Particle Swarm Imaging (PSIM) - Innovative Gamma-Ray Assay – 13497

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ABSTRACT

Particle Swarm Imaging is an innovative technique used to perform quantitative gamma-ray assay. The innovation overcomes some of the difficulties associated with the accurate measurement and declaration of measurement uncertainties of radionuclide inventories within waste items when the distribution of activity is unknown. Implementation requires minimal equipment, with field measurements and results obtained using only a single electrically cooled HRGS gamma-ray detector. Examples of its application in the field are given in this paper.

The Benefit

The PSIM technique iteratively 'homes-in' on the true location of activity concentrations in waste items by making use of gamma-ray measurements taken from different locations around the object. It accurately locates activity within waste items and produces an image of the activity distribution. PSIM differs from conventional assay techniques by allowing only viable solutions - that is those that could actually give rise to the measured data - to be considered. Thus PSIM avoids the major drawback of conventional analyses, namely, the adoption of unrealistic assumptions about the activity distribution that can lead to the declaration of pessimistic, or in many cases optimistic, activity estimates and uncertainties.

The Solution

PSIM applies an optimisation technique based upon 'particle swarming' methods to determine a set of candidate solutions within a 'search space' defined by the interior volume of a waste item. Each candidate solution, consisting of one or more point sources of activity, has an associated position (x, y and z) and activity within the search space. The search space is defined by a mathematical model generated by the user to represent as closely as possible the waste item geometry (physical dimensions, material compositions, etc.) and the detector positions for each individual measurement. The PSIM model does not use pre-defined 'template' geometries but instead is specified by a series of quadric surfaces and voxels providing the user with the flexibility to specify more representative and complex geometries.

The PSIM optimisation initialises a 'swarm' of solutions within the search space. The positions and activities of the swarm are used in conjunction with the mathematical model to simulate the measurement response for the current swarm location. The swarm is iteratively updated (with modified positions and activities) until a match with sufficient quality is obtained between the simulated and actual measurement data. This process is repeated to build up a distribution of candidate solutions, which is subsequently analysed to calculate a measurement result and uncertainty along with a visual image of the activity distribution.

INTRODUCTION

Babcock International Group has over 40 years of experience in the development, delivery and operation of non-destructive assay systems both in the UK and internationally. In 2011 Babcock patented an innovative technique known as PSIM to perform quantitative radiometric measurements of waste items, Ref. [1].

As part of the on-going development and innovation strategy, a review of the existing technologies was performed with the aim of developing new and novel measurement techniques. The concept of Particle Swarm Imaging (PSIM) was developed as part of this process, being driven by the increasing demand for novel techniques with improved levels of accuracy and performance whilst keeping the cost and complexity of measurement systems to a minimum.

In the UK there are ever increasing requirements for ‘service’ based solutions that offer rapid yet accurate measurements with minimal equipment. PSIM has been applied successfully in the ‘field’, meeting these challenges by delivering a simple cost effective alternative to existing technologies.

The concepts behind the PSIM technology and example applications are provided.

PARTICLE SWARM IMAGING

To illustrate the concept of PSIM consider a measurement geometry comprising of an arbitrary volume (referred to as the ‘search space’) containing n sources of activity, with each point source (position x, y, z) possessing an activity A_n. Consider the deployment of M detectors around the waste item (or alternatively M measurements using the same detector at M different positions) and let each individual point source have a detection efficiency ε with respect to each detector. The goal of the measurement is to determine the total activity within the search space. A schematic of the measurement arrangement is shown in Fig. 1.

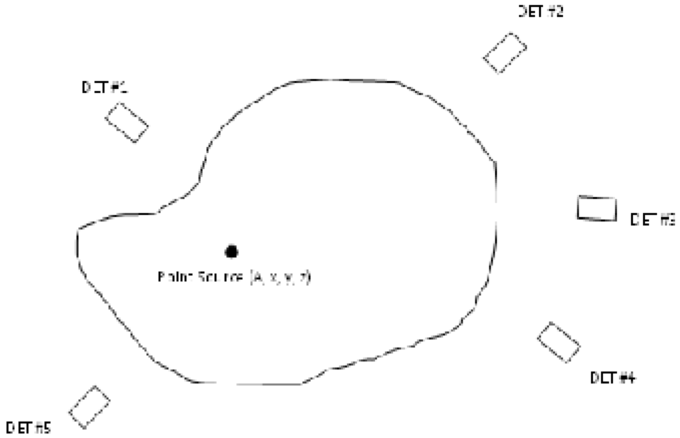

Fig.1: Measurement geometry containing point sources of activity which are constrained to lie within a 3D ‘search space’ such as the interior volume of a drum or box, the surfaces of a wall, interior of a glovebox etc.

The total measured count rate C_T and the true total activity A^{true} within the search space are given by the following expressions

$$C_T = \sum_{j=1}^{M} C_j = \sum_{j=1}^{M} \sum_{i=1}^{n} A_i \varepsilon_{j,i}(x,y,z) = \sum_{i=1}^{n} A_i \theta_i(x,y,z) \qquad \text{(Eq. 1)}$$

$$A^{true} = \sum_{i=1}^{n} A_i \qquad \text{(Eq. 2)}$$

where:

C_j = count rate measured by detector or measurement position j

A_i = activity of source i

$\varepsilon_{j,i}(x,y,z)$= detection efficiency of point source i with respect to detector j

$\theta_i(x,y,z)$= net detection efficiency of source i

An estimate of the total activity within the search space can be found by using an appropriate ‘calibration factor’ θ_{cal} to convert the total measured count rate into our measured activity i.e.

$$A^{meas} = \frac{C_T}{\theta_{cal}} \qquad \text{(Eq. 3)}$$

Combining (Eq.1), (Eq. 2) and (Eq. 3) yields the following expression

$$\frac{A^{meas}}{A^{true}} = \frac{1}{\theta_{cal}} \left(\frac{\sum_{i=1}^{n} A_i \theta_i(x,y,z)}{\sum_{i=1}^{n} A_i} \right) \qquad \text{(Eq. 4)}$$

