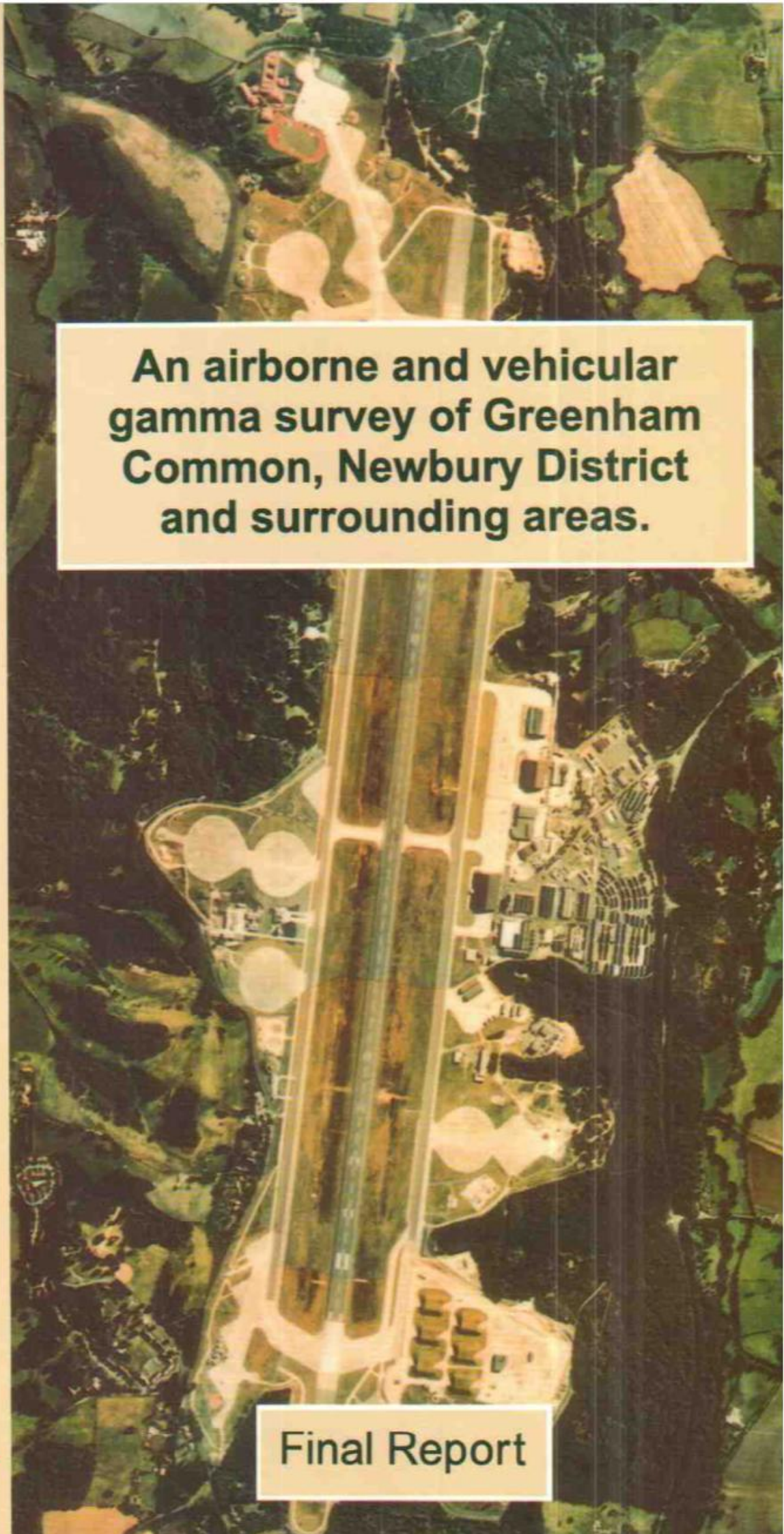

An airborne and vehicular gamma survey of Greenham Common, Newbury District and surrounding areas.

Final Report

SURRC

An Airborne and Vehicular Gamma Survey of Greenham Common, Newbury District and Surrounding Areas

Final Report

June 1997

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Commissioned by Newbury District Council and Basingstoke & Deane Borough Council

Executive Summary

The airborne gamma ray survey recorded more than 40,000 scintillation spectra and 20,000 spectra from semiconductor detectors. The vehicular survey produced a further 1346 and 763 spectral sets respectively. The installation, calibration, recording and analysis followed SURRC procedures which have been developed and validated over many years and are fully documented. Pre-flight checks on detector performance for energy calibration, energy resolution and sensitivity were performed on a daily basis. Background readings over water were taken on a daily basis. All data were registered and backed up in duplicate to form a digital archive of the survey. Subsequent analysis and mapping has used a combination of standard procedures established over many years, and new techniques developed to analyse the low energy spectra. All results have been retained to facilitate traceability and further analysis in the future. The sensitivity of the aircraft and vehicle were also checked at Greenham Common by collecting a set of 31 core samples for independent laboratory analysis.

The key points arising from the airborne survey of the entire area show that there has been sufficient sensitivity to record variations in the natural background. The levels of ^{137}Cs are consistent with weapons' testing fallout, and are substantially lower than in other parts of the UK and Europe. The average levels of K (0.5%), U (1 ppm) and Th (3 ppm) are lower than national averages and show variations within the area which reflect local geology and landcover. The area as a whole therefore is one of low environmental radiation background compared with national averages. There is no evidence of signals at Greenham Common or in its vicinity which would present a local radiation hazard. However, signals were detected in the vicinity of Harwell and the Rutherford laboratory which would, at the time of the survey, represent radiation projected off-site as a result of materials stored on-site or on-site activities.

Examination of the low energy gamma ray spectra recorded from the semiconductor detectors reveals no evidence, within the sensitivity limits of the method, for excess gamma ray signals at the energies associated with ^{235}U around Greenham Common, Newbury and Thatcham. The low energy data are sufficiently sensitive to record variations in the distribution of natural activity in the area. There is tentative evidence for ^{241}Am in the vicinity of AWE Aldermaston.

The vehicular survey demonstrated that the grass areas in between the runway and taxi lanes, and around the hardstand associated with the 1958 fire have retained weapons' testing ^{137}Cs. This supports the view that these represent authentic undisturbed areas for sampling. The built surfaces remaining at the time of the survey were of lower natural activity and ^{137}Cs content than their surroundings. High resolution gamma ray spectra at selected sites were also consistent with the known sources of background radioactivity.

On the basis of the results, Newbury District and surrounding areas represent an area with low environmental radioactivity compared with national and European averages. There is no evidence to substantiate fears about the quality of the radiation environment in the vicinity of Greenham Common.

The SURRC Airborne Survey Group

The Scottish Universities Research and Reactor Centre was originally established in 1963 by a consortium of Scottish Universities to provide shared access to research facilities in the nuclear and isotopic sciences. Since then the scientific programme has broadened to include extensive facilities and expertise for research environmental sciences, isotope geoscience, environmental radioactivity, and dating. The NERC Scientific Services Radiocarbon dating laboratory is located at SURRC, as are NSS facilities for stable isotope measurements and Ar-Ar dating. SURRC has a wide portfolio of external research contracts supported by research councils and charities, government departments and industry.

Dr David Sanderson (project manager) is a senior Lecturer in physics at the Scottish Universities Research & Reactor Centre, East Kilbride. He is a physicist with 20 years research experience and over 70 scientific publications and reports. His team has conducted 18 airborne gamma ray surveys for local and central government, nuclear operators, charities and industry. He was a member of the International Commission for Radiation Units report committee on environmental gamma ray spectrometry, and is coordinating a European project to harmonise methods and reporting conventions for Airborne Gamma-ray Spectrometry (AGS). The physics group also conducts research in luminescence dating and dosimetry.

Dr David Allyson is a senior research assistant in the physics group at SURRC. He has 17 years research experience in applied nuclear physics and has authored 34 reports and papers. His PhD topic was the Monte-Carlo simulation and calibration of airborne gamma ray spectrometry. He has participated in 14 airborne surveys.

Dr Alan Cresswell is a postdoctoral research assistant at SURRC with 5 years research experience and 9 papers and reports. He studied physics at Liverpool where he gained his PhD in nuclear structure physics prior to joining the group at SURRC. He is currently working on a project to characterise the response of airborne gamma spectrometers to short lived fission products with support from MAFF and DoE.

Dr Paul McConville is a lecturer at SURRC with multidisciplinary interests with 15 years experience and more than 15 papers. Following a PhD with Professor G.Turner FRS developing laser based Ar isotope dating, he spent 5 years in the University of Berkeley with Professor John Reynolds prior to returning to the UK. At SURRC he led an industry funded research project developing new laser based approaches for analysis important phases in North Sea hydrocarbon resources prior to taking up his lectureship. He is currently involved in a portfolio of environmental projects involving isotope measurements and geographical information.

Preface

This report has been prepared for Newbury District Council and Basingstoke & Deane Borough Council who have commissioned this investigation into the extent of radiation contamination in their districts and in parts of the surrounding area. The investigation was carried out as a result of public concerns over the possibility of radioactive contamination in the area and accidents involving radioactive material.

The investigation commenced in August 1996 and a public report was delivered to the sponsoring bodies for the first time on February 25th 1997 without any previews. The survey was carried out by the University of Southampton and the Scottish Universities Research & Reactor Centre.

This, the second and final report, relates to the findings from the Airborne Survey and contains all appropriate text, supporting analytical data and other relevant information. The University of Southampton group are providing a similar final report relating exclusively to the Ground Survey. The research undertaken by the two groups has been completely independent and has not been subject to pressure by any bodies. The research strategy, data acquisition, report writing and the interpretation of the research results are entirely those of the research team.

The purpose of this report is to provide the complete data-set from the airborne survey and to inform the public of the general situation in relation to radiation in the district. It is not to be relied upon by anyone in relation to their particular situation or by anyone intending to invest in a particular property in the district. The report is produced as a whole and is to be read in its entirety and not in parts.

Acknowledgements

We are extremely grateful to McAlpines Helicopters and Operational Support Services (OSS) for their support with aircraft engineering and operations; particularly to John Williams and his team at Oxford Airport, Kidlington, to Jim Laird, Norman Osment and Ian Thompson for flying the aircraft accurately at low altitude, and Chris Forest, Peter Bakke and colleagues for operational support including arranging for CAA permission to conduct the survey.

Professor Mike Tite from the University of Oxford kindly facilitated liquid nitrogen supplies.

Richard Osgood kindly arranged a landing site at Newbury Racecourse, and Julian Chafer and colleagues from the Defence Land Agency were helpful in permitting access to the Greenham Common site.

We are particularly grateful to John Kidd and Alan Williams of the Newbury District Council IT section for providing digital mapping data , and to Dr W. Fojt of English Nature for facilitating vehicular access to the SSSI's at Greenham.

Quality Statement

The Airborne Survey

All the procedures and practices used by the Survey team have been rigorously tested to ensure they meet the highest standards of accuracy and precision. Regular checks were made to ensure that all data sets were consistent and compatible and that no coding errors occurred. All data has been archived and is available for further investigation if necessary.

Significant developments were carried out, within a short time scale, to enable the deployment of both a high sensitivity scintillation detector array and an externally mounted pair of semiconductor detectors for radionuclide specific measurements. In addition, developments with differential GPS enabled high precision flying at tight line spacing with considerable skill shown by the pilots concerned.

No data have been eliminated and all are presented in the appendices.

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Tables and Figures

1. Introduction

1. Introduction

This study was commissioned by Newbury District Council and Basingstoke & Deane Borough Council in response to public concern following disclosures about events at Greenham Common in the 1950s, and the suspicion that there may have been an accident involving a nuclear weapon leading to off-site contamination at the airbase. The Greenham Common airbase is at an advanced stage of decommissioning with parts of the site already re-developed for industrial and leisure purposes and material being removed for use in construction of the Newbury by-pass. The success of such developments is critically dependent on public confidence in the quality of the environment, both near the site, and more generally throughout the area. For this reason the study was commissioned with the aims of:

I. defining the radiation environment of the whole district and parts of its surrounding areas

II. examining whether there is any evidence of radioactive contamination in the vicinity of the Greenham Common airbase

III. assessing the evidence that there may have been a release of nuclear material from the site.

The work involved a collaboration between scientists from the Scottish Universities Research and Reactor Centre, who conducted airborne gamma ray surveys to define the general radiation environment of the area, and scientists from the University of Southampton (Southampton Oceanography Centre) who collected an extensive range of samples for high sensitivity radiochemical analyses. This report presents the findings from the airborne and vehicular surveys, and its implications.

1.1 History of the Greenham Common Incident

'Revealed: nuclear fallout at UK air base'

This headline appeared in the Sunday Telegraph (14th July 1996) and the ensuing article gave details of a leaked 1961 report by two scientists from AWRE Aldermaston (F.H. Cripps and A. Stimson) which stated that elevated levels of an isotope of uranium, ^{235}U, had been detected around the American airbase at Greenham Common and that this activity was possibly linked to an aircraft fire on the airbase in February 1958. Their suggestion was that the B-47 bomber involved in the fire had been carrying a nuclear weapon which had been damaged in the fire releasing some of the fissile material. The two scientists argued, from their very limited data-set, that a dumbbell-shaped pattern of dispersion to the south west and north east of the runways was consistent with aircraft disturbing particles (contaminated with very low levels of activity) during take-off and landing. However, the paucity of data meant that firm conclusions were difficult to draw.

The existence of the 1961 AWRE report, originally classified as secret then regraded to confidential in 1985, had been known for several years prior to the Sunday Telegraph report. A series of Parliamentary Questions have been asked by several MPs (T. Dalyell, L. Smith and D. Rendell) over the years from 1985-1996 and responses have been made by the MoD. In 1985 a Parliamentary Question was raised by Tam Dalyell. In 1995 the document was leaked and a Parliamentary Question was raised by Llewellyn Smith (Labour Blaenau Gwent) on the 3rd July 1995 relating to the report. In a reply to these questions the Junior Minister for Defence, Roger Freeman, stated that the 1961 report was being retained under Section 3(4) of the Public Records Act, 1958, 1967.

The Sunday Telegraph article was rapidly followed in the week by accounts of the 1958 fire and suggestions of possible link between the supposed deposition of enriched uranium from the 1958 fire and alleged leukaemia clusters found in the Newbury area. Two later reports, one by AWRE in 1985 (Boocock and Marriage; supposedly prompted by a Parliamentary Question from MP Tam Dalyell, July 1986) and a second by the Defence Radiological Protection Service (DRPS) in 1994 stated that the findings of the 1961 report could not be replicated and that no evidence of radioactive contamination could be detected around the Greenham Common airbase. The AWRE report by Boocock and Marriage (1985) found no reason to discredit the 1961 study. It was suggested that the failure to reproduce the earlier findings was due to the alleged deposited uranium being

washed into the soil and diluted to an undetectable level by natural uranium.

Public concern remained unabated and both the MoD and Newbury District Council commissioned independent surveys of the area in the summer of 1996. The MoD survey was carried out by the National Radiological Protection Board (NRPB, Didcot) which reported its findings in late December 1996. The Newbury District Council survey was awarded as a collaborative project to the University of Southampton and the Scottish Universities Research and Reactor Centre (SURRC) in August 1996.

1.1.1 The Greenham Common Fire

The fire referred to in the AWRE 1961 report occurred on the 28th February 1958. An airborne B47 bomber (Incident B-47; Nr 53-6216 28 Feb 1958) experienced difficulties one minute after takeoff. The aircraft commander thought the plane had a serious wing and multiple engine fire and requested immediate emergency landing. Due to the high fuel load on the plane the commander decided to release full drop tanks in the 'on-base' drop area. These areas were normally only designated for dropping empty tanks and full tanks should have been dropped west of Lundy Island in the Bristol Channel. At Greenham Common the local base regulations did not specify a drop zone. The dropping of the tanks was advised by a tower operator who had insufficient expertise to advise on the timing of the drop. A series of human errors led to the fiasco that occurred and these are detailed in the USAF Enquiry Board Report (President of the Board Col. Wm. F. Coleman, 7th Air Division (SAC) USAF New York).

The emergency resulted in the jettisoning of two external wing tanks prior to an anticipated emergency landing. Due to excessive smoke obscuring the runway the plane was diverted to Brize Norton, Oxon where it landed safely. One of the jettisoned fuel tanks hit a hangar on the Greenham Common airbase while the second tank fell onto another B-47 on the hard standing outside the hangar. The accident resulted in two fatalities and one serious injury to USAF personnel. Five airmen were also hospitalised with minor burns. Both the hangar and the second aircraft were destroyed. Two other B-47s received slight damage. It was estimated that the total damage cost US$ 2.5 million. An official USAF assessment of the incident was produced in 1958 but the Report remained embargoed until recently; this heavily censored (redacted) document was received from the American authorities by the MoD in 7 August 1996. At the time, and subsequently, the USAF and Defence have denied that the destroyed B-47 was carrying nuclear weapons and this view was also maintained by ground-crew working at the base. First hand anecdotal evidence from two former US airmen from the base was presented at a Public Meeting in Newbury (July 1996) who denied that the destroyed aircraft was carrying any nuclear weapons from circumstantial evidence.

1.1.2 Exercise 'Overture' and the AWRE 1961 report

Exercise 'Overture' was instigated in the late 1950s (Cripps & Morgan, 1960; Cripps & Farrington, 1960; Cripps, 1960; Cripps & McCormack, 1961; Cripps & Stimson, 1961). A recent official statement from the MoDs Directorate of Nuclear Policy at Whitehall recently stated:

'The 1961 report by Cripps and Stimson emanated from the work related to Exercise Overture. This was the name given to a study conceived in the 1950s, at the height of the Cold War, to determine whether it might be possible to gather information about foreign nuclear weapon development activities by sampling the environment for traces of nuclear materials in locations remote from nuclear facilities. In order to test the theory, measurements were carried out at various distances from our own Atomic Weapons Research Establishment at Aldermaston. While analysing samples of vegetation taken from the vicinity of Greenham Common, some 5 miles west of Aldermaston, levels of uranium-235 slightly higher than those occurring naturally were found. It was these results which led to the study reported in 1961. Overture was not a health-related environmental monitoring programme. It was aimed at detecting traces of materials well below levels of significance in public health terms.'

As elevated levels of ^{235}U had been found which did not agree with those estimated from dispersion models from AWRE Aldermaston a further investigation was carried out to determine the extent and, if possible, the source of the deposited activity. Evergreen leaves were chosen for analysis as they acted as natural collectors for

atmospheric deposition and contained very small amounts of natural uranium making the measurement of deposited uranium more sensitive. The limited survey showed elevated levels of ^{235}U in samples collected around the Greenham Common airbase. Crude contours were derived from the data which suggested that the deposition extended in two lobes from both ends of the main runway. The results were contained in the 1961 report which showed the location and distribution of the elevated ^{235}U and the authors precluded that the contamination had originated from AWRE. An alternative origin from global weapons fall-out was also discounted due to the absence of enhanced levels of plutonium and the authors concluded that the most likely source was from an incident at Greenham Common itself. The characteristic lobes were explained by the distribution of particulate material containing the elevated ^{235}U which had been disturbed by aircraft taking off and landing. The only known incident to have occurred at the airbase was the 1958 fire and so it was suggested that this was the source of the contamination.

It was suggested in the 1961 report that this anomaly could be explained if the evergreen plants were selectively absorbing deposited ^{235}U through their roots with subsequent translocation to the leaves. There is no evidence, though, for such a mechanism as any deposited U would be strongly bound in organic humic substances in the soil and would not be available to the plant. A letter (dated 11 August 1961) attached to the 1961 report of Cripps and Stimson from F. Morgan confirmed these concerns and stated that '...it is possible that local contamination is normal around Strategic Air Command bases; you may therefore care to consider whether a small number of analyses should be made around each base in this country: as a guide, I think this would take 9-12 man-months'. In this letter Morgan suggested a study of other airbases performing similar functions to see if this was the case. It is not known if his suggested studies were carried out.

1.1.3 The AWRE 1986 and DRPS 1994 Reports

In 1986, following a Parliamentary Question from Tam Dalyell MP, the MoD contacted the US Authorities requesting a possible public release of the 1961 report. The US Authorities were concerned over the interpretation of the data since they denied any weapons damage at Greenham Common. A second study was commissioned by the MoD to review the findings of the 1961 report. The resulting report was prepared by AWRE. and titled 'Greenham Common Revisited'. In this report the authors, G Boocock and J W Marriage, reviewed the data contained in the 1961 Cripps and Stimson report and concluded that there was no evidence to disbelieve the original findings. The new survey analysed fresh evergreen leaves collected in 1986 using mass spectrometry and fission-track analysis (a sensitive technique for identifying the presence of any extant particulate deposition of fissile material). They were unable to confirm the presence of any anomalous ^{235}U around the airbase.

In 1994, following the departure of the American airforce from the Greenham Common base, the RAF requested a survey to confirm that no radioactivity remained from any USAF operations. The survey was performed by the Defence Radiological Protection Service (DRPS) and a report issued entitled 'RAF Greenham Common Environmental Monitoring Report' (by A Bartlett). Rudimentary radiometric measurements were unable to find any evidence for contamination on the airbase apart from slightly elevated levels of 137Cs in one drain which was probably derived from Chernobyl fall-out.

In summary, although no evidence could be found to dispute the findings of the 1961 report, it was also the case that no collaborative evidence for contamination could be found. This left unresolved the question of what exactly had been found in 1961 by Cripps and Stimson and its origin.

1.1.4 The Aldermaston Court Flood (1989)

When considering possible radioactive contamination in the Newbury District, the Greenham Common incident is not isolated. The Atomic Weapons Research Establishment (AWRE) at Aldermaston has operated since the 1950s and has released radioactive material (reportedly 16 grams ^{235}U and 3 milligrams ^{239}Pu up to 1960; Overture Reports 1, 2, 3 & 4). Micron-sized particles have escaped through particulate filters to the atmosphere.

In July 1989, severe weather conditions resulted in the overflow of a pond complex on the AWE site into the marsh, lake and grounds of Aldermaston Court. Flood waters from Aldermaston Court also passed into

Aldermaston village. A survey and clean-up of the area was instigated by AWRE and an internal report issued in March 1992. This report was passed to Newbury District Council following public concern who commissioned an independent assessment by the National Radiological Protection Board (NRPB; Wilkins, 1995).

Although obviously not linked to the 1961 survey, the 1989 flood has had an effect on the levels of contamination in the local area and needs to be considered when evaluating data in recent studies, particularly those where U and Pu have been measured.

The survey commissioned by Newbury District Council and reported here is the result of the culmination of a number of events and studies that have been undertaken over the last 35 years.

1.2 Airborne Gamma Ray Survey and Vehicular Survey

The airborne gamma ray survey aimed to characterise the general radiation environment of Newbury District and surrounding areas, to identify any areas with potentially hazardous levels of external gamma radiation, to examine the relative importance of naturally occurring and artificial radionuclides and to examine the presence of anomalies in the distribution of gamma radiation in the Greenham Common area and its immediate environment. The strengths of the airborne gamma survey method lie in its ability to cover the whole area in a representative manner. The sensitivity is sufficient to measure variations in natural radioactivity and to identify gamma ray sources which might present a significant hazard. However, the sensitivity to weak sources of small spatial dimensions is limited and therefore the survey was complemented by a short vehicular investigation and by the more sensitive radiochemical approaches adopted following sampling. A final objective of the airborne and vehicular survey therefore was to provide a radiological context for the ground survey conducted by Southampton University (Croudace *et al*, 1997a, 1997b).

At the planning stages a division was made between areas to be surveyed with 300 m line spacing and areas of special interest requiring more detail to be surveyed at 50 m line spacing. The main area (Area 1) surveyed at 300 m line spacing comprised a 40x23 km area in Newbury District enclosed by OS coordinates SU 300620, 700620, 700850 and 300850, with a 5x22 km southern extension into parts of Basingstoke & Deane enclosed by grid references SU 400570, 620570, 620620 and 400620. Detailed areas of interest were defined around Newbury, Thatcham and Greenham Common, where a 9x6 km box (coordinates SU 450630, 540630, 540690, 450690) for 50 m line spacing and around the vicinities of Harwell, Aldermaston and Burghfield. The aim was to survey these last three sites with 50 m resolution in 3x3 km grids; however this was not possible since permission to overfly the last two sites was not granted and therefore radial flights up to the site perimeters were organised. Figures 1.1 and 1.2 show the locations of Areas 1 and 2.

The airborne survey aims included measuring the gamma ray dose rate, the levels of ^{137}Cs from weapons' testing fallout and gamma ray emission associated with natural potassium, uranium (represented by the decay product ^{214}Bi) and thorium activity (represented by the decay product ^{208}Tl), as well as looking for any additional sources of activity. In addition a set of low energy gamma ray detectors was deployed with the aim of attempting to examine the energy region where ^{235}U has specific gamma ray emission. This aspect involved developmental work, with the emphasis being on examining the low energy gamma ray environment of Area 2 to search for any anomalies that might be associated with ^{235}U.

The vehicular survey objectives were to supplement the airborne survey with ground based observations on parts of the Greenham Common site, and an external control area, to provide additional sensitivity and a smaller spatial resolution for two possibilities. In the event that the airborne survey detected anomalies at Greenham this would be used for confirmation at ground level; in the event that the airborne survey showed no anomalies the vehicular system would be used to increase sensitivity, albeit in more limited areas.

