Scottish Universities Research & Reactor Centre

AGS REPORT

AN AERIAL GAMMA RAY SURVEY OF THE SURROUNDING AREA OF SIZEWELL NUCLEAR POWER STATION

1 OCTOBER - 3 OCTOBER 1996

IMC REF: RP/GNSR/5031
ISSUED: 1997

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SIGNATURE OF AUTHORISING OFFICER

CONFIDENTIALITY STATEMENT

EXECUTIVE SUMMARY

An airborne gamma ray survey of the surroundings of the Sizewell nuclear power station was conducted to define the present levels of radiation background for reference purposes. A twin engine helicopter fitted with a high volume NaI detector and two semiconductor detectors was used. A 20x30km area around the site was surveyed with 500 m line spacing, with an inner zone of 6x6 km being investigated with 250 m line spacing.

More than 10,000 gamma ray spectra were recorded between 1st and 3rd October 1996 at a survey height of 200-300 feet above ground level and used to prepare maps showing the distribution of ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and gamma ray dose rate. The data set has been retained digitally in an archive which can be used in the future should the need arise to measure change resulting from long term site operations, or for emergency response.

^{137}Cs levels are typically around 2 kBq m^{-2}, derived mainly from weapons' testing fallout, with slight Chernobyl input. Peak levels of some 6 kBq m^{-2} around the tidal inundation limits of estuarine and marsh areas may be associated with marine discharges from nuclear fuel reprocessing at Sellafield. Natural radionuclides show a distribution which reflects the geological and geomorphological variations within the landscape, and are the major contributors to dose rates within the survey zone. The gamma ray dose rate maps also show the position of the ^{41}Ar plume emitted from the Magnox station at Sizewell during the survey. At the time in question the plume was projected over the sea in the SE direction. The gamma ray survey data crossing the plume show clear evidence of dispersion downwind with plume broadening as a result of gaseous diffusion with increasing distance. Ground level gamma ray dose rates were recorded at 8 routine district monitoring sites using a mini-series 680 survey meter operated by Sizewell staff and a portable scintillation spectrometer. The mean dose rates recorded with the 680 meter (24.7 nGy hr^{-1}) are in good agreement with the results of ground based (27.4 nGy hr^{-1}) and the nearest airborne gamma dose rate results (24.6 nGy hr^{-1}).

Airborne survey methods are uniquely well suited to rapid environmental data capture from large areas. This has important emergency response potential which is increasingly recognised in the context of nuclear sites. The data recorded in this study provide a frame of reference against which future changes can be measured.

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The survey was commissioned by Magnox Electric plc on behalf of the Industry Management Committee (IMC).

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1. INTRODUCTION

An airborne gamma ray survey of the area surrounding Sizewell nuclear site was conducted between 1st-3rd October 1996 to define the present radiation background for emergency reference purposes. This provides a comprehensive data set which will allow future changes in the radiation environment to be assessed. The method also provides a means of rapid response to any future incident leading to the release of radioactivity to the environment.

Information on radioactivity and radiation levels off-site is needed at all stages of response to accidents involving release of radioactivity into the environment. While it may be necessary to base some early countermeasure decisions on limited observations and prognostic models, comprehensive environmental measurements would be required urgently to justify or modify them, and to support later decisions. Measurements are also needed to record the return to normal conditions and to provide public assurance that all potential hazards have been recognised.

AGS uses equipment operated from fixed or rotary wing aircraft for environmental radiation measurements. For studies of airborne activity, measurements can be taken at a wide range of altitudes, however, contamination of the aircraft may be an issue. For measurements of deposited radioactivity, surveys are conducted from low flying aircraft typically at ground clearances below 100-200 m. As a result of the high mobility, data capture rate and sampling area, airborne gamma spectrometry (AGS) has an important role to play in response to accidents involving release of radioactivity. Airborne gamma spectrometry has been used following the 1957 Windscale accident[4], to locate fragments of a nuclear powered satellite which landed in Canada in 1978[5,6], and for rapid national mapping of Sweden in 1986[7]. The United States has had a series of fully equipped aircraft on emergency standby for over 20 years[8]. The environmental applications and capabilities have been recently extended in the UK [9-14] through a programme of surveys and developments conducted by SURRC. This has included searches for lost sources[15,16], detailed post-Chernobyl mapping and baseline studies of upland areas[17-21], studies of the variations in natural radioactivity for epidemiology[22], detailed mapping of the environment of nuclear sites[23-25] an international joint exercise between other European aerial survey teams[31-32].

Features of AGS

The main features which determine the emergency response potential relate to the spatial response, the sensitivity, the rate of data capture, and the relationships between AGS results and other information.

Gamma radiation penetrates up to a few hundred metres in air, depending on energy; with good quality primary information available at ground clearances of up to approximately 30 m, for low energy gamma emitters (<100 keV), or 50-100 m for higher energy radiation. By recording a sequence of gamma ray spectra, together with positional information and ground clearance measurements, it is possible to quantify and map terrestrial activity levels. Both fixed wing aircraft and helicopters have been used, each having advantages depending on circumstances.

The field of view of a gamma ray spectrometer increases rapidly with ground clearance, dependent, again on energy, and on the angular response of the radiation spectrometer and the vertical distribution of the activity source. For high energy (E>500 keV) gamma rays under typical AGS conditions some 90% of detected radiation originates from a field of view of radius 4-5 times the ground clearance[1-3].

Sensitivity depends on detector type, sampling rate, and ground clearance. High volume scintillation spectrometers can make measurements capable of detecting 5% changes in natural radiation background, or of quantifying fission product deposition at kBq m^{-2} levels in a few seconds. Individual high purity Ge detectors are approximately 10-20 times less sensitive in short periods, but are far better at distinguishing between individual gamma ray lines. With longer integration times, or using large arrays, detection limits can surpass those of scintillation spectrometers. For practical and economic reasons such large arrays are not generally available. However, there is a growing number of combined systems featuring both NaI and Ge detectors.

With some 10^3 observations per hour and fields of view of 10^4-10^5 m^2, AGS can cover large areas some 10^5-10^6 times faster than ground based in-situ measurements. It is thus possible to conduct effectively total landscape surveys, which are important in searches for missing sources.

Detection limits for deposited nuclides depend on gamma ray energy and yield, the other sources of radioactivity in the environment, detector volume, ground clearance and sampling time. For fission products with high gamma ray yields, detection limits below 1 kBq m^{-2} can be obtained with high volume NaI detectors in measurement times of a few seconds. Further details of detection limits for ^{137}Cs are given in appendix C. For natural nuclides detection sensitivity is sufficient to permit measurements of small (eg 5-10%) changes in local concentrations of natural ^{40}K, ^{214}Bi, ^{208}Tl, and small dose-rate increments. Detection limits for point sources again depend on energy and ambient background levels. During the RESUME95 exercise[31], it was possible to detect ^{60}Co sources down to 0.7 mCi (25 MBq) in a relatively high natural radiation environment; whereas detection limits for ^{137}Cs, in an environment with some 10^5 Bq m^{-2} Chernobyl deposition were more than one order of magnitude higher. The system is thus sufficiently sensitive to measure environmental changes at levels of radiological interest.

In determining the relationship between ground based and airborne observations, it is important to take account of the different fields of view of each observation, which, in the presence of spatially variable radiation and contamination fields, may present problems of comparison[35]. However, when spatially representative comparisons are made, airborne results can be shown to be in quantitative agreement with ground based measurements and can also be calibrated to measure dose rate.

One of the main sources of uncertainty in calibrated deposition (Bq m^{-2}) measurements of anthropogenic nuclides arises from uncertainty in the activity depth distribution in the environment[34,35]. This too applies to ground based in-situ spectrometry, which is also more sensitive to local topographic variations (buildings, trees etc.). For recently deposited activity, near surface deposition may be reasonably assumed[34] - however, it is important that calibration assumptions are stated, and taken into account in interpretation of in-situ and AGS results.

Currently, the most common approach to dose rate quantification is to calibrate a spectral integral by ground to air comparison. Providing this is done in a representative radiation field, satisfactory results are obtained, as observed in many published studies including those of nuclear sites. However, in circumstances where the energy distribution differs significantly from that assumed in calibration, or where there are serious departures from semi-infinite source geometry, data must be interpreted cautiously.

An important feature of modern AGS systems is the ability to produce rapid colour maps of environmental radiation fields on emergency timescales. There have been significant advances in this area over the last few years, and also with integration of radiometric maps with geographic information, which add to the utility of the method.

Relevance to Emergency Response

The relevance to emergency response results from the high rate of data capture, high fields of view, and the mobility of the airborne platform. Fixed wing aircraft are well suited to rapid exploratory measurements, while helicopters are capable of performing more detailed measurements in a range of environments, unimpeded by local obstacles, and capable of operating effectively in inaccessible terrain and over water. It should be borne in mind that air operations can be delayed by poor weather, that night time operations may not be practicable, and that there are cases (eg transport accident with α or pure β activity) where AGS would be inappropriate. Having stated these limitations, however, AGS has a number of extremely important functions at different stages of response.

