

In-Situ Assays Using a New Advanced Mathematical Algorithm - 12400

B. M. Oginni*, V. Atrashkevich**, F. L. Bronson*, M. B. Field*, J. Lamontagne*,
P. J. LeBlanc*, K. E. Morris* and W. F. Mueller*

*Canberra Industries Inc., 800 Research Parkway, Meriden, CT 06450

**Verdansky Institute of Geochemistry and Analytical Chemistry, Moscow,
Russia

ABSTRACT

Current mathematical efficiency modeling software for in-situ counting, such as the commercially available In-Situ Object Calibration Software (ISOCS), typically allows the description of measurement geometries via a list of well-defined templates which describe regular objects, such as boxes, cylinder, or spheres. While for many situations, these regular objects are sufficient to describe the measurement conditions, there are occasions in which a more detailed model is desired. We have developed a new all-purpose geometry template that can extend the flexibility of current ISOCS templates. This new template still utilizes the same advanced mathematical algorithms as current templates, but allows the extension to a multitude of shapes and objects that can be placed at any location and even combined. In addition, detectors can be placed anywhere and aimed at any location within the measurement scene. Several applications of this algorithm to in-situ waste assay measurements, as well as, validations of this template using Monte Carlo calculations and experimental measurements are studied.

INTRODUCTION

The commercially available ISOCS software [1 - 11] is a tool that can be used for calculating efficiencies of different geometric sources using mathematical algorithms. The use of mathematical efficiency modeling relieves the users from requiring large stock of radioactive sources for calibration of a wide range of geometries. These algorithms are generally valid within 5% at high energies and about 10% at low energies [1]. The product has been used successfully for over a decade, and allows for a variety of applications in in-situ gamma spectroscopy including decommission and decontamination activities and waste assay characterization. The main advantages are ease of set up, speed, and accuracy. The user interface allows the individuals to create geometries based on a broad range of templates, including for example spheres, boxes, pipes, cylinders, planes and cones. While these templates are suitable for a large proportion of necessary applications, there are some configurations in which it is desirable to be able to model a more complex geometry.

A new template has been developed which combines all the advantages of the ISOCS software and also allows the development of very complex geometries. This new template includes shapes that are currently unavailable in the present

software. This includes elliptical cylinders, prolate and oblate spheroids, and torroids etc. These shapes can be combined with an arbitrary number other standard shapes such as cubes, cylinders, and trapezoids. It allows these different shaped geometries to be stacked on one another and a surface plane to be defined which can be used to eliminate portions of objects. This new template also allows detectors to be placed in any geometric location and pointing in any direction within the virtual space. This new template therefore allows one to develop very complex geometries that extend beyond what is available with the present templates. Figure 1 shows a cross section of some of the allowed geometric shapes in the new template.

This new template can be applied in many configurations and has been validated with respect to the current ISOCS, Monte-Carlo N-Particle eXtended (MCNPX [12]) code and measured data. We present in this paper the validation results of this new template.