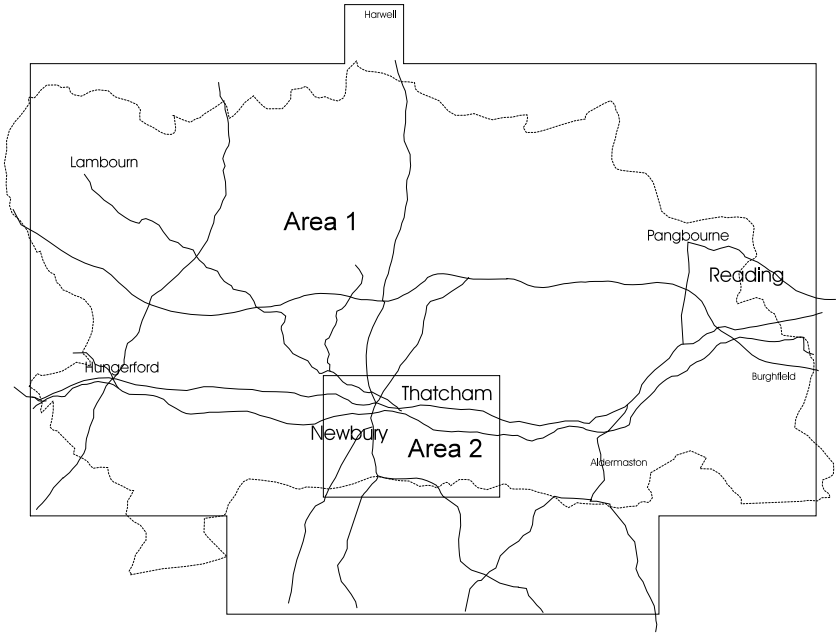

Figure 1.1 Map showing the areas to be surveyed at 300 m resolution (Area 1) and at 50 m line spacing (Area 2).

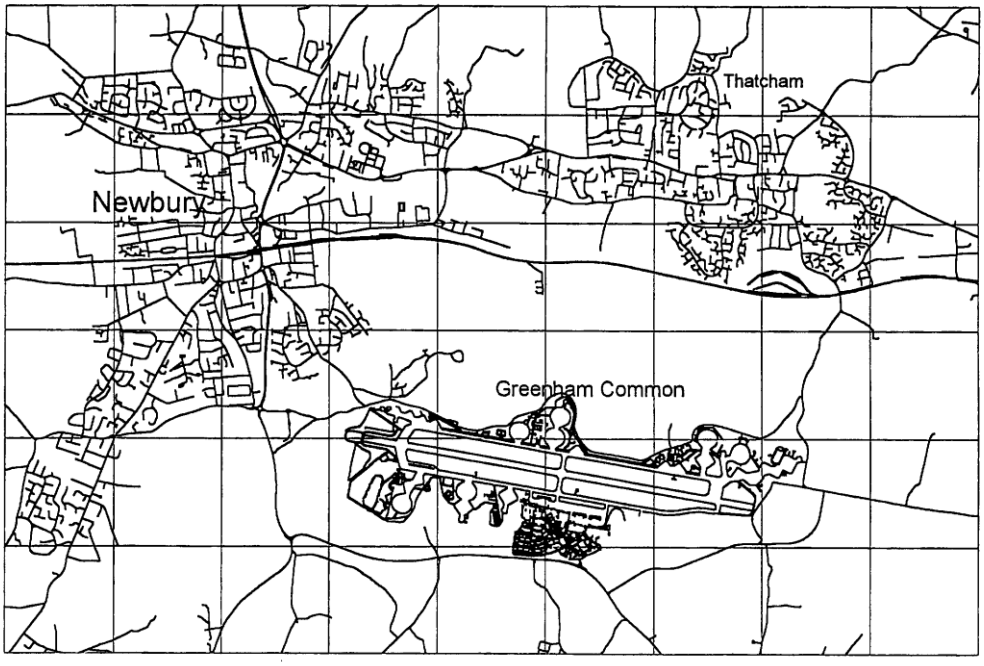

Figure 1.2 Detail of Area 2.

2. Analytical Methodologies & Implementation

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2.1 Airborne Gamma Spectrometry

The airborne gamma spectrometry (AGS) method uses aircraft equipped with highly sensitive spectrometry systems flying close to the ground to record variations in the local radiation environment. The methodology for airborne survey is well established (Sanderson *et al*, 1994a, 1994b) for a variety of purposes including environmental assessments of contamination (1990a, 1990b), Chernobyl fallout mapping (Sanderson *et al*, 1989a, 1989b, 1990c, 1994c), the effects of marine discharges along the coastal fringes of the Irish Sea (Sanderson *et al*, 1994c), baseline mapping around nuclear establishments (Sanderson *et al*, 1990d, 1992, 1993b, 1994d), epidemiological studies (Sanderson *et al*, 1993a) and radioactive source searches (1988b, 1991). In addition, a european collaborative effort is currently being made to address a variety of research topics, review data processing techniques, dose rate calculations and calibrations. A joint exercise with airborne survey teams from Scandinavia, Germany and France was undertaken in Finland during 1995 to establish the european capability and links for co-ordination in the event of major nuclear accident (Sanderson *et al*, 1997a, 1997b).

A sequence of gamma ray spectra, positional information and ground clearance data are recorded simultaneously and used to quantify levels of individual radionuclides and the general gamma ray dose rate. Having defined the areas to be flown, and recognised the need to examine both high energy gamma-rays associated with the major sources of environmental radioactivity, and the low energy photon spectrum a number of features became apparent. To obtain useful information in the low energy region it is important to fly the aircraft as close as possible to the ground; yet to fly closer than 500 feet from a structure or person requires CAA permission. Much of Area 2 is an urban zone, and therefore a carefully constructed case for exemption, based both on safety and public benefit was needed. A second practical difficulty is that whereas many airborne surveys looking at high energy radiation can be conducted satisfactorily using detectors mounted inside the aircraft, the lowest energies are scattered and absorbed in the aircraft skin, leaving little information.

It was decided to deploy a combined spectrometer comprising a high volume scintillation detector with 16 litres of NaI inside the aircraft, and two cryogenically cooled Germanium detectors mounted on the outside of the aircraft. Whereas the NaI detector is well-established, and had been used on many previous occasions, the use of a coupled pair of low energy Ge detectors outside the aircraft had not been attempted before. These detectors are known to be sensitive to vibrations; moreover it is essential that aircraft-mounted equipment is properly designed and engineered by an approved authority. The SURRC spectrometers have been developed for use in AS350 and AS355 Aerospatiale "Squirrel" helicopters. Fortunately, the main UK importer and engineering authority for these aircraft (MacAlpines) is in Oxford and agreed to help develop a damped mounting system for the low energy detectors. A twin-engine AS355 helicopter used by Operational Support Services (OSS), the associated charter company to MacAlpines, was hired for the survey. The twin-engine aircraft is widely used by UK Police forces in built up areas and for air ambulance duties. The probability of a single engine failure in flight is low, but even in this event the twin-engine aircraft can be operated in a manner which allows it to fly on a single engine. Having considered the mode of operation, and consulted with Newbury District Council on the public interest case for the survey, CAA issued an exemption permitting flights down to 200 feet in the urban areas within Areas 1 and 2.

The area also includes restricted flight zones around the nuclear sites of Harwell, Aldermaston and Burghfield. The UK position regarding flying around nuclear sites is rather variable. Exclusion zones exist around some sites, but not others, and to a varying distance. Access to fly within such zones can be sought from CAA, and may be granted if the site operator is agreeable. In this manner SURRC has conducted flights close to, and on occasion within, a number of nuclear sites - including Hinkley Point, the Devonport Dockyard, Trawsfynydd, Sellafield, Springfields, Chapelcross, Hunterston and Torness. It is usually possible to conduct a meaningful survey without compromising nuclear safety by arranging control-led flights to avoid certain safety critical features, while recording data from their surroundings. With a twin engine aircraft a very high level of safety could be demonstrably achieved. There is a large international literature on airborne gamma ray surveys of nuclear sites including overflights. On this occasion, however, the request from Newbury District Council that permission be granted to overfly Harwell, Aldermaston and Burghfield was not successful. Permission to fly up to the perimeter fences of these sites was granted, and this was done.

The equipment comprising the two radiation detectors described above together with associated instrumentation was installed in the aircraft at Oxford airport and tested on 14th September 1996 prior to deployment for the survey. The survey was conducted between then and the 28th September, operating out of Oxford airport on a daily basis, and refuelling the aircraft at a landing site on the Newbury Racecourse. Prior to each days flight a series of tests were performed to check the detector calibration and sensitivity.

Two differential satellite navigation systems were used to position the aircraft and locate the data; one was pre-programmed to display an indication of position relative to each planned flight line to the pilot - the other fed positional data with a precision of ±5-10 m to the data recording system. Gamma ray spectra were recorded every 3 seconds in the NaI spectrometer, and every 6 seconds in the pair of Ge detectors. Radar altimetry was used to record the time-averaged ground clearance for each observation. At the end of each day's flying two independent copies of the data set were made and stored separately from the aircraft, the flight lines were plotted, and the system prepared for the following day's work. By the end of the survey period and with a total of 50.5 hours flying, more than 40,000 NaI and 20,000 Ge spectra had been recorded from both Areas 1 and 2 in accordance with the survey plan. The flight paths taken are shown in figure 2.1.

Background readings were taken over Farmoor reservoir each day on the way to the survey grid, and used to subtract signals from radioactivity in the aircraft and equipment, and from airborne radon gas and its decay products. Elevated levels of radon daughter activity were recorded between 23rd and 25th September in a period following wetter weather, as shown in figure 2.2. The analysis of a variable background contribution and the corresponding effects on the radiometric maps is dealt with later in section 4.

Figure 2.3 shows both the airborne system and the vehicular system later deployed to supplement airborne measurements. At the end of the survey a set of 31 soil cores was collected from an area south of the runway at Greenham Common in a standard expanding hexagonal pattern to develop sites for comparison between ground based and airborne spectrometry. Half of these samples were analysed at Southampton University, and the other half at SURRC to provide a cross-calibration between the two groups. Airborne measurements were taken at this calibration site (centre position 51°22.732'N 1°17.467'W) at a range of heights to confirm height correction coefficients and provide a means of tracing the airborne results to laboratory gamma spectra. Additional information is provided in section 4 and Appendix C.

2.2 Vehicular Gamma Survey

Supplementary data were collected between 4th and 6th December on the Greenham Common site using a vehicular spectrometer based on a Vauxhall Frontera ATV. An 8 litre NaI detector was mounted on roof rails on the vehicle together with a GPS receiving antenna and differential correction receiver. Two 50% relative efficiency GMX detectors were mounted on a rack attached to the rear of the vehicle. The system was used to collect gamma spectra across part of the Greenham Common site, around the calibration point, and the hard-standing areas reported to be where the 1958 aircraft fire occurred. During the vehicular survey NaI spectra were recorded every 15 seconds and GMX spectra every 30 seconds with a forward velocity of approximately 5 kph. Totals of 1376 and 763 spectra were recorded from each detector respectively on the base. Static 2000 s Ge spectra were also recorded on the grass between the runway and southern taxi lane, on grass next to the hard standing (believed to be associated with the fire) in a quarry site where material from the hangar destroyed in 1958 would have been placed, and at a control site in Lockinge well-removed from the base. These data were plotted up in the field, and duplicate back-up copies made prior to return to East Kilbride.

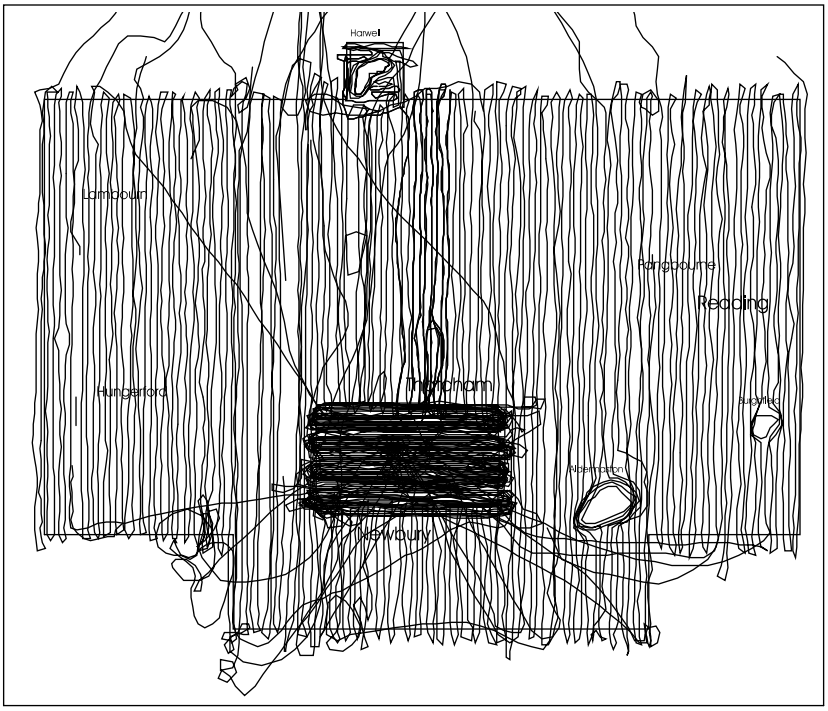


Figure 2.1 The airborne survey flight lines.

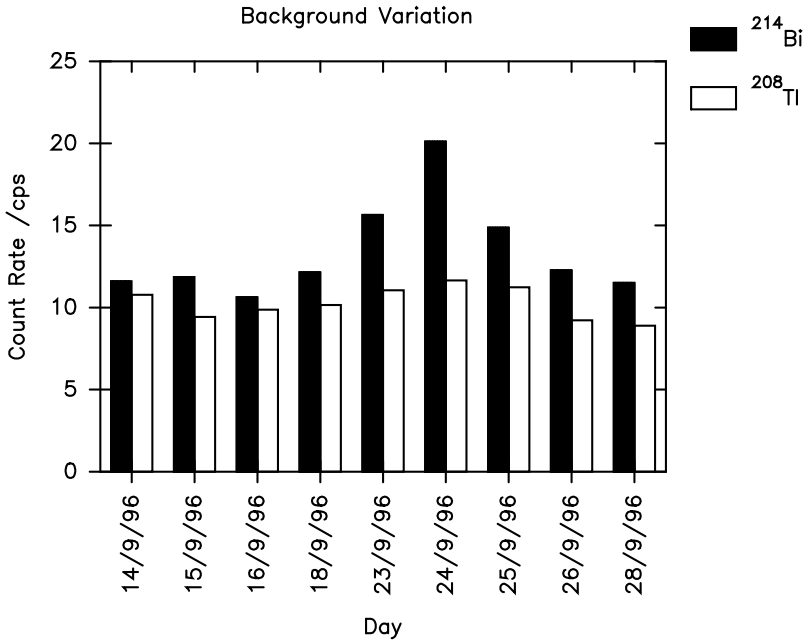


Figure 2.2 The daily radon variations.

Figure 2.3 The airborne and vehicular gamma-ray spectrometry systems.

3. Soil Analysis and Calibration

3. Soil Analysis and Calibration

3.1 Greenham Common Calibration Site

In order to relate ground to air measurements and confirm the working calibration factors for the terrestrial radionuclides ^{137}Cs, ^{40}K, ^{214}Bi and ^{208}Tl, a calibration site was established at Greenham Common in accordance with internationally recognised procedures developed by SURRC (Sanderson *et al*, 1996; Tyler, 1996).

For natural radioelement mapping it has become conventional to perform ground to air comparisons using in-situ spectrometry systems calibrated with the same concrete calibration pads as used to characterise airborne gamma spectrometers, thus providing a means of projecting the response of the small scale pads onto larger calibration ranges (IAEA, 1974, 1976, 1979, 1989; Grasty, 1975). Whilst this provides a means of determining system sensitivities for airborne spectrometers relative to pads (Lovborg, 1982), it does not lead directly to absolute concentrations, and does not in general take account of variations in soil density, and the heterogeneity of source distribution both in the spatial vertical and horizontal planes. Consideration must also be given to the detector field of view (Grasty, 1979; Duval, 1971). Calibration of systems for mapping anthropogenic radionuclides, can be approached on theoretical grounds (Allyson, 1994) or more conventionally by ground to air comparison using in-situ measurements or soil samples (Tyler, 1994). Since the primary photon fluence rates for anthropogenic nuclides are strongly influenced by source distribution the use of soil samples to make traceable estimates of activity per unit area, and to investigate the vertical source distribution is the preferred approach.

With environmental ^{137}Cs concentrations corresponding to typically 10^{-15} and 10^{-12} parts by weight deposited in a heterogeneous matrix it is unsurprising that individual core samples are of limited value in representing the fields of view of in-situ and airborne measurements, with spatial dimensions which are some 10^5 - 10^7 times greater than soil cores. Matching soil samples to in-situ and aerial spectrometric measurements should take account of spatial variability of environmental radioactivity and field of view of the detector. Calibration sites therefore must be selected and sampled to: i) represent the field of view of airborne detectors for various altitudes, ii) account for within site variability, and iii) examine source depth characteristics.

The calibration procedures adopted here utilises methods developed by SURRC, based on an expanding hexagonal sampling pattern (figure 3.1). Core samples analysed by high resolution spectrometry provide traceability to international reference materials. The sampling plan consists of a series of concentric hexagons, spaced apart by a partial geometric progression. This provides an efficient sampling scheme for determining activity concentrations and their spatial variability over dimensions of several hundred metres for calibrating airborne detectors. It is possible to compensate for spatial variability within the site by evaluating weighted expectation values for radiometric variables, taking account of observation height, energy, detector angular response and the source distribution.

Core samples were collected at the centre of the site and at the apexes of each hexagonal shell the radial dimensions of which expand out in a progressive interval (eg. x2 or x4). Sample spacing therefore increases for each successive shell. In this instance samples were collected at 2, 8, 32, 128 and 256 metres from the central point. The site was flat, and at least 500 m across.

The sampling pattern was laid out from the 26th September 1996. The pattern was constructed with the reference axis towards direction 342° (figure 3.2). The labelling convention used is shown in table 3.1. The soil coring tool had a diameter of 72.5 mm and was driven as deeply as possible, with a gravel layer at Greenham Common making this possible only to a depth of about 15-16 cm.

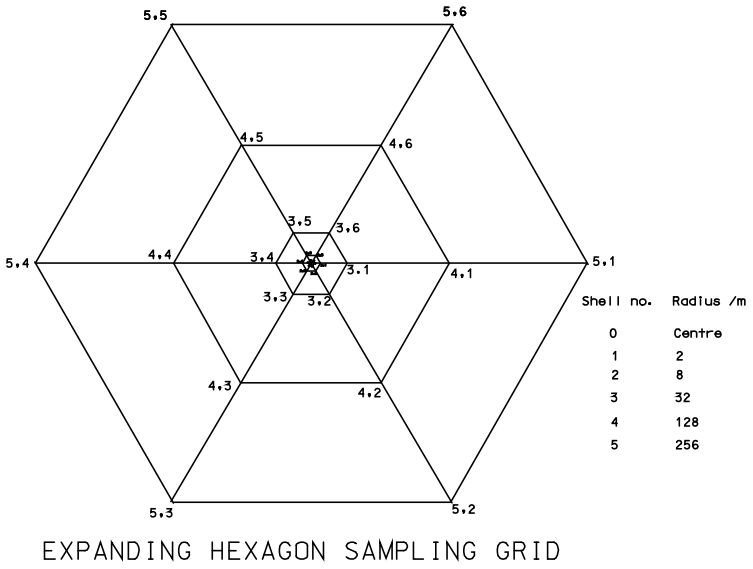


Figure 3.1 Hexagon pattern sampling scheme.

3.2 Sample Treatment and Allocation

The ground based soil coring program for the calibration site resulted in a set of 31 samples. Each core was sectioned at intervals of 0-5 cm, 5-10 cm and 10-15 cm, although some were taken slightly deeper and thus forming about 93 individual samples for high resolution gamma-ray spectrometry. The samples were returned to the Southampton Oceanography Centre (SOC), University of Southampton, where approximately half were dried and counted in standard containers, and the remaining half sent to SURRC. The latter samples were dried for 2-3 days at 105°C to constant weight to assess moisture content. These samples were then homogenised in a high capacity mixer-mill and dispensed into standard containers of 100 cm^3 capacity and sealed prior to gamma spectrometry. The containers were agitated to allow samples to settle, and were fully packed without compressing the material. Although the container lids were sealed with gas sealing tape, it is likely that some radon leakage may still have occurred. Samples of two standards were used to calibrate the soil samples collected for analyses by SURRC: An internal standard CAER STND and IAEA-375 reference material, both of 100 cm^3 volume.

The internal standard was prepared from a larger quantity of marine saline gley from a site near the Irish sea, containing ^{241}Am, ^{137}Cs, ^{134}Cs, with additional quantities of potassium, uranium and thorium derived from IAEA RG-K, RG-U and RG-Th reference materials (Sanderson *et al*, 1994). The working values for the internal standard had been previously determined relative to a series of soils labelled with NPL multinuclide reference solutions, and Amersham calibrated spikes.

Gamma spectra from samples and standards were measured for 6000-60000 seconds using a hyperpure Ge spectrometer (GMX detector), housed within low background lead shields. The samples were presented to the detector in an identical manner to the reference materials. Full gamma ray spectra from 30 keV to 1.6 MeV were stored and analysed using Ortec software to estimate full-energy peak count rates for the following radionuclides:

anthropogenic nuclides -
^{241} Am (59.5 keV), ^{137}Cs (662 keV), ^{134}Cs (796 keV)

natural nuclides -
^{40}K (1461 keV), ^{214}Bi (609 keV), ^{208}Tl (583 keV).

Other gamma-ray lines were additionally measured but were not part of the calibration procedure. Dry activity concentrations were calculated relative to standards after subtraction of background count rates for each gamma-ray line. For Cs nuclides the activities per unit area (Bq m^{-2}) for each depth layer were calculated using the dry bulk weight of the original sample layer, and the core area. These were then summed vertically to obtain the total inventory down to the sampling depth (15 cm). For the natural nuclides the wet activity concentrations of each layer, and the weighted mean activity concentrations were calculated taking the mass fractions and moisture contents of each core layer into account.

A similar procedure was adopted by Southampton University using samples counted in marinelli beakers. Data on ^{137}Cs and ^{40}K were returned; for these radionuclides comparisons between the SURRC and Southampton results have been made and both sets used to estimate site averages. For other nuclides, the SURRC values have been used to define the calibration site.

Results for the calibration site at Greenham Common are presented in three parts. The results from each position are considered first. Thereafter weighted mean estimates are evaluated for the effective activities observed with detectors at 1 m, 50 m and 100 m are presented. Finally the depth distribution is discussed in section 3.5. Primary data are presented in Appendix C.

Table 3.1 Labelling system.

Radius /m	**Shell number, clockwise orientation (Ref.no.)**					
0	Centre position: 0, 0					
2	1,1 (363)	1,2 (364)	1,3 (365)	1,4 (366)	1,5 (367)	1,6 (368)
8	2,1 (370)	2,2 (371)	2,3 (372)	2,4 (373)	2,5 (374)	2,6 (375)
32	3,1 (376)	3,2 (377)	3,3 (378)	3,4 (379)	3,5 (380)	3,6 (381)
128	4,1 (382)	4,2 (383)	4,3 (384)	4,4 (385)	4,5 (386)	4,6
256	5,1 (388)	5,2	5,3 (390)	5,4 (391)	5,5 (392)	5,6 (393)

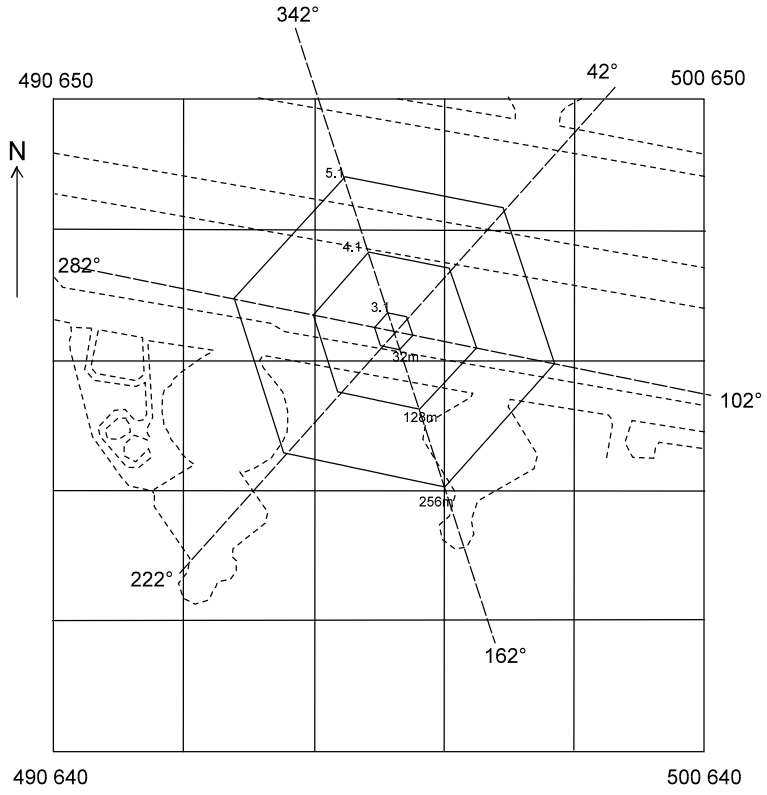


Figure 3.2 Location and orientation of calibration site.

