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Radioactive Waste Assay for Reclassification

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1. Introduction

Following the ban on deep sea disposal of radioactive wastes in 1983 the Atomic Weapons Establishment (AWE) in the United Kingdom (UK) has stored plutonium (Pu) and uranium (U) contaminated wastes on site in 200 l steel drums or as wrapped packages containing filters or other materials. This was because of difficulty in demonstrating compliance with the with the 100 Bq/g Pu alpha activity limit for waste disposal at the national Low Level Waste (LLW) repository at Drigg in Cumbria (UK) and the absence of a national Intermediate Level Waste (ILW) repository. Wastes that were potentially only lightly contaminated were consigned to Drigg as LLW because of difficulties in demonstrating that they could be disposed of as either Very Low Level Waste (VLLW) or Exempt Waste (EW). Table 1 summarises the current situation in the UK regarding disposal route and costs for each waste category. This UK classification system is different from that recommended by the IAEA or that used in the USA.

Category	**Activity range (Bq g^{-1})**	**Disposal route**	**Disposal cost (£ per 200l drum)**
ILW	> 4,000 Pu, U > 12,000 beta	Indefinite storage at AWE until a national ILW repository is available	40,000
LLW	< 4,000 U < 12,000 beta	LLW repository at Drigg	250
LLWD	< 100 Pu alpha	LLW repository at Drigg	250
VLLW	< 4 Pu, U	As authorised	50
EW	< 1 U < 0.15 Pu	As AWE policy dictates	20

Table 1. Waste disposal routes and costs

In recent years AWE has successfully developed robust techniques for reducing both the quantity and category of its Pu and U contaminated wastes. The objective was to reduce costs and ensure that wastes provisionally classified as ILW were reclassified to LLW for off-site disposal to Drigg where possible and that the limited space available at Drigg was used for genuine LLW and not VLLW or EW. This chapter describes the waste reclassification techniques, recently developed at AWE, for ILW reclassification to LLWD (i.e. LLW

acceptable to Drigg) and for VLLW reclassification to EW that is not subject to regulatory control in the UK. The techniques were applied to almost all waste streams encountered at AWE and around 50 % of provisionally classified ILW was downgraded to LLW and 70- 90 % of provisionally classified VLLW to EW. However, further development is required in order to address the problems posed by the most challenging waste streams. These problems are discussed and suggestions are made for future work.

2. Reclassification techniques

Measurement of 200l steel waste drums, at the 100 Bq/g Pu alpha threshold, was beyond the capabilities of most assay techniques because the low yields of neutron or photon emissions from plutonium isotopes gave detection limits that were several hundred or thousand Bq/g (Miller, 2002). Hence it was necessary to develop techniques that measure the relatively low energy (60 keV), but high yield (36 %) photon from Am-241 (Pu-241 daughter) and apply the Pu alpha/Am-241 activity ratio to calculate the total Pu alpha activity. The main drawback with this strategy is the potential for underestimating Pu in scenarios where photon attenuation is severe due to the presence of high density and high atomic number (Z) materials in the waste. However, this was not found to be a problem for waste drums encountered at AWE because activity was well distributed within the waste (Miller, 2009b). Three techniques were developed. Firstly, High Resolution Gamma Spectrometry (HRGS), using a High Purity Germanium (HPGe) crystal detector and Spectral Non-destructive Assay Platform (SNAP) analytical software to calculate isotopic activities together with associated errors and Detection Limits (DL). Secondly, Low Resolution Gamma Spectrometry (LRGS), using a thin NaI(Tl) crystal detector calibrated using a traceable Am-241 source and simulated waste. Thirdly, Gross Counting (GC) using plastic scintillation photon detectors.

2.1 HRGS/SNAP

The SNAP assay system consists of standard HRGS hardware coupled with SNAP analytical software. This allows the photon detector calibration to be corrected for both counting geometry (e.g. drum dimensions and detector location) and gamma ray attenuation (e.g. waste matrix density and composition. Figure 1 shows the standard counting geometry with the detector end cap located at 60 cm from the centre/middle of the drum wall.

Fig. 1. SNAP assay system monitoring a 200l waste drum on a rotating turntable

The gamma spectrum, for the waste drum, was stored in the form of a Region of Interest (ROI) report (.Rpt) file containing the counting data for the photons of interest (e.g. Am-241 @ 60 keV) and imported into SNAP for radionuclide identification, modelling, assay calculation and reporting. Radionuclide identification can be performed using a full radionuclide library or a sub-library pertaining to the waste-stream of interest (e.g. plutonium). Each ROI in the spectrum was selected, by the analyst, from the library and the spectrum saved as a RPu file.

The RPu files can then be imported into the SNAP modelling. Early versions of the SNAP software have two models: a cylinder or a box. More recent versions have additional models, such as a disk. The dimensions of the cylinder (height and diameter) or the box (height, width and depth) pertain to the dimensions of the waste material within the waste package. For a completely filled waste drum this would be the internal dimensions of the drum that define the size of the item being assayed.

The detector location, relative to the waste, was defined by three measurements: the detector to item distance was measured from the detector end cap to the surface of the waste material; the detector height was measured from the base of the waste to the detector axis and the left of centre was measured from the centre of the waste to the detector axis. The detector calibration was selected together with the collimator position (e.g. flush with the detector end cap).