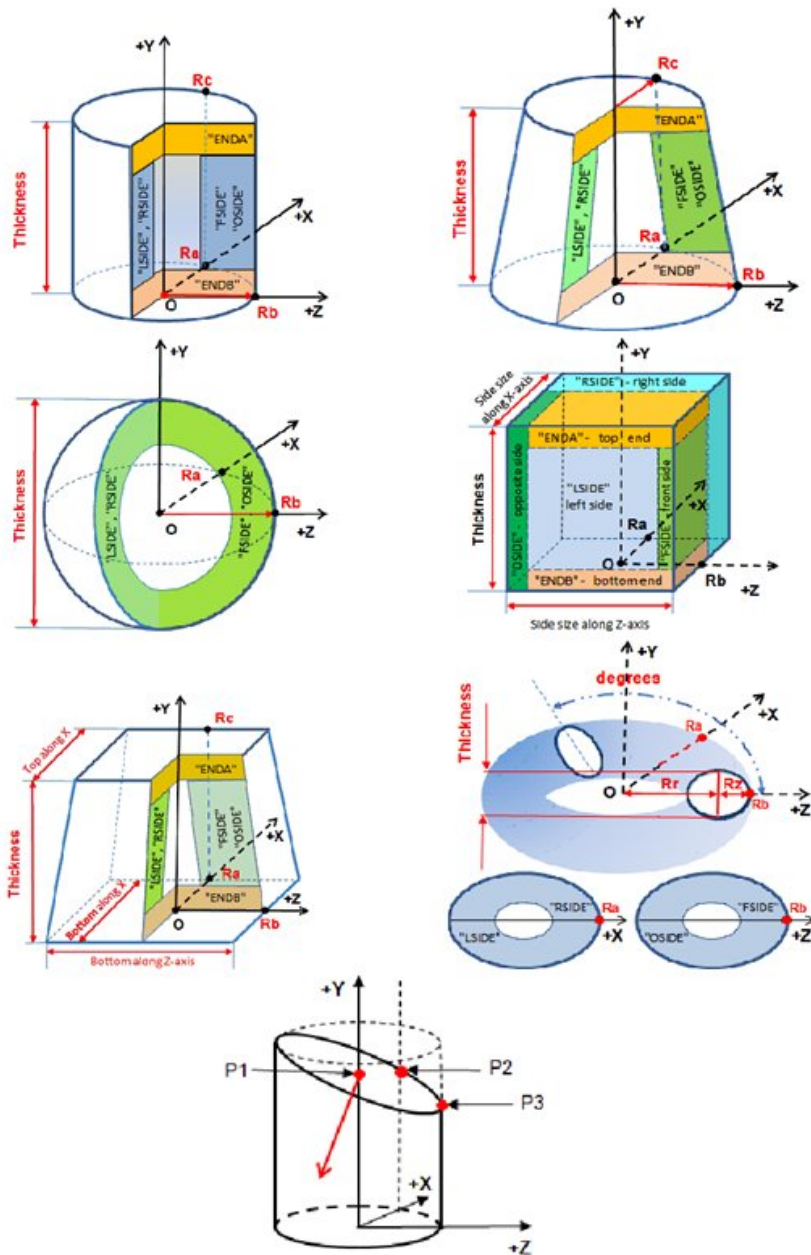


Figure 1: A selection of the geometric shapes allowed in the new template.

METHOD

New Template vs. Standard ISOCS

For this analysis, a number of geometries were created with the ISOCS software and similar geometries were replicated with the new template; the comparisons are presented in Fig. 2. The agreement between the new template and standard ISOCS were within 1.5% at all energies with typical deviations much less than 1%. These deviations are consistent with the algorithms used to determine convergence in the efficiency analysis. The error bars on the points are from the

convergence limit of 1% for the ISOCS and 1% for the new templates which are combined in quadrature to give about 1.4%.

Different materials, source concentration and absorber thicknesses were used for each of the geometries. The top geometry in Fig. 2 is a stainless steel cylinder of thickness of 0.16 cm which has two layers of radioactive soil with source concentration of 0.25 and 0.75 in the top and bottom regions respectively. The detector used in the study is a broad energy Germanium detector (BEGe) [13] and is inserted in a cylindrical collimator; there are two absorbers of copper and lead, respectively, in front of the detector. The diameter of the cylinder is 58.8 cm while the height is 82.4 cm. The middle geometry used the same detector and collimator configuration as the previous one. It however has Plexiglas and wood material as absorbers; it also has four different layers of radioactive soil with a spherical radioactive hot spot. The height of the cylinder is 82.4 cm while the diameter is 58.8 cm. The bottom geometry represent a box-like source, it has an aluminum material container. It has two absorbers of acrylic and glass of thicknesses 2 cm and 2.5 cm respectively. It has four layers containing radioactive wood, soil and concrete. The length is 100 cm while the breadth and height are 15 cm and 42 cm respectively.

The agreement between the new template and standard ISOCS shows that the new template is as accurate as the current algorithms. The duration taken during the running of the mathematical calculations is quite comparable. The strength of the new template does not lie on the ability to reproduce the current ISOCS templates, but to calculate the efficiencies of geometries that are not possible to do in the current ISOCS. To validate this, more complex geometries are compared with MCNPX and measured data in the following sections.