In the case of a reactor accident AGS could be used for plume tracking, providing that the risks and consequences of contamination were recognised and accepted. Otherwise, the main early functions would be to locate areas of high radiation or deposition so that ground based resources were used effectively. Again in the early stages, quantitative information on dose rates would be important - if necessary using a working calibration which could be improved by subsequent ground to air comparison. With mobilisation timescales within one day, and results available in digital and mapped form within the same day, AGS could help to justify early countermeasures such as those dealing with Iodine prophylaxis, sheltering, evacuation or temporary relocation.

Decision makers confronting such questions in the absence of comprehensive environmental measurements would be under considerable pressure and would need robust measured data as soon as possible. At later stages, the emphasis would move towards more detailed mapping and quantification of deposition, particularly in areas where food production might be affected.

Airborne gamma spectrometry also has the important function, through its capacity for total area survey and the means of data presentation, to show clearly which areas are not affected. This, together with the role of directing ground based work to areas of need, could have a major impact on assuring the public that emergency response was correctly focused.

2. SURVEY DETAILS

2.1 The Survey Area

The main survey area comprised an area 20x30 km bounded by OS coordinates (sheet no. 156 and 169) of TM280780, TM480780, TM480480, TM280480 flown at 500 m line spacing and a smaller area of 6x6 km (TM430660, TM490660, TM490600, TM430600) flown at 250 m line spacing, up to the boundary of the nuclear site. This also included a number of flights along the coastal margin and river estuaries at Southwold, Aldeburgh and Orford).

The survey was conducted using a twin engine AS355 helicopter chartered from OSS in Oxford. OSS obtained CAA low flying exemptions to permit operations down to 200 feet general ground clearance in the rural parts of the area, with a clearance of 500 feet over urban areas. Low flying in urban areas can be conducted using twin engine helicopters, subject to CAA exemptions, and might be necessary under emergency conditions, where there is a clear public interest justification in gathering data from the villages. However on this occasion it was felt that sufficient baseline data could be obtained without subjecting the villages to flights below 500 feet. The SW part of the survey comes close to the Woodbridge airfield - an active training site for army helicopters. Arrangements were made to truncate NS flight lines in this area to avoid interactions with the training activities during the day, and to collect data from this area in a short series of EW flight lines conducted at a quiet time of day.

No flights were made directly over the nuclear site, however arrangements were made to use the designated helicopter landing site at Sizewell for refuelling during the day.

2.2 Equipment Installation

The spectrometer comprised a 16 litre NaI(Tl) detector and an SURRC airborne survey instrumentation rack. A set of externally mounted EG&G Ortec LoAx semiconductor detectors was carried which provided additional information in the low energy region below 400 keV. The equipment incorporated uninterruptible power supplies, instrumentation power supplies, a spectrometer facility with dual pulse height analyser, multi-DGPS satellite navigation, multi-ADC's, and a data logging system based on a 486 computer. Both detector and spectrometer were mounted on CAA approved baseplates and frames which can be rapidly installed when required. The equipment records a sequence of full gamma ray spectra during the flights, interleaved with positional data from GPS and ground clearance measurements by radar altimetry.

The radiometric instrumentation and DGPS antennae were installed at Oxford airport and flight tested prior to the survey. The radar altimeter was calibrated against barometric altitude, and a series of measurements made over a fixed point on the airfield to verify altitude correction coefficients. Instrumental checks on system calibration and energy resolution were performed at Kidlington Airport, Oxford on Monday 30th September. The aircraft was flown to Theberton Country Hotel on the morning of 1st October for start of survey.

2.3 Survey Parameters

The survey was conducted with a ground clearance of 200'-300' and ground speed of approximately 120 kph, making minor lateral detours to avoid direct overflights of buildings, and increasing ground clearance over the villages. Flight lines were arranged in NS orientation with nominal line spacing 250 m nominal in the inner 6x6 km zone, and with 500 m spacing in the outer area. Flight lines were extended out to sea by at least 1 km to define marine background levels beyond the influence of terrestrial radiation. Waypoints defining the start and end of each flight line within the survey zone were calculated and programmed in to the DGPS equipment. This was then used to guide the pilot throughout the survey.

Radiometric measurements took 3 and 6 seconds for the scintillation and semiconductor detectors respectively. The gain of the scintillation spectrometer was continuously monitored during flight using the natural ^{40}K peak at 1461 keV, and maintained at better than 1% stability throughout the survey. Appendix A summarises the survey parameters, data logging and processing information, together with spectral windows.

2.4 Data Recording and Processing

The SURRC recording technique and data nomenclature have been designed to make checks of spectrometer operation possible during flight, and to enable rapid checks on all data during reduction and analysis. Data reduction stages are all self-recording, and the archive is structured so that primary data can be examined where any unusual features have been located. The archive is fully retrievable, doubly backed up, and uses ASCII files for all data storage to facilitate quality assurance in accordance with procedures developed over many surveys. These procedures have been designed to ensure a high level of data integrity and traceability, and are periodically reviewed to take account of system developments.

The data reduction procedures[12] follow a sequence of isolation and quantification of signals corresponding to individual nuclides, and estimation of ground level dose rate. Initial processing comprises extraction of count rate data from selected energy regions corresponding to the full-energy peaks for individual nuclides. This takes place in real time during the flight, for predefined nuclides, and can be supplemented by full spectral analysis afterwards if required. The resulting summary records of the flight and its series of individual count rates are then calibrated in four stages. Firstly net count rates are obtained by subtraction of background values from recorded gross count rates. Secondly spectral interferences between nuclides are separated using a matrix stripping procedure. The data are then standardised to remove the effects of altitude variations, and finally converted to calibrated activity per unit area, activity concentrations or dose rate values as appropriate. Data can be mapped rapidly at any stage of this procedure.

For this survey, spectral windows corresponding to ^{137}Cs (661 keV), ^{60}Co (1172 keV), ^{40}K (1461 keV), ^{214}Bi (1764 keV), ^{208}Tl (2615 keV) and total count rate above 450 keV (for estimation of ground level dose rate) were predefined. Stripping coefficients used were measured at SURRC using a set of doped concrete blocks, layered sources and laminar absorbers, as utilised for previous surveys[13,14,28,29]. Background rates were checked at the start of survey, and periodically throughout, using data recorded over sea. Coefficients for altitude correction and calibration were taken from previous aerial surveys[18,19,20,24,25], where they had been validated by extensive ground sampling, with the exception of ^{60}Co. For this radionuclide stripped count rates standardised to 100 m clearance were evaluated and mapped. For other nuclides results were calibrated in terms of activity per unit area, integrated to a soil depth of 0.3 m.

A series of ground based dose rate measurements were made with Sizewell Health Physics Staff at eight points regularly measured. These have been cross compared with AGS estimates and measurements made with a portable scintillation detector for the same locations.

3. RESULTS AND DISCUSSION

3.1 The Radiometric Maps

More than 10,000 gamma ray spectra with associated positional data were recorded by the NaI detector from the area during the survey period. An additional 5,000 Ge spectra were also recorded. Figure 3.1 shows the flight line record. The NaI detector results were processed following standard SURRC procedures previously described, and radiometric maps were prepared from these data to include ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and estimated total gamma dose rate. An overlay of local roads, rivers and coastline has been superimposed to aid visual location of the mapped features.