The waste material was defined by three or four variables: the matrix mass, primary matrix percentage by volume, primary matrix material and (if applicable) secondary matrix material. Three layers of shielding material and thickness may be applied, but for a 200 l drum 0.11 cm of iron was used with the other two layers set to 0 cm of 'none'.

Modelling was completed by entering the count time, height above sea level, detection limit required (i.e. Critical Level or Minimum Detectable Amount) and number of sides of the waste package counted (2 or 4) for computation of the Geometric Attenuation (GA) error. This was the percentage difference in activity between a uniformly distributed matrix and activity compared to a single point source of activity at a 'worst case' location.

Assay calculations were performed once all of the above modelling information had been entered. This gave radionuclide activities, based on uniform activity and matrix distribution, for each photon measured. All photon energies, for a given radionuclide, should yield consistent results. If not the modelling was adjusted to get the best agreement. For example, if the 60 keV signature from Am-241 was underestimating by a factor of two, compared to the 662 keV Am-241 photon, increasing the steel shielding thickness by 1 mm would give better agreement.

Another feature is the lump correction routine for U and Pu waste-streams. For example, the main photons from Pu are at 129 and 414 keV. Underestimation at 129 keV compared to 414 keV is often an indication of photon self-absorption within Pu. The software allows the analyst to progressively increase the size of the Pu until consistent results are obtained at 129 and 414 keV.

When the analyst is satisfied with the modelling the software can be used to generate an htm report file. This summarises all of the sample details, modelling and results for presentation to the customer as an electronic or paper copy.

The software is easy to use and a complete assay, from spectrum acquisition to report generation, takes only a few minutes. This can be further streamlined by using the software to generate calibration curves when the only significant variable is the matrix mass . As the mass increases the calculated activity increases and the response factor is yielded from the ratio of the count rate to calculated activity. In this situation the observed net count rate, divided by the response factor, yields the radionuclide activity or mass as required.

The main limitation of the software is that it is less accurate for objects counted very close to the detector due to solid angle and inverse square law effects. Normal counting geometry is with the detector at one drum diameter from the drum wall.

There are a number of other software packages available that can be used as an alternative to SNAP. However, SNAP has a proven record at both Los Alamos National Laboratory (LANL) in the USA and AWE. Also inter-comparison studies, against benchmark techniques like the Segmented Gamma Scanner (SGS), have shown that SNAP gives similar results with the advantages of simplicity, speed, lower costs and improved detection limits (Miller, 2008). Eberline Services have reported similar results (Lasher, 2009).

2.2 LRGS

The IS 610 LRGS was originally developed by AWE for the detection of low energy photons from low level Pu and U ground contamination. It can be used as a hand held monitor or mounted on its tripod (figure 2).

Fig. 2. LRGS positioned for HEPA filter monitoring

The Pu version of the IS610 uses a 75 mm diameter by 1 mm thick NaI(Tl) crystal and three ROIs at 10-24, 47-72 and 10-72 keV for detection of Am-241 @ 60 keV and L x-rays @ 17 keV . The U version has a thicker (10 mm) crystal with ROIs at 10-28, 48-74 and 161-237 keV for detection of the higher energy U-235 photon @ 186 keV.

The IS610 is cheaper and easier to use than SNAP, but is much less versatile and has poorer detection levels. It was therefore only used in less challenging scenarios, where it could be calibrated using a traceable source and simulated waste, such as Pu contaminated HEPA filters where the only significant photon yield is at 60 keV (Miller, 2003).

2.3 GC

Better detection levels were achieved using a GC system. This detects all photons from 50 keV up to 2 MeV and has a 350 l counting chamber (63.5 cm high, 63.5 cm wide, 87 cm deep). All six sides of the chamber are surrounded with plastic scintillation photon detectors (50 mm thick) and lead shielding (25 mm thick). The aluminium base plate of the chamber is linked to a load cell in order to provide a measure of the waste mass. Waste items are introduced and removed using doors at the front and rear of the monitor (figure 3).

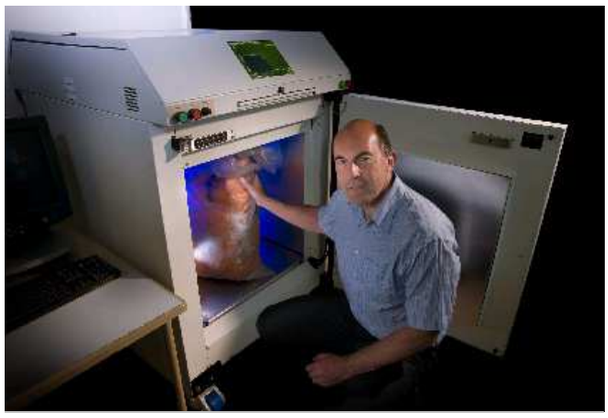

Fig. 3. GC system being loaded with bagged waste

The GC system must be well shielded and sited in an area with a low and non-fluctuating photon background. Furthermore wastes must be carefully segregated to provide materials with low photon attenuating properties, low Naturally Occurring Radioactive Material (NORM) content and an isotopic fingerprint that is consistent with the calibration (Miller, 2010).