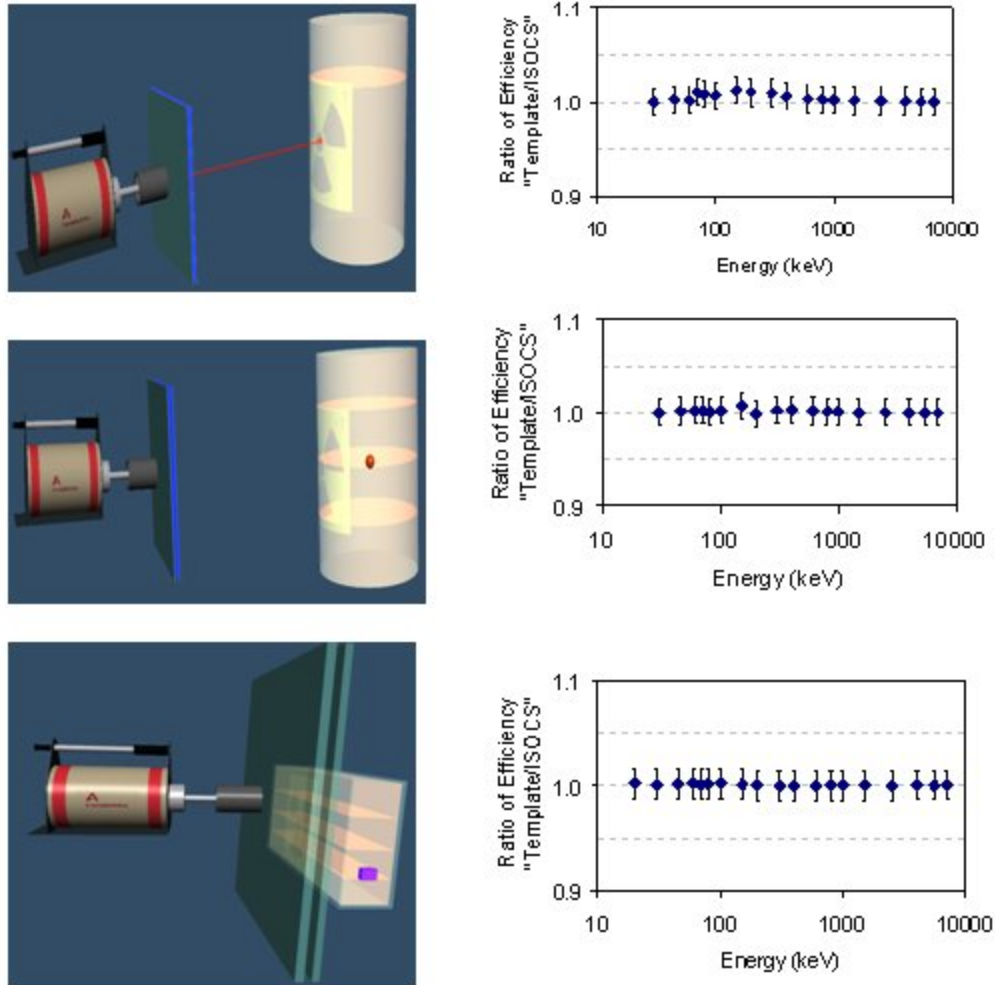


Figure 2: Three geometries that are modeled in ISOCS and have been replicated in the new template. The left side shows the pictures of different geometries that were used to evaluate efficiencies while the right hand side shows the ratio of the efficiencies obtained using the new template with respect to the efficiencies from ISOCS.

New Template vs. MCNPX

In order to validate a broad range of geometries with our new template, we use the MCNPX [12] code as a bench mark. Different geometries are shown to check the applicability of the template. Some of the geometries are elliptical cylinders, a combination of three elliptical cylinders, a 208 liter drum measured from the top and the side, a toroid and a ten drum overpack.

Figure 3 shows the different geometries studied with this new template and the corresponding ratios of the full energy peak efficiencies obtained from the new template with respect to that from the MCNPX code. The detector used in this sub-section is a 20% relative efficiency coaxial Germanium detector [14]. The error bars on the data are a combination of the relative errors from the MCNPX

model and a 4% systematic uncertainty that is consistent with the demonstrated uncertainty of standard ISOCS. This new template is preferred to the MCNPX owing to its much faster speed of computation, at least by four orders of magnitude depending on the complexity of the source geometry and the measurement scene; it is also relatively easy to set up because of the nice user interphase. The results of the MCNPX and the new template are quite comparable.

The template in Fig. 3A is an elliptical cylinder; it is made from radioactive water material and placed at a distance of 10 cm from the detector. The height, major radius and minor radius of the cylinders are 51 cm, 15 cm and 10 cm respectively. The template showed an agreement within 3% of the MCNPX model at all energies considered (100 keV to 3.2 MeV).

