Scottish Universities Research & Reactor Centre

AN INVESTIGATION OF OFF-SITE RADIATION LEVELS AT HARWELL AND RUTHERFORD APPLETON LABORATORY FOLLOWING AIRBORNE GAMMA SPECTROMETRY IN 1996

FINAL REPORT

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SUMMARY

An airborne gamma ray survey was commissioned to define the radiation environment of Newbury District and surrounding areas. The survey measured signals in the vicinity of UKAEA Harwell and the Rutherford Appleton Laboratory (RAL) arising from activities or materials on-site. These signals, detected in a series of perimeter flights lasting less than one hour on 25th September 1996, were not fully accounted for by the published environmental monitoring reports of UKAEA. Following discussions with UKAEA and RAL, the Vale of White Horse District Council commissioned additional work to examine the relation between the airborne results and existing information, to identify the sources or activities responsible for off-site radiation, and to identify any gaps in existing routine monitoring and dose assessments. The issues addressed include the radiological implications to the general public of radiation shine off-site, and the nature and reporting of the routine UKAEA Harwell monitoring programme.

This report presents the results of further analysis of the airborne survey data, the identification of the sources responsible for off-site features, information made available by UKAEA, the Environment Agency and the RAL to define the relevant dose rates, and the results of a short vehicular radiation survey conducted in June 1997.

The airborne survey results show 4 principal areas where on-site radiation produces prominent radiometric signals off-site, and a further 2 areas associated with minor signal levels. These 4 areas are (i) the area to the south of Tandem Van de Graaff accelerator, (ii) the area between the ISIS accelerator (RAL) and the UKAEA materials processing facilities (HELIOS), (iii) areas to the W and NW of the site perimeter influenced by the presence of stored radioactive materials in the B462 complex and (iv) areas adjacent to the liquid effluent treatment plant (LETP) to the north of the main site. Minor signals were detected to the SW of the reactor blocks, and to the E of the RAL. These radiometric signals were restricted to areas close to the site, and did not penetrate more than a few hundred metres from the perimeter fence.

Perimeter monitoring conducted over many years by UKAEA, and published in annual reports on radioactive discharges and environmental monitoring, is based on 30 fixed thermoluminescence dosimetry (TLD) stations arranged around the boundaries of the licensed site. Of these, stations 1-28 have shown levels very close to natural dose rates (typically 40-60 nGy h^{-1}) over recent years, and have been used to form a "site average" statistic. The remaining 2 stations (29,30) which are close to the LETP have detected local dose rates of 200-400 nGy h^{-1} in recent years. The perimeter monitoring data accounts for the signals detected near the LETP in September 1996, but not for the elevated signals recorded from other areas.

Additional information has been made available to this study from UKAEA, the RAL, and the Environment Agency to facilitate interpretation of the airborne results. Routine health physics monitoring, undertaken on-site by UKAEA on a regular basis for occupational radiation protection purposes, was supplemented by an instrumental perimeter survey conducted in March 1997 in response to the publication of the Newbury survey, and by further observations in the vicinity of the Tandem accelerator.

The RAL undertook a survey of dose rates on each individual fence post around their perimeter in March 1997. The environment agency made available unpublished data collected by ICI Tracerco between 1989 and 1994 on behalf of the Department of the Environment, comprising annual instrumental dose rate readings at 65 locations around the perimeter of the Harwell site.

A vehicular survey was conducted in June 1997 by SURRC as part of this study to augment information on the site perimeter, and to investigate the extent to which radiometric features at the perimeter fence project onto surrounding areas at ground level.

This study confirms that the major features observed in the airborne survey correspond to identifiable radiation sources or radioactive materials stored on site, which have measurable enhanced dose rates at ground level.

The significance of these features has been examined relative to ICRP and NRPB recommended criteria. In particular the dose constraint concept is relevant to sources of direct radiation. It is recognised that the direct radiation pathways have received less attention in past radiological assessments than doses due to radioactive discharges. However the decommissioning of the Harwell materials testing reactors and other changes to the nature of work on the site have resulted in lower radioactive waste discharges over the last decade. Changes to the licensing, management and site boundaries have also taken place within recent years, and the nature and quantities of radioactive wastes stored on site are clearly undergoing changes. The peripheral areas of the site are undergoing re-development as part of the process of diversification from previous nuclear interests. Against this background it is clear that direct radiation exposure close to the site perimeter represents a more significant exposure pathway than recognised in past radiological assessments.

The features discussed in this study would be capable of delivering dose constraint exposures to individuals spending an average of 1-2 hours per day in the most affected areas close to the perimeter fence. It is recognised that the actual occupancy of these areas is unlikely to be as high as this. Moreover it is recognised that the dose constraint level of 300 $\mu Sv\ yr^{-1}$ represents a radiation dose increment which is within the range of variations of natural radiation exposure, and which corresponds to a very small level of risk to an individual. Nevertheless current recommendations at both international and national levels are clear, in that such radiation exposure should be justified, and minimised where practicable.

The Harwell and the RAL sites maintain both statutory and non-statutory radiation monitoring programmes. These programmes consist primarily of measurements using Thermoluminescence Dosemeters (TLD's) in fixed locations, which are replaced and analysed on a monthly or bi-monthly basis, and of supplementary measurements at fixed locations using portable dose rate meters. This study has identified some areas in which the routine monitoring programmes have failed to fully identify and characterize radiation sources with off-site radiation consequences. This is also true of the monitoring conducted independently by NRPB in 1992 in support of the most recent published dose assessment. Independent monitoring commissioned by HMIP between 1989 and 1994 as a regulatory check identified more of these features; however these results were neither published nor communicated to UKAEA, and therefore their potential for influencing site assessments will have been limited.

Supplementary monitoring conducted as a result of the airborne survey, and the vehicular survey conducted for this study have confirmed the existence of the main features observed in the airborne survey and have indicated where improvements should be made in routine monitoring. In addition the vehicular survey identified a number of small areas outside the licensed site boundary with low level uranium contamination. Further work is needed to identify the source, extent and significance of this material, and to ensure that its presence does not present hazards to the redevelopment of areas of the former airfield which were used by AERE in the early years of the nuclear programme.

On the basis of this study a number of recommendations are made for consideration. It is suggested that the Vale of White Horse District Council raise these points with the site operators and their regulators, and follow up the responses:

1) Steps should be taken to prevent or minimise public radiation exposure resulting from on-site activities including those identified here. Consideration should be given to limiting public access to the affected areas, to provision of supplementary shielding around radiation sources on-site, and to re-arranging the locations of radioactive materials to minimise off-site dose rates.

2) Justification for radiation levels remaining after such work should be reviewed subject to the normal process of consultation.

3) The additional radiation features discussed in this report, principally the Tandem Van de Graaff accelerator, the ISIS and HELIOS accelerators and the B462 complex with the associated ISO storage compound, should form part of future dose assessments.

4) Routine monitoring programmes conducted by the site operators should be adapted to respond more positively to perimeter dosimetry and its changes. In this respect consideration should be given to the location of fixed monitoring stations, to the use of instrumental methods which respond to dynamic situations in addition to integrating dosimetry, and to conducting periodic perimeter surveys to ensure that critical areas are being kept under review.

5) Consideration be given to incorporating monitoring and assessment of off-site consequences into operational procedures for moving radioactive materials on-site.

6) Any revisions to the routine perimeter monitoring programme be published in annual reports, but that the practice of reporting a "site average" based on a partial set of monitoring data be discontinued.

