Further Development of an ISOCS – based Advanced In Situ Gamma Spectrometry Services Tool for Waste Measurements - 17452

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ABSTRACT

CANBERRA's In Situ Object Counting System is an established tool used for gamma spectrometry allowing a physical representation of complex geometries and mathematical calculation of the calibration function while avoiding the need for radioisotope standards. The ISOCS Uncertainty Estimator tool can be used to calculate defensible systematic calibration uncertainties. However the uncertainties depend on knowledge of the properties of the item being measured and for poorly characterized materials these can be large, often leading to large costs for waste sentencing.

An ISOCS–based advanced *in-situ* gamma spectrometry services tool has been developed to reduce those uncertainties. This system is based on generating and comparing a range of candidate geometry models that yield figures of merit indicative of improved consistency between modelled data and available diverse measurement data.

The approach and results of initial performance testing have previously been published, demonstrating an analysis procedure and enhanced accuracy for measurement of a low density 200 litre waste drum, based on measurements with known sources placed at different positions. It was shown how the accuracy of assay of Am-241 in a light matrix can be significantly improved.

Further analysis has now been performed, with reference to measurements of a second drum, containing a standard matrix of higher density, and with a multiple radionuclide line source (Ba-133, Cs-137, Eu-152 and Am-241). These measurements represent a more challenging waste assay scenario, corresponding to potentially much larger assay uncertainties. Our results show how the assay uncertainty can be reduced, by careful application of AIGS, from relative values of the order of 100% to a few 10's of %. Furthermore, we demonstrate, through extended analysis of the test drum data, how an AIGS measurement program can be optimized to reduce the number of required measurement positions substantially. This paper describes these new results with comment on their importance and potential application for real waste assay projects.

INTRODUCTION

CANBERRA's In Situ Object Counting System (ISOCS) [**1**,**2**] is a well-established numerical calculation tool used to derive absolute efficiencies of gamma ray detectors when performing quantitative evaluation of nuclear material activities by performing spectrometric assays. The ISOCS application uses pre-set geometry templates to describe a given measurement geometry. To capture the specific geometry of the measurement conditions, those rely on the discrete entry of key parameters. Efficiency results derived by ISOCS therefore carry some intrinsic systematic errors associated with the validity of the assumptions taken to describe the measured item/measurement geometry. Conscious of this limitation Canberra has extended the ISOCS capability to support an ISOCS Uncertainty Estimator [**3**,**4**]. This automated application allows the user to specify distributions of values for all parameters used in a traditional ISOCS template and automatically sample those through multiple ISOCS calculations. The result is a powerful tool to establish the importance of key uncertain parameters on the accuracy of ISOCS efficiency results. ISOCS-IUE also allows calculating the overall distribution of efficiency results derived from those multiple ISOCS calculations, thus determining the overall modelling systematic uncertainty associated with an ISOCS efficiency calibration.

Although being able to reliably calculate the systematic uncertainty associated with an ISOCS efficiency calibration may be an advantage for some measurement applications, the real gain in terms of cost of waste disposal clearly lies in being able to reduce these uncertainties. This could be achieved by being able to identify which ISOCS models, generated by IUE, exhibit the best consistency between modelled data/derived activities and the available measurement data.

The Advanced *in-situ* Gamma Spectrometry (AIGS) services offered by Canberra involve performing an ISOCS geometry optimisation aimed at improving the accuracy of the measurement results. For each generated model the AIGS algorithms calculate a set of Figures of Merit (FoM), which allow the ranking of each model's efficiency results against the consistency, or inconsistency, of the specified measurement data. For example, in the case of the measurement of a radionuclide emitting several gamma-rays the Linear Activity Consistency Evaluation (LACE) which looks at the consistency of the derived nuclide activity across all energies can be used as a FoM to evaluate the validity of the shape of the ISOCS efficiency curve. The AIGS analysis can also be performed by evaluating the consistency of the ISOCS results obtained when analysing multiple spectra collected when measuring the same item under different fields of view (sides, below, above…)

The AIGS approach is based on trying to identify models within physical parameter ranges representing the possible spread of real values that show a "best-fit" with the observed measurement results. It is therefore perfectly conceivable that, within the set modelling assumptions, several different models may return consistent answers through the calculated FoM, yet yielding a spread of activity results. This is taken into account in the AIGS analysis by reporting an uncertainty result on the "best optimized efficiency" that is illustrative of the level of convergence of the optimisation.

The AIGS analysis supports ISOCS model generation using a numerical method based on the SIMPLEX technique. This allows a very significant reduction of the computation times that would otherwise be required if using only a pure random sampling (known as “Best Random Fit”) of the model’s variable parameter space [**5**].

Mirion Technologies has performed several exercises to evaluate the AIGS capabilities and demonstrate the practical benefits that can be realised [**6**, **7**].

Early research has focussed on laboratory applications and also 200 litre drum measurements using Eu-152 point sources, which represent idealised sources for physics testing [**8**]. More recent efforts have been directed towards applications in waste management, such as those reported last year for the measurements and AIGS analysis for a set of measurements using a 200 litre waste drum filled with a low-density matrix [**9**]. This work focussed on Am-241 assay, representative of typical Very low level plutonium assay in low density soft wastes, and showed overall some degree of improvement in the accuracy of the assay results.

The present work is an extension of the results reported to date for a set of measurements performed using a 200 litre drum filled with higher density matrix and a multi-energy line source positioned at various positions in the drum. The work details the empirical work performed at the Harwell facility in 2015 and their subsequent analysis using the AIGS approach.

EMPIRICAL WORK

A standard 200 litre (≈55 Gal.) waste drum, shown in Figure 1, filled with particle board (density 0.681 g.cm^{-3}), was extensively measured. The diameter of the drum is 570 mm and the height of the drum is 870 mm.