The geometry in Fig. 3B is a set of three elliptical cylinders made from radioactive water materials. The purpose of this is to check how well the template accounts for shadowing effect as a result of another radioactive source placed in its path. Each of the elliptical cylinders has similar dimensions as the one above. The agreement between the geometries and the MCNPX model are again within 3%.

The geometry in Fig. 3C is a 208 liter drum; this is a typical geometry for waste assay. In this set up, we used two detector positions, one at the top and one on the side. The drum is made of 0.14 cm thick stainless steel and it has internal height and diameter of 84.8 cm and 56.5 cm respectively. The detectors are placed at 10 cm from the drum at both positions. The content of the drum is made of radioactive cellulose. Cellulose is made up of 6.22% of hydrogen, 44.45% of Carbon and 49.34% of Oxygen and has a density of 0.45 g/cm^3 . The ratios of the sum of efficiencies from the two detector positions are determined. The agreement between the template and the MCNPX for this geometry is within 3%.

The geometry in Fig. 3D is a toroid. This is a complex shape that can be used to represent pipe corners. When used in conjunction with the cut plain and standard cylinders, it is possible create complex pipe systems. For the current example, we illustrate a full toroidal ring. It has a distance of 15 cm from the center of the ring to the center of the tube while the radius of the circular tube is 2 cm; the detector was placed at a distance of 10 cm from the center of the ring. The agreement between the new template and the MCNPX is within 3% at all energies.

The last geometry in Fig. 3E shows a ten drum overpack configuration. The container has five drums arranged in a ring and stacked on another set of five drums. The overall container is made from stainless steel of 0.5 cm thick and internal diameter and height of 160 cm and 180 cm respectively. The dimension of each of the inner tens drum is similar to the 208 liter drum described above. The full peak energy efficiencies from the new template and the MCNPX were in agreement to within 8% for this complex configuration.

