Sanderson, D.C.W. and Cresswell, A.J. (2007) *Preliminary Report on Airborne Radiometric Survey of the Thurso Area, 15-17 November 2006.* Project Report. Scottish Universities Environmental Research Centre, East Kilbride, UK.

Scottish Universities Environmental Research Centre

Preliminary Report on Airborne Radiometric Survey of the Thurso Area, 15th to 17th November 2006.

D.C.W. Sanderson, A.J. Cresswell
Scottish Universities Environmental Research Centre

East Kilbride Glasgow G75 OQF Telephone: 01355 223332 Fax: 01355 229898

CONTENTS

FIGURES AND TABLES

1. INTRODUCTION

An airborne survey of the area around Dounreay in 1998 revealed a number of small ^{137}Cs features on meander-bends of Forss Water (ref needed). This survey was restricted to the area in the immediate vicinity of the Dounreay site, and didn’t include the upper reaches of the river or the catchment.

The survey reported here intended to better define these features, assess the ^{137}Cs distribution in the catchment area of Forss Water to assist in determining the source of this activity, and examine River Thurso to determine if similar features exist there. In addition, a sparse survey of the region has been conducted to provide an overview of the radiation environment in this region.

A 15x20 km survey area, with corners at ND010680 and ND160480, covered the Forss Water and much of the length of River Thurso, with some of the catchments of these two rivers. The westernmost 5 km of this area was surveyed at 250 m line spacing, with the remainder at 500 m line spacing. In addition, free-flown flights were conducted along the lengths of the two rivers. This survey provides detailed information on the radiation environment immediately relevant to the definition of the extents and potential sources of the ^{137}Cs features on the river systems. A larger 60x31 km area, with corners at NC700660 and ND300350, was defined to provide an overview of the general radiation environment of the region. Lines were flown at 5 km spacing. These areas are shown in figure 1.1.

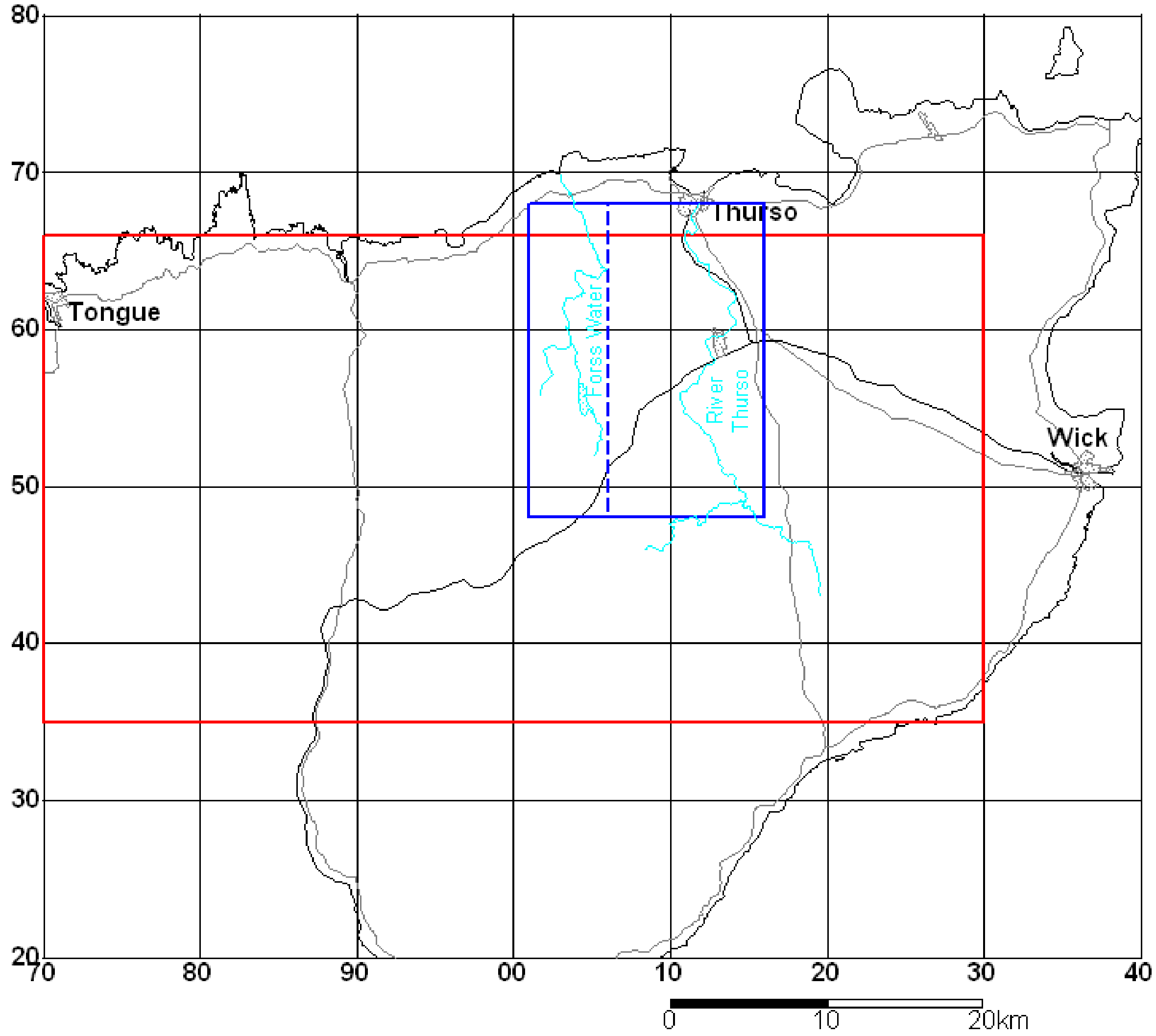

Figure 1.1: Survey areas for this work, showing the areas for regional overview survey (red) and detailed survey around the Forss Water and Thurso River (blue, with the 500 m line spacing to the east of the dashed line, and 250 m line spacing to the west).

2. FIELDWORK AND DATA COLLECTED

The SUERC AGS equipment was installed in a twin engine AS255 Squirrel helicopter at Inverness Airport on Tuesday 14th November 2006. The functionality of the equipment was verified, and the radar altimeter input to the system calibrated on the morning of the 15th November before deployment to the survey area.

Between the 15th-17th November, some 13.5 hours of data was logged. This included all the detailed survey area, with some lines truncated at the north to avoid the exclusion zone around Dounreay and the urban area of Thurso, flights along both the Forss Water and River Thurso, a calibration manoeuvre at the Decommissioning and Environmental Remediation Centre (DERC) near Thurso, and most of the western part of the larger regional survey area. Data that was collected outwith standard survey parameters (eg: where the ground clearance was too high or low, or where the GPS position wasn't defined) were removed from the data set. Figure 2.1 shows the location of each data point logged within survey parameters.

A stripping matrix was determined from measurements on the calibration pads at SUERC prior to the survey. No specific background measurements were recorded. Some data were collected on the 15th November while crossing the Moray Firth, and were used as background values for initial analysis. However, these values proved to be significantly above background, resulting in an oversubtraction of the background from the survey data. Revised background values were then determined from data collected over Loch Calder, Loch Shurrery and Loch Rimsdale. It is recognised that these lochs are smaller than would be ideal for background measurements, and potentially too shallow, though the values determined from this data are similar to background measurements from other recent surveys.

The hover manoeuvre at DERC was used to define altitude correction coefficients for the system. Presently, working sensitivity factors have been used, with the dose rate and radionuclide activity at the calibration site determined using these. These working values were derived from measurements over a terrestrial calibration sites in SW Scotland in 1993, with a series of other terrestrial sites sampled for comparison (Sanderson *et al* 1993). This working calibration has been used for several surveys since then, and compared to ground measurements. Thirteen gamma spectrometry measurements were made on the site using a 2x2" NaI spectrometer mounted on a tripod at 1 m above the ground, from a centre point and the 2 m and 8 m rings of the standard SUERC calibration pattern.

