# Measurement Uncertainty from *In-Situ* Gamma Spectroscopy of Nonhomogeneous Containers and from Laboratory Assay

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## ABSTRACT

During a D&D or ER process containers of radioactive waste are normally generated. The activity can commonly be determined by gamma spectroscopy, but frequently the measurement conditions are not conducive to precise sample-detector geometries, and usually the radioactive material is not in a homogeneous distribution. What is the best method to accurately assay these containers – sampling followed by laboratory analysis, or *in-situ* spectroscopy? What is the uncertainty of the final result? To help answer these questions, the Canberra tool ISOCS Uncertainty Estimator [IUE] was used to mathematically simulate and evaluate several different measurement scenarios and to estimate the uncertainty of the measurement and the sampling process.

Several representative containers and source distributions were mathematically defined and evaluated to determine the *in-situ* measurement uncertainty due to the sample non-uniformity. In the First example a typical field situation requiring the measurement of 200-liter drums was evaluated. A sensitivity analysis was done to show which parameters contributed the most to the uncertainty. Then an efficiency uncertainty calculation was performed. In the Second example, a group of 200-liter drums with various types of non-homogeneous distributions was created, and them measurements were simulated with different detector arrangements to see how the uncertainty varied. In the Third example, a truck filled with non-uniform soil was first measured with multiple *in-situ* detectors to determine the measurement uncertainty. Then composite samples were extracted and the sampling uncertainty computed for comparison to the field measurement uncertainty.

## INTRODUCTION

Gamma spectroscopy is a very useful tool to quantify the activity of various items, such as samples in the laboratory, or waste assay containers, or large items *in-situ* . An efficiency calibration is needed convert the peak area into activity or concentration of each nuclide. In addition to the activity or concentration of the sample, an uncertainty estimate is also needed to fully understand and present the quality of the measurement. This uncertainty estimate should include the uncertainty in the efficiency calibration of the instrument, as well as many other parameters. For most D&D and ER samples, it is the efficiency uncertainty that is the dominant component to the total propagated uncertainty [TPU] of the measurement.

Efficiency vs. energy calibrations have been traditionally determined using well-known radioactive sources distributed in carefully prepared geometries to best represent the sample being measured. For small samples typical in the laboratory and simple samples like water this is relatively easy. But for large items and/or non-water samples mathematical calibrations are very common, can be quite accurate, and are much quicker and more convenient. One such mathematical calibration tool is the Canberra ISOCS [In-Situ Object Calibration Software]. This software can quickly compute an efficiency calibration formula for a wide range of sample types and shapes. [1] [2] However, this calibration software, and essentially all other mathematical or source-based calibration methods, assumes that the source to be measured is exactly like the calibration source model. Likewise, even a perfect laboratory assay assumes that the sample is truly representative, and that there is no sampling uncertainty. This is rarely the case. Most DD/ER measurement situations are with non-uniform sources in non-standard conditions. It is important to evaluate this major component of the TPU.

When building a calibration source or creating a mathematical calibration model, exact discrete values for the physical dimensions and materials of the source or model are used. But the real sources being measured are not exactly the same. Differences between the real source and the calibration source or model include: container wall thickness; container diameter; sample height in the container; sample density; sample matrix composition; sample uniformity; source-detector distance, etc.

A typical method to address these is to assume worst-case values for each of these, either singly or all together. In most situations, all of these differences between the reference calibration and the measured sample exist concurrently. Therefore, the simplistic methods of considering only one item at a time will likely have uncertainty values too small, and using the worst-case values of all of them together will likely have uncertainty values too large.

## ISOCS UNCERTAINTY ESTIMATOR

A new tool called ISOCS Uncertainty Estimator [IUE] has been developed to improve the quality of the gamma spectroscopy uncertainty estimate, to improve the ease of generating it, and to document how it was generated. [3]

The user first runs the ISOCS efficiency calibration software in the normal manner to compute the normal reference efficiency for the sample being measured. This efficiency file has encoded within it the inherent uncertainty in the ISOCS efficiency calibration method – i.e. 4-8%. As with most efficiency calibrations, this assumes the calibration model is a perfect representation of the sample.

The IUE software is then used to create the model-to-model uncertainty which will then be combined with the calibration uncertainty and the counting statistics uncertainty. The software can also be used for a sensitivity analysis, to find those parameters which contribute the most to the uncertainty. If the source is potentially non-uniform, IUE can be used to examine various non-uniform distributions to estimate that portion of the TPU.

