Scottish Universities Environmental Research Centre

Mobile Gamma Spectrometry Measurements of Coneyside Beach, Cumbria

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

D. Maneuski
Dept. Of Physics and Astronomy, University of Glasgow

November 2010

East Kilbride Glasgow G75 0QF Telephone: 01355 223332 Fax: 01355 229898

Summary

Environmental radioactivity arises from natural and anthropogenic sources: ^{238}U, ^{232}Th and their decay products, and ^{40}K in differing concentrations in rocks and soils; natural materials transformed by industrial processes to enhance the concentrations of some radioactive isotopes; materials discharged from some nuclear processes; fallout from nuclear accidents and weapons testing; radioactive sources that may have been lost or stolen; and radiation shine from sites using nuclear technology. Mobile gamma spectrometry provides powerful methods of measuring the distribution of radioactivity in the environment; airborne platforms allow the rapid survey of large areas, and ground based platforms more detailed surveys of smaller areas.

Airborne surveys in 1990 (conducted to produce a baseline data set for the Sellafield site) and 2000 (as part of a large study on spatial and temporal aspects of airborne measurements) showed several radiometric features along the coast, including elevated ^{137}Cs activity along a beach in West Cumbria between St Bees and Nethertown, in an environment comprising pebbles and gravel where this was unexpected. An additional short survey of this area was conducted during the 2000 survey, at reduced ground clearance and speed, to verify the existence of these unexpected signals. With increased interest in the search and recovery of particulate activity from the beaches in the vicinity of Sellafield, this data was reviewed in 2008 to illustrate the use of airborne methods in locating potential particulate activity on beaches and to aid in the planning of further ground based investigations. SUERC conducted an exploratory ground based survey in June 2010; to investigate whether the features observed in the airborne surveys were still present, to define the spatial distribution of activity more precisely, and to attempt to assess the form of the activity and whether it had been redistributed since 2000. This report presents the 2000 airborne measurements reviewed in 2008, with the results of the June 2010 survey.

A portable gamma spectrometry system has been developed at SUERC. This consists of a 3x3" NaI(Tl) detector with digital spectrometer, a GPS receiver and netbook computer. The system is lightweight, easy to use and can be carried over terrain that would be inaccessible to vehicular systems. By holding the detector close to the ground the extent of any observed enhanced activity feature can be determined more precisely. Two of these systems have been field tested on the 22-23rd June 2010 along this beach.

The exploratory survey has clearly demonstrated the utility of the SUERC backpack system in producing detailed maps of the distribution of radioactive materials in the environment. A survey using two systems successfully mapped an area of approximately 50x200m with very high density measurements in a period of approximately 2h.

It has shown that the enhanced ^{137}Cs activity is still present on the beach, in locations that are consistent with the earlier airborne measurements. The more detailed survey shows a pattern of patches of enhanced ^{137}Cs activity. Samples collected from some of these had concentrations of 50 Bq kg^{-1}, which would account for the observed ^{137}Cs count rate. The nature of the material that carries this activity is at present unknown.

Contents

List of Figures

List of Tables

1. INTRODUCTION

During a large airborne survey of Cumbria conducted as part of a project funded by the Department of Transport, Environment and the Regions (DETR) and other agencies (Sanderson et.al. 2001) a survey of the coastline was conducted between Carlisle and the Duddon Estuary in March 2000 (Sanderson et.al. 2000). This survey was conducted in sections at low tide, with nominal 100m line spacing and typically four lines along each section of coast (one along the back of the beach, one along the low water mark and two in between) at a ground clearance of 200ft and airspeed of 70 knots.

Along a section of coast between Nethertown and St Bees enhanced ^{137}Cs activity was observed on beaches composed of gravel and pebbles. ^{137}Cs discharged into the Irish Sea from Sellafield adheres to fine mud particles, resulting in very high activity concentrations on mud flats and estuarine salt marshes. However, it is not expected to accumulate in environments dominated by sand, gravel or pebbles. At the end of a subsequent survey flight while returning to the operating base to refuel, an additional short survey was conducted over this area at reduced ground clearance (50ft) and air speed (15-20 knots) to further examine this unexpected feature. The results of these survey flights were communicated to the Environment Agency during the survey and mentioned in the subsequent project reports, but no further investigations were conducted at the time. Similar features had been observed in the 1990 baseline survey of the Sellafield site (Sanderson et.al. 1990).

In recent years, radioactive particles have been recovered from sand beaches in Cumbria (Hemming 2008, D'Souza 2009, 2010). This raised the question of whether the earlier observations were due to such particles, or other ^{137}Cs contamination that might influence the ability of systems to locate such particles. Therefore, in 2008 the airborne data were reviewed and analysed in detail, and presented to Sellafield Ltd and the Environment Agency as an illustration of the ability of airborne systems to locate anomalous signals, potential due to particulate activity, and aid in the ongoing ground based search and recovery operations. In June 2010, the beach was surveyed again to test the performance of a lightweight portable gamma spectrometry system developed at SUERC and attempt to further characterise the observed ^{137}Cs signals. The intention of this exploratory backpack survey was to investigate whether the features observed in the airborne surveys were still present and define the spatial distribution of activity more precisely, and to attempt to assess the form of the activity and whether it had been redistributed since 2000.

