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Recovery and Reanalysis of Archived Airborne Gamma Spectrometry Data from the 1991 Dounreay Survey

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Abstract

Archived Airborne Gamma Spectrometry (AGS) data from the 1991 NIREX characterisations of Caithness have been recovered. The separate gamma spectrometry and positional data streams for approximately 120000 measurements have been combined into a single data stream using the European Radiometrics and Spectrometry (ERS) data format. An analysis using working calibration coefficients and spectral stripping procedure has verified that the original survey recorded high quality data. The converted data stream is in a format more accessible to future research use, including evaluation of environmental change in the Caithness region.

Keywords: Environmental radioactivity, airborne gamma spectrometry, data analysis

Introduction

In the late 1980s and early 1990s, UK Nirex Ltd conducted extensive geophysical characterisations of Caithness and West Cumbria, as part of their geological

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investigations of these two areas as possible sites for the deep disposal of intermediate level radioactive waste. This work included airborne geophysical surveys using electromagnetic sensors and gamma ray spectrometers (Norton *et.al.* 1997, Millett 1991).

For the Caithness study, the airborne survey was conducted by Global Earth Sciences Ltd, commissioned by AEA Technology, in January and February 1991. Two survey tasks were completed; a high level survey at 330m ground clearance of a 40x40km area centred on Dounreay using magnetometers, and a more detailed low level survey at 120m ground clearance of a 20x20km area using gamma spectrometers and VLF instruments. Figure 1 shows the flight lines for the low level survey taken from Millett (1991). Total survey time was in excess of 175 hours, at a cost of over £300,000.

The gamma spectrometry system used two 16 litre NaI(Tl) detector packs in the main cabin of the helicopter, with a further 4 litre NaI(Tl) detector in the baggage hold shielded from terrestrial radiation using lead. Spectra were logged using a Geometrics GR800D 256-channel spectrometer with a 1s integration time.

The count rates in pre-defined spectral windows were not converted to equivalent ppm U, Th and K concentrations “due to the lack of a comprehensive spectrometer test range in the United Kingdom” (Millett 1991). Maps at 1:25000 and 1:10000 were plotted for the count rates in the total spectrum and U, Th and K windows, but not published. The data were archived, and currently held at the National Geoscience Data Centre at Keyworth, and no further analysis conducted on them.

In recent years, the use of airborne gamma spectrometry data has developed as an important tool in measuring environmental change. In Caithness, a later airborne survey in September 1998 (Adsley *et.al.*1998) revealed some concentrations of ^{137}Cs on bends in the Forss Water, most likely due to the sorption of radiocaesium from the peaty catchments of the river onto mineral grains caught in sediment traps and flood plains. Similar redistribution of radiocaesium has been observed elsewhere, for example in the Raithburn Valley in Ayrshire (Tyler & Heal 2000). To help explore whether the ^{137}Cs was sourced from the Chernobyl accident or atmospheric weapons testing, comparisons between the 1991 airborne survey and subsequent data sets would be useful. To this end, the Nirex data set was obtained from the BGS archive and converted into a modern data format which combines the positional and spectrometric data, and approximate calibration factors estimated.

This paper reports the conversion of the archived data set and production of calibrated natural and anthropogenic activity distributions measured in 1991. Comparisons between this data set and later airborne surveys, and assessments of the changes in the environment, is ongoing and will be reported later.

Method

Data Recovery and Conversion

The data from the 1991 survey were recorded in two parallel streams. Positional data from a Racal Micro-fix navigational system, which utilised transmission time of C-

band microwave transmissions to determine position to within 1m, were recorded on 3.5” floppy disks as ASCII format text files, with the position recorded every second. Data from the gamma spectrometer and electromagnetic sensors were recorded on 9-track magnetic tape. These records have an ASCII header recording the date and time of the measurement with a fiducial, and some summary data from the electromagnetic sensors and integrated counts for windows in the NaI(Tl) spectra, followed by binary data for the two NaI(Tl) detectors. The binary data format was not fully described in the documentation archived with the data. The data were synchronised by setting the data acquisition clock to the Micro-fix CMU prior to each flight, and checking time synchronisation at the end of each flight.