### Data Required

To create an ISOCS efficiency calibration file, the user needs to know the radiologically important physical parameters of the object, such as shape of the container, dimensions of the container and sample, composition of the container and sample, detector location with respect to the container, and detector response function. Depending upon the item's complexity, and assumptions the user might feel comfortable making, this could be as few as 5 parameters, or as many as 50 or more parameters.

**Efficiency Calibration**

The efficiency calculation is very quick – normally a few minutes. For each of the user-defined energy values, the ISOCS software computes the efficiency, and assigns an uncertainty. This group of energy-efficiency-uncertainty triplets is then fit with an appropriate function to interpolate between points. This function is then used within the Genie spectral analysis to compute activity and concentration. If this is all that is done, then the analysis represents both the statistical counting uncertainty and the efficiency calibration certainty, assuming a well known calibration source and a sample that perfectly matches it. But this is rarely the case.

**ISOCS UNCERTAINTY ESTIMATOR – IUE**

Some of the ISOCS data entry parameters are well known and do not vary appreciably; e.g. the container might always known to be type 304 stainless steel. Other [or most in many situations] parameters are not well known, e.g. the wall thickness of the container or the density of the contents. It is these not well known parameters that contribute to the uncertainty in the calibration efficiency. For each not well known parameter, the user is required to provide to the IUE software an estimate as to how much that parameter varies, determined, for example, by measuring a group of containers or consulting the manufacturing specifications for the containers or just by making educated guesses. The parameters that can be varied include dimensional parameters [diameter, distance, thickness, density, …], as well as material composition of each item in the model.

For each not well known parameter, the user provides upper and lower limits [e.g. maximum and minimum density] and a distribution form that the parameter values within those limits are assumed to follow. As an example of this distribution form, if the values were determined by a series of measurements, then the limits can be assigned to represent 1 standard deviation, 2 standard deviations, or 3 standard deviations. If the values are just known as limits, then they could be assigned a uniform distribution function [all values equally probably] or a triangular distribution function [zero probability beyond the limits increasing linearly to the maximum probability in the middle].

**IUE Data Entry Method**

The user first points the software to one of the intermediate files created in the normal process of performing an ISOCS efficiency calibration. This file contains all the physical parameters of the normal [assumed perfect] calibration model.

The user is then presented with a series of screens showing all the parameters from the calibration model, and given an opportunity to make each of them a variable parameter. If that parameter is to be varied, then the user enters for each parameter the minimum value, the

maximum value, and the distribution function to be used. Two examples of these screens are shown below as Figures 1 and 2.

