The Gamma Excavation Bucket Monitor (GEM) System

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1 INTRODUCTION

Nuvia has extensive experience in dealing with both large complex projects and smaller scale initiatives for the characterisation and remediation of radioactively contaminated land. In the UK, the drive to build new houses and commercial developments on previously developed, or brownfield, sites is central to town planning and land-use policies; and encompassed within the definition of a brownfield site is any land that has been contaminated with radioactive material. In the nuclear industry, the focus is on decommissioning, remediation and delicensing to reduce hazards and contamination legacies, enabling the release of land for other uses.

On nuclear licensed sites, contamination may arise from historical disposal and discharges from degraded stored wastes. Radioactive contaminated land can also arise from a wide range of industrial practices that extract or process feedstocks containing naturally occurring radioactive material (NORM). These industrial activities include the processing of rare earth elements, metal smelting and the former practices of extracting radium for luminising and thorium for gas mantles. In many cases, these industrial practices occurred before the products and wastes were regulated as radioactive substances, therefore, materials were disposed of without the controls that are now enforced.

Remediation of radioactively contaminated land to enable reuse does, however, present some challenges, one of which is the management of waste. Radioactive waste disposal can be a costly process, particularly if materials are required to be sent to the UK Low Level Waste Repository. Therefore, critical to any clearance operation is the minimisation of the resulting waste. This is achieved by measuring and segregating materials according to their radioactivity concentration. Technologies used to assay materials need to be capable of measuring to very low levels of radioactivity in accordance with UK legislation, which is regulated by the Environment Agency (SEPA in Scotland). Furthermore, contractors are required to keep to tight deadlines as the costs associated with remediation are high; assay technologies therefore need to be rapid so that downtime is minimal.

Over many years Nuvia has worked on a system capable of real-time assay of excavated materials in support of clearance initiatives. Known as the Gamma Excavation bucket Monitor (GEM), this bulk monitoring system has gained EA approval for effective material segregation and waste minimisation. However, the system was never fully developed into a hardened integrated instrument until recently, when Nuvia was involved in an extensive land remediation project in London. In preparation for a major construction project, the client was under pressure to move over 7000 tonnes of material which was contaminated with NORM. At the time, systems that were available to us had very limited throughput rates of approximately five tonnes per hour. This was not going to meet the client's deadlines, so there was a requirement for us to build a system capable of increasing the throughput from five to hundreds of tonnes per hour.

The following Section describes the early development stages and use of the assay technology. This is followed by a description of the latest system and its deployment on the London site.

2 EARLY DEVELOPMENTS IN BULK MONITORING

The system is based on the measurement of gross gamma activity in mechanical excavator buckets. The gross gamma counts can then be related to a radionuclide fingerprint, *i.e.* radionuclide ratios for a particular operational area, to determine the specific activity (Bq/g) of the material, which may be soil, concrete, brick etc. As it would be both difficult and wasteful to calibrate the system using a mass of soil deliberately contaminated with the relevant radionuclides, the calibration is performed using a radiation transport code, MCNP, which uses the Monte Carlo technique to simulate gamma radiation paths through materials. Physical properties, such as the dimension of the excavation bucket, density of the material and position of the bucket in relation to the detector, are entered into the modelling software and used to calculate the response of the detector to the required radionuclides.

Early versions of the system were used in land remediation projects where soil was excavated then measured to determine its activity content for sentencing purposes. Measurements were taken using a hand-held instrument positioned over the top of the mechanical excavation bucket (Figure 1). The method improved the speed of the assay process, but it did require the excavator to move out of the gamma active area, into a low background location, before measurements could begin, and the safety aspects of having manual handling close to moving machinery was still an issue.

Figure 1 Photograph showing an excavator bucket load of soil being monitored using a hand-held instrument.

A second stage of development was to position the detector in the middle of the excavator bucket to shield it from background radiation, but this failed to improve the throughput or safety aspects. To overcome the issue of enhanced background radiation contributing to the measurement, a third stage of development was to position the detector in the middle of a shielded frame, over which the excavator bucket could be positioned (Figure 2); however, manual supervision and close proximity to moving machinery was still an issue.

Figure 2 Photograph showing the operation of the gross gamma system with the detector placed in the centre of a shielded frame over which the bucket was placed.

3 THE GAMMA EXCAVATION BUCKET MONITOR SYSTEM

The final and most recent stage of development was to build an integrated system that automatically started and stopped the measurement count time, without the need for manual control.

The requirement for such a system became apparent during a major land remediation project in London. Initially NORM contaminated soil was loaded into $1m^3$ builders bags and measured using a portable gamma spectrometry system. This method identified and quantified the radionuclides and automatically generated an Excel spreadsheet that reported the appropriate sentencing route, i.e. Exempt under the UK Radioactive Substances Act PSRE Exemption Order, or Low Level Waste (LLW). However, the rate limiting factors to this assay method were the loading of material into a bag, so that the material (or source) to detector geometry remained consistent, and the positioning of the one tonne container on a turntable in front of the detector.

As the scale of the project increased, the speed of the assay system was clearly not adequate to meet the client's timescales. However, by establishing a radionuclide fingerprint for the material, the gamma spectrometry system enabled us deploy the faster gross gamma measurement technique and to build an automated system to reduce manual control and hence increase safety. In addition, rather than use MCNP to calibrate the system, a range of builders bags, analysed by the gamma spectrometer, were selected and loaded into the bucket, one at a time, to generate a linear correlation between specific activity and monitor response in counts per second (cps). From this the cps that equate to the boundary between Exempt waste and LLW was determined, and this figure was programmed into the electronics.

