Portable Gamma-Ray Spectrometry for Decommissioning: Anywhere, Anytime, Anything

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Abstract

The recent development of extended-source modeling software for portable gamma-ray spectrometers has been a boon to large nuclear projects in the field. This paper reports AECL's experience with such instruments during the first phase of decommissioning the Whiteshell Nuclear Research Establishment (now Whiteshell Laboratories). They have been used for routine measurements of soil cores, for estimates of radionuclide content of waste packages, for surveys of potentially contaminated terrain adjacent to a waste storage facility, and for scans of drums containing likely-clean material. The instruments have been found to be sufficiently sensitive and almost as accurate as laboratory spectrometers using reference sources and calibrated counting geometries.

1. Introduction

Decommissioning a large nuclear site calls for tight coordination among teams of specialists working in the field. Chemical and radiochemical analysis results are often required at short notice, since the outcome of analyses may guide the progress of the work. When the site has been occupied for decades, with some loss of institutional memory, evidence from field measurements becomes even more important in keeping on schedule despite finding unexpected complications. Indeed, decommissioning can be considered as a succession of non-routine activities conducted with incomplete information at a location full of surprises. Minimizing those surprises during execution is significantly assisted by the capability of making measurements in the field.

The Whiteshell Nuclear Research Establishment (now Whiteshell Laboratories) was constructed beginning in 1963 in the forests of eastern Manitoba. It has hosted large projects in several areas of nuclear technology, including innovative reactor concepts, research into interim dry storage and geological disposal of used fuel, severe accident studies, and materials irradiation research. Major facilities included an organic-cooled test reactor (WR-1), a prototype heating reactor (SDR), combustion test facilities, electron and proton accelerators, a neutron generator, hot cells, an active liquid waste treatment centre, and a nuclear waste management area. In 1995 the decision was made to wind down research at this laboratory, and transfer most projects to AECL's larger laboratory at Chalk River, Ontario. AECL received a decommissioning licence from the Canadian Nuclear Safety Commission in 2003, on the basis of a preliminary decommissioning plan calling for several decades of remediation work. The comprehensive environmental assessment of the decommissioning project indicated that impact to the environment would be minimal. The federal Nuclear Legacy Liabilities Program, administered through Natural Resources Canada, provides the funding for decommissioning the Whiteshell Laboratories.

The administrative structure of Whiteshell Laboratories was updated for effective use of resources during decommissioning. The decommissioning planning team is supported by an expanded complement of specialists in decommissioning execution, with multiple support groups. Among these, the Operations division ensures continued availability of services from several nuclear facilities, including hot cells, waste management area, liquid waste treatment, and radiochemical laboratories. Under the banner of Analytical Science, these laboratories had previously supported research & development activities on site, but have since been adapted to support both routine and non-routine analytical aspects of decommissioning.

Prominent among the arsenal of chemical, radiochemical, and instrumental analysis techniques offered by the Analytical Science group is gamma spectrometry. Since the 1970s, the spectrometry section has focused on high-throughput, rapid-turnaround measurements to support Whiteshell Laboratories operations and R&D [1]. Multiple high-resolution germanium detectors handled the load, in heavily shielded enclosures with automated sample changers. The operations support has continued, of course, but now there is additional emphasis on keeping up with all phases of the decommissioning work as well. Until recently, that meant having the lab-based spectrometers ready to receive samples from decommissioning staff for screening, confirmatory, or exploratory measurements. The idea of taking the spectrometers to the work face began with trials in several areas in the early 2000s. More intensive work with a portable instrument in the lab and in the field was conducted in 2006. The success of those endeavours led to more routine use of the instrumentation, and eventually to the acquisition of several instruments and hiring of additional staff to run them.

2. Instrumentation and software

The first portable gamma spectrometer acquired by the Whiteshell Laboratories Decommissioning Project was the *In-Situ* Object Counting System (ISOCS™), manufactured by Canberra. This system consists of a germanium detector, acquisition electronics, and a laptop computer, all mounted on a wheeled cart. The liquid nitrogen dewar supplied with this system has a holding time of five days, and can be operated in any orientation. Modular lead shielding is also supplied, to block gamma rays from reaching the detector from all but the forward direction. Details of the hardware can be found in manuals and application notes supplied by Canberra [2].