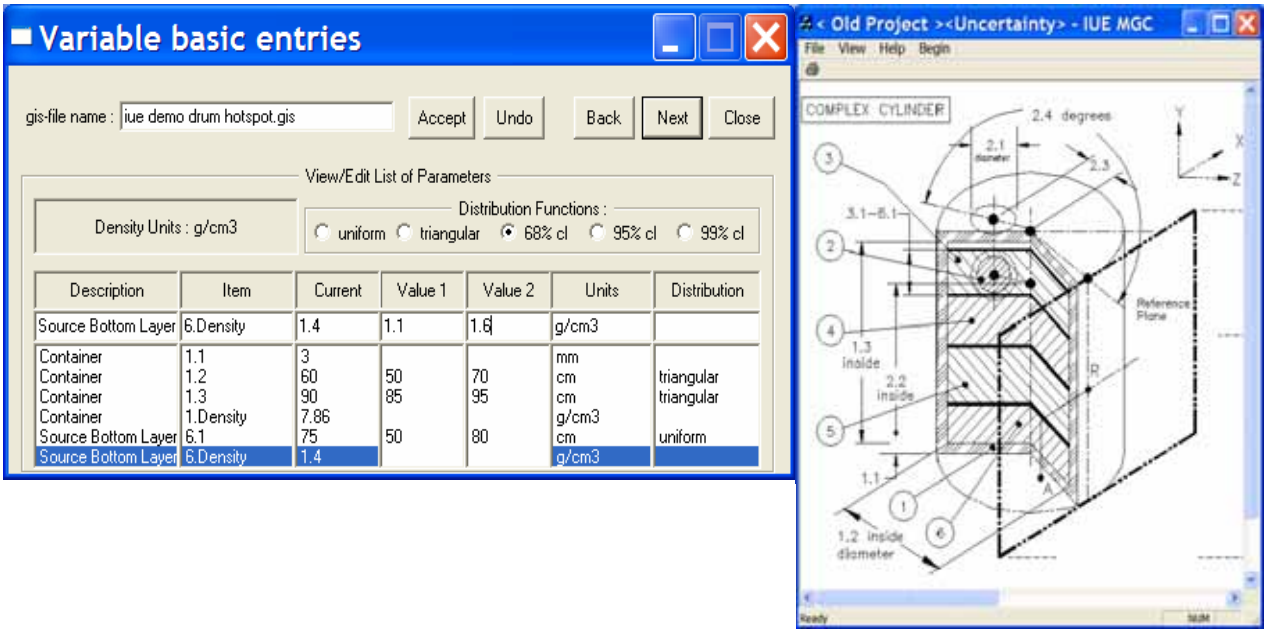


**Figure 1 Typical IUE data input screen (above). Parameters are entered here to describe the amount and type of variation for the model. Entries correspond to the numbers on the graphic on the Figure 2 (right).**

In the case where the variable parameter is a material, the user enters a series of discrete materials, along with a weighting factor denoting the likelihood of that particular material being present.

All input parameters are stored in a file, and in a printed report for the project record.

## Calculational Methodology

The method used in this software is Probabilistic – all variables are assumed to vary randomly, but in a manner as described by their individual probability distribution function. All variables [except a few that are noted elsewhere] are assumed to vary independently from others, to the extent that it is physically possible.

Using these rules, the IUE software creates the files for a series of ISOCS calibration models. A random process is used to generate values for each not well known parameter, according to the probability distribution function rules and limits defined by the user. These values are combined to create an ISOCS model. A large number of these models are created and checked for validity.

The IUE software then computes the efficiency for a large number of energies using each of the valid random models. The IUE software now contains an array of efficiency values at each energy.

For each energy, the IUE software then computes the mean efficiency, and the standard deviation of those efficiency values at that energy. This standard deviation now represents the uncertainty from the combined effect of all the not well known parameters.

This uncertainty is then combined with the basic ISOCS calibration uncertainty and embedded within the efficiency calibration.

When this efficiency calibration is used to analyze a sample, this total calibration uncertainty is propagated with counting statistics uncertainty and other uncertainties for the final total measurement uncertainty.

**Other Software Features**

For measurements situations that use multiple detectors, the software allows the user to specify how many detectors, and determine their placement around the object. Therefore it can be used to calibrate or estimate uncertainty from common field measurement systems like box or truck counters.

For measurement situations that use rotating samples, the software allows the user to specify this, and to define how many discrete steps are used to simulate a continuous rotation. For measurement situations that use scanning detectors, the software allows the user to specify this, and define how many discrete steps are used to simulate a continuous scan. This allows the software to be used to calibrate and estimate uncertainty for common drum measurement systems.

Some measurement situations have non-uniform sample concentration. Several of the ISOCS sample types allow non-uniform distributions, including “hot spots”. The IUE software expands that by allowing a multiple [or variable] number of hotspots and the size of the hotspots [fixed or variable] to be included in the model. In addition to computing the efficiency uncertainty from non-uniformity, the software also simulates the sampling uncertainty from extracting a sample or series of samples from the non-uniformly distributed radioactivity. Now the IUE software can be used to determine the impact on TPU from sample non-homogeneity, and can compare the differences between the *in-situ* measurement uncertainty and the sampling uncertainty.

Although most of the variables are treated as independent variables, a few of them can be inter-dependent. A common example is sample height in a container, sample density, and sample weight. The weight is typically the most well known parameter, as it is rather easy to determine. The IUE software lets the user enter the weight as a variable parameter and then computes either sample height or sample density.

The software computes the arithmetic mean efficiency and standard deviation, as well as the geometric mean efficiency and standard deviation. For measurement situations where attenuation is the dominant factor, the values are more likely to be in a log-normal pattern, where the geometric values are more relevant.

The IUE software also operates in a Sensitivity Mode, where only 1 parameter is varied at a time. This provides the user with feedback as to which of the parameters are the major

contributors to the total uncertainty, thus allowing the user to concentrate data collection resources on those dimensions that are most important.