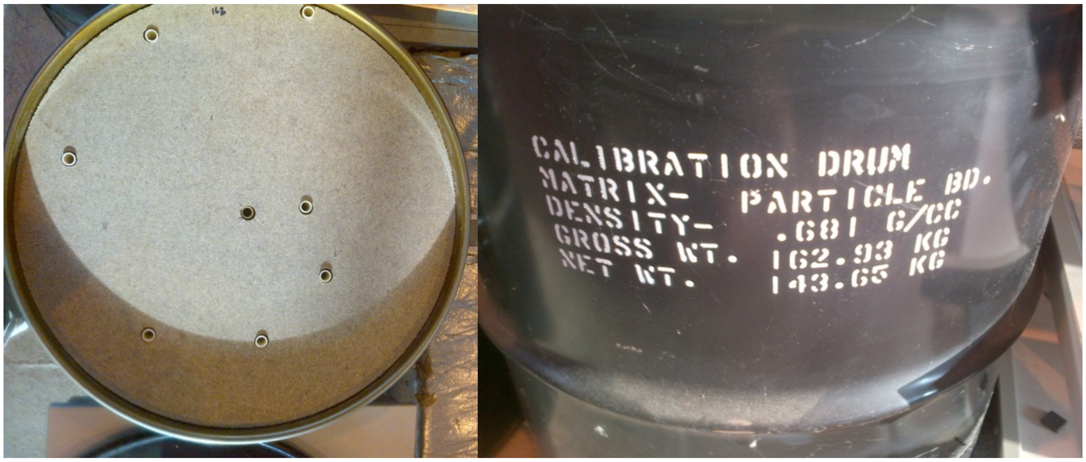


Figure 1 Side and Top view of the drum

A well characterised short line source, ≈ 280 mm long, containing uniformly distributed activities of Am-241, Ba-133, Cs-137 and Eu-152, was placed in the drum inserts. Measurements were made with the source at 3 different heights (Top/Height 1, Middle/Height 2 and Bottom/Height 3) and 3 different radial positions: one at the edge of the drum (Radial Position c), one at a mid-radial (Radial Position b) and the last in the centre of the drum (Radial Position a). These positions are shown in Figure 2.

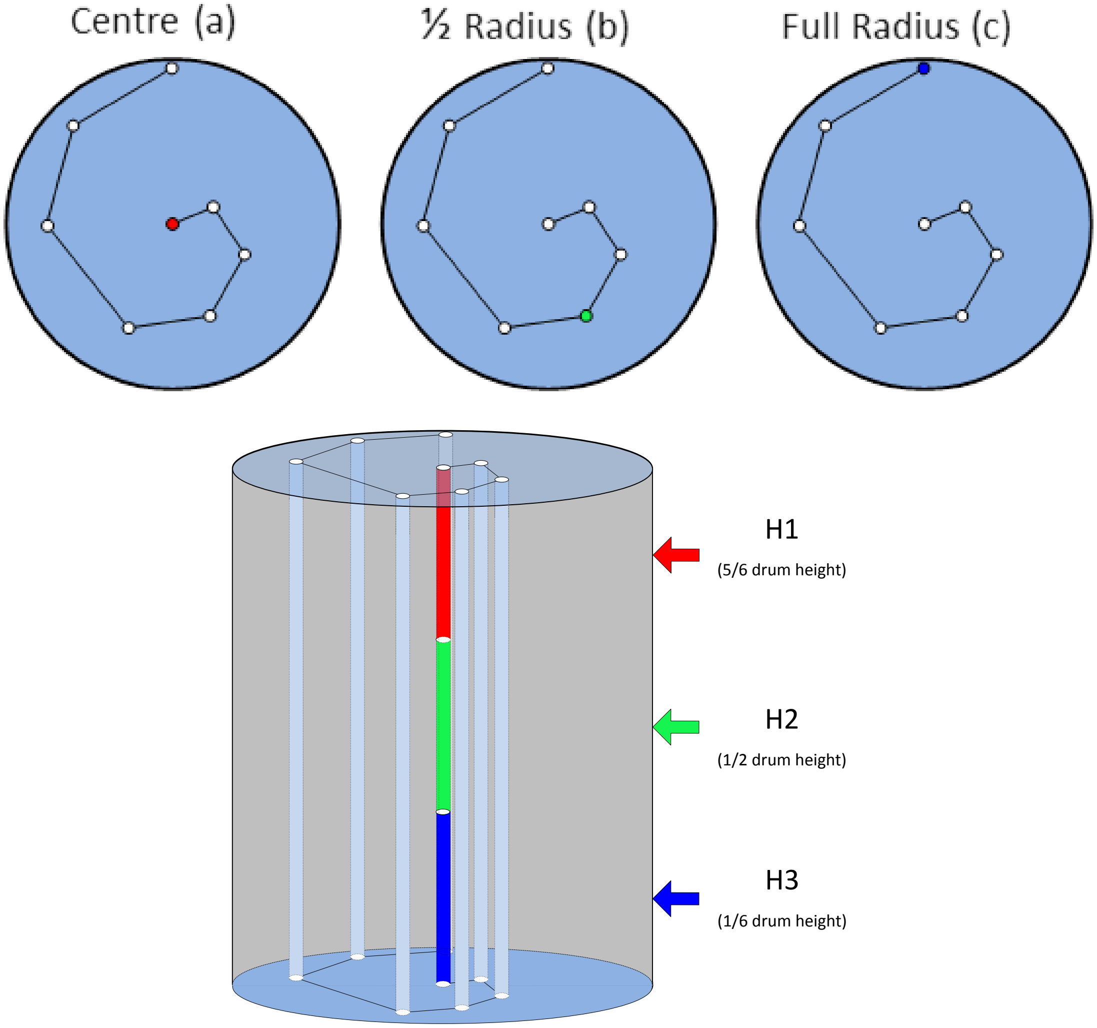
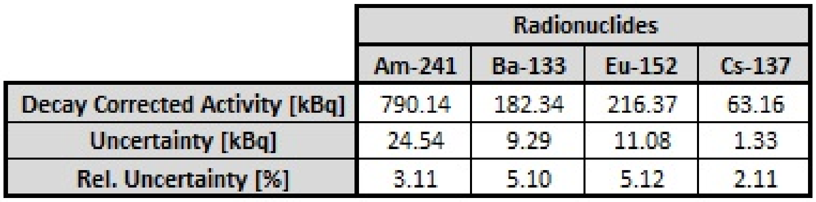


Figure 2 Representation of the source localisation in the waste drum and angular and vertical positions of the HPGe detector relative to the drum / source

The drum was static during each measurement and rotated (by 45 degrees for each step) between acquisitions to generate a different counting geometry. Each source position could therefore produce up to 24 spectra (8 angular positions, 3 detector heights as shown in Figure 2), each representing 2000 seconds of live data acquisition. Overall, this data set probably holds far more information than would reasonably be expected to be available when assaying a single 200 litre waste drum. However, it constitutes a good set to evaluate the sensitivity of the AIGS approach to the availability of measured data. The empirical data set collected during the available time and used in the present work consisted of 6 spectral sets, 1a – 3 spectra, 1b – 24 spectra, 1c -24 Spectra, 2a – 12 spectra, 2b – 24 spectra, 2c -19 spectra. As such, it was possible to study the performance of AIGS when using different combinations of spectra, ranging from just 3 spectra to 24 spectra. This allows an evaluation to be made of the impact of using different multiples of spectra in the AIGS process. This is an instructive evaluation as the higher the number of measurements, the greater the measurement-time required, subsequently the analysis becomes more time-consuming, and the whole process becomes more costly, while the gain in the quality of the results may be minimal in a real-life situation.