Data collection for the gamma spectrometer ran continuously throughout the survey and included measurements during transit flights and turns at the end of survey lines. Separate positional files were formed for each survey line. The positional records for each line were combined into single files for each day, with occasional missing positions filled in by interpolation between positions on either side of the gaps. Some files were corrupt and unreadable.

The data processing report (Millett 1991) described the field data recording format, with bytes 101-757 containing the binary data for the gamma spectrometers. Examination of the binary files and exploratory recombination of the values stored in each byte allowed the data format to be interpreted. For the main spectrometer, channels 18-158 were stored as 16 bit data in bytes 140-420 with channels 159-256 stored as 8 bit data in bytes 421-518. Channels 18-256 for the upward detector were

stored as 8 bit data in bytes 519-757. Channels 1-17 were not recorded, and assumed to contain no counts.

A program was written to sequentially read data from both navigation and spectrometry files. The first entry from each file was read and decoded. The time given on each entry was compared, if they match then the next position entry was read and the mid point of the measurement interpolated between them. If the times did not match then the next entry in the data file with the earliest time was read until a match was found. The process was repeated until all the entries in the spectrometry file had been read. The data were output to a file using the European Radiometrics and Spectrometry (ERS) data format (Guillot 2003), with the file containing both spectrometric and positional data. For compatibility with the SUERC software, which records 512 channel NaI(Tl) spectra, each channel in the input spectra was split between two channels within the software for processing.

Data Reanalysis

Data had been recorded from the BGS concrete calibration pads at Tollerton airfield near Nottingham prior to the survey in 1991, and repeated following the survey. In addition, the data set included measurements with a ^{137}Cs test source at Dounreay airfield during the survey and some measurements near the Dounreay site that included ^{60}Co radiation. These data were used to determine the detector gain, set suitable spectral windows for anthropogenic and natural radionuclides and estimate a stripping matrix. Table 1 lists the spectral windows used, corresponding to those routinely used by SUERC (Cresswell *et.al.* 2006), with the corresponding windows

for the natural series used in the original 1991 analysis. The stripping matrix is given in table 2. The data were collected with 1s real-time measurements and no information on detector dead time. The stripping matrix has been calculated assuming no significant difference in dead time for the pad measurements compared to the data collected during the survey.

Extensive parts of the 1991 survey were conducted over water to collect electromagnetic data. This provides an extensive data set to produce background count rates. Altitude correction coefficients, using a standard exponential relationship, were determined from the mean of literature values (Allyson 1994, IAEA 1991, Løvberg 1984). Sensitivity parameters were estimated from those for the 16l NaI(Tl) used by SUERC, scaled by a factor of two to account for the greater detector volume used in the 1991 survey. For the natural series activities, calibrations were determined from theoretically derived coefficients verified by field measurements (Allyson 1994, Sanderson *et.al.* 1997). For ^{137}Cs, a calibration determined from the Inch Farm calibration site for the ECCOMAGS exercise (Sanderson *et.al.* 2003), with a mean mass depth of 8.5g cm^{-2}, was used. The backgrounds, altitude correction and sensitivity coefficients are given in Table 3.

Data from each flight were then examined to verify the conversion procedure, and to check that the positioning of the data by registering the water-land boundaries and other readily identifiable features. A few data files were found to be corrupt or otherwise unusable, and were not included in the final complete data file. Finally, maps of the natural and anthropogenic radionuclide distributions and the gamma dose rate were produced.

Results

A total of over 120000 spectra were recovered. Figure 2 shows the location of these spectra. It can be seen by comparison with figure 1 that three lines running SW to NE near the coast were not converted, and a further 20 lines running NW to SE between Thurso and Dounreay and to the SW of Dounreay. Approximately 12% of the data were thus lost. This results in a reduction of measurement density in these areas, but there are only a few locations where the missing lines intersect that significant gaps in the data occur.

Figure 3 shows the total gamma ray dose rate determined from the recovered spectra. This shows the general features of the area. The dose rate to the west and south of the area is reduced to very low levels as a result of the peat cover suppressing the geological radiation, with higher values registered along rivers where the erosion of peat and fluvial deposition has resulted in more mineral rich river banks and flood plains. The lochs and coast line register clearly. There is a high dose rate due to radiation from within the Dounreay site. It is noted that signals observed at airborne heights may not be relevant at ground level due to shielding effects.

