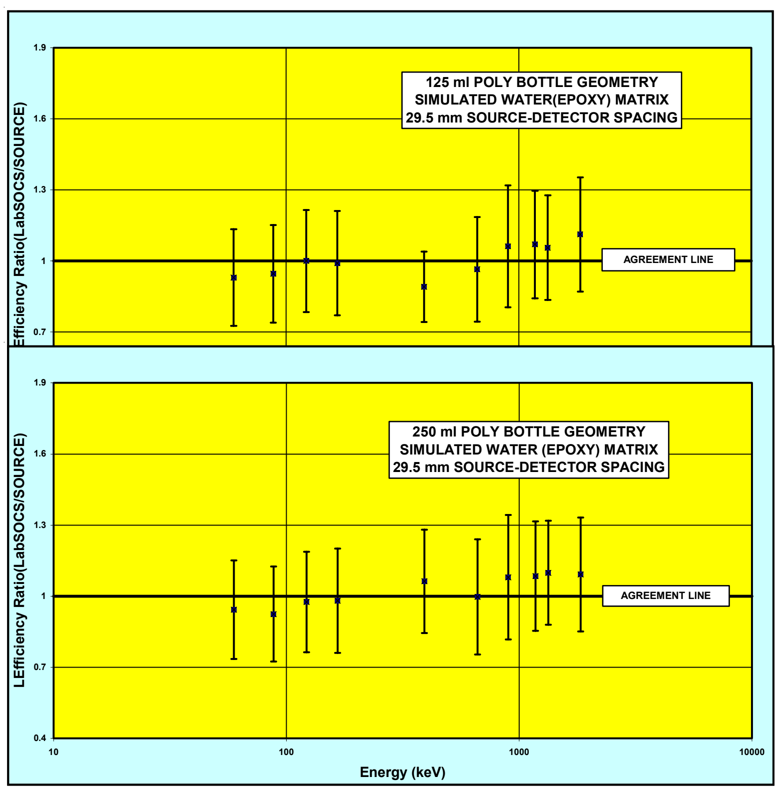

25 cc GA-MA AIR SAMPLER
SIMULATED AIR MATRIX
5.44 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
25 cc GA-MA AIR SAMPLER
SIMULATED AIR MATRIX
97.0 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
0.4
0.7
1
1.3
1.6
1.9
10
100
1000
10000
Energy (keV)

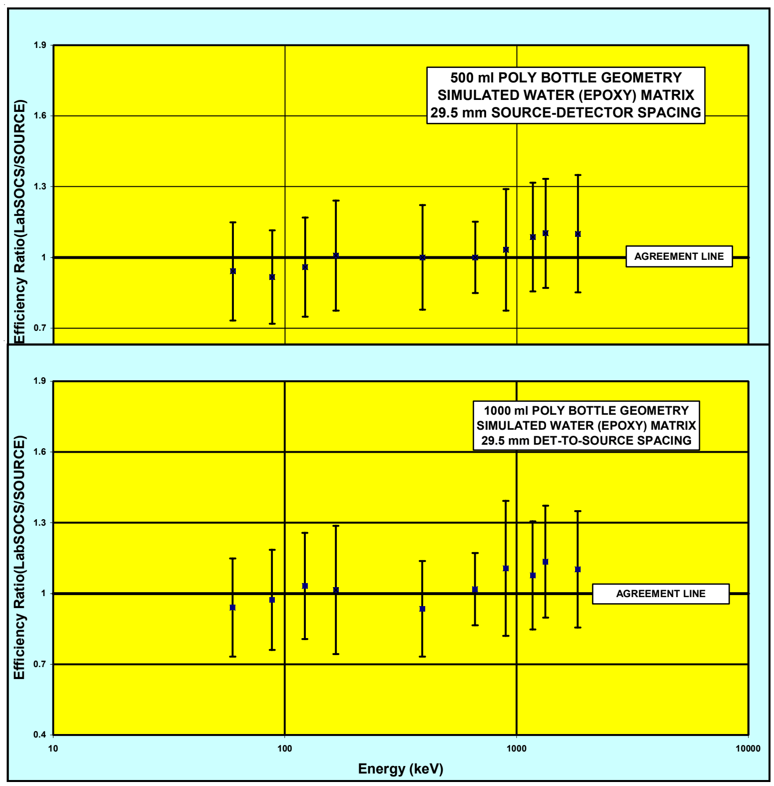

250 ml GA-MA LIQUID MARINELLI BEAKER
SIMULATED WATER (EPOXY) MATRIX
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
1.9
1.6
1.3
1
0.7
500 ml GA-MA LIQUID MARINELLI BEAKER
SIMULATED WATER (EPOXY) MATRIX
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
0.4
10
100
1000
10000
Energy (keV)