The goal of the measurement is to obtain a measured activity which equals the ‘true’ activity within the search space and therefore from (Eq. 4) the following expression for the desired calibration factor is obtained

$$\theta_{cal} = \frac{\sum_{i=1}^{n} A_i \theta_i(x,y,z)}{\sum_{i=1}^{n} A_i} = \frac{\sum_{i=1}^{n} w_i \theta_i(x,y,z)}{\sum_{i=1}^{n} w_i} \qquad \text{(Eq. 5)}$$

The calibration factor can be seen as a weighted average of the detection efficiencies for each of the *n* sources of activity (with weighting factors *w*); having maximum and minimum values corresponding to the case when all sources of activity are located either at the position of highest and lowest detection efficiency ($\theta_{max}, \theta_{min}$) within the search space.

It can be stated with confidence (ignoring any other sources of uncertainty such as random counting statistics) that the 'true' activity must lie between the following upper and lower bounds

$$A^{max} = \frac{C_T}{\theta_{min}}, A^{min} = \frac{C_T}{\theta_{max}} \qquad \text{(Eq. 6)}$$

Prior to performing a measurement the spatial distribution of sources within the search space and the activities of the sources are unknown. Therefore to determine a more realistic 'best estimate' of the total activity, assumptions as to the size of the weighting factors, the number of sources present and their position within the search space must be made.

Conventional Approach

Conventionally it is assumed that the activities or weights of the *n* sources are identical, producing a revised calibration factor given by

$$\theta_{cal} = \frac{\sum_{i=1}^{n} \theta_i(x, y, z)}{n} \qquad \text{(Eq. 7)}$$

Making the assumption that the probability of any one source occupying a position (*x*, *y*, *z*) within the search space is constant, then the only solution to Eq. (7) that does not rely on making any assumption as to the number and location of the sources within the search space is when *n* is large (i.e. as $n \to \infty$).

In this case the resulting calibration factor becomes the 'uniform distribution' approximation given by

$$\theta_{cal} = \left. \left| \frac{\sum_{i=1}^{n} \theta_i(x, y, z)}{n} \right| \right._{n=\infty} = \theta_{UD} \qquad \text{(Eq. 8)}$$

Using the uniform distribution assumption results in a 'best estimate' of activity given by

$$A^{best} = \frac{C_T}{\theta_{UD}} \qquad \text{(Eq. 9)}$$

Whilst it is certain that the results given by (Eq. 6) will span the 'true' activity within the search space, we cannot ignore the fact that the best estimate activity is based upon assumptions that may not be valid, and that the maximum and minimum activities (i.e. the uncertainty in the result), are pessimistic in both extremes and therefore are likely to assign 'phantom' activity to the final measurement result. Phantom activity is undesirable and could adversely impact on the downstream movement, storage or treatment of the waste.

Particle Swarm Imaging Approach

Consider now the same measurement scenario but this time from the standpoint of 'Particle Swarm Imaging' (PSIM). The PSIM approach makes use of the information contained within each of the individual measurements taken around the search space shown in Fig. 1.

The count rates measured at each of the *M* measurement positions must be dependent upon the position and activity of each source within the search space. Representing the source distribution as a sequence of source activities at discrete locations (*x, y, z*), the measured count rates may be written

$$\begin{aligned} \hat{C}_1 &= A_1\varepsilon_{1,1} + A_2\varepsilon_{1,2} + \ldots A_n\varepsilon_{1,n} \\ &\vdots \\ \hat{C}_M &= A_1\varepsilon_{M,1} + A_2\varepsilon_{M,2} + \ldots A_n\varepsilon_{M,n} \end{aligned} \qquad \text{(Eq.10)}$$

Although the individual source activities and their locations required to solve (Eq. 10) explicitly are not known, it is possible nevertheless to evaluate the 'quality' of the agreement between any 'potential' distributions of activity within the search space and the measured count rates. One measure of the quality (or figure of merit, *FOM*) of the agreement is given by the following function

$$FOM = \sum_{j=1}^{M} \left(\frac{C_j - \hat{C}_j}{C_j} \right)^2 \qquad \text{(Eq. 11)}$$

Thus source distributions that yield small *FOM* values are a better fit to the measured count rates. Collecting the unknown parameters ($A_i, \varepsilon_{j,i}$) into a vector **p**

$$FOM(\mathbf{p}) = \sum_{j=1}^{M} \left(\frac{C_j - \hat{C}(\mathbf{p})_j}{C_j} \right)^2 \qquad \text{(Eq. 12)}$$

The PSIM approach initialises a 'swarm' of solutions within the search space. The positions and activities of the swarm (given by **p**) are used in conjunction with a mathematical model (describing the measurement geometry) to simulate the measurement response for the current swarm location. The swarm is iteratively updated (with modified positions and activities) until a match with sufficient quality is obtained between the simulated and actual measurement data i.e. until a solution is found which yields a low *FOM* value. This process is repeated to build up a distribution of candidate solutions, which is subsequently analysed to calculate a measurement result and uncertainty along with a visual image of the activity distribution.

The benefit of this approach is that only viable solutions - that is those that could actually give rise to the measured data - are considered. And this, in turn, facilitates accurate quantification of total activity and activity distribution. PSIM avoids the major drawback of conventional analyses, namely, the adoption of unrealistic assumptions about the activity distribution that can lead to the declaration of pessimistic, or in many cases optimistic, activity estimates and uncertainties.

Swarming Concept

Particle Swarming is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality, see (Eq. 12).