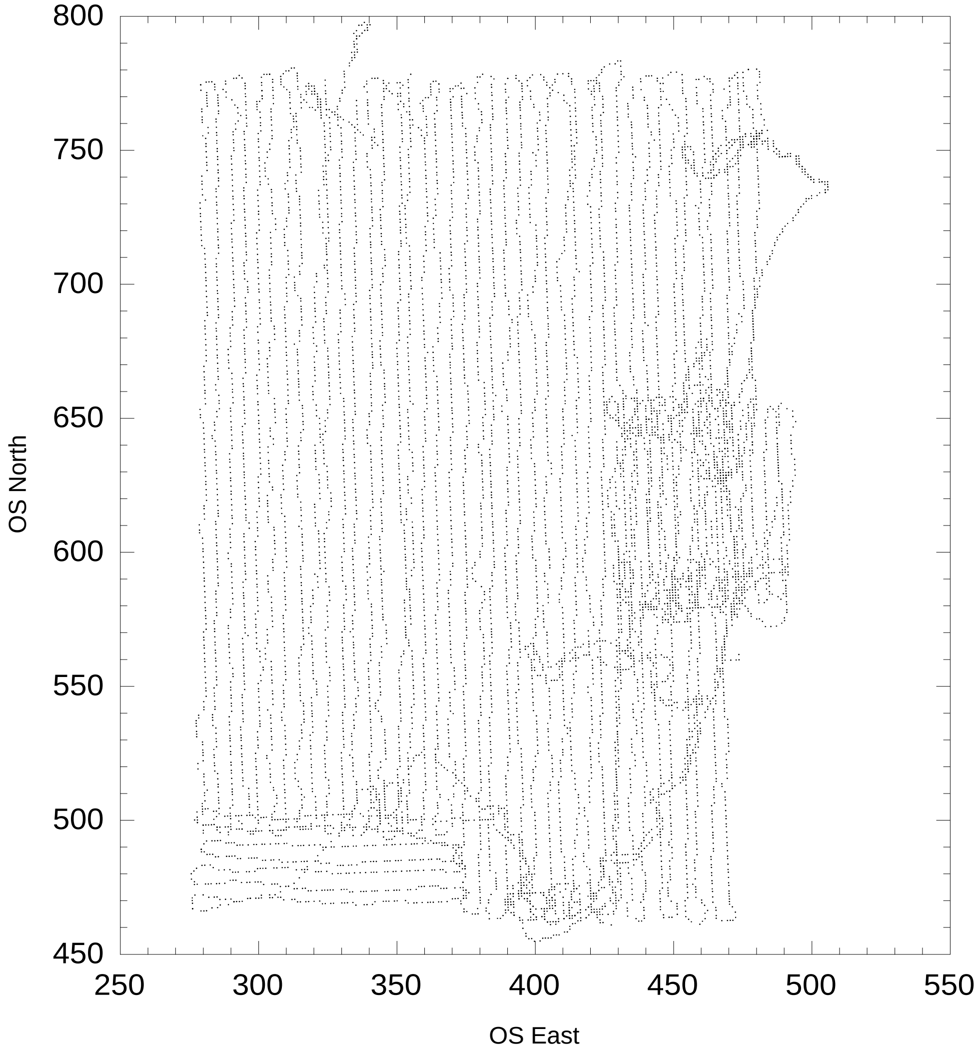

Figure 3.1 Flight track record

3.1.1 ^{137}Cs Map

The radiometric map of ^{137}Cs is shown in figure 3.2 and shows typical levels of weapons fallout of about 2 kBqm^{-2} with some localised higher levels of about 6 kBqm^{-2}. The apparent feature downwind of the station is due to ^{41}Ar interference (see section 3.2) which introduces scattered radiation to the ^{137}Cs energy window. The stripping model used has not attempted to separated this component. Overall ^{137}Cs levels are largely consistent with weapons' testing fallout, presumably with some additional component from Chernobyl fallout. Slightly higher levels are observed in the upper reaches of the intertidal limits of the Blyth, Alde and Butley estuaries. These probably correspond to areas with slight local concentrations of ^{137}Cs from marine discharges from Sellafield, which have been noted from ground based analyses conducted as part of the Sizewell environmental monitoring programme.

3.1.2 ^{40}K Map

The radionuclide of natural potassium ^{40}K emits a single gamma-ray at 1461 keV. Its abundance in the environment, like ^{214}Bi and ^{208}Tl, is a function of the local geology and soil overburden. The ^{40}K map is shown in figure 3.3. Interesting features that may be associated with Coralline Crag sedimentary formations are noted along Sudbourne, Aldeburgh and Gedgrave Marshes. There are clear distinctions from the nearby London Clays at Orford Ness and Norwich Crag, Red Crag and Chillesford Clays which predominate further inland. Similar features are seen in the ^{208}Tl and gamma dose rate maps. Once again there is an uncorrected interference between the ^{41}Ar plume and the ^{40}K map.

3.1.3 ^{214}Bi Map

The map of ^{214}Bi is shown in figure 3.4. It represents a decay product from the ^{238}U series and is often assumed to be in decay equilibrium. However a precursor of ^{214}Bi is the gaseous product radon, which can under certain circumstances be transported from the immediate vicinity of its formation, and consequently lead to local disequilibrium. This data set however appears to show a similar distribution of U series activity as the more stable potassium and ^{208}Tl maps - implying that radon movements were relatively constant during the survey.

3.1.4 ^{208}Tl Map

The map of ^{208}Tl is shown in figure 3.5. This radionuclide is a decay product from natural thorium (^{232}Th) series and its distribution in the environment is an indication of geological factors. The spatial distribution of ^{208}Tl is highly correlated with that of ^{40}K.

3.1.5 Total Gamma Dose Rate Map

The gamma-ray dose map (figure 3.6) shows the contributions from the total gamma field (above 450 keV), the most significant components are those from the natural radionuclides. It is notable that the main features in the upper reaches of the river valleys correspond quite closely to identified features on the soil survey maps for the area. In particular, according to the Soil Survey 1983 maps for the region[36], inland areas of slightly higher gamma ray dose rate correspond with clay loams derived from chalky boulder clay, whereas the river valleys are filled with sandy and loamy soils, whose boundaries appear to correlate closely with features on the gamma ray map; as do areas coastal and river marshes. The airborne results have a higher spatial resolution than the regional soil maps, and therefore may be of further interest to geomorphologists working in the area. We are grateful to Mr Richard Parlone in supplying the soil map of the Suffolk area.

The ^{41}Ar plume from the single "A" station reactor which was operating at time of survey is again well detected in the total gamma dose rate map. The dose rate calibration used for this survey does not take account of the finite nature of the plume and it's geometry relative to aircraft position and ground. Therefore it does not, at this stage provide a direct basis for estimation of the associated ground level dose rates from the ^{41}Ar plume. There is potential for using the data with an appropriate model to predict ground level dose rates, but this has not yet been attempted.

The gamma ray dose rates within the general area show a slight local enhancement to the north of the "A" station may be due to building materials associated with the "B" station, or materials stored on-site. In any event the implied dose rate at ground level falls within the variation of natural dose rates observed throughout the survey zone.

Figure 3.7 shows two spectral plots of data recorded over land (a) and in the 41Ar plume over water (b). Each plot consists of the sum of 20 individual 3 second measurements.

