Testing and Performance Validation of a Shielded Waste Segregation and Clearance Monitor Designed for the Measurement of Low Level Waste-13043

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ABSTRACT

This paper describes the development, testing and validation of a shielded waste segregation and clearance monitor designed for the measurement of low-density low-level waste (LLW). The monitor is made of a measurement chamber surrounded by detectors and a shielded outer frame. The shielded chamber consists of a steel frame, which contains typically 1.5 inches (3.81 cm) of lead and 0.5 inches (1.27 cm) of steel shielding. Inside the shielding are plastic scintillator panels, which serve as gross gamma ray detectors. The detector panels, with embedded photomultipliers, completely surround the internal measurement chamber on all 6 sides. Care has been taken to distribute the plastic scintillator detectors in order to optimise both the efficiency for gamma ray detection and at the same time achieve a volumetric sensitivity, which is as uniform as possible. A common high voltage power supply provides the bias voltage for each of the six photomultipliers. The voltage signals arising from the detectors and photomultipliers are amplified by six sensitive amplifiers. Each amplifier incorporates a single channel analyser with both upper and lower thresholds and the digitised counts from each detector are recorded on six scalars. Operation of the device is by means of a microprocessor from which the scalars are controlled. An internal load cell linked to the microprocessor determines the weight of the waste object, and this information is used to calculate the specific activity of the waste. The monitor makes background measurements when the shielded door is closed and a sample, usually a bag of low-density waste, is not present in the measurement chamber. Measurements of the minimum detectable activity (MDA) of an earlier large volume prototype instrument are reported as part of the development of the Waste Segregation and Clearance Monitor (WSCM) described in the paper. For the optimised WSCM a detection efficiency of greater than 32% was measured using a small Cs-137 source placed in the centre of the measurement chamber. Small sources have also been used to determine the spatial variation of the detection efficiency for various positions within the measurement chamber. The data have been used to establish sentencing limits and different "fingerprints" for specific waste streams including waste streams containing fission products and others based on other radionuclides including Am-241. Some of the test data that are presented have been used to validate the instrument performance. The monitor is currently in routine use at a nuclear facility for the measurement and sentencing of low-density low activity radioactive waste.

INTRODUCTION

This paper describes the development, testing and validation of a shielded waste segregation and clearance monitor (WSCM) designed for the measurement of low-density low-level waste (LLW) and waste that can be consigned as below regulatory concern (BRC) or out of scope of regulation (OOSOR waste, formerly Exempt). Because it is used for measuring low-density, low activity waste contained in bags, the WSCM is often referred to as a "bag monitor". The work was performed over a period of time and led to the optimisation of the ANTECH model G3301-200 WSCM. In the paper the mechanical design of this instrument is described as is the microprocessor based electronic counting system it employs. The counting and basic operation of the monitor is controlled by firmware, which runs in the microprocessor. A laptop or panel PC connected to the WSCM by a USB communications link runs an ANTECH software application which provides a user interface to the microprocessor to enable the system to be configured, measurements initiated, data recorded and analysed, results printed and data saved.

As part of the development process for the WSCM, measurements have been made on a prototype and upgraded legacy instrument. Minimum detectable activity is reported for a variety of radionuclides including Am-241. The measurement of Am-241 is of particular importance as it can be used as an indicator of Pu-239, which has a low specific activity. In contrast, Am-241 produces an abundant signature of 60 keV gamma rays. An improved MDA for Am-241 is reported for the WSCM.

DESIGN OF AN OPTIMISED SHIELDED WASTE SEGREGATION MONITOR FOR GROSS GAMMA COUNTING

Plastic scintillator detectors and a shielded outer frame surround the measurement chamber of the waste segregation monitor. The shielded chamber consists of a steel frame, which contains typically 1.5 inches (3.81 cm) or more of lead shielding. Inside the lead shielding are plastic scintillator panels, with embedded photomultipliers, which serve as gross gamma ray detectors. The internal measurement chamber is completely surround by detector panels on all 6 sides in a 4 π geometry. Care has been taken to distribute the plastic scintillator detectors in order to optimise both the efficiency for gamma ray detection and at the same time achieve a volumetric sensitivity, which is as uniform as possible.

A common high voltage power supply provides the bias voltage for each of the six photomultipliers. Detected gamma rays produce scintillations in the plastic scintillator detectors. The light scintillations are converted to voltage pulses in the photomultipliers and the resulting voltage signals are amplified in the six sensitive amplifiers. Each amplifier incorporates a single channel analyser with both upper and lower level discriminator thresholds and the digitised counts from each detector are recorded in six microprocessor-controlled scalars. The upper and lower level discriminator thresholds can be set to reject high or low energy gamma rays and thus optimise measurements.