Figure 4, 5 and 6 show the activity concentrations for the naturally occurring radionuclides ^{40}K, ^{214}Bi and ^{208}Tl. These nuclides reflect the local geology and soils, and like the dose rate show low values in the south and west as a result of the extensive peat cover with the river systems showing more mineral rich soils.

Figure 7 shows the activity per unit area for ^{137}Cs derived from fallout following atmospheric weapons testing and the Chernobyl accident. There are higher values of ^{137}Cs recorded on the mineral rich soils, but even on the peat soils there is some ^{137}Cs suggesting a more recent deposition associated with the 1986 Chernobyl accident rather than the older weapons testing fallout. There are elevated activity levels associated with activity on the Dounreay site, and also with meander bends on the Forss Water where it was subsequently noted in the 1998 survey. Initial investigation shows that the ^{137}Cs activity contained in these features is greater in 1998, and that the positions of the features vary slightly. The reconstructed 1991 data show evidence of ^{134}Cs in the general environment at greater levels than for the river features, indicating a probable weapons testing fallout origin with subsequent Chernobyl fallout contributing to them. The results of the comparisons between the 1991 survey and subsequent surveys will be reported more fully later.

To confirm whether the reconstruction performed here produces reasonable activity concentrations, the results can be compared with the 1998 survey. The activity concentrations for a 5x5km area common to both surveys, in the mineral rich area west of Thurso, have been determined and the mean and standard deviations for these are given in Table 4. The natural series activity for the 1998 survey were expressed a %K and ppm eU and eTh, these have been converted to Bq kg^{-1} for ^{40}K, ^{214}Bi and ^{208}Tl using factors derived from the JEFF 2.2 database (NEA 2000). The ^{137}Cs concentration was expressed in Bq kg^{-1} in the 1998 survey, calibrated using a site with uniform activity to a depth of 20cm, this has been converted to kBq m^{-2} assuming a soil density of 1200 kg m^{-3}. It can be seen that there is generally good agreement

between the reconstructed 1991 data and the subsequent 1998 survey, although the ^{40}K activity concentration determined from the 1991 data is lower than for the later survey. It should be noted that given the approximations required to calibrate the reconstructed 1991 data a perfect agreement between the two data sets is not expected.

Discussion

The majority of the 1991 Nirex AGS survey data has been successfully converted into the European Radiometrics and Spectrometry (ERS) data format, combining spectral and spatial data in the same file, with approximately 12% of the data lost due to corrupt source files. An analysis using working calibration values has confirmed the high quality of the data collected during the original survey. The processing for anthropogenic radioactivity has shown the presence of ^{137}Cs and ^{60}Co radiation from within the Dounreay site, and ^{137}Cs present on the peaty soils indicating that a substantial quantity of the ^{137}Cs is due to fallout from the Chernobyl accident. ^{137}Cs features on the Forss Water seen in later work are evident in this data. Determining the origins of these features is a substantial challenge, with multiple sources of radiocaesium potentially contributing. The data recovery reported here makes a significant contribution to such investigations of the environmental processes involved, allowing an examination of ^{134}Cs distribution from Chernobyl fallout and also time series analysis with later surveys of the area.

The working calibration values applied here are unlikely to be optimal, and this contributes to the small differences in absolute concentration estimates compared with

the subsequent 1998 survey. Further processing and reanalysis of the data set, for example to determine more optimal calibration values or apply different processing techniques, would be possible with the data converted to the ERS format. The data is thus in an accessible form for use in future research and studies of the Caithness environment.

Acknowledgements

The 1991 Nirex survey data were supplied by the British Geological Survey, as raw binary spectral files for the reanalysis reported here. As successor to Nirex, NDA(RWMD) is tanked for access to the data. Dr Richard Shaw of BGS kindly transferred the data onto an FTP site for download. Processed data for the 1998 survey were supplied by UKAEA.