3. Pu waste reclassification

All three techniques described above have been applied to low activity Pu waste streams to give an Am-241 activity or detection limit that was subsequently converted to a Pu activity or detection limit using the known Pu/Am-241 activity ratio for the item measured. Equipment calibrations were checked, using waste package standards prepared by the National Physical Laboratory (NPL) and measured Am-241 activities were found to be within a few percent of the true values (Miller, 2011). The following sections review, for each application, the calibration and performance (i.e. detection levels and uncertainties) checks done and subsequent results achieved with real wastes where monitored.

3.1 Reclassification of soft drummed Pu ILW using SNAP

Detector response factors (cps/Bq) were measured for an Am-241 source at various locations within 200 l waste drum calibration standards containing low Z (soft), low bulk

density paper and PVC matrices over the range 16.6-72.5 kg net (34.6-90.5 kg gross). These factors were weighted, according to the relative volumes which they represent, in order to derive a uniform response factor and quantify the systematic error for non-uniform activity distributions. Detection levels and random errors were also derived from the counting data (Miller, 2002). Figure 4 shows how the maximum, minimum and uniform response factors reduced as gross drum mass increased. The results were fitted with polynomial curves.

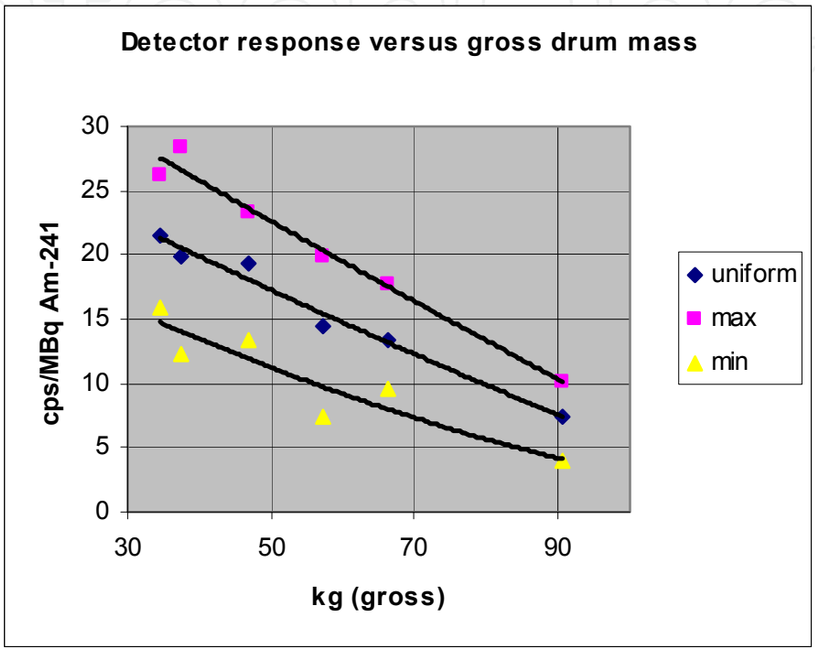

Fig. 4. SNAP response factors

The calibration curve, generated using SNAP software, was virtually identical to the uniform response curve in figure 4 that was achieved using waste drum standards (Miller, 2009b). Maximum and minimum response was within +/- 30 % of uniform for the lighter drums and within +/- 50 % for the heavier drums.

Repeat measurements, on blank drums, indicated that the background standard deviation (σ) was similar to the square root of the background counts (√B). Hence, equation 1 gave a Pu DL (2σ) of 1.2 Bq/g Pu, given: B = 30 counts, T = 100s count time, F = 15 cps/MBq, G = 60 kg and R = a Pu alpha/Am-241 activity ratio of 10.

$$DL = (2\sqrt{B}/TFG)R \quad (1)$$

Over the past nine years (December 2002 til June 2011) 4071 legacy drums, provisionally classified as ILW for long term storage at AWE, were assayed using SNAP. Only 535 (13.1 %) were confirmed ILW, with 1287 LLW (31.6 %) and 2252 LLWD (55.3 %). Similar figures were obtained for recently generated drums from decommissioning operations: 535 ILW (16.7 %), 1636 LLW (51 %) and 1037 LLWD (32.3 %). These figures include the results for both soft and hard drummed wastes.

3.2 Reclassification of hard drummed Pu ILW using SNAP

Drum radiography indicated that a number of drums contained high Z (hard) wastes, such as metals, so it was necessary to verify that the calibration curves in figure 4 were also applicable to these waste streams. This was achieved by comparing SNAP results (Pu g) with Passive Neutron Multiplicity Counting (PNMC) results (Pu g) for drums having progressively more metal content and Pu content (Miller, 2009b), but under 100 kg gross. Figure 5 shows that consistent results were obtained with the 60 keV Am-241 signature and more penetrating emissions from Pu-239 (129 & 414 keV) and fast neutrons from Pu-240 for drums containing 100 % metal waste. The SNAP results at the three photon energies were plotted against the PNMC results and fitted using linear trend-lines (figure 5).