The measurements were made with an ISOCS characterised Broad-Energy Germanium (BEGe-3825) and a 180° 50-mm thick Lead collimator. The electronics acquisition chain was based on a Canberra Model 2002 RC pre-amplifier and a Canberra Lynx multichannel analyser. The front face of the detector end-cap was positioned at 70 cm of the drum edge. The short line source contained 4 different nuclides with the evaluated activity listed in TABLE I.

TABLE I. Reference activity and 1-sigma uncertainties associated with the line source when decay corrected to the measurement date



	Radionuclides			
	Am-241	Ba-133	Eu-152	Cs-137
Decay Corrected Activity [kBq]	790.14	182.34	216.37	63.16
Uncertainty [kBq]	24.54	9.29	11.08	1.33
Rel. Uncertainty [%]	3.11	5.10	5.12	2.11

ISOCS MODELLING

Geometry

Standard ISOCS models of the drum were developed using the complex cylinder template, as shown in Figure 3. These models, one for each detector position, assume uniform distribution of the source activity in the particle board matrix. A secondary model introducing a small “hot spot” concentrating all the activity as a point source was also developed to perform ISOCS-IUE and AIGS analysis. All ISOCS models assume the same matrix material composition and reference density of 0.681 g.cm^{-3}.

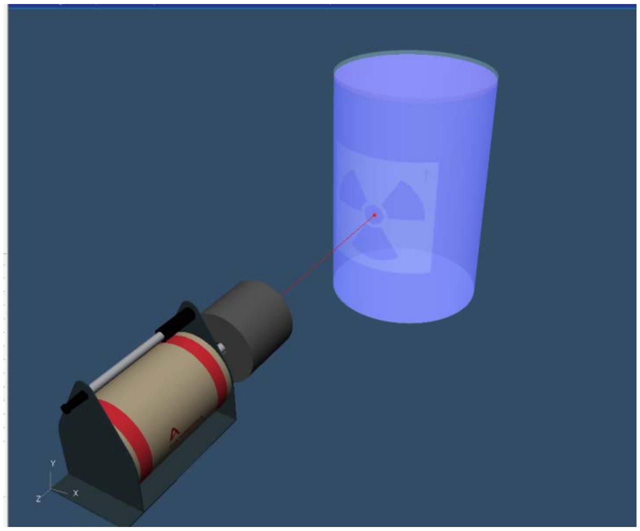


Figure 3 Standard ISOCS model of the measurement geometry with the detector in the H2 position

BASELINE AIGS ANALYSIS

To perform an AIGS analyses, the 6 sets of spectra acquired during the empirical work have been pre-analysed to identify nuclides in these spectra. This preliminary step was performed using a nuclide library defining the 4 nuclides present in the line source. However, despite the 2000 seconds data acquisition time, a significant number of spectral analyses did not identify Am-241 as being present in the drum. The AIGS optimisation process can be performed on a nuclide by nuclide basis. However, in the present work, and to limit the amount of work, it was configured to optimize the modelled geometry based on a co-location assumption for all detected nuclides. The lack of information for the Am-241 in some data sets meant that the AIGS optimisation was only performed for Ba-133 (276, 303, 356, 386 keV), Cs-137 (662 keV) and Eu-152 (121, 244, 344, 411, 443, 779, 867, 964, 1085, 1112, 1408 keV).

Note nevertheless, that Am-241 quantifications were possible, when detected, using the “best” AIGS efficiency data, based on the AIGS optimisation for Ba-133, Cs-137 and Eu-152 (all assumed to be co-located with Am-241) and this data is reported in the following sections.

The first AIGS optimisation was performed with all available measurement data. The optimisation was set-up to limit the unknown modelling parameters simply to the position of a single hot spot, anywhere in the waste drum. This of course is not necessarily representative of how AIGS would be used to quantify the activity of an uncharacterised waste drum, but it represents a reasonable baseline example showing the AIGS capability at honing onto the right activity evaluation and is considered a reasonable approximation for the present tests where the activity is within a small line source. The ISOCS geometry optimisation was run using both “Best Random Fit” (BRF), in other words - pure random sampling, and the “Simplex” algorithm. The optimisation was performed only on the basis of a multi-spectra FoM.

Computation times for the BRF method ranged from several hours up to 24 hours. The Simplex methodology never exceeded 3 hours with most optimisations completed within 1 hour.

Best-fit efficiency results computed by the AIGS application for each detector position were subsequently used to analyse the measured spectra. For Eu-152 and Ba-133 activity determination the overall results were obtained using individual line activities combined as a weighted average using the inverse square of the relative uncertainty of each line activity as the weighing factor.

Figure 4 shows graphically the individual line results for Eu-152 obtained for the AIGS optimisations (BRF and Simplex) and when using “standard” ISOCS Models (as shown in Figure 3). The results shown cover the 6 line source positions within the waste. The “standard” ISOCS results represent the use of a basic model in which the activity is assumed to be uniformly distributed throughout the drum and the activity is calculated by averaging over all the detectors. This approach represents standard practice with conventional ISOCS techniques where no information is available on the spatial distribution of activity. From these computations one can observe the following:

- BRF and Simplex optimisation results are generally consistent with each other for all cases where consistent data was obtained for each method.
- AIGS results tend to slightly overestimate the Eu-152 activity in the drum, especially when the source was located at the “Edge” of the drum.
- Standard ISOCS results perform poorly for this measurement set-up and AIGS provides a significant improvement in accuracy.