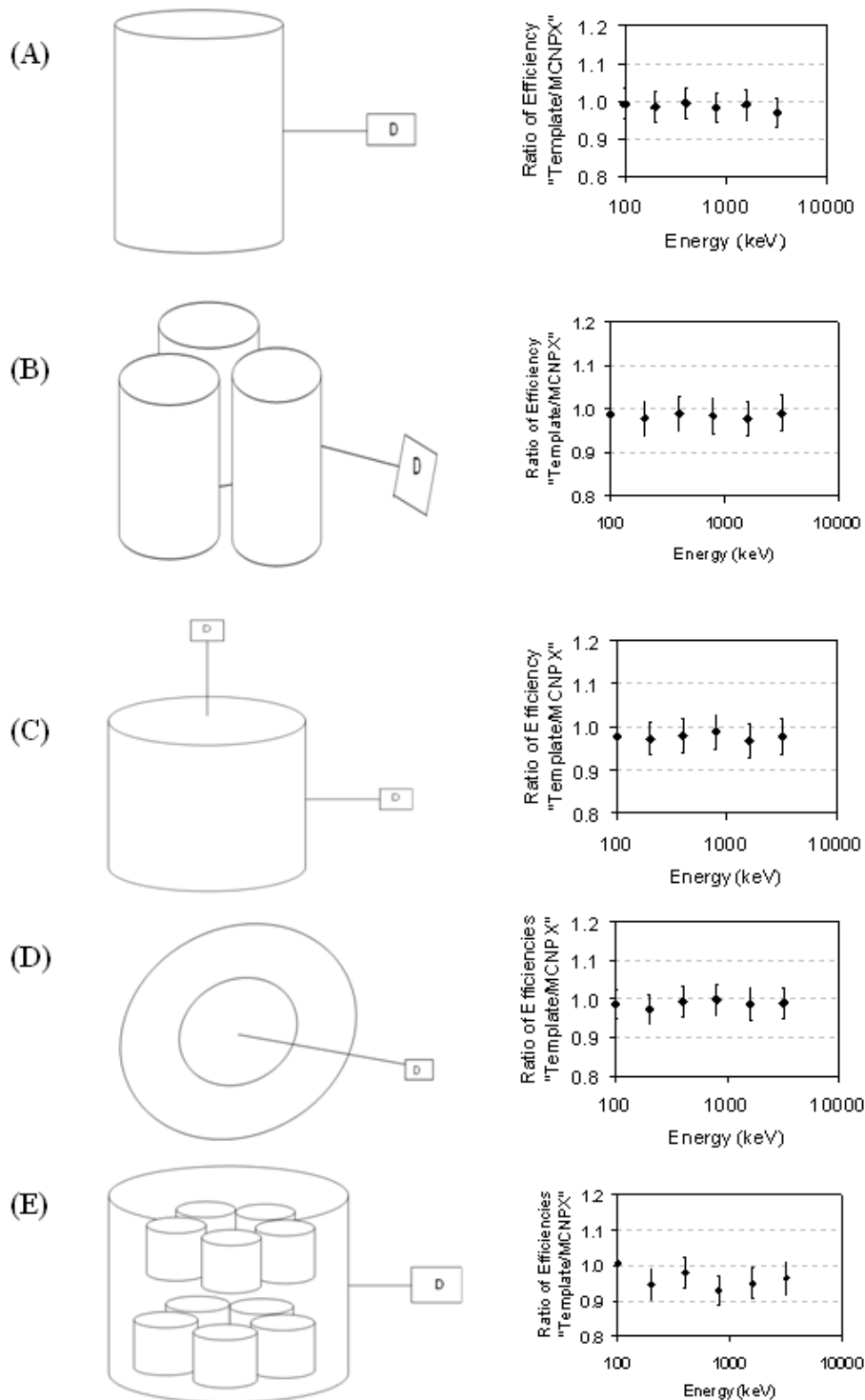


Figure 3: Different geometries that have been used as part of the validation of this new template. The first figure is the elliptical cylinder, followed by the three elliptical cylinders, then the 208 liter drum, the toroid and finally the ten drum overpack.

New Template vs. Measurement Data

This new template has also been used for validation against measured data. Figure 4 shows series of pictures and their corresponding graphs. The graph highlights the ratio of efficiencies of the new template with respect to the efficiencies of the measured data. The measurements described here were performed with a 45% relative efficiency reverse-electrode germanium detector (REGe) [15]. This detector has been characterized at the factory so that it can be used for the mathematical modeling. The typical one standard deviation certified uncertainty in the activities of the sources used is 4%. We consider an uncertainty of 4% due to the approximation in the modeling algorithms and 2% uncertainty for the geometric set up. All geometries were measured with a length of time sufficient that the statistical uncertainties for all peaks of interest were less than 1%. The total uncertainty for all measurements is taken as the combination of all of the above uncertainties in quadrature, which is approximately 6%.

Figure 4A shows a mixed gamma vial source used to make measurement with the REGe detector, this sample is typically used for laboratory calibrations. The vial has an external height of 5.08 cm, external radius of 1.43 cm, thickness of 0.16 cm and was placed at a distance of 31.12 cm from the REGe. The corresponding graph shows the ratio of the efficiencies obtained from the mathematical algorithms with respect to the measured data. There is a good agreement between the model and the measured data at all peak energies.

The set up in Fig. 4B is an elliptical cylinder with an external major diameter of 29.9 cm, minor diameter of 20.4 cm, height of 39.8 cm and placed at a vertical distance of 14.8 cm from the REGe detector. The approximate thickness of the container is 0.5 cm and made from polyethylene of density of 0.95 g/cm^3 . The content was prepared with a National Institute of Standard Technology (NIST) traceable Eu-152 source solution mixed with resin to provide a uniform activity concentration. This is the upper torso of the standard phantom family called the BOttle Manikin ABsorption phantom (BOMAB). This is used for calibration of uptake of radioactive material by human. Though the application may not necessarily be of interest to waste management, the comparison of the efficiencies obtained as compared to the efficiency from the new template is quite relevant. The comparisons of the efficiency from the new template to the measured data are shown in the right-hand graph. All the efficiencies are within 10% of the measured results, with typical comparisons that are less than 5%.

Figure 4C is a set up made up of four cylinders that contain known amount of radiological activity. The set up consists of two regular and two elliptical cylinder sources. This is typically used for simulating a child with the elliptical “head” cylinder which has a major diameter of 19.1 cm, minor diameter of 14.2 cm, height of 19.9 cm; a larger elliptical cylinder which has a major diameter of 29.9 cm, minor diameter of 20.4 cm, height of 39.8 cm; and two identical regular cylinders with each having diameter of 12.8 cm and height of 40.4 cm. The materials of the containers and its content are the same as in the previous case. The set up was placed at a vertical distance of 14.5 cm from the REGe detector.

The corresponding graph shows the ratio of the efficiencies obtained from the mathematical algorithm to that of the measured data. The greatest deviation between the new template and the measured results for this geometry is less than 8%, with typical comparisons that are less than 5%.