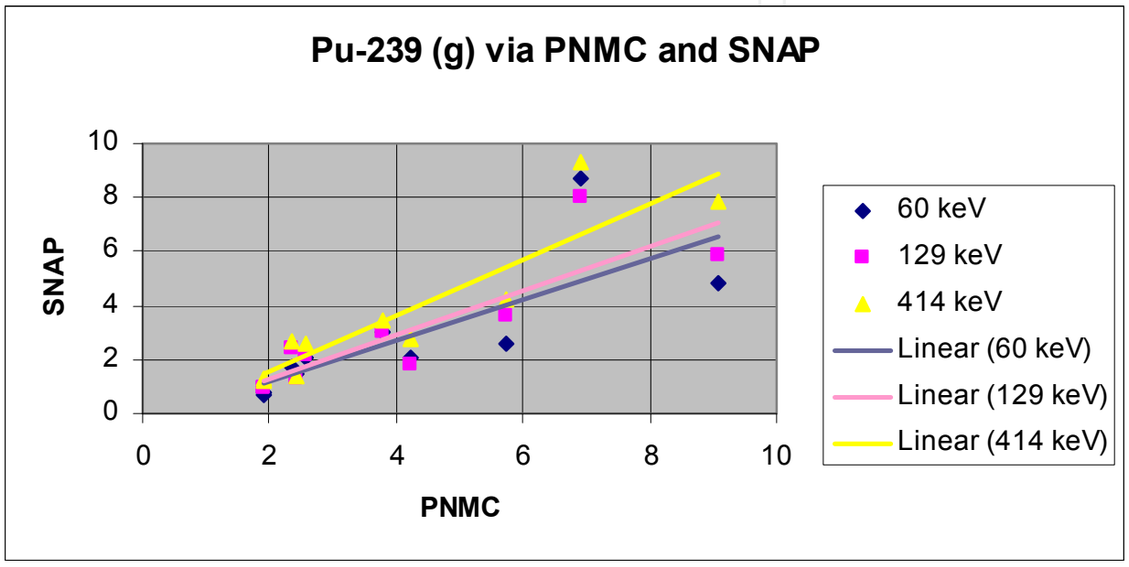

Fig. 5. Comparative results for drums containing metallic wastes

3.3 Reclassification of Pu ILW HEPA filters using SNAP and LRGS

Uniform, maximum and minimum response factors, for Am-241 in HEPA filters, were derived for the SNAP (HRGS) and IS610 (LRGS) detectors (Miller 2003). Table 2 summarises the DLs (2σ) calculated using equation 1, for a filter counted at 60 cm on two sides, given: T = 100s; G = 20 kg; R = 10; B = 0.3 cps for SNAP and 10 cps for LRGS; F = maximum, minimum and uniform response factors for SNAP and LRGS.

Technique	Uniform	Minimum	Maximum
SNAP	0.48	0.43	0.59
LRGS	2.14	1.64	3.09

Table 2. Pu DLs (Bq/g) for HEPA filter assay

Both techniques gave adequate performance for the 100 Bq/g Pu alpha Drigg LLWD threshold and around 2,000 filters have been downgraded from ILW to LLWD. Further development is needed to meet the latest EW threshold of 0.15 Bq/g total Pu alpha and beta

activity when R was > 10. This might be achieved by counting for longer within a fully shielded room as used for In-Vivo Monitoring (IVM) of Am-241 in lungs.

3.4 Reclassification of soft bagged Pu VLLW using SNAP

Exempt clearance levels, in the UK, have recently reduced from < 11.1 to < 1 Bq/g for U wastes and from < 0.4 to < 0.15 Bq/g for Pu wastes. It can be seen, from table 1, that VLLW categorization avoids relatively costly LLW disposal charges and utilization of limited space at the UK national LLW repository at Drigg. The lower EW categorization gives a relatively smaller cost saving compared to VLLW.

Hence, the principal objective of this application was to develop portable HRGS (SNAP) for the best detection levels and lowest measurement uncertainties for low density soft wastes generated at AWE. Studies have focused on a typical 10-11 kg bag of waste that can be conveniently contained in a reproducible counting geometry by placement inside a standard shortened 200 l plastic waste drum liner. This was monitored as a rotating cylinder and as a disk counted on each broad side in order to determine the counting geometry with the best combination of low detection levels and uncertainties.

3.4.1 Measurements on rotating cylinder

The plastic drum liner was cut to 50 cm in height and had an internal diameter of 55 cm and external diameter of 56.4 cm. Soft waste was represented by 11 kg of paper rolls, with a fill height of 38 cm, giving a typical soft waste bulk density of 0.12 g/cc. The cylinder was placed on a rotating turntable and a general purpose, flush collimated, HRGS detector (HPGe, N-type, crystal: 6.14 cm diameter x 8 cm thick) located at 10, 20, and 25 cm offsets from the centre/middle of the lead brick shielded drum liner (figure 6).

Fig. 6. Counting Geometry for cylinder

A traceable Am-241 source (259 kBq encapsulated in thin plastic) was placed inside the waste material and the detector response (cps/Bq) measured at different locations. Each detector response factor was weighted, according to the volume element represented by the source position, in order to derive the detector response for uniform distribution of Am-241. This was plotted against detector offset, together with the maximum and minimum detector response (figure 7). Data points in figures 7 and 8 were fitted using polynomial (poly) curves.