7) The site regulators consider the re-instatement of an independent programme of perimeter monitoring, to replace that which was discontinued by HMIP in 1994. The results of such monitoring should be published, and action taken to ensure that any gaps in the operators routine monitoring are identified and corrected.

8) The nature, extent and origins of patches of low level Uranium contamination on the former airfield should be identified. The presence of other similarly contaminated areas should be investigated, and consideration should be given to removing such material from areas outside the current licensed site.

GLOSSARY

Absorbed dose measures the energy deposited in a unit mass. It is measured in Grays, where 1 Gy=1 J kg^{-1}.

Equivalent dose measures the biological damage associated with a radiation dose, and accounts for the varying effects of different types of radiation. It is measured in Seiverts (Sv), and is the absorbed dose multiplied by a radiation weighting factor. For gamma rays, which is the radiation considered in this report, the radiation weighting factor is unity, and the two units are effectively interchangeable. The measurements made by the SURRC group are given in Gy, the measurements from other sources are given in the units used in by those groups.

Radionuclide deposition is measured in kBq m^{-2} (kilo Becquerels per square metre, or x10^3 Bq m^{-2}), where Bq are units of activity (1 Bq equals 1 disintegration per second).

The principal radionuclides measured are:

- ^{40}K (natural)
- ^{214}Bi (natural, U-series)
- ^{208}Tl (natural, Th-series)
- ^{137}Cs (fission product, produced in nuclear weapons or reactors)

Annihilation radiation is generated by the mutual annihilation of an electron and positron, creating two 511 keV gamma rays. High energy gamma rays (E>1.02 MeV) can interact with matter to generate and positron-electron pairs ("pair production"). The positron annihilates with an electron to produce annihilation radiation.

Bremsstrahlung radiation consists of an x-ray continuum generated as high energy electrons (either from accelerators or beta particles) interact with atomic nuclei.

Quoted uncertainties are ± 1 standard deviation (±1σ)

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Newbury District Council, Basingstoke and Deane Borough Council made primary data from the airborne survey conducted on their behalf available to the study. That data remains covered by the copyright owned by Newbury District Council, Basingstoke and Deane Borough Council. This present report and associated work was commissioned by the Environmental & Housing Services Department, of the Vale of White Horse District Council.

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CONTENTS

1. INTRODUCTION

An airborne survey was commissioned by Newbury District Council and Basingstoke and Deane Borough Council, to define the radiation environment of Newbury District and surrounding areas, and was conducted during the period 14-28th September 1996 (Sanderson *et al*, 1997a; Croudace *et al*, 1997a, 1997b). This included surveys of the vicinities of the nuclear sites at Harwell, Aldermaston and Burghfield. The survey of the Harwell site was conducted on the 25th September 1996 between 16:00-17:00 approximately, with 500 radiometric readings taken from four circuits of the Harwell and Rutherford Appleton Laboratory (RAL) perimeter fences and at increasing distances beyond, together with general infill flying in a surrounding 3x3 km box. A complex series of spectral features were recorded, which included eighteen signals associated with accelerator machine signals and isotopic sources. These data showed more signals near the perimeter than would have been expected from recent UKAEA reports on radioactive discharges and environmental monitoring.

This current study reported here was commissioned by the Vale of White Horse Council to further investigate the off-site radiation features around Harwell. Specifically, the study has undertaken to examine the airborne data in greater detail and to identify the sources responsible for the features noted. Existing ground based data have been examined, using both published data, and unpublished results. This includes routine on-site health physics monitoring by UKAEA conducted for occupational radiation protection purposes, and supplementary measurements conducted by UKAEA and the RAL to investigate perimeter dose rates in support of this study. Additional ground based measurements were conducted as required to characterize the nature and extent of measured features more fully, including an assessment of any potential hazard these might represent to members of the public and staff at Harwell. The study also discusses the routine monitoring programme and makes recommendations for future monitoring.

The Harwell and RAL sites maintain both statutory and non-statutory radiation monitoring programmes. The results of these programmes, and measurements conducted by other agencies, were reviewed and compared with the airborne results. An additional survey at ground level was undertaken on behalf of Vale of White Horse District Council after discussions with UKAEA Harwell, the RAL, and the Environment Agency (EA). This consisted of a vehicular survey, using the same principles as the airborne survey, within and around the perimeters of Harwell and the RAL on the 19th and 20th June 1997.

This study takes place against a context of significant and ongoing changes to the activities, nature, management and regulation of the Harwell site. Recent changes in recommended radiological protection standards have also set increasingly stringent targets for constraining low level exposure to members of the public. It is therefore timely to review off-site dosimetry and monitoring procedures in the light of these changes, as well as in response to the airborne survey results.

2. BACKGROUND

2.1 Harwell Historical Background

UKAEA Harwell, located approximately 15 miles south of Oxford, houses the headquarters of the United Kingdom Atomic Energy Authority (UKAEA) and is the largest of their sites. The site occupies about 500 acres within the perimeter fence, with adjacent land also owned by UKAEA. The site is managed by UKAEA, the main tenant being AEA Technology with the adjacent land being occupied by organizations including UK Nirex, the National Radiological Protection Board and the Medical Research Council. The RAL also occupies an adjacent site.

The site, previously an RAF base constructed shortly before the second world war, was transferred to the Ministry of Supply in 1946 following Cabinet committee approval and became the Atomic Energy Research Establishment (AERE). The main requirements of such an establishment were accessibility, and good power and water services (Gowing, 1965). The United Kingdom Atomic Energy Authority was formed on 19th July 1954, following the Atomic Energy Act of 1954. It was divided into three groups (Simpson, 1986); research, weapons research and production (or industrial group). Military work was concentrated at Aldermaston which became the Atomic Weapons Research Establishment (AWRE) in 1973, and for which responsibility was transferred to the Ministry of Defence. Harwell concentrated on civil technology, in support of the nuclear power programme. The fuel production and reprocessing activities of the UKAEA (conducted at other establishments) was transferred to British Nuclear Fuels Limited in April 1971. In 1986 the UKAEA underwent a significant shift in emphasis in its business which had diversified into non nuclear activities and became a trading fund, allowing commercialization. Eight years later, in 1994, the UKAEA was split into three divisions; Government (UKAEA), Commercial (AEA Technology plc) and Facilities Services (Procord), the last two of which have since been privatised.

As the headquarters of the Atomic Energy Research Establishment, the Harwell site and adjacent facilities have a distinguished history of more than 50 years of nuclear research, which has involved a diverse range of reactors, accelerators, radioactive materials and associated wastes. A small reactor pile (GLEEP, the Graphite Low Energy Experimental Pile) commenced operation in August 1947, and was followed in 1948 by the much larger BEPO (British experimental pile) which operated until 1968. Both of these were air-cooled graphite piles. The site also housed two Materials Testing Reactors (MTR's), DIDO and PLUTO, which ceased operating at the end of March 1990. All four of these reactors are currently partially decommissioned. Other facilities on the site include an Active Handling facility, a Liquid Effluent Treatment Plant, a Tandem Van de Graaff accelerator and the HELIOS accelerators. There are also radiochemical laboratories and waste stores.

Whereas much of the early work of UKAEA comprised classified work, a major regulatory change took place in 1990 with the licensing of the Harwell site under the nuclear installations act. UKAEA as site licensee retained responsibility for the licensed site, and for the decommissioning programme associated with the government research programme; particularly the test reactors, radioactive wastes, fuel reprocessing, and fusion research. AEA Technology plc is focused on commercial activities based on both nuclear and non-nuclear expertise. The site itself is changing rapidly, with multiple tenancy of the main site, and an active programme of development of science and technology centres both within and beyond the site perimeter.