## EXAMPLES OF IUE CALCULATIONS

### Example 1: 200 Liter Drum Assay Under Field Conditions

This is a common field measurement situation. An *in-situ* Ge gamma spectroscopy system is being used to assay a group of 200 liter drums filled with radioactive soil from an environmental remediation project. The site had contaminated soil of many different types, and consequently many different densities. These ranged from wet sandy material at density of around 1.8 g/cc down to soil mixed with decayed vegetation at densities of 1.0. The soil composition of the containers was estimated to be normal soil approximately 50% of the time, mostly sand approximately 25% of the time, and soil and decayed vegetation about 25% of the time. The drums were filled from material that had been stored in piles and are rather well mixed, therefore it is reasonable to assume that the radioactivity in each individual container is homogeneous.

The composition and density of each individual drum is not known, but the total weight of each drum is known. The weight of the containers varied from 400 to 800 lbs. A random sampling of the weights showed that 95% of them were between 450 and 750 lbs.

The fill height of each drum is not known, and it is neither practical nor desirable to open each drum for inspection. But from discussions and procedures during the fill operations, the containers were filled until they were approximately 70-90% full.

The ISOCS cart and detector were wheeled up next to the drums, at approximately 100cm from the side of the drum. That distance was measured, and the cart repositioned if the distance was not between 90 and 110 cm. The detector in the ISOCS cart is 26 cm from the ground, and aimed at the center of the drum. But since the ground is not flat, there could be a 10cm variation in the detector height.

The drum specifications from the manufacturer claim that the diameter and height of the container are controlled to within 1cm of the nominal value, and the wall thickness is controlled to within 20% range.

The nuclides of interest for this site are Am-241 at 60 keV and depleted Uranium, using the Pa-234m daughter at 1001 keV.

There are 8 uncontrolled variables in this problem. Which ones will cause the largest variation in the efficiency? To answer that question the program was first run in the Sensitivity Analysis mode. The upper and lower boundary of each parameter is entered. The software varies these one at a time and computes the change from the base efficiency. The results are shown in Table 1. They are expressed as a percent variation from the reference position. In this case, it is the sample density that is the worst offender for both low and high energies, followed by container thickness but only for the low energy.

| Table 1 Sensitivity analysis results for 200 l drum | | |
|---|---|---|
| **Variable** | **% Variation at 60keV** | **% Variation at 1001 keV** |
| Drum diameter | +/- 2 | +/- 2 |
| Drum height | 0 | 0 |
| Drum wall thickness | +/- 29 | +/- 2 |
| Sample height | +/- 3 | +/- 1 |
| Sample density | +39 -28 | +31 -20 |
| Sample composition | +9 -6 | +/- 1 |
| Detector distance | +18 -14 | +18 -15 |
| Detector height | +0 -4 | +0 -2 |

What uncertainty is to be assigned to the combination of all these variables when counting an individual drum? It might appear to be quite bad. To answer this question the same data were used with the addition of the distribution parameter, with the software in the Uncertainty Analysis mode. The program created several hundred mathematical calibrations which were analyzed for standard deviation. Table 2 shows the 95% CL uncertainty estimate. The first row in the data is when all the parameters were allowed to vary as described before. From the sensitivity analysis, the user knew that density was a big factor, and wanted to hypothetically explore what would happen if he would more accurately determine it. The next row shows the result. Still not satisfied, the user found an ultrasonic probe to accurately measure the wall thickness, which removes that variable and gives the results in the last row.

| Table 2 Uncertainty analysis results for 200 l drum | | |
|---|---|---|
| **Condition** | **95% CL at 60keV** | **95% CL at 1001keV** |
| All items variable | 36% | 20% |
| After fixing the density | 30 | 14 |
| After fixing the container wall | 16 | 14 |

**Example 2: Best Way to Assay 200 Liter Non-homogeneous Drum *In-Situ***

This exercise will illustrate the usefulness of the IUE software to optimize a counting geometry, and then to assign an uncertainty to the efficiency calibration for that optimum geometry. In this scenario, there exist a large number of 200 liter drums filled with soil, at an average density of 1.2 g/cc. The radioactivity in the soil is known to be quite non-uniform. The radioactive soil is contained in grapefruit-sized nodules [hotspots] which are interspersed in non-radioactive soil of the same composition and density. The nuclides of interest have energies of 60 keV and 1000 keV. What is the optimum counting geometry if the purpose is to minimize the total uncertainty of the drum assay?