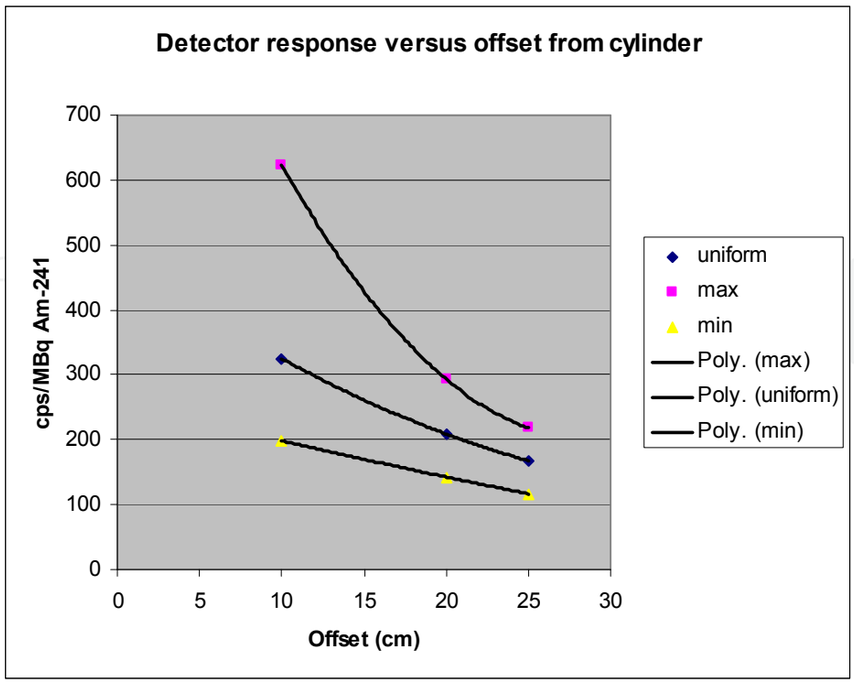

Fig. 7. Detector response factors for cylinder

As the offset reduced detector response increased, but uncertainties increased more sharply. SNAP software was used to generate comparative uniform response factors that were similar to those measured (table 3).

Detector offset (cm)	Measured	SNAP
10	324.7	283.5
20	208.7	194.3
25	167.5	161

Table 3. Response factors (cps/MBq) for cylinder assay

3.4.2 Measurements on waste disk

The Am-241 source was measured at 5 cm intervals along the detector axis and at 5 cm intervals at 7.9, 15.7, 23.6 and 27.5 cm off axis. All response factors were adjusted for attenuation by 0.1 g/cc density soft waste by using tables of mass attenuation coefficients and path-lengths from the source positions to the detector. The uniform response factor, for a 10 kg disk of waste measuring 55 cm in diameter by 40 cm depth, was then calculated by weighting each source location according to the volume element that it represented for detector locations at 10, 20 and 25 cm from the centre of the broadside of the disk. For two sided counting (i.e. inverting the bag halfway through the count), the maximum response was calculated as the average of the maximum and minimum on-axis response factors. The minimum response was achieved for a source location at the mid edge of the disk. Figure 8 shows that all response factors increased as detector offset reduced, but uncertainties rose even more sharply than noted for the cylinder (figure 7).

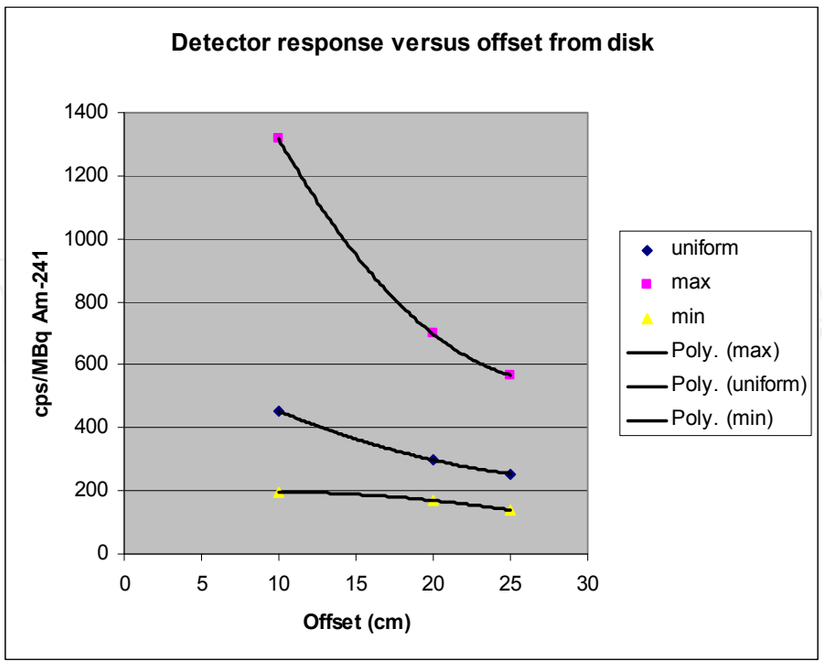

Fig. 8. Detector response factors for disk

Table 4 summarises the close agreement between measured response factors for the disk geometry with those calculated using SNAP software.

