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Demonstration of lightweight gamma spectrometry systems in urban environments

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ABSTRACT

Urban areas present highly complex radiation environments; with small scale features resulting from different construction materials, topographic effects and potential anthropogenic inputs from past industrial activity or other sources. Mapping of the radiation fields in urban areas allows a detailed assessment of exposure pathways for the people who live and work there, as well as locating discrete sources of activity that may warrant removal to mitigate dose to the general public. These areas also present access difficulties for radiometric mapping using vehicles or aircraft. A lightweight portable gamma spectrometry system has been used to survey sites in the vicinity of Glasgow to demonstrate the possibilities of radiometric mapping of urban areas, and to investigate the complex radiometric features such areas present. Variations in natural activity due to construction materials have been described, the presence of ^{137}Cs used to identify relatively undisturbed ground, and a previously unknown NORM feature identified. The effect of topographic enclosure on measurements of activity concentration has been quantified. The portable system is compared with the outputs that might be expected from larger vehicular or airborne systems. For large areas airborne surveys are the most cost effective approach, but provide limited spatial resolution, vehicular surveys can provide sparse exploratory data rapidly or detailed mapping of open areas where off-road access is possible. Backpack systems are ideally suited to detailed surveys of small areas, especially where vehicular access is difficult.

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1. Introduction

Radiometric surveys are routinely conducted for a variety of purposes, including monitoring contamination, tracing environmental pathways, geophysical exploration and security applications (Sanderson et al. 1994a, b; IAEA, 2004). Urban environments present particular challenges to radiometric techniques, and have been relatively neglected in survey programmes that have favoured the less complicated rural areas. Rural areas typically have relatively simple environments, in most areas with limited topographic or land use variation within the field of view of radiometric detectors. On the other hand, urban areas can include significant geometrical variation from buildings and rapidly changing land use with roads, buildings, gardens, parks and other surfaces. In addition, there may be a substantial variety of construction materials with different natural activity concentrations and, particularly in the case of structural steel, potentially incorporating anthropogenic activity. Industrial activity may result in contamination with Technologically Enhanced Naturally Occurring Radioactive Material, TENORM (Vearrier et al. 2009).

Airborne surveys are restricted by the need to obtain specific clearances for low altitude flights, especially for urban areas where there are a greater number of obstacles to navigation compared to rural environments. Airborne surveys of urban areas have been conducted at low level, below 100 m ground clearance, in response to specific potential radiological hazards; eg: potential uranium contamination in Newbury and Thatcham that may have been released during an aircraft fire on the nearby Greenham Common airbase in 1957 (Sanderson et al. 1997, 2000a), and radium contamination in Carlisle associated with the disposal of luminous aircraft dials (Sanderson et al. 2000b). Ground vehicle systems are commonly used on roads, where a large proportion of the field of view is the road surface (Korsbech et al. 1999; Mellander et al. 2002; Sanderson et al. 2003), although may be used on open ground with a suitable off-road vehicle. Backpack systems carried by pedestrians offer the possibility of coverage of any accessible space, and even areas within buildings once a positional reference system has been established. Backpack systems have been available

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for many years, with systems developed by the Swedish Radiation Safety Authority (formerly the Swedish Radiation Protection Institute (SSI)) in the mid 1990s (Sanderson and Ferguson, 1997; CORDIS, 2002) and now produced by several manufactures, particularly for use in security applications. A backpack system has recently been used to compare data from airborne and ground based measurements in rural areas of Sweden (Kock and Samuelsson, 2011). A backpack system has also been used to measure dose rates around nuclear sites in Ghana (Amekudzie et al. 2011).

In addition to access, urban areas present other challenges for radiometric surveys. Sparse vehicular surveys of Copenhagen (Aage et al. 2006), and elsewhere, have demonstrated the highly variable dose rates of urban environments compared to local rural areas. Systems are calibrated to open field conditions, where the source geometry is approximately controlled. However, the source geometry of urban areas is much more complex with enclosed geometries and building material variations. These effects need to be considered in interpretation of the data calibrated under the assumption of open field geometries. The use of collimators to restrict the field of view of in-situ detectors to mitigate the potentially complex geometry has been suggested (ICRU, 1994), and is an approach regularly used in decommissioning nuclear facilities or assessing contamination on nuclear sites where additional radiation sources in the vicinity are present (eg: Hrnecek and Feichtinger, 2005). This approach requires extended measurements from fixed locations, and the use of heavy collimators, that make it impractical for large area surveys.

Small portable systems have the potential to map the variations in natural and anthropogenic activity with spatial resolution of a few metres or less, in locations where the general public live, work and spend their leisure time. A portable gamma spectrometry system developed at the Scottish Universities Environmental Research Centre (SUERC) was used in this study. Surveys of the vicinity of SUERC and the University of Glasgow are presented that demonstrate the capability of such systems to conduct surveys with high spatial resolution, issues relating to source geometry, and the identification of anthropogenic radiation signals due to construction materials, residual industrial legacies, fallout radionuclides and sources.