The PSIM algorithm works by having a population (called a swarm) of candidate solutions (called particles). Each particle is assigned an activity value and position (*x, y, z*) within the search space (for example the volume of a waste drum). The particles are moved around in the search space according to a few simple formulae. The movements of the particles are guided by their own best known position in the search space as well as the entire swarm's best known position. When improved positions are discovered these will then guide the movements of the swarm. The process is repeated until a match of sufficient quality is obtained with the measurement data. The particle swarming approach used by PSIM is a hybrid of the 'Particle Swarm Optimisation' or PSO approach originally attributed to Kennedy, Eberhart, Ref. [2] and 'Artificial Bee Colony Optimisation' or ABC attributed to D. Karaboga, B. Basturk, Ref. [3].

Having established a good 'match' to the measurement data the swarm is allowed to evolve (either explore, expand or contract) seeking other candidate solutions that also produce a good 'match' to the measured data. Over time the swarm effectively searches the entire search space producing a distribution of solutions from which the final activity result and associated uncertainties are derived.

It is important to note that no assumption as to the physical size of the swarm is made (with the exception of the initial swarm configuration) as the swarm effectively adjusts its size as necessary throughout its lifetime. Furthermore the approach does not seek a 'global' minimum i.e. a single 'best' solution as it not possible to find a unique solution to most measurement scenarios. In reality there are many solutions that will match the measurement data, all of which will be equally valid. However over the lifetime of the swarm, regions of 'preferred' space result, leading to regions where the solution density is higher. Regions of high solution density therefore correspond to the most likely position of the activity within the search space.

Mathematical Model (Gamma-ray Assay)

The distribution of activity can be represented as a sequence of point sources at discrete locations, producing the count rates given by (Eq. 10). To calculate the count rates at our measurement positions we require a model that calculates the efficiencies for each particle (or point source of activity) within the swarm. If the efficiencies are known then the count rates at the detector positions can be evaluated.

The PSIM model is defined firstly by a series of quadric surfaces which define the measurement geometry. A quadric surface is represented by the following expression:

$$Ax^2 + By^2 + Cz^2 + Dxy + Exz + Fyz + Gx + Hy + Iz + J = 0 \qquad \text{(Eq. 13)}$$

where A, . . . ,J are constants.

This notation allows the user to specify complex geometries including shapes that can be constructed from multiple planes, spheres, cylinders, cones etc. In addition to the surfaces that make up the measurement geometry it is necessary to define the cells within the geometry. Each cell is defined by a series of ‘senses’ with respect to each surface which uniquely defines the spatial extent of the cell volume within the measurement geometry. Each cell must be assigned a material density and mass attenuation coefficient corresponding to the gamma-ray of interest.

The PSIM model does not use pre-defined ‘template’ geometries such as the well established ISOCS, Ref. [4] and ISOCART, Ref. [5] assay systems. Instead specifying the geometry by a series of quadric surfaces provides the user with much greater flexibility to specify more representative and complex geometries.

‘Source’ cells are identified as part of the geometry configuration. Only these cells are permitted to contain sources of activity (an example of a ‘source’ cell would be the matrix within a drum or a vessel within a glovebox). This definition ensures that the swarm does not explore regions of the geometry within which no activity can exist. There is no restriction on the number of source cells allowing complex geometries to be considered (an example may be the measurement of multiple waste items within a room, a scenario which may be difficult to interpret using only pre-defined geometries due to the measurement cross-talk between individual objects and the measurement positions).

The final part of the configuration is to define the locations at which the measurements were performed and the detector response. The measurement positions are simply defined by the central (x, y, z) co-ordinates of the front face of the detector within the measurement geometry. The orientation of the detector with respect to the search space is defined by the normal vector perpendicular to the front surface of the detector. The detector response is pre-calibrated as a function of the incident gamma-ray energy. This detector calibration is the only model parameter that requires any pre-calibration prior to performing a measurement.

Comparison with ‘Conventional’ Assay Methods

A comparison is to be made between the results obtained using PSIM with those using more ‘conventional’ analysis methods for a typical measurement scenario.

Consider the gamma-ray assay of a 200 litre drum (84 cm in height, 28.5 cm inner radius) containing a matrix of ‘soft’ compacted waste (the chemical composition of which is known) having a uniform density of 1.0 g/cc. The waste contains 1.00 MBq of Cs-137 contamination and the presence of significant ‘hotspots’ of activity cannot be ruled out. The only equipment available to perform the measurement is a single 15% efficient HpGe detector (open collimator arrangement), a turntable, and a trolley to deploy the detector at various heights and positions around the drum.

In the absence of any further information the conventional analyst uses a mathematical model to establish the uniform distribution, maximum and minimum ‘calibration factors’ described earlier. Note that this is readily achievable using commercially available assay systems such as ISOCS, Ref. [4] and ISOCART, Ref. [5] using defined template geometries. The conventional analyst uses the measurement geometry depicted in Fig. 2 (left). The detector is located at the mid-height of the drum at a distance of 25cm from the drum surface. During the measurement the turntable is rotated to reduce the effect of any non-uniformity in the distribution of activity within the drum.

In contrast the PSIM analyst does not rotate the drum but instead performs eight discrete measurements around the drum. Four measurements are performed at a height of 20 cm relative to the base of the drum, and four measurements at a height of 64 cm. Each of the eight measurements is offset by 45 degrees as shown in Fig. 2 (right) and performed for 1/8 that of the time used by the conventional analyst. The distance of the detector from the drum outer surface is 25 cm. Unlike the conventional analyst the PSIM analyst does not need to calculate a ‘calibration’ factor prior to performing the measurement.

Table I compares the results obtained using the two different measurements.