3.3 Summary of Results from Each Shell and Position

In the tables 3.2 and 3.4 are listed the radionuclide deposition and inventories for ^{137}Cs and ^{40}K. Each shell number represents increasing distance from the centre point. Each hexagonal apex is listed as a clockwise orientation from the main reference axis along the direction 342°. Mean values are shown for each shell and are incorporated into the weighted activity estimates shown in section 3.4.

Sampling date: 26th September 1996
Gamma spectrometry SURRC/SOC October 1995-January 1996
Reference date: 1 February 1997
Traceable to IAEA-375 and SURRC CAER STND

Table 3.2 Greenham Common: ^{137}Cs activity 0-15 cm / kBq m^{-2}

		Clockwise Orientation						
Shell	Radius /m	1	2	3	4	5	6	Mean ±Std dev
0	0	-						-
1	2	1.96 ±0.13	1.67 ±0.15 *	1.93 ±0.09	1.85 ±0.15 *	1.27 ±0.09	1.68 ±0.13 *	1.73 ±0.25
2	8	1.52 ±0.13 *	1.60 ±0.06	2.03 ±0.16 *	2.03 ±0.10	1.88 ±0.15 *	1.81 ±0.09	1.81 ±0.21
3	32	1.81 ±0.09	2.37 ±0.17 *	1.52 ±0.09	1.77 ±0.10 *	1.80 ±0.08	1.90 ±0.14 *	1.86 ±0.28
4	128	4.46 ±0.18 *	6.43 ±0.20	1.97 ±0.12 *	1.33 ±0.09	1.85 ±0.11 *	-	3.2 ±2.2
5	256	1.53 ±0.09	-	1.63 ±0.06	2.61 ±0.14 *	8.78 ±0.14	2.24 ±0.14 *	3.36 ±3.06

* Analysed by SURRC (remainder analysed by SOC).

Table 3.3 Comparison of ^{137}Cs data between SURRC and SOC.

Shell	SURRC (±sd, no. of data)	SOC (±sd, no. of data)	Overall Mean
1	1.73±0.10 (3)	1.72±0.39 (3)	1.73±0.25
2	1.81±0.26 (3)	1.81±0.22 (3)	1.81±0.24
3	2.01±0.32 (3)	1.71±0.17 (3)	1.86±0.28
4	2.76±1.47 (3)	3.9±3.6 (2)	3.2±2.2
5	2.43±0.26 (2)	4.0±4.2 (3)	3.36±3.06
Overall Mean	2.13±0.42 (14)	2.5±2.2 (14)	2.3±1.6 (28)

Table 3.4 Greenham Common: ^{40}K activity 0-16cm / Bq per kg (wet)

		Clockwise Orientation						
Shell	Radius /m	1	2	3	4	5	6	Mean ±Std dev
0	0	-						-
1	2	174.0 ±112.2	102.3 ±50.0 *	115.3 ±69.0	190.7 ±47.4 *	214.7 ±100.2	133.7 ±43.0 *	155.1 ±44.7
2	8	119.8 ±44.2 *	114.0 ±37.0	76.3 ±21.3 *	164.0 ±80.0	128.8 ±52.0 *	140.0 ±94.0	123.8 ±29.2
3	32	168.0 ±107.0	199.7 ±42.2 *	139.0 ±113.0	186.6 ±47.1 *	392.3 ±53.0	90.2 ±39.9 *	195.9 ±103.8
4	128	167.1 ±29.5 *	39.9 ±23.5	53.1 ±24.7 *	90.3 ±32.6	211.9 ±106.2 *	-	112.3 ±74.2
5	256	124.7 ±84.0	-	95.7 ±57.5	55.9 ±16.9 *	123.7 ±54.5	276.4 ±73.8 *	135.3 ±83.7

* Analysed by SURRC (remainder analysed by SOC).

3.4 Weighted Activity Estimates

The mean inventory estimates from each shell were weighted to match the spatial averaging of a detector at 1, 50 and 100 m altitude. The source depth tends to narrow the field of view of the detector, but the effect on the shell weighting factors is small given the unrefined nature of the field sampling. The weighting factors are given below in table 3.5 and the effective radionuclide concentrations at different detector heights given in table 3.6.

Table 3.5 Shell weighting factors.

	Detector Height /metres		
Shell	1	50	100
1	0.80	0.02	0.01
2	0.17	0.13	0.04
3	0.03	0.60	0.40
4	0	0.20	0.35
5	0	0.05	0.10

Table 3.6 Effective radionuclide concentrations at Greenham Common.

Detector Height /m	Mean ^{137}Cs / kBq m^{-2}	Mean ^{40}K / Bq per kg	Mean ^{214}Bi / Bq per kg	Mean ^{208}Tl / Bq per kg
1	1.75±0.20	151.0±36.2	7.27±2.64	3.24±1.05
50	2.19±0.49	166.0±64.0	9.42±2.83	4.79±0.89
100	2.29±0.84	137.7±49.7	8.61±2.2	4.49±1.02

3.5 Depth Distributions

3.5.1 ^{137}Cs

The most common approximation of radiocaesium concentration profile in soil is the exponential distribution, described in ICRU (1994), where α/ρ is the exponential mass activity distribution coefficient, ρ is the density of the soil and the activity concentration is given in Bq kg^{-1} in soil at the depth z. The inverse of α/ρ is the relaxation mass per unit area, ß.

In figure 3.3, the ^{137}Cs activity concentration profile measured from Greenham Common is plotted in semi-logarithmic scale. The cores were sectioned too sparsely to show clear distribution characteristics, but a decreasing trend with depth is observed, consistent with the exponential deposition history and subsequent diffusion of activity through the upper soil layer. The three uppermost layers (0-5 cm, 5-10 cm and 10-15 cm) were used in a tentative exponential fitting. The values for the distribution coefficient α/ρ are shown in table 3.7. The mean α/ρ value is 0.12±0.03 cm^2 g^{-1} (mean ß=9.0±2.0 g cm^{-2}).

A number of points outlie the general trend however: at position 4,1 (ref.no. 382) 0-5 cm layer yielded 35.1 Bq kg^{-1} ^{137}Cs; the 5-10 cm layer 32.5 Bq kg^{-1}. At position 4,2 (ref. no. 382) the 0-5 cm layer gave 56.3 Bq kg^{-1}. At position 5,5 (ref. no. 392) 0-5 cm layer gave 74.8 Bg kg^{-1} and 5-10 cm layer 45.8 Bq kg^{-1}. The points 4,1 and 4,2 both lie close to and parallel with the main runway, possibly reflecting some run off. The point 5,5 lies next to the hardstand adjacent to the one where the aircraft fire occurred, possibly indicating some wash off again.

The mean wet soil density (0-15 cm depth) was 1.17±0.22 g cm^{-3} in September 1996. At the 0-5 cm layer, the wet density was found to be 1.08±0.21 g cm^{-3}; 1.32±0.28 g cm^{-3} at the 5-10 cm layer; 1.12±0.26 g cm^{-3} for 10-15 cm.

Table 3.7 Exponential distribution factors for ^{137}Cs at Greenham Common.

Shell	**1**	**2**	**3**	**4**	**5**
α/ρ	0.109	0.094	0.111	0.093	0.165
ß	9.22	10.67	9.04	10.73	6.05

Although significant non-exponential profiles are encountered in some contexts, Tyler *et al* (1996) have shown that calibration factors are shape dependent but that valid calibration coefficients on salt marsh sites can be determined using an appropriate sampling regime. Hillmann *et al* (1996) have approximated depth distribution by the Lorentz function and Macdonald *et al* (1996) have investigated the diffusion between Gaussian and exponential profiles in studies in North Wales. The exponential profile can be parameterized; Tyler *et al* (1996) has used the empirical mean mass depth ß, defined from general shapes to correct four depth variations for the exponential profile. It is notable that the value of ß obtained at Greenham Common is consistent with general guidance from ICRU, for deposition and that the coefficients are in good agreement with AGS sensitivity implying that any undetected non-exponential behaviour has little effect on sensitivity.

3.5.2 Natural radionuclides

The ^{40}K, ^{214}Bi and ^{208}Tl activity concentration distribution profiles are shown in figure 3.4-3.6. The soil profiles on the calibration site showed evidence of potassium enrichment in the surface layer of some samples. While this may be indicative of soil disturbance, it does not constitute evidence of decontamination.

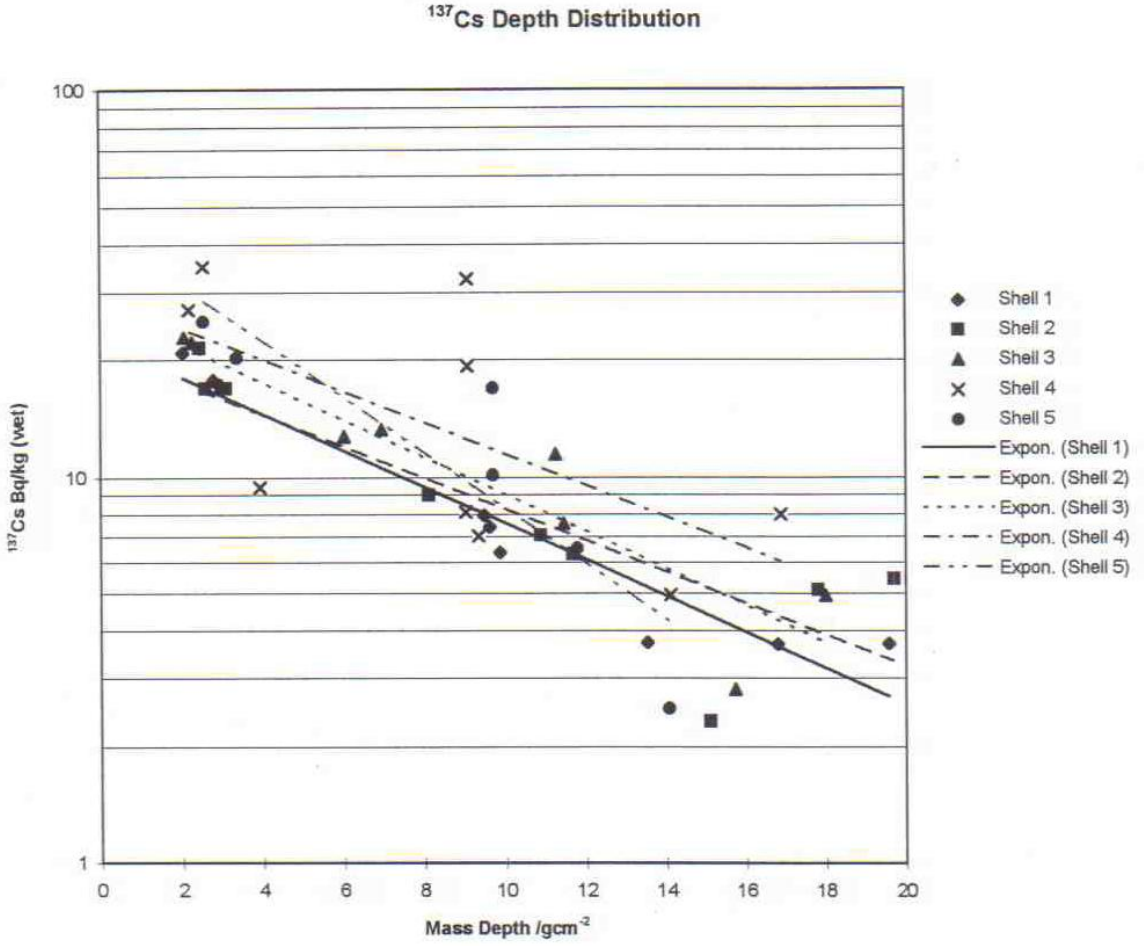


Figure 3.3 ^{137}Cs Depth distribution at Calibration site.

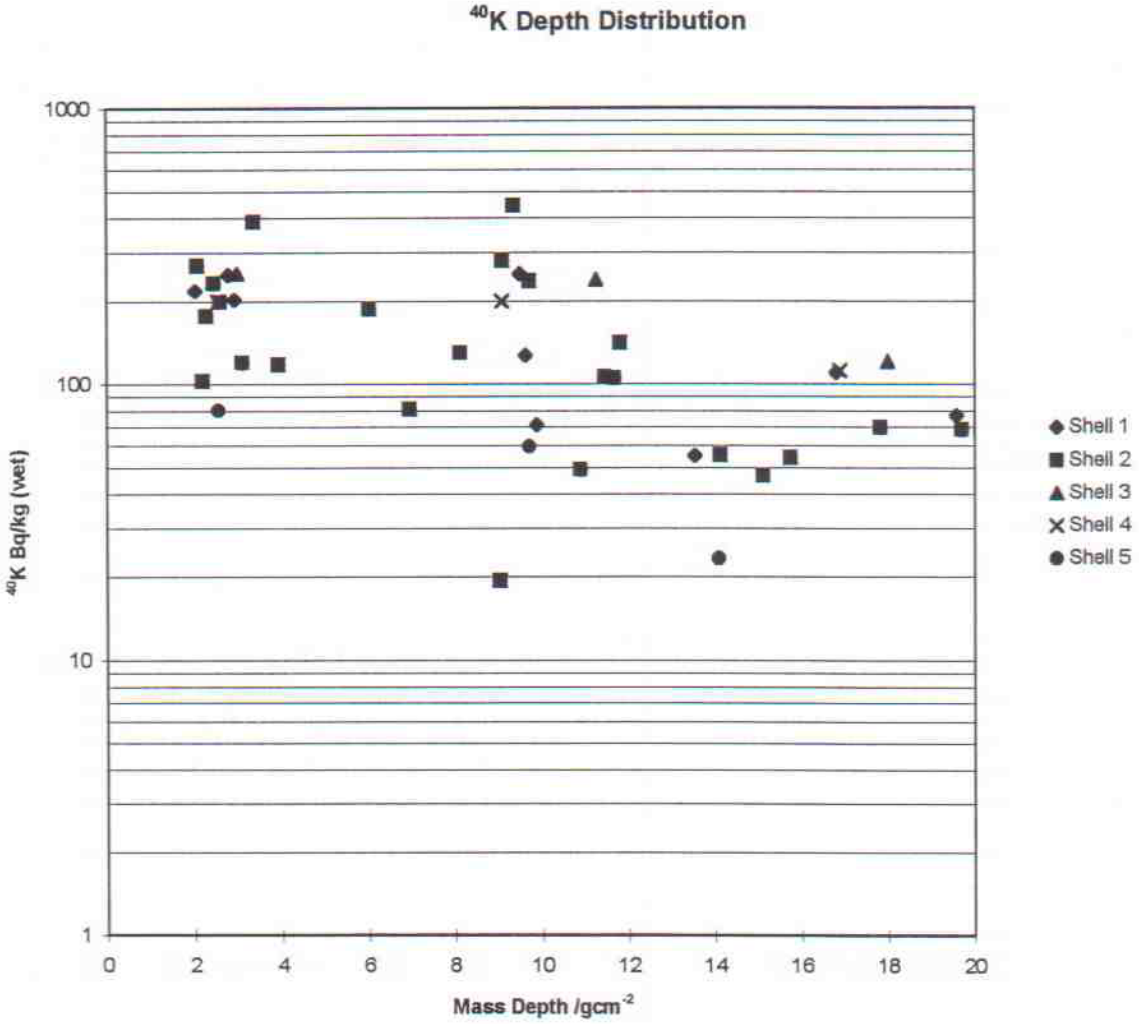


Figure 3.4 ^{40}K Depth distribution at Calibration site.

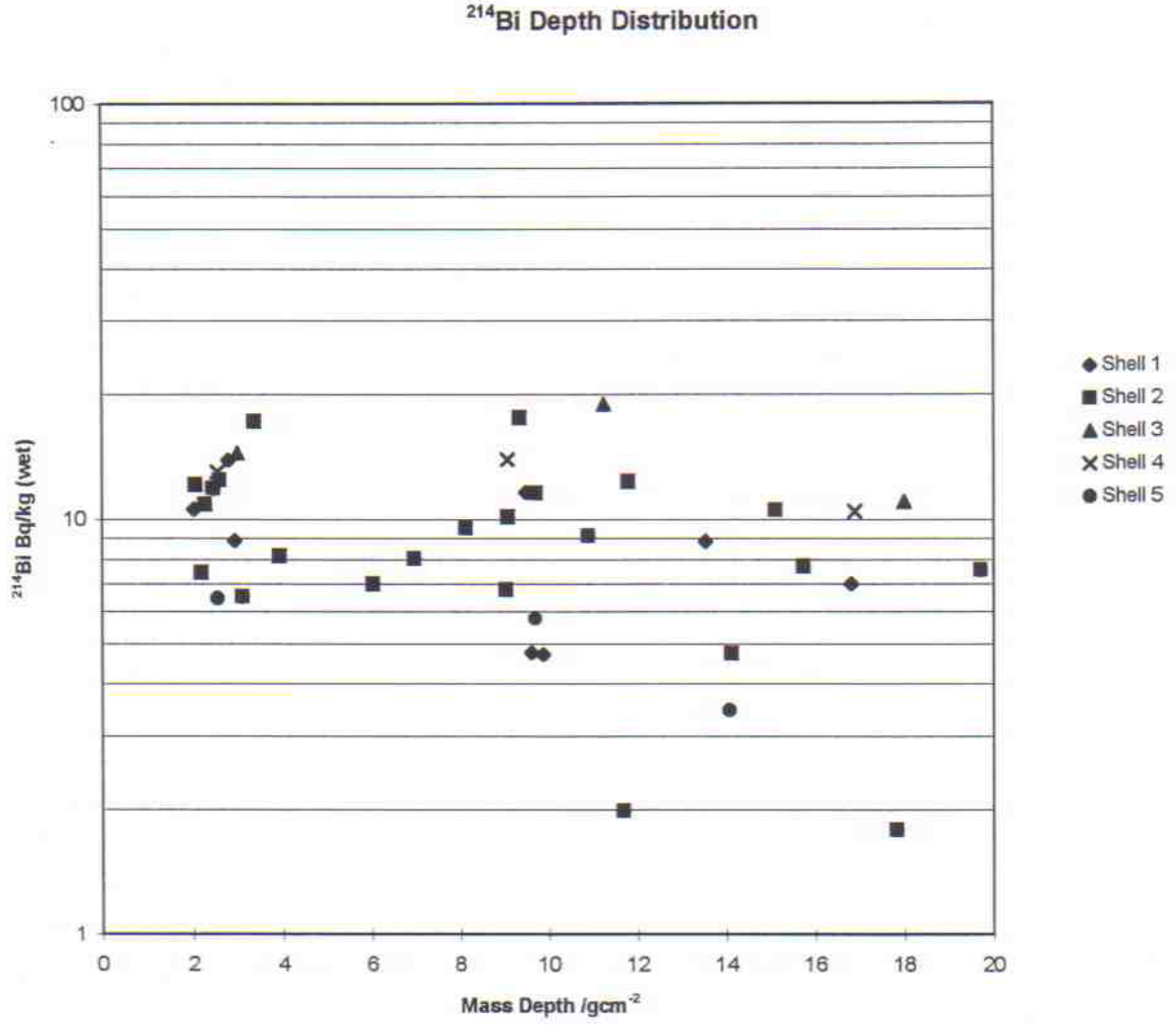


Figure 3.5 ^{214}Bi Depth distribution at Calibration site.

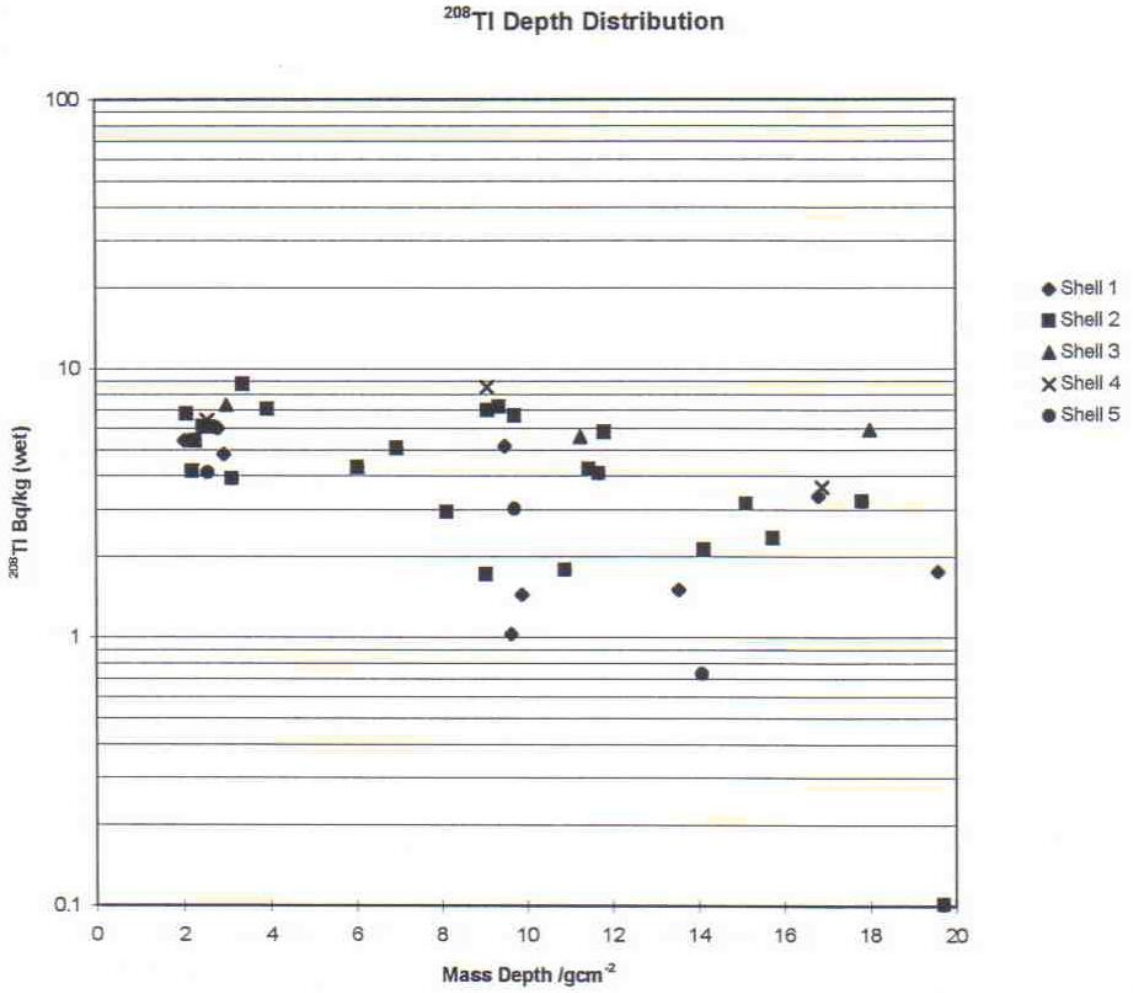


Figure 3.6 ^{208}Tl Depth distribution at Calibration site.

3.6 Calibration Factors

The calibration constants considered were based on a combination of sensitivities determined at the Greenham Common calibration site, and theoretical sensitivity data derived from Monte-Carlo simulation (Allyson, 1994). The calibration factors used are those implemented for exercise RÉSUMÉ 95 (Sanderson *et al*, 1996). Table 3.8 shows a comparison of calibration factors calculated from field sampling (table 3.6) and the mean count rate at 100 m height above the calibration site, and by a theoretical approach successfully used during exercise RÉSUMÉ 95 assuming depth characteristics associated with ^{137}Cs and the natural radionuclides (assumed to exhibit a uniform depth distribution). For the case of ^{137}Cs, a mean relaxation mass depth of 9.0±2.0 g cm^{-2} was observed over the calibration site. Using this figure and assuming a soil density of 1 g cm^{-3}, a theoretically based calibration factor of about 0.15 kBq m^{-2} cps^{-1} can be calculated. Given the uncertainties across the whole of the hexagonal pattern, the relatively low levels of ^{137}Cs which are derived from weapons' testing fallout and a relatively small amount of Chernobyl deposition, and the significant amount of concrete (non-uniformity across the site), it was decided to retain the RÉSUMÉ 95 calibration factor as probably being more representative in this instance. The calibration factors from RÉSUMÉ 95 for the natural radionuclides were similarly used as these were more extensively sampled.

Table 3.8 Calibration factors.

Radionuclide	Effective concentration	cps at 100 m	Calibration Factor (Field based)	Calibration Factor (Sanderson *et al*, 1996)
^{137}Cs	2.29±0.84 kBqm^{-2}	16.8	0.14±0.05 kBq m^{-2} /cps	0.11 kBq m^{-2} /cps
^{40}K	137.7±49.7 Bq kg^{-1}	13.08	10.5±3.8 Bq kg^{-1} /cps	6.77 Bq kg^{-1} /cps
^{214}Bi	8.61±2.2 Bq kg^{-1}	3.98	2.2±0.6 Bq kg^{-1} /cps	3.16 Bq kg^{-1} /cps
^{208}Tl	4.49±1.02 Bq kg^{-1}	7.5	0.60±0.2 Bq kg^{-1} /cps	0.47 Bq kg^{-1} /cps

3.7 Comparison with In-Situ Measurements

On the 4th October 1996, a series of in-situ gamma-ray measurements were taken at the Greenham Common calibration site, using a 3x3" NaI and Ortec Series 10 portable spectrometer. Measurements were taken for 1000s at the centre and apexes of (1,4), (2,1), (2,2), (3,3), (3,4), (3,6) and (4,1). The results are shown in table 3.9 for comparison with the soil samples at the corresponding shell positions.

Table 3.9 Comparison between soil analyses and in-situ measurements.