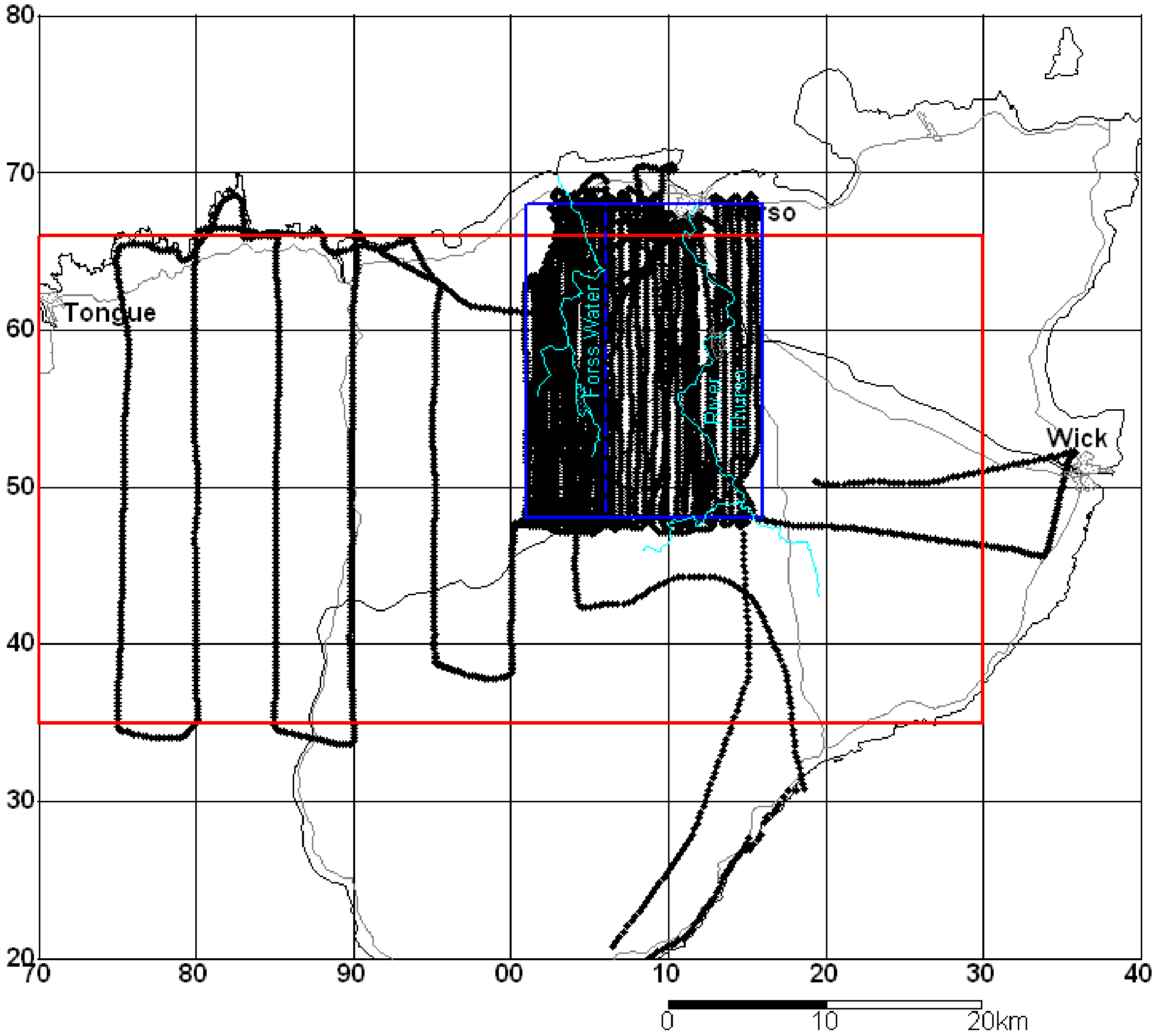

Figure 2.1: Location of data points collected within survey parameters.

3. DATA ANALYSIS

The data were analysed using a standard method of integrating spectral windows, stripping out interferences and calibrating the data (Sanderson *et al* 1994a,b, ICRU 1994, Allyson & Sanderson 2001, Cresswell *et al* 2006). The methods used extended the geological survey based techniques described by IAEA (IAEA 1991, 2003), in particular in addressing deconvolution of natural and anthropogenic spectral components and in combining empirical and theoretical sensitivity determinations for calibrating radiometric data. Preliminary calibrated data were determined using a combination of inherited calibration constants and values determined in the survey.

The ground based spectrometry data from the field near DERC were used to check the suitability of the working values of the sensitivity coefficients for the airborne data. The site is too small, and in the absence of soil sample data too poorly characterised, to provide a primary calibration. To determine the natural series activity concentrations on the site spectra recorded from three calibration pads at SUERC were fitted to the measured spectrum using a least squares fitting approach for energies above 1 MeV. Figure 3.1 shows the measured spectrum with the three fitted components and the residual spectrum. This results in an excellent fit to the measured spectrum, with a residual spectrum showing a clear ^{137}Cs peak and some scattered components.

Using activity concentrations and geometric correction factors for the pads (Grasty *et al* 1991), the concentrations of ^{40}K, ^{214}Bi and ^{208}Tl on the field can be determined. Dose rate can be estimated by several methods; using the count rate above 450 keV or 1350 keV or the energy deposited in the field spectrometer, or from the calculated concentrations of radionuclides. Table 3.1 gives the estimates of radionuclide concentrations and dose rate from both field and airborne data. Uncertainties of 10% are given for the ground based data, based on 5% standard deviation for the 13 dose rate measurements, 5% uncertainties on the least squares fitting and 1-2% uncertainties on the pad concentrations. The airborne data uncertainties are a combination of the standard error on the 50 measurements over the site and a 5% systematic uncertainty.

It can be seen that the ^{208}Tl and ^{40}K activity concentrations agree within 3σ, the airborne dose rate is a little bit higher and ^{214}Bi activity concentration much lower. Nevertheless, these do indicate that the airborne spectrometry system is operating in a manner that's comparable to the system used when the working calibration was originally defined, and hence that the working calibration is still suitable for this work.

Parameter		Ground Data	Airborne Data
^{137}Cs (kBq m^{-2})			5.8±0.4
^{40}K (Bq kg^{-1})		340±34	288±15
^{214}Bi (Bq kg^{-1})		18.5±1.9	10.0±0.7
^{208}Tl (Bq kg^{-1})		4.2±0.4	4.3±0.2
Dose Rate (mGy a^{-1})	>450 keV	0.271±0.015	0.33±0.02
	>1350 keV	0.273±0.015	
	E dep	0.296±0.015	
	ICRU53	0.26±0.03	
	Luminescence	0.29±0.03	

Table 3.1: Comparison between ground based and airborne data on the field at DERC.