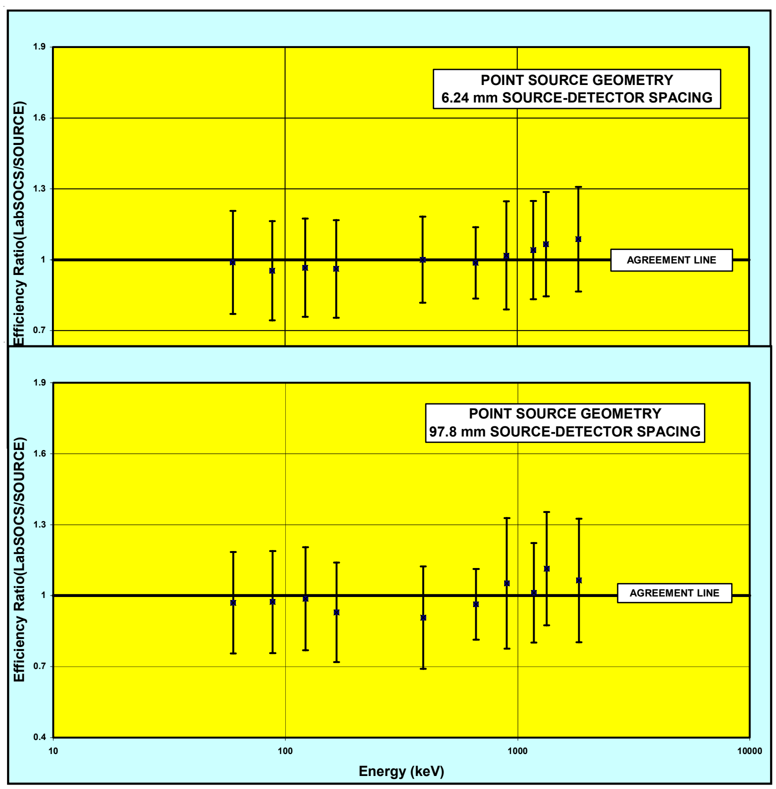

1000 ml GA-MA LIQUID MARINELLI BEAKER
FILLED TO 800 ml
SIMULATED WATER (EPOXY) MATRIX
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
1.9
1.6
1.3
1
0.7
4000 ml GA-MA LIQUID MARINELLI BEAKER
FILLED TO 3500 ml
SIMULATED WATER (EPOXY) MATRIX
AGREEMENT LINE
LabSOCS to Source-based Efficiency Ratio
0.4
10
100
1000
10000
Energy (keV)