Lastly, the new template was validated using ten cylinders stacked on each other; this is usually used in the calibration of a typical adult. The total length of the configuration is approximately 173 cm. Figure 4D shows the picture of the set up and the corresponding graphs shows the ratio of the efficiencies obtained from the mathematical algorithms with respect to the measured data. The greatest deviation between the new template and the measured results for this geometry is about 8%, with typical comparisons that are less than 5%.

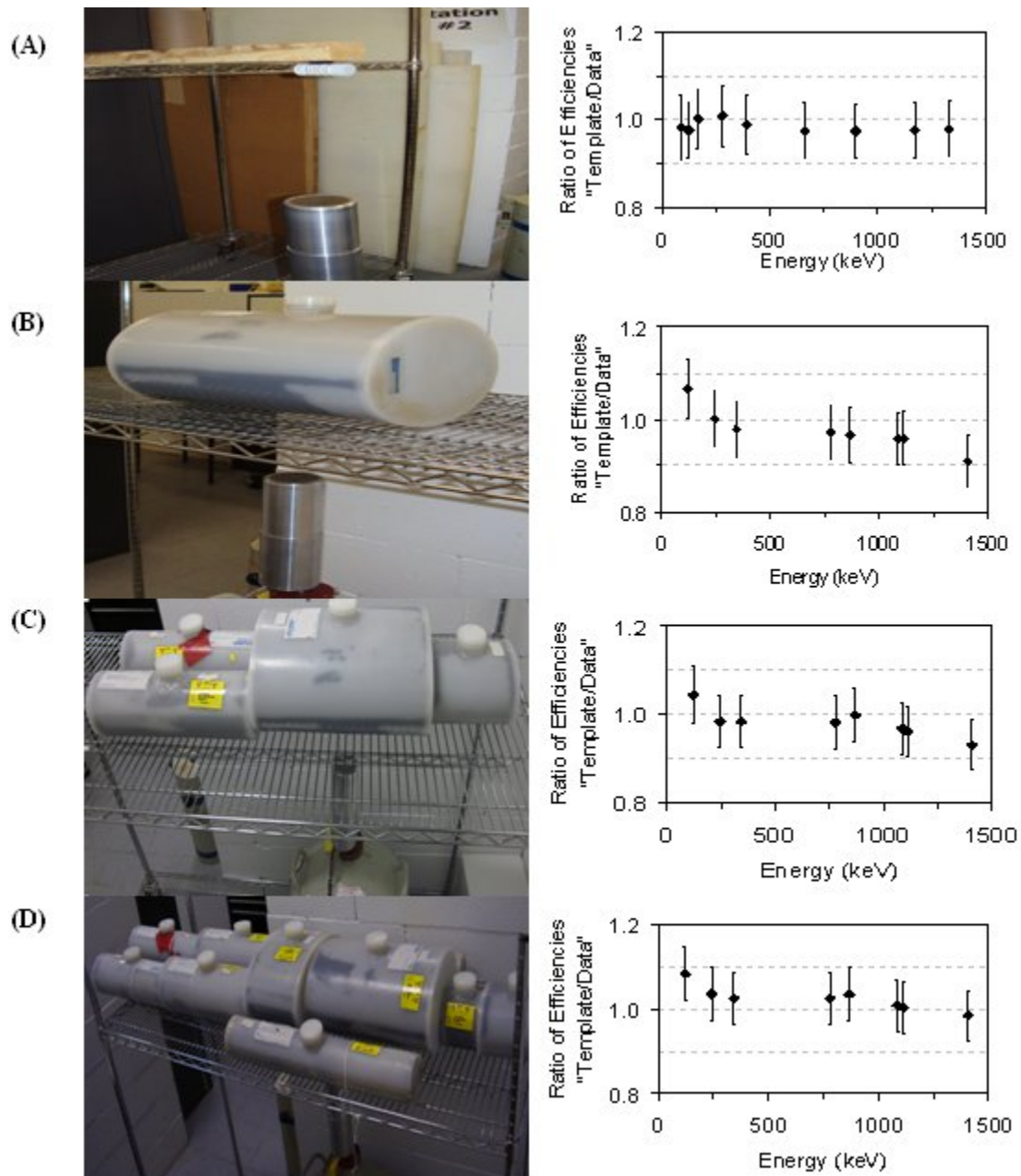


Figure 4: Set up for measured data that are compared with efficiency results using the template. The left side shows the set up pictures while the right side shows the ratios of efficiencies of template with respect to the measured data.