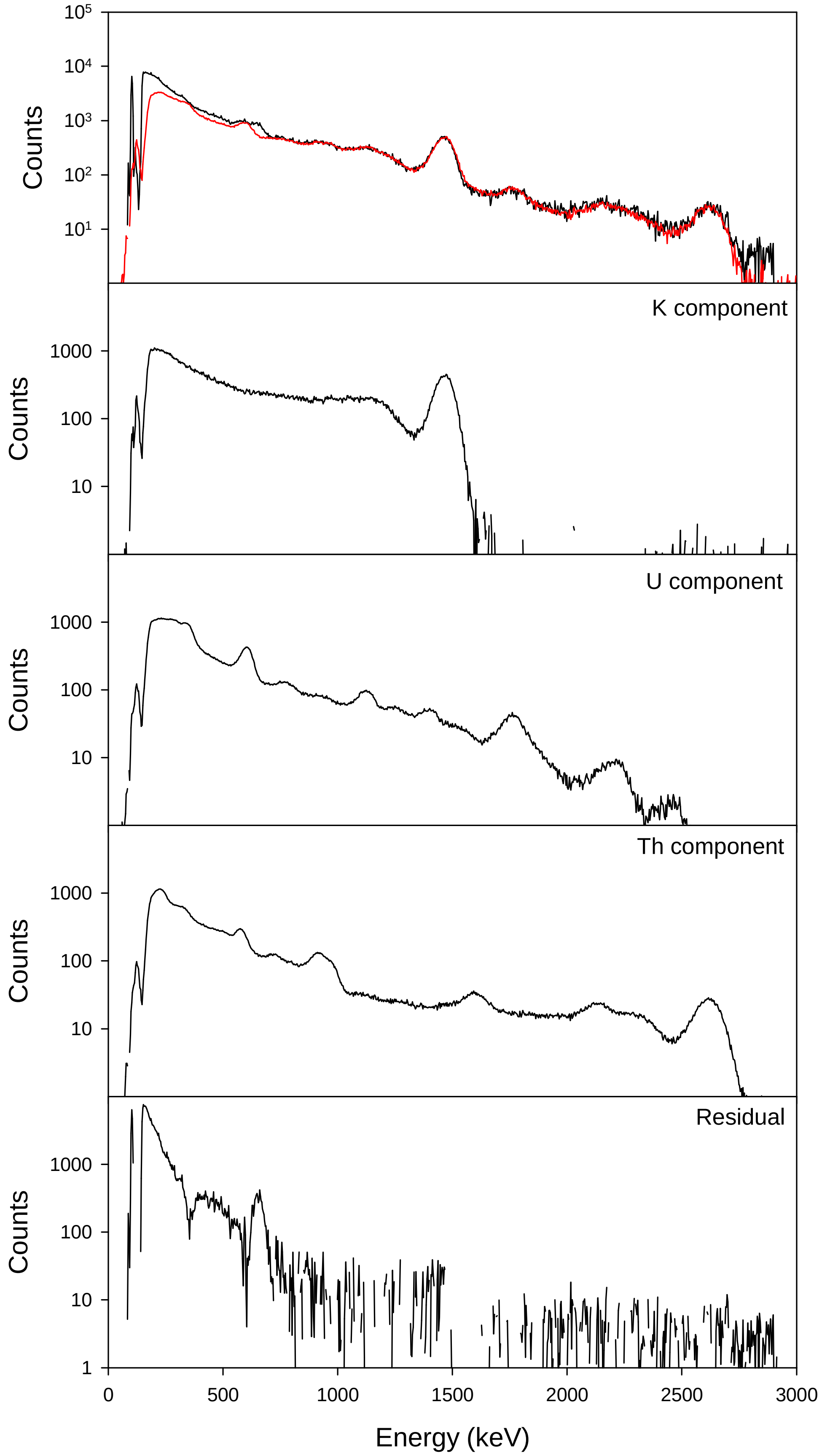

Figure 3.1: Measured spectrum from the field at DERC with the natural series components determined by least squares fitting above 1 MeV, the resulting fitted spectrum (in red) and residual spectrum.

The data were mapped with the SUERC AGS mapping software, which uses a modified inverse-distance weighted algorithm to produce bitmaps that are then registered into GIS systems. Working maps have been produced for ^{137}Cs (in kBq m^{-2}), for ^{40}K, ^{214}Bi (proxy for uranium) and ^{208}Tl (proxy for thorium) in Bq kg^{-1}, and for estimated gamma dose rate (in mGy a^{-1}).

4. RESULTS

The regional scale maps of the radiation environment are shown in figures 4.1-4.5 for ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and the gamma dose rate respectively.

The more detailed maps of the radiation environment of the Forss Water and Thurso River areas are shown in figures 4.6-4.10 for ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and the gamma dose rate respectively.

All the maps show similar large scale distributions, with activity registered on areas with mineral soils or exposed rock and very low activity on areas with peat cover and lochs. The water-logged organic rich peat carries little activity, and shields radiation from the underlying geology.

The ^{137}Cs distribution shows higher levels on the higher ground between the Thurso River and Forss Water, to the south of the survey area along the coast near Dunbeath, and a small area to the west of Wick (though this is from a small number of measurements on a transit line at slightly above normal survey height and speed). There are activity levels slightly above the detection limit along Strath Halladale, the hillier land to the south of the regional mapping area and along the northern coast. The detailed area shows the concentration of ^{137}Cs activity to the east and north of Loch Calder and other areas where the environment isn’t dominated by peat. There are several enhanced features on Forss Water; two near Knockglass at ND055635 and ND040637, another near Broubster at ND035602 and a larger feature near ND040583. There are a couple of smaller features on the Thurso River near ND125535 and ND145490.

There are some small differences between the distribution patterns for the natural series activity reflecting differences in the geology and soils. The gamma dose rate is driven by the natural activity, with no significant contribution from the ^{137}Cs activity.

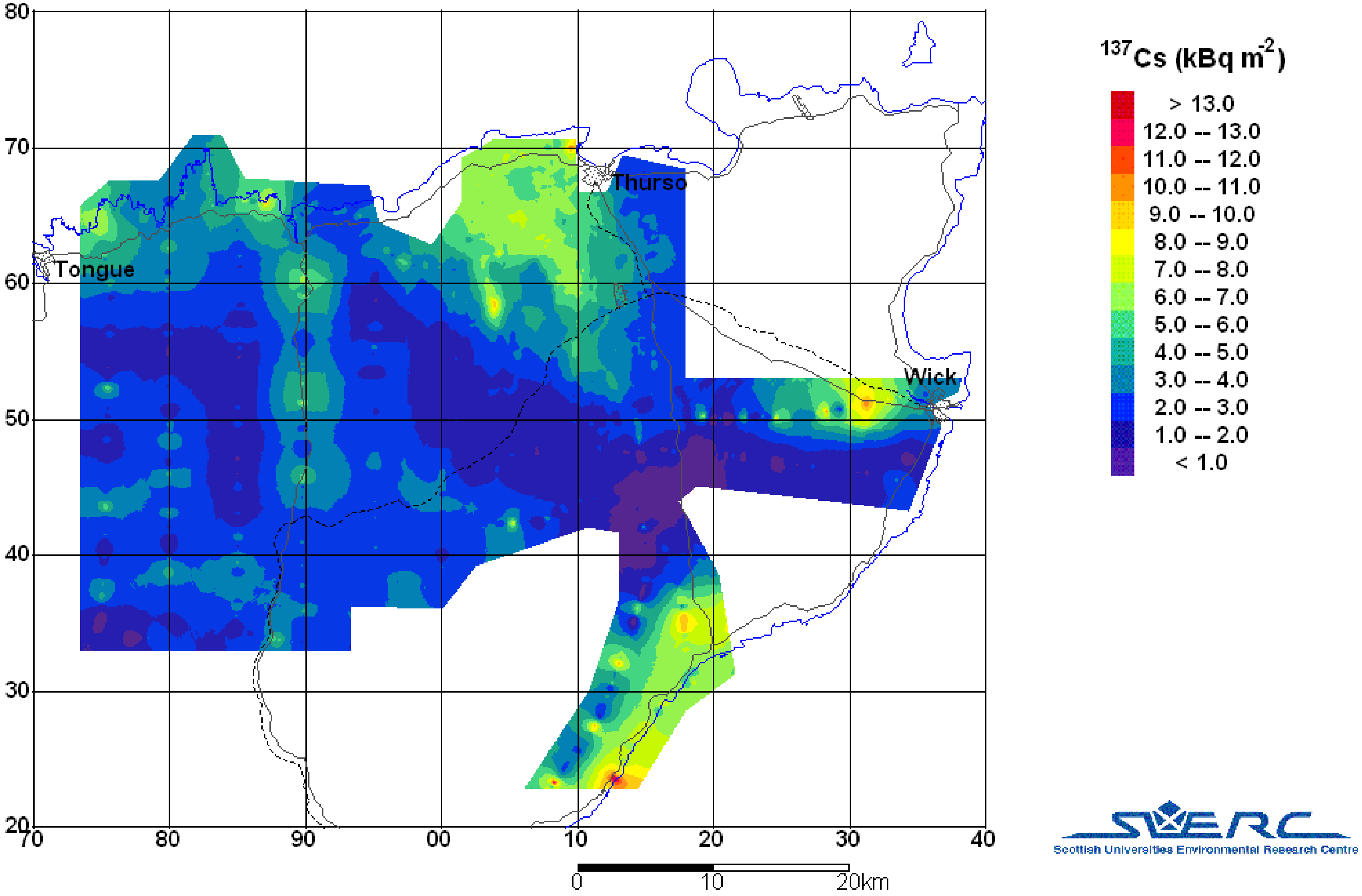

Figure 4.1: ^{137}Cs distribution in the Caithness region.