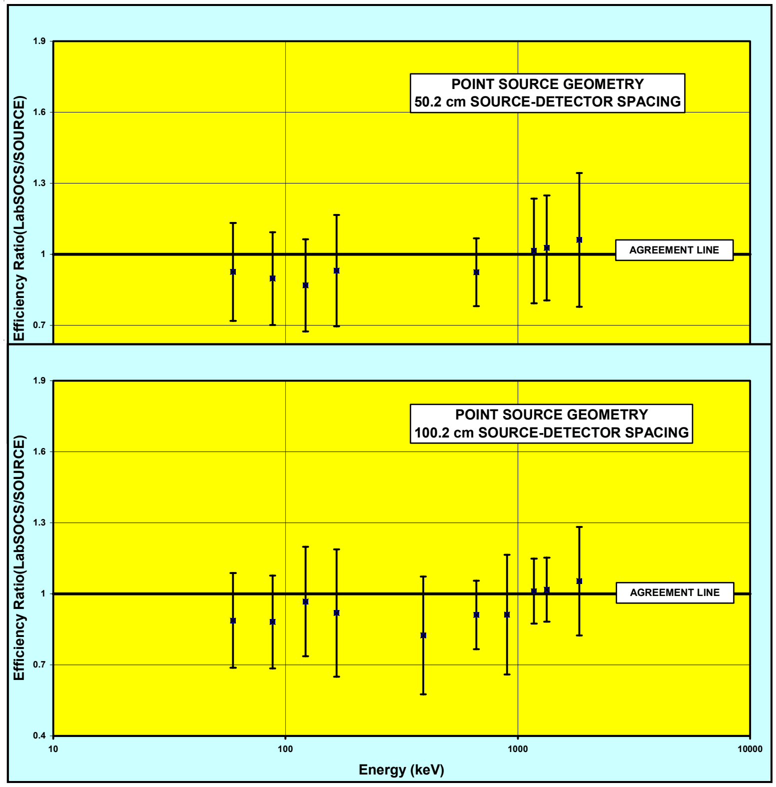



GA-MA 1240 cc GAS MARINELLI BEAKER
AGREEMENT LINE
LabSOCS to Source-based Efficiency Ratio
Energy (keV)
1.9
1.6
1.3
1
0.7
0.4
10
100
1000
10000

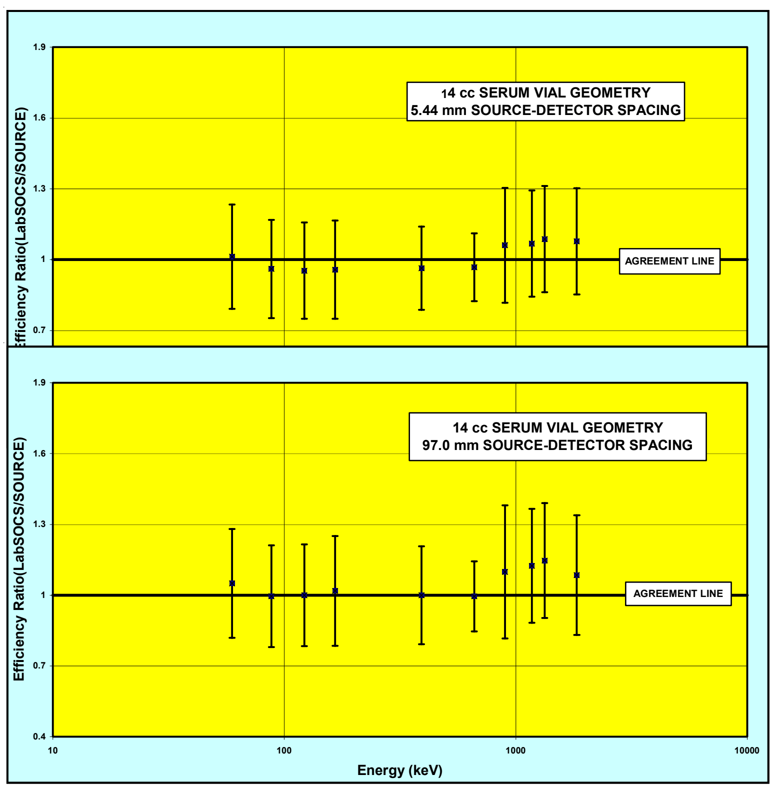

125 ml POLY BOTTLE GEOMETRY
SIMULATED WATER(EPOXY) MATRIX
29.5 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
250 ml POLY BOTTLE GEOMETRY
SIMULATED WATER (EPOXY) MATRIX
29.5 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
LEfficiency Ratio(LabSOCS/SOURCE)
Energy (keV)
1.9
1.6
1.3
1
0.7
0.4
10
100
1000
10000


500 ml POLY BOTTLE GEOMETRY
SIMULATED WATER (EPOXY) MATRIX
29.5 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
1000 ml POLY BOTTLE GEOMETRY
SIMULATED WATER (EPOXY) MATRIX
29.5 mm DET-TO-SOURCE SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
Energy (keV)


POINT SOURCE GEOMETRY
6.24 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
POINT SOURCE GEOMETRY
97.8 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
Energy (keV)


POINT SOURCE GEOMETRY
50.2 cm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
POINT SOURCE GEOMETRY
100.2 cm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
Energy (keV)


#2041


14 cc SERUM VIAL GEOMETRY
5.44 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
14 cc SERUM VIAL GEOMETRY
97.0 mm SOURCE-DETECTOR SPACING
AGREEMENT LINE
Efficiency Ratio(LabSOCS/SOURCE)
Energy (keV)