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Figures

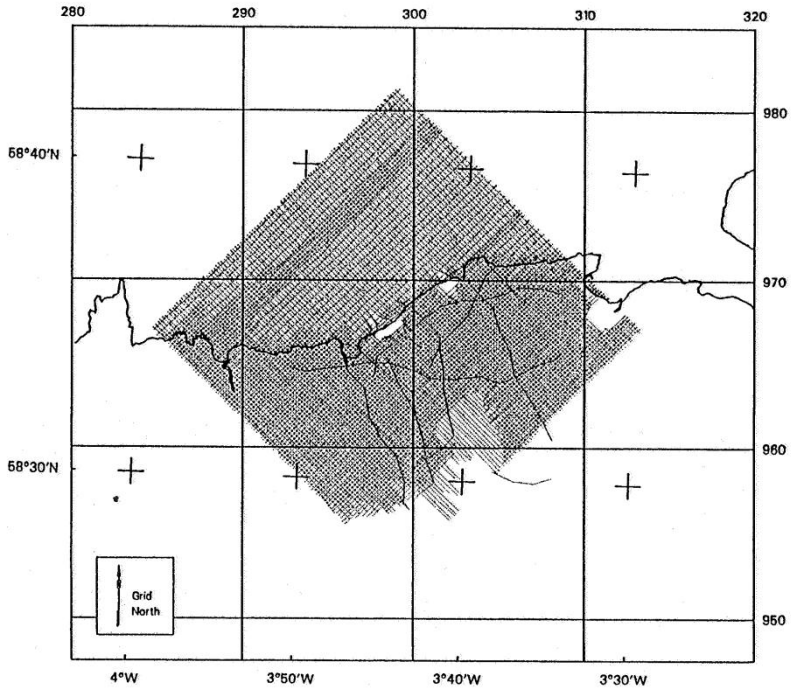

Figure 1: Flight lines for the low level survey (Millett 1991).

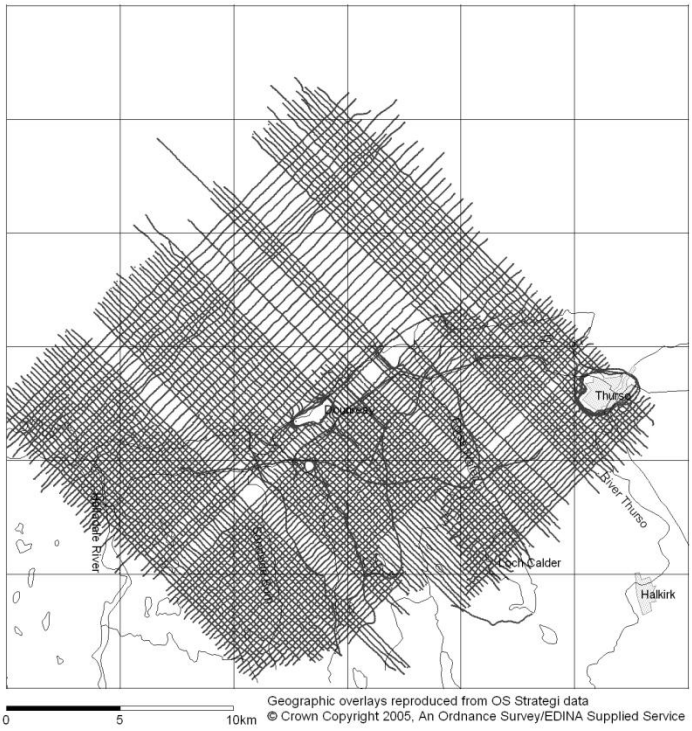

Figure 2: Data points recovered during the reprocessing reported here.