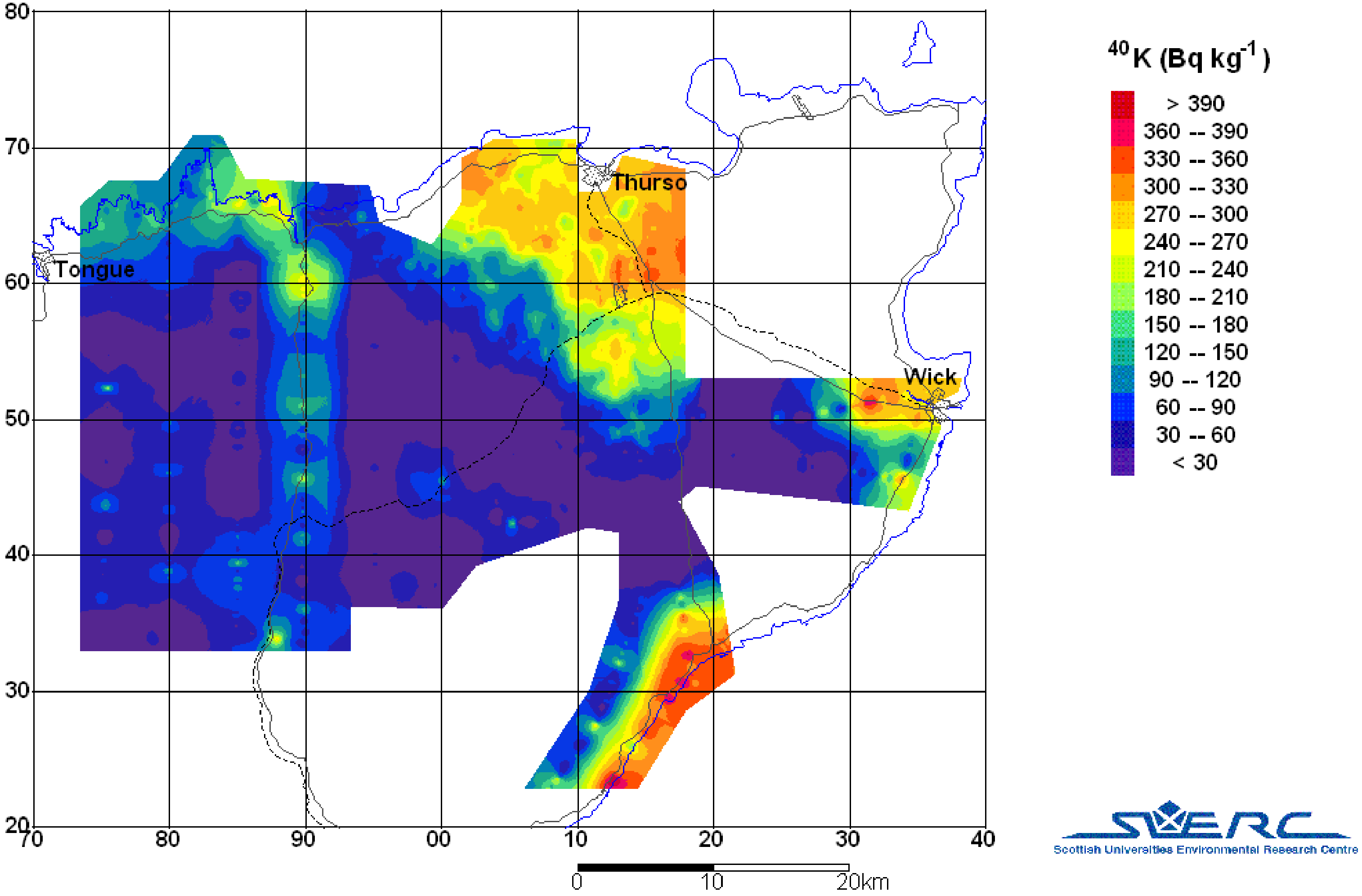

Figure 4.2: ^{40}K distribution in the Caithness region.

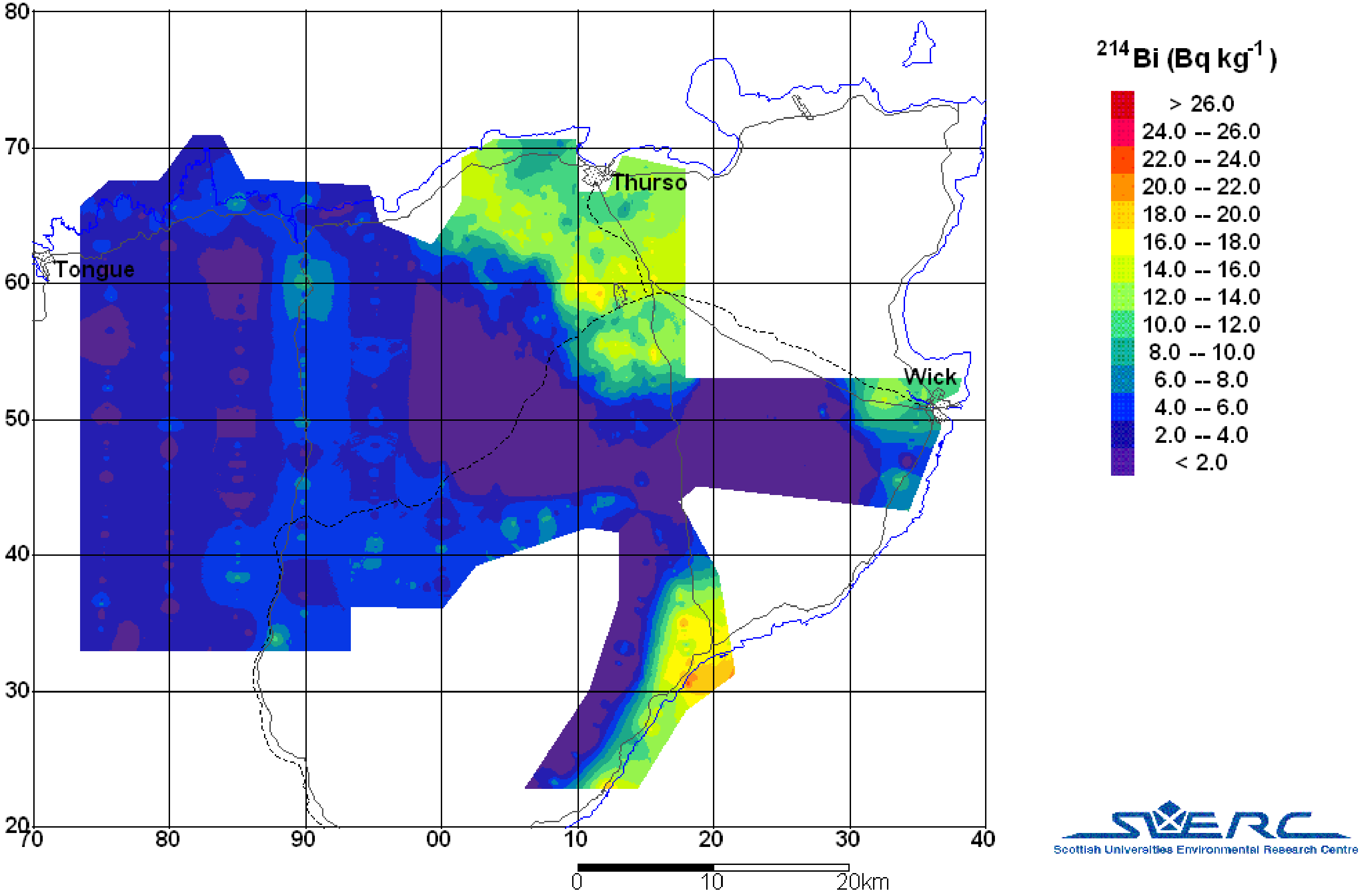

Figure 4.3: ^{214}Bi distribution in the Caithness region.