CONCLUSION

Presented in this paper is a new template of the mathematical algorithms for evaluating efficiencies. This new template combines all the advantages of the ISOCS and it allows the use of very complex geometries, it also allows stacking of geometries on one another in the same measurement scene and it allows the detector to be placed anywhere in the measurement scene and pointing in any direction. We have shown that the template compares well with the previous ISOCS software within the limit of convergence of the code, and also compare well with the MCNPX and measured data within the joint uncertainties for the code and the data. The new template agrees with ISOCS to within 1.5% at all energies. It agrees with the MCNPX to within 10% at all energies and it agrees with most geometries within 5%. It finally agrees with measured data to within 10%. This mathematical algorithm can now be used for quickly and accurately evaluating efficiencies for wider range of gamma-ray spectroscopy applications.

REFERENCES

- [1] R. Venkataraman, F. L. Bronson, V. Atrashkevich, B. M. Young, and M. Field, “*Validation of In Situ Object Calibration System (ISOCS) Mathematical Efficiency Calibration Software*”, Nuclear Instruments and Methods in Physics Research (A), 422 (1999), pp 450-454.
- [2] D. Nakazawa, F. Bronson, S. Croft, R. McElroy, W. F. Mueller, and R. Venkataraman, “*The Efficiency Calibration of Non-Destructive Gamma Assay Systems Using Semi-Analytical Mathematical Approaches - 10497*”, Waste Management Conference (March 7 – 11, 2010, Phoenix, AZ).
- [3] K. E. Morris, W. F. Mueller, P. J. LeBlanc, F. Bronson, S. Croft, M. B. Field, D. R. Nakazawa, R. Venkataraman and H. Ziu, “*The Efficiency Characterization of Germanium Detectors at Energies less than 45 keV - 10479*”, Waste Management Conference (March 7 – 11, 2010, Phoenix, AZ).
- [4] N. Menna, D. Nakazawa, H. Yang, S. K. Smith, D. Petroka and M. Villani, “*An Integrated Waste Assay System using Tomographic and Segmented Gamma Scanning for Nuclear Power Plant Applications - 10375*”, Waste Management Conference (March 7 – 11, 2010, Phoenix, AZ).
- [5] Hwa-Jou Wei, Tsuey-Lin Tsai, Ching-Ho Yang, Lee-Chung Men and Hung-I Tsai, “*Validation of Efficiency Calibration for the Clearance Measurement System - 10086*”, Waste Management Conference (March 7 – 11, 2010, Phoenix, AZ).
- [6] G. Geurkov, V. Atrashkevich, A. Bosko, F. Bronson, S. Croft and B. Young, “*Probabilistic ISOCS Uncertainty Estimator: Application to the Segmented Gamma Scanner*”, 2006 IEEE Nuclear Symposium Conference.
- [7] F. Bronson, V. Atrashkevich, G. Geurkov and B. Young, “*Probabilistic uncertainty estimator for gamma spectroscopy measurements*”, Journal of Radioanalytical and Nuclear Chemistry, Vol. 276, No 3 (2008) 589 – 594.
- [8] A. Bosko, S. Croft and Ed Gulbransen, “*Estimated Uncertainty in Segmented Gamma Scanner Assay Results due to the Variation in Drum Tare Weights - 9332*”, Waste Management Conference (March 1 – 5, 2009, Phoenix, AZ).
- [9] F. L. Bronson, R. McElroy, S. Phillips, W. Russ and S. Croft, “*The Application of Mathematical Modelling for Commercial Nuclear Instrument Design, Development and Calibration*” ANIMMA International Conference (June 7 – 10, 2009, Marseille, France).

[10] A. Bosko, G. Geurkov, S. Croft and R. Venkataraman, “*Advanced Approach for Calibration of the Segmented Gamma Scanner for the Radioassay of Drummed Waste*”, 2006 IEEE Nuclear Science Symposium Conference.

[11] Canberra Technical Reference Manual V4.0 9231205E.

[12] Monte Carlo team, “*MCNPX – A general Monte Carlo for neutral particle transport code*”, Los Alamos National Laboratory Report LA-UR-02-2607 (April 2002).

[13] www.canberra.com/products/485.asp

[14] www.canberra.com/products/486.asp

[15]. www.canberra.com/products/494.asp