G3102-4216

Excavator Mounted Bucket Assay System (Embassy)

Introduction

The Excavator Mounted Bucket Assay System EMBASSY is designed to assay and determine the radiological contents of an excavator bucket [1]. It was intended for detecting, assaying and segregating Technically Enhanced NORM (Naturally Ocurring Radioactive Material) but it can be applied to almost any radionuclide contaminant found in soil, gravel or rubble. These encompass both activation products and fission products including Co-60 and Cs-137.

A great advantage of the EMBASSY System is that material handling is greatly reduced as uncontaminated soil or rubble may be returned directly to the source or excavation site with no further handling required. The identified contaminated material can then be sentenced for direct disposal or futher handling and processing as necessary. The sentencing parameters that can be set-up and achieved can be In-Scope vs Out-of-Scope, VLLW vs LALLW, LALLW vs LLW or any other subsets as applicable. This therefore enables real-time, in-situ waste sentencing and thereby reduces time and cost associated with sentencing based upon comprehensive, representative waste sampling and analysis.

Description and Operation

EMBASSY uses a Gamma Ray Spectroscopy Assay and Measuring Technique, which is able to identify and quantify a wide range of gamma ray emitting radionuclides. It also employs Gamma Ray Fingerprint Data to infer and quantify other radionuclides which are not gamma emitters or which have low branching ratios.

The device consists of a large Gamma Ray Scintillation Detector Assembly mounted in a shadow shielded housing which is temperature controlled. The detector consists of a high efficiency 4 x 2 x 16-inch collimated thallium-doped Sodium Iodide (NaI(Tl)) Scintillator with a relative efficiency of greater than 200% and it is housed in a graded lead and steel shield. The detector is mounted in a manner to include temperature stabilization and vibration reduction. The detector assembly can be seen in Figure 1, above and in front of the excavator operator's cab.

The shielded detector unit is fixed to a shaft with a cam follower mechanism to cause the detector assembly to rotate as it descends along the shaft.

Fig 1. This photograph of the EMBASSY System shows the shielded detector assembly in the upper storage position, rotated towards the front of the operator cab. Note: that the excavator bucket is in the measuring position.

The shaft is fixed at two positions to the heavy steel protective grille, which is located in front of the excavator operator's cab. Alternatively, the shaft may be fixed to a frame system, which is bolted to fixing positions on both the front and top of the excavator. An electric hoist mounted above the operator's cab, raises and lowers the shielded detector, which in-turn moves along the shaft.

As the detector assembly is lowered, it moves down the shaft and simultaneously rotates so that as it reaches the bottom of the shaft it is correctly positioned above the excavator bucket, (NOTE: the bucket is in the measurement position). The excavator bucket (shown in the measurement position) and the detector assembly in the upper storage position can be seen in Figure 1. EMBASSY derives electrical power (24VDC) from the excavator.

Performing a Measurement

When not in operation, the shielded detector is raised to the storage position above the operator and at the top of the cab assembly. In order to perform a measurement, the operator fills and levels the contents of the excavator bucket and positions the filled bucket at the pre-determined measurement position underneath the excavator boom as shown in Figure 1 and 2.

With the bucket in the measurement position, the shielded detector is lowered (and rotated) from the storage position using the electric cable hoist. The shielded detector is thus moved to a position in front of the cab and immediately above the filled excavator bucket. By positioning the bucket in line with the spring-loaded rod fixed to the front of the operator cab, the excavator operator has only to consider accurate positioning of the bucket curl angle. The shielded detector is shown in the measurement position in Figure 2.

Fig 2

This photograph of the EMBASSY System shows the shielded detector assembly at the bottom of its travel down the shaft and rotated into the measurement position. Note: that the excavator bucket is in the measurement position below the detector.

Measurements using the EMBASSY System are controlled and approved by a Measurement Technician who remains outside of the radius of the operational arc of the excavator. He employs a ruggedized tablet computer, which communicates directly with the EMBASSY System over a wireless link.

Once the excavator operator has positioned a loaded bucket for measurement, the Measurement Technician repositions the shielded detector assembly over the excavator bucket, performs the measurement and then returns the detector assembly to the storage position. Following the measurement the analysis computer (which is part of the EMBASSY System) analyses the measurement data and transmits the measurement results to the tablet computer operated by the Measurement Technician. The data is also stored as an industry standard, vendor independent, XML N42 file format for nuclear instrument files, enabling easy data interrogation (if required).

The analysed measurement data includes the measured Gamma Ray Spectrum and the calculated specific activity of selected radionuclides and other radionuclides using fingerprint data. With this data the Measurement Technician determines and approves the disposition of the contents of the excavator bucket and instructs the excavator operator as to the appropriate disposition of the bucket contents.

The excavator operator does not require any special training and it is a simple matter to position the excavator bucket in the measurement position for which a guide feature is provided on the EMBASSY support frame. The Measurement Technician requires only a basic knowledge of Gamma Ray Spectroscopy. The Measurement Data Analysis Process is automated so that in most cases, the analysis process makes the sentencing decision for the excavator bucket contents, which is always pre-approved by the Measurement Technician. The data presented to the Measurement Technician includes the analysis results as well as the measured Gamma Ray Spectrum, so that he can assess the quality of the measurement.

Measurement Performance

Although the EMBASSY can be employed for gross gamma measurements, it was designed with full Gamma Ray Spectroscopic capability in order to measure and sentence a wide range of radionuclide contaminates in soil and rubble. As an excavator bucket monitor, EMBASSY has the great advantage that uncontaminated material can be immediately returned to the site with no further handling or processing or enables segregation / stockpiled for sentencing as contaminated waste from the point of excavation to the designated disposal or treatment destination.