Figure 1.1 shows the location of the area under investigation in this work.

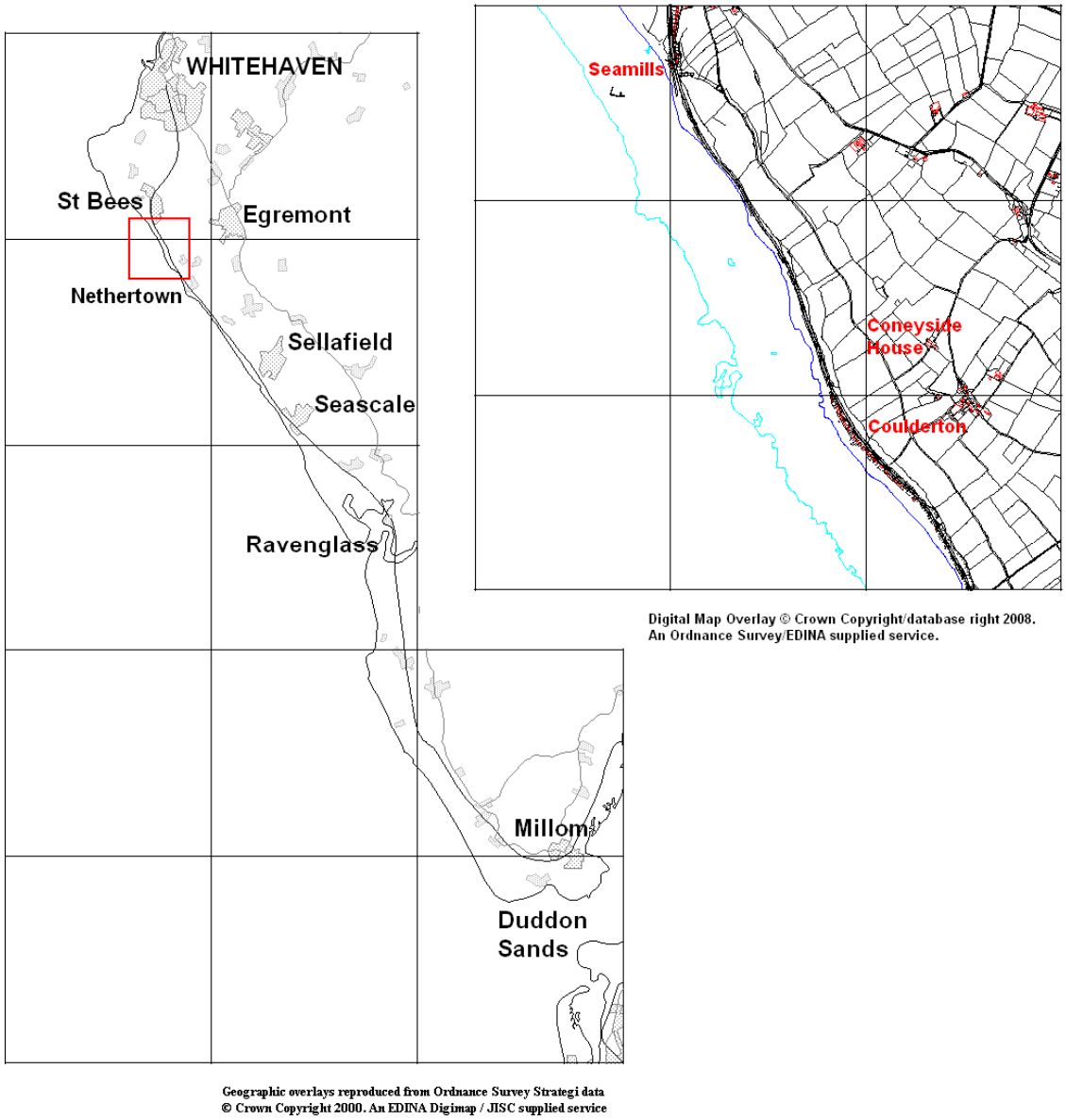


Figure 1.1: Map showing the location of the area of investigation for this study.

2. RESULTS

2.1 March 2000 Airborne Survey

The initial coastline survey was conducted on March 17th 2000, with four lines flown between St Bees and Duddon at a survey height of ~70m and speed of ~100kph. Gamma spectrometry data were collected from a large volume (16 litre) NaI(Tl) detector with a 2s integration time and a 50% relative efficiency HPGe (GMX) detector with a 4s integration time. A small number of individual NaI(Tl) measurements registered relatively high ^{137}Cs activity concentrations, as shown in Figure 2.1.

A more detailed survey was conducted on the 18th March, at a survey height of 15-20m and speed of 20-35kph. This survey lasted 10 minutes, and covered approximately 1km of beach near Coneyside House (NX9709). Gamma spectrometry measurements were collected with the same instruments and integration times used in the initial coastline survey. This survey registered some clusters of higher activity readings along the top of the beach, with some additional small single readings elsewhere, as shown in Figure 2.2.