Filename	Position	^{137}Cs /kBq m^{-2} (Soil analysis)	^{137}Cs /kBq m^{-2} (In-situ)
GCCAL001	3,3	1.5±0.1	1.3
GCCAL002	Centre	-	bdl
GCCAL003	1,4	1.8±0.2	bdl
GCCAL004	2,2	1.6±0.1	bdl
GCCAL005	3,6	1.9±0.1	1.4
GCCAL006	3,4	1.8±0.1	1.3
GCCAL007	2,1	1.5±0.1	1.1
GCCAL008	4,1	4.5±0.2	1.02

The in-situ measurements are close to the minimum detectable limit (approx. 1 kBq m^{-2}). The disparity between in-situ measurements and soil analysis for point 4,1 is probably due to the proximity of the main runway contributing a significant fraction of the field of view and correspondingly less ^{137}Cs activity component.

4. Results and Discussion

4. Results and Discussion

4.1 Airborne gamma survey

The airborne gamma ray survey results have been analysed to address the objectives stated in section 1 in stages. The NaI results have been used for characterisation of the general radiation environment, and to examine whether there are any significant external gamma ray hazards in Areas 1 and 2. The low energy Ge data have been used to search for any evidence of anomalies in the energy region associated with U isotopes, and also for evidence of ^{241}Am - a decay product of ^{241}Pu which can be a minor component of Pu-bearing nuclear weapons.

4.1.1 Analysis of NaI spectra

The NaI data were analysed using standard procedures. During flight count rates were evaluated at energies corresponding to ^{137}Cs, ^{60}Co, ^{40}K, ^{214}Bi, ^{208}Tl and a total count rate > 450 keV. After survey all spectra were re-integrated to evaluate count rates in energies of 40-100 keV, 100-200 keV, 200-300 keV, 300-450 keV and the energy sum in the crystal in pJ/s for dose rate evaluation. Background values for each of these count rate variables were subtracted from the recorded data. This was initially achieved using background readings recorded each morning over Farmoor reservoir, given in table A.6. However, this resulted in the over-subtraction of background, particularly in the ^{214}Bi channel, for data collected on four days of the survey (23-26/9/96) producing pronounced stripes on the resulting maps. It was noted that on the first three of these days the background readings were significantly higher than the mean values for the rest of the survey, possibly as a result of contamination of the aircraft by radioactive daughters of airborne ^{222}Rn gas. The effect of this contamination was corrected for, as described in appendix D, and the resulting background subtracted from the data removing the stripes from the maps. In this final report, the ^{214}Bi map has been subject to correction procedures which has improved the spatial consistency of the features compared with the original report. The main conclusions regarding general levels of U in the original report are not significantly altered by this re-levelling.

For the nuclide specific windows listed above the data were then subjected to a matrix stripping procedure, based on coefficients determined at SURRC using calibration blocks of concrete containing enhanced levels of natural potassium, uranium and thorium, together with planar and point sources representing ^{137}Cs, ^{60}Co respectively. Perspex absorbers with an equivalent thickness of 50 m of air were used to simulate atmospheric scattering. The stripped data from the identified nuclides, and the integrated count rate data were then corrected for variations in ground clearance, using a standard exponential correction procedure with coefficients determined from calibration manoeuvres at Oxford airport, and at the Greenham Common calibration site. The altitude corrected count rate data for each nuclide were then calibrated to produce data in kBq m^{-2} for ^{137}Cs, Bq kg^{-1} for the natural nuclides.

There was no significant evidence for ^{60}Co for the rural parts of Area 1, or in the vicinity of Greenham Common and Newbury, therefore this channel was not calibrated. Gamma ray dose rates have usually been evaluated in airborne surveys using a "total count rate" channel converted to ground based dose rate by comparison with field instrumentation. An alternative approach based on the use of the full spectrum was investigated in this study, by evaluating the energy deposition rate (in pJ/s) corresponding to each spectrum, and cross calibrating this with the conventional approach for the complete data set. Both approaches produced highly consistent results throughout the survey, however, the new technique was adopted since it would respond to all detected signals in the spectrum.

The mean values of the quantified radionuclides and variables are given in table 4.1. Individual maps showing the distribution of each nuclide and dose rate are presented in figures 4.1 to 4.5

4.1.2 ^{137}Cs levels in Newbury District and Surrounding Areas

^{137}Cs is a fission product with a 30.27 year half life, produced in nuclear reactors and as a result of nuclear

Table 4.1 Mean values of ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and gamma dose rate throughout the survey area.

Area 1	^{137}Cs kBq m^{-2}	^{40}K Bq kg^{-1}	^{214}Bi Bq kg^{-1}	^{208}Tl Bq kg^{-1}	Gamma Dose Rate /mGy a^{-1}
Mean Value	1.65	147	12	4.8	0.18
Std. Dev.	1.24	73	10	2.1	0.07

weapons' detonations. The levels observed in the area - which vary from below 0.3 kBq m^{-2} to about 4 kBq m^{-2}, with a mean value of 1.65 kBq m^{-2} are largely due to weapons' testing fallout, with the possibility of a small enhancement from Chernobyl. Figure 4.1 shows the distribution of ^{137}Cs, which represents a combination of the deposition pattern and subsequent redistribution due to environmental processes. It is notable that the wetland areas around the Kennet and Avon are markedly depleted - possible due to the greater mobility of Cs in these contexts. The area around Greenham Common is also one of low Cs concentration, as are the urban areas of Newbury and Thatcham, possibly as a result of greater removal by run-off and resuspension due to air and vehicular traffic in the areas. There is a slight indication of greater local concentrations along the line of the Greenham Common runway - as discussed further in the vehicular results section.

A number of features are notable in the vicinity of the Harwell and Rutherford Laboratories; to the north of the licensed site there is evidence of enhanced ^{137}Cs signals - most probably the result of stored materials on site, while to the south the two apparent "negative" anomalies correspond to locations where high energy gamma rays, probably from machine sources (i.e. accelerators) were detected. In this second case the high energy spectra result in over-subtraction of the natural background present at 662 keV at the spectral stripping stage. The signals around the nuclear site do not originate from uniform sources, and therefore the activity levels cannot be estimated directly from the airborne results.

Overall the ^{137}Cs levels are low by comparison with other parts of the UK and Europe. Weapons' testing fallout reaches 2-4 kBq m^{-2} in parts of the country with higher average rainfall, such as NW England and Western Scotland. Chernobyl deposition reached 15-30 kBq m^{-2} in North Wales, West Cumbria and parts of Scotland, and exceeded 50-100 kBq m^{-2} in parts of Germany and Scandinavia. Coastal contamination of the fringes of the Irish sea, resulting from marine discharges of waste from reprocessing nuclear fuel at Sellafield exceeds 100-500 kBq m^{-2} in many places. The levels in this survey are thus relatively low. The contribution that these levels of ^{137}Cs makes to environmental dose rates can be estimated using conversion factors published by ICRU (1994), assuming an average depth distribution coefficient. The air kerma rate corresponding to the mean activity inferred in the survey is 1.25 nGy h^{-1} equivalent to 0.0108 mGy a^{-1} assuming a mass relaxation depth of 10 g cm^{-2}.

4.1.3 Natural Sources of Radioactivity in Newbury District and Surrounding Areas

4.1.3.1 Potassium

The maps showing the distribution of ^{40}K, ^{214}Bi, ^{208}Tl reflect the underlying distribution of the main dose contributing sources of natural radioactivity. The potassium distribution shows a structure revealing the changing geomorphology of the river valleys and woodlands of the area. The geology of the area to the north of Newbury is dominated by the Chalk, with infill of Palaeogene and Eocene sediments, the boundaries apparently also being reflected in the potassium distribution. Mean potassium levels are lower than typical; for example in a survey of 2500 km^2 of SW Scotland conducted in 1993 levels of ^{40}K varied from <50 Bq kg^{-1} to 600 Bq kg^{-1} (Sanderson et al, 1994) while a survey of three disjointed grids in SW England for the Leukaemia Research Fund showed levels ranging to over 1200 Bq kg^{-1} with mean values from 486 to 647 Bq kg^{-1} in each area. The mean level in this survey of 147 Bq kg^{-1} contributes an air kerma of some 5.4 nGy h^{-1} or 0.047 mGy a^{-1}, again using ICRU conversion values. It also corresponds to an elemental concentration of approximately 0.48% K by weight - which is significantly lower, than the average crustal abundance.

4.1.3.2 Uranium series activity

The ^{214}Bi map is partially a reflection of the distribution of uranium in the district at the time of survey. The ^{238}U series comprises a series of some 8 alpha decays and 6 beta decays leading to the formation of stable ^{206}Pb. If all decay products were retained in a natural system the series would be in equilibrium, and ^{214}Bi can be used to estimate uranium activity and concentration. However, ^{214}Bi occurs below radon gas in the uranium series, and therefore is susceptible to movements in radon under certain weather conditions. Enhanced radon backgrounds were observed at Farmoor reservoir on three days during the survey, and there is some evidence of levels changes in the ^{214}Bi maps resulting from this. It has been possible to re-level the data set to correct for these features with further work. Fortunately the majority of observations were taken on other days – particularly the dense set of observations in Area 2, and therefore mean values may not be significantly biased by this effect. At present the maps show a combination of the geological features observed in the ^{40}K and ^{208}Tl maps, and influences which can be attributed to radon movements. The two point features south of the Harwell site are due to interferences with high energy sources believed to be from accelerators at the Rutherford Laboratory.

Under equilibrium circumstances the mean value for ^{214}Bi of 12 Bq kg^{-1} would correspond to the same activity of ^{238}U, and thus to a concentration of 0.96 ppm by weight. The gamma ray dose rate above a surface corresponding to the full decay series with no radon loss would be 0.055 mGy a^{-1} or some 6.2 nGy h^{-1}. Given likely radon movements these figures must be taken for guidance only. However, it is notable that the recent NRPB (Fry & Wilkins, 1996) study of the area measured ^{238}U levels ranging from 1.7 to 25.6 Bq kg^{-1} with an average value of 13.3±4.8 Bq kg^{-1} from a range of on-site and off-site contexts in the area; corresponding to an average uranium concentration of 1.06 ppm. The mean value of U determined by mass spectrometry in the samples taken by Southampton University was approximately 1.6 ppm (Croudace *et al*, 1997). These values are all in broad agreement given the variability in environmental matrices and the differences in analytical method. The levels of uranium in the area, by any of these indicators, are lower than typical average values of some 3 ppm - again consistent with the evidence that the area has lower level of natural radioactivity than the national average.

4.1.3.3 Thorium series activity

The ^{208}Tl results (Figure 4.4) show a similar distribution to that of ^{40}K, again largely influenced by the distribution of different geological and geomorphological structures in the environment. Once again there are interesting signals in the Harwell/Rutherford laboratory area, in this case from three distinct locations which may include stored materials and machine sources. The river valleys correspond to areas of lower than average ^{208}Tl concentration, as do the immediate surroundings of the Greenham Common airbase which can be identified on the geological maps as Eocene sediments. ^{208}Tl is a decay product in the ^{232}Th decay series, and again under similar equilibrium assumptions, which in this case are more robust to environmental change, the parent Th activity can be estimated. The mean value of ^{208}Tl of 4.8 Bq kg^{-1} would correspond to 13.4 Bq kg^{-1} of ^{232}Th, equivalent to 3.3 ppm - again low by comparison with a typical crustal abundance of 10 ppm. The full series gamma dose rate associated with the mean activity would be 0.08 mGy a^{-1}, or some 9 nGy h^{-1}.

4.1.4 Gamma ray dose rates

The gamma ray dose rate map (Figure 4.5) shows a combination of the features identified above. With the exception of the signals detected in the vicinity of Harwell, the gamma dose rates can be explained by the combination of the natural sources. The mean gamma dose rate measured directly from the spectra of 0.18 mGy a^{-1} corresponds to 21 nGy h^{-1}, the level varying within the survey by a factor of 2-3. By comparison the recent NRPB study reported gamma dose rates of 26 nGy h^{-1} on site at Greenham Common, and 20 nGy h^{-1} in the vicinity, while the national NRPB 10 km x10 km dose rate survey produced an estimate of 22 nGy h^{-1}. These values are clearly all in agreement with each other. The sum of the dose rate estimates for each identified nuclide is 0.19 mGy a^{-1}, which is also in reasonable agreement with the measured value when the

likelihood of radon loss and the effects of distribution of activity are considered.

The general area maps therefore do not provide any evidence to identify radiation hazards in the vicinity of Greenham Common or Newbury. Apart from the signals detected close to Harwell, all the features can be associated with natural sources or weapons' testing and Chernobyl fallout. The area as a whole has a lower radiation background than most parts of the UK.

Figure 4.1 ^{137}Cs Map.

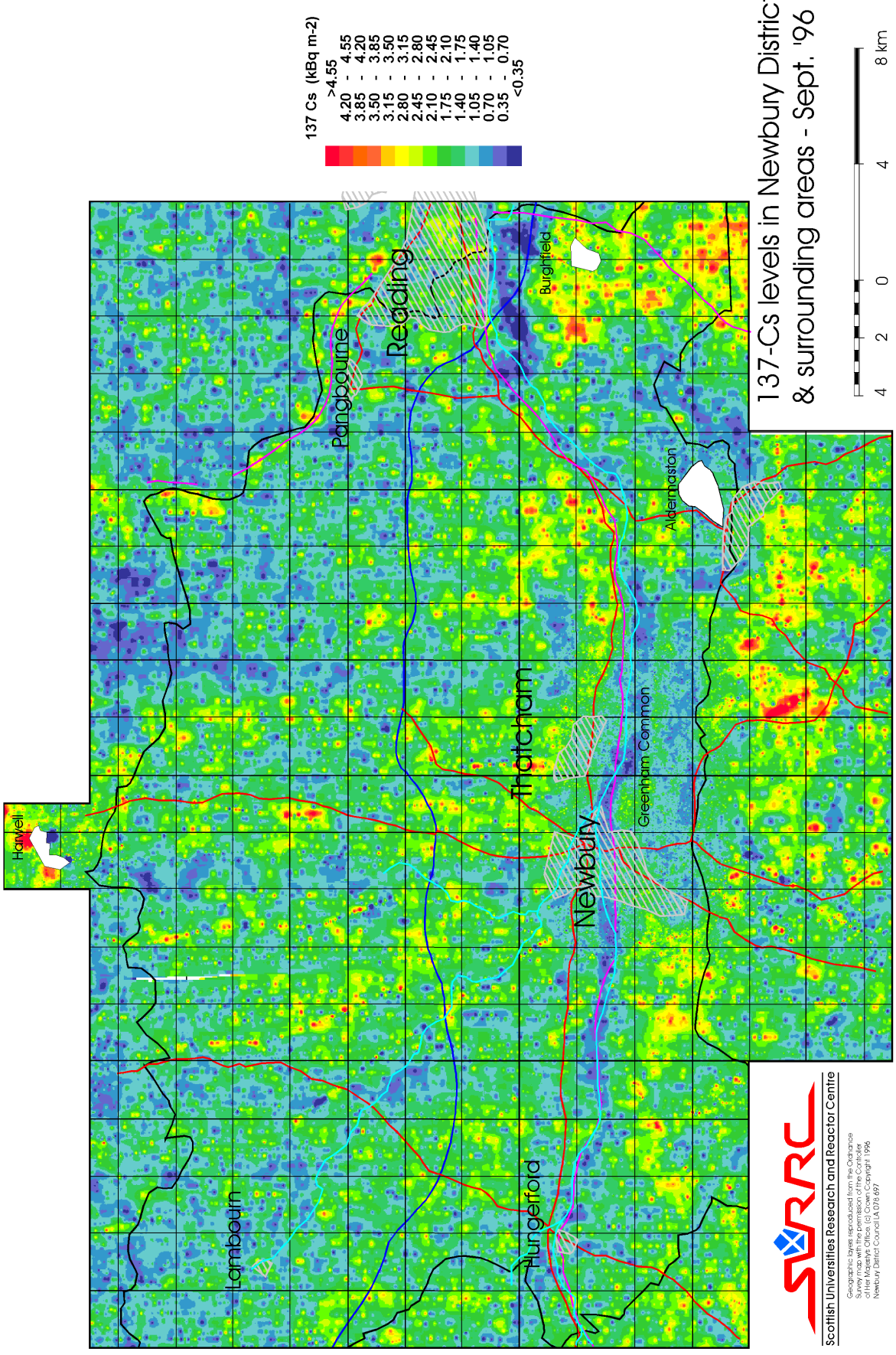


Figure 4.2 ^{40}K Map.

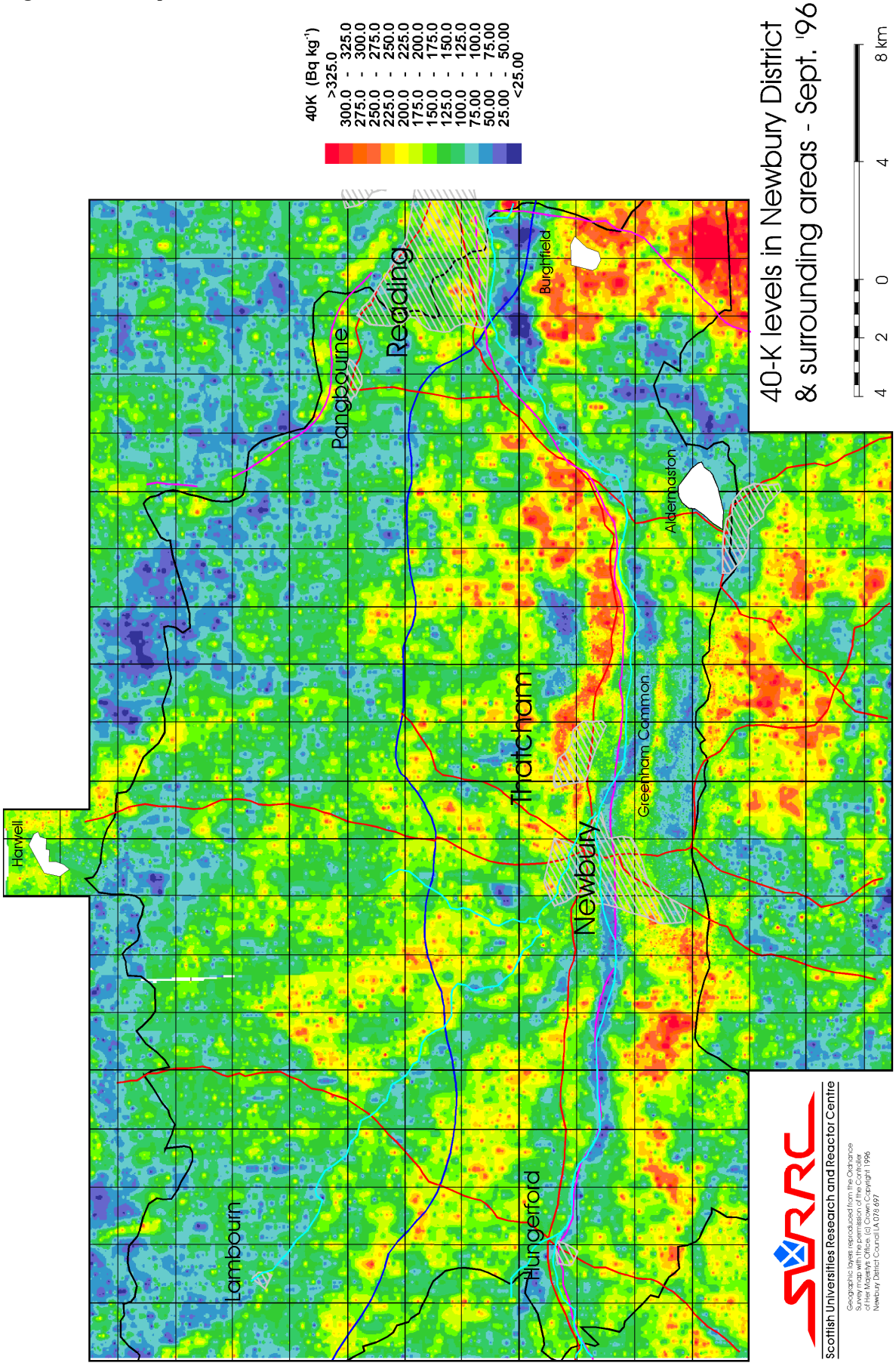


Figure 4.3 ^{214}Bi Map.

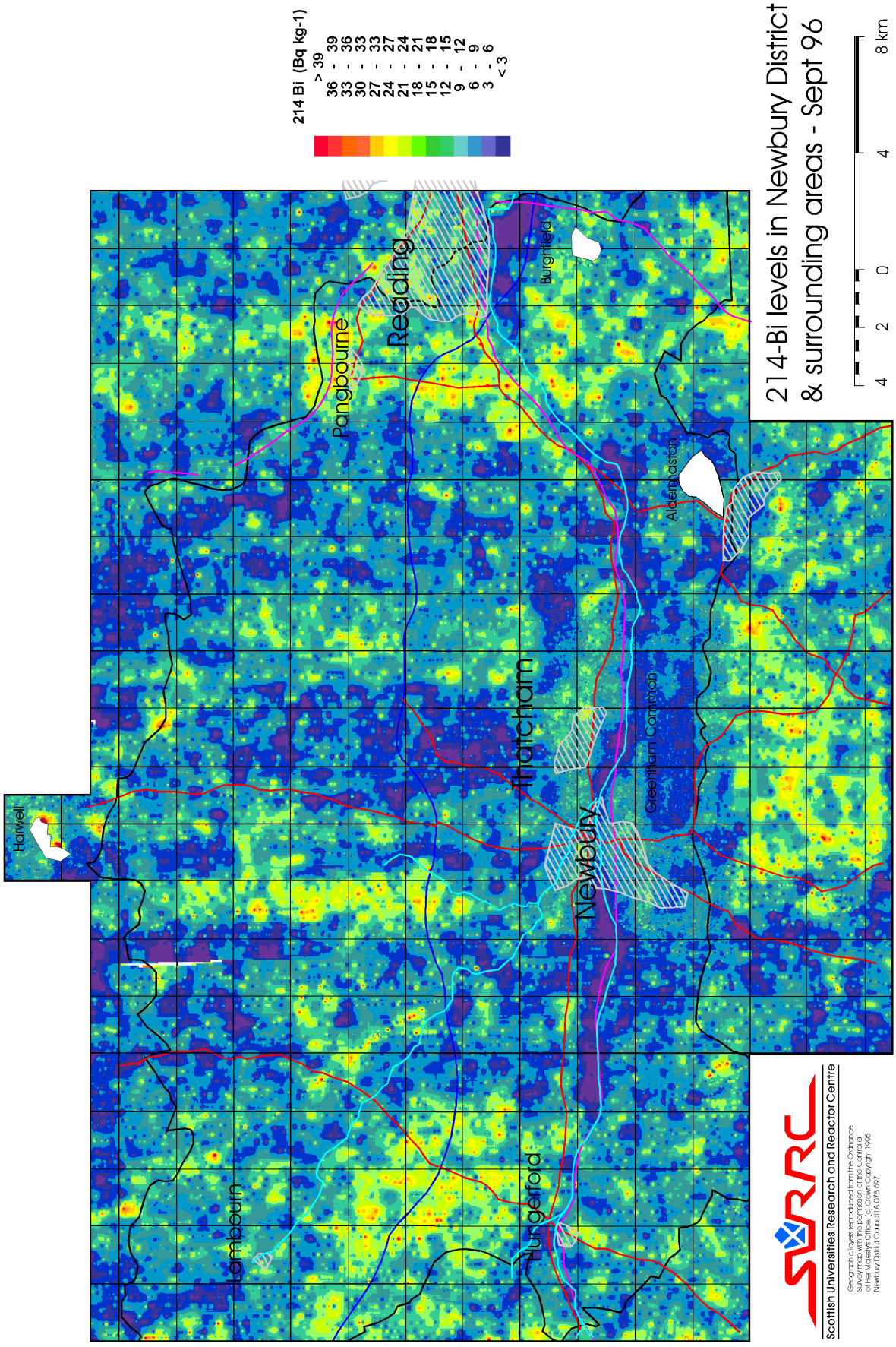


Figure 4.4 ^{208}Tl Map.