Figure 3 (and the attached video) shows the GEM system in operation, with the excavator picking up a bucket load of material, which is then positioned over the top of the detector, housed within the heavily shielded frame. The presence of the bucket triggers the proximity switch (metal detector) to initiate the counting routine.

Figure 3 Photograph showing the GEM system in operation with the loaded excavator bucket placed over the detector, thereby initiating a proximity switch the start the analysis.

The count time is dependant on the activity levels required. In this instance, materials with activity levels below the upper limit to the PSRE Exemption Order (14.8 Bq/g per radioelement) were to be separated from soil above this level, which fell into the LLW category requiring disposal at the National LLW Repository. The count time required to achieve the required accuracy of measurement was calculated at 10 seconds and this was programmed into the GEM system. At the end of the count time, the illumination of a green light indicated Exempt waste and a red light indicated LLW. For lower threshold levels, *e.g* the Substances of Low Activity (SoLA) Exemption Order with an upper limit of 0.4 Bq/g, a longer count time of 20 seconds would be required. Furthermore, an additional waste category could be programmed into the system if required, and activities falling into this range would cause the amber light to be illuminated.

At all times the display lights could be seen by the mechanical digger operator, and the data for each bucket load was automatically stored in the log file. The system, therefore, eliminated the need for operatives to be in close proximity to the moving bucket thereby improving the safety aspects of the process. Using this technique Nuvia was able to measure a maximum of 400 tonnes per day, and stored data was downloaded onto a laptop so that a record could be kept of the radioactive inventory and quantities of material. Over a period of twenty-seven working days, 7000 tonnes of material was successfully assayed and the client was able to complete the groundwork ahead of schedule for the construction company.

3.1 Overview of the GEM system

The bucket monitor was built by Bretby GammaTech Ltd (BGT) to Nuvia design requirements, and measures 1.5 x 1.5 metres. It is fitted with a 76 x 152 mm Caesium Iodide (CsI) crystal, which is heavily shielded with lead to minimise the background contribution to the total gross gamma counts. The upper platform is protected by a sheet of polycarbonate, under which is an inductive proximity switch and the gamma sensor. Two banks of coloured lights are mounted on opposite sides of the frame, each bank having a clear, green, amber and red light. The electronic enclosure and battery are also mounted within the metal frame.

When the system is first switched on, the indicator lights are switched on and off, to check that all the lights are working. Once this sequence is complete the system is placed in standby mode, awaiting the first bucket load of material. In the electronic enclosure, the liquid crystal display (LCD) unit gives the following information:

- The date, time and battery voltage.
- The message, 'Waiting for Bucket Load'.
- The date, time, record number, average counts per second (cps) and status level of the last bucket load analysed.

When a filled bucket is placed on top of the frame, the inductive proximity switch is triggered and the message 'Bucket Load Detected' appears on the LCD. In addition, all the lights are illuminated on each side of the frame. The system then waits for 5 seconds to allow time for the bucket to be placed in the correct position on the frame. All four lights, on each side, are then switched off. The message 'Analysing Bucket Load' appears on the LCD, and the system starts the average cps routine, where the cps rate is measured over a user-selected analysis time period. During the analysis time, the clear lights flash once per second, to indicate that the system is collecting data.

Once the analysis time is completed, the message 'Analysis Complete' and the results of the bucket load are displayed on the LCD. In addition, the clear lights are switched off. The average cps is then compared with the 'Lower Level' cps and the 'Upper Level' cps that have been programmed into the system following calibration. The status of the load can then be set to low, medium or high cps. If the average cps is below the 'Lower Level' then the green light is illuminated and the status set to 'Low'. If the average cps is between the 'Lower Level' and the 'Upper Level' then the amber light is illuminated and the status set to 'Med' (medium). If the average cps is above the 'Upper Level' then the red light is illuminated and the status set to 'High'. These lights will remain illuminated until the bucket is lifted from the frame or 5 seconds have passed, whichever is the longer. The date, time, record number, average cps and status are stored in the Log file. This file can be downloaded onto a laptop for later analysis. If the medium status facility is not required then the 'Lower Level' cps and the 'Upper Level' cps are set to the same value.

If the bucket is lifted from the frame before the analysis has been completed, the message 'Analysis Incomplete – Bucket Moved' appears on the LCD and all the lights flash at 0.5 Hz for 5 seconds. If the battery voltage is below 11.0 volts, when a bucket is detected, instead of all the lights being illuminated, the lights flash in pairs for 5 seconds. The system then continues to analyse the bucket load as normal. This facility is to warn the operator that the battery is becoming discharged and should be changed as soon as possible.

4 CONCLUSIONS

The GEM system is capable of rapidly measuring large volumes of material to aid segregation into different waste streams in accordance with UK legislation. The increase in throughput afforded by this system reduces the costs passed onto the client and enables the developer to keep to tight deadlines. Bretby Gammatech Ltd built the equipment to Nuvia specifications, which incorporates added safety features, and Nuvia have progressed its use and have the calibration expertise.

The investment cost was £12,725, which was borne by the client, as was the hire cost of £500 per week. Furthermore, the equipment was a crucial factor in the successful and timely delivery of a £1M programme of works.

The main interest in this site characterisation tool would be from land remediation and nuclear decommissioning/delicensing, and efforts have been made to publicise the equipment and its capability in these areas for the benefit of these industries as a whole, not just as a specific Nuvia product. Nuvia recognises that the capability of the technique should be widely disseminated and have thus included information about the device in meetings, conferences and publications. Presentations on the instrument performance have been provided at the UK Cross Industry Assay Working Group, a SAFESPUR event in sharing good practice in nuclear decommissioning and waste management, the annual IBC Energy NORM conference in London, an IAEA conference on land remediation in Astana, Kazakhstan and a special edition of Journal of Environmental Radioactivity, which covers the proceedings of this conference.