Both AIGS optimisations were performed for all measured spectra. If results are not shown in Figure 4, it indicates that for these particular cases (1a for BRF, 1c for Simplex) the AIGS results showed inconsistent activity evaluations between evaluated “best” models. By this, it is understood that the efficiency data resulting from the AIGS analysis showed very large relative uncertainties (of the order of 80 to 150%), indicating that the models judged as optimum resulted in very different efficiency results. In other words AIGS optimisations, using and comparing both computational methodologies (BRF and Simplex), can be used to infer the level of reliability of the optimised efficiency models.

Although the method of approximating the activity distribution to be uniform within the drum, as shown in the standard ISOCS results, shows very poor performance, especially when the line source is placed at the centre of the drum, it is to be noted that these results were obtained from the averaging of a number of static measurements. A standard ISOCS measurement approach would have been conducted by continuously rotating the drum while performing data acquisition. This would have provided a single “homogenised” response spectrum, thus potentially improving slightly the standard ISOCS results when compared to the data results shown in Figure 4. However this would not give an improvement approaching what can be achieved by AIGS.

Overall activity results for all four nuclides for the 6 source positions are shown in Figure 5.

The 6 plots show graphically how the AIGS analysis improves significantly the baseline assay results independently of the line source position in the drum.

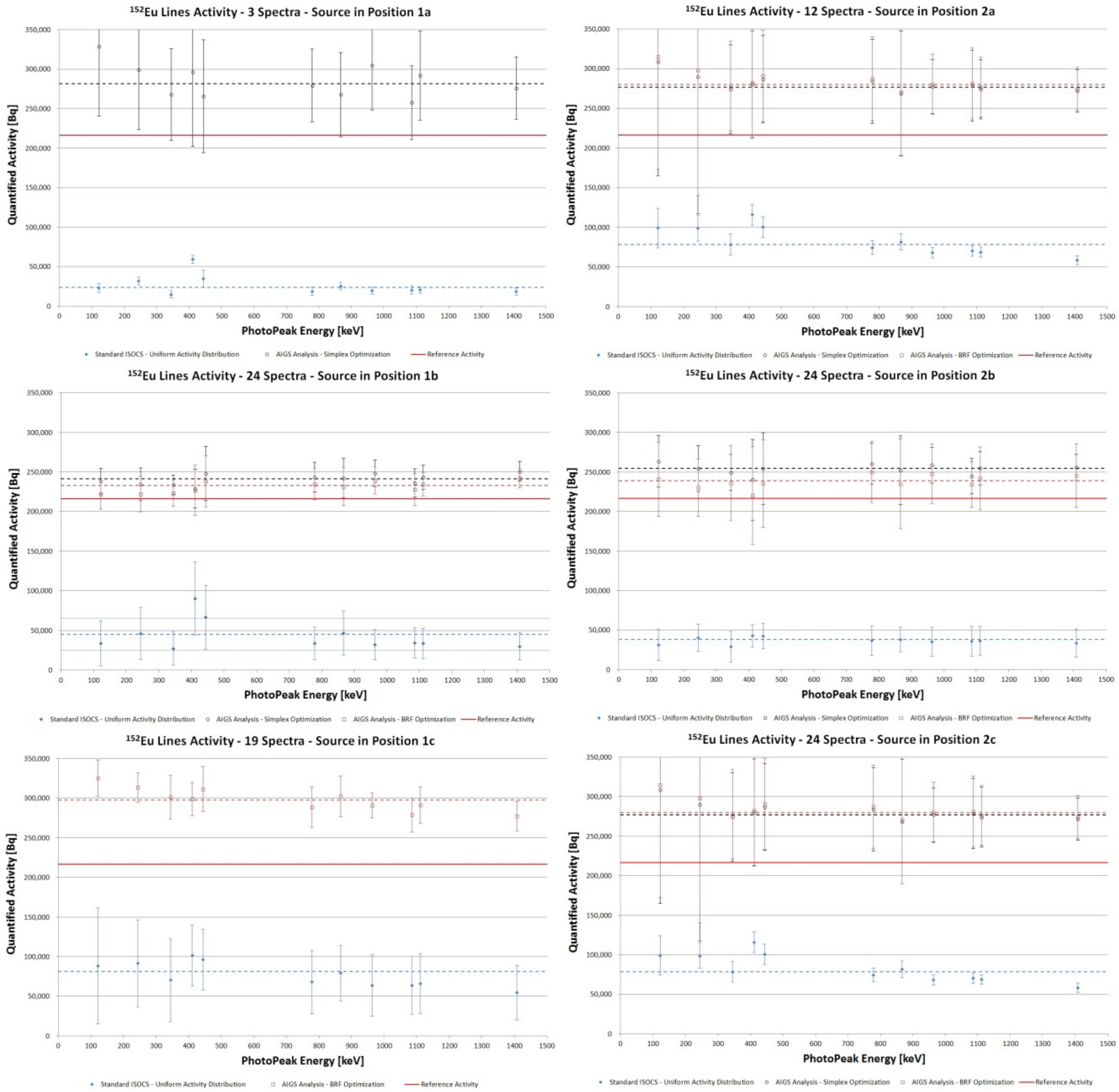
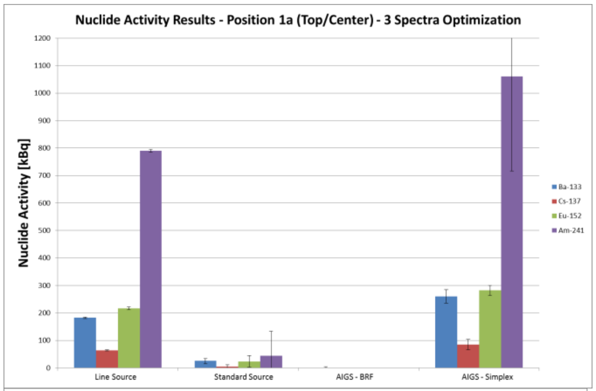
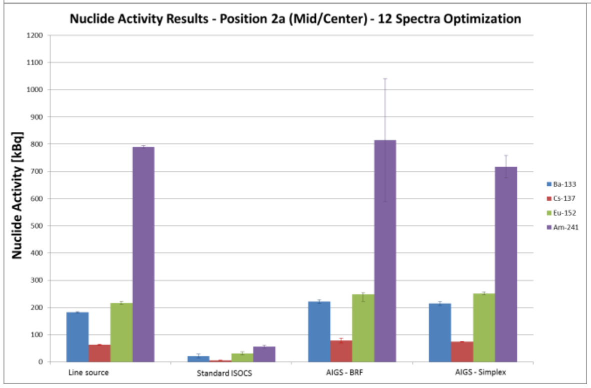