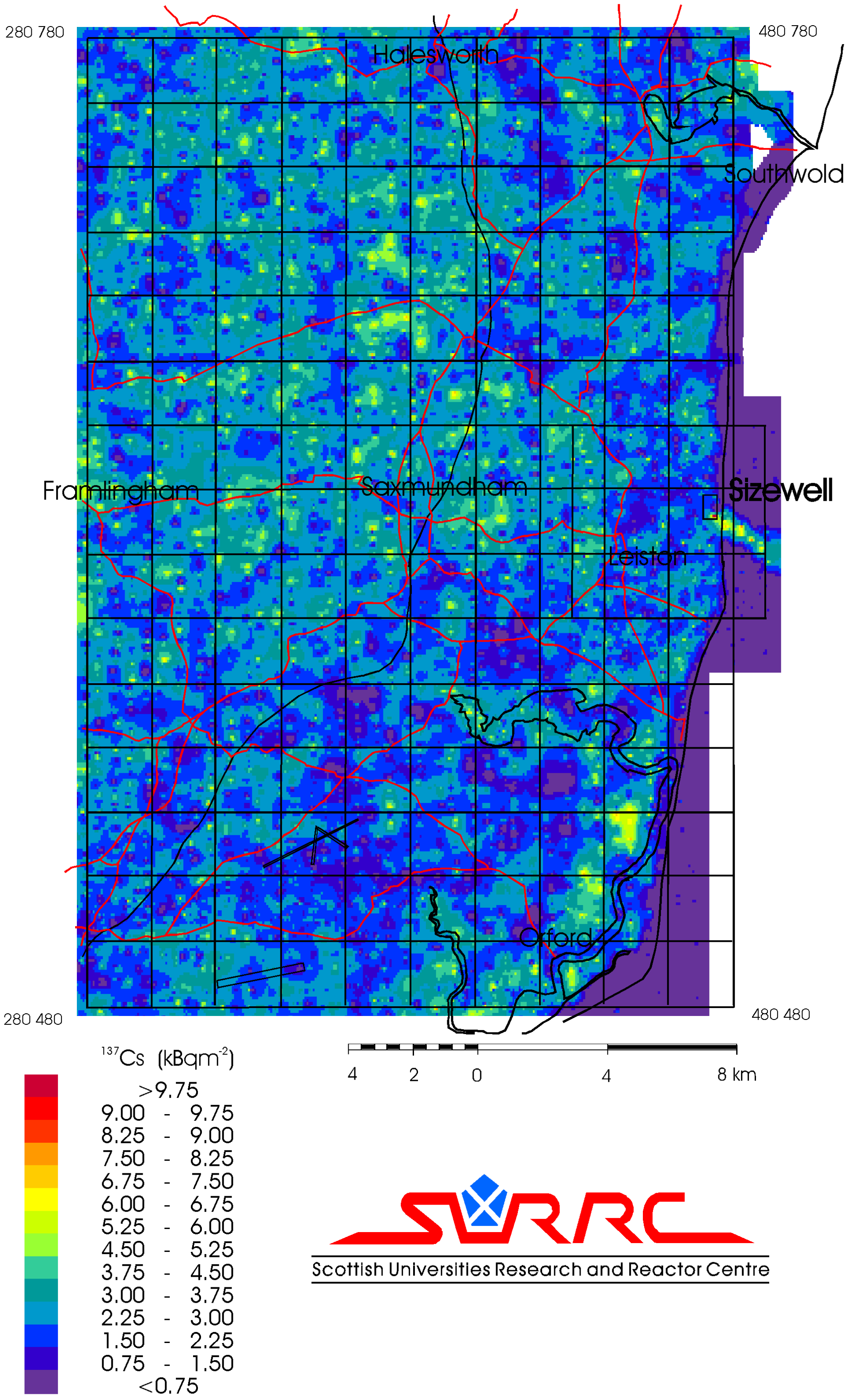

Figure 3.2 ^{137}Cs Map

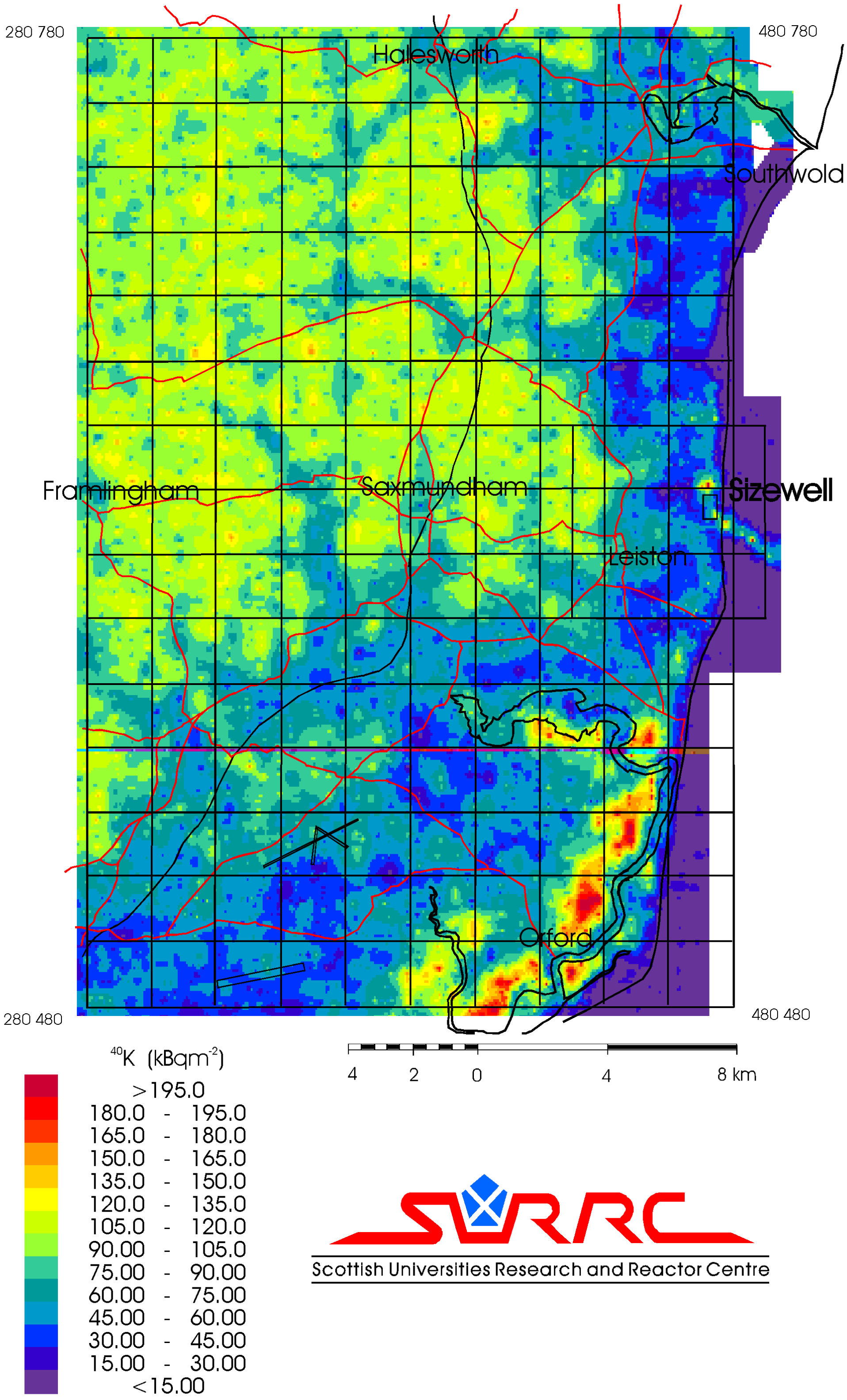

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Figure 3.3 ^{40}K Map

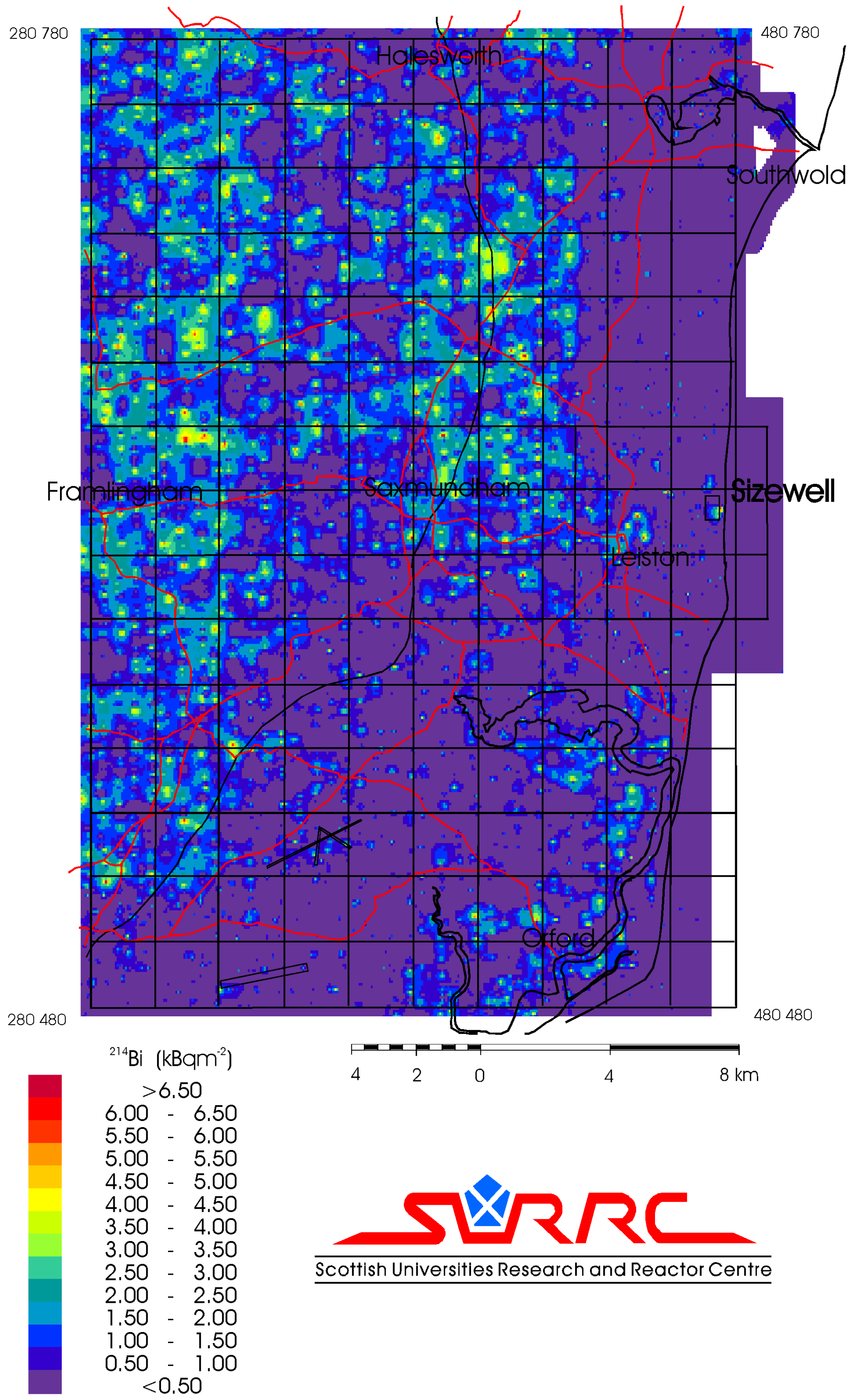

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Figure 3.4 ^{214}Bi Map

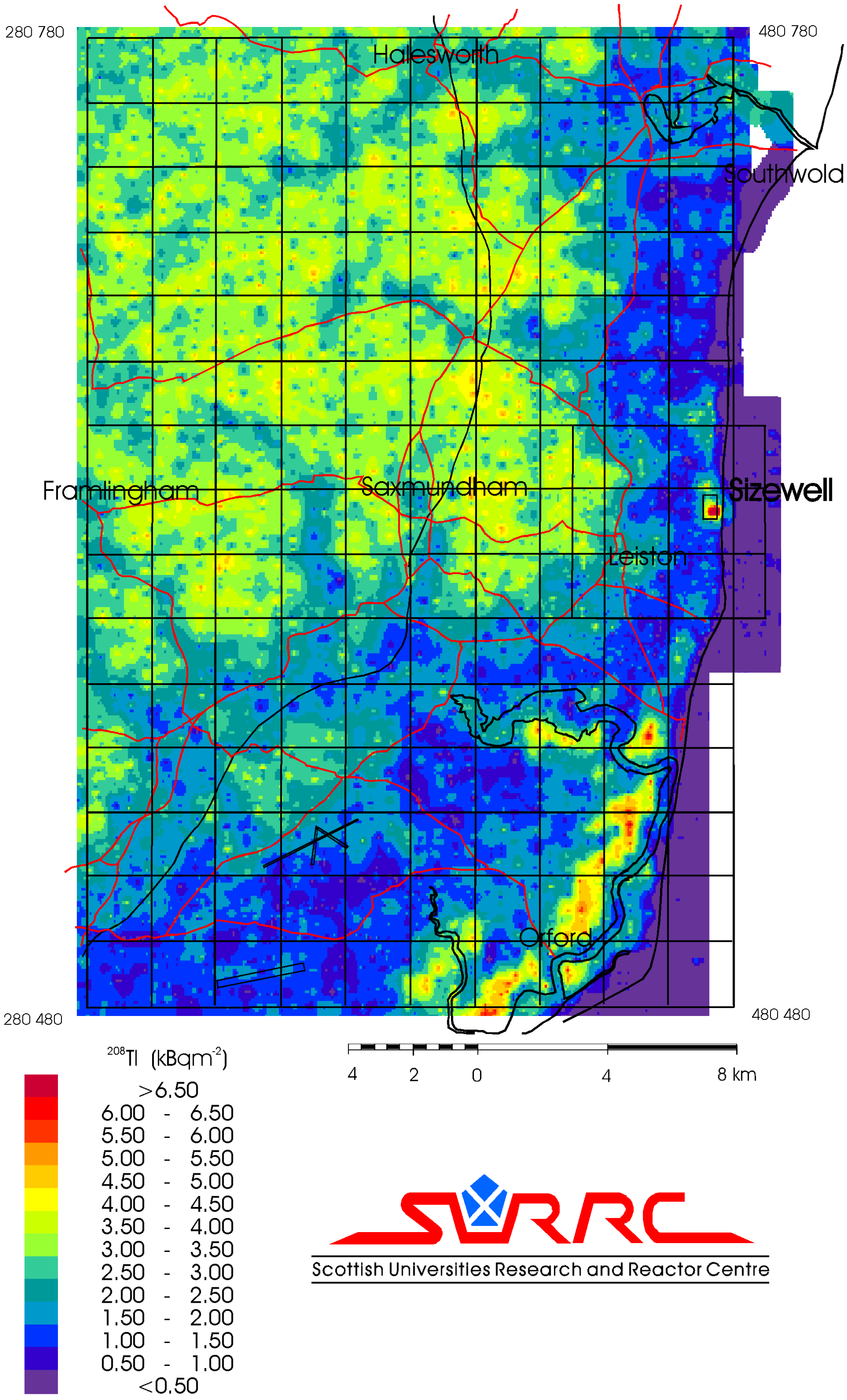