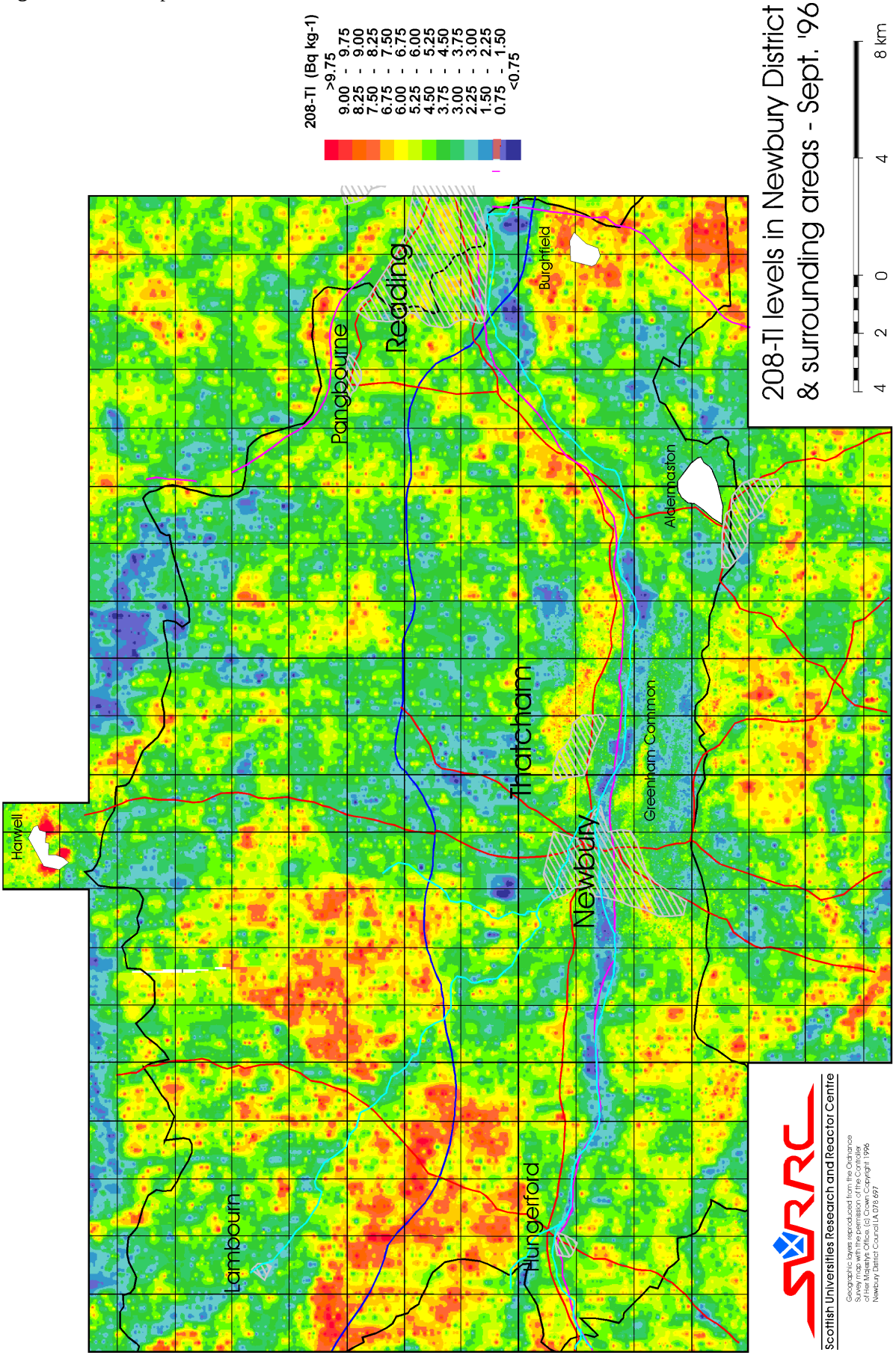
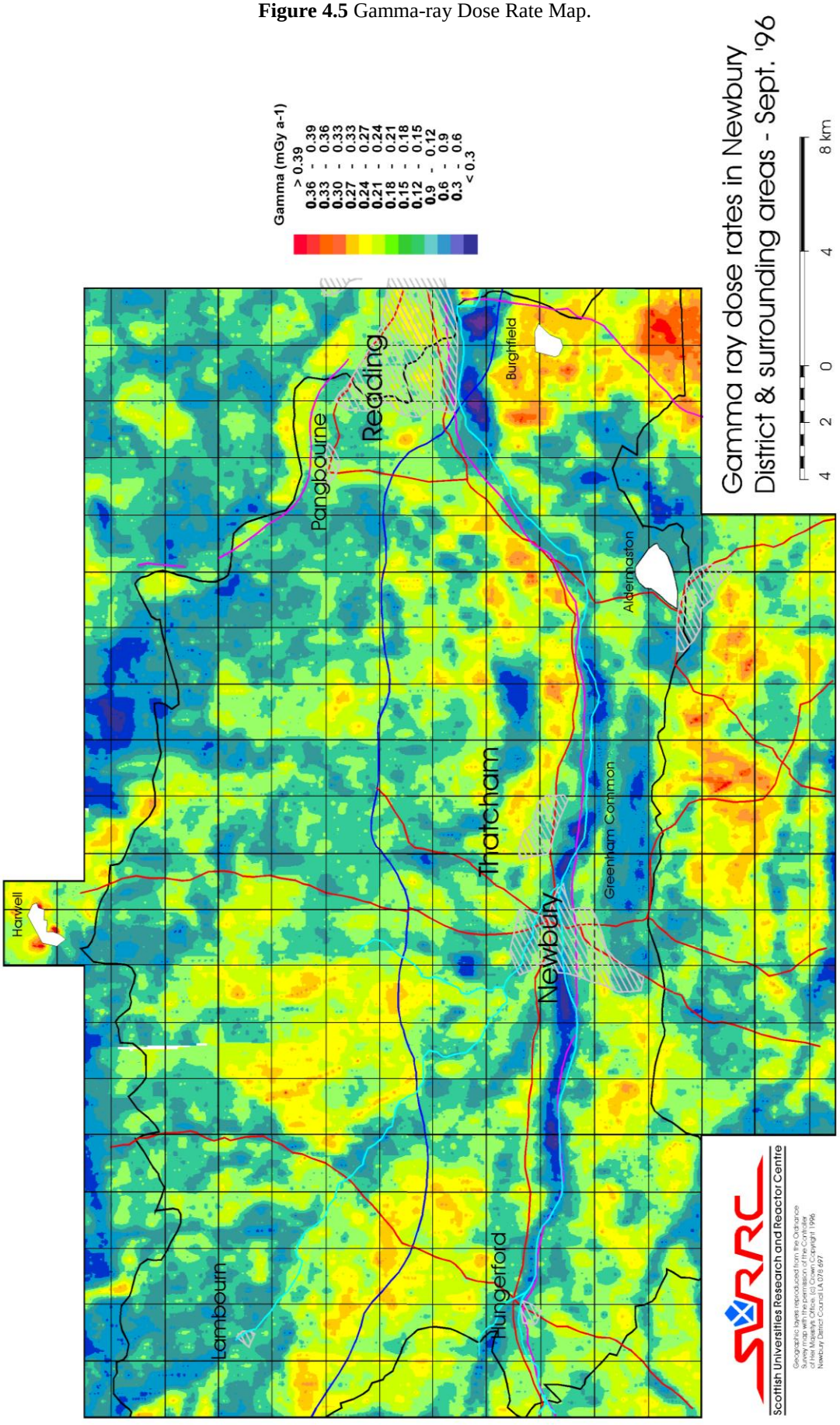


Figure 4.5 Gamma-ray Dose Rate Map.



4.1.5 Low Energy Gamma Rays

The low energy parts of the NaI spectra were also examined, in particular for evidence of excess signals in the 100-200 keV region which might be associated with ^{235}U. No such features were present in any of the integrated spectral regions. When the ratios of radiation fluence between 100-200 keV and 200-300 keV to that in the 300-450 keV region was examined (Figures 4.6 and 4.7 respectively) there were again no features associated with the Greenham Common area - although two anomalies were detected which may have been due to shielded industrial sources in the Newbury/Thatcham areas and not mentioned in the earlier report. The identities of one of these sources was discovered to have been a local x-ray machine source, although from the absolute gamma ray intensities it is clear that they did not project a significant radiation dose to the environment.

Source searches were made during an airborne survey exercise conducted in Finland in 1995 (Sanderson, 1997a), and demonstrated that low energy channel ratios can be successfully used to locate point sources and shielded sources.

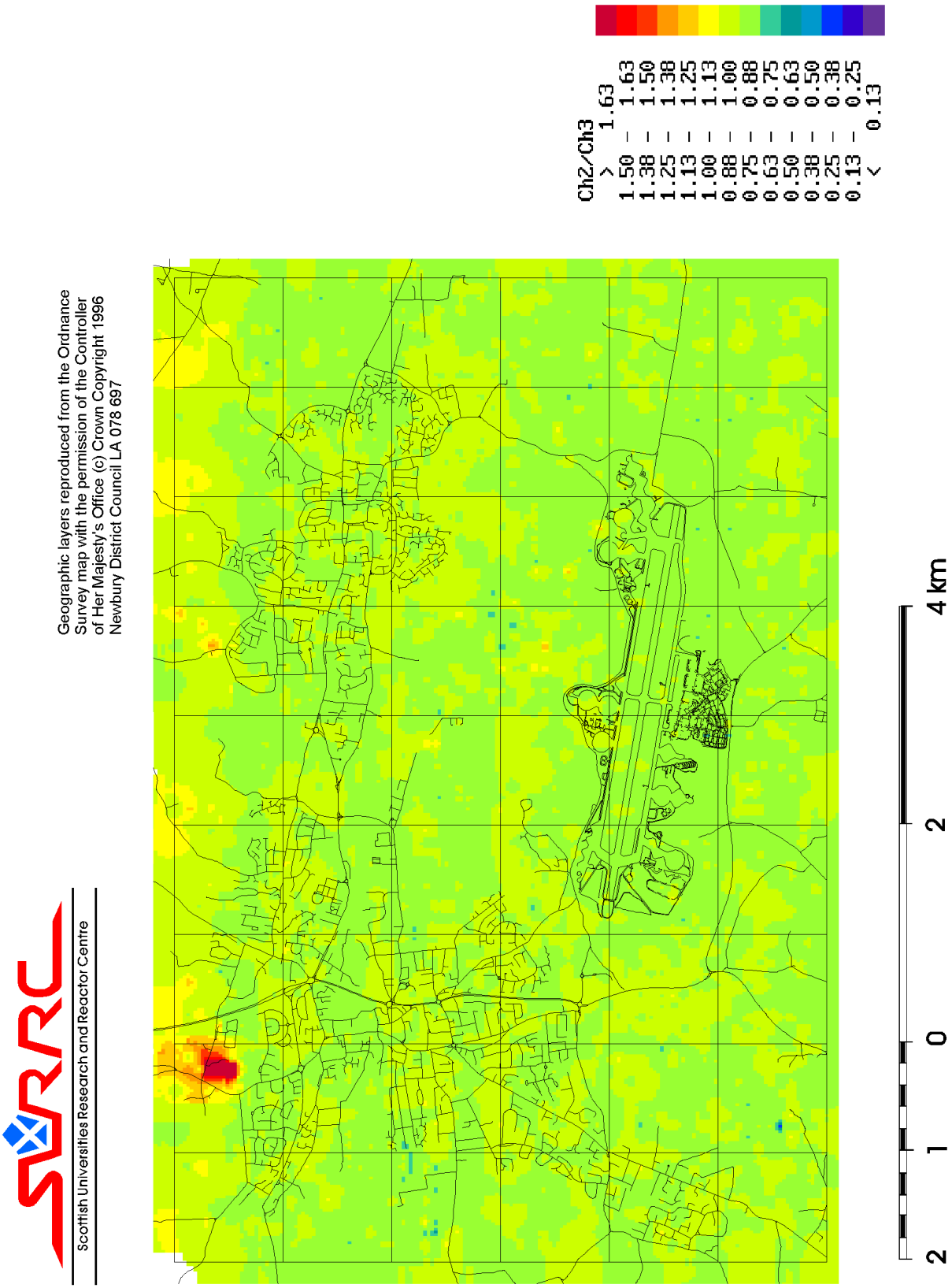


Figure 4.6 Ratio of Channel 2 (100-200 keV)/ Channel 3 (200-300 keV) Results.

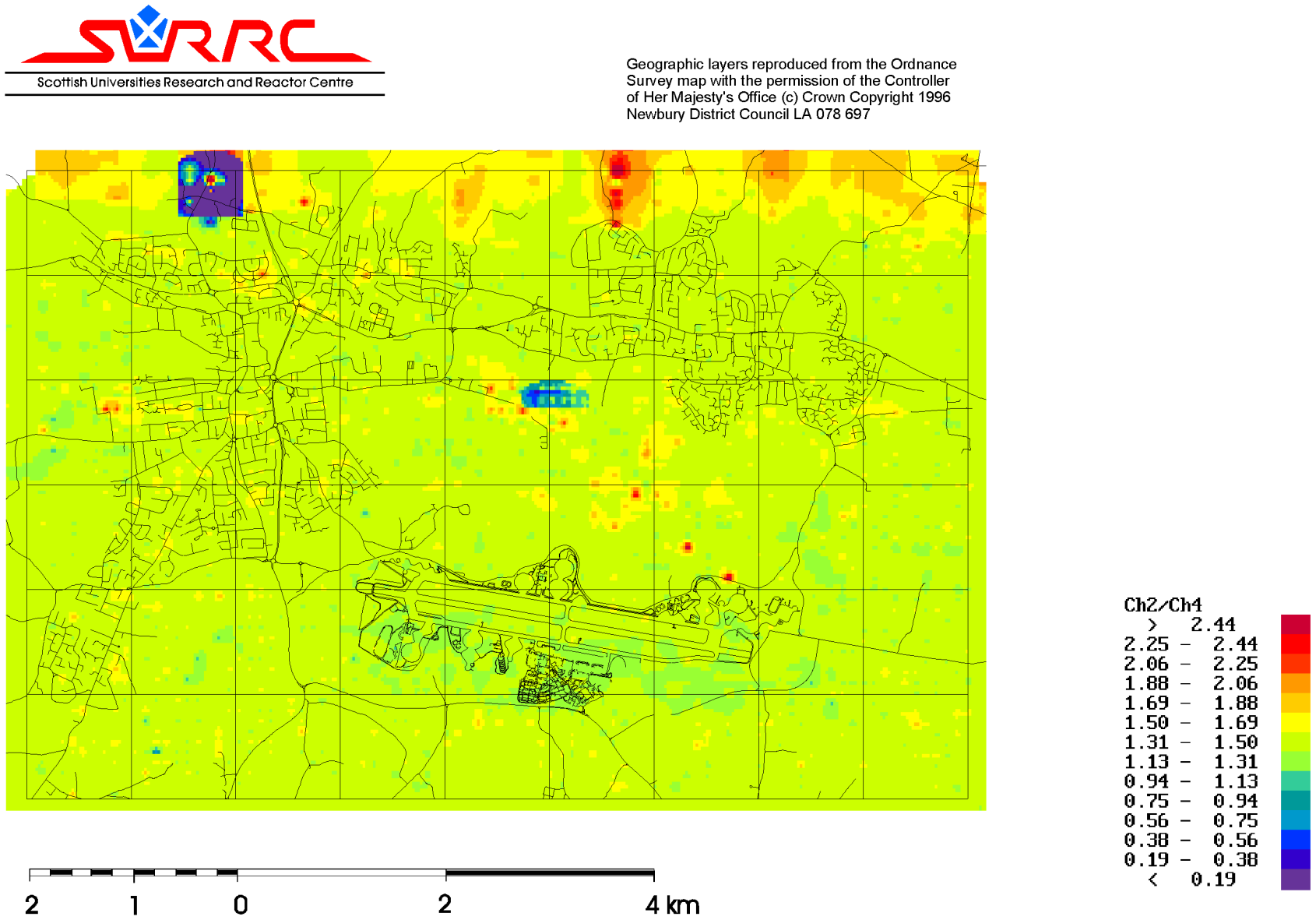


Figure 4.7 Ratio of Channel 2 (100-200 keV)/ Channel 4 (300-450 keV) Results.

4.1.6 LoAx^{TM} detectors

The data from the two externally mounted Germanium detectors were also examined for evidence of low energy sources. The low energy detectors functioned well during the survey - vibration effects were detected in a minority of spectra, and in these cases introduced noise which was generally confined to energies below 50 keV. The majority of spectra recorded over Area 2 were free from such microphonics. The count rates from these detectors with 6 second measurement periods were extremely low; however, when the set of 20,000 spectra are considered spatially it is possible to draw some conclusions. During flight the counts detected were integrated into several energy regions corresponding to activities of interest. These included integrals at 243.8 and 163 keV which correspond to specific emission energies of ^{235}U, integrals at 63.3 and 92.8 keV corresponding to ^{234}Th, which is in equilibrium with ^{238}U, and at 186 keV corresponding to both ^{235}U and ^{226}Ra (from the ^{238}U decay series). The count rates at these energies include both scattered radiation and full-energy signals - the former increasing with ground clearance. Nevertheless the presence of radiologically significant quantities of ^{235}U in the absence of accompanying ^{238}U and its natural decay products would be detected as a positive feature in the first and third of these energy regions.

Figure 4.8 shows three maps indicating the variations of low energy gamma ray fluence in these three energy regions across Area 2. In all three cases the general pattern of radiation signals is similar. The outline of the River Kennet, and the lower activities associated with Eocene sediments around the Greenham Common airbase are evident in all three maps confirming that these detectors are capable of responding to the natural distributions observed with the NaI spectra. On the basis of these results there is no evidence for excess ^{235}U in the vicinity of the base, or the surroundings. While the sensitivity of these observations would be sufficient to detect radiological important changes, it is not of course as high as can be achieved by mass spectrometry. On the other hand the whole area has been covered in this manner without identifying features which should be explicitly sampled.

The other low energy emitter of interest is ^{241}Am, which has a gamma energy at 59.5 keV. To improve detection statistics from these low count rate spectra results were pooled into 500 m x 500 m cells, screening each spectrum for evidence of microphonic noise below 50 keV. The net count rates at 59.5 keV were estimated by interpolating a scattered background across the energy corresponding to ^{241}Am, and evaluating the counting errors associated with both gross and net counts. Four areas were considered in this way; the vicinity of Greenham Common (within Area 2), the surroundings of Aldermaston, the area around Harwell, and a control area within the western 6 km of Area 1. Of the 45 cells around Greenham Common none produced significant net ^{241}Am counts at the 95% confidence level. Around Harwell one cell out of 35 considered showed net counts at the 2 sigma limit (95% confidence limit), but none at the 3 sigma limit. In the control area of 200 cells examined 5 showed evidence of net activity at ^{241}Am energies at the 2 sigma limit and none at the 3 sigma limit. Around Aldermaston, of 60 cells considered 6 satisfied the 2 sigma criterion for net signals, of which 2 satisfied the 3 sigma criterion. Four of these locations were adjacent to each other. There is therefore tentative evidence to suggest the possibility of ^{241}Am contamination in the vicinity of Aldermaston, at very low levels. The Southampton University team collected a sample from this area in January 1997. After 200,000 s count there was evidence of ^{241}Am at a low level (estimated to be < 1 Bq kg^{-1} (Croudace, pers. comm.). It is also noted that Fry & Wilkins (1996) recorded slightly higher levels of ^{239}Pu near Aldermaston than at other control sites.

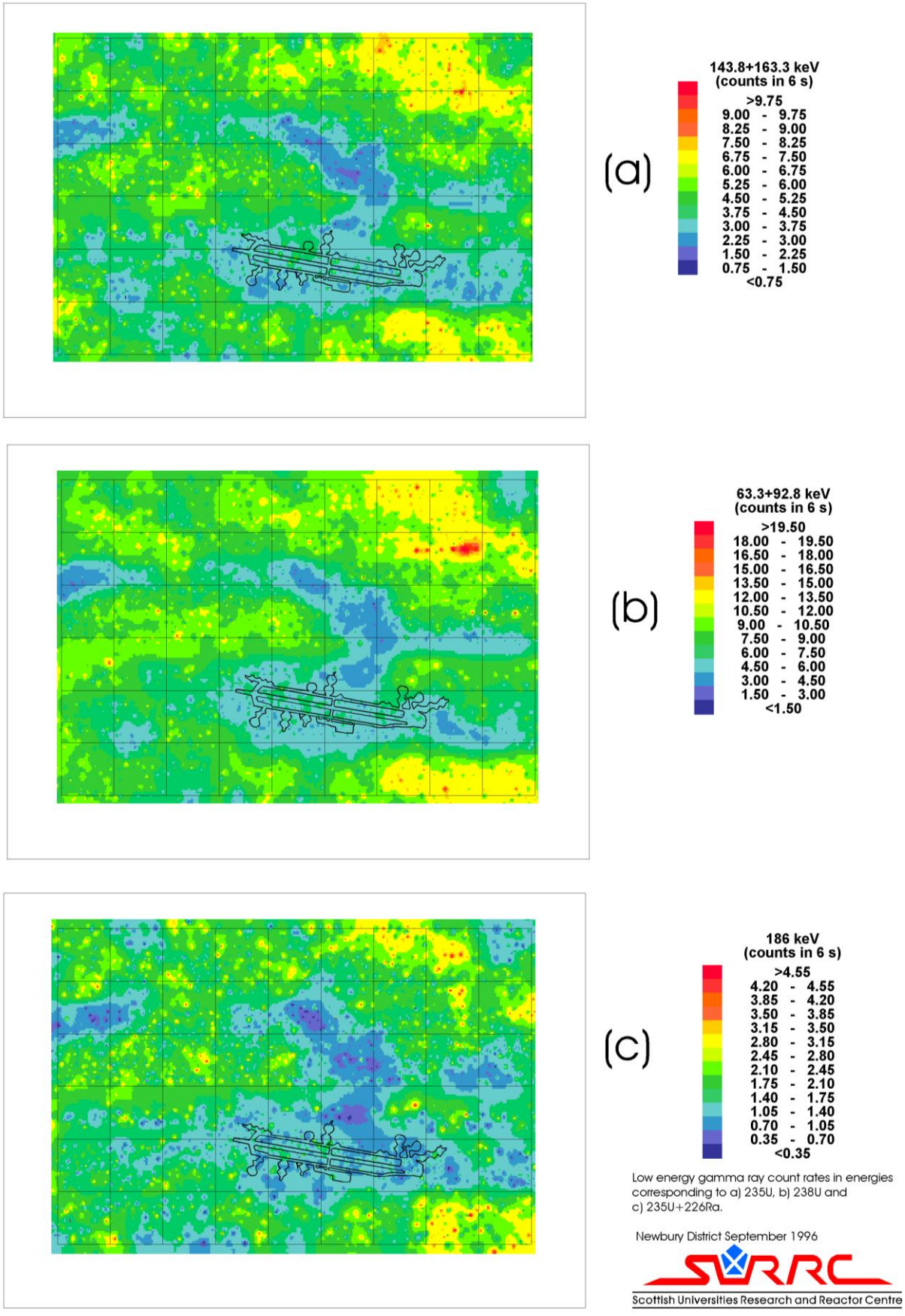


Figure 4.8 Low energy gamma-ray count rates measured from airborne detectors.

4.2 The Vehicular Survey

It was noted that the area around Greenham Common appeared consistently with lower levels of natural radionuclides and radiocaesium than the district at large. Indeed this also seems to have been noted in the original Aldermaston work - in that the uranium content of the ash from laurel leaves near Greenham Common was lower than typical - which may have facilitated the detection of slight enrichments from fallout. In planning the project, provision was made for a limited vehicular survey to build additional sensitivity beyond that which the airborne measurements could offer. Having examined preliminary airborne results it became clear that the main question to examine was whether there were undisturbed surfaces at Greenham Common which had retained weapons' testing fallout. A secondary aim was to collect static, high resolution spectra at key locations on the base for comparison with control sites. Further data is shown in Appendix B.

Data were recorded using the vehicular system between 4-6th December as described in section 2.2. The NaI detector used had an 8 litre volume, giving equivalent sensitivity to the airborne detector when atmospheric attenuation is considered, but from a more restricted field of view. Whereas the airborne signals are spatially averaged over some 10^4-10^5 m^2, the vehicular field of view is some 10^2 m^2. The Germanium detectors used were GMX detectors with 50% relative efficiency. A pair of detectors was deployed, but data gathered from one in order to maintain optimal energy resolution. The same energy regions were examined from the NaI detector as from the airborne survey, processing including spectral stripping, but without attempting to conclude an absolute calibration. The GMX data were kept as nuclide specific count rates.

Four individual sites were measured using static high resolution gamma spectrometry. The spectra from (a) the calibration site between taxi lane and runway (b) grassland adjacent to the hardstand (c) a quarry site to the SE of the main runway where material from the fire was dumped and (d) from a control site at Lockinge near Wantage are shown in Figure 4.9. Apart from ^{137}Cs, the gamma rays are all of natural origin. There is evidence of excess ^{210}Pb on the heathland site, suggesting a further means of verifying the authenticity of the stratigraphy if needed. The ratios of the ^{234}Th line intensities (at 63.2 and 92.8 keV) to those from the 186 keV line from ^{235}U ,^{226}Ra tabulated below in table 4.2 for these sites.

Figure 4.10 shows the signals obtained from ^{40}K and ^{137}Cs with the NaI detector, as well as the ^{137}Cs signals from the GMX detector. The area surveyed covers the ground around the hardstand associated with the 1958 aircraft fire and the runway. The site is set in woodland, which limited vehicular access to the southern limits of the hardstands. Immediately to their north the southern taxi lane has a Tarmac surface, the majority of which appears to have been renewed, but which also had portions of older material at part of its northern limit. This is then followed by an area of heathland with mixed vegetation including heather and gorse, beyond which is the runway. At the time of survey the Tarmac on the runway had been removed, leaving a freshly exposed concrete surface. It is immediately apparent from figure 4.10 that the built surfaces have lower levels of natural activity, and of ^{137}Cs than both areas of grassland around the hardstand, and the heathland on the northern side. Given that much of the ^{137}Cs will have been deposited in the 1960's this lends some support to the view that the areas between built surfaces represent authentic sampling locations for studies of the Greenham Common site. Both the recent NRPB study and the Southampton samples include this context.

In summary therefore, neither the airborne nor the vehicular data sets provide evidence for any hazard associated with a possible weapons' accident at Greenham Common, although they are evidently sufficiently sensitive to record both the structure and minor variations in the radiation background, including temporary changes in radon concentrations in air. At Greenham Common the built environment and natural environment have distinct radiation levels, in this case the materials used being of even lower U, Th and K concentrations than an already low natural environment. The retention of ^{137}Cs in areas of grassland suggests that these are authentic contexts for sampling, and the evidence of ^{210}Pb on the heathland suggests means of verifying this if there are any residual doubts.

