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Environmental radioactivity in the UK: the airborne geophysical view of dose rate estimates

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ABSTRACT

This study considers UK airborne gamma-ray data obtained through a series of high spatial resolution, low altitude surveys over the past decade. The ground concentrations of the naturally occurring radionuclides Potassium, Thorium and Uranium are converted to air absorbed dose rates and these are used to assess terrestrial exposure levels from both natural and technologically enhanced sources. The high resolution airborne information is also assessed alongside existing knowledge from soil sampling and ground-based measurements of exposure levels. The surveys have sampled an extensive number of the UK lithological bedrock formations and the statistical information provides examples of low dose rate lithologies (the formations that characterise much of southern England) to the highest sustained values associated with granitic terrains. The maximum dose rates (e.g. >300 nGy h^{-1}) encountered across the sampled granitic terrains are found to vary by a factor of 2. Excluding granitic terrains, the most spatially extensive dose rates (>50 nGy h^{-1}) are found in association with the Mercia Mudstone Group (Triassic argillaceous mudstones) of eastern England. Geological associations between high dose rate and high radon values are also noted. Recent studies of the datasets have revealed the extent of source rock (i.e. bedrock) flux attenuation by soil moisture in conjunction with the density and porosity of the temperate latitude soils found in the UK. The presence or absence of soil cover (and associated presence or absence of attenuation) appears to account for a range of localised variations in the exposure levels encountered. The hypothesis is supported by a study of an extensive combined data set of dose rates obtained from soil sampling and by airborne geophysical survey. With no attenuation factors applied, except those intrinsic to the airborne estimates, a bias to high values of between 10 and 15 nGy h^{-1} is observed in the soil data. A wide range of technologically enhanced, localised contributions to dose rate values are also apparent in the data sets. Two detailed examples are provided that reveal the detectability of site-scale environmental impacts due to former industrial activities and the high dose values (>500 nGy h^{-1}) that are associated with former, small-scale Uranium mining operations.

1. Introduction

Terrestrial gamma radiation accounts for >80% of the total dose of ionising radiation to which the population is exposed. The average annual dose to the UK population is estimated to be 2.7 mSv with 2.2 mSv (or 81% of the total) of this coming from natural radiation (Hughes et al., 2005). Two national gamma-ray dose surveys conducted in 1989 found arithmetic means of 34 nGy h^{-1} and 23 nGy h^{-1} for Great Britain (Green et al., 1989) and Northern Ireland (Caulfield and Ledgerwood, 1989), respectively. The first national-scale gamma spectrometry survey was reported by Tyler and Copplestone (2007) using 128 field spectrometric measurements sampled across the UK. The air absorbed dose rates (Air Kerma) for the UK were reported to be in the range from 8 to 60 nGy h^{-1}.

Airborne radiometric (gamma-ray spectrometric, referred to here as airborne spectrometry (AS) measurements routinely acquire information on the ground concentrations of the three most significant, natural primordial radionuclides in the environment. Uranium (^{238}U) and Thorium (^{232}Th) undergo radioactive decay through a series of decay products eventually producing stable isotopes of lead. These two radionuclides, together with Potassium (^{40}K), are present in bedrock, superficial geology and soils. Gamma dose rates largely reflect the natural variation of Potassium, Uranium and Thorium across the environment. Their natural variability across significant areas of the UK has been assessed in a series of airborne radiometric surveys conducted over the past decade. The high spatial resolution of the surveys, and their continuous local to

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regional scale, allow assessments of both the geological background and its spatial variability together with localised concentrations due to industrial/technological processes. The data sets obtained thus provide a basis for both NORM (naturally occurring radioactive materials) and TENORM (technologically enhanced naturally occurring radioactive materials) studies of dose rates. Of significance is the fact that the airborne studies provide continuous local to regional scale assessments. The airborne assessments of dose rates may be considered in relation to existing, and more conventional, soil sampling and above ground assessments. Conventional dosimetry assessments are undertaken using soil sampling and subsequent laboratory (e.g. X-ray fluorescence, XRF) analysis (e.g. Johnson et al., 2005). These techniques are referred to here as soil spectrometry (SS). Alternative ground-based spectrometer surveys (sometimes called in-situ surveys) may be undertaken (Macdonald et al., 1996; Tyler et al., 1996). Such techniques are referred to here as ground spectrometry (GS). These measurements, together with airborne observations, provide direct measures of dose rates in air (air absorbed dose, AAD). The ground spectrometric observations, obtained at an elevation of about 1 m, are typically most sensitive to a ground area of typical radius of 8 m (e.g. Tyler et al., 1996); in the airborne case, with typical elevations of >60 m, the footprint radius will exceed 100 m.