The largest contribution to the uncertainty is the number and location of the radioactive hotspots in the drum. Therefore all other items were considered “well-known” and were not varied. The

variables were simply the number of radioactive sources per drum. Situation one assumed that there were 1-5 radioactive hotspots per drum, all values equally probably, and all sources randomly distributed. Situation two assumed that there were 10-20 hotspots per drum.

The counting geometries that were investigated were distance from the side of the drum [20cm, and 100cm], counting from a single side or from two sides of the drum, fixed or vertically scanning detectors, and stationary or rotating drum.

Table 3 presents the results. For both energies, there are two different standard deviation values. The column labeled "%sdA" is the "normal" or arithmetic standard deviation of the efficiency values, expressed as a percent of the mean efficiency. The column labeled "sdG" is the geometric standard deviation, expressed as a factor of the geometric mean efficiency value. Whereas arithmetic standard deviations are added and subtracted from the mean, geometric standard deviations are multiplied and divided by the mean to yield the upper and lower confidence intervals.

**Table 3 Uncertainty for 200 Liter Drum with Hotspots**

| | | | 60 keV | | 1000 keV | |
|---|---|---|---|---|---|---|
| **distance** | **motion** | **hotspots** | **%sdA** | **sdG** | **%sdA** | **sdG** |
| 20cm | stationary | 1-5 | 256 | 28.00 | 81 | 2.44 |
| 20cm | scanning | 1-5 | 300 | 27.00 | 93 | 2.50 |
| 100cm | stationary | 1-5 | 184 | 18.50 | 60 | 2.02 |
| 20cm | rotate 180deg | 1-5 | 167 | 6.33 | 43 | 1.49 |
| 100cm | rotate 180deg | 1-5 | 115 | 3.94 | 25 | 1.28 |
| 20cm | rotating | 1-5 | 88 | 2.80 | 22 | 1.24 |
| 20cm | scan+rotate | 1-5 | 85 | 3.24 | 24 | 1.27 |
| 100cm | rotating | 1-5 | 89 | 3.30 | 23 | 1.26 |
| 20cm | stationary | 10-20 | 71 | 2.10 | 20 | 1.23 |
| 20cm | scanning | 10-20 | 70 | 2.31 | 22 | 1.25 |
| 100cm | stationary | 10-20 | 48 | 1.73 | 15 | 1.17 |
| 20cm | rotate 180deg | 10-20 | 46 | 1.63 | 11 | 1.12 |
| 100cm | rotate 180deg | 10-20 | 37 | 1.50 | 8 | 1.09 |
| 20cm | rotating | 10-20 | 30 | 1.40 | 8 | 1.08 |
| 20cm | scan+rotate | 10-20 | 28 | 1.36 | 8 | 1.08 |
| 100cm | rotating | 10-20 | 20 | 1.24 | 5 | 1.05 |
| | | | + - | × ÷ | + - | × ÷ |

In these analyses, especially at the 60 keV energy, the data are disproportionately distributed on the low energy side of the mean. A skewness evaluation indicates that the geometric standard deviation is the more proper one to use. As the standard deviation is improved, either by better geometry or higher energy or more hotspots, the skewness decreases and the two standard deviation measures approach each other. Both are presented here for comparison.

Several trends can be seen from the data.

- Low energies have considerably higher standard deviation than high energies.

- A detector up close at 20cm has the highest standard deviation;
- Scanning the detector up and down the full drum height doesn't improve the standard deviation very much for this situation where the radioactivity is randomly distributed, but might be useful if there were the potential for the hotspots to settle;
- Moving the detector back to 100 cm definitely helps, but also reduces the efficiency a factor of 2 at low energies and 4 at high energies, and therefore will increase the counting statistic component of the total propagated uncertainty;
- Keeping the detector at 20cm and rotating it 180 degrees half-way through the count is even better and retains the high efficiency;
- Rotating the drum 180 degrees half-way through the count with the detector at 100cm is somewhat better;
- Continuously rotating the drum during the count is the best, and it is somewhat better at 100cm than 20cm, but doesn't matter very much if the detector is scanning;
- Increasing the number of hotspots dramatically reduces the standard deviation for all geometries and for all energies.