Table 4.2 Ratios of line intensities from ^{234}Th and ^{235}U+^{226}Ra from static high resolution gamma spectrometry.

Location	Net Ratio (63.3+92.8)/186 keV Energy Intensities
Calibration Site: 51°22.731'N 1°17.390'W	1.7±0.9
Grass by hardstand: 51°22.633'N 1°17.202'W	3.6±1.6
Quarry site: 51°22.470'N 1°15.423'W	1.4±0.6
Control site (Lockinge): 51°34.943' 1°22.957'W	2.1±0.4

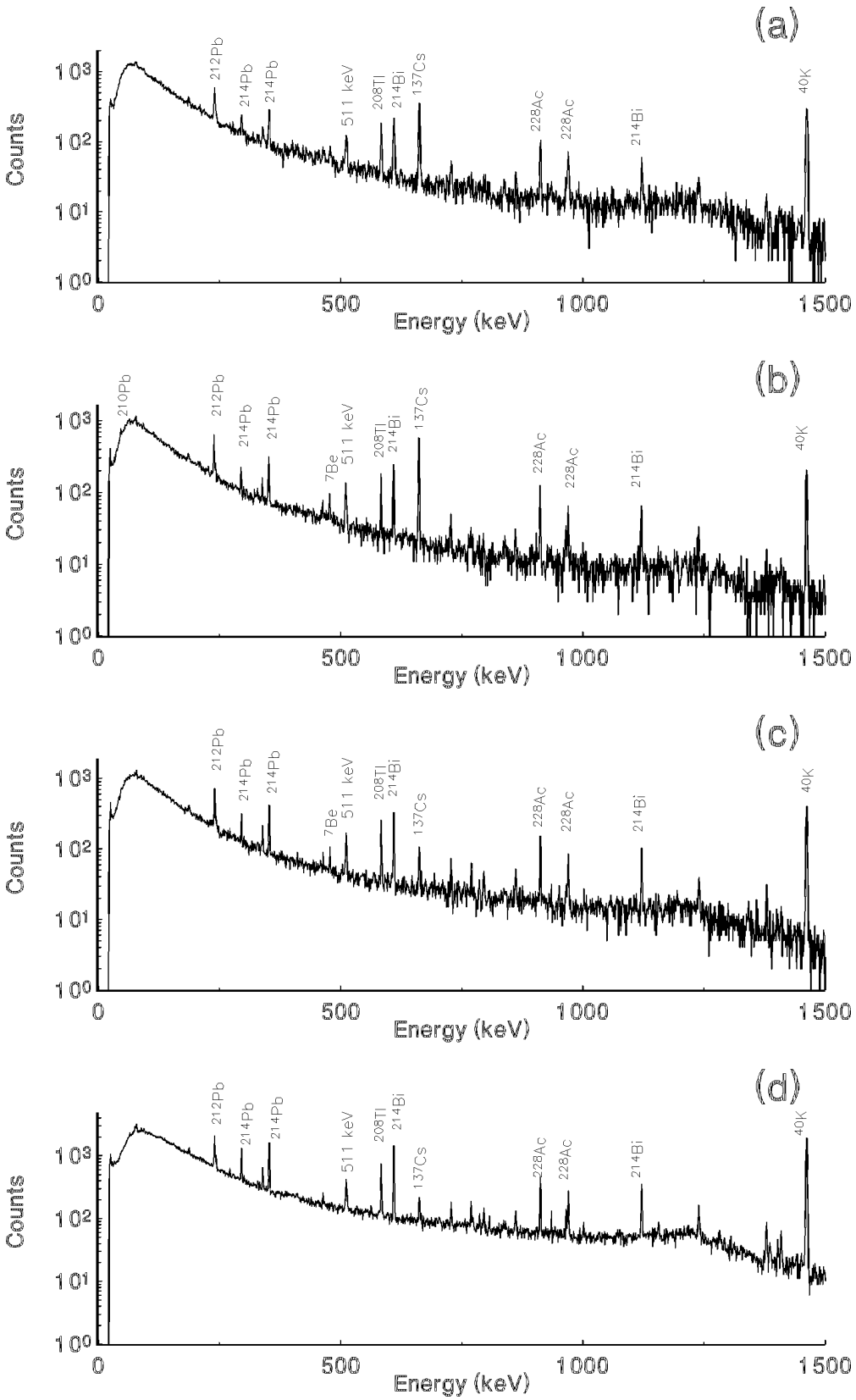
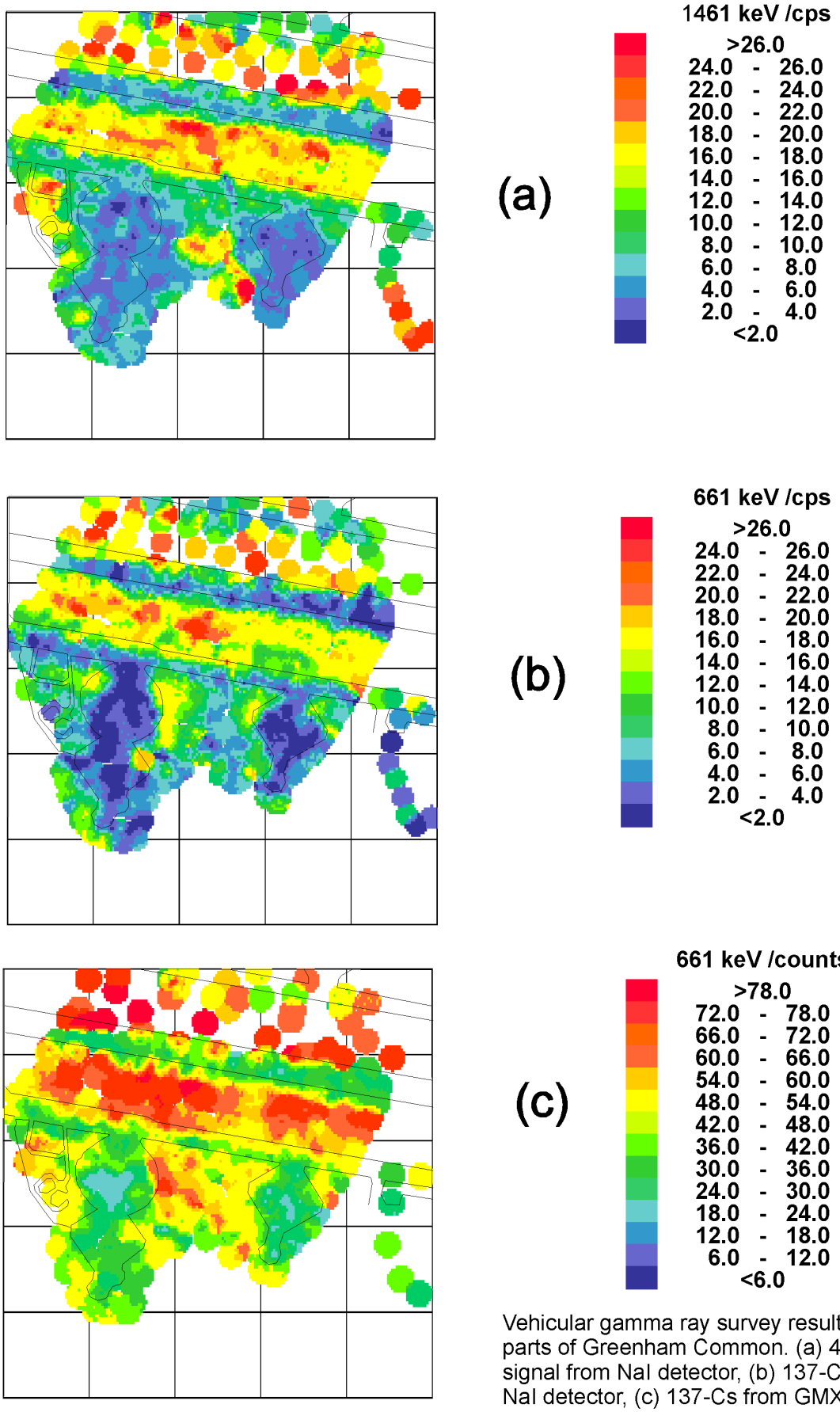


Figure 4.9 2000s GMX spectra from (a) the calibration site centre at Greenham Common, (b) the grass adjacent to the aircraft hardstand, (c) the Quarry site and (d) a control site at Lockinge.



Vehicular gamma ray survey results from parts of Greenham Common. (a) 40-K signal from NaI detector, (b) 137-Cs from NaI detector, (c) 137-Cs from GMX detector

Figure 4.10 Vehicular gamma-ray survey results.

5. Conclusions

5. Conclusions

The airborne gamma ray survey recorded more than 40,000 scintillation spectra and 20,000 spectra from semiconductor detectors. The vehicular survey produced a further 1346 and 763 spectral sets respectively. The installation, calibration, recording and analysis followed SURRC procedures which have been developed and validated over many years and are fully documented. Pre-flight checks on detector performance for energy calibration, energy resolution and sensitivity were performed on a daily basis. Background readings over water were taken on a daily basis. All data were registered and backed up in duplicate to form a digital archive of the survey. Subsequent analysis and mapping has used a combination of standard procedures established over many years, and new techniques developed to analyse the low energy spectra. All results have been retained to facilitate traceability and further analysis in the future. The sensitivity of the aircraft and vehicle were also checked at Greenham Common by collecting a set of 31 core samples for independent laboratory analysis.

The key points arising from the airborne survey of the entire area reveal that there has been sufficient sensitivity to record variations in the natural background. The levels of ^{137}Cs are consistent with weapons' testing fallout, and are substantially lower than in other parts of the UK and Europe. The average levels of K (0.5%), U (1 ppm) and Th (3 ppm) are lower than national averages and show variations within the area which reflect local geology and landcover. The area as a whole therefore is one of low environmental radiation background compared with national averages. There is no evidence of signals at Greenham Common or in its vicinity which would present a local radiation hazard.

Signals were detected in the vicinity of Harwell and the Rutherford laboratory which would, at the time of the survey, represent radiation projected off-site as a result of materials stored on-site or on-site activities and should be taken into account in dose assessments. Recent work coordinated with the Vale of the White Horse, UKAEA Harwell, Rutherford Laboratory and nuclear regulator has resulted in the identification of most of the sources. Additional ground level measurements have been taken and will be reported elsewhere.

Examination of the low energy gamma ray spectra recorded from the semiconductor detectors reveals no evidence, within the sensitivity limits of the method, for excess gamma ray signals at the energies associated with ^{235}U around Greenham Common, Newbury and Thatcham. The low energy data are sufficiently sensitive to record variations in the distribution of natural activity in the area. There is tentative evidence for ^{241}Am in the vicinity of AWE Aldermaston, which although radiologically insignificant deserves further investigation.

The vehicular survey demonstrated that the grass areas in between the runway and taxi lanes, and around the hardstand associated with the 1958 fire have retained weapons' testing ^{137}Cs. This supports the view that these represent authentic undisturbed areas for sampling. The built surfaces remaining at the time of the survey were of lower natural activity and ^{137}Cs content than their surroundings. High resolution gamma ray spectra at selected sites were also consistent with the known sources of background radioactivity.

On the basis of the results, Newbury District and surrounding areas represent an area with low environmental radioactivity compared with national and European averages. There is no evidence to substantiate fears about the quality of the radiation environment in the vicinity of Greenham Common. As far as events at Greenham Common are concerned these surveys, and the associated ground sampling programme conducted by Southampton University, do not provide evidence which indicates contamination attributable to dispersal of enriched uranium in a weapons' fire. Whether such an incident occurred cannot be determined at this late stage. None of the studies which are in the public domain have corroborated the original findings of Cripps and Stimson leaving their scientific status as that of unconfirmed findings coupled to speculative interpretation. Croudace *et al* (1997a, 1997b) have discussed specific hypotheses concerning the mass spectrometric data and their interpretation - which still leaves the meaning of the original work unclear. However, the gamma ray surveys have clearly shown that Greenham Common itself is a low natural radiation enclave within a low radiation environment. It is worth noting that the original sample obtained by Cripps and Stimson, which led to their further speculative investigations, was a laurel leaf of unusually low natural uranium content. Perhaps if the context of the natural environment had been more fully appreciated at the time, this result would not have been regarded as so remarkable.

The combination of the surveys and associated ground sampling present a compelling demonstration of the quality of the radiation environment at Greenham Common. The historical truth regarding past events is harder to define on the basis of, at best, a partial documentary record. Unanswered questions will have to remain part of the enduring fascination with which the Greenham Common site and its eventful past are inextricably linked.

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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 MacAlpines Helicopters. The operations were based at Kidlington, Oxford Airport.

Data collection flying time: 50.1 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 (90-135 ch.)	Detector * Sensitivity (Net) /cps (90-135 ch.)
14/9/96	9.3	2339±5	1844±7
15/9/96	9.9	2379±5	1846±7
17/9/96	9.4	2351±5	1835±7
21/9/96	9.9	2344±5	1833±7
22/9/96	9.7	2328±5	1821±7
23/9/96	9.6	2353±5	1834±7
24/9/96	9.7	2380±5	1829±7
25/9/96	10.1	-	1812±7
26/9/96	9.5	2358±5	1839±7
28/9/96	9.5	2350±5	1838±7

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

Table A.2 LOAX semiconductor system performance check

Date	Resolution at 122 keV ^{57}Co / keV	Detector * Sensitivity (Gross) /cps (610-620 ch.)	Detector * Sensitivity (Net) /cps
21/9/96	1. 0.61 @ ch. 609.78 2. 0.61 @ ch. 610.16	47.75 58.86	46.58 58.16
22/9/96	1. 0.60 @ ch. 609.8 2. 0.60 @ ch. 609.8	35.45 54.1	34.2 52.1
29/9/96	1. 0.62 @ ch. 610.2 2. 0.61 @ ch. 610.5	- -	31.7 61

Detector #1: LOAX 32-TN30706C (pilots side, -3000 V, used at -2500 V)
Detector #2: LOAX 32-TN30702B (-2500 V, used at -2000 V)

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: AERONW12.BAS (.sm1 data)
(based upon AERONEW2.BAS) AEROPLT2.BAS
(AERONW13.BAS- reintegrated data analysis)
AERONW14/15.BAS -GMX (.sm2 data)

Survey Altitude: > 200′ over Newbury (50 m spacing, 60 knots)
> 230′ Newbury District (300 m spacing, 75-80 knots)

Liquid Nitrogen: Supplied courtesy of Archaeological Research Laboratory, Oxford University. Approximately 2 litres consumed per day per 3 litre dewar

Pilot Names: Norman Osment
Ian Thompson
Jim Laird

Table A.3 Filenames

Filenames	Filenumbers	Date	Counting Times /s
NDA01	1,806	14/9/96	3,6
NDA02	1,650	14/9/96	3,6
NDA03	1,733	15/9/96	3,6
NDA04	1,924	16/9/96	3,6
NDA05	1,926	16/9/96	3,6
NDA06	1,213	16/9/96	3,6
NDA07	1,681	16/9/96	3,6
NDA08	1,999	17/9/96	3,6
NDA09	1,940	17/9/96	3,6
NDA10	1,161	17/9/96	3,6
NDA11	1,870	17/9/96	3,6
NDA12	1,239	18/9/96	3,6
NDA13	1,741	18/9/96	3,6
NDA14	1,703	18/9/96	3,6
NDA15	1,296	18/9/96	3,6
NDA16	1,724	23/9/96	3,6
NDA17	1,594	23/9/96	3,6
NDA18	1,144	23/9/96	3,6
NDA19	1,874	23/9/96	3,6

Table A.3 continued Filenames

Filenames	Filenumbers	Date	Counting Times /s
NDA20	1,102	23/9/96	3,6
NDA21	1,40	24/9/96	3,6
NDA22	1,359	24/9/96	3,6
NDA23	1,919	24/9/96	3,6
NDA24	1,168	24/9/96	3,6
NDA25	1,665	24/9/96	3,6
NDA26	1,300	24/9/96	3,6
NDA27	1,999	25/9/96	3,6
NDA28	1,231	25/9/96	3,6
NDA29 (Harwell)	1,999	25/9/96	3,6
NDA30	1,221	25/9/96	3,6
NDA31 (Aldermaston)	1,828	26/9/96	3,6
NDA32	1,428	26/9/96	3,6
NDA33	1,270	26/9/96	3,6
NDA34	1,51	26/9/96	3,6
NDA35	1,860	28/9/96	3,6
NDA36	1,323	28/9/96	3,6
NDA37	1,359	28/9/96	3,6
NDA38 (Burghfield)	1,620	28/9/96	3,6
NDA39	1,513	28/9/96	3,6
GCA01	1,50	26/9/96	3,6
NDCAL	1,5	18/9/96	30,60
NCAL2	1,30	23/9/96	3,6

2). Spectral Windows

Table A.4 Measurement windows

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

Table A.5 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

Table A.6 Backgrounds over Farmoor Reservoir

File/ Date	^{137}Cs	^{60}Co	^{40}K	^{214}Bi	^{208}Tl	Gamma
NDA01 (9-13) 14/9/96	52.86 ±3.0 ±0.95	20.62 ±1.97 ±0.62	21.88 ±1.68 ±0.53	11.6 ±1.22 ±0.39	10.78 ±2.3 ±0.73	201.4 ±10.6 ±3.4
NDA03 (727-733) 15/9/96	55.86 ±5.92 ±1.58	20.81 ±2.73 ±0.73	22.81 ±3.23 ±0.86	11.86 ±2.59 ±0.69	9.43 ±2.02 ±0.54	210.4 ±23.6 ±6.3
NDA04 (40-46) 16/9/96	52.46 ±7.89 ±2.11	19.73 ±2.51 ±0.67	20.04 ±2.78 ±0.74	10.63 ±2.49 ±0.66	9.87 ±1.98 ±0.53	196.3 ±16.5 ±4.4
NDA12 (1-5) 18/9/96	54.68 ±4.73 ±1.5	20.48 ±3.66 ±1.16	20.83 ±2.47 ±0.78	12.15 ±1.96 ±0.62	10.15 ±1.75 ±0.55	208.7 ±13.6 ±4.3
NDA16 (19-28) 23/9/96	**69.24 ±6.22 ±1.39**	**27.32 ±3.07 ±0.71**	**26.59 ±3.19 ±0.71**	**15.64 ±2.39 ±0.53**	**11.05 ±2.32 ±0.52**	**251.6 ±11.7 ±2.6**
NDA21 (30-37) 24/9/96	**83.42 ±5.67 ±1.42**	**33.46 ±2.66 ±0.67**	**30.31 ±4.17 ±1.04**	**20.11 ±2.95 ±0.74**	**11.65 ±3.41 ±0.85**	**306.6 ±19.5 ±4.9**
NDA27 (26-29) 25/9/96	**62.95 ±4.5 ±1.84**	**23.77 ±2.36 ±0.96**	**23.62 ±2.35 ±0.96**	**14.87 ±2.33 ±0.95**	**11.23 ±1.32 ±0.54**	**238.0 ±10.6 ±4.3**
NDA31 (29-32) 26/9/96	56.3 ±3.72 ±1.32	20.82 ±2.03 ±0.72	19.92 ±2.15 ±0.76	12.27 ±1.85 ±0.65	9.23 ±1.73 ±0.61	206.0 ±7.4 ±2.6
NDA35 (15-19) 28/9/96	56.29 ±2.67 ±0.85	20.19 ±2.49 ±0.79	21.43 ±1.96 ±0.62	11.5 ±1.13 ±0.36	8.89 ±1.55 ±0.49	208.8 ±9.91 ±3.13
Mean except 23-25/9/96	**54.62 ±5.37 ±0.66**	**20.41 ±2.57 ±0.32**	**21.22 ±2.65 ±0.33**	**11.6 ±2.05 ±0.25**	**9.73 ±1.94 ±0.24**	**205.0 ±15.99 ±1.97**

Note. GPS not operational at reservoir for NDA12.SM1 (1-24)

3) Stripping Ratios

Stripping ratios were measured 7th August 1995 on doped concrete calibration pads, ^{137}Cs plane source and ^{60}Co point source, at an equivalent altitude of 50 m (5 perspex sheets) in the SURRC Pad Calibration Facility.

Table A.7 Stripping ratios

	^{137}Cs	^{60}Co	^{40}K	^{214}Bi	^{208}Tl
^{137}Cs	1	0	0	0	0
^{60}Co	0.534	1	0.55	0	0
^{40}K	0.492	0.44	1	0.03	0
^{214}Bi	2.98	1.46	0.95	1	0.06
^{208}Tl	2.4	0.67	0.63	0.44	1

4) Calibration Constants

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

Table A.8 Calibration factors

Window	Radionuclide	a	b	c	Notes
1	^{137}Cs	0.013	0.11	0	Theoretically based
2	^{60}Co	0.01	1	0	cps at 100 m
3	^{40}K	0.01	6.767	0	Fieldwork based
4	^{214}Bi	0.009	3.164	0	Theoretically based
5	^{208}Tl	0.007	0.4715	0	Theoretically based
6	Total	0.0098	0.0007	0	

Appendix B: Greenham Common Ground Survey 4-6 December 1996

Single 50% GMX detector (resolution: 2.3 keV at 662 keV) on bike carrier
8 Litre NaI on roof rack of Vauxhall Frontera

Windows:

Ch1: ^{241}Am	(59.5 keV)	62-66 ch
Ch2: ^{234}Th	(63 keV)	66-70 ch
Ch3: ^{208}Tl	(583 keV)	578-590 ch
Ch4: ^{214}Bi	(609 keV)	604-615 ch
Ch5: ^{137}Cs	(662 keV)	655-666 ch
Ch6: ^{40}K	(1461 keV)	1450-1463 ch
Ch7: ^{228}Ac	(911 keV)	906-914 ch
Ch8: 186 keV		187-192 ch

Logging software: GREN1.BAS/EXE

Date: 4/12/96 Area "A"

On calibration spot: 51° 22.732'N 1° 17.467'W

GRN01.CHN (GMX) 2001s LT
(662 keV in channel 662)

GRN01001..GRN01216.MCA 15,30s

Date: 5/12/96

On calibration spot Area "A": 51°22.731'N 1° 17.390'W (10 m precision)

GRN02A.CHN (GMX) 2000s LT
GRN02B.CHN (8l NaI) 1600s LT

GRN02001..GRN02281.MCA 15,30s

GRN03001..GRN03074.MCA 15,30s (after recharge at lunchtime)

Radiocarbon Dating Lab. (R. Otlet): 51°34.943'N 1° 22.957'W

GRN04A.CHN (GMX) 2000s LT
GRN04B.CHN (8l NaI) 2000s LT

Date: 6/12/96

Quarry/dump Area: 51°22.470'N 1° 15.423'W (8 m precision)- on mound.

GRN05A.CHN (GMX) 2000s LT
GRN05B.CHN (8l NaI) 2000s LT

GRN05001..GRN05102.MCA 15,30s
(Problems with DGPS: area within hollow and behind wood)

On grass adjacent to hardstand (diamond): 51°22.633'N 1° 17.202'W (15 m)

GRN06A.CHN (GMX) 2000s LT
GRN06B.CHN (8l NaI) 2000s LT

Data Analysis Software: AERONW14.BAS (GRNEW01-GRNEW06.XYZ, GMX)
AERONW15.BAS (GRNAI01-GRNAI06.XYZ, 8 litre NaI)

Appendix C: Greenham Common Calibration Site Soil Samples.