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Figure 3.5 ^{208}Tl Map

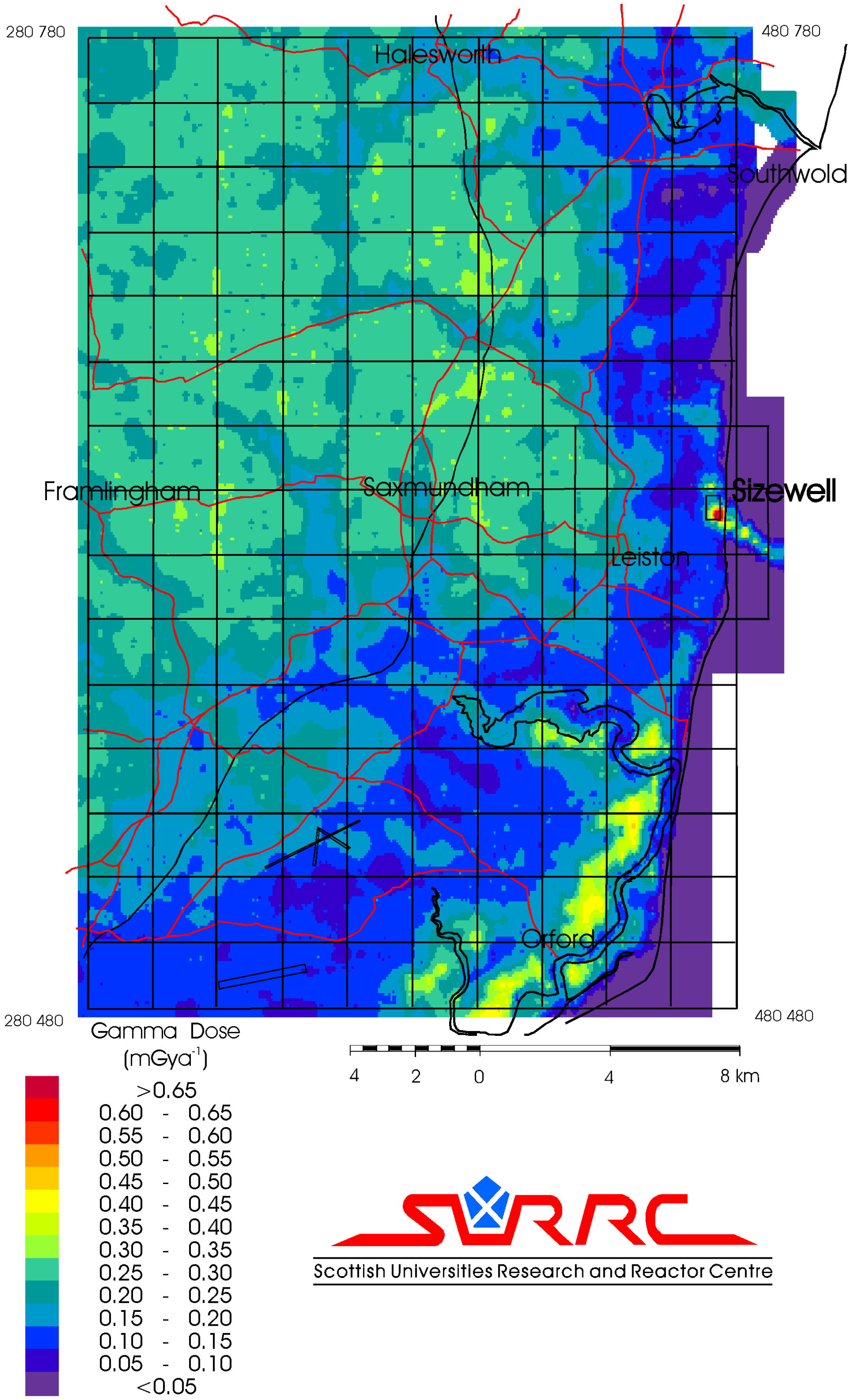

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Figure 3.6 Total Gamma Ray Dose Rate Map

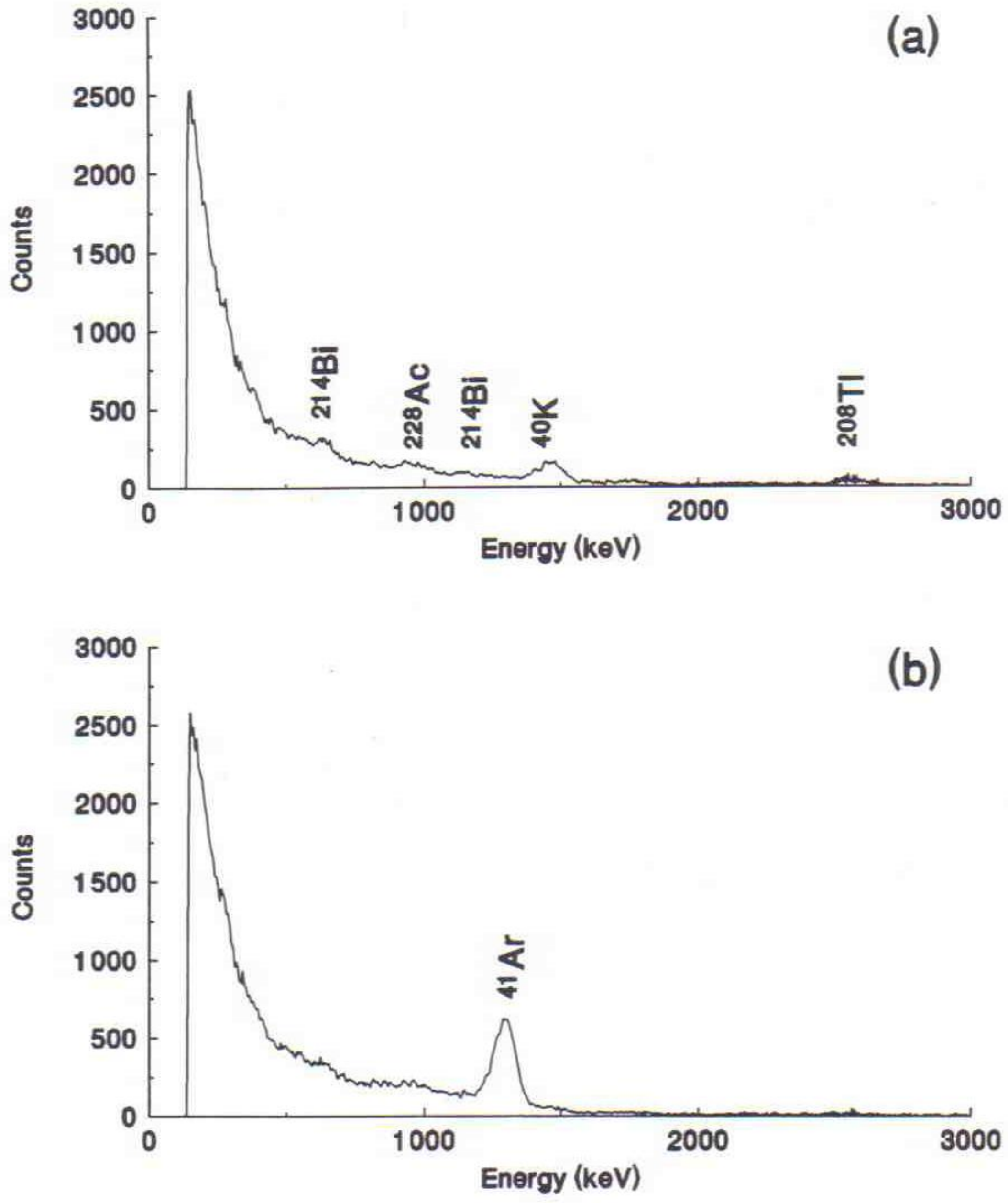


Figure 3.7 a) 20x3 second spectra recorded over land (W. edge of 250 m grid), b) 20x3 second spectra recorded in ^{41}Ar plume over water.