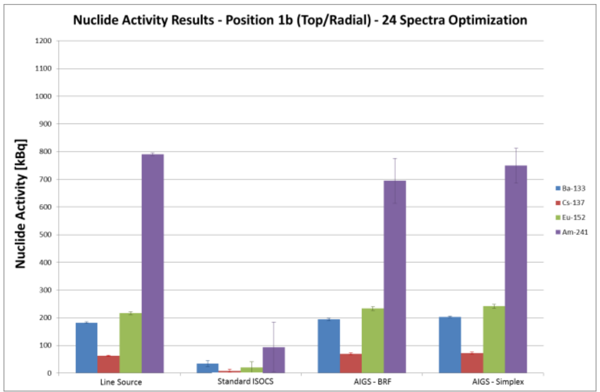
Figure 4 ISOCS/AIGS analysis results for Eu-152 lines for 6 source positions within the drum

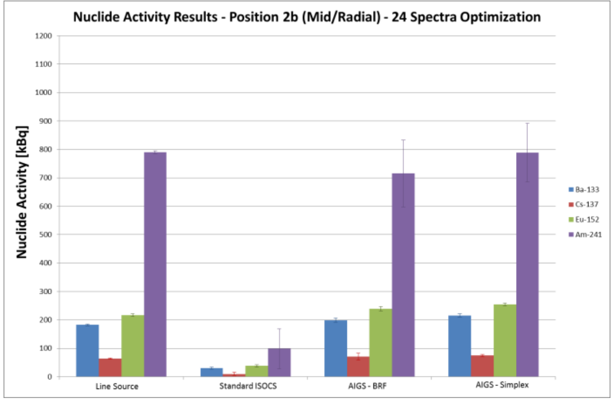
Uncertainties on the overall nuclide activities were derived by calculating a weighted standard deviation from the individual spectrum results.

The graphs, shown in Figure 5, show that the AIGS method yields significant improvement on the overall accuracy of the assay. AIGS results obtained when the source was positioned at a radial position show good agreement with the reference data of the line source, as shown on the left side of each plot. Source configurations where the source is positioned in the centre of the drum show a tendency for AIGS results to slightly over-estimate the reference values, although within the stated uncertainties.









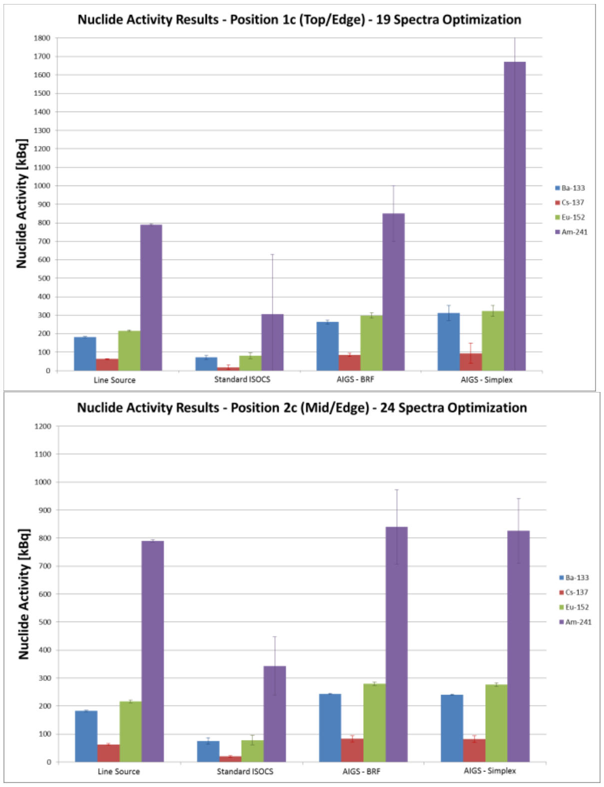


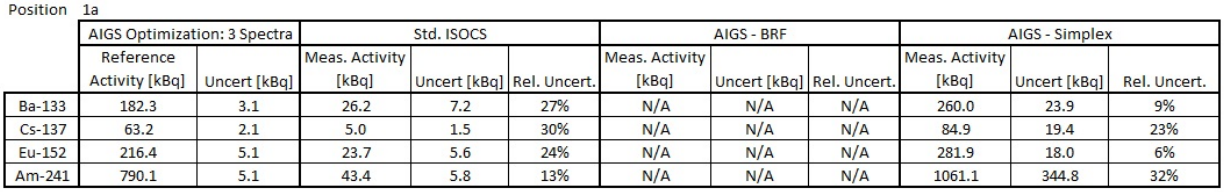
Figure 5. Graphical representation of the overall nuclide activity quantifications using ISOCS and AIGS analyses for 6 source positions

The overall assay results and differences relative to the line source activity are given in TABLE II and TABLE III respectively. In TABLE III, a purely indicative colour coding has been used to visualise the cases showing large discrepancies (larger than a factor 2, shown in Red), significant discrepancies (more than 20 % relative difference, shown in Yellow) and relative small relative difference (less than 20 % relative difference, shown in green).

FURTHER AIGS ANALYSIS

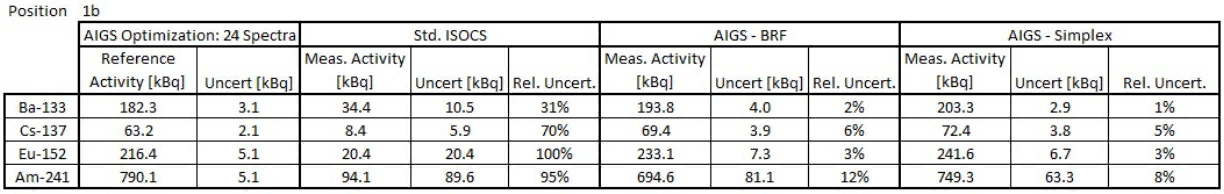
The results shown in the previous section have shown that both AIGS analyses performed well under the conditions and amount of data available to perform the optimisation. To further evaluate the AIGS approach, complementary work was performed to study the reliability of the obtained results with changes in the amount of available measured data used to perform the AIGS geometry optimisation.