The biggest impact on the efficiency uncertainty estimate is having more hotspots in the drum. At 60 keV, if there are 1-5 hotspots, the uncertainty is a factor of 28, while if a reasonable assumption can show that there are 10-20 hotspots in the drum, then the uncertainty is only a factor of 2 for the simple and efficient 20cm stationary count, and down to 30-40% with the better geometries. At high energies, even when up close, the uncertainty is a factor of 2-3 for the simple up-close stationary count, reducing down to a 5-10% with the better geometries.

As a commentary – is it really necessary to have a very low standard deviation? No – but what IS required is to accurately present the quality of the result so that the proper interpretation can be made. Using the above case as an example, if the measurement result for Am-241 at 60 keV was a factor of 100 below the "limit" then even the quick simple 20cm stationary measurement would be adequate to prove that the item is "acceptable". If most of the samples are like this, then this simple geometry is a good one to use. If then a few of the samples have results closer to the limit, then those few could be recounted in a more precise method – perhaps on a rotating platform at 100cm.

**Example 3: *In-situ* Measurement Uncertainty vs. Sampling Uncertainty**

Here it is assumed that field screening measurements have detected soil contamination that must be removed for disposal. These measurements also indicated that while most of the soil is not contaminated, basketball-sized clumps of contamination exist. The soil has been excavated and placed into a large vehicle, nominally 8'wide x 20' long and filled to 6' high. Two disposition alternatives exist – a low cost one for low concentration material, otherwise a high cost one. Which is the better method to assay the vehicle contents – *in-situ* measurements or sending a sample to an excellent laboratory?

***In-situ gamma spectroscopy assay method of total vehicle***

The field assay was assumed to be conducted using gamma spectroscopy. The detector was placed 1 meter from the vehicle. Six spectra were taken along the 20' side of the vehicle, 3 on one side of the vehicle and 3 on the other. The spectra were added together for a single analysis. The vehicle was assumed to contain 10, 30, 100, 300, or 1000 hotspots, with the rest of the soil uncontaminated. The radioactive volume percentage of the total volume thus varied from 0.31% to 31%. In a similar manner as in the preceding analysis, many randomly generated calibration models were generated and the efficiency uncertainty evaluated at 100, 200, 600, and 1000 keV. **Table 4 and Figure 3** show the results. For the 10 hotspot per vehicle situation, the measurement uncertainty is very high [a factor of 13] for low energy nuclides, as expected, but decreases to a factor of 1.6 for high energy nuclides. As the number of hotspots and therefore the percentage volume occupied by those hotspots increases, the uncertainty decreases, to where it is negligible compared to other uncertainties at the 300-1000 hotspot range.

**Table 4 Vehicle *in-situ* measurement standard deviation**

| Number of hotspots | % Geometric SD | | | | Hotspot %volume |
|---|---|---|---|---|---|
| | 100 keV | 200 keV | 600 keV | 1000 keV | |
| 10 | 1300 | 660 | 280 | 160 | 0.31 |
| 30 | 213 | 144 | 88 | 63 | 0.92 |
| 100 | 48 | 40 | 31 | 25 | 3.1 |
| 300 | 22 | 18 | 14 | 11 | 9.2 |
| 1000 | 7.2 | 5.1 | 3.4 | 2.5 | 31 |