Spectra recorded with the two systems, shown in Figure 2.3 for measurements within one cluster of enhanced ^{137}Cs readings, clearly show that there is ^{137}Cs in the environment rather than the measurements being the result of imperfect spectral analysis. The observed count rates (~150cps in the NaI(Tl) and ~1.5cps in the HPGe) are consistent with a point source of ~10MBq, or an extended source or collection of sources of similar total activity.

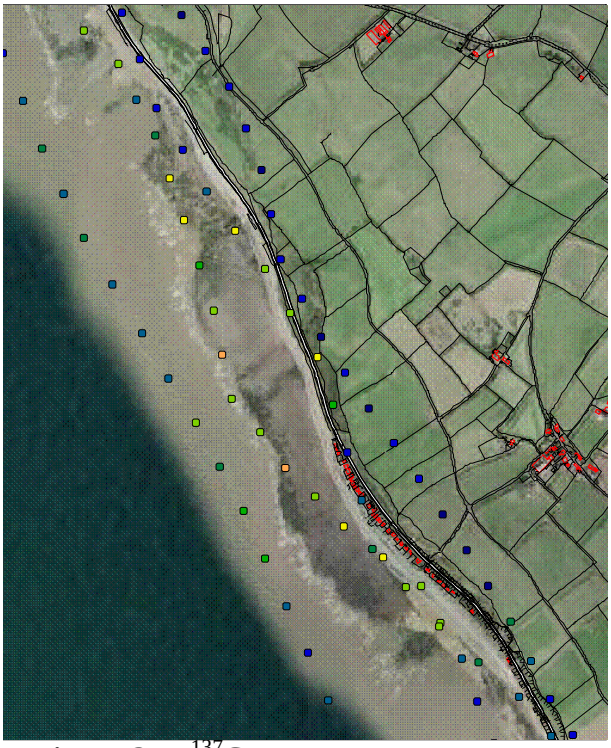


Figure 2.1: ^{137}Cs activity measurements along a 3km section of beach from the initial survey, 17th March 2000.

Figure 2.2: ^{137}Cs activity measurements along a 1km section of beach from the follow-up survey, 18th March 2000.

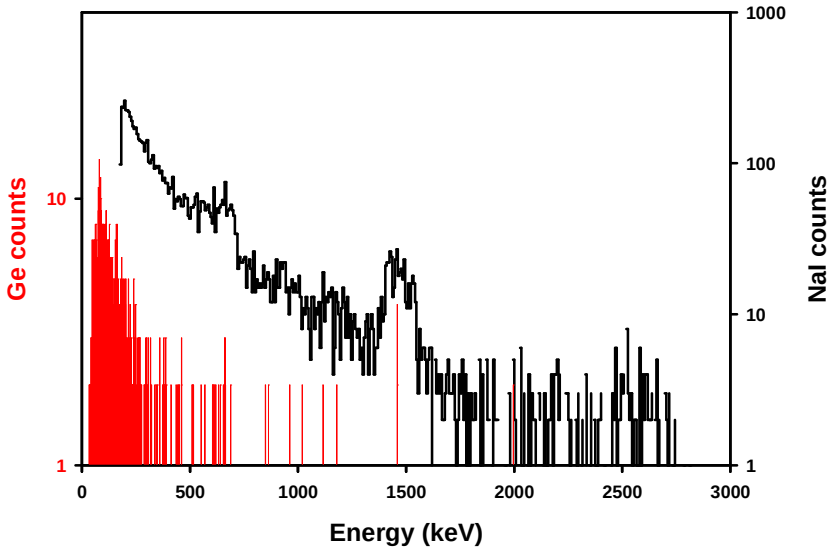


Figure 2.3: Individual spectra from the NaI(Tl) spectrometer (2s integration time) and HPGe spectrometer (4s integration time) from within a cluster of enhanced ^{137}Cs signals to the south of the detailed survey area (NX977092), 18th March 2000.

2.2 June 2010 Backpack Survey

An exploratory survey of the beach area identified in March 2000 was conducted on the 22-23rd June 2010, using a lightweight backpack spectrometry system, to determine if the signals observed in 2000 are still present in the environment and attempt to further characterise the nature of these signals if they were still present.

The system used for this survey consists of a 3x3" NaI(Tl) detector with an Ortec digiBASE™ integrated HV supply, and digital signal processing chips. The detector is connected to a netbook computer via a USB cable, and a button GPS receiver is used to log the detector position. The SUERC data acquisition continuously logs the spectra with GPS position, conducts real-time analysis to report natural series activity concentrations (^{40}K, ^{214}Bi and ^{208}Tl in Bq kg^{-1} assuming uniform distribution within the detector field of view) and gamma dose rate (in mGy a^{-1}). ^{137}Cs can be reported as activity per unit area (kBq m^{-2}, assuming a laterally uniform distribution within the field of view with a defined depth profile) or as a stripped count rate for the 662keV peak having removed interferences from other spectral components. For this work, the stripped count rate has been used. Working values for background count rates and the stripping matrix determined in August 2009 were used. The software also includes user-defined alarm criteria; the alarm criteria used for this work are listed in Table 2.1. The significance alarm is determined by comparing the count rates in the measured spectrum with a filtered rolling average background (Cresswell & Sanderson 2009). Two backpack systems were used for this exploratory investigation.