Planning permission has also been granted for building new houses on the former southern housing area of the authority, located on the southern sides of the former air base. Parts of the airbase, outside the present perimeter fence, have been used for activities associated with the early nuclear research programme, and for disposal of wastes. The condition of these parts of the airbase, while not central to this study, is of interest to the Vale of White Horse District Council and others.

2.2 Present Activities and Harwell Site Facility Information

A number of facilities on the Harwell site with potential for explaining the airborne results were identified at an early stage in the study. These included the Building 462 (B462) Active Handling facility and associated complex, the Liquid Effluent Treatment Plant (LETP), Tandem Accelerator and HELIOS 1 & 2 (B418) accelerators.

The B462 Active Handling Facility building and complex contains storage and radioactive waste repackaging facilities, below ground storage silos, and ISO container storage within a fenced compound. The compound is situated in the centre of the Harwell site, between the MRC compound and the western perimeter.

The Liquid Effluent Treatment Plant (LETP) processes and stores liquid waste streams. It is located in a separate fenced compound to the north of the main site, although it is still part of the licensed site. The North Housing Estate and parts of the Harwell sports club border the LETP complex.

The inventories for both the B462 and LETP complexes include ^{137}Cs, ^{60}Co, ^{90}Sr (which has no associated gamma ray emission), and other fission products with identifiable gamma rays together with low energy scattered gamma components. At the time of the airborne survey significant quantities of Thorium waste were also stored in the complex.

The Tandem Van de Graaff Accelerator (B477) facility and the HELIOS 1 & 2 accelerators are used for commercial irradiation operations by AEA Technology and Electron Beam Irradiation Services (EBIS) respectively. The Tandem uses high energy proton beams, and the HELIOS machines are linear electron accelerators. The expected radiation from these facilities is bremsstrahlung and annihilation gamma rays of 511 keV. The Tandem is located at the eastern end of the site, just north east of the bus park, and the HELIOS accelerators are located in the southern part of the site, near the perimeter fence adjacent to the RAL site. The Tandem accelerator is located within approximately 50 m of the perimeter fence in a relatively open and accessible area. The HELIOS facilities share a common boundary with the RAL site in an otherwise relatively enclosed situation, although the Fermi gate entrance to the UKAEA site is quite close to these facilities.

The partially decommissioned DIDO and PLUTO Material Testing Reactors are located at the extreme south of the site.

A map showing the locations of these, and other, facilities is included in the back of this report.

2.3 The Rutherford Appleton Laboratory and other Facilities separate from the Harwell Site

The NERC RAL was set up in 1957 and occupies a site adjacent to the Harwell facility. The RAL contains the ISIS accelerator facility (building R55). This is situated near the HELIOS accelerators, the Harwell boundary fence being between both facilities. The ISIS accelerator is surrounded by a substantial earthworks to the west and SW sides, which has the effect of limiting off-site radiation exposures in southerly directions leading to Ridgeway farm and other accessible locations open to the public. The northern boundary is common to the Harwell site and is less well shielded.

The ISIS accelerator is used to generate high intensity neutron pulses. An ion source produces H^- ions which are accelerated to 665 keV in a pre-injector column. A second stage linear accelerator, comprising four rf cavities, accelerates the ions to 70 MeV. A very thin alumina foil strips the electrons from the ions, producing a proton beam which is injected into synchrotron, where they are accelerated to 800 MeV. The accelerator produces 50 pulses per second, each pulse consisting of 2.5×10^{13} protons and lasting 0.4 μs, which are focused onto a heavy metal spallation target to generate neutrons by chipping nuclear fragments from the heavy metal nucleus.

UKAEA owns land adjoining the Harwell/RAL sites including areas occupied by the National Radiological Protection Board (NRPB), Atlas Computing Centre, NIREX, and Medical Research Council (MRC) Radiation & Genome Stability Unit, and MRC Mammalian Genetics Unit. These sites are outside the licensed nuclear site, and are not regulated by the NII.

2.4 Current Regulatory Framework

The UKAEA holds the nuclear site licence for Harwell and is regulated by the Nuclear Installations Inspectorate (NII), part of the Health and Safety Executive. The UKAEA Safety Directorate is responsible for setting standards and policy. UKAEA as licensee is responsible for arrangements for complying with the Nuclear Installations Act through the site licence. The NII in turn has regulatory responsibilities for ensuring the adequacy of such arrangements.

Thus the use of radioactive material and the accumulation of radioactive waste at a licensed nuclear site is regulated by the NII, and this has been the case at Harwell since licensing in 1990. The discharge and disposal of radioactive waste from these sites are regulated by the EA under the Radioactive Substances Act 1993, the responsibility for authorization of such discharges having moved from Her Majesty's Inspectorate of Pollution to the EA in 1996. The EA requires Harwell to conduct appropriate monitoring of discharges in the vicinity of the site to demonstrate the effectiveness of controls.

The EA commissions independent monitoring to check on Harwell's returns and assess the exposure to the public, however this programme does not apparently include measurements of direct radiation at the perimeter fence. Radioactivity in foodstuffs and the food chain in the vicinity of the site is monitored by the Ministry of Agriculture, Fisheries and Food.

It can be seen from the foregoing sections that the nature of activities on the site and its vicinity, the associated corporate structure of the occupants and the regulatory framework have undergone significant changes in recent years. This itself has consequences in terms of radiation protection responsibilities for the workforces, and for members of the public. Moreover radiation protection standards themselves have undergone recent changes, as outlined below.

2.5 Radiation Protection Criteria

National regulations on radiation protection in most countries, including the United Kingdom, are based on the recommendations of the International Commission on Radiological Protection (ICRP). Exposure to ionising radiation is generally regarded as hazardous, leading to acute effects at high radiation exposures, and to increased risks of chronic effects (such as mutagenic effects) at low levels. The working assumption of the ICRP recommendations is that the probability of chronic effects is increased with increasing radiation doses at all levels, without thresholds. Thus a series of fundamental principles have been established which recognise the negative influence of radiation exposure. These are :

> **The justification of a practice.** Practices involving the use of ionizing radiation shall only be adopted if there is sufficient benefit to exposed individuals or society to offset the detriment it causes.
>
> **The optimization of protection.** In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposure should all be kept as low as reasonably achievable, economic and social factors being taken into account.
>
> **Individual dose limits.** The exposure of individuals resulting from the combination of all relevant practices should be subject to dose limits, aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable.

The dose limits incorporated into the UK Ionising Radiations Regulations 1985 (HMSO 1986) were adopted from the recommendations published in ICRP Publication 26 (ICRP 1977). However a re-evaluation of the risks of exposure to ionising radiation, following revised dosimetry and epidemiological studies of the effects of the nuclear weapons at Hiroshima and Nagasaki in the late 1980's have resulted in revised recommendations published in ICRP Publication 60 (ICRP 1990). Although UK legislation has yet to be updated to implement ICRP60 the National Radiological Protection Board has published recommendations re-affirming the three fundamental principles listed above, and proposing that UK dose limits be revised as suggested by ICRP60 (NRPB 1993a,b). Recommended dose limits (excluding natural radiation and doses incurred by medical treatment or diagnosis) are as follows. For occupationally exposed radiation workers the limit is 20 mSv yr^{-1}, averaged over 5 years with the dose in any one year not exceeding 50 mSv. For members of the public the dose limit is 1 mSv yr^{-1}.