1. Southampton Oceanography Centre (SOC), University of Southampton

Sample number	Relative number	CS137 /kBq m^{-2}	K40 Bg kg^{-1}	DATESAVE	SAMPSIZE
363	1	18.5	282	12/13/96	0.2440 kg
363	2	9.6	182	12/13/96	0.2610 kg
363	3	4.29	58	12/12/96	0.2518 kg
365	1	17.31	193	11/7/96	0.2660 kg
365	2	8.37	92	11/6/96	0.2300 kg
365	3	6.1	61	11/7/96	0.2400 kg
367	1	12.1	272	11/26/96	0.2695 kg
367	2	11.4	273	11/26/96	0.1050 kg
367	3	3.67	99	11/26/96	0.2160 kg
369	1	23.4	254	12/5/96	0.1820 kg
369	2	11.3	125	12/5/96	0.2150 kg
369	3	5.24	67	12/6/96	0.3520 kg
371	1	14.56	141	12/20/96	0.1980 kg
371	2	12.73	129	12/21/96	0.1840 kg
371	3	6.21	72	12/23/96	0.2190 kg
373	1	19.2	176	12/2/96	0.1930 kg
373	2	14.9	237	11/13/96	0.2285 kg
373	3	6.28	79	11/14/96	0.2020 kg
375	1	17.6	247	11/15/96	0.2680 kg
375	2	6.6	104	11/15/96	0.2985 kg
375	3	4.46	70	11/14/96	0.1720 kg
376	1	15.81	262	12/9/96	0.2540 kg
376	2	10.5	190	12/9/96	0.2390 kg
376	3	2.6	50.9	12/7/96	0.3620 kg
378	1	16.7	268	11/13/96	0.1960 kg
378	2	9.92	86	12/1/96	0.1750 kg
378	3	5.25	62	11/29/96	0.2400 kg
380	1	21.6	369	1/9/97	0.1990 kg
380	2	11.29	355	1/9/97	0.2240 kg
380	3	3.21	453	1/8/97	0.1870 kg
383	1	56.3	67	11/8/96	0.3290 kg
383	2	15	0	11/8/96	0.2920 ltr
383	3	8.5	28.1	11/10/96	0.4300 kg
385	1	16.2	126	11/4/96	0.2300 kg
385	2	3.97	62	11/5/96	0.2700 kg
385	3	2.61	83	11/5/96	0.2660 kg
388	1	11.52	123	11/6/96	0.1570 kg
388	2	6.49	86	11/6/96	0.3240 kg
388	3	3.92	66	11/7/96	0.1950 kg
390	1	16.46	161	12/11/96	0.2840 kg
390	2	5.37	73	12/11/96	0.2890 kg
390	3	2.57	53	12/12/96	0.1990 kg
392	1	74.8	178	12/31/96	0.3030 kg
392	2	45.8	124	12/29/96	0.2200 kg
392	3	12.5	69	12/29/96	0.2820 kg

2. SURRC Soil Samples

Log Sheet:

File	Sample	Depth /cm	Vol /cc	Mass /g	Live Time /secs	Wet Mass /kg	Dry Mass /kg	%Moisture content
NDC3641	NDC 364 1/3	0-5	100	96.6	60000	0.1675	0.128	23.58209
NDC3642	NDC 364 2/3	5-10	100	128.7	6000	0.3237	0.2915	9.947482
NDC3643	NDC 364 3/3	10-16	100	113.2	6000	0.3633	0.3149	13.32232
NDC3661	NDC 366 1/3	0-5	100	95.5	60000	0.2301	0.1835	20.25206
NDC3662	NDC 366 2/3	5-10	100	122.5	6000	0.2762	0.2489	9.884142
NDC3663	NDC 366 3/3	10-18	100	113	6000	0.371	0.3431	7.520216
NDC3681	NDC 368 1/3	0-5	100	100.6	60000	0.2418	0.1989	17.74194
NDC3682	NDC 368 2/3	5-10	100	110.4	6000	0.2759	0.2583	6.379123
NDC3683	NDC 368 3/3	10-15	100	90.1	6000	0.1886	0.1756	6.892895
NDC3701	NDC 370 1/3	0-5	100	83.6	60000	0.2137	0.1544	27.74918
NDC3702	NDC 370 2/3	5-10	100	102.3	6000	0.2283	0.2101	7.971967
NDC3703	NDC 370 3/3	10-15	100	105.6	6000	0.2635	0.25	5.12334
NDC3721	NDC 372 1/3	0-5	100	96.5	60000	0.2565	0.2161	15.75049
NDC3722	NDC 372 2/3	5-10	100	100.19	6000	0.321	0.2962	7.725857
NDC3723	NDC 372 3/3	10-15	100	118.2	6000	0.3281	0.3026	7.772021
NDC3741	NDC 374 1/3	0-5	100	92.7	250000	0.2022	0.1606	20.57369
NDC3742	NDC 374 2/3	5-10	100	104	6000	0.3808	0.3522	7.510504
NDC3743	NDC 374 3/3	10-14	100	105.8	6000	0.2026	0.1906	5.923001
NDC3771	NDC 377 1/3	0-5	100	95.1	59558	0.2467	0.1927	21.88893
NDC3772	NDC 377 2/3	5-10	100	105.9	6000	0.3407	0.3019	11.38832
NDC3773	NDC 377 3/3	10-17	100	107.1	6000	0.3309	0.3041	8.099124
NDC3791	NDC 379 1/3	0-5	100	87.1	60000	0.1706	0.1358	20.39859
NDC3792	NDC 379 2/3	5-10	100	94.6	6000	0.1633	0.1413	13.47214
NDC3793	NDC 379 3/3	10-14	100	89.2	6000	0.1767	0.1537	13.01641
NDC3811	NDC 381 1/3	0-5	100	83.2	60000	0.1872	0.1297	30.71581
NDC3812	NDC 381 2/3	5-10	100	98.1	6000	0.1932	0.1693	12.3706
NDC3813	NDC 381 3/3	10-18	100	119	6000	0.4053	0.3757	7.303232
NDC3821	NDC 382 1/3	0-5	100	97.3	60000	0.2102	0.1651	21.45576
NDC3822	NDC 382 2/3	5-10	100	106.6	6000	0.2693	0.2364	12.21686
NDC3823	NDC 382 3/3	10-15	100	109.3	6000	0.2851	0.2674	6.208348
NDC3841	NDC 384 1/3	0-5	100	98.6	60000	0.1807	0.1304	27.83619
NDC3842	NDC 384 2/3	5-10	100	116.3	6000	0.2821	0.2599	7.86955
NDC3843	NDC 384 3/3	10-15	100	107.1	6000	0.2004	0.1887	5.838323
NDC3861	NDC 386 1/3	0-5	100	109	60000	0.325	0.262	19.38462
NDC3862	NDC 386 2/3	5-10	100	111.1	6000	0.2119	0.1821	14.06324
NDC3863	NDC 386 3/3	10-12.5	100	59.3	6000	0.0695	0.0573	17.55396
NDC3911	NDC 391 1/3	0-5	100	99	60000	0.2108	0.1484	29.60152
NDC3912	NDC 391 2/3	5-10	100	104.4	6000	0.2949	0.2468	16.31061
NDC3913	NDC 391 3/3	10-15	100	109.6	6000	0.1909	0.1791	6.181247
NDC3931	NDC 393 1/3	0-5	100	89.7	60000	0.2781	0.2777	0.143833
NDC3932	NDC 393 2/3	5-10	100	104.1	6000	0.2614	0.2253	13.81025
NDC3933	NDC 393 3/3	10-15	100	81.9	6000	0.1503	0.1346	10.44578

Inventory (kBq/m2):

File		137Cs 661.7 keV kBq/m2	+/-
NDC3641		0.845991	0.033767
NDC3642		0.499175	0.09323
NDC3643		0.325739	0.107102
	Totals:	1.670905	0.145955
NDC3661		0.991218	0.045972
NDC3662		0.530643	0.088928
NDC3663		0.330777	0.116874
	Totals:	1.852638	0.153887
NDC3681		1.01295	0.046548
NDC3682		0.496562	0.096269
NDC3683		0.169939	0.070146
	Totals:	1.679451	0.127886
NDC3701		0.877442	0.042636
NDC3702		0.497291	0.084626
NDC3703		0.148511	0.085165
	Totals:	1.523243	0.127406
NDC3721		1.052953	0.052013
NDC3722		0.547087	0.114105
NDC3723		0.431994	0.092407
	Totals:	2.032034	0.15577
NDC3741		1.055477	0.035706
NDC3742		0.580661	0.130631
NDC3743		0.250126	0.069406
	Totals:	1.886264	0.152173
NDC3771		1.031569	0.047802
NDC3772		0.946008	0.132482
NDC3773		0.394229	0.10236
	Totals:	2.371806	0.174109
NDC3791		0.944158	0.038457
NDC3792		0.503774	0.069434
NDC3793		0.323547	0.070826
	Totals:	1.77148	0.106378
NDC3811		1.005037	0.039269
NDC3812		0.619596	0.07596
NDC3813		0.275288	0.113631
	Totals:	1.899921	0.142211
NDC3821		1.787197	0.053602
NDC3822		2.122366	0.13697
NDC3823		0.55248	0.106904
	Totals:	4.462043	0.181831
NDC3841		1.185532	0.038733
NDC3842		0.553261	0.086532
NDC3843		0.239838	0.067874
	Totals:	1.97863	0.116597
NDC3861		0.742094	0.050847
NDC3862		0.989446	0.086001
NDC3863		0.1184	0.039632
	Totals:	1.849941	0.107481
NDC3911		1.286683	0.042768
NDC3912		1.208574	0.117192
NDC3913		0.115836	0.062849
	Totals:	2.611093	0.139689
NDC3931		1.365632	0.070718
NDC3932		0.641708	0.100392
NDC3933		0.237118	0.063329
	Totals:	2.244457	0.138167

Inventory (Bq/kg): wet weight

File		210Pb 46 keV Bq/kg	+/-	241Am 59.5 keV Bq/kg	+/-	234Th 92.6 keV Bq/kg	+/-	226Ra 186.2 keV Bq/kg	+/-	212Pb 238.6 keV Bq/kg	+/-	214Pb 351.9 keV Bq/kg	+/-	208Tl 583.2 keV Bq/kg	+/-	214Bi 609.3 keV Bq/kg	+/-	137Cs 661.7 keV Bq/kg	+/-	134Cs 795.8 keV Bq/kg	+/-	228Ac 911 keV Bq/kg	+/-	40K 1461 keV Bq/kg	+/-
NDC3641		41.06204	14.41113	-0.232799	0.763882	19.89146	26.6029	13.92108	11.36169	19.88913	2.575671	11.38692	1.478856	5.396421	0.901972	10.56737	1.799831	20.85028	0.632218	0.044925	0.039219	15.07543	4.037296	217.7993	20.5289
NDC3642		22.32345	16.91092	0.712506	1.061925	31.48444	25.18185	26.6759	12.5328	6.761647	1.804532	3.510936	2.064186	1.440837	1.160247	4.721497	2.618229	6.368056	1.188972	0.028943	0.047357	1.821379	4.652649	71.16789	18.07433
NDC3643		-1.097913	18.42097	0.192824	1.043468	37.48527	27.58414	5.254617	13.40853	4.044186	1.843153	6.593856	2.157804	1.761372	1.270119	-0.188487	2.718195	3.701387	1.217005	-0.048645	0.051955	10.03215	5.362765	76.62443	17.55832
	Wtd Means	16.03876	12.72121			31.75572	5.385036	15.06819	6.489383	8.179543	5.102918	6.365532	2.390167	2.352494	1.323162	3.779878	3.24287					7.834589	4.093344	102.3157	50.02957
NDC3661		39.66303	15.15934	-0.285745	0.806427	-4.260859	28.02473	10.6561	11.98941	23.16885	2.943278	13.1522	1.569751	5.988419	0.964027	13.84898	1.936067	17.78334	0.824771	0.036802	0.041289	15.24793	4.302023	248.906	23.32484
NDC3662		27.42537	17.80911	-1.506277	1.179163	30.14689	26.45104	16.76398	12.89122	18.20146	2.974171	12.34344	2.278741	5.151299	1.308786	11.60271	3.048173	7.931212	1.329159	0.012273	0.049711	7.913557	5.407565	250.3153	29.14735
NDC3663		19.94947	19.12397	-0.029135	1.240458	4.168859	29.13086	19.61553	14.34278	13.28791	2.580436	7.963521	2.416817	3.362703	1.285511	6.999572	3.064063	3.686631	1.300478	0.008604	0.055294	4.966412	6.308995	110.3255	21.58972
	Wtd Means	27.47361	5.860331			10.13655	10.56055	16.36788	2.69533	17.42643	2.90921	10.7118	1.63714	4.614484	0.789814	10.24525	2.056046					8.590917	3.117646	190.7461	47.35527
NDC3681		40.24435	14.89238	0.519272	0.786874	18.79035	27.47754	11.20597	11.72891	15.76304	2.180791	10.52759	1.514068	4.799045	0.916159	8.874989	1.845888	17.29388	0.794699	0.040381	0.040299	10.02294	4.136718	202.4591	19.46595
NDC3682		32.5268	21.87069	0.284799	1.28553	28.47239	30.1081	10.82146	14.8525	6.992604	2.131697	5.917414	2.388787	1.030526	1.404883	4.765629	3.172293	7.429689	1.440443	0.050775	0.061425	4.350833	6.22679	127.1802	21.89803
NDC3683		39.63654	25.82754	-2.214919	1.495471	29.98679	36.86345	-3.880071	17.73196	2.128389	2.311423	6.70443	3.049277	1.504963	1.614336	8.838145	3.674342	3.719736	1.535402	0.010864	0.069818	2.394557	7.585896	55.23135	21.29559
	Wtd Means	37.06737	2.50611			25.56215	3.547691	7.027412	5.023309	8.696274	4.035634	7.705848	1.440277	2.447355	1.198757	7.259923	1.379471					5.770288	2.314026	133.7396	42.99656
NDC3701		52.38826	15.86603	0.201078	0.827189	19.8113	29.0541	11.43637	12.40882	20.68172	2.703111	12.41189	1.615584	6.041429	0.982645	12.3832	1.978104	16.95019	0.823622	0.038948	0.042559	16.67242	4.426369	198.9739	19.58883
NDC3702		45.14674	21.88835	0.743669	1.436281	14.31862	32.04022	17.31641	16.42555	11.01196	2.529229	10.24499	2.6579	2.937047	1.494844	9.520541	3.370617	8.992186	1.530239	-0.018296	0.060799	14.3172	6.823869	129.9531	22.0436
NDC3703		16.10348	21.64597	-2.183968	1.302562	15.83588	32.00467	-3.373472	15.4168	10.07172	2.389528	10.81911	2.655134	3.149985	1.406861	10.52202	3.199113	2.326888	1.334258	-0.034903	0.060795	1.239348	6.595168	46.78116	17.42487
	Wtd Means	36.49276	11.13058			16.54907	1.644131	7.807765	8.179559	13.58981	3.40421	11.11579	0.650716	3.956913	1.00514	10.7617	0.842615					10.14611	4.819138	119.7957	44.17096
NDC3721		39.87158	15.76724	-0.005986	0.831911	-9.427885	29.29608	3.778936	12.49432	16.47054	2.288254	8.716262	1.606256	3.91355	0.963699	6.521489	1.95539	16.94659	0.837111	0.015643	0.042661	5.74834	4.390361	120.1	14.12779
NDC3722		19.47878	22.20166	-0.209264	1.396036	19.38088	32.63839	4.147302	15.8037	6.526068	2.272118	7.329325	2.716499	1.78546	1.439647	9.123681	3.276546	7.035778	1.467439	-0.018731	0.062246	9.907458	6.770057	49.22472	18.97961
NDC3723		22.37635	18.25292	-0.17729	1.162732	13.75283	27.64154	3.513824	13.389	7.137915	2.070186	2.640569	2.196844	0.101522	1.217982	7.553609	2.775644	5.435411	1.162672	-0.011055	0.056336	11.32061	5.204244	68.80236	17.61562
	Wtd Means	26.30458	6.405988			9.182104	6.865956	3.812818	0.184639	9.564396	3.235962	6.023416	1.848641	1.778122	1.109188	7.817803	0.760814					9.241424	1.681907	76.31981	21.26874
NDC3741		47.57008	15.01937	0.267647	0.762207	9.428642	28.60473	12.85416	12.02508	21.95127	2.767343	11.70944	1.463104	6.083262	0.911668	11.83749	1.790167	21.54906	0.728991	0.044407	0.040373	15.83155	4.155702	232.7545	21.16554
NDC3742		33.1548	21.5296	1.842839	1.355176	49.10946	32.09239	4.004692	15.26027	4.926301	2.147449	9.982781	2.627422	4.082984	1.399059	1.98814	3.157377	6.294886	1.416155	0.080684	0.060617	1.226752	6.52814	105.1696	21.92936
NDC3743		7.331291	20.72538	-1.053985	1.350124	11.62063	31.66301	23.9347	15.58693	11.68693	2.546948	6.35003	2.624177	3.22474	1.478784	1.787246	3.156864	5.096599	1.414232	-0.045517	0.064349	4.145176	6.528808	69.59618	18.80533
	Wtd Means	30.20537	12.36262			29.22823	13.52493	11.42218	6.055316	11.05175	5.198223	9.490337	1.658859	4.376487	0.889452	4.471386	3.46397					5.738417	4.686579	128.8337	52.02512
NDC3771		47.96266	15.08633	0.231206	0.801528	18.81068	27.62114	17.53196	11.81761	26.78652	3.322618	16.46483	1.561429	7.304585	0.967245	14.39622	1.901831	17.26196	0.79991	0.030191	0.040424	18.07348	4.237192	252.2522	23.3327
NDC3772		25.79571	20.86721	-0.59096	1.33567	36.19893	30.10181	30.41979	15.29826	17.14443	3.037863	17.18375	2.830827	5.556657	1.480562	18.86084	3.646687	11.4626	1.605262	0.106892	0.057528	12.92472	6.46488	238.5662	30.53375
NDC3773		-7.689938	20.65078	0.79157	1.301984	28.32169	30.63064	23.60339	15.04229	15.81217	2.911985	6.268022	2.649978	5.90526	1.525897	11.01723	3.218479	4.916276	1.277007	0.072556	0.054703	12.04722	6.011838	120.4076	21.83406
	Wtd Means	19.68462	16.32884			28.68838	5.073902	24.50127	3.757663	19.2547	3.49022	13.05724	3.558196	6.151851	0.539158	14.83506	2.292951					13.99173	1.897422	199.6657	42.24983
NDC3791		53.92452	16.78443	1.00943	0.881712	19.49212	30.71715	16.5139	13.12634	23.05982	2.983936	12.54291	1.69368	6.774259	1.048124	12.08448	2.078893	22.84685	0.930585	0.036675	0.044965	16.55918	4.67555	269.1348	25.08586
NDC3792		26.23064	22.08674	1.807734	1.465663	39.04675	32.9008	33.79214	16.04891	13.31845	2.784319	8.474345	2.825953	4.309643	1.52586	6.997461	3.423479	12.73534	1.755281	0.060409	0.062085	24.42163	6.452697	187.6282	26.84006
NDC3793		9.088674	22.73091	0.619279	1.478784	-1.142915	34.51626	3.816003	16.73293	17.08967	3.247721	9.193995	2.87944	4.241897	1.624802	-0.680057	3.461756	7.558958	1.654686	-0.019832	0.065906	17.34879	7.54072	105.9069	22.61367
	Wtd Means	29.55142	13.06869			18.60504	11.60916	17.64555	8.691472	17.87829	2.837341	10.08277	1.254229	5.109668	0.833491	6.040211	3.711934					19.347	2.500925	188.5801	47.14425
NDC3811		55.22508	15.40282	-0.077515	0.800392	12.82771	27.95928	17.4541	11.95179	19.34833	2.54677	10.46313	1.547688	5.399532	0.942281	10.84215	1.876868	22.16342	0.865968	0.044722	0.041079	13.44855	4.25303	176.9081	17.68111
NDC3812		23.69554	21.5583	-0.288547	1.354099	26.42989	32.05048	14.56023	15.64746	9.32283	2.424914	4.628069	2.635257	5.070383	1.581539	8.042897	3.344865	13.23922	1.823078	0.003879	0.060346	11.70346	5.954457	81.0006	21.29339
NDC3813		15.63723	18.18555	1.912683	1.189559	18.16702	27.76585	20.04862	13.65337	9.63577	2.195828	3.145137	2.297697	2.355384	1.149339	7.716708	2.771268	2.803959	1.157396	0.070672	0.056673	4.361815	5.720119	54.52355	16.31726
	Wtd Means	27.05089	12.95322			18.92668	4.243094	18.08088	1.699869	11.87292	3.529095	5.253359	2.395236	3.748285	1.034357	8.541581	1.063719					8.332086	2.985511	90.19334	39.8668
NDC3821		56.22483	14.98308	0.218751	0.779457	8.158444	27.09736	12.87229	11.59237	22.30337	2.835586	15.45685	1.523921	6.392348	0.934848	12.96874	1.852815	35.09946	1.052708	0.059291	0.040026	16.78393	4.15486	199.9862	19.26187
NDC3822		33.35695	20.59631	-0.108212	1.313778	45.00459	29.71158	8.07975	14.72091	18.35841	3.102123	13.81736	2.665324	8.5464	1.489516	13.91711	3.253722	32.53453	2.099662	0.079792	0.056199	16.56108	6.374135	199.5819	25.72856
NDC3823		8.920652	20.00475	0.216095	1.300743	14.14723	30.56445	7.407227	14.72597	11.49956	2.471285	9.352093	2.534947	3.629313	1.429305	10.43678	2.898845	7.99982	1.547951	0.019611	0.058003	2.793168	6.299713	112.1284	21.5279
	Wtd Means	30.53199	13.76686			23.36911	11.50654	9.146523	1.734296	16.88545	3.181523	12.60309	1.83867	6.120781	1.434403	12.35886	1.047052					11.49568	4.667038	167.0838	29.45159
NDC3841		46.9623	13.53391	0.780333	0.702883	10.69041	24.57618	7.353706	10.49627	-2.105197	1.119574	8.143786	1.347756	4.171993	0.818878	7.448463	1.643585	27.0842	0.88487	0.052853	0.036431	8.86838	3.714593	103.1027	11.94436
NDC3842		27.82938	19.77944	0.503081	1.201312	39.68388	28.38542	12.91252	13.87671	5.919618	1.887685	1.257409	2.336206	1.726763	1.238751	6.77527	2.965874	8.096313	1.266291	0.008326	0.050062	7.778872	5.542557	19.40016	16.0226
NDC3843		16.70378	20.52132	0.55834	1.333266	3.476881	31.12096	15.36804	15.40189	3.397173	1.993849	7.427556	2.59543	2.12844	1.458646	4.742489	3.288765	4.940608	1.398197	-0.012456	0.063478	6.57206	6.14799	55.47729	17.24914
	Wtd Means	29.68063	9.00879			20.84341	11.28052	12.13991	2.416939	2.970912	2.415469	4.99816	2.228571	2.514382	0.771846	6.344445	0.829232					7.711063	0.676129	53.10779	24.71269
NDC3861		29.16339	13.32499	0.278365	0.714288	8.822895	24.8296	6.209652	10.60606	25.50523	3.137602	7.540888	1.368338	7.06047	0.876604	8.160959	1.66254	9.426194	0.64587	0.030593	0.036396	18.70663	3.839197	117.6504	13.01808
NDC3862		52.12867	19.58124	-0.323971	1.234271	30.81754	27.8059	18.99569	13.63769	19.33779	3.143279	14.49511	2.614823	7.001895	1.389065	10.10583	3.049984	19.27622	1.675449	-0.025277	0.055894	11.94789	5.976273	280.2668	31.67583
NDC3863		57.8132	34.78859	-2.979991	2.119401	37.96885	49.86772	7.080808	24.34566	29.38269	5.114391	14.69812	4.296999	7.22127	2.457841	17.53711	5.480969	7.032798	2.354104	-0.088326	0.094337	22.12732	10.23723	444.3253	54.7327
	Wtd Means	40.47194	9.859462			19.84913	9.873247	10.77744	4.643412	23.79448	3.292693	10.79126	2.648633	7.058431	0.073831	9.915183	3.21639					16.73691	3.367029	211.9154	106.1679
NDC3911		40.6871	13.01686	0.553781	0.681787	7.429809	23.67057	12.38779	10.20276	12.40706	1.770043	8.017011	1.314829	4.122076	0.792768	6.466823	1.595035	25.19775	0.837556	0.018884	0.034775	7.98296	3.572311	80.3967	10.39847
NDC3912		35.91979	20.08053	0.739484	1.216313	26.00149	28.81227	11.17511	14.33218	10.74255	2.383684	10.56972	2.479584	3.003795	1.333532	5.770902	2.999955	16.9184	1.640526	0.038105	0.054287	9.375117	5.611686	59.42568	16.87051
NDC3913		26.38952	20.03704	1.937838	1.305757	27.27801	30.55054	17.48737	14.6978	6.175958	2.115987	3.735882	2.410163	0.73062	1.336565	3.458678	3.039872	2.504949	1.359111	-0.027973	0.057895	3.187709	5.98247	23.32415	16.29882
	Wtd Means	34.81124	4.333025			20.73129	6.533632	13.27193	1.97002	9.994797	1.897428	7.924455	2.030895	2.719249	1.016396	5.347842	0.926172					7.258202	1.909023	55.86924	16.97047
NDC3931		61.85403	20.38194	0.333666	1.074966	0.787871	37.37268	18.47386	15.98725	35.72163	4.437205	19.5155	2.105689	8.761696	1.294329	17.20645	2.564242	20.27185	1.049758	0.074896	0.055335	25.65146	5.763256	387.3918	35.30021
NDC3932		56.68812	20.97204	-0.584747	1.321628	31.10012	29.58044	20.3327	14.5107	19.84523	3.228482	15.51535	2.682056	6.698128	1.561821	11.56431	3.266085	10.13428	1.585462	-0.001513	0.059767	16.67108	6.408734	236.058	30.21273
NDC3933		-7.447459	25.48363	-1.505601	1.661285	-5.641632	38.70645	21.04822	19.15728	21.5587	3.812957	5.701828	3.080902	5.811212	1.933752	12.31238	4.096214	6.512769	1.739424	0.011496	0.073877	16.37723	8.048515	141.3729	27.37613
	Wtd Means	44.79636	22.95762			10.87379	11.66834	19.73919	0.790194	26.61931	5.181739	15.64346	3.251264	7.33607	0.900372	14.002	1.8223					20.22759	3.134856	276.4389	73.79205