TABLE II. Overall Nuclide Activity Results for the 6 Source positions.



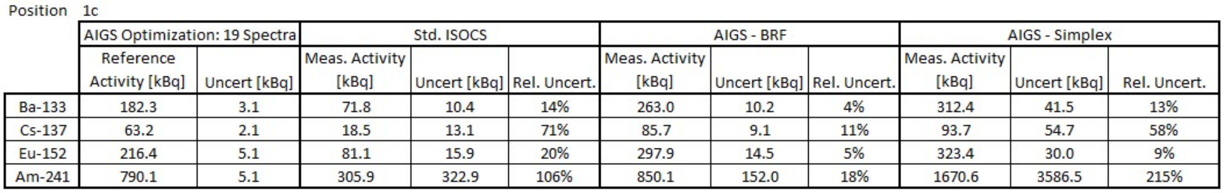
Position 1a

	AIGS Optimization: 3 Spectra		Std. ISOCS			AIGS - BRF			AIGS - Simplex		
	Reference Activity [kBq]	Uncert [kBq]	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.
Ba-133	182.3	3.1	26.2	7.2	27%	N/A	N/A	N/A	260.0	23.9	9%
Cs-137	63.2	2.1	5.0	1.5	30%	N/A	N/A	N/A	84.9	19.4	23%
Eu-152	216.4	5.1	23.7	5.6	24%	N/A	N/A	N/A	281.9	18.0	6%
Am-241	790.1	5.1	43.4	5.8	13%	N/A	N/A	N/A	1061.1	344.8	32%



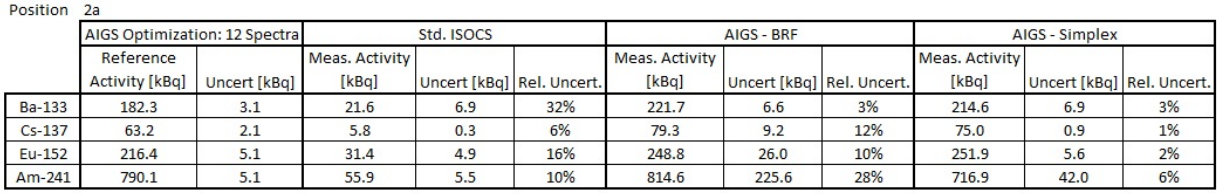
Position 1b

	AIGS Optimization: 24 Spectra		Std. ISOCS			AIGS - BRF			AIGS - Simplex		
	Reference Activity [kBq]	Uncert [kBq]	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.
Ba-133	182.3	3.1	34.4	10.5	31%	193.8	4.0	2%	203.3	2.9	1%
Cs-137	63.2	2.1	8.4	5.9	70%	69.4	3.9	6%	72.4	3.8	5%
Eu-152	216.4	5.1	20.4	20.4	100%	233.1	7.3	3%	241.6	6.7	3%
Am-241	790.1	5.1	94.1	89.6	95%	694.6	81.1	12%	749.3	63.3	8%



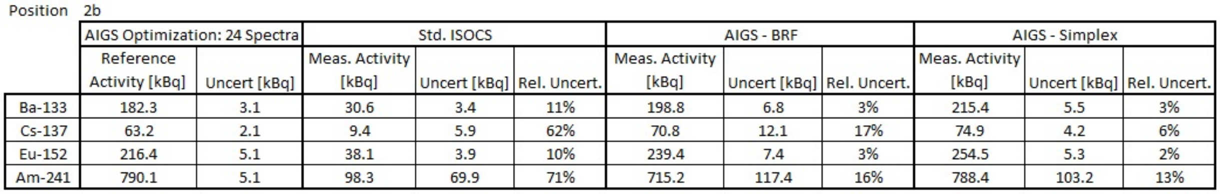
Position 1c

	AIGS Optimization: 19 Spectra		Std. ISOCS			AIGS - BRF			AIGS - Simplex		
	Reference Activity [kBq]	Uncert [kBq]	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.
Ba-133	182.3	3.1	71.8	10.4	14%	263.0	10.2	4%	312.4	41.5	13%
Cs-137	63.2	2.1	18.5	13.1	71%	85.7	9.1	11%	93.7	54.7	58%
Eu-152	216.4	5.1	81.1	15.9	20%	297.9	14.5	5%	323.4	30.0	9%
Am-241	790.1	5.1	305.9	322.9	106%	850.1	152.0	18%	1670.6	3586.5	215%



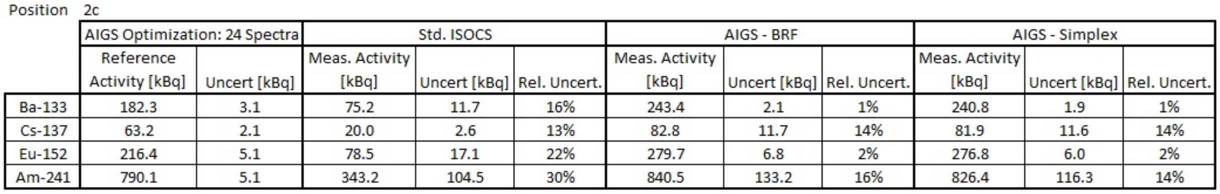
Position 2a

	AIGS Optimization: 12 Spectra		Std. ISOCS			AIGS - BRF			AIGS - Simplex		
	Reference Activity [kBq]	Uncert [kBq]	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.
Ba-133	182.3	3.1	21.6	6.9	32%	221.7	6.6	3%	214.6	6.9	3%
Cs-137	63.2	2.1	5.8	0.3	6%	79.3	9.2	12%	75.0	0.9	1%
Eu-152	216.4	5.1	31.4	4.9	16%	248.8	26.0	10%	251.9	5.6	2%
Am-241	790.1	5.1	55.9	5.5	10%	814.6	225.6	28%	716.9	42.0	6%