ICRP60 also recognised the possibility of the combined effects of radiation exposure from more than one source of radiation, and recommended a system of dose constraints to prevent the cumulative exposure from exceeding dose limits. NRPB has recommended the adoption of a public dose constraint of 0.3 mSv yr^{-1} from any controlled source, where a controlled source is the sum of all operations at a single site under common management (NRPB 1993b).

Although these recommendations are not, at present, statutory limits in the UK they set clear radiation protection targets, which are being adopted by most nuclear operators and regulators. Moreover, a recent review of radioactive waste management policy (Cm 2919, 1995) has confirmed that the Government accepts the NRPB recommendation for a single dose constraint of 0.3 mSv yr^{-1} to be applied to existing facilities. This document also recommends abandoning the "target dose" of 0.5 mSv yr^{-1} (an interim concept applied temporarily by regulators between 1987 and 1995 both anticipating and following ICRP60), applied to integrated doses due to radioactive wastes and discharges from a single site, and replacing it by a "site constraint" of 0.5 mSv yr^{-1} to incorporate all sources including discharges from a single location arising from sites with contiguous boundaries which may be owned or operated by more than one organisation. It is not clear whether the "site constraint" - introduced in Cm 2919 to deal with privatisation of nuclear power stations - applies to the case of the Harwell site which has multiple organisations operating in an extended area, but does not have a contiguous boundary even for the licensed nuclear site. However the constraint of 0.3 mSv yr^{-1} for single sources will in any case apply to the features under consideration individually and collectively within this report. We have noted that UKAEA Safety Directorate adopted the 0.3 mSv yr^{-1} constraint level in 1997 (UKAEA 1997) in preference to the 0.5 mSv yr^{-1} target mentioned in earlier environmental reports.

For the purpose of the present study, it should be noted that whereas radiation exposure to the workforce on site may well be justified in some cases, by occupational benefits, and should be optimised and limited accordingly, the situation with regard to potential public exposure by radiation projected off-site is considered somewhat different. Such exposure may well not be justified - in that exposed individuals or society may not derive benefit from the associated activity and it may to a large extent be avoidable entirely by simple measures. It should accordingly be limited in a manner consistent with the new dose constraints.

Having noted these factors it is worth pointing out that radiation exposure at the lower dose constraint implies an extremely small risk to an individual, and that a dose increment of 0.3 mSv yr^{-1}, is a relatively small addition to the radiation exposure which most individuals receive from natural sources (2.2 mSv per yr^{-1}). Nevertheless ICRP have clearly stated that "The fact that a man-made practice involving radiation causes doses which are small in comparison with the background doses does not necessarily imply that the practice is justified" (ICRP 60, para C74, p192).

With this in mind it is clearly important that pathways whereby on-site activities can lead to possible exposure of members of the public in off-site locations are fully identified, and that all reasonably practicable steps are taken to eliminate unnecessary radiation exposure from them.

The radiation fields detected in the vicinity of the Harwell site are discussed relative to these radiological criteria in sections 5.2 and 6.

2.6 Published Information

Routine monitoring of radiation and radioactivity levels in and around the Harwell site is conducted by UKAEA. These consist of sampling of discharges of radioactive material into the atmosphere and into the Thames at Sutton Courtenay, and measurements of external dose rates using thermoluminescence dosimetry (TLD) monitors at 30 fixed locations on or within the perimeter the Harwell site, and a further 11 locations in the surrounding district. The results from bi-monthly TLD measurements are reported in UKAEA Harwell Annual Reports, *Radioactive Discharges and Environmental Monitoring*. Of these, stations 1-28 have shown levels near to natural dose rates (typically 40-60 nGy h^{-1}) over recent years, and have been used to form a "site average" statistic. The remaining 2 stations (29,30) which are close to the LETP have detected local dose rates of 200-400 nGy h^{-1} in recent years. These 30 data points account for the airborne gamma spectrometry signals detected near the LETP in September 1996 but not for the signals recorded from the other areas, which appear to represent radiation fields of equal or greater magnitude.

Additional monitoring by health physics staff using portable dose meters is conducted on a regular basis at various locations; the results of these measurements have not been published but have been made available for this study. Further details of the routine on-site and perimeter monitoring, including measurements recorded at the time of the airborne survey, are given in chapter 4 of this report.

Monitoring of radioactivity in food and associated food chains is conducted by the Ministry of Agriculture, Fisheries and Food under the Terrestrial Radioactivity Monitoring Programme (TRAMP). These results are published annually in *Terrestrial Radioactivity Monitoring Programme: Radioactivity in food and agricultural products in England and Wales* (until 1994), and *Radioactivity in Food and the Environment* (after 1995).

The Department of the Environment, Transport and the Regions commissions independent monitoring of radioactivity in the air, including deposition, and drinking water. The information from these programmes is reported annually, and reports are placed in the public domain; however again there is little information concerning direct radiation projected at the site boundary. During the course of this study unpublished perimeter monitoring data collected by Tracerco under contract to HMIP (DOE) between 1989 and 1994, for the purpose of regulatory checks, were made available. These data are discussed further in sections 3 and 4.

An assessment of the radiation doses to members of the public around Harwell, Aldermaston and Burghfield (Dionian *et al*, 1987) was conducted in response to an increase in the rate of childhood leukaemia in west Berkshire. This report concentrated on exposure to populations 5 km from these sites, and the only external exposure pathway considered to be significant was that due to ^{41}Ar, principally discharged from BEPO prior to 1968. Although this report does not specifically assess radiation doses received due to external radiation at the perimeter fence of the Harwell site, it does contain extensive assessments of the exposure to the public from natural sources, weapons fall-out and activities at these nuclear sites during the period 1947-1985.

A more recent assessment by NRPB (Robinson et al, 1994) gave more attention to direct radiation exposure pathways, recognising that the reduced levels of radioactive discharges following reactor closures in 1990 increased the contribution to the total dose by such pathways. This dose assessment of direct radiation was based on a survey conducted in 1992 by NRPB, which has not been published, but the results of which have been made available to this study. The survey comprised dose rate measurements at 43 locations in the vicinity of the site taken over a 2 day period in July 1992. These data show similar enhancements (approximately 200-300 nGy h^{-1}) in the vicinity of the LETP as seen in the UKAEA programme. There are slight indications of enhancements (20-30 nGy h^{-1}) to an area to the east of the partially decommissioned Material Testing Reactors. However the Tandem, ISIS/HELIOS, and B462 signals were not detected in this survey. The principal area where off-site direct radiation was recognised in the 1994 dose assessment was thus around the northern boundary in the vicinity of the liquid effluent treatment plant.

2.7 Recent Monitoring

On 7th March 1997 following publication of the results of the airborne survey, a survey of the interior of the site perimeter was conducted by UKAEA using portable dose rate meters. Locations where dose rates exceeded 60 nGy h^{-1} (which approximates to the normal background in the area) were noted. At this stage the Tandem accelerator was not operating, the other accelerators appear to have been operating at the time. Additional health physics measurements in the vicinity of the Tandem were taken later on when the machine was operating.

The Health Physics section of the Rutherford Laboratory also undertook a series of perimeter measurements in response to the airborne survey, which have been made available to the study. A collimated NaI detector was used to measure dose rate originating at each one of the 720 fence posts surrounding the site. Where intense signals were recorded the dose rates were calibrated using an ionisation chamber.

Further details of these additional measurements are given in section 4 of this report.