Window	Gross Count Rate	Stripped Count Rate	Significance
^{137}Cs	40cps	15cps	3.50
450-3000keV	100cps	-	3.50

Table 2.1: Alarm thresholds active for the backpack survey, June 2010.

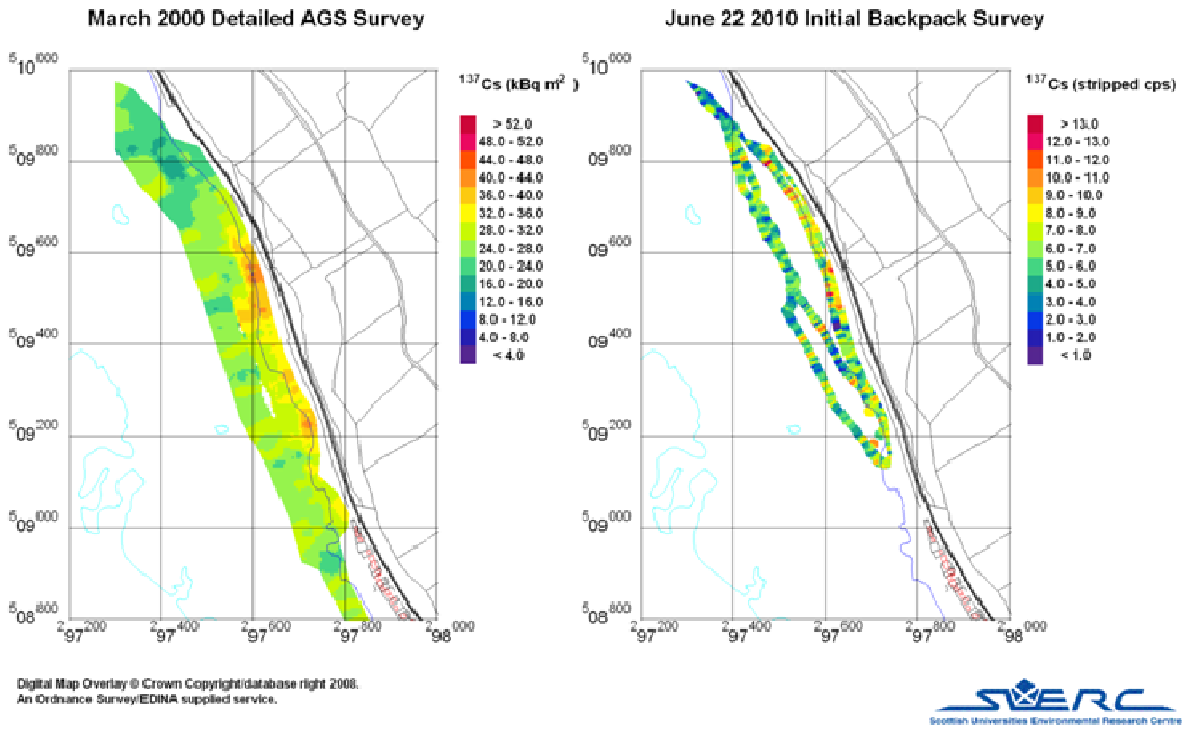
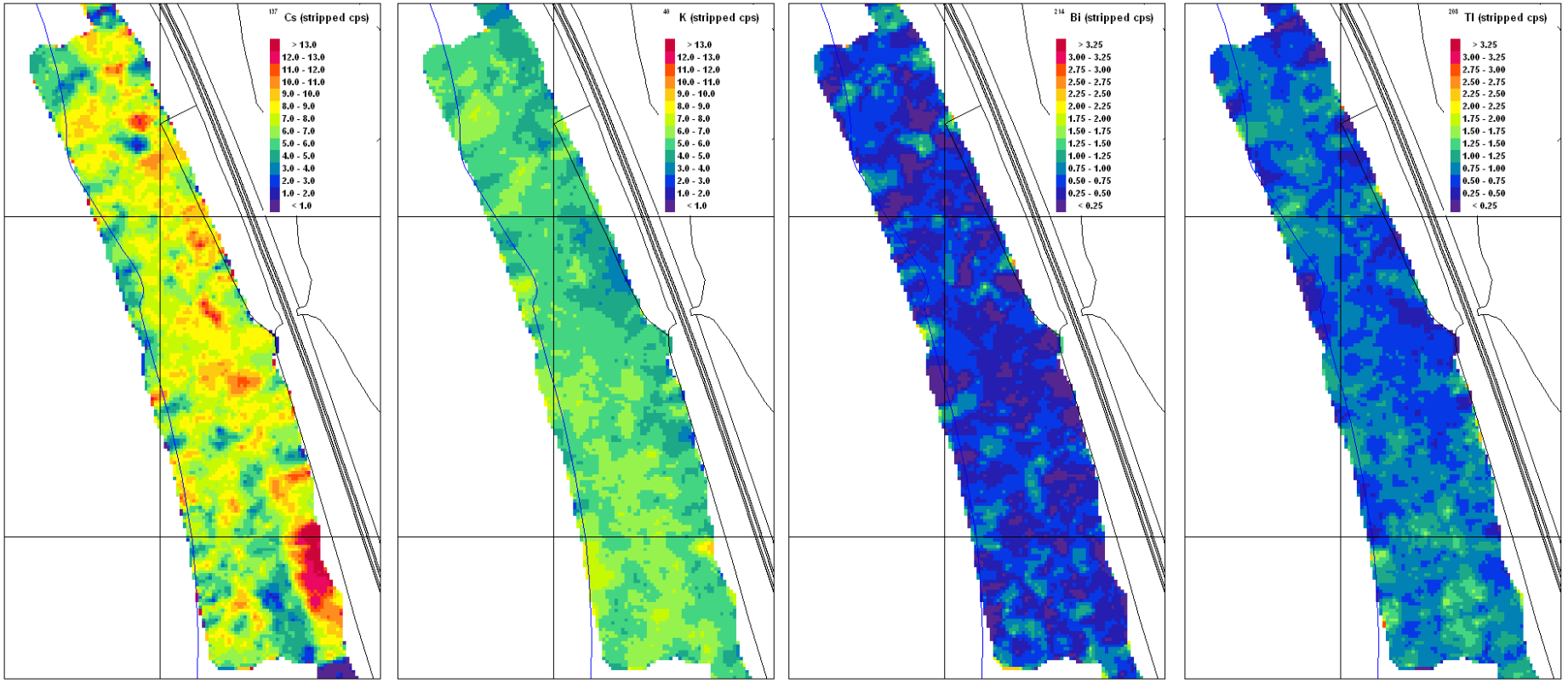