2. Method

The SUERC Portable Gamma Spectrometry system comprises a $3 \times 3''$ NaI(Tl) detector with digital spectrometer, automatic gain correction, GPS receiver and a computer running a complete data acquisition and spectral analysis package from the airborne system. The complete system (detector, computer and harness) weighs approximately 4 kg, which is lighter than comparable systems. Spectra are recorded continuously with integration times of typically 5–10 s in 512 channels over an energy range of 30 keV to 3 MeV while the operator carries the system at slow walking speeds of 0.5–1.0 m s^{-1}. During survey, spectra are analysed using a spectral windows method with stripping of interferences between radionuclide windows (Cresswell et al. 2006; Sanderson et al. 1994a; IAEA, 1991). The data are processed to produce distribution maps of the activity concentration (Bq kg^{-1}) for naturally occurring radionuclides (^{40}K, ^{214}Bi in the ^{238}U decay series and ^{208}Tl in the ^{232}Th decay series), activity per unit area (kBq m^{-2}) for ^{137}Cs and other fallout nuclides and gamma dose rate (mGy a^{-1}). Waterfall plots of the gross and differential spectra, produced by subtracting a filtered rolling average background from each measurement (Cresswell and Sanderson, 2009), are displayed to aid the user in identifying potential anomalies. Alarms can be triggered on count rates or significance thresholds. Analysis may also include least squares spectral fitting of natural components, and other data reduction techniques. Data outputs include the European Radiometric and Spectrometry (ERS) data format (Guillot, 2003) to facilitate data exchange between organisations.

Two sites have been used to demonstrate the system capability, each survey using a pair of detector systems. The first was the Scottish Enterprise Technology Park (SETP) in East Kilbride, which is light commercial site occupied by the National Engineering Laboratory (NEL), Building Research Establishment, SUERC and several other technology companies. An accelerator mass spectrometry laboratory, with two accelerators, is located on the site. The Kelvin Laboratory, owned by the University of Glasgow Department of Physics and Astronomy, was located on the site and housed a linear accelerator that was closed down in the late 1980s. SUERC was originally established by a consortium of Scottish Universities in the early 1960s to operate a small research reactor which was shut down in 1995 with the reactor buildings removed in 2001/2 and the site was delicensed in 2008. There is an ongoing programme of renovation on the site, including demolition of old buildings and new construction along with landscaping operations. The site was surveyed in August 2009, with additional measurements taken in October 2010, with a high density pattern of survey lines approximately 1–2 m apart covering approximately 5 ha.

The second site was the main campus of the University of Glasgow, and includes a variety of buildings of different ages, with extensive landscaping features. The 19th century buildings are mainly sandstone construction, with more modern buildings using brick and concrete. Within the buildings housing the Department of Physics and Astronomy there is a neutron source and isotope store. Sealed and unsealed radioactive materials have been used for research purposes in many buildings. The campus was surveyed in November 2010 in a low density pattern following the paths and roadways to cover the majority of the site.

3. Results

3.1. Calibration

Background measurements recorded from a plastic hulled boat on Loch Lomond produced count rates for the total gamma dose rate window (450–3000 keV) of 5.0 ± 0.1 cps, corresponding to a dose rate of 0.03 mGy a^{-1}. These measurements included data collected with the systems on the back of an operator and with the systems as far from the operators as possible. There was no significant difference in the background rates due to activity within the body of the operator. Stripping matrices were determined from measurements with doped concrete calibration pads and anthropogenic sources. Estimates of conversion factors between stripped count rate and radionuclide concentration were derived from experimental and theoretical studies using similar detectors for in-situ gamma spectrometry in the early 1990s (Allyson, 1994; Tyler, 1994). For natural activity the calibration assumes a uniform activity distribution within the detector field of view, and for ^{137}Cs a shallow depth profile (2 g cm^{-2} mean mass depth) appropriate for Chernobyl fallout at that time. The gamma dose rate is proportional to the integral count in a scintillator above a threshold energy (Løvborg and Kirkegaard, 1974; Mercier and Falguères, 2007), in the region of 250–500 keV for NaI(Tl) detectors, for this work a 450 keV threshold was used, following the method of Murray et al. (1978).

Measurements on Caerlaverock Merse, Dumfries and Galloway, were conducted using one of the detectors used in this work in a prototype configuration. An expanding hexagonal calibration pattern had been established on this site in 1992 (Sanderson et al. 1992, Tyler et.al. 1996) and renewed in 1999. Three calibration sites were established in the outer Solway as part of the ECCOMAGS International Intercomparison Exercise (Sanderson et al. 2003,

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