3. AIRBORNE SURVEY PERIMETER FLIGHTS OF HARWELL AND RAL SITES

3.1 Introduction to the Airborne Survey

An airborne gamma-ray survey, commissioned by Newbury District Council and Basingstoke & Deane Borough Council, was conducted in September 1996. The primary aim was to characterise the general radiation environment of Newbury District and surrounding areas, and provide a radiological context for the ground survey conducted in September 1996 by Southampton University (Croudace *et al*, 1997a, 1997b). A vehicular survey of Greenham Common by SURRC was carried out in December 1996. The results of these three surveys were presented in February 1997 (Croudace *et al*, 1997a) with the final reports in June 1997 (Sanderson *et al*, 1997a, Croudace *et al*, 1997b).

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) and has been used for a variety of purposes (Sanderson *et al*, 1988-1996).

The main survey area comprised a 40x23 km area in Newbury District with a 5x22 km southern extension into parts of Basingstoke & Deane and was surveyed at 300 m line spacing. Detailed areas of interest were defined around Newbury, Thatcham and Greenham Common, where a 9x6 km box with 50 m line spacing was flown, and around the vicinities of Harwell, Aldermaston and Burghfield. 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 and thorium activity, 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.

A sequence of gamma ray spectra, positional information and ground clearance data were recorded simultaneously and used to quantify levels of individual radionuclides and the general gamma radiation environment. 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 was deployed. Differential satellite navigation systems were used to position the aircraft and locate the data with a precision of ±5-10 m. Gamma ray spectra were recorded every 3 seconds in the NaI spectrometer, and every 6 seconds in the pair of Ge detectors. The aircraft used was a twin engine AS355 Squirrel helicopter of a type used for air ambulance and police work at low levels in urban areas. CAA exemptions were obtained to permit low flying down to 200 feet ground clearance over the general area, and the urban areas of Newbury and Thatcham, supported by a safety case by the aircraft operator and a public interest case from Newbury District Council. Permission was granted to fly within the Harwell air exclusion zone, up to the perimeter of the licensed nuclear site, but not on this occasion to fly within the boundaries of the licensed site. The flight plans were agreed with the Safety Directorate of UKAEA.

The survey of the vicinity of the Harwell site was conducted on September 25 1996, commencing at 16:00. Flights comprised four circuits of the Harwell perimeter at increasing distances from the fence, taking about 20 minutes, and general infill flying in the surrounding 3x3 km box, taking a further half hour. A complex series of spectral features was recorded, particularly in the first 3 circuits, including machine signals and isotopic sources. The largest of these represent significant dose increments above natural levels at the aircraft position, originating from 4 or 5 main areas. Monitoring data published by UKAEA identified only one of these features. The first report on the Newbury airborne survey (Croudace *et al*, 1997a) recommended a further investigation, taking account of local shielding and ground level geometry to ensure that all relevant features were identified in ground based dose assessments. Section 4 reports the results of a variety of ground based measurements from several sources, including a vehicular survey of the areas around the Tandem accelerator and other locations conducted by the SURRC in June 1997. The airborne results are considered in more detail below to identify and group the observed radiation anomalies, with a view to establishing their origins.

3.2 The Survey Findings

Figure 3.1 shows an enlarged colour map of the main areas of enhanced gamma dose rate in the Harwell vicinity measured by the airborne survey. The dose rate shown is based on a calibration assuming an infinite planar source, which is appropriate to general conditions around open areas. However in the case of finite sources, such as those facilities on site presumed to have generated the signals observed, the relationship between airborne and ground based dose rate levels is different, and therefore this representation should be used primarily to locate the anomalies rather than to quantify their dose rates, which would generally be underestimated using this standard calibration. Note that no observations were taken within the Harwell nuclear site, and therefore contours within the unmapped area do not predict local levels. Moreover the combination of GPS errors, the spatial response of the airborne detectors, and the absence of readings directly above the sources means that the results show which areas around the site are subjected to radiation, but does not directly identify the origins or locations of individual sources.

The airborne results show 4 principal areas where off-site radiation produces prominent radiometric signals, and a further 2 areas associated with minor signal levels. These 4 areas correspond to (i) the area to the south of Tandem Van de Graaff accelerator, (ii) the area between the ISIS accelerator (Rutherford Laboratory) and the UKAEA materials processing facilities (HELIOS), (iii) areas to the W and NW of the site perimeter influenced by the presence of stored radioactive materials in the B462 complex and (iv) areas adjacent to the liquid effluent treatment plant (LETP) to the north of the main site. The minor signals were detected to the SW of the reactor blocks, and to the E of the Rutherford laboratory.

A colour encoded spectral plot of the first 500 spectra recorded during the airborne survey is shown in figure 3.2, from which eighteen features have been identified, A to R. Figure 3.3 shows the locations of these features, where it is clear that they are associated with five areas around the site, except for feature O. The characteristics of these features are summarised in table 3.1, which also includes timing information. The 18 features were found to correspond to locations, most notably at, the Tandem Van de Graaff accelerator (A,F), ISIS/HELIOS (RAL/Harwell sites respectively) accelerators (B,G,K), west and slightly NW of B462 Active Handling Facility (D,I,P and E,J,M respectively), and at the Liquid Effluent Treatment Plant (N,R,Q). Lesser features are also apparent to the west and SW of the partially decommissioned research reactors (C,H,L) as well as a broad generalised signal on the RAL Sports field (O). Profile plots and flight details are given in Appendix A.

The signals from the area to the south of the Tandem accelerator (A,F) are characterised by scattered radiation at all measured spectral energies up to, and presumably above, 3 MeV. This indicates a machine source for the radiation.

The first two of the four circuits flown around the Harwell site, corresponded to periods when the ISIS accelerator was operating. The spectra recorded include all energies up to 3 MeV, and also annihilation gamma-rays (B,G). A minor ^{60}Co signal was observed immediately after the helicopter had passed the main radiation signal, which has been associated with material stored in one of the buildings to the SW of the ISIS accelerator. Based on timing information subsequently obtained from the Rutherford Laboratory the ISIS accelerator was not operating during the third and fourth circuits. The signal in the vicinity of ISIS appears to have reduced to approximately 20% of that recorded from the previous circuits, and to comprise mainly scattered photons (K). This may be due to a combination of spatial variations, and the residual signals originating from the HELIOS accelerators on the Harwell site, in which case is suggests that the major dose contributor to these locations is ISIS, but that HELIOS also contributes.

To the west of the Reactor buildings, in the SW area of the Harwell site, there appears to be a small scale signal (C,H,L) which could potentially arise either from radiation projected off, or even through the site from RAL, or from local contamination at ground level. The spectral characteristics of the airborne observations showed a component of low energy radiation, and that the feature was not a natural U,Th or K anomaly. It is also apparent from figure 3.1 that the feature is at most a minor enhancement to local dosimetry. However the location close to the reactors, and spatial pattern suggested the possibility of an origin associated with the site.

To the west and NW of the site, in the vicinity of the B462 complex, two major radiation features can be identified from figures 3.1 and 3.2. On the western side of the site (D,I,P) there was considerable spectral evidence of thorium series activity and scattered radiation; whereas slightly further north (E,J,M) the signatures showed evidence of ^{60}Co, ^{137}Cs and scattered radiation during the first circuit. It was thus assumed that these two sets of features originated with radioactive waste materials stored on site in the B462 and ISO compound, which is used to store International Standardisation Organisation approved containers.