Figure 2.4: ^{137}Cs activity per unit area determined from the March 2000 airborne survey and stripped ^{137}Cs count rates for the initial June 2010 backpack survey.

Upon arrival in the area on the afternoon of the 22nd June, an initial survey was conducted from the Seamills carpark (NX970107) along the beach to NX977091 (just north of sea-front properties at Coulderton) and back. A total of almost 1200 spectra were recorded with a 10s integration time. The ^{137}Cs stripped count rate from this data was mapped in the evening. Comparison with the March 2000 data showed an area approximately 600m north of the Coulderton cottages (at NX976096) where enhanced ^{137}Cs was present in both data sets. This area was selected for further investigation on the following day. Figure 2.4 shows the backpack data collected from this initial survey, with the corresponding area mapped from the March 2000 airborne data.

On the 23rd of June this target area was surveyed in more detail. Each system was used to collect data from survey lines of approximately 100m length and 1m linespacing, one system with lines north of the centre of the area of interest and the other south. A total of 5200 spectra with 2s integration times were recorded, covering an area of approximately 200x50m. The stripped count rates for ^{137}Cs and natural series activity are shown in Figure 2.5. It can be seen that the ^{137}Cs count rate shows a large number of patches of enhanced activity that are not correlated with natural activity variations. The ^{137}Cs feature to the south east of the area corresponds to a patch of brambles and low bushes encroaching into the beach area, the other features are all on areas of gravel and pebbles. It is estimated that 10cps in the stripped ^{137}Cs window would be due to a point source of 50-100kBq near the surface, or an activity of approximately 200kBq uniformly distributed through the detectors field of view. Figure 2.6 shows the locations where the alarms triggered. The trigger levels for ^{137}Cs stripped count rate and 450-3000keV significance could be raised to reduce the false positive rate.



SUERC
Scottish Universities Environmental Research Centre

Figure 2.5: ^{137}Cs and natural series stripped count rates for the detailed back pack survey, 23rd June 2010.