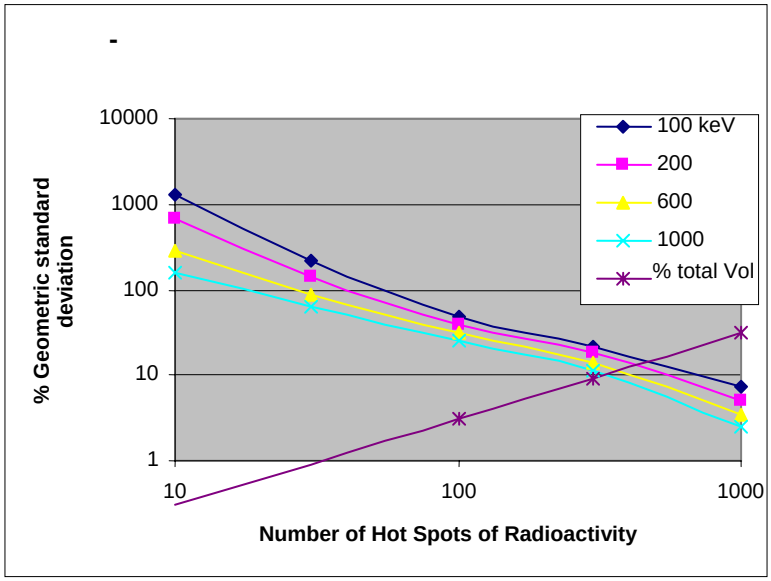


**Figure 3 Truck of Non-Uniform Soil *In-situ* measurements**

*Vehicle sampling uncertainty*

For laboratory analysis, it was assumed that 40 lbs of soil would be extracted and sent back to the laboratory for homogenization and analysis. Two types of sampling methods can be examined: core samples (a randomly located cylinder from top to bottom), and a "grab" sample (a randomly located sphere). Four different sampling strategies were evaluated: 15 each 1" diameter cores, 4 each 2" diameter cores, 15 each 5" diameter spheres, and 4 each 8" diameter spheres. The samples were randomly taken and the concentration of radioactivity in the composite sample compared to the concentration of radioactivity in the container. This process was repeated a large number of times and the uncertainty computed, as presented in **Table 5 and Figure 4.**

**Table 5 Vehicle sampling standard deviation**

| Number of hotspots | % Arithmetic SD | | | |
|---|---|---|---|---|
| | 1"Cx15 | 2"Cx4 | 5"Sx15 | 8"Sx4 |
| 10 | 156 | 298 | 368 | 539 |
| 30 | 88 | 158 | 185 | 292 |
| 100 | 49 | 82 | 109 | 180 |
| 300 | 25 | 46 | 57 | 86 |
| 1000 | 11.5 | 19.5 | 28.2 | 34.4 |

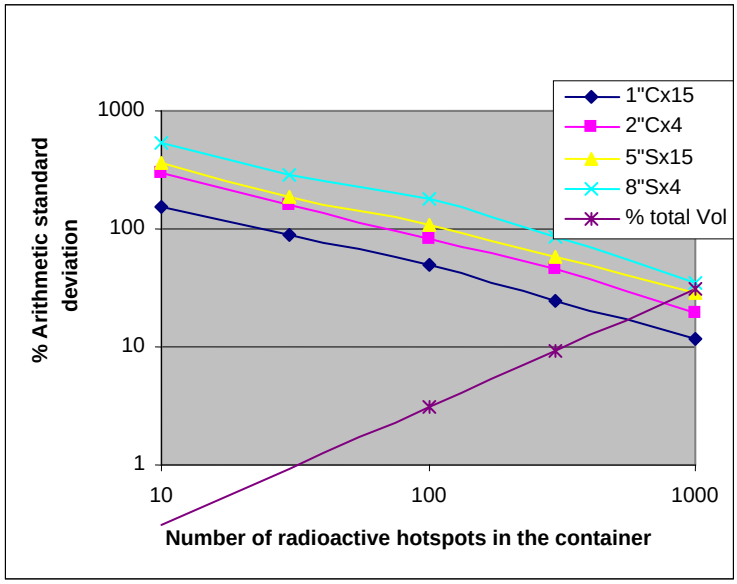


**Figure 4 Truck of Non-Uniform Soil - Sampling**

As expected, the sampling uncertainty is high for the vehicles with few hotspots and gets much lower when there are more hotspots. Increasing the number of hotspots reduces the uncertainty by approximately the square root of the increase. The data also indicates that the more discrete sub-samples per vehicle that are composited together, the lower the uncertainty. Increasing the number of sub-samples from 4 to 15 reduces the uncertainty approximately a factor of 2.

Somewhat unexpectedly, going from a spherical sampling method to a cylindrical full-height sampling method, but keeping the number of samples the same also reduces the sampling uncertainty a factor of 2.

***Comparison between in-situ assay and sampling uncertainties***

So, which is better -- *in-situ* assay of the vehicle, or extracting and assaying a portion? For most all situations at 30 hotspots and more, the *in-situ* uncertainty is less than the sampling uncertainty. This is even more so for high energies, and for the worse-performing sampling strategies. However, for the 10-30 hotspot range, both methods have a quite high uncertainty [hundreds of percent] and the choice might depend upon sampling strategy and gamma energy. However, any practical sampling strategy of a sparsely populated non-uniform material will frequently fail to extract any part of the radioactivity, and therefore give a result of zero for the laboratory analysis – falsely indicating that the container has no radioactivity. Those figures are shown in **Figure 5.** For the 10-30 hotspot range, the samples have 50% of more chance of zero radioactivity. This should probably lead one to conclude that the *in-situ* technique is to be preferred, all other things being equal.