Detector offset (cm)	Measured	SNAP
10	453	446
20	297.9	308.4
25	253.9	255.1

Table 4. Response factors (cps/MBq) for disk assay

3.4.3 DL calculations

The DLs (2σ) in table 5 were calculated using equation 1 with: B = 0.2 cps; T = 1000s; G = 10 kg; R = 10 and the response factors in tables 3 and 4 and figures 7 and 8 at 10 cm detector offset.

Geometry	Uniform	Minimum	Maximum
Disk	0.063	0.021	0.14
Cylinder	0.087	0.045	0.14

Table 5. Pu DLs (Bq/g) for bagged waste assay

Better DLs were achieved with the disk geometry. However, the 0.15 Bq/g clearance level for Pu compositions was only just achieved for activity located at the minimum response position within the waste bag. Furthermore, Pu compositions with higher Pu/Am-241 activity ratios could not be confidently placed in the exempt category.

The performance of the technique could be enhanced by using a larger diameter HPGe crystal since Am-241 response factors are proportional to the detector frontal surface area. For example an 85 mm diameter probe should improve DLs by a factor of two.

Compressing the disk and increasing the waste mass, was also estimated to give a factor of two improvement in DLs. However, spectral summing could give a factor of ten improvement if the spectra from 100 bags were added together (equation 1).

A further factor of 3 improvement could be achieved by monitoring within a shielded room, such as that used for in-vivo monitoring (IVM), where backgrounds are a factor of 10 lower. At present this technique is still being developed and not yet being routinely used to reclassify wastes.

3.5 Reclassification of soft bagged Pu VLLW using GC

GC had the potential to assay wastes with consistent isotopic fingerprints, at the new exempt thresholds of < 1 Bq/g U and < 0.15 Bq/g Pu, when sited in areas with low/non-fluctuating photon background. However, careful segregation of wastes was required because the background counts were significantly modified by waste characteristics, such as: NORM content, density, composition and distribution in the counting chamber.

3.5.1 Measurements on uncontaminated materials

Only low bulk density, low Z materials were examined because of the difficulties in GC calibration for high density, high Z objects (Miller, 2010). Approximately 35 kg of each material type was spread evenly throughout the 350 l counting chamber to give a bulk density of 0.1 g/cc. Repeat 600 s counts were done to generate ten measurements for each material. Table 6 summarises the mean and σ values achieved for the net counts (i.e. gross counts minus counts for the continuously updated GC background).

Material	Net cps	σ	Net cps + 2σ
Empty chamber	1.8	9.7	21.2
PVC	3.4	6.1	15.6
Tyvek	25.0	3.8	32.6
Paper	41.1	9.0	59.1
Marigold gloves	61.5	16.3	94.1
Overshoes	66.1	5.9	77.9
Supertex coveralls	68.0	15.1	98.2
Orange coveralls	138.4	6.9	152.2

Table 6. GC results for uncontaminated materials

The results in table 6 highlight the importance of segregating waste into material types having similar net cps above background. Detection levels (2σ) of 0.09 Bq/g Pu were calculated using equation 2, where: σ = 10 cps; F = 0.0606 cps/Bq Am-241; G = 35 kg; R = 10. Variations in F (DL) with source location were around +/- 25 % (Miller, 2010).

$$DL = (2\sigma/FG)R \quad (2)$$

3.5.2 Measurements on Pu wastes

Table 7 summarises the results for eight bags of waste produced by a Pu facility. The sample activity was calculated by dividing the net cps by the Pu counting efficiency and the sample mass. The blank activity (i.e. blank cps/FG) was then subtracted to give the Pu activity measured above the apparent Pu activity indicated for the blank.

Material	kg	Net cps	Sample (Bq/g)	Blank (Bq/g)	Pu (Bq/g)
PVC	29.9	-8.6	-0.047	0.016	-0.063
PVC	30.2	-5.4	-0.030	0.016	-0.046
PVC	33.7	25.4	0.124	0.016	0.108
PVC	28	10.2	0.060	0.016	0.044
PVC	35.3	9.8	0.046	0.016	0.030
Orange coveralls	17.2	152.5	1.463	0.653	0.810
Tyvek	13.1	1944	24.488	0.118	24.370
Cotton gloves	30.8	35.1	0.188	0.112	0.076

Table 7. GC results for Pu contaminated materials

The tyvek bag indicated a total activity of 24.37 x 13.1 = 319.2 kBq Pu which was equivalent to 31.92 kBq Am-241 since the GC was calibrated using an Am-241 source and a Pu/Am-241 activity ratio of 10/1 because Pu makes no significant contribution to the photon count rate.

The tyvek bag was placed in a standard 200 l waste drum and assayed using SNAP. This indicated 38.8 kBq Am-241 which was 22 % higher than the GC, but within the +/- 25 % uncertainty established for both techniques.