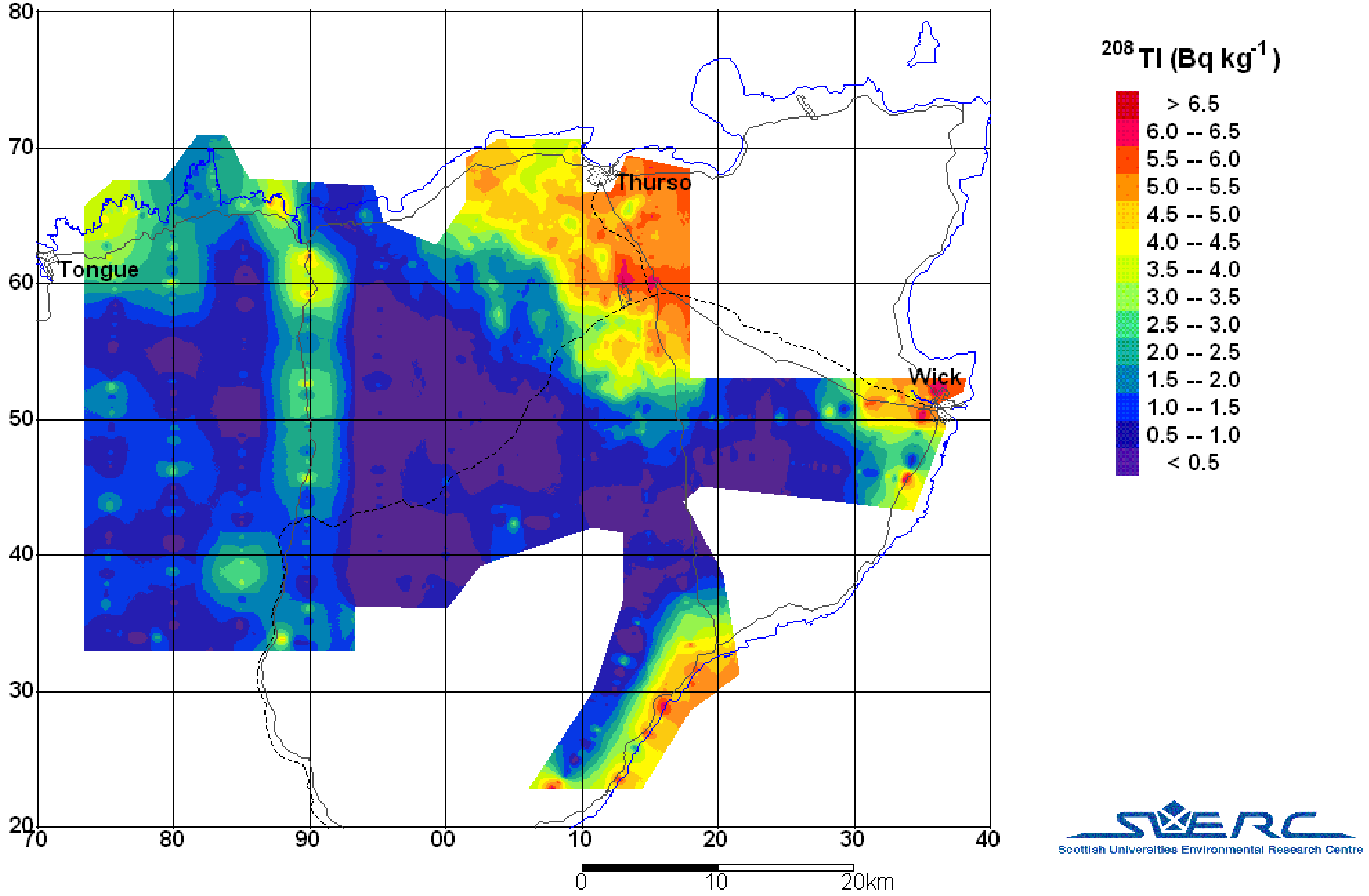

Figure 4.4: ^{208}Tl distribution in the Caithness region.

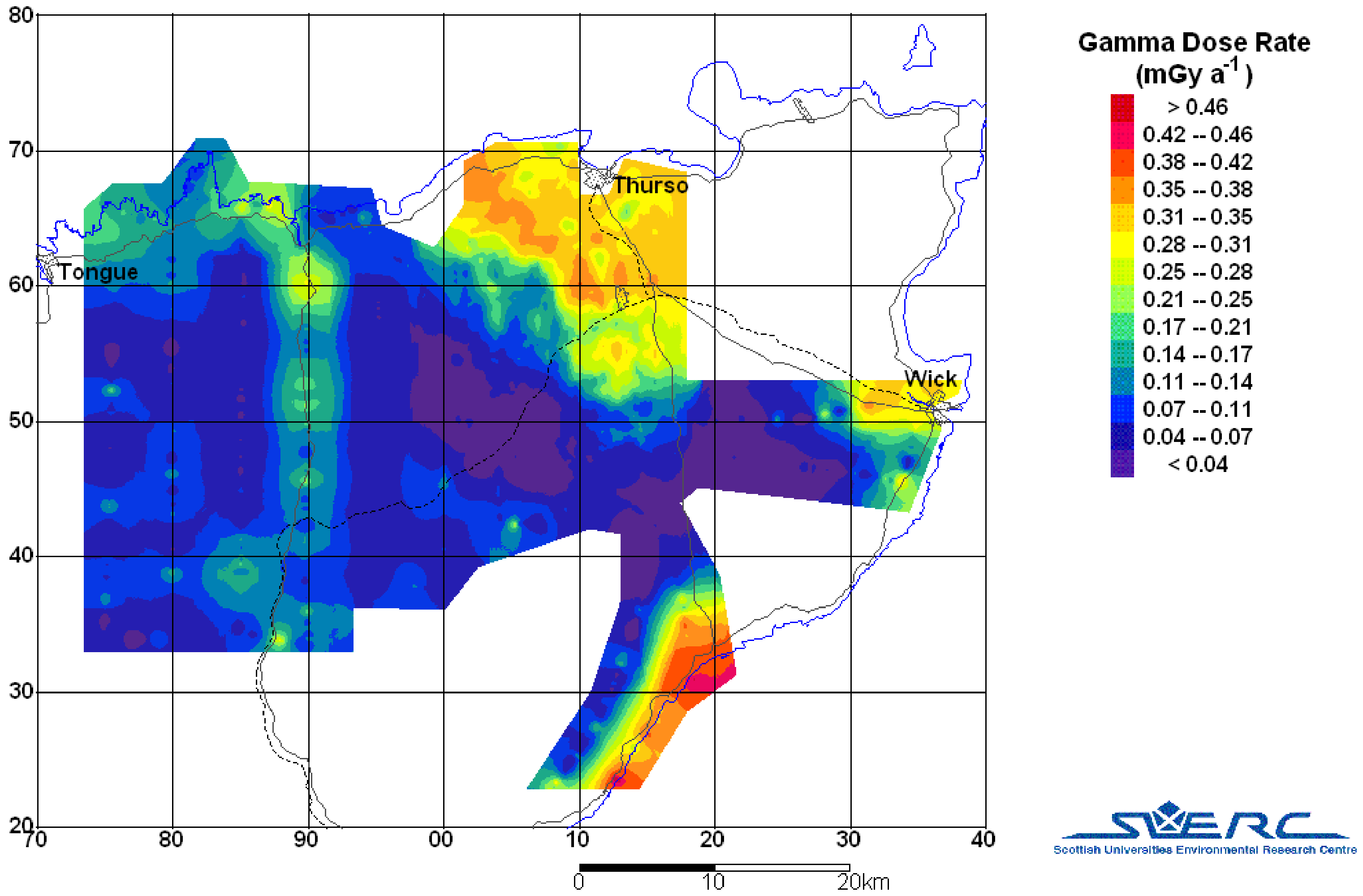

Figure 4.5: Gamma Dose Rate distribution in the Caithness region.