An internal load cell linked to the microprocessor determines the weight of the waste object, and this information is used to calculate the specific activity of the waste. The monitor makes background measurements when the shielded door is closed and a sample, usually a bag of low-density waste, is not present in the measurement chamber.

DETERMINATION OF MINIMUM DETECTABLE ACTIVITY (MDA)

Measurements were made using an available prototype large volume legacy clearance monitor of 300-litre capacity (with upgraded detectors, electronics and software) designated AWM1. The purpose was to establish the MDA values for a range of relevant radionuclides and especially Am-241 as an indicator of plutonium. Background measurements were made and relevant small point sources of known activity were counted to determine the count-rates above background. The samples were placed in the centre of the measurement chamber and data were collected including background data with no source present in the measurement chamber. The counting efficiency was established by making repeat background measurements and source measurements. The performance was evaluated by calculating detection levels, for a range of radionuclides including Am-241, using the Currie [1] formula presented below:

$$MDA = 3 + (4.65\sigma T \text{ or } \sqrt{(BT)})/(TEM), \qquad \text{(Eq. 1)}$$

Where, the symbols have the following meaning and units:

MDA = Minimum Detectable Activity [Bq/g]

σ = standard deviation of background count rate [counts per second - cps]

B = background count rate [cps]

T = count time [s]

E = counting efficiency [cps/Bq]

M = mass of soft waste [g].

The measured and calculated data for the upgraded legacy counter for different radionuclides of interest using Equation 1 are displayed in Table I.

TABLE I. Measured and calculated data used to compute the MDA for the upgraded legacy counter AWM1.

Radionuclides	**Cs-137**	**Na-22**	**Co-60**	**Cd-109**	**Ba-133**	**Am-241**
Source activity (Bq)	8568.0	3693.28	11742.44	9774.05	21019.02	76500.0
cps above background	1764.0	2993.0	6860.0	248.0	4519.0	5892.0
Response factor (Counting efficiency)	0.2059	0.8104	0.5842	0.0254	0.2150	0.0770
Background (cps) at Wallingford	1466.0	1466.0	1466.0	1466.0	1466.0	1466.0
Count time (seconds)	600.0	600.0	600.0	600.0	600.0	600.0
Mass (g)	3000	3000	3000	3000	3000	3000
Minimum Detectable Activity (MDA) (Bq/g)	0.0118	0.0030	0.0041	0.0955	0.0113	0.0492

The data in Table I for various small source measurements include the background data and the resulting MDA based on the use of Equation 1. The variation of the response factor or counting efficiency has to do with the variation of the number of gamma rays and branching ratios of the nuclides and the efficiency of the chamber for the different gamma ray energies. The results for Am-241 are relatively poor compared to the results presented later in the paper for the G3301-200 instrument, which was optimised as a result of the initial study employing the upgraded AWM1. Although the counting efficiency of the legacy counter was increased as a result of the upgrade, which included installing larger plastic scintillator panels on 5 of the 6 internal surfaces, the counting geometry remained a limitation. Due to the original design of the instrument, it was not possible to locate a plastic scintillator panel below the measurement chamber so that 4 π counting geometry was not achieved.

PERFORMANCE EVALUATION FOR THE G3301-200 WSCM

In part as a result of the work reported above, a higher efficiency waste segregation clearance monitor with a 200-litre measurement chamber volume was developed and designated the G3301-200. This optimised instrument employs plastic scintillation detectors in near 4 π counting geometry (detectors on 6 sides of a rectangular counting chamber) and counts all photons from around 50 to 2,000 keV. The measured detection limit is about 400 Bq (10.8 nCi) for Am-241 in 60 s for a photon background of about 0.1 μSv/hr. Lead and steel shielding of 50 mm thickness is used surrounding the counting chamber with a volume of 200 litres. The G3301-200 has a temperature operating range of 5 to 45 ^{o}C with up to 90 % non-condensing humidity. The unit is shown in Figure 1. Figure 2 shows the interior of the unit during commissioning and testing at ANTECH.

Figure 1. Model G3301-200 Waste Segregation and Clearance Monitor

Figure 2. Interior of the measurement chamber of the Model G3301-200 Waste Segregation and Clearance Monitor showing the bar code of a waste bag being recorded.

MEASUREMENT PERFORMANCE

A number of small Cs-137 sources were employed to evaluate and calibrate the G3301-200 WSCM. The sources were placed at the centre of the chamber and the count-rate was measured for successive measurements as the activity was increased with the addition of small sources. The sources and their activity are displayed in Table II.