3.5.3 Measurements on NPL standard

GC calibration has been achieved using a volume weighted technique (Miller, 2010). Verification has been done using a certified NPL volume source that fills the GC counting chamber. This consists of a corrugated carton (62x62x84 cm) containing a series of nine filter papers (each 58x58 cm), each spiked uniformly with a standard solution of Am-241 and each separately laminated. The filter papers were interspersed within the carton between a series of ten polythene inactive low density inserts (each 60x60x8 cm). The total Am-241 activity was 2857 +/- 12 Bq (reference time 01/01/10) in 29 kg (around 0.1 Bq/g and 0.1 g/cc).The mean cps/Bq Am-241 counting efficiency for the source (6.14 %) was similar to that achieved using volume weighted Am-241 point source measurements in soft waste (6.06 %). A blank NPL source, with no added Am-241, gave no net counts above background.

4. U waste reclassification

The lower specific activity of U compositions, compared to Pu compositions, results in a relatively low proportion of U ILW. For example, at the 4,000 Bq/g ILW threshold, a typical 60 kg 200 l drum would contain: 80 mg Pu (3 GBq/g); 80 g Enriched Uranium (EU, 3 MBq/g) and 12 kg Depleted Uranium (DU, 20 kBq/g). Studies have shown that most drums contain < 1g of Pu or U and underestimation of activity, due to self absorption within lumps

of Pu or U, was relatively rare at low activities and was be addressed using the SNAP lump correction routine (Miller, 2007, 2008, 2009a).

4.1 Reclassification of drummed U ILW using SNAP

Around 100 of the most active EU drums were assayed using SNAP and the SGS. Figure 9 shows that the results correlated reasonably well, but the SNAP results were higher because small lump corrections were required to obtain consistent results at all photon energies. The need for a lump correction was flagged by abnormally low 143/205 kev peak ratios, but was not performed by the SGS.

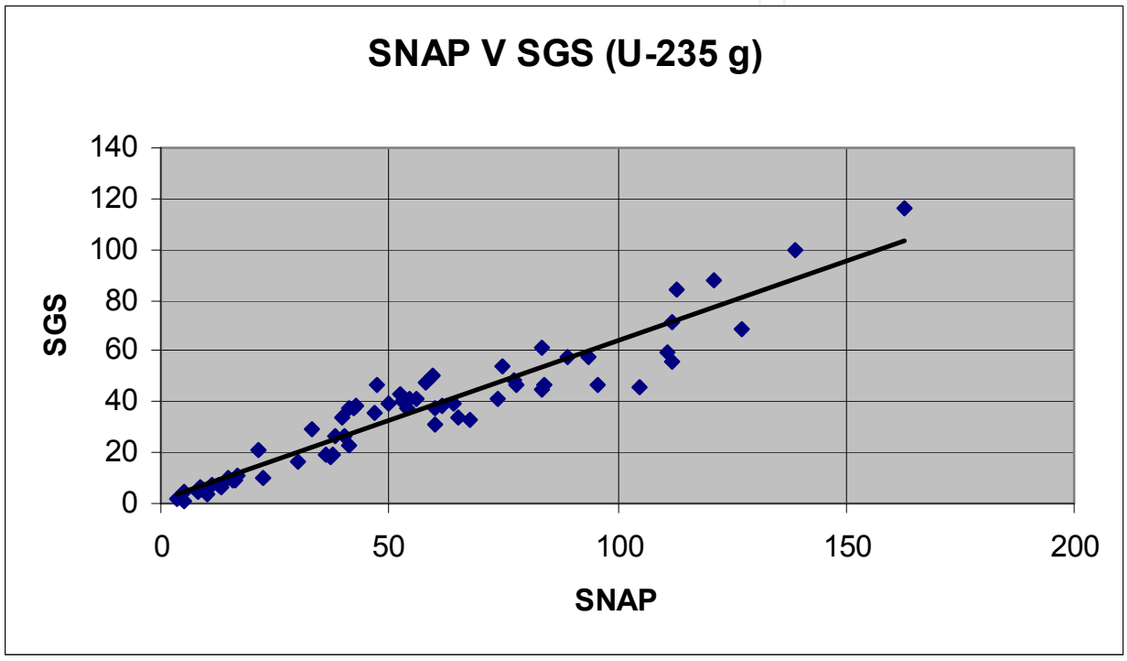

Fig. 9. Comparative results for SNAP and SGS

4.2 Reclassification of bagged U VLLW using SNAP

SNAP software was used to calculate detector response factors, for bagged U VLLW in a disk geometry, like those presented in table 4 for Am-241 @ 60 keV. For DU the 93 keV photon from Th-234 was assumed to be in secular equilibrium with U-238. For EU the 186 keV photon was a direct measurement for U-235. Table 8 summarises the comparative uniform response factors.

The DLs (2σ) in table 9 were calculated using a background count rate of 0.2 cps for each photon, 1000s count time, 10 kg waste, the response factors in table 8 and figure 8 at 10 cm and typical isotopic multipliers (i.e. Am-241 x 10 = Pu; U-235 x 40 = EU; Th-234 x 1.55 = DU).