Position 2b

	AIGS Optimization: 24 Spectra		Std. ISOCS			AIGS - BRF			AIGS - Simplex		
	Reference Activity [kBq]	Uncert [kBq]	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.
Ba-133	182.3	3.1	30.6	3.4	11%	198.8	6.8	3%	215.4	5.5	3%
Cs-137	63.2	2.1	9.4	5.9	62%	70.8	12.1	17%	74.9	4.2	6%
Eu-152	216.4	5.1	38.1	3.9	10%	239.4	7.4	3%	254.5	5.3	2%
Am-241	790.1	5.1	98.3	69.9	71%	715.2	117.4	16%	788.4	103.2	13%



Position 2c

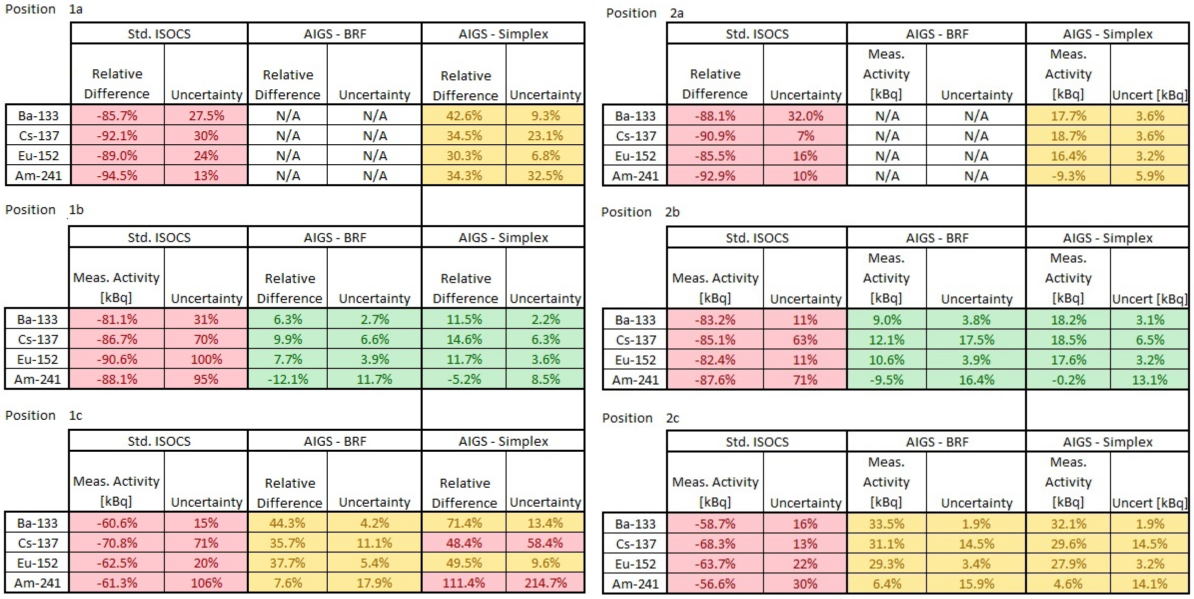
	AIGS Optimization: 24 Spectra		Std. ISOCS			AIGS - BRF			AIGS - Simplex		
	Reference Activity [kBq]	Uncert [kBq]	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.	Meas. Activity [kBq]	Uncert [kBq]	Rel. Uncert.
Ba-133	182.3	3.1	75.2	11.7	16%	243.4	2.1	1%	240.8	1.9	1%
Cs-137	63.2	2.1	20.0	2.6	13%	82.8	11.7	14%	81.9	11.6	14%
Eu-152	216.4	5.1	78.5	17.1	22%	279.7	6.8	2%	276.8	6.0	2%
Am-241	790.1	5.1	343.2	104.5	30%	840.5	133.2	16%	826.4	116.3	14%

Measured Data Availability

To evaluate the impact of the availability of measured data (in this case, corresponding to number of measurement positions) on the quality of the resulting optimised efficiency fits, the AIGS analysis was repeated with 6, 4 and 2 measured spectra, separately. The list of spectra retained for this study and the corresponding angular position/height of the detector are shown below:

- 6 Spectra: H1-P3, H1-P7, H2-P1, H2-P5, H3-P3, H3-P7
- 4 Spectra: H1-P3, H1-P7, H2-P1, H2-P5
- 2 Spectra: H1-P1, H3-P5

TABLE III. Relative Difference between Nuclides Line Source Activities and ISOCS/AIGS quantifications



Position 1a

	Std. ISOCS		AIGS - BRF		AIGS - Simplex	
	Relative Difference	Uncertainty	Relative Difference	Uncertainty	Relative Difference	Uncertainty
Ba-133	-85.7%	27.5%	N/A	N/A	42.6%	9.3%
Cs-137	-92.1%	30%	N/A	N/A	34.5%	23.1%
Eu-152	-89.0%	24%	N/A	N/A	30.3%	6.8%
Am-241	-94.5%	13%	N/A	N/A	34.3%	32.5%

Position 2a

	Std. ISOCS		AIGS - BRF		AIGS - Simplex	
	Relative Difference	Uncertainty	Meas. Activity [kBq]	Uncertainty	Meas. Activity [kBq]	Uncert [kBq]
Ba-133	-88.1%	32.0%	N/A	N/A	17.7%	3.6%
Cs-137	-90.9%	7%	N/A	N/A	18.7%	3.6%
Eu-152	-85.5%	16%	N/A	N/A	16.4%	3.2%
Am-241	-92.9%	10%	N/A	N/A	-9.3%	5.9%

Position 1b

	Std. ISOCS		AIGS - BRF		AIGS - Simplex	
	Meas. Activity [kBq]	Uncertainty	Relative Difference	Uncertainty	Relative Difference	Uncertainty
Ba-133	-81.1%	31%	6.3%	2.7%	11.5%	2.2%
Cs-137	-86.7%	70%	9.9%	6.6%	14.6%	6.3%
Eu-152	-90.6%	100%	7.7%	3.9%	11.7%	3.6%
Am-241	-88.1%	95%	-12.1%	11.7%	-5.2%	8.5%

Position 2b

	Std. ISOCS		AIGS - BRF		AIGS - Simplex	
	Meas. Activity [kBq]	Uncertainty	Meas. Activity [kBq]	Uncertainty	Meas. Activity [kBq]	Uncert [kBq]
Ba-133	-83.2%	11%	9.0%	3.8%	18.2%	3.1%
Cs-137	-85.1%	63%	12.1%	17.5%	18.5%	6.5%
Eu-152	-82.4%	11%	10.6%	3.9%	17.6%	3.2%
Am-241	-87.6%	71%	-9.5%	16.4%	-0.2%	13.1%