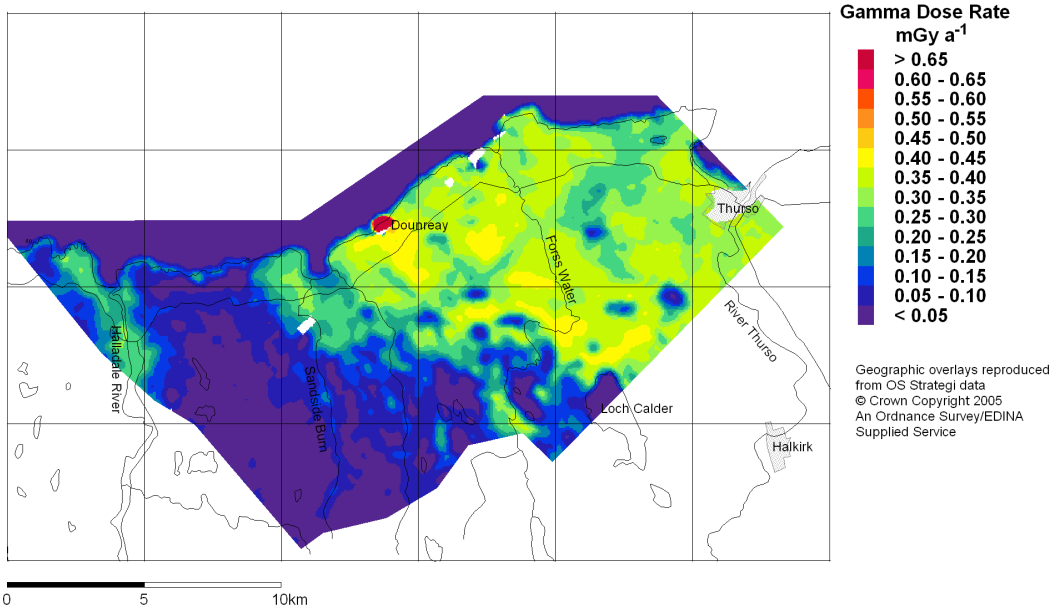

Figure 3: Total gamma ray dose determined from reprocessing of 1991 survey data.

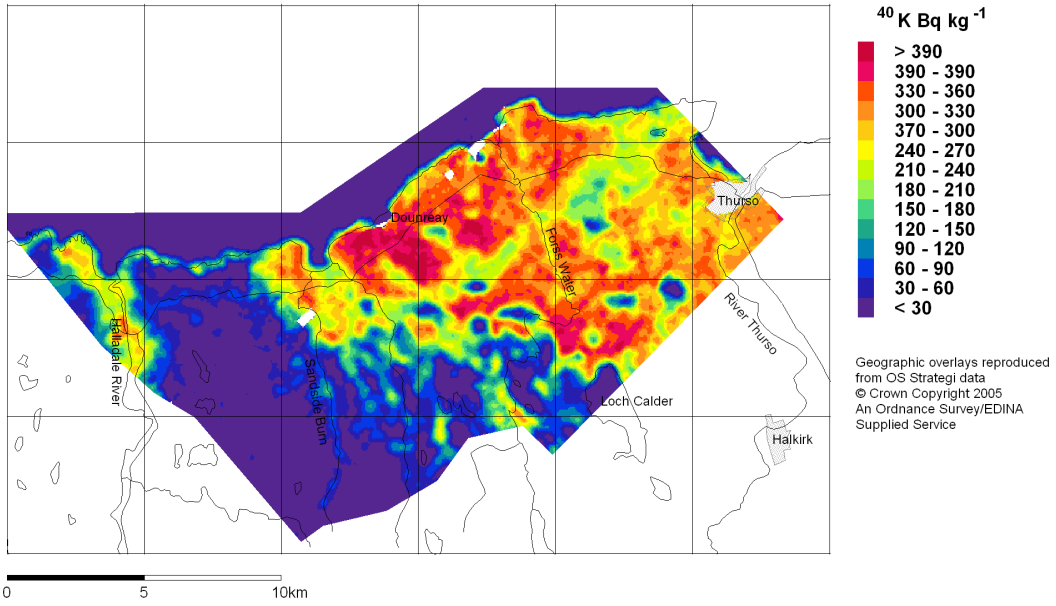

Figure 4: ^{40}K activity concentration determined from reprocessing of 1991 survey data.