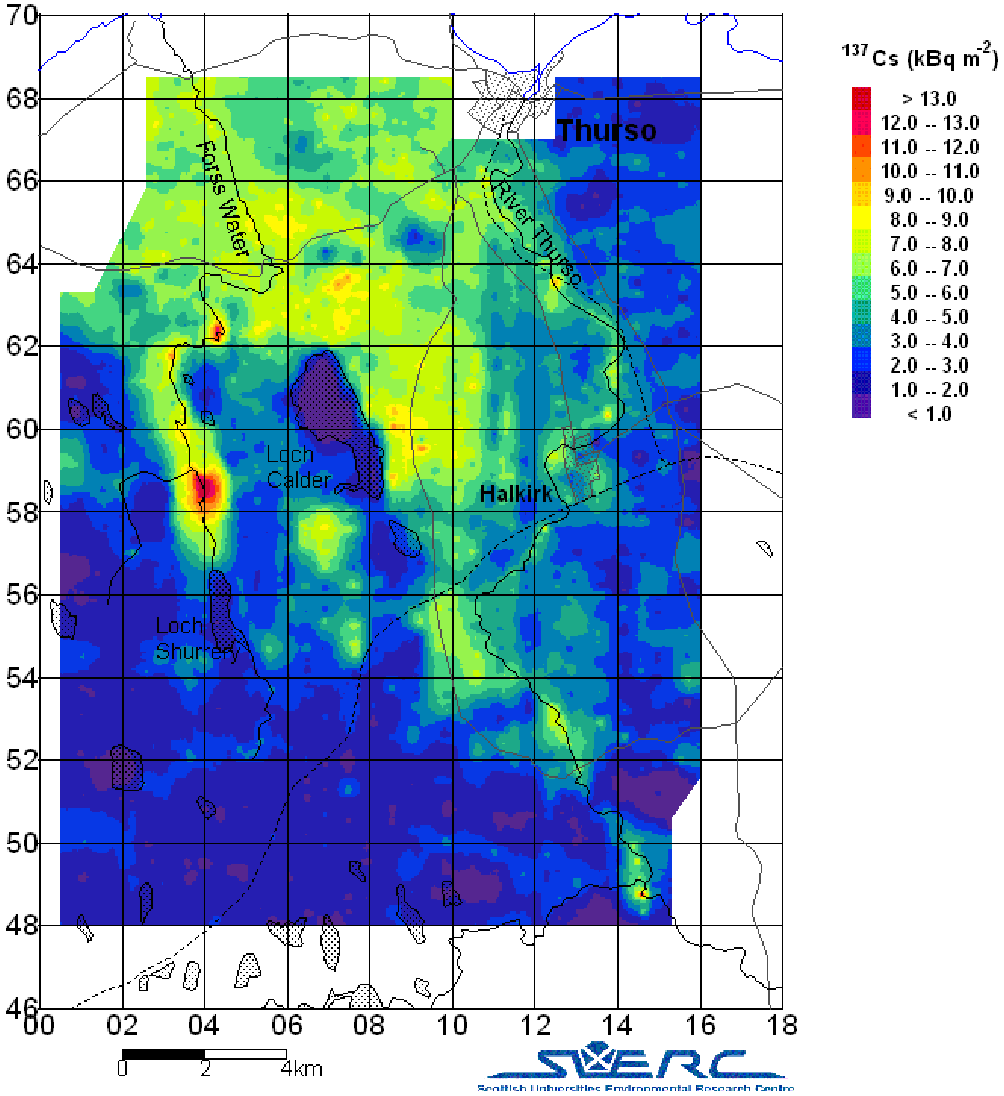

Figure 4.6: ^{137}Cs distribution in the area around Forss Water and the Thurso River.

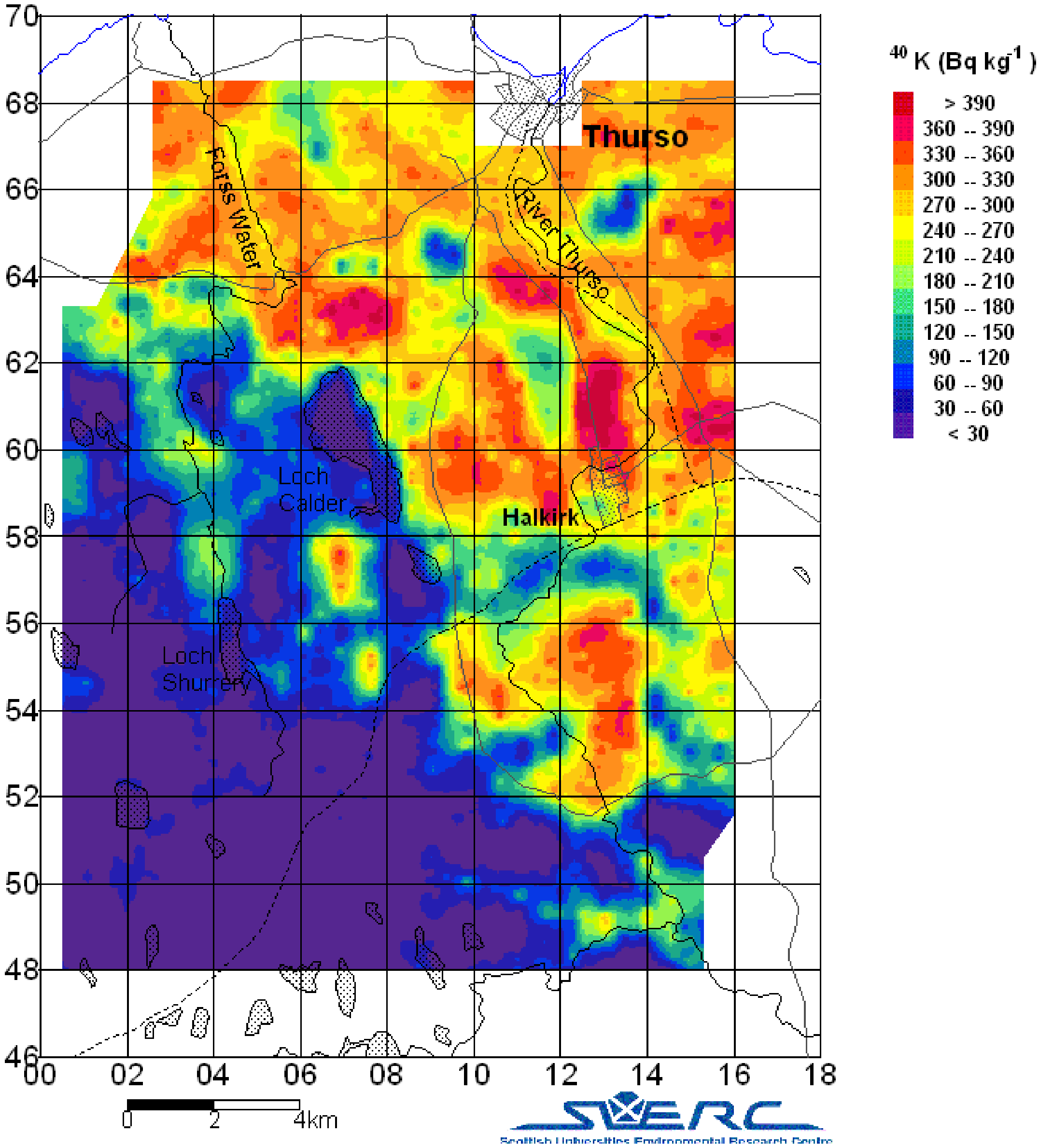

Figure 4.7: ^{40}K distribution in the area around Forss Water and the Thurso River.