The EMBASSY System was originally designed to measure Naturally Occurring Radioactive Materials (NORM), specifically Ra-226 in an excavator bucket with sensitivity of better than 0.5 Bq/g (13.5 pCi/g). Fission and activation products, based on measuring either Cs-137 or Co-60, can be measured at even lower detection levels. MDAs for a range of radionuclides of interest are displayed in Table 1.

Table 1 is a compilation of calculated Minimum Detectable Activities (MDA) and UK In-Scope / Out-of-Scope Threshold Concentrations for a range of radionuclides.

Radionuclide	Co-60	Cs-137	Eu-152	Ra-226 (NORM)	U-235+	U-238+ (Pa-234m)	Am-241
Gamma Ray Energy (keV)	1173.2	661.66	344.3	186.2	182.3	1001	59.5
Measurement Time (s)	60	60	60	60	60	60	60
Detector Efficiency	1.88E-04	2.08E-04	2.17E-04	1.81E-04	1.81E-04	1.94E-04	9.12E-05
MDA (Bq)	9896	9508	17360	-	17676	794716	120906
Specific MDA (Bq/g)	7.5E-03	7.2E-03	1.3E-02	5.0E-02	2.3E-02	6.0E-01	9.1E-02
In-Scope / Out-of-Scope Threshold (Bq/g)	0.1	1.0	0.1	0.5	1.0	1.0	0.1

In the case of NORM measurements, preliminary test measurements of soil containing both Ra-226 and elevated levels K-40 confirm that the Ra-226 content can be determined with precision of about 30% at a specific activity of 0.05 Bq/g (1.35 pCi/g) and with precision of about 12% at a specific activity of 0.15 Bq/g (4.05 pCi/g).

The data in Table 1 have been calculated based on a background spectrum measured by EMBASSY, assuming a Sand Matrix (density 1.579 g.cm^{-3}) and an excavator bucket volume of 0.84 m^3. EMBASSY can be configured to work with a variety of excavator types and bucket sizes. The operation of EMBASSY is based on the assumption that both the source distribution and the density of material in the bucket are uniform. The measurement model takes into consideration the attenuation of the Gamma Ray Measurement Signal from the material within the bucket and the background shielding provided by the steel which makes up the excavator bucket.

The Detection Limit Count Rate is calculated using the ISO standard 11929-3, as follows:
(1)

$$R_{DL} = 2k_{1-\alpha}\sqrt{\frac{R_0}{t}\left(1+\frac{b}{2l}\right)}$$

Where $K_{1-\alpha}$ is the Weighing Value for a given Confidence Interval ($k_{1-\alpha}$ = 1.96 for a 95% Confidence Interval) R_o is the Background Counting Rate for a given ROI, *l* is the width in channels of the regions on the side of the ROI that are used to estimate R_o, and *b* is the width of the ROI in channels.

The minimum Detectable Activity *(MDA)* of a specific nuclide is related to the DL Count Rate, R_{DL}, *by:*
(2)

$$MDA = \frac{R_{DL}\cdot}{\varepsilon(E)\cdot\gamma\ 0.01}$$

Where *ε(E)* is the Detection Efficiency of the detector for photons of the energy *E* and *γ* is the Branching Ratio (in %) for the particular gamma-ray of the specific nuclide.

The results for the MDA and specific MDA are given in Table 1, above.

Calibration

The calibration of the EMBASSY instrument is quite complex due to the nature of the measurement geometry and therefore differs from the calibration process employed in more conventional Scintillation Detector applications [2]. The Scintillation Detector is modelled as a Distributed Detector and the bucket represents a Distributed Source. An MCNP Monte Carlo model is employed to determine the Detector Calibration Function.

The calibration was confirmed by measuring a bucket containing a known amount of KCl dissolved in solution with known K-40 content. The measurements agreed to better than 10% despite a high K-40 natural background at the measurement location.

Conclusions

EMBASSY provides an efficient and convenient methodology of achieving Laboratory Quality Measurements in the field. The typical conservative throughput of EMBASSY, assuming the bucket size and soil type of Table 1 and a bucket measurement time of 60 seconds is between 10 and 20 metric tonnes per hour. This is based on an estimated 3 minute measurement and analysis cycle time and a conservative total of two minutes for the excavator operator to fill and position the bucket and subsequently empty the bucket ready for the next cycle. In practice significantly higher throughput can be achieved.

The great advantage of the EMBASSY System is that uncontaminated material can be returned to the excavation site once it has been measured, with no further requirement for handling or processing. EMBASSY also provides significant time and cost saving as only the material measured above the contamination threshold is retained for further processing, transport and disposal. EMBASSY enables efficient segregation of contaminated and uncontaminated material at the point of excavation which ultimately means that disposal costs and off-site sentencing timescales are significantly reduced.

References

1. Robin Strange, John Mason, Chris Hannon, Nick Chambers, Lynn Cooper, Marc Looman, Lawrence Odell, Tom Jennings, David Maina, Antoine Libens and Michael West, "*Design and Development of an Automated Instrument for Measuring Radioactivity in an Excavator Bucket*", WM2016 Conference, March 6-10 2016, Phoenix Arizona USA (WM16-16246)

2. John A. Mason, Marc R. Looman, Adam J. Poundall, Daniel Pancake and Richard Creed, *"Development and Testing of a Novel Gamma Ray Camera for Radiation Surveying, Contamination Measurement and Radiation Detection"*, Proceedings of INMM2012, Orlando Florida July 2012 (12-A-409-INM)