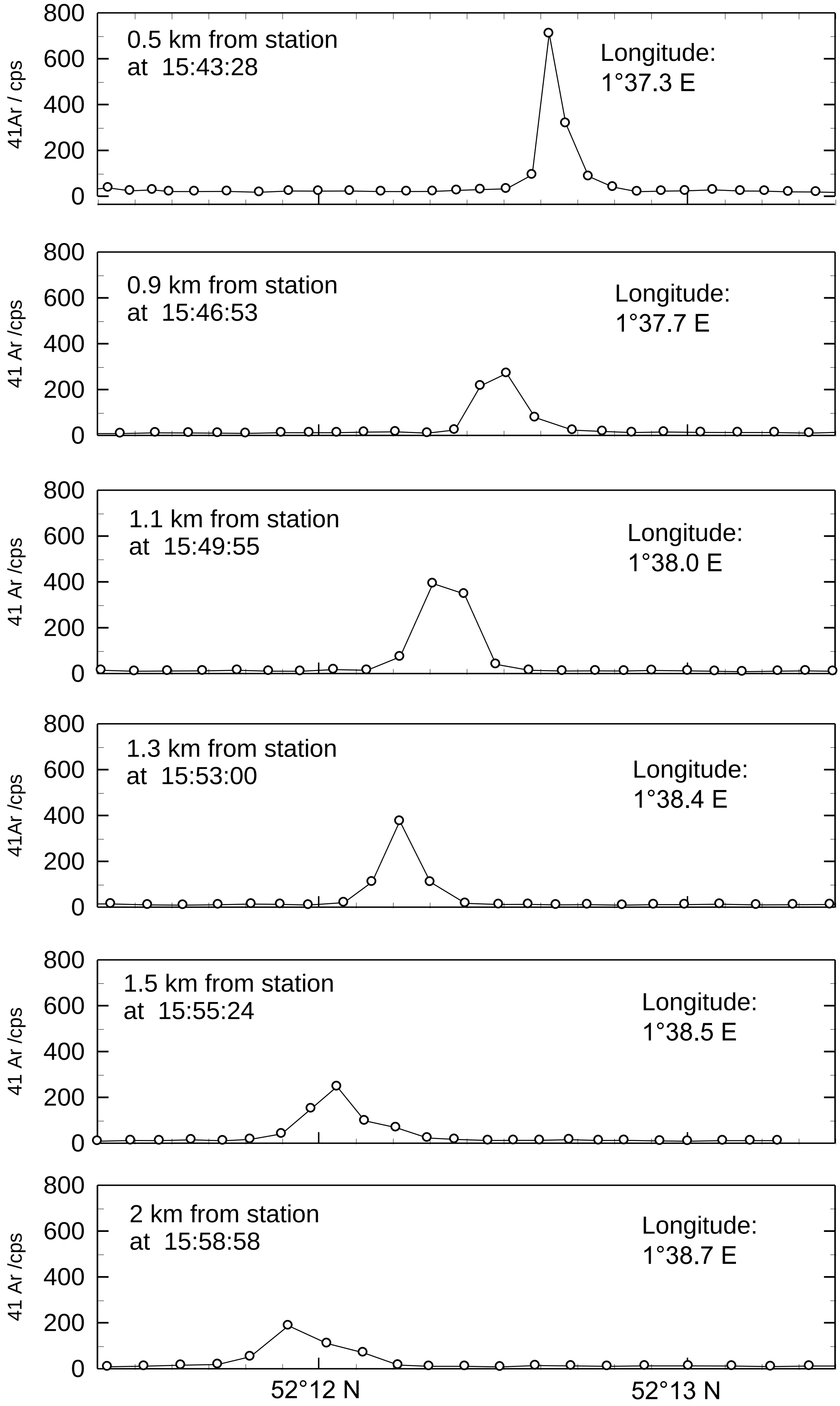
3.2 ^{41}Ar Plume Measurements

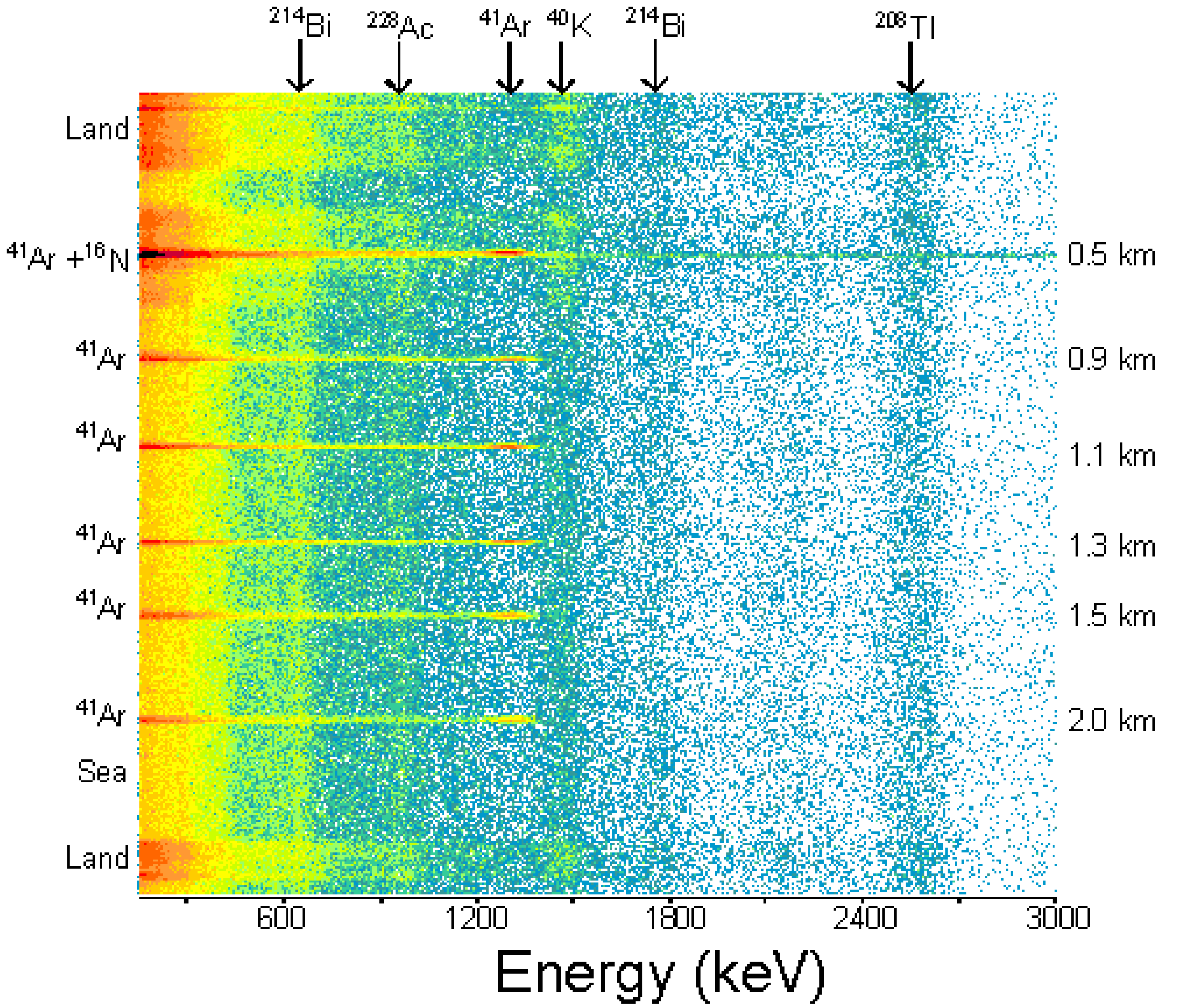
The ^{41}Ar plume from the Sizewell "A" station was encountered while surveying the inner zone on the afternoon of 1st October. During this period the wind direction varied from 310-320° with a speed of 20 knots, resulting in a relatively steady plume projected in a SE direction out to sea. Weather category "D" applied to this day. The gamma ray activity from the plume was readily detected against the low marine gamma ray background, out to the edge of the survey area, as can be seen in the Cs, K and gamma dose rate maps.

Figure 3.8 shows the gross count rate variations observed at a height of 265±26 feet (81±8 m) as the aircraft crossed the plume at increasing distances from the station over the course of a 15 minute period. The plume was intercepted at distances of 0.5, 0.9, 1.1, 1.3, 1.5 and 2 km in the south easterly direction expected. Interestingly the transect plots show a general diminution of peak height and broadening, as expected from diffusion about the centre line. It would be interesting to compare the observed increase in width with predictions based on standard gaussian plume models.