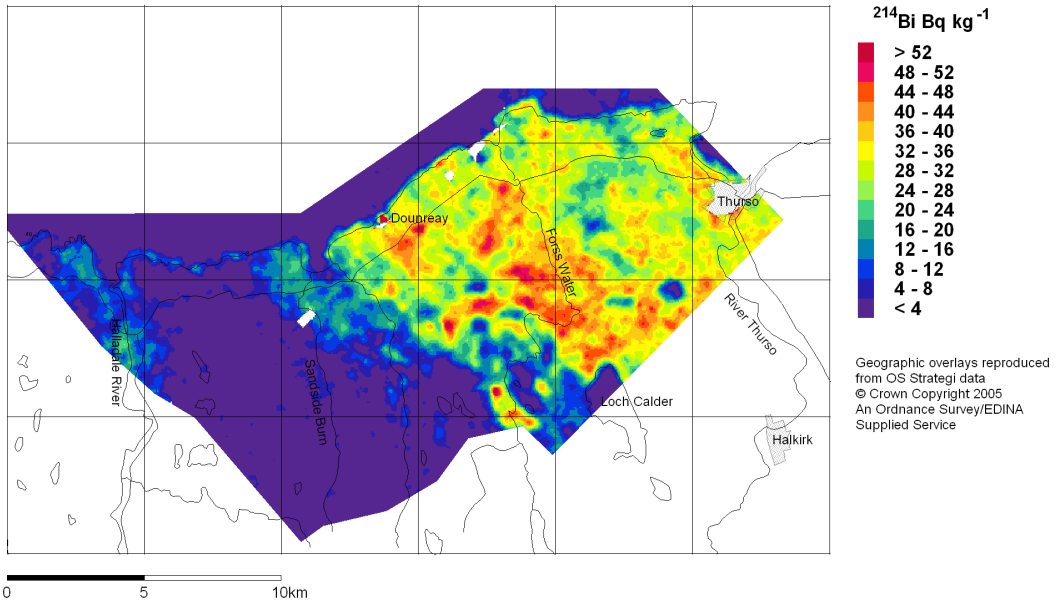

Figure 5: ^{214}Bi activity concentration determined from reprocessing of 1991 survey data.

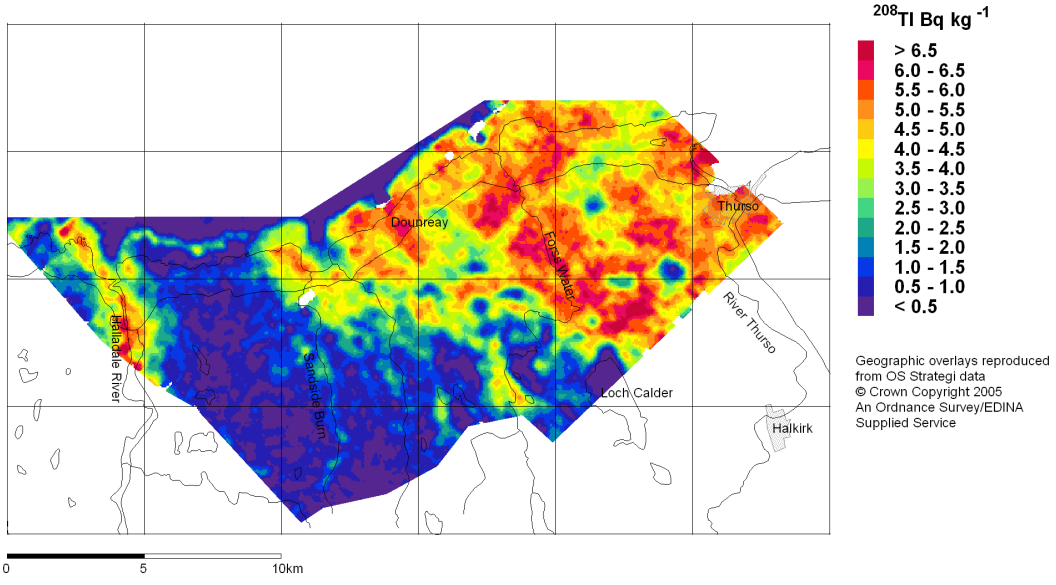

Figure 6: ^{208}Tl activity concentration determined from reprocessing of 1991 survey data.