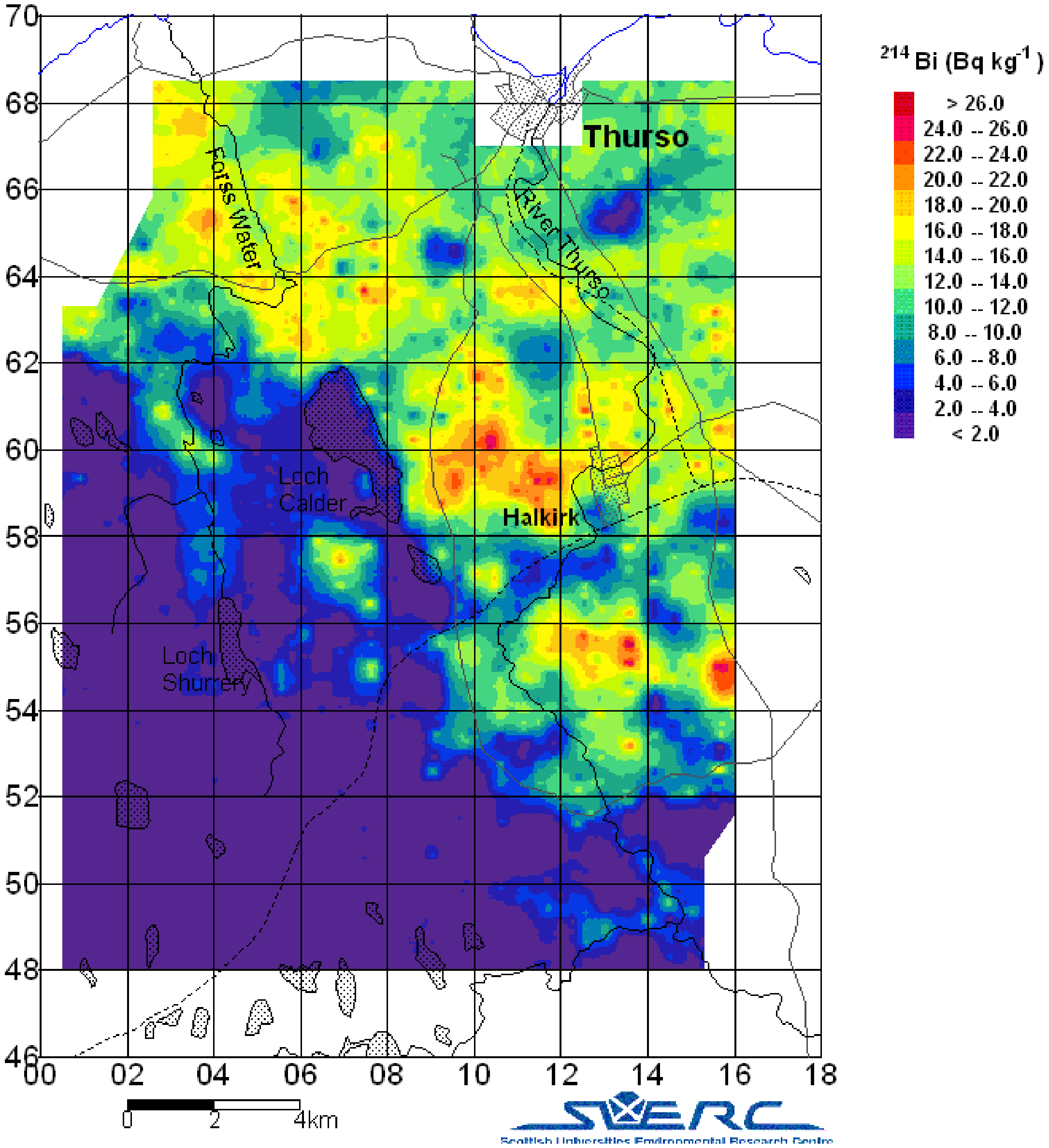

Figure 4.8: ^{214}Bi distribution in the area around Forss Water and the Thurso River.

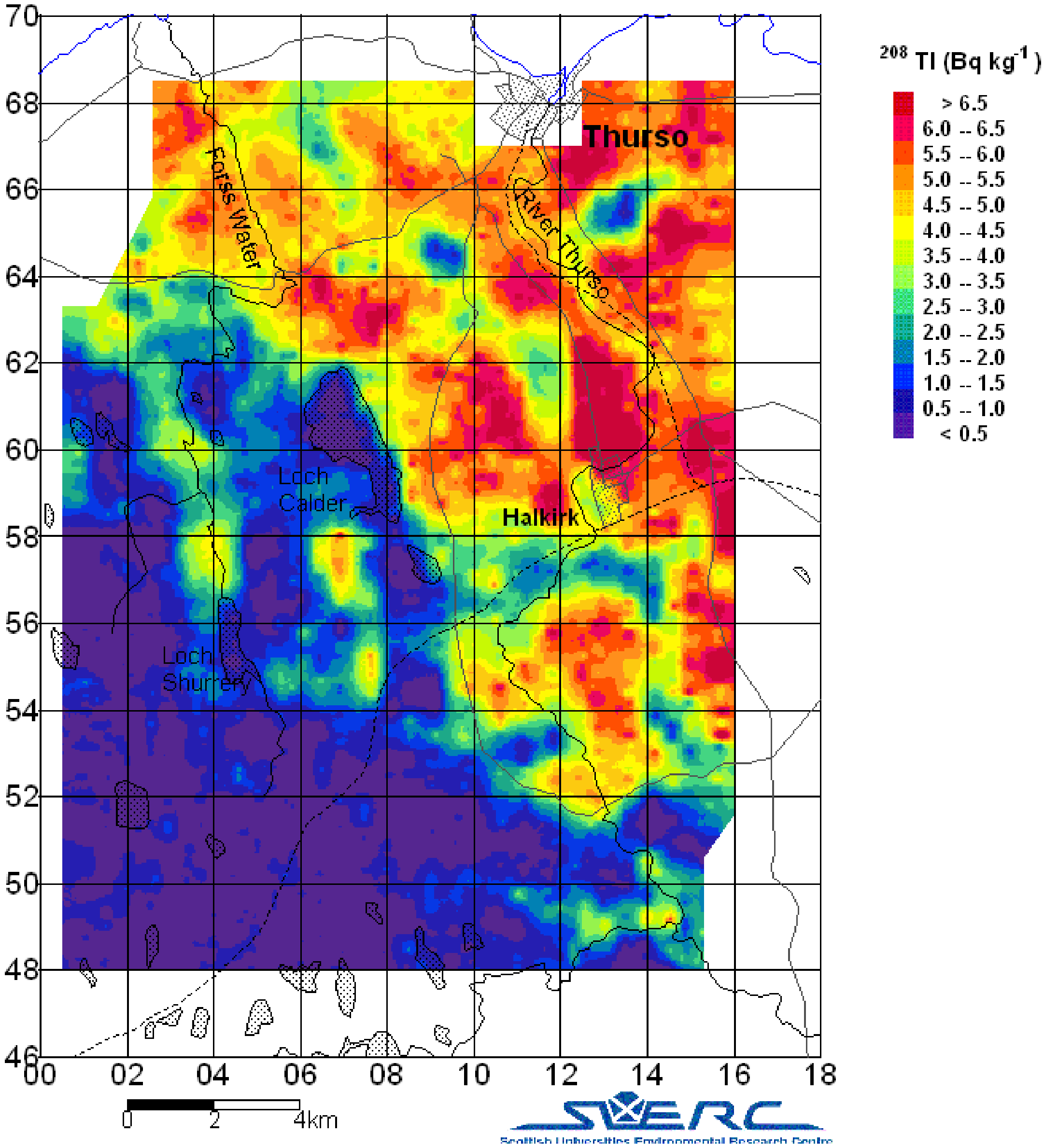

Figure 4.9: ^{208}Tl distribution in the area around Forss Water and the Thurso River.