Figure 3.9 shows an example of a colour encoded spectral plot produced from data collected during the 250 m line spacing flights, near Sizewell and out to sea. The land-sea boundary is clearly seen together with the ^{41}Ar plume. An interesting note is the presence of ^{16}N (6.1 MeV, 7.13 secs half-life) at 0.5 km from the station, over the sea, and its absence at distances of 0.9 km or greater. The presence of high energy components, rather than multiply scattered radiation from ^{16}N suggests that the signal is from ^{16}N gaseous discharge rather than from radiation associated with contained activity. At the wind velocities pertaining (approximately 10 ms^{-1}) the 0.9 km measurement is separated by 5-6 ^{16}N half-lives from that at 0.5 km - thus explaining why the spectrum only shows ^{41}Ar at greater distances.

Figure 3.8 ^{41}Ar Plume Tracking.





Colour encoded spectral plot of the 250m linespacing area east of Sizewell, showing the land-sea boundary and the argon plume.

Figure 3.9 Colour encoded spectral plot.

3.3 Ground based observations

Ground based measurements were taken during the survey to compare dose rate estimates with airborne survey results at district monitoring points. Assistance was provided by Health Physics staff who simultaneously took readings with a Mini-Instruments 680 (Inst. no. 5117) and SURRC using a calibrated 3x3" NaI detector. Table 3.1 shows the eight monitoring points, with grid references and a comparison of net dose rate (nGy/hr) from the 680 and hand held NaI detectors. Sizewell "A" (reactor 1) was operating at 700 MW(Th) and Sizewell "B" was operating at full load.

The results from the 680 were calibrated with a certified factor of 20.3 cps per µGy/hr. The 3x3" NaI results were converted to dose rate estimates by integrating the 450-3000 keV region, subtracting a 2.2 cps background component and multiplying by a calibration factor of 6.963×10^{-4} µGy/hr per cps.

Both ground level detectors will have a slightly different field of view owing to their distinct angular responses. Furthermore the aerial survey estimates of ground level gamma-dose rate are calculated from 100 m normalised altitude. Therefore, the field of view of the detector is quite different to ground level measurements and much larger (400-500 m in diameter, compared with 10-30 m). The effect of this is to average radiation response, and level out local enhancements within the cone from which radiation is received by each detector. For these reasons slight differences between individual observations are most likely to be partly due mean values across all sampling points for the 680 and scintillation detector are 24.7±12.4 nGy/hr and 27.4±8.5 nGy/hr respectively. The mean gamma-dose rate across all eight sites for the aerial survey detector is 24.6±8.4 nGy/hr. It is noted that a higher gamma dose rate was measured at TM 411591 by the 680 team. It is possible that this may have been due to a nearby geological outcrop, although both ground level 3x3" NaI and airborne systems gave similar values at this location. Given the environmental variability of gamma dose rates within the aerial survey zone, which spans a factor of five, these results are in acceptable agreement with each other.

Table 3.1 Comparison of dose rate measurements at local monitoring points

OS Location	680 Mini -Monitor / nGy hr^{-1}	3x3" NaI / nGy hr^{-1}	Airborne Survey (nearest point) / nGy hr^{-1}
TM 455571	18.8	23.3	13.7
TM 411591	52.6	16.1	14.0
TM 438639	28.5	39.3	28.8
TM 427636	23.6	33.8	31.7
TM 436658	14.4	23.8	33.2
TM 384612	13.4	18.5	16.4
TM 353660	25.1	27.9	29.2
TM 351710	21.1	36.6	29.9
Means:	24.7±12.4	27.4±8.5	24.6±8.4

4. CONCLUSIONS

A baseline survey using airborne gamma ray spectrometry was conducted in the area surrounding the Sizewell nuclear site during 1st-3rd October 1996. This establishes a reference data set to assess any future changes in gamma radiation levels. Airborne spectrometry is increasingly being used in studying the environments of nuclear sites and in support of emergency preparedness in the UK and Europe.

The area was flown north-south, along a predefined path guided by differential GPS, with a line spacing of 250 m and 500 m in two zones including flights along the coastal margin and river estuaries. The aircraft was equipped with two detector systems comprising 16 litre NaI carried inside the cabin, and a pair of Ge detectors externally mounted and examining the region 0-400 keV.

More than 10,000 gamma ray spectra were recorded from which estimates of ^{137}Cs deposition, the natural environment consisting of ^{40}K, ^{214}Bi and ^{208}Tl (the latter two being members of the U and Th decay series respectively). In addition, an estimate of the gamma dose rate was made across the region 450-3000 keV. The maps show the radiation environment to be predominantly due to the natural radionuclides, and reflects underlying geology and soil over-burden in the area. Gamma ray dose rates vary by a factor of five from place to place in the survey area.

The inner zone was flown on the afternoon of the 1st October, during which one of the Sizewell "A" station reactors was operating. An ^{41}Ar plume was observed during this part of the survey, being carried out to sea in south easterly direction. The plume direction only varied slightly over the 10-15 minute period in question. This radionuclide can be seen as an interference in the ^{137}Cs and ^{40}K maps, and also in the gamma dose rate map. The survey provides an effective indication of plume conditions at time of survey. As yet the data have not been used to estimate the ground level dose increment associated with ^{41}Ar. Apart from the ^{41}Ar signal the station itself has a relatively small impact on local gamma ray dose rates. A slight local enhancement to the north of the "A" station may be due to building materials associated with the "B" station, or materials stored on-site. In any event the implied dose rate at ground level falls within the variation of natural dose rates observed throughout the survey zone.

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APPENDICES

APPENDIX A. Summary of Detector Calibration and Data Processing

Survey aircraft: Aerospatiale AS 355 Twin Squirrel (G-TMMC) operated by OSS and McAlpines Helicopters. The operations were based at Kidlington, Oxford Airport.

Data collection flying time: 16 hours

1) Detector and Data Collection System

16 litre NaI(Tl) detector array (4 crystal pack):
Serial numbers: IA510, JA894, IV43, HR762
EHT: 1000V (nominal)

Pair of LOAX Semiconductor detectors operated in parallel with scintillation detector:
Serial number: 32-TN30706C Pop Top (EHT: -3000V)
Serial number: 32-TN30702B Pop Top (EHT: -2500V)

Table A.1 16 litre NaI system performance check

Date	Resolution at 661 keV / %	Detector * Sensitivity (Gross) /cps	Detector * Sensitivity (Net) /cps
1/10/96	9.5	2412±5	1827±7
2/10/96	9.3	2363±5	1835±7
3/10/96	9.4	2356±5	1833±7

***** 2 ^{137}Cs calibration sheets (#1+#2, numbers up, #1 over #2)

486PC logging computer. SURRC 19" rack and NIM. DPS MkII power supply
NavStar GPS operated in conjunction with RDS3000v3 to enable DGPS operation (10m accuracy, 1200 Baud)

Garmin GPS 89 provided cross track error information to pilot

28 Vdc aircraft power supply, with active noise suppression fitted

Recording software: NDA1.BAT/.BAS/.EXE (twin MCB, NaI and LOAX detectors)

Summary software: NDSM1.BAS, NDSM2.BAS (.SM1 AND .SM2 respectively)
Data analysis software: AERONEW2.BAS

Table A.2 Filenames

Filenames	Filenumbers	Logging Programme	Counting Times /s
SWLA1	1,768	NDA1	3,6
SWLA2	1,883	NDA1	3,6
SWLA3	1,491	NDA1	3,6
SWLA4	1,490	NDA1	3,6
SWLA5	1,900	NDA1	3,6
SWLA6	1,742	NDA1	3,6
SWLA7	1,190	NDA1	3,6
SWLA8	1,461	NDA1	3,6
SWLA9	1,820	NDA1	3,6

2). Spectral Windows

Table A.3 Measurement windows

Window	Radionuclide	NaI Array	
		Channel Number	Background /cps
1	^{137}Cs (661 keV)	95-128	53.84
2	^{60}Co (1172 keV)	170-208	20.07
3	^{40}K (1461 keV)	220-270	21.52
4	^{214}Bi (1764 keV)	270-318	11.66
5	^{208}Tl (2615 keV)	390-480	8.94
6	Total >450 keV	75-500	201.7

Table A.4 Measurement windows

Window	Radionuclide	LOAX Pair	
		Channel Number	Background /cps
1	^{241}Am (59.5 keV)	288-306	0
2	^{235}U + ^{226}Ra (186 keV)	917-937	0
3	^{212}Pb (238.6 keV)	1183-1203	0
4	^{214}Pb (351.9 keV)	1750-1770	0
5	^{235}Ua (143.8 keV) + ^{235}Ub (163.3 keV)	(709-722) +(807-827)	0
6	^{234}Tha (63.3 keV) + ^{234}Thb (92.8 keV)	(308-326) +(456-472)	0

3) Stripping Ratios

Stripping ratios used were those measured for the Scottish Nuclear Torness/Hunterston surveys (1994) on doped concrete calibration pads, ^{137}Cs plane source and ^{60}Co point source, at an equivalent altitude of 80 m in the SURRC Pad Calibration Facility.