Inventory (Bq/kg): dry weight

File		210Pb 46 keV Bq/kg	+/-	241Am 59.5 keV Bq/kg	+/-	234Th 92.8 keV Bq/kg	+/-	226Ra 186.2 keV Bq/kg	+/-	212Pb 238.6 keV Bq/kg	+/-	214Pb 351.9 keV Bq/kg	+/-	208Tl 583.2 keV Bq/kg	+/-	214Bi 609.3 keV Bq/kg	+/-	137Cs 661.7 keV Bq/kg	+/-	134Cs 795.8 keV Bq/kg	+/-	228Ac 911 keV Bq/kg	+/-	40K 1461 keV Bq/kg	+/-
NDC3641		53.73352	18.85831	-0.30464	0.999611	26.02984	34.81239	18.21704	14.86783	26.02679	3.370507	14.90085	1.935222	7.061722	1.180315	13.82839	2.355248	27.28455	1.089036	0.058788	0.051321	19.72761	5.283141	285.0107	26.86399
NDC3642		24.78937	18.77895	0.791214	1.179228	34.9401	27.96352	29.6226	13.91722	7.508559	2.003867	3.898785	2.292203	1.599997	1.288411	5.243048	2.907447	7.09927	1.320309	0.03214	0.052588	1.800461	5.166595	79.02932	17.84965
NDC3643		-1.266662	21.25227	0.222461	1.203848	43.24674	31.82381	6.06225	15.46941	4.665752	2.126444	7.607329	2.489457	2.032095	1.485336	-0.217457	3.135981	4.270289	1.404058	-0.056121	0.059941	11.57409	6.18702	88.63232	20.25703
	Means:	25.75208	15.86448			34.7389	4.971111	17.9673	6.802433	12.7337	6.697015	8.802316	3.231743	3.564604	1.753002	6.284662	4.087999					11.03406	5.182157	150.8908	67.11725
NDC3681		49.73549	19.00907	-0.35831	1.01122	-5.342908	35.14164	13.36222	15.03414	29.0526	3.690727	16.49221	1.968391	7.509184	1.208842	17.36594	2.427733	22.29943	1.034223	0.045698	0.051775	19.12016	5.394526	312.1184	29.2482
NDC3682		30.43345	19.76245	-1.67149	1.308498	33.45348	29.35226	18.60269	14.30516	20.19784	3.300385	13.6973	2.52868	5.716306	1.452337	12.87533	3.382504	8.801128	1.474945	0.013619	0.055164	8.781536	6.000681	277.7705	32.34431
NDC3683		21.57171	20.67908	-0.031504	1.341329	4.50786	31.49971	21.21061	15.5091	14.36844	2.79027	6.63272	2.613346	3.636149	1.390046	7.568759	3.313224	3.97993	1.40623	0.009304	0.05979	5.370268	6.822026	119.2969	23.34534
	Means:	33.91355	8.314304			10.87281	11.84294	17.72518	2.307726	21.20629	4.268834	12.94074	2.300158	5.620546	1.119074	12.60334	2.831471					11.09065	4.133758	236.3953	59.38283
NDC3681		48.92451	18.10443	0.831271	0.956592	22.84317	33.40406	13.62294	14.25867	19.16291	2.651158	12.79824	1.840632	5.834133	1.113763	10.7892	2.244021	21.02394	0.966105	0.049091	0.048991	12.18475	5.028951	246.1268	23.66449
NDC3682		34.74311	23.36091	0.314886	1.373124	30.41244	32.1596	11.55881	15.86452	7.469065	2.276946	6.320613	2.551554	1.100744	1.500608	5.090348	3.388446	7.936146	1.538592	0.054234	0.065611	4.647289	6.65107	135.846	23.39012
NDC3683		42.57091	27.73961	-2.378894	1.606183	32.20677	39.59252	-4.16732	19.0447	2.285969	2.482542	7.200772	3.275021	1.616378	1.733849	9.49245	3.94636	3.995115	1.649071	0.011668	0.074987	2.571831	8.147494	59.32023	22.87214
	Means:	42.07951	4.101184			28.48746	2.869285	7.004808	5.617754	9.639314	4.991335	8.77321	2.028492	2.850418	1.499265	8.457333	1.72461					8.467955	2.920511	147.0976	54.21906
NDC3701		72.50888	21.95966	0.278306	1.144886	27.42018	40.21283	15.82871	17.17464	28.6249	3.741287	17.17889	2.236077	8.361745	1.380047	17.13919	2.73783	23.4602	1.139948	0.053907	0.058904	23.07575	6.126393	275.3933	27.11199
NDC3702		49.0576	23.78444	0.80809	1.560699	15.55898	34.81571	18.81645	17.84842	11.96588	2.748325	11.13247	2.888141	3.19147	1.624336	10.34526	3.662598	9.771138	1.662797	-0.019881	0.066068	15.55744	7.197664	141.2103	23.95313
NDC3703		16.97307	22.81485	-2.301902	1.372901	16.69102	33.73292	-3.555639	16.24931	10.61559	2.518563	11.40334	2.795511	3.320084	1.48494	11.09021	3.371665	2.45233	1.408307	-0.036788	0.064078	1.306272	6.951307	49.30737	18.36581
	Means:	46.17985	18.09625			19.89006	3.779215	10.38317	7.012646	17.06879	5.791188	13.23823	1.97188	4.957768	1.702394	12.85822	2.151258					13.31315	6.383706	155.3036	65.64468
NDC3721		47.32559	18.71493	-0.007106	0.987437	-11.19043	34.77299	4.483037	14.83014	19.54971	2.716044	10.34577	1.906549	4.64519	1.143884	7.740685	2.320951	20.11476	0.99361	0.018567	0.050636	6.822995	5.211141	142.5527	16.78899
NDC3722		21.10969	24.06054	-0.226785	1.512922	21.00359	35.37111	4.494544	17.1269	7.072499	2.462356	7.942989	2.948112	1.934951	1.560184	9.887582	3.550884	7.624864	1.590304	-0.020299	0.067457	10.73686	7.336895	53.34617	20.56872
NDC3723		24.262	19.79109	-0.19223	1.2824	14.91178	29.97088	3.809716	14.51729	7.739425	2.244618	2.863089	2.381754	0.110077	1.320621	8.190149	3.009547	5.893451	1.26065	-0.011966	0.061083	12.27459	5.842804	74.38346	19.10008
	Means:	30.89909	8.263507			8.241644	9.8739	4.262432	0.226383	11.45388	4.052493	7.050616	2.205665	2.230073	1.317464	8.606139	0.853727					9.944855	1.622813	90.09412	26.92318
NDC3741		59.89209	18.90982	0.336976	0.95964	11.87093	38.01417	16.18375	15.13992	27.63728	3.484165	14.74252	1.84209	7.659001	1.147816	14.90374	2.253871	27.13089	0.91782	0.05591	0.05083	19.93238	5.232148	293.0446	26.64802
NDC3742		35.84709	23.27789	1.992485	1.465221	53.09734	34.69842	4.329888	16.49946	5.326336	2.32183	10.78342	2.840778	4.414538	1.512668	2.149564	3.413768	6.808033	1.531152	0.087236	0.065539	1.326369	7.05825	113.7097	23.7101
NDC3743		7.792862	22.03023	-1.120321	1.435127	12.35226	33.65648	25.44161	16.56827	12.42273	2.707301	6.749822	2.789393	3.427767	1.571887	1.899789	3.355617	5.417477	1.50327	-0.048383	0.0684	4.406152	6.939856	73.97789	19.9893
	Means:	34.51068	15.05459			25.77351	13.66262	15.31841	6.109767	15.12878	6.581201	10.76192	2.307348	5.167102	1.278098	6.317699	4.293627					8.554967	5.75776	160.2441	67.38359
NDC3771		61.40315	19.31651	0.295996	1.026138	24.08196	35.36138	22.44491	15.12924	34.29286	4.25371	21.07874	1.998988	9.351537	1.238295	18.43045	2.434778	22.09925	1.024068	0.038652	0.051753	23.13816	5.424573	322.9404	29.87118
NDC3772		29.11096	23.54905	-0.86691	1.50733	40.84894	33.97048	34.32932	17.26438	19.34783	3.428267	19.39219	3.194643	6.270795	1.677614	21.28482	4.115357	12.93577	1.811589	0.12063	0.064921	14.5858	7.295743	269.2266	34.45793
NDC3773		-8.387644	22.47071	0.88133	1.416726	30.81765	33.33008	25.68353	16.36795	17.20568	3.166815	6.820416	2.883517	6.425684	1.680372	11.98816	3.50212	5.351718	1.389548	0.07895	0.059524	13.10893	6.541654	131.019	23.75828
	Means:	27.38215	20.15983			31.91618	4.871274	27.48592	3.547123	23.61546	5.374396	15.76378	4.498109	7.349339	1.002097	17.23448	2.74953					16.9443	3.126147	241.062	57.16466
NDC3791		67.74317	21.0856	1.268106	1.107659	24.48715	38.5887	20.74573	16.49009	28.96911	3.748597	15.75715	2.127701	8.510225	1.316716	15.18124	2.811628	28.70157	1.169056	0.046074	0.056488	20.80262	5.873702	338.1031	31.51435
NDC3792		30.31467	25.52558	2.089192	1.693862	45.12621	38.02335	39.05348	18.54767	15.39209	3.21783	9.793776	3.285948	4.980642	1.7632	8.086945	3.956505	14.71819	2.028573	0.069815	0.071751	28.22401	7.457383	216.8413	31.01898
NDC3793		10.44872	26.13241	0.71195	1.700072	-1.313943	39.68135	4.387038	19.23689	19.64701	3.733717	10.5698	3.310326	4.876863	1.867941	-0.781822	3.97978	8.690097	1.902297	-0.0228	0.075788	19.9449	8.66913	121.755	25.99763
	Means:	36.16886	16.7965			22.76847	13.4337	21.39542	10.01261	21.33607	4.009304	12.04024	1.871905	6.12251	1.194235	7.495455	4.61782					22.99051	2.628438	225.5665	62.60648
NDC3811		79.70806	22.23137	-0.11186	1.15523	18.51462	40.35448	25.19204	17.25038	27.92605	3.675831	15.10176	2.233825	7.79331	1.380023	15.64881	2.708942	31.98914	1.249879	0.064549	0.059291	19.41071	6.13853	255.3389	25.51989
NDC3812		27.04063	24.60166	-0.329281	1.545257	30.16099	36.57503	16.61569	17.85641	10.63893	2.767238	5.281411	3.007275	5.786167	1.804804	9.178309	3.617058	15.10819	1.852207	0.004427	0.068865	13.35563	6.795045	92.43542	24.29937
NDC3813		16.86923	19.61832	2.063376	1.28326	19.59833	29.95321	21.62617	14.72907	10.39494	2.368629	3.39293	2.478724	2.540956	1.238891	8.324679	2.989606	3.024873	1.248582	0.07624	0.061138	4.705486	6.170786	58.81925	17.60283
	Means:	41.20597	19.47368			22.75798	3.714701	21.1453	2.487522	16.31997	5.803465	7.925366	3.629372	5.373478	1.5302	11.0506	2.312274					12.4906	4.267014	135.5305	60.68413
NDC3821		71.58364	19.07597	0.278507	0.992379	10.38707	34.49949	16.38858	14.75904	28.39593	3.610177	19.67916	1.940207	8.138531	1.190219	16.51138	2.358945	44.6875	1.340274	0.075467	0.05096	21.36875	5.28958	254.616	24.52359
NDC3822		37.99926	23.46271	-0.123272	1.496617	51.26792	33.84656	9.204216	16.76983	20.91337	3.533848	15.74033	3.036259	9.73581	1.696813	15.85397	3.706545	37.06239	2.391874	0.090897	0.06402	18.88869	7.261229	227.3579	29.30923
NDC3823		9.511137	21.32892	0.230399	1.386843	15.08368	32.5876	7.897533	15.70073	12.26076	2.634898	9.971135	2.702743	3.869548	1.523915	11.12762	3.090728	8.529352	1.650414	0.020909	0.061842	2.978056	6.71671	119.5505	22.9529
	Means:	39.69801	17.93891			25.57956	12.91554	11.16344	2.639659	20.52335	4.661905	15.13021	2.81902	7.247963	1.751008	14.49765	1.695672					14.41183	5.761542	200.5081	41.23655
NDC3841		65.07736	18.75443	1.081335	0.97401	14.81408	34.0561	10.1903	14.54506	-2.917248	1.551434	11.28514	1.867635	5.781281	1.134748	10.3216	2.277547	37.53155	1.226196	0.07324	0.050483	12.28923	5.147446	142.8731	16.55174
NDC3842		30.20649	21.46895	0.546053	1.303925	43.07358	30.81004	14.01547	15.06203	6.425257	2.048927	1.364814	2.535759	1.874259	1.344562	7.353996	3.219212	8.78788	1.374454	0.00904	0.054339	8.443324	6.015988	21.05727	17.39121
NDC3843		17.73947	21.79371	0.592959	1.415933	3.692459	33.05055	16.3209	16.35685	3.607809	2.117473	7.888088	2.756355	2.26041	1.549087	5.036538	3.492679	5.246942	1.48489	-0.013228	0.067414	6.979546	6.529185	58.91706	18.31864
	Means:	37.67444	14.16624			20.52671	11.72169	13.50889	1.787788	2.371939	2.786835	6.846013	2.910764	3.305317	1.242991	7.570713	1.52951					9.237369	1.563359	74.28248	35.99466
NDC3861		38.17596	16.5291	0.3453	0.886044	10.94443	30.80008	7.702812	13.15637	31.63617	3.892064	9.354155	1.694685	8.758217	1.08739	10.12333	2.062312	11.6928	0.801175	0.037949	0.045148	23.20479	4.782383	145.9404	16.14838
NDC3862		60.65933	22.78564	-0.376987	1.436255	35.86071	32.35624	22.10426	16.10217	22.50235	3.657665	16.86718	3.042729	8.14773	1.616403	11.75962	3.549102	22.43071	1.94963	-0.029413	0.065041	13.90311	6.954268	326.1315	36.85946
NDC3863		70.12247	42.19316	-3.814474	2.570652	46.05297	80.48528	8.588414	29.5292	35.63869	6.203316	17.82756	5.211892	8.758763	2.981151	21.27101	6.647947	8.530182	2.855327	-0.107132	0.114423	26.83855	12.41688	538.9286	66.38609
	Means:	55.65259	10.11421			30.95271	10.42783	12.7985	4.659901	29.9264	3.887521	14.68297	2.67879	8.55491	0.20359	14.38465	3.475429					21.31548	3.851772	337.0001	113.576
NDC3911		58.07952	18.49026	0.786638	0.968469	10.55393	33.9078	17.59687	14.49288	17.62405	2.51432	11.38805	1.867695	5.855351	1.126144	9.186026	2.265724	35.79303	1.189736	0.026824	0.049397	11.33968	5.074415	114.1597	14.77067
NDC3912		42.92037	23.99412	0.883805	1.453368	31.06904	34.18865	13.35308	17.12544	12.83821	2.848228	12.6297	2.962842	3.589219	1.593431	6.89562	3.58463	20.2157	1.960256	0.045531	0.064868	11.20228	6.705374	71.00743	20.15848
NDC3913		28.1282	21.35718	2.065512	1.391787	29.07522	32.56337	18.63952	15.66617	6.582861	2.255399	3.982021	2.568957	0.778757	1.424624	3.686553	3.240154	2.869987	1.448656	-0.029816	0.06171	3.397731	6.376624	24.86086	17.37267
	Means:	43.0427	8.646419			23.56606	6.531475	16.52976	1.616617	12.34771	3.19686	9.333255	2.699519	3.407776	1.488292	6.589399	1.594927					8.846562	2.624715	70.00933	25.78319
NDC3931		61.94313	20.4113	0.334147	1.076515	0.789006	37.42652	18.50047	16.01028	35.77308	4.443597	19.54361	2.108722	8.774318	1.296194	17.23123	2.567936	20.30105	1.05127	0.075004	0.055415	25.68841	5.771557	367.9498	35.35106
NDC3932		65.77131	24.33241	-0.676442	1.533393	36.08332	34.32013	23.59062	16.83577	23.02505	3.745784	18.00138	3.111804	7.769054	1.812073	13.41727	3.789413	11.7581	1.839502	-0.001755	0.069344	19.34231	7.43581	273.8818	35.05375
NDC3933		-8.316145	28.45609	-1.681217	1.85506	-6.299683	43.22125	23.50333	21.39182	24.07335	4.257708	9.716826	3.440265	6.489043	2.159308	13.74852	4.576238	7.272431	1.942314	0.012837	0.082495	18.2875	8.987309	157.8629	30.57157
	Means:	39.79943	24.08316			10.19088	13.10695	21.8648	1.662357	27.62383	4.085849	15.75394	3.051211	7.677472	0.66129	14.79901	1.219866					21.10607	2.311315	273.2315	66.42117

Appendix D. Method to correct for potential contamination of the aircraft by radon daughters.

Four hypotheses relating to the background for measurements made in the survey were considered.

1) The background was constant throughout the experiment
2) The background was constant throughout each day, but varied from day to day
3) The background on some days was due to contamination of the aircraft overnight
4) The background on some days was due to contamination of the aircraft in flight

Background measurements were recorded over Farmoor reservoir every day. These showed that for three days in the middle of the survey the background was significantly higher than the mean background for the other days, ruling out hypothesis 1. In addition, when maps of activity were produced on the basis of hypothesis 2, distinct boundaries between the areas surveyed on different days were observed, ruling out this hypothesis at least for some of the occasions.

The last two hypotheses share some similarities, both assume that the aircraft was contaminated by radon daughters. The U-series produces ^{222}Rn with a 3.83d half life, and on still days this can accumulate in the atmosphere. This radon then decays to ^{218}Po (3.05m half life), ^{214}Pb (26.8m), ^{214}Bi (19.9m) and other daughters. These daughters can be absorbed onto surfaces of the aircraft, and give higher than expected background readings as a result of γ-rays associated with ^{214}Bi.

For hypothesis 3 the contamination occurs mainly as a result of radon accumulating around the aircraft overnight. In this case, radon and its daughters are in secular equilibrium (they all have the same activity) until the aircraft takes off. The Pb and Bi isotopes then start to decay, with the ^{214}Bi activity, A_2, being given by:

$$A_2=\frac{\lambda_2 A_{10}}{\lambda_2-\lambda_1}(e^{-\lambda_1 t}-e^{-\lambda_2 t})+A_{20}e^{-\lambda_2 t} \qquad (1)$$

where A_{10} and A_{20} are the initial activities, and λ_1 and λ_2 are the decay constants for ^{214}Pb and ^{214}Bi respectively. In this scenario, $A_{10}=A_{20}$.

For hypothesis 4 the contamination occurs mainly during flight as the aircraft passes through radon clouds. In this case, radon is not in equilibrium with its daughters, and if it is assumed that the contamination occurs as a deposition of ^{214}Pb, A_{10}, over a short time scale the ^{214}Bi activity is given by:

$$A_2=\frac{\lambda_2 A_{10}}{\lambda_2-\lambda_1}(e^{-\lambda_1 t}-e^{\lambda_2 t}) \qquad (2)$$

Figure D.1 shows the variation of the activity of ^{214}Bi for each of these hypotheses. It is possible to test these hypotheses using data collected at different times of the day. In addition to the background readings recorded over Farmoor reservoir in the morning of each
day, there were also periods when spectra were recorded at altitudes in excess of 200m (usually flying between the end of a survey leg and refuelling at Newbury). A plot of the excess activity in the ^{214}Bi channel (ie: the counts in this channel less the mean background level for the normal background days) for these "background" readings can be produced. Figure D.2 shows such a plot for the data recorded on the 24/9/96, the data clearly fit a hypotheses 4 scenario.

The dashed line on figure D.2 shows the expected excess ^{214}Bi activity for the contamination occurring over a short time period. This clearly is not a particularly good fit, indicating that the contamination occurred over a more extended period. If ^{214}Pb is deposited at a constant rate R then the activities of ^{214}Pb, A_1, and ^{214}Bi, A_2, will be given by:

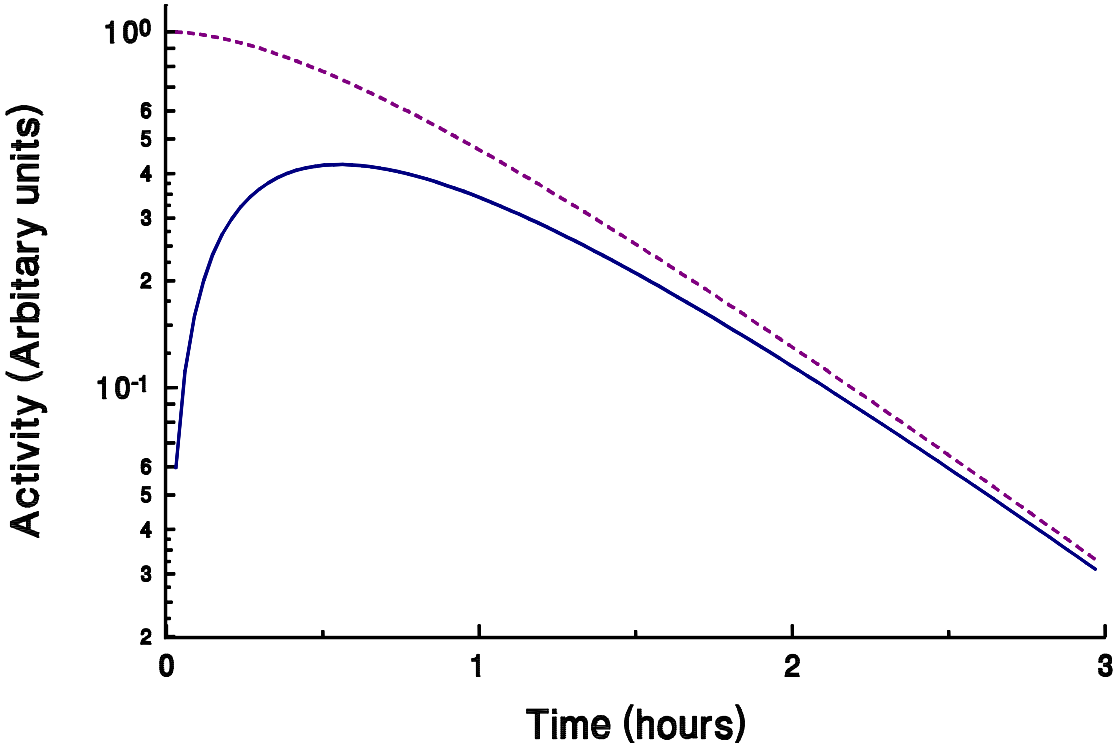

Figure D.1 Variation of ^{214}Bi activity for hypothesis 3, where the contamination occurs overnight (dashed line) and hypothesis 4, where the contamination occurs in flight (solid line).

$$A_1 = R(1-e^{-\lambda_1 t}) \tag{3}$$

$$A_2 = R(1-e^{-\lambda_2 t}) + \frac{R\lambda_2}{\lambda_2 - \lambda_1}(e^{-\lambda_2 t} - e^{-\lambda_1 t}) \tag{4}$$

The solid curve on figure D.2 shows the expected excess ^{214}Bi activity for contamination occurring over an extended period of time, T, and then decaying following equation (1) with A_{10} and A_{20} being A_1 and A_2 at time T. The time T and contamination rate R were adjusted to fit the data.

Having determined the contamination in the ^{214}Bi channel, the contribution of the contamination in the other channels, C_i, can be estimated by:

$$C_i = f_i A_2 \tag{5}$$

where I is the channel number, and f_i is scaled to fit the data recorded over Farmoor reservoir. The background for each channel is simply the sum of C_i and the mean background for the days with normal background levels. This is then subtracted from the survey data to produce net counts for each channel, and the data is then processed as normal.

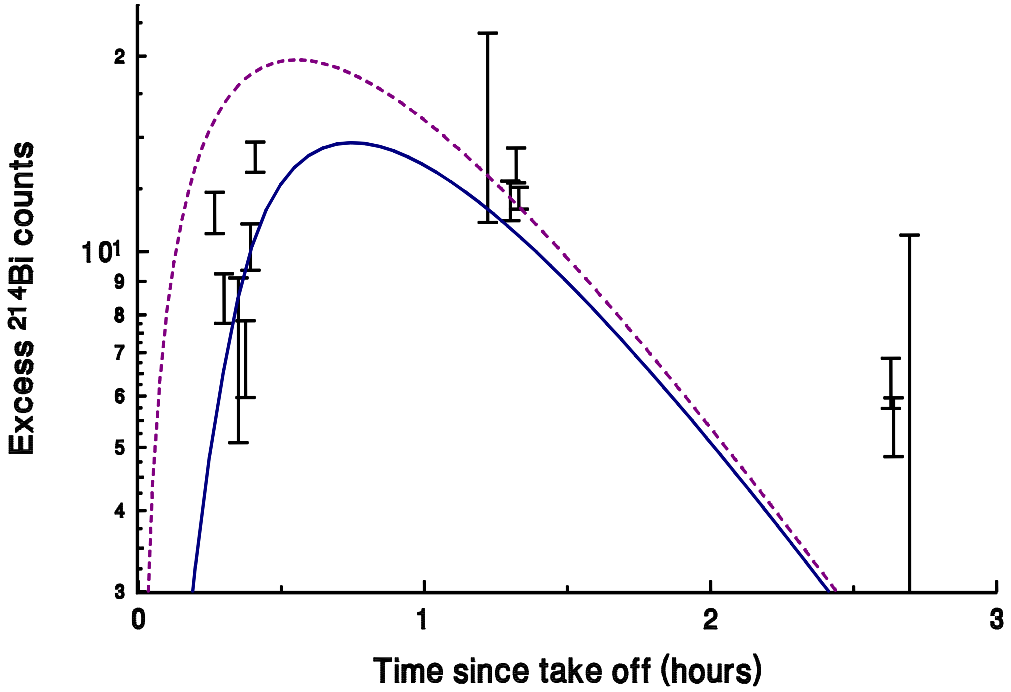

Figure D.2 Excess ^{214}Bi background activities recorded on the 24/9/96. The dashed line is a fit assuming the contamination was deposited in a short period at take off from Oxford. The solid line is a fit assuming the contamination was deposited at a constant rate over the first 20 minutes of flight.