The airborne measurements may be used to provide assessments to the dose rate contributions made by the individual radioelements. About one half of the annual UK terrestrial dose rate of 2.2 mSv is estimated to come from indoor radon (Watson et al., 2005). Radium (^{226}Ra) is the fifth daughter product of Uranium (^{238}U) and radium is also the parent of the natural gas radon ^{222}Rn responsible for radon exposure of the population. The airborne measurements of Uranium therefore provide one of the supporting techniques in the estimation of indoor radon levels alongside known and predicted geological controls (Emery et al., 2005a; Appleton et al., 2008). Radon potential information in the UK (Scheib et al., 2013) is produced by assessing measurements of radon concentration in homes grouped by underlying geology. Detailed studies of the relationships between radon potential, ground spectrometry (GS) and airborne measurements (AS) are provided by Emery et al. (2005a). Ground gamma spectrometry measurements of Uranium, Potassium and Thorium were found to be correlated with the airborne measurements at the 99.95% level.

References are made by the International Atomic Energy Agency (IAEA, 2010) to a range of previous publications of relevance to the data discussed here. Gamma spectrometry data were historically collected to aid Uranium exploration. The preparation of these data for radioelement baselines, and their application to environmental assessment, is summarised by Tauchid and Grasty (2002); examples of national compilations using airborne, car-borne and ground gamma spectrometry are also provided. Sanderson et al. (2002) also report on international comparisons of such measurements.

There exist a number of comparisons of ground concentration estimates from soil sampling, ground (in-situ) spectrometry and airborne data sets. A set of detailed comparisons across two colliery spoil sites in the UK is presented by Emery et al. (2005b). With no reduction factor applied to the soil sample estimates it was found that the soil sample estimates of Potassium, Thorium and Uranium were persistently higher than the ground estimates. Despite the differences in footprint scale between ground and airborne spectrometry, the studies also indicate good agreement between estimates obtained by the GS and AS methods. Ideally for each airborne observation point, the ground-based measurements should be obtained across the footprint scale of the airborne measurement, noting that this is also a non-linear function of distance from the sampled point. One approach, using a hexagonal pattern beneath the centre of an airborne measurement, produced a good correlation between sets of ground (in-situ) and airborne measurements (Tyler, 1994; Sanderson et al., 2002).

Radiometric ground concentrations, typically obtained from the upper 30–50 cm of the soil (or superficial) profile (see Beamish, 2013), are understood to be derived from the parent bedrock material. In the UK, attenuation zones have been found to be a pervasive feature of the airborne radiometric data sets. Peat soils, in particular, produce readily identifiable attenuation effects. The radiometric data can therefore be used for peat mapping and hence assessments of the lateral extent of the associated carbon store (Beamish, 2014). Although the bedrock provides a specific radiogenic level with associated radiochemical attributes, attenuation of the signal level is controlled by soil moisture content in conjunction with the density and porosity of the soil cover. A valid interpretation model for UK radiometric data, and hence dose values, therefore requires a joint assessment of both soil/superficial and bedrock variations.

The present study is based on data from several high-spatial resolution UK airborne surveys flown since 1998 (Fig. 1). Several previous studies have considered the detailed characteristics of radioelement distributions classified by UK subsurface geology (Beamish and White, 2011; Beamish, 2013). Due to the detailed spatial scales involved these are best undertaken on a survey-by-survey basis. The purpose of the present study is to summarise the UK-wide geological associations of observed low and high-value dose rates and to present some local scale effects due to industrial and technological enhancements that have been observed. Case studies of the type of information obtained from the airborne data are presented. Additionally the nature and importance of the attenuating effect of soils, in reducing above-ground exposure levels is theoretically quantified and discussed alongside the results presented. The composite information then represents a limited audit of radiation exposure (AAD) due to terrestrial sources in the UK environment obtained from airborne measurements.

2. Methodology

2.1. Airborne radiometric data

The six UK surveys flown between 1998 and 2013 are shown in Fig. 1. All the surveys were undertaken using a fixed-wing platform and radiometric data were acquired alongside other geophysical

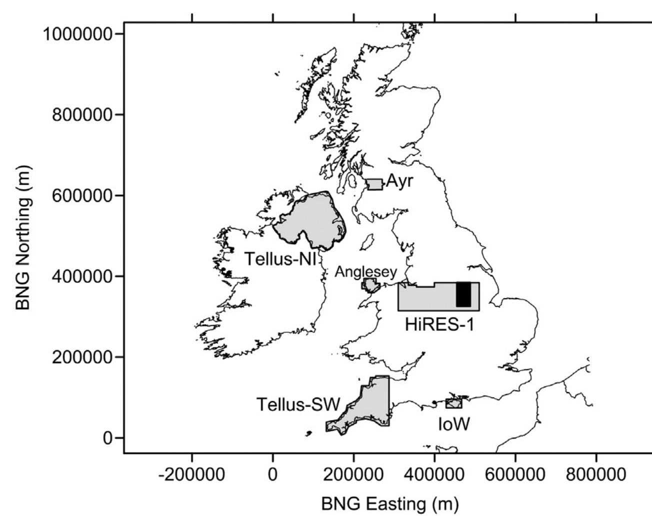

Fig. 1. High resolution airborne geophysical surveys conducted in the UK 2008–2013. Six surveys are identified. The black rectangle within the HiRES-1 survey is a study area discussed in the text. BNG refers to British National Grid.