Table A.5 Stripping ratios

	^{137}Cs	^{60}Co	^{40}K	^{214}Bi	^{208}Tl
^{137}Cs	1	0	0	0	0
^{60}Co	0.568	1	0.45	0	0
^{40}K	0.655	0.45	1	0.03	0
^{214}Bi	3.42	1.56	1.06	1	0.17
^{208}Tl	2.81	0.94	0.75	0.53	1

4) Calibration Constants

a: exponential altitude coefficient
b: slope of calibration line
c: calibration intercept

Table A.6 Calibration factors

Window	Radionuclide	a	b	c	Notes
1	^{137}Cs	0.00962	0.198	0	Working value
2	^{60}Co	0.0073	1	0	cps at 100 m
3	^{40}K	0.006	2.79	0	Fieldwork based
4	^{214}Bi	0.0066	0.606	-0.67	Fieldwork based
5	^{208}Tl	0.004	0.245	-0.2	Fieldwork based
6	Total	0.0062	0.0007	0	Fieldwork based

5) Mapping Coordinates

Grid Origin: 51.67°, 359.112° (East)
Grid Angle (φ): 357.75°

Contouring parameters: 6,-1.8,1,1

Formed in two halves: 270, 550, 5km (N)
270, 450, 5km (S)
Colour Palette: SURRC2.PAL (Aldus Photostyler)
Corel Draw file: SIZWELL1.CDR

6) XYZ File Formation (data possibly includes ^{16}N)

SIZCS01 1,10850 (includes ^{41}Ar plume)
SIZC01 (includes ^{41}Ar plume)
SIZK401 (includes ^{41}Ar plume)
SIZBI01
SIZTL01
SIZGA01

7) Routes

Rte 1:	SWS001 - SWS020	(250m spacing)
Rte 2:	SWS021 - SWS038	
Rte 3:	SWL001 - SWL030	(500m spacing)
Rte 4:	SWL031 - SWL060	
Rte 5:	SWL061 - SWL082	
Rte 6:	SWL083 - SWL100	

Woodbridge airfield free flown east-west

APPENDIX B. Emergency Response Plan

The following section defines a provisional "safe approach" flight plan to be used as a opening manoeuvre in the event of emergency response to Sizewell. The design requirements requirements for a flight plan are listed below and have been used for similar plans, which have been exercised for BNFL at Sellafield and Chapelcross nuclear sites, and have also been defined for SNL sites at Hunterston and Torness, and for the Clyde submarine base.

The standard SURRC criteria are as follows:

1.1 It should be possible to conduct initial exploratory measurements immediately on arrival at Sizewell, without stopping for fuel.

1.2 The collected data should define range and trajectories of radionuclide deposition within an approximate 10 km radius of the site, assuming that this is centred at Sizewell.

1.3 The flight plan should be navigable under as wide a range of meteorological conditions as possible.

1.4 In the event of navigational failure, it is desirable to be able to navigate the path and reconstruct the data by dead reckoning.

1.5 Radiological risks of flying into areas exposing personnel to high dose rates, of contaminating the aircraft and resuspending deposited activity should be minimised.

1.6 It should be possible to analyse the results rapidly and compare them with previous results so that changes can be quantified and further survey actions defined.

The following list of waypoints represents an implementation of these principles - which requires further elaboration through exercises if the scheme is to implemented within a "standby" arrangement.

Table B.1 Emergency response flight plan.

Waypoint Number	Location	OS Coordinate
1	Southwold, river estuary	TM 504748
2	Windmill	TM 486737
3	Car Park, nr Westwood Lodge	TM 468736
4	Junction of A144 & A12T	TM 414715
5	Leisure Park	TM 365652
6	The Maltings	TM 392574
7	The Firs	TM 431534
8	Sudbourne Beach	TM 460534
9	Car Park, N. Aldeburgh	TM 467574
10	Knodishall Church	TM 426619
11	Middleton Church	TM 430678
12	Trig. Point at Minsmere Cliffs	TM 477684
13	The Sluice	TM 478661
14	Car Park/radio mast, nr Old Abbey	TM 452639
15	Turn in power lines	TM 459617
16	Ness House	TM 476612

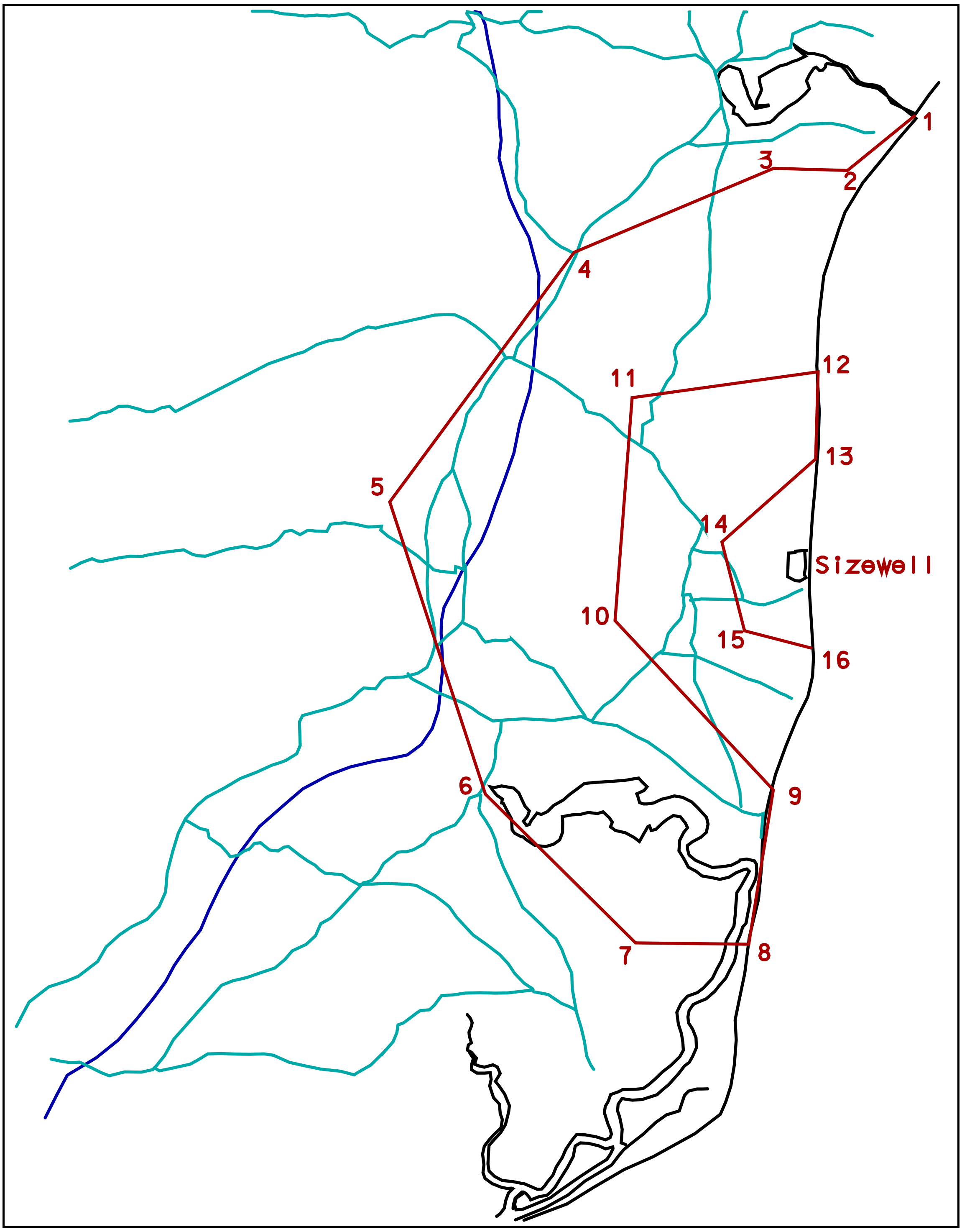

Figure B.1 Emergency response waypoint locations

Appendix C. Minimum Detectable Level Estimates for SURRC radiometric systems.

The mimimum detectable levels for airborne or mobile gamma spectrometry depend on (i) gamma ray energy and yield (ii) detector sensitivity and resolution (iii) background from other (natural or anthropogenic) nuclides (iv) integration time and (v) any systematic uncertainties in spectral deconvolution or analysis.

The following tables show estimates for the minimum detectable levels of ^{137}Cs for two NaI based systems and a single Ge detector operated inside the aircraft. The two NaI based systems are (A) a standard 16 litre pack based on 4 10x10x40cm NaI crystals and (B) a small 1 litre NaI system based on the SURRC designed 5x10x20 cm prismatic crystal. This small system has been designed with possible carborne or emergency response use in mind. Minimum detectable levels have been estimates using a simple model which takes account of the statistical uncertainties in both signals and backgrounds, both for a low background environment, and a mean natural environment.

CASE A : LOW BACKGROUND ENVIRONMENT 137-CS AT 50-100 M			
Detector	A	B	C
Type	NaI	NaI	Ge
Size	16 l.	1 l.	50% rel. eff.
Integration time /s	MINIMUM DETECTABLE LEVEL / kBq m^{-2}		
1	1.9	5.7	13
2	1.3	4	9
5	0.8	2.5	6
10	0.6	1.8	4
30	0.35	1.04	2
60	0.24	0.73	1.7

CASE B : TYPICAL NATURAL ENVIRONMENT 137-CS AT 50-100 M			
Detector	A	B	C
Type	NaI	NaI	Ge
Size	16 l.	1 l.	50% rel. eff.
Integration time /s	MINIMUM DETECTABLE LEVEL / kBq m^{-2}		
1	3.8	11	26
2	2.6	8	18.6
5	1.7	5	12
10	1.2	3.6	8
30	0.7	2.1	4
60	0.5	1.4	3.4