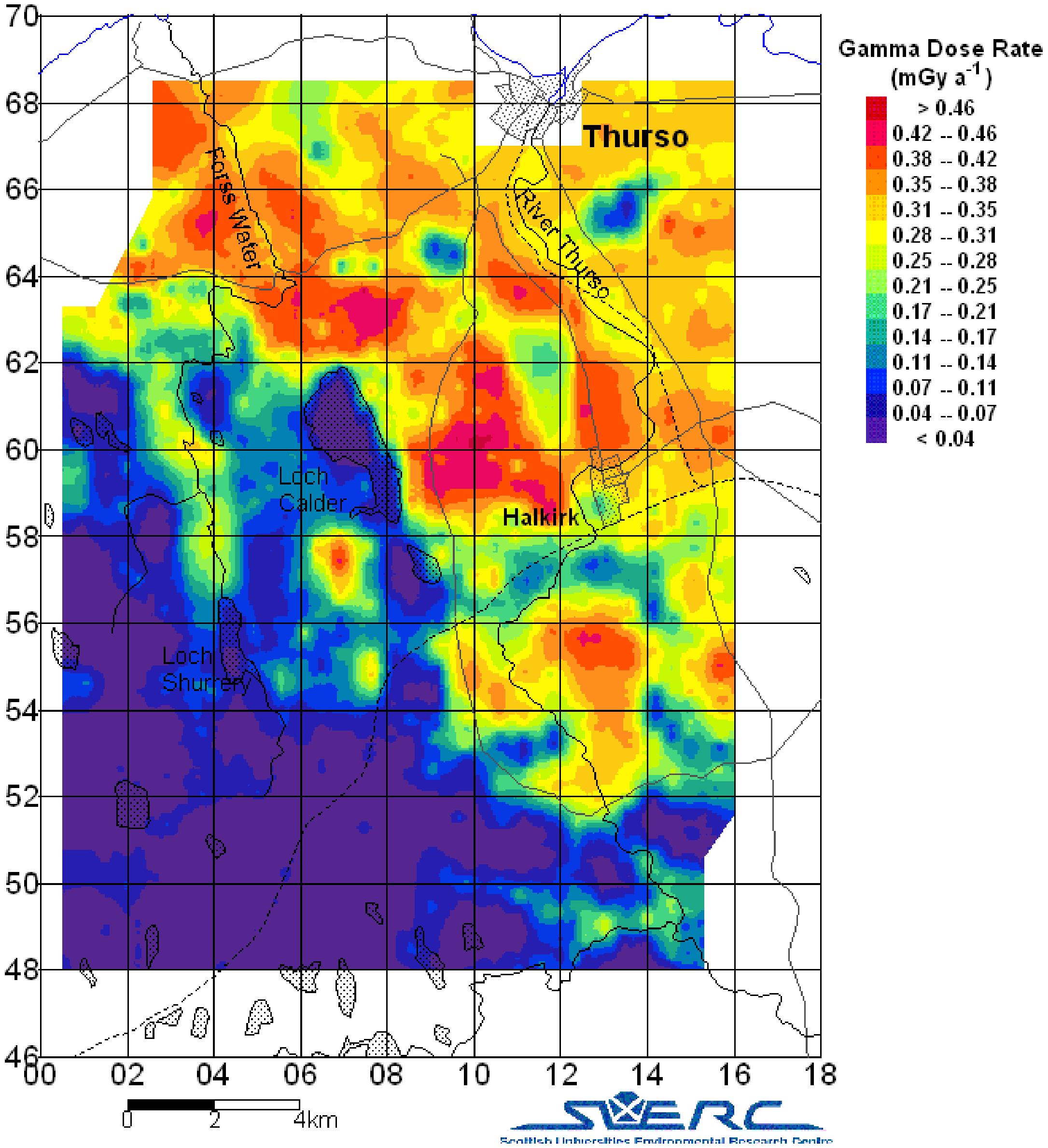

Figure 4.10: Gamma Dose Rate distribution in the area around Forss Water and the Thurso River.

5. DISCUSSION AND CONCLUSIONS

A brief airborne survey of part of Caithness has been conducted, giving data for the distribution of radioactivity on a regional scale at wide line spacing and more detailed data around the Forss Water and River Thurso. Data for naturally occurring ^{40}K, ^{214}Bi and ^{208}Tl, anthropogenic ^{137}Cs and the gamma dose rate have been mapped for both the regional scale and detailed areas.

The region has considerable areas of saturated peat, which along with open water suppress radiation from underlying geology. The ^{137}Cs data also show strongly suppressed signals from these areas indicating that any fallout on these areas has migrated down through the peat. Soil cores would need to be collected and analysed to determine whether any ^{137}Cs fallout on these areas is retained in the peat layers, or whether it was sufficiently mobile enough to have drained from these areas entirely.

In the detailed mapping area, ^{137}Cs activities of up to 10 kBq m^{-2} have been observed on the drier land. These levels are consistent with Chernobyl fallout, though lower than those observed for Chernobyl fallout in other parts of Scotland where 20-30 kBq m^{-2} are often recorded. The regional scale survey doesn’t have sufficient coverage or detail to determine the fallout pattern over the wider area, and the suppression of radiation by the peat makes it impossible to evaluate the fallout on those areas from this data. There are some definite ^{137}Cs features on meander bends of Forss Water, and to a lesser extent on the River Thurso, that are associated with the accumulation of sediment carrying activity from elsewhere in the catchment areas.

REFERENCES

Allyson J.D., Sanderson, D.C.W. (2001). Spectral deconvolution and operational use of stripping ratios in airborne radiometrics. *Journal of Environmental Radioactivity* **53**, 351-363.

Cresswell, A.J., Sanderson, D.C.W., White, D.C. (2006). ^{137}Cs measurement uncertainties and detection limits for airborne gamma spectrometry (AGS) data analysed using a spectral windows method. *Applied Radiation and Isotopes* **64**, 247-253.

Grasty, R.L., Holman, P.B., Blanchard, Y.B. (1991). *Transportable Calibration Pads For Ground and Airborne Gamma-ray Spectrometers.* Geological Survey of Canada 90-23.

IAEA (1991). *Airborne Gamma Ray Spectrometer Surveying.* IAEA Technical Report Series No. 323.

IAEA (2003). *Guidelines for Radioelement Mapping using Gamma Ray Spectrometry Data.* IAEA-TECDOC-1363.

ICRU (1994). *Gamma-ray Spectrometry in the Environment.* ICRU Report No. 53.

Sanderson, D.C.W., Allyson, J.D., Tyler, A.N., Ni Riain, S., Murphy, S. (1993). *An Airborne Gamma Ray Survey of Parts of SW Scotland in February 1993. Final Report.* SURRC Report for Scottish Office Environment Department.

Sanderson, D.C.W., Allyson, J.D., Tyler, A.N. (1994a). Environmental applications of airborne gamma spectrometry. *Application of Uranium Exploration Data and Techniques in Environmental Studies*. IAEA-TECDOC-827, pp 71-91.

Sanderson, D.C.W., Allyson, J.D., Tyler, A.N. (1994b). Rapid quantification and mapping of radiometric data for anthropogenic and technologically enhanced natural nuclides. *Application of Uranium Exploration Data and Techniques in Environmental Studies*. IAEA-TECDOC-827, pp 197-216.

Sanderson, D.C.W., Cresswell, A.J., White, D.C., Murphy, S., McLeod, J. (2001). *Investigation of Spatial and Temporal Aspects of Airborne Gamma Spectrometry. Final Report.* SURRC report for DETR. DETR/RAS/01.001.

Sanderson, D.C.W., Cresswell, A.J., Lang, J.J. (eds) (2003). *An International Comparison of Airborne and Ground Based Gamma Ray Spectrometry. Results of the ECCOMAGS 2002 Exercise held 24th May to 4th June 2002, Dumfries and Galloway, Scotland.* University of Glasgow. ISBN 0 85261 783 6.

Tyler, A.N., Sanderson, D.C.W., Scott, E.M. (2000). The elusive topographic anomaly: empirical comparisons between airborne, in-situ and soil sample ^{137}Cs activity estimates across an upland valley. *Recent Applications and Developments in Mobile and Airborne Gamma Spectrometry.* Sanderson, D.C.W., Lang, J.J. (eds). University of Glasgow. ISBN 0 85261 685 6.

APPENDIX

Window	Range (keV)	Range (channels)	Background (cps)
^{137}Cs	530-775	93 – 132	38.7±1.1
^{60}Co	1027-1279	173 – 214	14.2±0.6
^{40}K	1359-1657	227 – 275	13.8±0.6
^{214}Bi	1690-2008	280 – 332	8.0±0.4
^{208}Tl	2486-2884	409 – 474	5.1±0.3
Total >450 keV	450-3000	75 – 480	133±3

Table A.1: Spectral windows used, with background count rates.

Window	^{137}Cs	^{60}Co	^{40}K	^{214}Bi	^{208}Tl
Ch1 (^{137}Cs)	1	0.555	0.643	3.315	2.799
Ch2 (^{60}Co)	0	1	0.473	1.511	0.711
Ch3 (^{40}K)	0.007	0.509	1	0.907	0.611
Ch4 (^{214}Bi)	0	0.058	0	1	0.501
Ch5 (^{208}Tl)	0.002	0.034	0	0.049	1

Table A.2: Stripping matrix used.

Window	Altitude Correction	Sensitivity
^{137}Cs	0.017	0.2 kBq m^{-2} cps^{-1}
^{60}Co	0.010	1.0
^{40}K	0.0115	6.65 Bq kg^{-1} cps^{-1}
^{214}Bi	0.0085	1.44 Bq kg^{-1} cps^{-1}
^{208}Tl	0.0080	0.58 Bq kg^{-1} cps^{-1}
Total >450 keV	0.0082	0.0007 mGy a^{-1} cps^{-1}

Table A.3: Altitude correction and sensitivity coefficients used.

Files	Date and time	Comments
THTS1123-201	15/11/06 11:11-11:27	Transit from Inverness to DERC for refuelling. At survey height, includes River Thurso.
THTS2043-827	15/11/06 12:18-14:56	Waypoints 31-32 (off line), then 61-80. Start survey along Forss Water (GPS drop out).
THTS3008-686	16/11/06 09:08-11:24	Transit from Wick to waypoint 60, then 60-45. Transit to DERC at survey height, hover manoeuvre at DERC.
THTS4013-908	16/11/06 12:16-15:16	Waypoints 15-30 and 33-44.
THTS5013-138	16/11/06 15:39-16:04	Waypoints 14-13 then transit to Wick.
THTS6132-637	17/11/06 09:07-10:49	River hotspots, then waypoints 1-12 and 31-32.
THTS7015-110 142-201	17/11/06 11:06-11:25 11:31-11:43	Forss Water (two flights)
THTS8022-146 286-828	17/11/06 12:15-12:40 13:08-14:57	Two replacement lines Coastal flight, then waypoints 83-96, coastal flight transit to Inverness

Table A.4: Summary of data files.