TABLE II. Small Cs-137 sources employed for the efficiency measurements used for Cs-137 calibration (reported in Table III).

Source	Activity (Bq)	Activity (μCi)
S12	52602	1.421
S23	279572	7.556
S32	8066	0.218
S33	6488	0.175

The data including the measured detection efficiency for Cs-137 are displayed in Table III, below.

TABLE III. Measured response function for a series of small Cs-137 sources placed at the centre of the measurement chamber.

Sources placed in centre of chamber	Total Source Activity (Bq)	Total 661.7 keV gamma rays emitted	Number of gamma rays detected	Source Detection Efficiency
33	6488	5488.8	2506.0	38.63%
32	8066	6823.8	2667.4	33.07%
32,33	14554	12312.7	5166.1	35.50%
12	52602	44501.3	17048.2	32.41%
12,33	59090	49990.1	19547.1	33.08%
12,32	60668	51325.1	19722.6	32.51%
12,32,33	67156	56814.0	22133.8	32.96%
23	279572	236517.9	94229.5	33.70%
23,33	286060	242006.8	96443.1	33.71%
23,32	287638	243341.7	96601.7	33.58%
23,32,33	294126	248830.6	98851.2	33.61%
23,12	332174	281019.2	109828.4	33.06%
12,23,33	338662	286508.1	112058.3	33.09%
12,23,33	340240	287843.0	112171.1	32.97%
12,23,32,33	346728	293331.9	114374.3	32.99%

Note that with the optimised design the unit achieves a central detection efficiency (sources placed in an empty chamber) of in excess of 32%. The calibration data for Cs-137 are displayed in Figure 3.

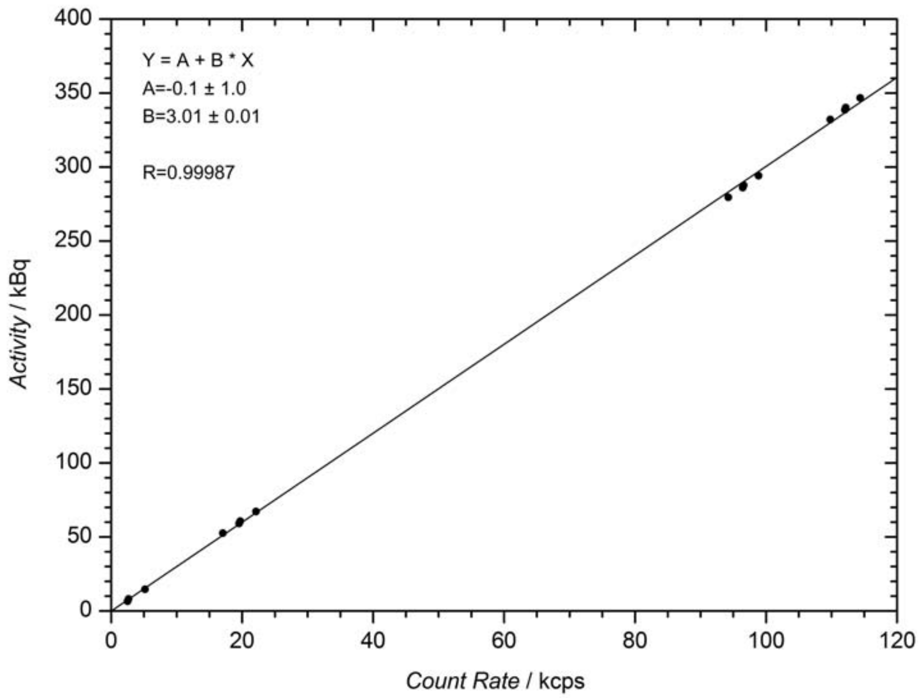

Figure 3. Calibration of the model G3301-200 WSCM for Cs-137.

A small Cs-137 source was placed at various positions on rectangular grids on horizontal planes at various heights in the measurement chamber and a response measurement was made in order to determine the spatial variation of the chamber response. The data for the rectangular grid measurements on the horizontal plane at the chamber mid-height are presented graphically in Figure 4. This plane at the mid-height of the chamber has the greatest variation of the response of all of the response measurements made on planes at different heights in the chamber.

The worst-case relative variation of the count rate on the mid-height plane (maximum – minimum) / maximum was 3.58% with the maximum relative standard deviation of the measured data of 4.20%. These worst-case results confirm that the design objective of minimising the variation of the response in the chamber has been achieved.