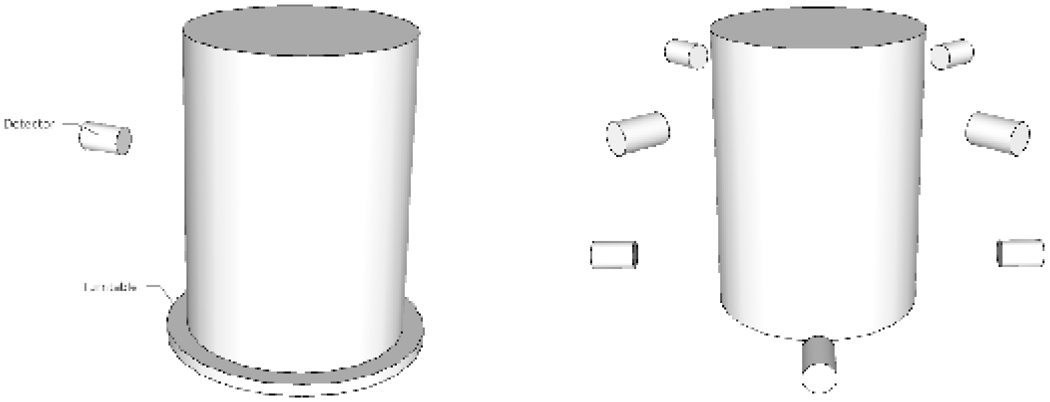

Fig.2: ‘Conventional’ measurement geometry with a single measurement position and turntable (left) and ‘PSIM’ measurement geometry showing eight measurement positions performed at two different heights (right).

Table I. Comparison of ‘Conventional’ and PSIM assay methods (true activity within drum =1.00 MBq)

Assay Method	Minimum Activity [i] (MBq)	‘Best Estimate’ Activity (MBq)	Maximum Activity [i] (MBq)
Conventional	0.14	0.35	1.63
PSIM	0.76	0.97	1.22

[1] Uncertainties expressed at 99% confidence

Whilst the ‘Conventional’ assay method produces maximum and minimum activity values that bound the true activity of 1.00 MBq, the uncertainties are significantly larger than those reported by PSIM and there is an obvious bias in the ‘Best Estimate’ activity (i.e. the ‘Conventional’ result is underestimating the true activity by a factor of 65 %).

The reason for the underestimate can be explained when the image of the activity distribution produced by PSIM is investigated. Fig. 3 shows planar views of the drum in the *x-y* plane (left), the *y-z* plane (middle) and the *x-z* plane (right).

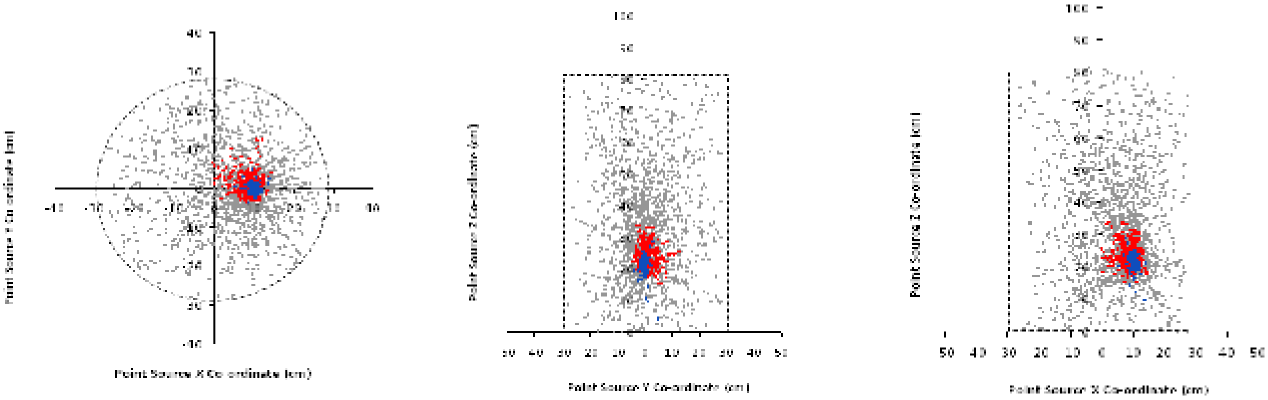

Fig.3: PSIM image of the activity distribution within the drum

The data shown in the colour grey represent the particle positions corresponding to each PSIM solution, representing therefore the extent of the search space explored by the swarm. The data in the colour red represents regions of search space where the density of solutions is greatest i.e. the most probable locations for the activity within the drum. The data shown in the colour blue represents the regions of search space containing the highest activity.

The PSIM image reveals that the activity is concentrated towards the centre of the drum, midway between the drum centre and the base. The position of this activity ‘hotspot’ is not well represented by the uniform distribution calibration assumed by the conventional analyst and consequently results in a best estimate activity that is an underestimation of the true activity within the drum.

Fig. 4 (left) shows the total activity histogram corresponding to each PSIM solution. From this histogram the PSIM results shown in Table I are determined. Fig. 4 (right) shows the measured count rates at each of the eight measurement positions along with the average PSIM imaged count rates and uncertainties.

The smaller uncertainties associated with the PSIM solution reflects the fact that PSIM only considers solutions that could have produced the count rate profile shown in Fig. 4. The assumption made by the conventional analyst that all the activity could have been located at the position of either maximum or minimum efficiency could not have produced these measured count rates, and are therefore not considered by PSIM.