The distinctive feature of this measurement system is its ability to calculate absolute radionuclide activities in objects containing extended distributions of gamma-emitting nuclides, without the need to perform a calibration using radioactive standards in the same arrangement. This ability is incorporated in the software supplied with the ISOCS system. It relies on an extensive detector response characterization performed by the manufacturer over a broad energy range (typically 45 keV to 7 MeV), using a large number of radioactive-source positions. The characterization includes a Monte Carlo model (carried out using MCNP software [3]) of the germanium detector active-volume dimensions validated using point source measurements. The detector response is modelled mathematically using linear interpolations between positional grid locations, and parabolic interpolations between gamma energy values [4]. Using this response model to calculate gamma detector efficiencies has been independently determined to provide results with an accuracy of better than ±10% [5]. This is consistent with the manufacturer's statement [6] that the results are "accurate to within 4-5% for energies greater than 400 keV and 7-11% at 1 standard deviation for energies between 50 and 400 keV."

To use the gamma spectrometer for absolute activity measurements, the dimensions and materials of the object being assessed must be provided to the software, as well as the orientation and distance of the detector with respect to the object, and the dimensions and materials of intervening objects. This information allows the software to convert measured radionuclide count rates into absolute activity values.

3. Laboratory and field applications

An early use of the ISOCS gamma spectrometer at the Whiteshell Laboratories was a trial performed in parallel with one of the fixed-position, lead-cave shielded laboratory gamma spectrometers. A set of drill cores consisting of soil and clay needed characterization for gamma activity. A jig was built to position each core slice centrally under the detector during the gamma spectrometry measurements. Using the portable spectrometer to analyse the 27 slices (varying in length and density) from each of several drill cores “as-is” (vs. sub-sampling for laboratory spectrometer analysis) freed the laboratory spectrometer for other work. Comparing the results from the selected samples measured with both instruments led to increased confidence in the validity of the modelling technique. At the same time, a quality assurance program for the measurements was developed. Daily measurements of ^{152}Eu standard sources to verify the stability of the instrument’s energy and efficiency calibrations, as well as regular detector background measurements to verify the lack of interferences, assure the proper operation of the spectrometer and the validity of the results.

Figure 1 In-situ soil survey outdoors

The ISOCS spectrometer was used for a variety of in-situ measurements, typically where the objects under study could not be moved (piping and walls), or where the objects were oddly shaped and so could not be analysed with the laboratory spectrometer (remote-manipulator arms) because the detector was not calibrated for those shapes. Approximate results were sufficient for those applications, where speed of analysis and reporting was more important than high accuracy. Later in 2006, a preliminary outdoor survey of terrain adjacent to an incinerator also proved successful. The instrument was operated by a student (under supervision) and the survey provided valuable experience with measurements made on uneven terrain (Figure 1). In fact the wheels of the original cart were not up to the task of cross-country jaunts, and a more rugged cart was subsequently purchased. The new cart weighs just over 100 kg on its own, or approximately 180 kg with detector, dewar, shielding, and electronics on board, but it is considerably more manoeuvrable than the original one.

Figure 2   ISOCS unit assaying a B-25 container

Following that outdoor test, the ISOCS unit was brought indoors to conduct a campaign of radioactive waste package characterization (Figure 2). The decommissioning project was beginning to fill up steel boxes called B-25 containers, each approximately 1.2 m × 1.2 m × 1.8 m. These containers were accompanied by a material inventory list on their way to the WL Waste

Management Area for storage, but they also needed an overall estimate of radionuclide content. Modelling this metal-box geometry was fairly straightforward, and the same dimensions could be used for every container. However the makeup of the box contents needed to be assessed, as the quantities and proportions of wood, glass, wire, and plastic waste varied. Four gamma spectra of each box were acquired, with the ISOCS detector facing each of the four sides. The four sets of results were averaged, and the radionuclide content of the box calculated assuming the activity was evenly distributed. The variability of the four measurements was used to estimate the validity of this assumption, and hence the precision of the results. For this work, a laser pointer was affixed to the detector shield, to ensure precise and reproducible aiming of the detector at a fixed location on the face of the container. Tests under controlled conditions indicated that the best detector location to use to optimize field of view as well as detector efficiency was at a distance from the object equivalent to the greatest diameter of the object.