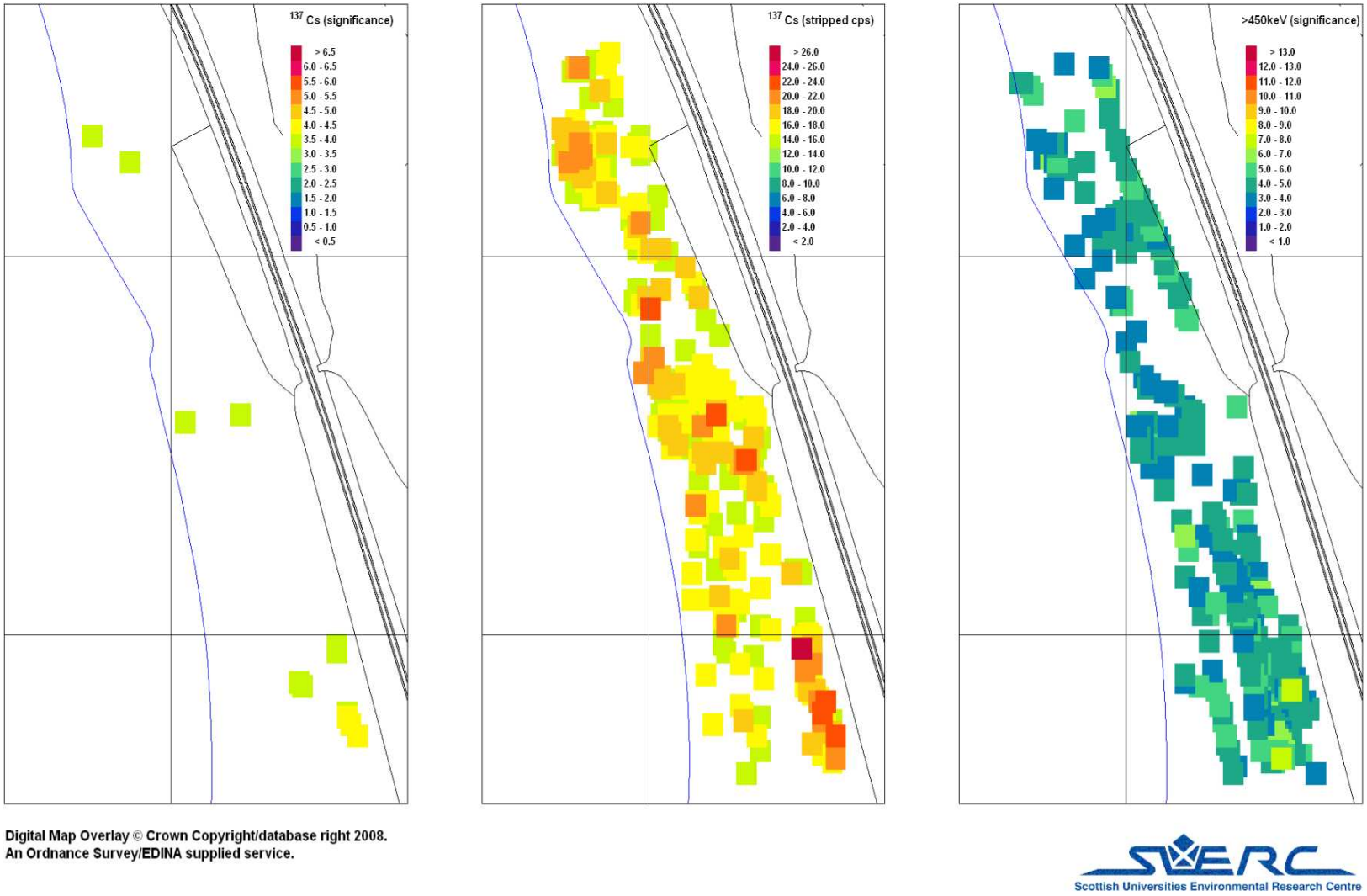


Figure 2.6: Locations where alarms set on ^{137}Cs significance (left), ^{137}Cs stripped cps (centre) and 450-3000keV significance (right) triggered.

During the survey, areas where alarms repeatedly triggered were marked. Upon completion of the main survey tasks, the two detectors were used to confirm higher ^{137}Cs levels observed in these marked locations with the other system. In most cases, the other detector system was able to replicate the enhanced ^{137}Cs count rate already observed. For a small number of the locations with enhanced ^{137}Cs count rate the detector was held just above the beach surface and moved slowly to attempt to better locate the feature. Figure 2.7 shows a spectrum recorded from one of these features. Monte Carlo simulations of the response of the 3x3" NaI(Tl) to uniformly distributed natural activity were run, and the resulting spectra for ^{238}U, ^{232}Th series and ^{40}K approximately fitted to the measured spectra. It can be seen in Figure 2.7 that the residual spectrum after subtracting the simulated natural spectrum confirms the presence of ^{137}Cs, with an activity concentration of approximately 110±3 Bq kg^{-1} if uniformly distributed or a point source of 87±3 kBq at approximately 5 g cm^{-2} mass depth. Note that the simulations assumed a detector height of 1m.

Samples of beach material were removed from seven locations, attempting to collect any material with enhanced ^{137}Cs activity. These were dried, ground and homogenised at SUERC and placed in sealed geometries for laboratory gamma spectrometry. The activity concentrations determined for these samples are given in Table 2.2.