Although not measured, the maximum DLs for U compositions are expected to be well within the 1 Bq/g clearance level for U wastes based on comparison with maximum an minimum Am-241 (Pu) source measurements (figure 8). This recently developed technique has not yet been used for routine measurements.

Detector offset (cm)	Nuclide	keV	Measured	SNAP
10	Am-241	60	453	446
20	Am-241	60	297.9	308.4
25	Am-241	60	253.9	255.1
10	Th-234	93	-	67.3
20	Th-234	93	-	46.5
25	Th-234	93	-	38.5
10	U-235	186	-	550.3
20	U-235	186	-	378.9
25	U-235	186	-	313.4

Table 8. Comparative detector response factors for VLLW disk (cps/MBq)

Material	Uniform	Minimum	Maximum
Pu	0.063	0.021	0.14
DU	0.065	-	-
HEU	0.21	-	-

Table 9. Comparative DLs for VLLW disk (Bq/g)

4.3 Reclassification of bagged U VLLW using GC

Thirty waste bags, from a enriched uranium facility, were assayed using Cronos. The waste was mixed material (PVC, paper, coveralls, gloves) and so it was not possible to subtract a blank activity for the apparent EU Bq/g from the waste material itself. Hence the net cps was divided by the EU counting efficiency and the sample mass to give a total EU activity which included the apparent EU activity from the waste material in addition to any EU present. The two most active bags were checked using SNAP and this gave consistent results (table 10). Around 70 % of the bags indicated < 1 Bq/g HEU (table 11). DLs, given a 30s count time and σ = 16 cps, were around 0.1 Bq/g for the heavier bags and 1 Bq/g for the lighter bags.

Bag	GC	SNAP	GC/SNAP
1	23.9	19	1.26
8	49.4	41.8	1.18

Table 10. Comparative EU mass (U-235 mg)

The background σ, achieved for 600 s counting (3.8-16.3 cps), was much greater than the square root of the background (√B = (√1800x600)/600 = 1.7 cps). Also, increasing count time from 60s to 600s gave little reduction in σ compared to the √10 = 3.2 x reduction in √B cps. This highlights the importance of locating GC in an area of low and non-fluctuating photon background. High energy photons from NORM (e.g. K-40 in building materials) and cosmic radiation can penetrate the GC lead shielding and generate lower energy photons that increase the background σ. Locating GC within a shielded room, as used for in-vivo monitoring equipment, would be a costly, but potentially very beneficial option.

Bag mass (kg)	Net cps	Bq/g
5.9	482	12.9
7.1	8.0	0.2
9.4	30.5	0.5
33.7	52.2	0.2
4.4	6.1	0.2
7.3	15.1	0.3
3.8	-9.3	-0.4
3.4	996.1	46.1
10.1	14.2	0.2
6.8	12.0	0.3
7.8	30.4	0.6
3.1	22.2	1.1
2.7	-6.6	-0.4
15.6	-0.7	0.0
6.0	110.1	2.9
4.1	10.4	0.4
11.0	132.7	1.9
5.9	12.5	0.3
6.1	22.8	0.6
7.5	8.4	0.2
10.3	7.3	0.1
11.7	49.7	0.7
4.2	20.8	0.8
2.2	13.6	1.0
10.3	41.9	0.6
5.4	61.0	1.8
5.5	16.8	0.5
4.4	21.5	0.8
3.9	150.9	6.1
6.0	59.1	1.6

Table 11. GC results for EU contaminated waste bags

5. Conclusions

The techniques presented have been successfully applied to the majority of waste streams encountered at AWE. However there are two main areas of weakness. Firstly, the potential for underestimation with high density, high Z waste streams. Secondly, achieving adequate DLs for Pu compositions with high Pu/Am-241 activity ratios.

The NPL Measurement Good Practice Guide, for radiometric non-destructive assay, indicates that underestimation caused by even the most severely attenuating wastes reduces to factors of 2 or 3 for distributed contamination that is typical of AWE wastes. Hence, the techniques can be applied, with caution, to the denser waste streams.

Improvement in DL performance may be achieved by a combination of improved shielding, more efficient detectors and spectral summing for similar waste packages.

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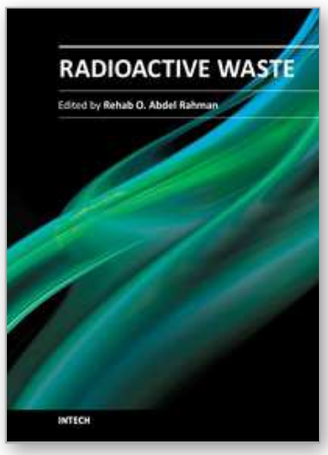

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The safe management of nuclear and radioactive wastes is a subject that has recently received considerable recognition due to the huge volume of accumulative wastes and the increased public awareness of the hazards of these wastes. This book aims to cover the practice and research efforts that are currently conducted to deal with the technical difficulties in different radioactive waste management activities and to introduce to the non-technical factors that can affect the management practice. The collective contribution of esteem international experts has covered the science and technology of different management activities. The authors have introduced to the management system, illustrate how old management practices and radioactive accident can affect the environment and summarize the knowledge gained from current management practice and results of research efforts for using some innovative technologies in both pre-disposal and disposal activities.

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