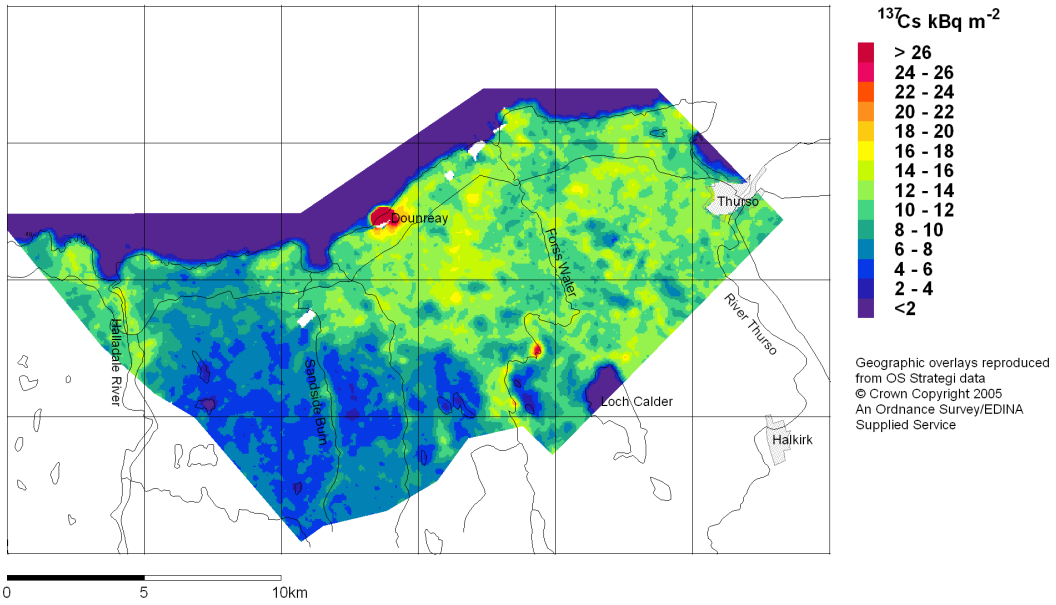

Figure 7: ^{137}Cs activity per unit area determined from reprocessing of 1991 survey data.

Tables

Nuclide	Energy (keV)	SUERC window		GES (1991) window	
		Energy (keV)	Channels	Energy (keV)	Channels
^{137}Cs	662	544-749	91-126	-	-
^{60}Co	1173	1009-1245	171-212	-	-
^{40}K	1462	1319-1629	225-279	1373-1574	234-269
^{214}Bi (^{238}U series)	1765	1629-1927	279-330	1668-1870	285-321
^{208}Tl (^{232}Th series)	2614	2374-2932	408-505	2414-2816	415-485
Gamma dose rate	>450			>200	

Table 1: Spectral windows used by SUERC in this work and Global Earth Sciences in the 1991 analysis. Note that the channel ranges refer to the 512 channel spectra converted from the 256 channel spectra recorded in 1991.

	Ch1 (^{137}Cs)	Ch2 (^{60}Co)	Ch3 (^{40}K)	Ch4 (^{214}Bi)	Ch5 (^{208}Tl)
^{137}Cs	1	0.005	0	0	0
^{60}Co	0.45	1	0.58	0.04	0.02
K	0.60	0.50	1	0	0
U	3.71	1.58	1.14	1	0.07
Th	2.85	0.69	0.81	0.47	1

Table 2: Stripping matrix determined from data collected on the Tollerton pads, with a ^{137}Cs test source at the Dounreay airfield and from measurements near Dounreay with ^{60}Co radiation.

Window	Background (cps)	Altitude correction	Sensitivity
Ch1 (^{137}Cs)	69.58±0.09	0.0071	0.16 kBq m^{-2}/cps
Ch2 (^{60}Co)	30.49±0.06	0.008	1 cps/cps
Ch3 (^{40}K)	45.42±0.07	0.009	3.37 Bq kg^{-1}/cps
Ch4 (^{214}Bi)	13.94±0.04	0.01	1.58 Bq kg^{-1}/cps
Ch5 (^{208}Tl)	12.46±0.04	0.0112	0.23 Bq kg^{-1}/cps
Ch6 (Dose Rate)	277.5±0.2	0.0077	0.00035 mGy a^{-1}/cps

Table 3: Background count rates, exponential altitude correction coefficients and sensitivities.

Survey	Quantity	Mean	Standard Deviation
1991	^{137}Cs kBq m^{-2}	12.0	5.5
1998	^{137}Cs Bq kg^{-1}	52	29
	^{137}Cs kBq m^{-2}	12.6	7.0
1991	^{40}K Bq kg^{-1}	297	98
1998	%K	1.42	0.26
	^{40}K Bq kg^{-1}	438	82
1991	^{214}Bi Bq kg^{-1}	38	16
1998	eU ppm	2.44	0.44
	^{214}Bi Bq kg^{-1}	30	5
1991	^{208}Tl Bq kg^{-1}	5.4	2.0
1998	eTh ppm	4.12	0.73
	^{208}Tl Bq kg^{-1}	6.0	1.1

Table 4: Comparison between radiometric data recovered from a common 5x5km area for the 1991 survey (9700 measurements) and subsequent 1998 survey (5900 measurements), with the 1991 ^{137}Cs data decay corrected to 1998.