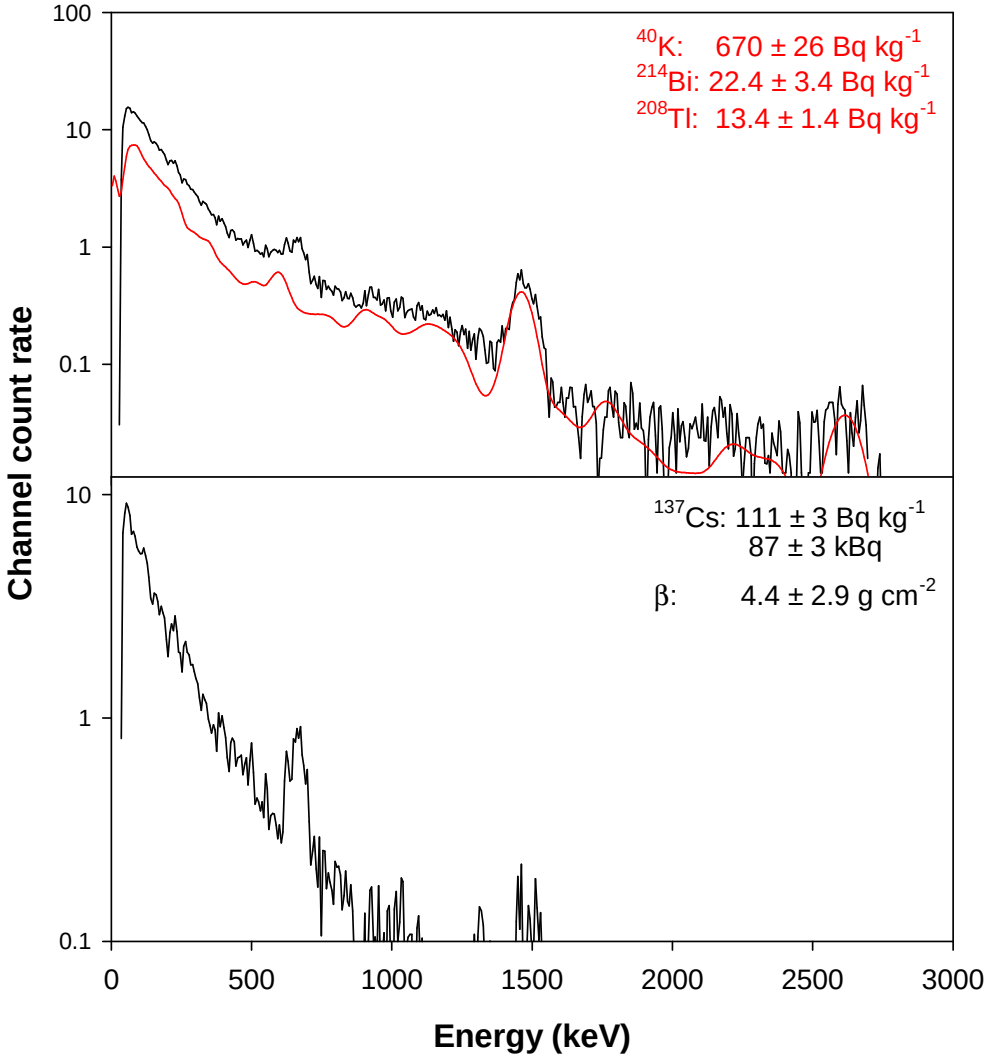


Figure 2.7: Summed measured spectrum from one of the spot measurements, with approximately fitted Monte Carlo natural spectrum. The residual spectrum after subtracting the simulated natural shows the ^{137}Cs peak and scattered radiation.

Sample No.	Location (BNG)		Activity Concentration (Bq kg^{-1}, dry weight)			
	Easting (m)	Northing (m)	^{137}Cs	^{40}K	^{214}Bi	^{208}Tl
GS431.01	297574	509628	50 ± 1	490 ± 30	24.8 ± 1.2	9.0 ± 0.1
GS431.02	297579	509618	53 ± 2	530 ± 30	27.6 ± 2.4	10.7 ± 0.2
GS431.03	297579	509624	52 ± 1	480 ± 30	24.1 ± 1.0	8.9 ± 0.1
GS431.04	297597	509604	52 ± 1	500 ± 30	24.1 ± 1.4	9.0 ± 0.1
GS431.05	297600	509568	54 ± 1	500 ± 30	26.1 ± 1.0	9.9 ± 0.1
GS431.06	297627	509540	53 ± 1	420 ± 30	19.5 ± 0.8	7.8 ± 0.1
GS431.07	297648	509482	108 ± 2	360 ± 20	20.6 ± 1.9	8.1 ± 0.2

Table 2.2: Activity concentrations for samples analysed by laboratory high resolution gamma spectrometry.

It can be seen that the ^{137}Cs activity concentrations are all consistent with 50 Bq kg^{-1}, with the exception of GS431.07 which had been collected from the area of brambles and low bushes. This is lower than the activity concentration estimated from the residual spot measurement. But, given that the field estimate assumed a 1m detector height these two values are in good agreement.

3. DISCUSSION AND CONCLUSIONS

An airborne gamma spectrometry survey in March 2000 identified a section of beach between St Bees and Nethertown in West Cumbria that exhibited enhanced ^{137}Cs activity in an environment where this would not be expected. In June 2010, an exploratory ground based survey of a section of the same beach using portable gamma spectrometry systems developed at SUERC confirmed that the enhanced ^{137}Cs activity observed ten years before is still present on the beach, in locations that are consistent with the earlier airborne measurements. The enhanced activity is localised to small features, mostly with dimensions of less than 10m, with the exception of a patch of brambles and other bushes at the back of the beach. By holding the detector close to the ground, it was possible to determine that these features were significantly smaller than survey data initially suggest. Samples collected from the gravel beach and analysed in the laboratory contain ^{137}Cs at concentrations of 50 Bq kg^{-1}. The consistency of activity concentrations between different samples suggests that it is unlikely that the activity is due to active particulates, since it would seem unlikely that each sample contained a particle with the same activity. The material carrying the activity has not been determined. ^{137}Cs at such concentrations distributed approximately uniformly within the <10m dimensions of the observed features would account for the observed signals.