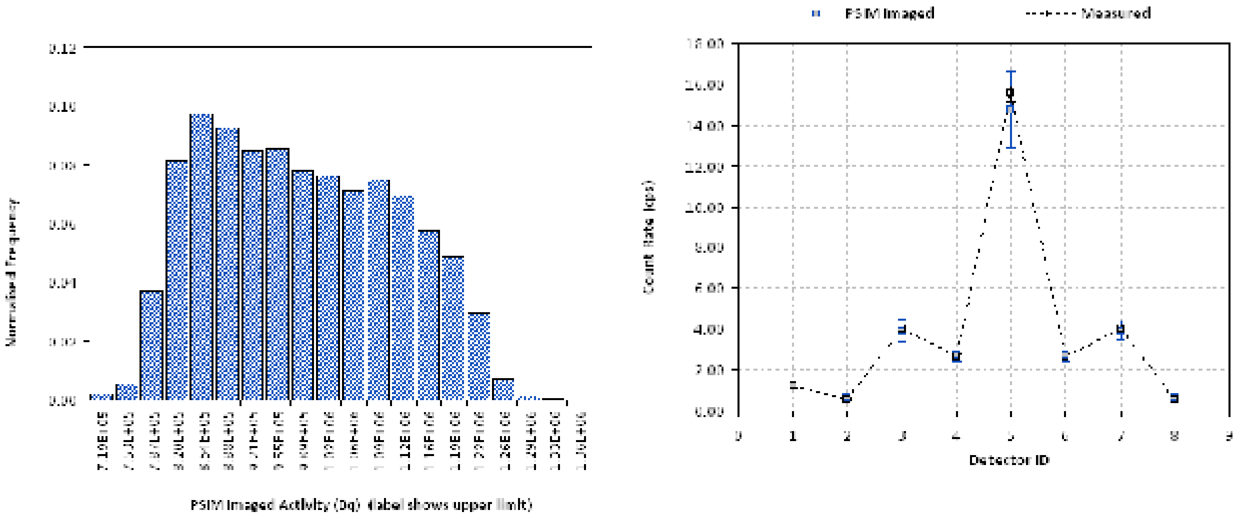

Fig.4: Total activity histogram produced by PSIM (left) and measured count rate at each measurement position compared with the PSIM average imaged value (right).

PSIM is able to image scenarios containing multiple ‘hotspots’ of activity. Illustrative examples are shown in Fig. 5 and Fig. 6.

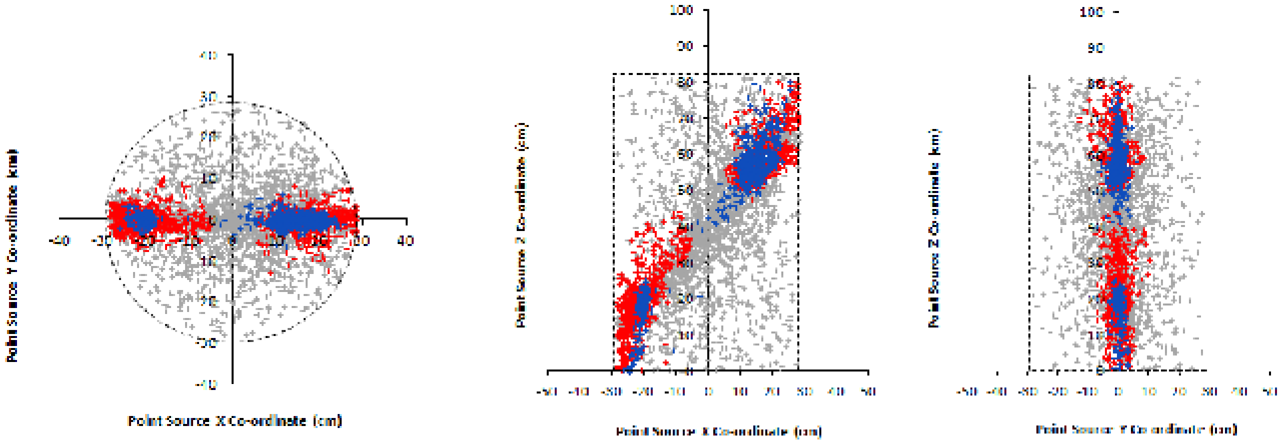

Fig.5: PSIM image resulting from two ‘hotspots’ of activity located at the top and bottom of the drum using the PSIM measurement geometry shown in Fig. 2.

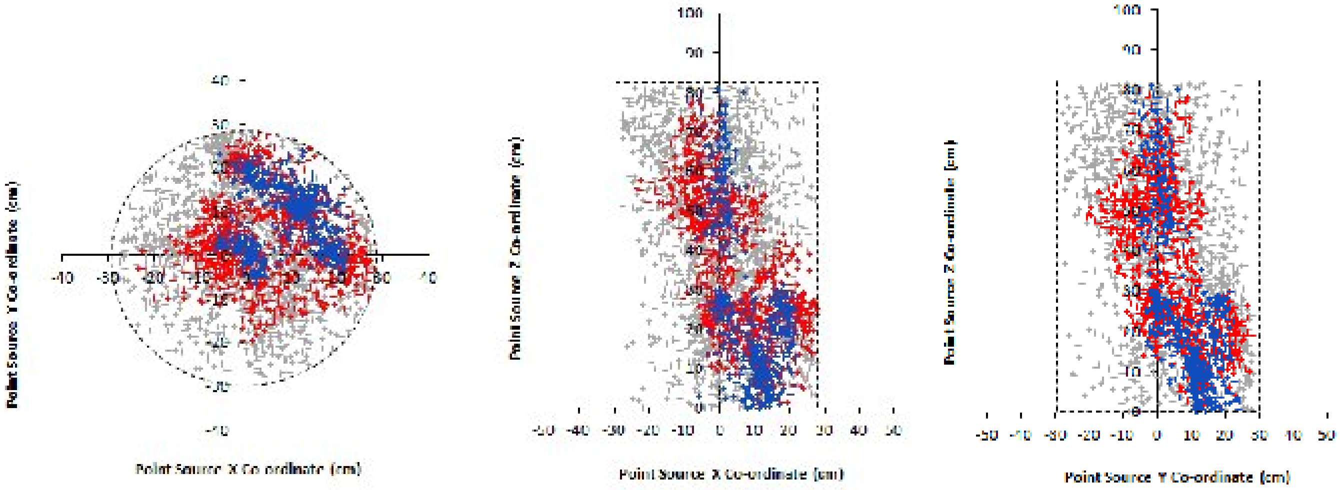

Fig.6: PSIM image resulting from multiple sources distributed non-uniformly within the drum using the PSIM measurement geometry shown in Fig. 2.