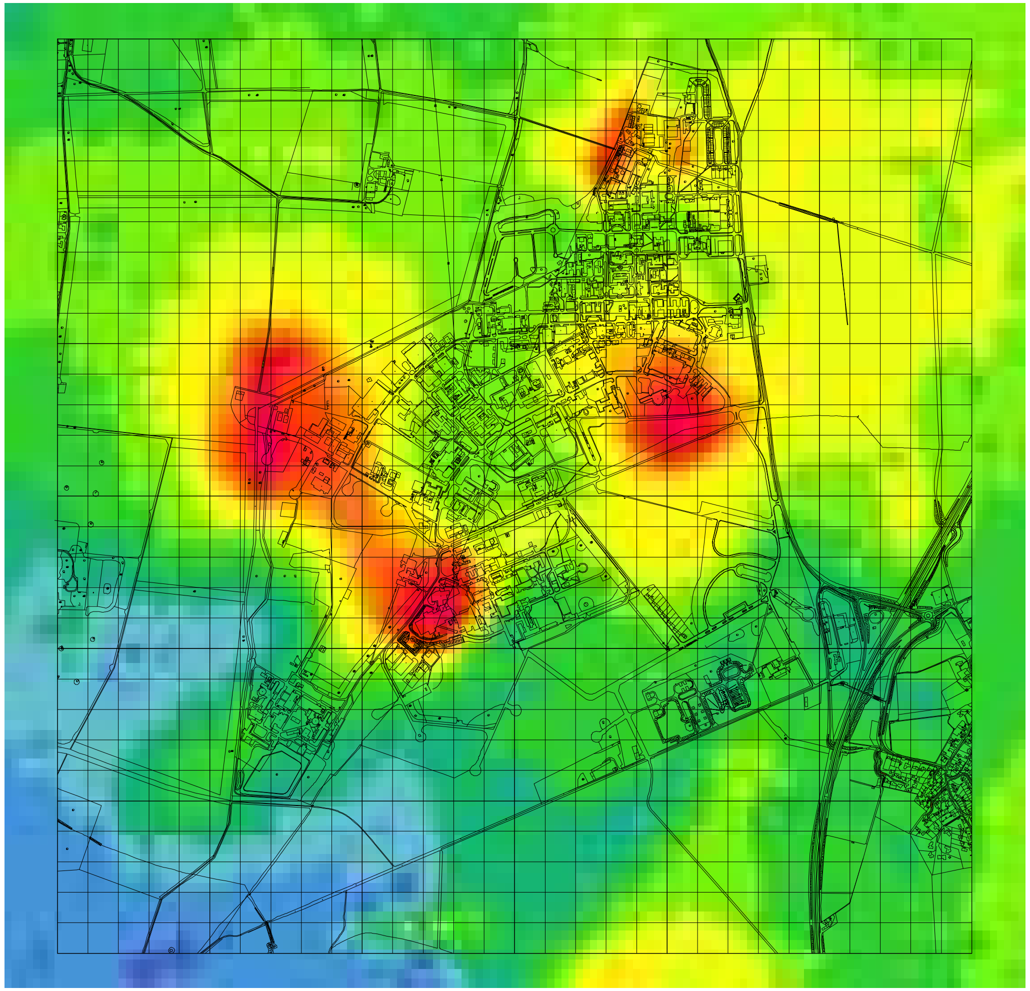
In the vicinity of the LETP, there was evidence of significant ^{137}Cs signals, and also ^{60}Co in the profile plots (N,Q,R), both of which might be expected in the waste treatment residues. Finally in the vicinity of the sports field to the east of the RAL a minor anomaly (O), with no specific spectral characteristics was noted.

This analysis has defined the nature of the signals recorded on 25th September more fully than in the Newbury report, and has associated them with areas on the Harwell complex, and identified their main characteristics. The majority of these signals were recorded in the first 500 spectra - over a 20 minute period, thus representing a short "snapshot" of the radiation environment of the site. Even during this short period changes in the radiation environment due to accelerator shut-down at RAL were noted, and have influenced the results. This draws attention to both the spatial variations in the radiation dosimetry of the site, and its dynamic nature - features which have been encountered elsewhere in the study, and to which routine and regulatory monitoring should adapt.

Airborne Survey 25 September 1996:

Gamma ray dose rates around Harwell & RAL sites

Scottish Universities Research and Reactor Centre



Gamma (mGy yr-1)

Gamma (mGy yr-1)
> 0.39
0.36 - 0.39
0.33 - 0.36
0.30 - 0.33
0.27 - 0.33
0.24 - 0.27
0.21 - 0.24
0.18 - 0.21
0.15 - 0.18
0.12 - 0.15
0.09 - 0.12
0.06 - 0.09
0.03 - 0.06
< 0.03

Calibration based on infinite plane source

AIRBORNE MEASUREMENT LOCATIONS

Figure 3.1 Enlarged colour map of the main areas of enhanced gamma dose recorded during the airborne survey.