Position 1c

	Std. ISOCS		AIGS - BRF		AIGS - Simplex	
	Meas. Activity [kBq]	Uncertainty	Relative Difference	Uncertainty	Relative Difference	Uncertainty
Ba-133	-60.6%	15%	44.3%	4.2%	71.4%	13.4%
Cs-137	-70.8%	71%	35.7%	11.1%	48.4%	58.4%
Eu-152	-62.5%	20%	37.7%	5.4%	49.5%	9.6%
Am-241	-61.3%	106%	7.6%	17.9%	111.4%	214.7%

Position 2c

	Std. ISOCS		AIGS - BRF		AIGS - Simplex	
	Meas. Activity [kBq]	Uncertainty	Meas. Activity [kBq]	Uncertainty	Meas. Activity [kBq]	Uncert [kBq]
Ba-133	-58.7%	16%	33.5%	1.9%	32.1%	1.9%
Cs-137	-68.3%	13%	31.1%	14.5%	29.6%	14.5%
Eu-152	-63.7%	22%	29.3%	3.4%	27.9%	3.2%
Am-241	-56.6%	30%	6.4%	15.9%	4.6%	14.1%

The AIGS optimisation using both the BRF and Simplex approach was performed for the position 1b case where the line source positioned at a mid-radial position in the drum had been measured at 8 angular positions and with the detector at 3 heights (24 spectra in total). Figure 6 shows the overall nuclide activity results derived from the AIGS analyses alongside the reference line source data on the left of the plot. The study kept all other modelling assumptions (number of hot-spots, matrix density…) unchanged compared to the optimisation results shown earlier.

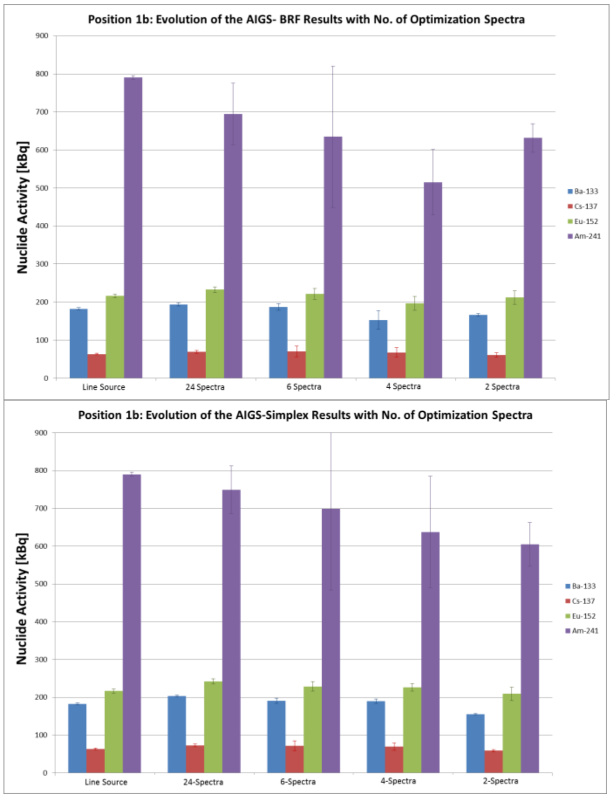


Figure 6. AIGS BRF (LHS) and Simplex (RHS) nuclide activity results for a variable number of available spectra and the line source in position 1b

This study showed that, for the selected modelling assumptions, a significant reduction of the number of available spectra does not result in the collapse of the algorithm and in fact the AIGS performance in reducing the uncertainty is almost as good for 2 spectra as for 24 spectra. As previously observed, simplex and BRF results were judged comparable, with a significant benefit in reduced computing time for the Simplex approach. Note also that all the reported quantitative results still provide a good level of agreement with the line source reference activities. In most cases (with the exception of Am-241) the AIGS uncertainties associated with nuclide activities tend to increase as the number of available spectra is reduced. This is indicative of the AIGS optimisation process (FoM calculations) being more prone to retaining a more diverse range of final “best” models, given that their selection of a “best” solution then relies on a more limited validation data set (e.g. 2, 4, 6 measurement vs. 24). In this regard, it is further demonstrated that the uncertainty calculated by the AIGS approach is intrinsically an indicator of the level of confidence of the optimisation process and of an overall improved accuracy. From a practical stand point, this limited analysis tends to confirm that an AIGS analysis, based on a reasonable set of measurements i.e. 4 or 6 measurements, can provide as reliable estimates as those that would be obtained with a complete set of 24 measured spectra.

CONCLUSION & FUTURE WORK

The work presented here is aimed at demonstrating the capabilities of the AIGS optimisation in generating accurate nuclide activity quantifications, when measuring items which present a non-uniform source distribution, within a homogeneous simulated-waste matrix. Although the measurement case described in this study and the subsequent AIGS analysis carried out on a set of empirical measurements only represents a small set of data to fully qualify the AIGS capabilities, it has shown that this approach returned accurate results that are far more reliable that what can be achieved by a standard ISOCS based quantification. For the drum studied, with density 0.681 $g.cm^{-3}$, our results have demonstrated that the use of AIGS with multiple detector positions around the drum can reduce the uncertainty from approximately 100% to a few 10's of % for a point source of Am-241, Cs-137, Eu-152 or Ba-133 at an unknown location. These results represent substantial uncertainty improvements that can be useful for waste sentencing applications.

The limited sensitivity analysis reported in this work on the impact of number of measured spectra on the AIGS optimisation process has shown that the AIGS result followed the expected behaviour. Importantly, these results show that the majority of the TMU improvements can be realised through the use of just a few separate detector positions and this will have minimal detrimental impact on throughput for field applications, compared to traditional ISOCS methods.

It also suggested that the reported AIGS uncertainty obtained when comparing optimisation results for a number of “best” geometries appears to be a good means to judge the validity of the AIGS results and that computations yielding significant spread in the derived efficiency data seem indicative of an unreliable or non-converging optimisation. Further sensitivity analysis work is needed, however these preliminary results provide some confirmation of the AIGS capability in providing more reliable and accurate measurement capabilities for waste sentencing.

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