PSIM Case Study #1: NPL Proficiency Test Exercise

In 2011, the UK National Physical Laboratory (NPL) ran their third bulk-waste proficiency 'test' exercise to enable UK laboratories involved in decommissioning and site clearance to test their bulk-waste gamma measurement procedures, Ref. [6].

For this third exercise NPL prepared a single 'mock waste' sample in a 200-litre steel drum. The drum contained metal, hard plastic and soft-waste material with a gross weight of 35 kg. The radionuclides Am-241, Co-60 and Cs-137 were declared as present and distributed in a heterogeneous manner.

The test drum was circulated to participants as a 'blind' sample and the exercise executed in two phases. In the first phase only the material constituents of the drum contents were provided to participants (no information was provided as to the layout of the materials within the drum). After measuring the drum participants were asked to submit their measurement results to NPL before Phase #2 commenced. In the second phase additional information was provided as to the details of the drum internal structure and the location of the radionuclides within the drum. Participants were then asked to resubmit a revised set of results after which an inter-comparison was performed by NPL.

For the first phase the PSIM model assumed the drum contents were 'smeared' throughout the drum volume with a uniform density of 0.10 g/cc. Measurements were taken at two different heights using a single HpGe detector in an open collimator arrangement. A total of eight measurements (of 300 s duration) were taken at each height with each separated by angle of 45 degrees (16 measurements in total). With the exception of the detector characterisation no other calibration was required prior to performing the measurements.

The PSIM results obtained for the Phase #1 measurements are provided in Table II.

Table II. PSIM results for NPL Proficiency Test Exercise Phase #1 (the actual activity of each radionuclide present is shown for comparison purposes)

Radionuclide	Minimum Activity [i] (kBq)	'Best Estimate' Activity (kBq)	Maximum Activity [i] (kBq)	Actual Activity [ii] (kBq)
Co-60	35.6	38.1	40.9	39.2
Cs-137	34.3	39.1	43.7	35.1
Am-241	68.1	80.0	98.6	97.5

[i] Uncertainties expressed at 99% confidence.

[ii] Note that the actual activities were not declared to participants until after Phase #2 was completed.

In the second phase NPL declared the drum contained a box-shaped structure consisting of Nylon 6-6 and BS 1449 steel. Two of the walls were steel (opposite each other and 1 mm in thickness) whilst the other two walls, and the base, were Nylon (1.0 cm in thickness). The top face of the 'box' was open. The activity was located on three filter papers (one per radionuclide) and had been deposited uniformly across each filter. Two of the filters containing Am-241 and Co-60, were taped to the outward-facing side of one steel wall, and the other containing Cs-137 was taped to the outward-facing side of the opposite steel wall. The spaces in and around the 'box' were filled with low density plastic.

The PSIM model was subsequently revised to take into account the complex box shaped structure within the drum and the material specifications. Again no assumptions were made in the calibration as to the distribution of activity within the drum.

The PSIM results obtained for the second phase measurements are provided in Table III.

Table III. PSIM results for NPL Proficiency Test Exercise Phase #2 (the actual activity of each radionuclide present is shown for comparison purposes)

Radionuclide	Minimum Activity [i] (kBq)	'Best Estimate' Activity (kBq)	Maximum Activity [i] (kBq)	Actual Activity [ii] (kBq)
Co-60	35.5	37.5	39.4	39.2
Cs-137	33.1	35.9	45.2	35.1
Am-241	88.56	119.0	203.1	97.5

[i] Uncertainties expressed at 99% confidence.

[ii] Note that the actual activities were not declared to participants until after Phase #2 was completed.

The PSIM images produced for the Phase #2 measurements are shown in Fig. 7 - 9. The locations of the center of each filter paper declared by NPL, also shown in Fig. 7 - 9 as yellow markers, correlated well with the positions of the three activity 'hotspots' identified by PSIM.

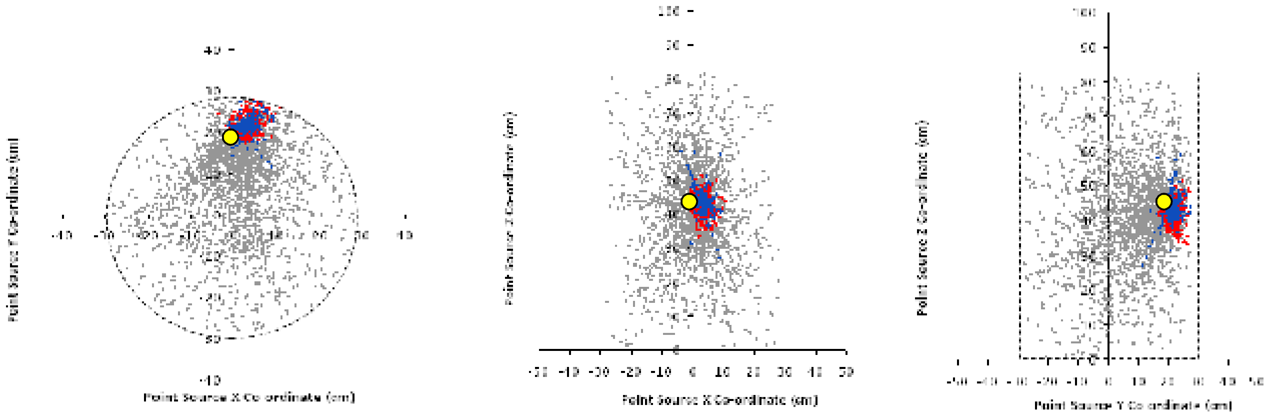

Fig. 7: Phase #2 PSIM Image: Distribution of Co-60 within the NPL ‘test’ drum.