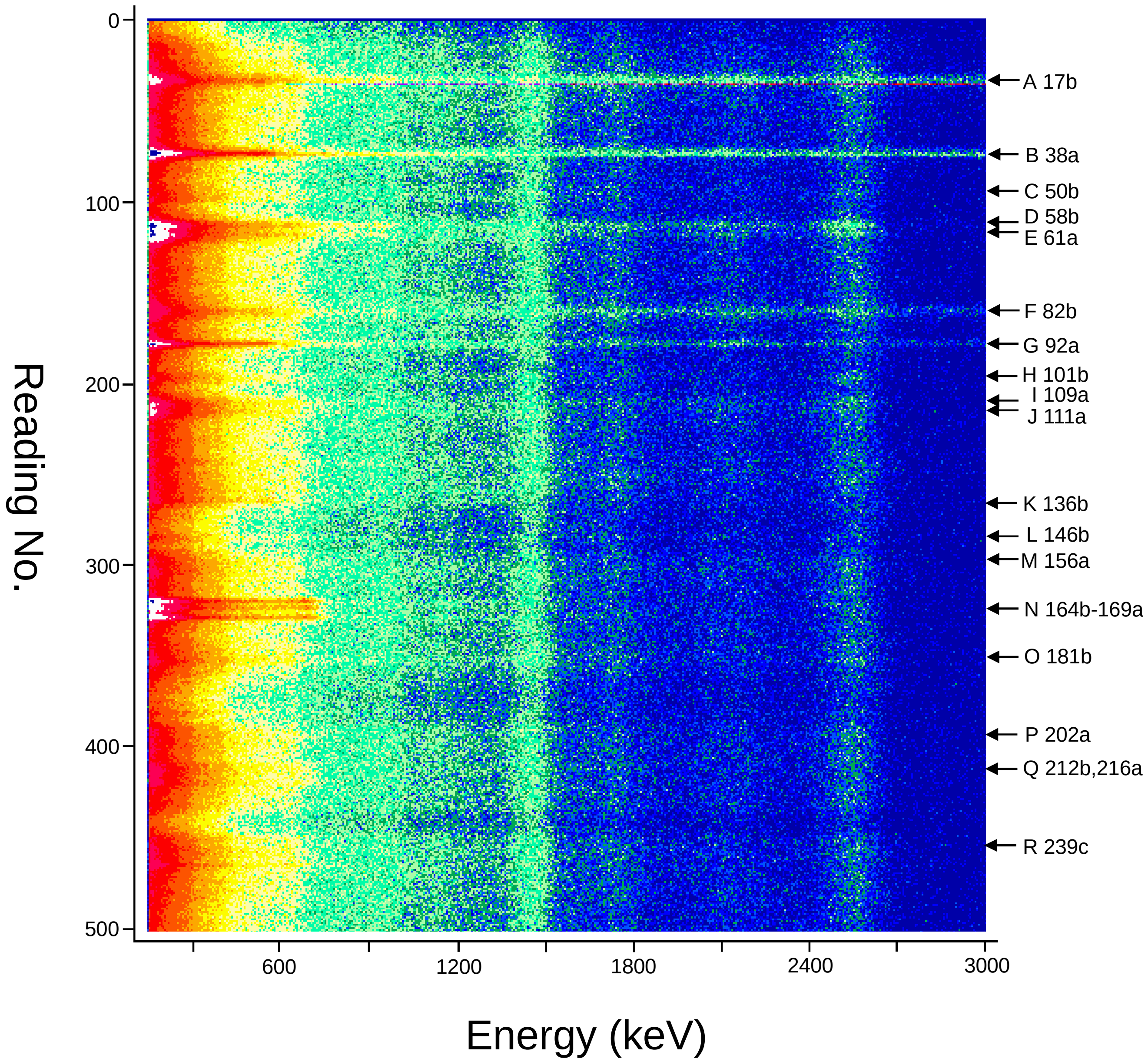
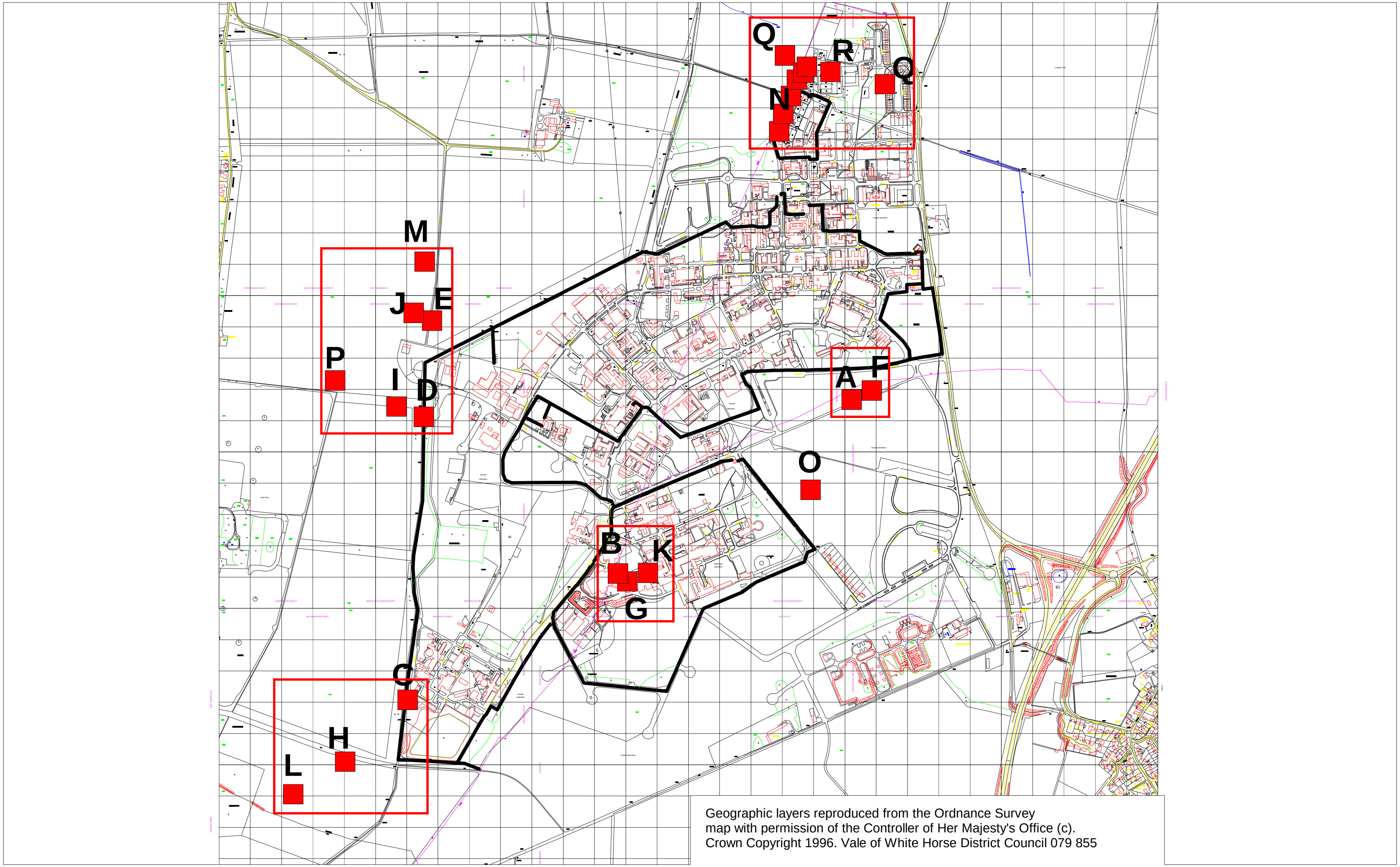


Figure 3.2 Colour encoded spectral plot of the first 500 spectra from the airborne survey, identifying 18 features. The plot shows a series of spectra from top to bottom. The colours indicate the number of counts in each channel, with blue the least counts increasing through yellow, red and white with black as the maximum. The full energy peaks for some radionuclides are indicated, the scattered components of high energy gamma rays appear as horizontal bands across the plot.



Geographic layers reproduced from the Ordnance Survey map with permission of the Controller of Her Majesty's Office (c). Crown Copyright 1996. Vale of White Horse District Council 079 855

Figure 3.3 Locations of eighteen features, A to R.

Table 3.1 Harwell and RAL site features observed from airborne survey.

Map Location	Reading No.	Spectrum No.	Time	Feature
A	34	17b	16:02:10	Near Tandem accelerator, spectra include all energies up to 3 MeV.
F	164	82b	16:09:22	Near Tandem, spectra include all energies up to 3 MeV.
B	75	38a	16:04:26	Near ISIS/HELIOS accelerators, spectra include all energies up to 3 MeV, complex spatial peak with two components. Minor ^{60}Co signal.
G	184	92a	16:10:25	Near ISIS/HELIOS and feature B. Max. intensity approx. 60-70% of B. Evidence of ^{60}Co close by.
K	272	136b	16:15:18	Near ISIS/HELIOS. Signal is approx. 20% of feature B: ISIS believed to be off. High energy photons no longer present.
C	100	50b	16:05:49	To the west of reactor buildings, mainly low energy scatter or ground contamination.
H	202	101b	16:11:27	SW of reactor buildings: mainly scattered radiation or ground contamination.
L	292	146b	16:16:23	Near feature H. Similar characteristics.
D	116	58b	16:06:42	SW of B462. Evidence of Th-series activity, scattered radiation, part of extended feature with two main peaks.
E	121	61a	16:06:59	West of B462, evidence of Th-series activity, ^{60}Co & ^{137}Cs.
I	217	109a	16:12:16	SW of B462, associated with feature D. Similar spectrum, although more scattered radiation; peak intensity <50% of D.
J	221	111a	16:12:30	Associated with E. Slightly elevated overall levels on the third circuit until K. Note no pronounced signal when passing Tandem at 16:14.
M	311	156a	16:17:26	N of features E and J. Slight evidence of ^{60}Co and scattered radiation.
P	403	202a	16:22:29	Associated with features J & I, W of B462.
N	328-337	164b-169a	16:18:22 -16:18:53	West side of LETP. Mainly ^{137}Cs with some evidence of ^{60}Co.
Q	424,431	212b,216a	16:23:38, 16:24:01	Near LETP, associated with feature N.
R	477	239a	16:26:32	Near LETP, associated with features N and Q.
O	362	181b	16:20:15	Broad generalised signal, approx. 400m SSW of Tandem (600m ENE of ISIS). Mainly scattered radiation.