4. Waste Clearance Facility

The next major category of use for the portable gamma spectrometry system was waste clearance. Decommissioning waste is sorted at source into categories designated “likely clean” and “contaminated” based on the history of the areas where they originated, and on screening surveys conducted by hand with radiation protection instrumentation. To confirm the uncontaminated nature of the likely-clean material prior to its disposal or shipment off-site for recycling, it is transported to a Waste Clearance Facility set up specifically for that purpose. In this facility, radiation protection surveyors had been carrying out detailed hand surveys of each item individually. Since this process is quite time-consuming (and therefore expensive), the hand scanning method was applied primarily to items and materials with a higher risk of potential contamination, and to surveying individual (non-bulk) items. The ISOCS was pressed into service to measure the gamma activity of lower-risk bulk material: standard-sized drums, boxes, and other packages containing sorted waste of known mass and composition such as demolished drywall, wood, and wire, but not mixed material types. Including the composition information into the model increased its accuracy, both for measured activity values and for calculated detection limits. The detection-limit information is used to populate radiological release forms, which are then evaluated to assess the confidence with which the uncontaminated nature of the material can be asserted.

During 2008, 64 likely-clean waste packages were processed by the ISOCS unit in the Waste Clearance Facility, for a total mass of 5720 kg, or almost six tonnes. Much of this material could be sent for recycling, including barrels of copper wire and other scrap metal. A detector failure in 2009 reduced the instrument’s annual throughput, but recently it has been brought back into service.

5. Lessons learned

The first few years using the portable gamma spectrometry system have given us valuable experience, which can be used to improve similar projects at Whiteshell Laboratories and elsewhere. The points below need to be kept in mind when implementing this relatively new technology in a new area of work:

- Thorough training of operators before beginning routine use of the instrument contributes to higher throughput in the long term

- Unrealistic expectations may arise from uncritical acceptance of manufacturers' claims with regards to equipment capabilities

- While personnel time is the main contributor to operating cost, throughput is limited primarily by spectral acquisition (gamma counting) time. Financial investment in high-efficiency detectors and low-background environments is quickly recouped.

- Portability means different things to different people. Attention to mechanical and ergonomic details in the design of wheeled and orientable instruments can greatly increase their effectiveness in the field.

- Evaluation of which modelling parameters are most critical to obtaining accurate results (i.e., performing a sensitivity analysis) can save time in setting up specific sample geometries for measurement.

- Incorporating deliberate similarities in software design between laboratory and portable systems results in major improvements in the learning curve of operators.

6. Conclusion

There have been enough applications for portable gamma spectrometry at the Whiteshell Laboratories to justify purchasing a second instrument. One of the two ISOCS systems will remain at the Waste Clearance Facility for the most part, while the other roams to various decommissioning work sites, both indoors and outdoors. The portable spectrometers will soon be included in the Analytical Science quality assurance system, which has been accredited to the ISO/IEC 17025:2005 measurement standard by the Canadian Association for Laboratory Accreditation (CALA). Gamma spectrometry is one of the techniques for which CALA has already declared us proficient [7].

The success of gamma spectrometry as a screening technique has led to more widespread use at the Whiteshell Laboratories. The decommissioning project has purchased a multi-detector scanning gamma spectrometry system specifically for assays of B-25 containers, which the Analytical Science group will operate. The decommissioning project has also made use of leased equipment for gamma imaging to assess the distribution of contamination in rooms and crawlspaces. Having a number of gamma-spectrometric measurement techniques at hand will continue to support efficient decommissioning of this complex and varied nuclear research centre.

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8. References

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