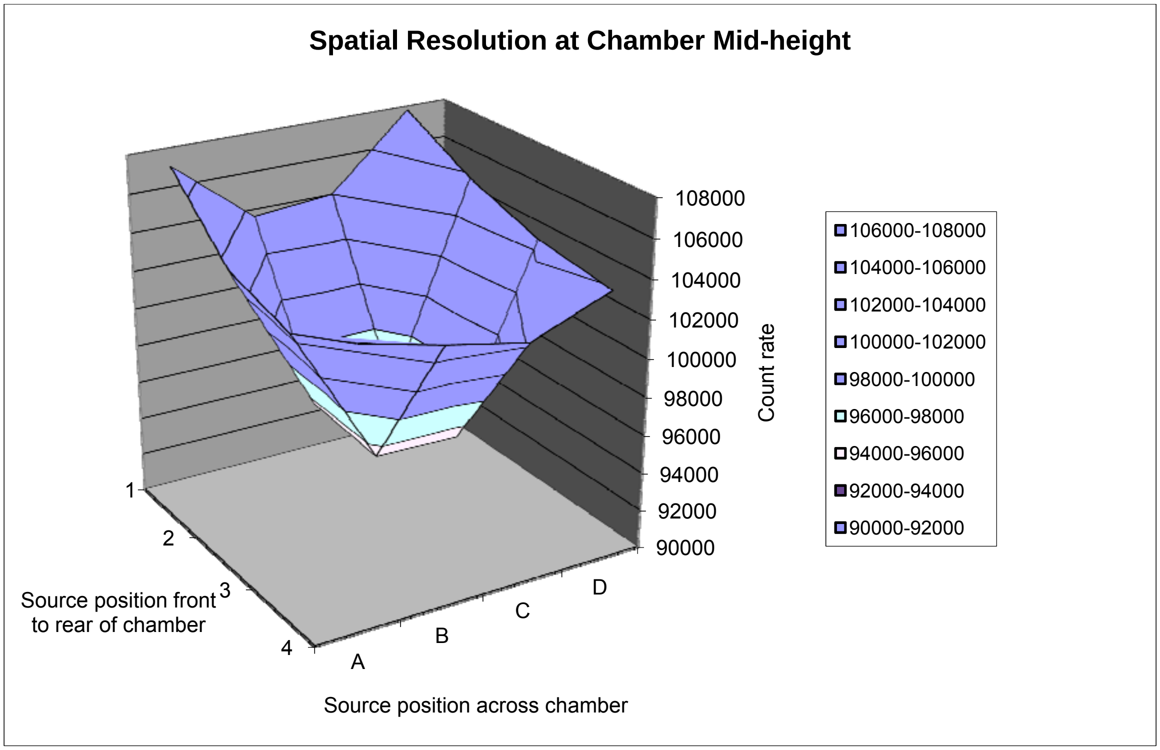

Figure 4. Plot of the spatial variation of the response function at the mid-plane of the measurement chamber based on measurements with a small Cs-137 point source.

Table IV summarises the results achieved, using two different count times (100 s and 600 s) and using either σT or √(BT) in Equation 1 to determine the MDA for measuring Am-241 using the WSCM. Note the significant improvement in the result compared to the earlier result for the AWM1. This is due in part to the smaller measurement chamber (200 rather than 300 litres) but also the more efficient geometrical design and an improvement in the amplifier technology employed in the G3301-200.

TABLE IV. G3301-200 Am-241 detection limits (Bq/g)

Monitor	100 s (σT)	100 s (√BT)	600 s (σT)	600 s (√BT)
G3301-200	0.019	0.008	0.007	0.003

CONCLUSIONS

This paper describes the development, the design and the performance of the model G3301-200 Waste Segregation and Clearance Monitor. The instrument is designed to sentence and assay low-density radioactive waste, which can be either low level waste, (LLW), very low level waste (VLLW) or potentially waste which is below regulatory concern (BRC) or, as it is now known, waste that is Out of Scope of Regulations (OOSOR). At the Dounreay Site, a G3301-200 is used to confirm consignor characterisation as being either radiologically clean or OOSOR. The potential application of the instrument for very low activity measurements is indicated by the MDA data, which have been presented for a less efficient system.

The work has identified the high detection efficiency achieved by the optimised measurement chamber of the WSCM as demonstrated by measurements with small Cs-137 sources and its use at the Dounreay Site for measuring OOSOR waste. Further detailed measurements have demonstrated that the chamber has achieved a high degree of uniformity of response with only small special variations.

REFERENCES

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2. Private Communication with Timothy J. Miller of AWE on detection level determination and the possible effect of the presence of NORM (naturally occurring radioactive material) in reducing the effectiveness of the determination of Am-241.

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