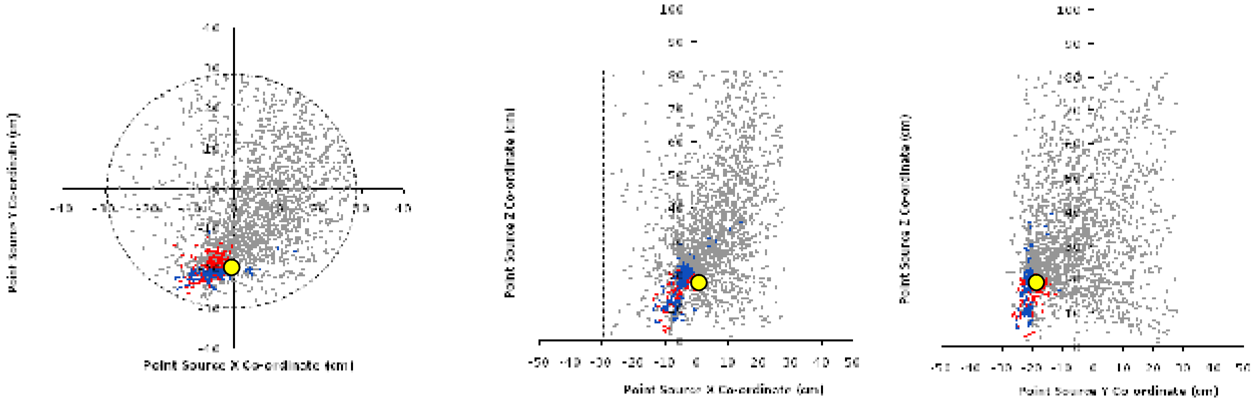

Fig. 8: Phase #2 PSIM Image: Distribution of Cs-137 within the NPL ‘test’ drum.

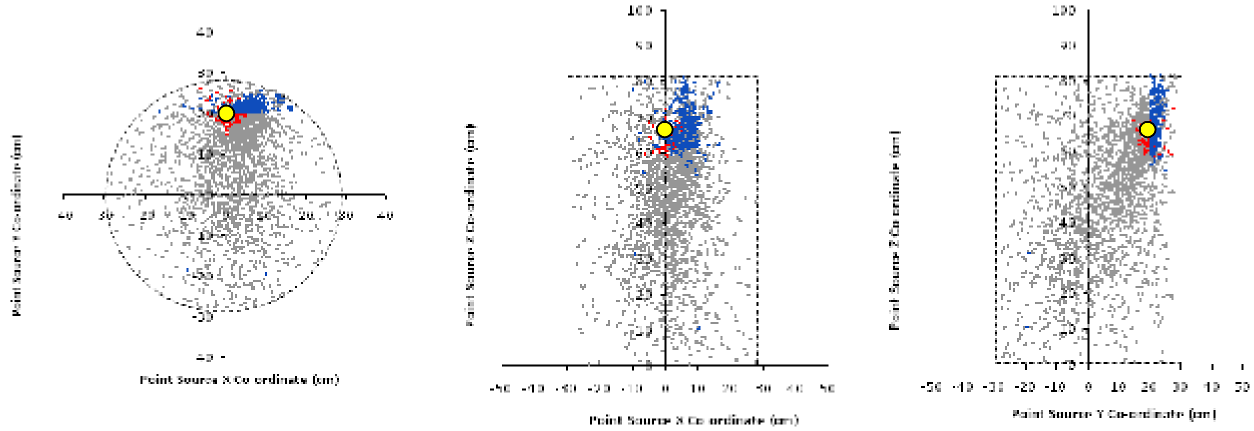

Fig. 9: Phase #2 PSIM Image: Distribution of Am-241 within the NPL ‘test’ drum.

PSIM Case Study #2: Multi-Element Bottle (MEB) Verification Monitoring

Babcock successfully provided on-site verification monitoring of an empty spent fuel Multi-Element Bottle (MEB) located at a metals recycling facility in the UK. The MEB was contained within a 15 m^3 isofreight container and Babcock performed an activity assessment of the MEB using PSIM.

A single background-shielded, weather-protected, electrically-cooled, battery-powered High Resolution Gamma Spectrometer was deployed to record gamma-ray measurements at various positions around the isofreight container. An accurate PSIM model of the measurement scenario was generated (see Fig. 10), and the radionuclide data from the gamma-ray measurements was analysed to determine the activity distribution within the MEB.

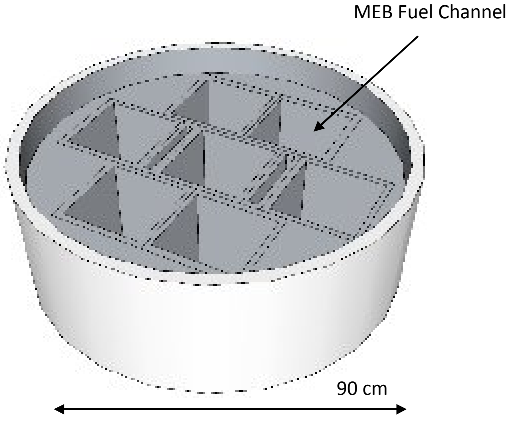

Fig. 10: Internal view of MEB top section only, showing the complex structure consisting of 7 empty fuel channels and Boral shielding plates between each channel. The PSIM model does not use pre-defined ‘template’ geometries, instead, specifying the geometry by a series of quadric surfaces provides the user with much greater flexibility to specify more representative and complex geometries as required for the MEB model.

Fig.11 shows the MEB located within the isofreight container before the measurements took place (left), and the assay equipment deployed at one of the measurement positions around the container (right).

Fig. 11: Multi-Element Bottle (MEB) located within the isofreight container (left) and the assay equipment deployed at one of the measurement positions around the container (right).

By determining the distribution of activity within the object, PSIM was able to accurately calculate the radionuclide activity itself, and so reduce the measurement uncertainties associated with this type of measurement scenario using a conventional approach. The PSIM results were compared with those provided by the customer’s own activity assessments.