The sampling strategy employed in the June 2010 survey was not optimised for the collection of radioactive particles. There is no evidence that any of the features sampled contained radioactive particles, although this can not be ruled out. Time constraints and the exploratory nature of the survey limited the level of control measurements conducted; longer time averaged spectra and samples were not collected from areas between the patches of enhanced ^{137}Cs activity determined from the survey. A control survey of a beach of similar physical characteristics where particulate activity would not be expected has also not yet been conducted. Similar work in the future could consider the differentiation of recovered materials into size and/or density fractions prior to homogenisation for laboratory gamma spectrometry to allow greater understanding of the materials that carry any activity.

Acknowledgements

The March 2000 airborne survey data was collected during a project funded by the Department of Transport, Environment and Regions (DETR), the Environment Agency (EA), the Ministry of Agriculture, Fisheries and Food (MAFF), British Nuclear Fuels Ltd (BNFL), the Industry Management Committee (IMC) and the SNIFFER fund.

References

Cresswell, A.J., Sanderson, D.C.W, (2009). The use of difference spectra with a filtered rolling average background in mobile gamma spectrometry measurements. *Nuclear Instruments and Methods* **A607**, 685-694.

D'Souza, J. (2009), *Annual Beach Monitoring Report 2008/09.* Report for Sellafield Ltd. SSEM/2009/75.

D'Souza, J. (2010), *Annual Beach Monitoring Report 2009/10.* Report for Sellafield Ltd. SSEM/2010/59.

Hemming, K. (2008), *Summary Report: Detection and Recovery of Radioactive Particulate from Beaches Associated with the Sellafield Nuclear Licensed Site. July 2003 to the end of March 2008.* Report for Sellafield Ltd. SSEM/2008/64.

Sanderson, D.C.W., Allyson, J.D., Cairns, K.J., MacDonald, P.A. (1990). *A brief aerial survey in the vicinity of Sellafield in September 1990.* SURRC Report 9101, for British Nuclear Fuels Ltd.

Sanderson, D.C.W., Cresswell, A.J., Murphy, S. (2000). *Investigation of Spatial and Temporal Aspects of Airborne Gamma Spectrometry: Preliminary Report on Phase II Survey of the Sellafield Vicinity, the Former RAF Carlisle Site, the Albright and Wilson Plant, Workington Harbour and the Cumbrian Coastline Conducted March 2000.* SURRC Report for DETR, Project Ref: RW 8/6/80.

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, Project Ref: RW 8/6/80.

Appendix: Data Processing Parameters Used

Window	Radionuclide	Channel range	Energy range (keV)	Background (cps)	
				System 1	System 2
1	^{137}Cs (661keV)	98 – 122	538 – 694	1.03 ± 0.02	1.03 ± 0.02
2	^{60}Co (1173keV)	184 – 208	1095 – 1251	0.32 ± 0.02	0.36 ± 0.01
3	^{40}K (1461keV)	228 – 254	1380 – 1549	0.39 ± 0.03	0.48 ± 0.01
4	^{214}Bi (1764keV)	272 – 303	1665 – 1866	0.14 ± 0.03	0.17 ± 0.01
5	^{208}Tl (2614keV)	403 – 440	2513 – 2754	0.103 ± 0.003	0.11 ± 0.01
6	Gamma dose	75 – 500	390 – 3140	5.00 ± 0.05	5.39 ± 0.05

Table A.1: Spectral windows and backgrounds.

	1 (^{137}Cs)	2 (^{60}Co)	3 (^{40}K)	4 (^{214}Bi)	5 (^{208}Tl)
^{137}Cs sheet	1	0	0	0.002	0
^{60}Co source	0	1	0	0	0
K pad	0.669	0.469	1	0	0
U pad	5.303	1.623	0.815	1	0.025
Th pad	4.946	0.755	0.592	0.642	1

Table A.2: Stripping matrix for system 1

	1 (^{137}Cs)	2 (^{60}Co)	3 (^{40}K)	4 (^{214}Bi)	5 (^{208}Tl)
^{137}Cs sheet	1	0	0	0.001	0
^{60}Co source	0	1	0	0	0
K pad	0.666	0.455	1	0	0
U pad	5.254	1.587	0.810	1	0.021
Th pad	4.887	0.729	0.642	0.652	1

Table A.3: Stripping matrix for system 2

Window	Calibration constant	Calibrated unit
1. ^{137}Cs	0.5	kBq m^{-2}
2. ^{60}Co	1	cps
3. ^{40}K	89	Bq kg^{-1}
4. ^{214}Bi	39	Bq kg^{-1}
5. ^{208}Tl	8.7	Bq kg^{-1}
6. Gamma dose rate	0.0061	mGy a^{-1}

Table A.4: Calibration coefficients