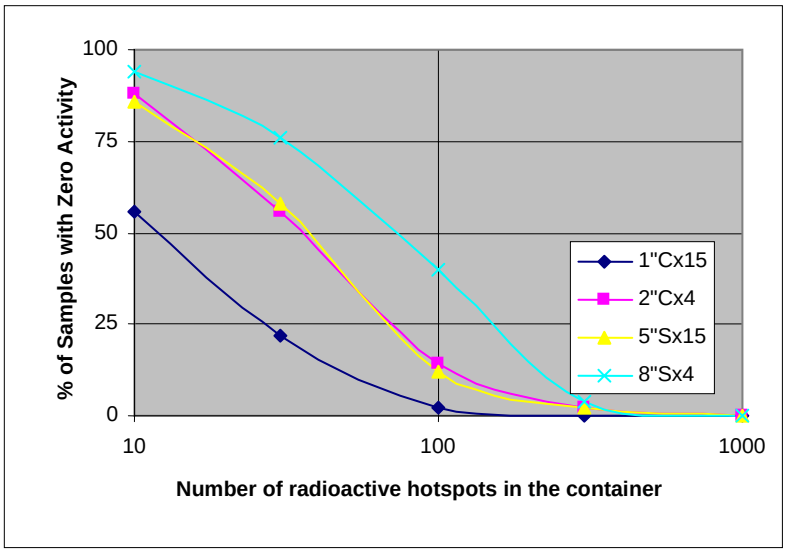


**Figure 5 Fraction of samples with Zero activity**

## CONCLUSION

This paper presents a brief description of the soon-to-be released ISOCS Uncertainty Estimator (IUE). The software builds upon the basic ISOCS software, which calculates the gamma-ray efficiency for a particular geometry based on input parameters (e.g. sample dimensions, densities, etc.) provided by the user. The IUE estimates the contribution to the efficiency uncertainty due to the uncertainties on the individual input parameters. It performs this uncertainty propagation numerically by probabilistically varying the input values. Three modes of operation have been discussed. The first mode estimates the total efficiency uncertainty for the measurement geometry by simultaneously varying all of the input values. The second mode estimates the uncertainty contribution from each of the input parameters separately. This mode is especially useful as a diagnostic tool to determine where to concentrate effort towards reducing the overall measurement uncertainty. The third mode can estimate sampling uncertainty when the radioactivity is distributed in a non-uniform manner. These functions are very powerful tools; they allow quick and easy uncertainty analyses that were previously very time-consuming and costly. They also allow hypothetical counting conditions to be evaluated for assay quality during the design process.

When determining the total uncertainty of an item there are many components that must be considered and propagated to the final Total Uncertainty. One of those items is the non-uniformity uncertainty. It is shown that the IUE software is a useful tool to examine the non-uniform contribution to uncertainty for various hypothetical analysis scenarios in order to choose the most appropriate method for the job under consideration.

For a typical measurement scenario, the uncertainty is calculated for both a total sample gamma spectroscopy measurement, and for a sampling process. It is shown that the larger the numbers of samples extracted, and the larger the sample volume extracted, the lower the uncertainty. For this scenario, it is shown that the sampling uncertainty is either greater than the total sample gamma spectroscopy uncertainty, or has other undesirable characteristics; therefore the total measurement method is preferred. All other scenarios analyzed have also reached the same conclusion. [4] That is not to say that total gamma spectroscopy measurements are always better than sampling and careful laboratory assay of the sample. But, it is concluded that for situations where the material cannot be assured to be totally homogeneous, careful consideration should be given to determination and reporting of the sampling error to the end user of the data. Replicate sampling and analysis would be one way of determining the sampling error. Multiple total sample measurements of the same sample in a random manner would be a way to evaluate the total sample measurement uncertainty. Multiple *in-situ* measurements viewing different locations of the sample would be another method.

At present the software is undergoing internal Quality Assurance testing and validation. When complete, the software will be available as a part of the ISOCS mathematical efficiency calibration software suite.

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