Fig. 12 shows the PSIM images of the activity distribution within the MEB.

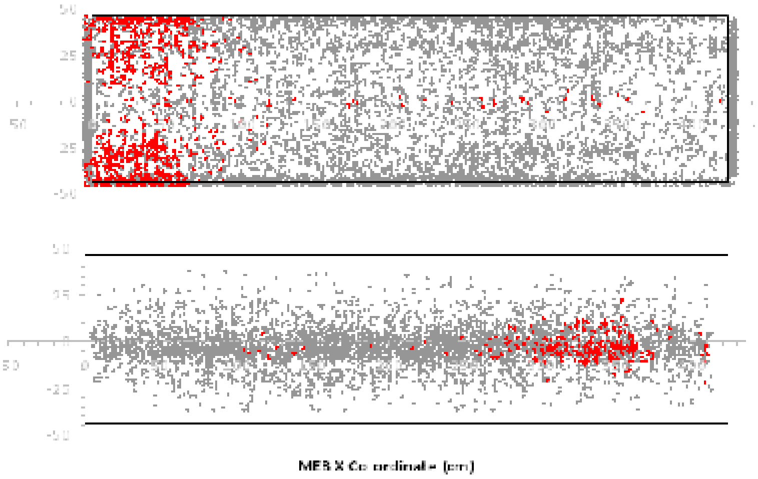

Fig. 12: The PSIM image showing the regions of high clustering revealed that the activity was dominated by Cs-137 on the external surfaces at the top of the MEB (upper figure) and internally distributed Co-60 activity at the base of the MEB (lower figure).

PSIM Case Study #3: Isofreight Container Verification Monitoring

Particle Swarm Imaging (PSIM) is being used to make accurate assessments of the activity levels within half and third-height isofreight containers in the UK. The 10 – 15 m^3 containers, which are consigned to the Low Level Waste Repository (LLWR) from nuclear facilities across the UK, contain a wide range of non-compactable radioactive waste materials.

Background-shielded, weather-protected, electrically-cooled, battery-powered High Resolution Gamma Spectrometers are deployed to record gamma-ray measurements at various positions around each container. An accurate computer model of the measurement scenario is generated by the PSIM software using all available information about the container e.g. loading plans, photographs, individual item descriptions, etc. The radionuclide data from the gamma-ray measurements is then analysed to determine the activity distribution within each container. By determining the distribution of activity within the containers, PSIM is able to accurately calculate radionuclide activities, and reduce the measurement uncertainties normally associated with the assay of large dense items such as these isofreight containers.

The PSIM results are used to verify the declared contents of the containers before they are consigned to the storage vaults. Babcock provides extra support when required to compare the PSIM output against consignor-declared data, in order to highlight sources of discrepancy and provide advice on best-practice waste characterisation methods.

PSIM produces a pictorial representation of the distribution of activity within the ISO container for each radionuclide as shown in Fig. 13. Knowing where the contamination is within the item allows more accurate determination of the total activity within.

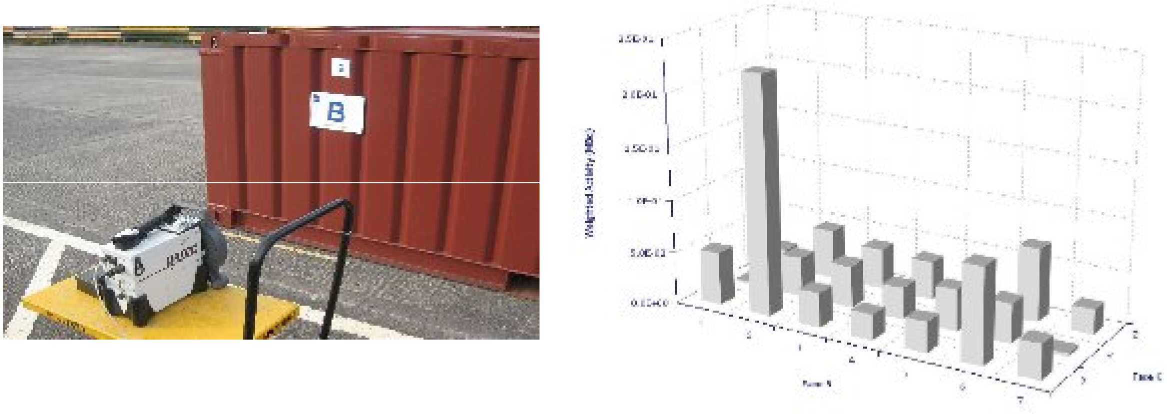

Fig. 13: Isofreight container measurement equipment deployed adjacent to one of the isofreight outer surfaces (left). PSIM produces a pictorial representation of the distribution of activity within the isofreight container for each radionuclide (right).

PSIM DEVELOPMENTS

Babcock has an on-going programme of research and development to enhance the PSIM technique. A summary of these developments is given below:

- Application of PSIM techniques to transmission based measurements to 'image' the contents (i.e. material type and density) of waste items enabling the user to refine the PSIM model before a measurement.
- Enhancement of PSIM modelling software.
- Extension to neutron imaging (for example glovebox material hold-up assessment using total and coincident neutron signals).
- Evaluation of suitability for 'safety' related measurements (pessimism reduction).

CONCLUSIONS

Particle Swarm Imaging (PSIM) is an innovative approach developed by Babcock to perform gamma-ray activity assay.

The key benefits of PSIM are summarised below:

- Requires minimal equipment (a single detector deployed around the waste item).
- Produces accurate results with reduced uncertainties compared with 'conventional' methods.
- Produces an image of the activity distribution within the measured item similar to that produced by segmented / tomographic gamma scanning systems.
- Flexible software allows representative and complex geometries to be modelled, ensuring the best use of all available underpinning information.

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