4. GROUND BASED MONITORING

4.1 UKAEA Ground Based Observations

4.1.1 Routine Surveys

Routine monitoring of the site by UKAEA includes monthly readings from 30 fixed TLD stations placed mainly around the site perimeter, and regular health physics surveys with portable dose meters around areas on-site known to be associated with enhanced dose rates. Data from the TLD monitoring stations for the period October 1986 to April 1997 and from the dose meter measurements for 1996 have been provided by UKAEA.

The Tandem Van de Graaff accelerator (B477) was operating during the time of the airborne survey, and on one day of the vehicular survey. On 25th September 1996, the Tandem was producing 8.86 MeV protons, reaching a maximum of 11 MeV. The two nearest TLD stations gave dose rates of 68-74 nSv h^{-1} during August 1996, levels which are close to natural background dose rates, and lower than implied by the airborne results for the general area. The TLD stations are situated some distance away from the Tandem building. The TLD's time average the local radiation environment and therefore, unless the machine is in full time operation, it's contributions to the integrated measurements will also be diluted relative to the natural radiation fields. It was not clear therefore whether positioning of TLD measurements, the effects of a low operational duty cycle on time-integrated measurements, or the influence of local ground level shielding in protecting the area relative to what was observed from aircraft heights, explained the difference between airborne measurements and the TLD results.

HELIOS 1 and 2 (B418) provide commercial irradiation operations for AEA Technology. The two machines have different beam orientations; HELIOS 1 produces a 20 MeV horizontal beam, and HELIOS 2 a downward 10 MeV beam. There are 2 TLD stations in the vicinity of the HELIOS accelerators and the boundary with the Rutherford laboratory. Health Physics measurements were also taken at 7 positions close to the HELIOS accelerators in February, March and April 1997. Of these measurement point 3 appears to consistently produce higher dose rates than the others; 240 nSv h^{-1} (24th April 1997), 110 nSv h^{-1} (22nd March 1997) and 100 nSv h^{-1} (25th Feb. 1997). This measurement point is on the northern side of building B418, towards the centre of the site. The two TLD stations gave dose-rates of 71 and 62 nSv h^{-1} during August 1996. These are positioned along the perimeter fence between the HELIOS and ISIS (RAL) machines. Again these routine measurements did not identify significant ground based signals projecting across the Harwell/RAL boundary.

The B462 Active Handling Complex is a separately fenced facility within the licensed nuclear site. There are underground storage silos for waste materials, and alongside the complex is a fenced ISO container compound. Within this complex there are 46 routine monitoring points immediately around the boundary of B462 and ISO compound. There is also a perimeter TLD station (no. 16) at the site fence. The health physics surveys of September 1996 show a mean of 1026±210 nSv h^{-1} for the 46 locations, with the highest levels at points 23 (6000 nSv h^{-1}), 35 (4000 nSv h^{-1}), 36 (7000 nSv h^{-1}) and 37 (3000 nSv h^{-1}). The fence perimeter TLD (station 16) gave 83 nSv h^{-1}. The October survey clearly showed a great reduction in levels at all the high value points previously measured in September, with a reduction in the mean to 490±71 nSv h^{-1}. This reduction is the consequence of disposal of radioactive wastes off-site, and the re-arrangement of stored materials on-site. The surveys are conducted on a monthly basis, but do not include perimeter measurements in the western and NW directions. Monthly measurements on-site throughout 1996 show variations from 500 nSv h^{-1} to 20,000 nSv h^{-1}, with both peak levels and positions changing frequently. It is not clear that the surveys are directly synchronised with the movements of radioactive waste, although consideration of perimeter implications of such movements would seem appropriate, given the proximity of the complex to SE and NW perimeters.

The LETP is part of the nuclear licensed site, but a separately fenced area to the north of the main Harwell site, and provides storage and processing of liquid waste streams. The perimeter fence of this area is one of the areas monitored using portable dose meters on a monthly basis. There are 21 perimeter monitoring points and 3 TLD stations in or near the LETP complex. The dose-rates recorded on 24 September 1996 (one day before the airborne survey) varied from 150 to 300 nSv h^{-1}, with a mean of 210±11 nSv h^{-1}. The TLD stations produced results ranging from 60 - 240 nSv h^{-1} for August to September 1996, with higher readings on the west side of the LETP. UKAEA also provided information regarding monthly health physics survey results over the period 20th April 1995 to 4th April 1997, and on TLD results from 1986 to April 1997. The mean values of instrumental readings since 1995 have been around 210 nSv h^{-1}, with a range of readings from 100-1500 nSv h^{-1}. Over the longer term it is apparent from the published TLD results that LETP dosimetry was higher before 1990, with dose rates from 600-2500 nSv h^{-1} recorded during the period when the research reactors were operating, and that there has been an overall reduction in levels over the last 5-7 years. The LETP area is close to parts of the northern housing area, and to tennis courts to the north of the main site. While the location in proximity to occupied areas is less than ideal, it is clear that dose rates are generally reducing, and also that the feature has been well recognised in both UKAEA monitoring programmes and in the recent NRPB critical group dose assessment (Robinson et al, 1994).

4.1.2 Special Health Physics Surveys, March-April 1997

Following publication of the airborne survey results, UKAEA conducted an additional survey on the 7th March 1997. The locations where dose rates exceeded 60 nSv h^{-1} were recorded and results provided for this study. The Tandem accelerator was not operating on this day, and therefore no features were reported in this area.

Dose rate readings on the eastern perimeter approach to the B462 complex were recorded ranging up to 450-600 nSv h^{-1}. In the vicinity of the HELIOS accelerators and ISIS boundary fence dose-rates of up to 800 nSv h^{-1} were recorded in small areas. One point with a dose rate 100 nSv h^{-1} was recorded by the main site perimeter in the area to the south of the shops and LETP.

A further survey was subsequently conducted near the Tandem accelerator during full energy operation. The accelerator building has an external shield wall at ground level, thicker in the eastern quadrant, presumably constructed to provide shielding in directions to the south and east of the facility. Measurements were taken at 25 points along the perimeter, against the shield wall at ground level, and above the shield wall. The dose-rates in the worst case operational situation is 6000-8000 nSv h^{-1} above the shield wall, this radiation shines in an upward direction so has little effect on ground level dosimetry. At ground level close to the shield wall peak dose rates of 400 nSv h^{-1}, were recorded in southern directions, reducing to 200-300 nSv h^{-1} at the perimeter. It is apparent from these data that the TLD stations are located too far to east and west of the facility to respond to the radiation field from the accelerator.

4.2 RAL Surveys March 1997

The Rutherford Appleton Laboratory provided dose-rate measurements at the RAL fence adjoining the Harwell site measured by health physics staff in March 1997. A collimated NaI detector was used to measure dose rate at each one of the 720 fence posts surrounding the site. Where intense signals were recorded the dose rates were calibrated using an ionisation chamber. An uncertainty of ±50% was quoted to take account of issues surrounding calibration of dose rate measurements in such mixed energy radiation fields, and uncertainties in the background subtraction.

The site perimeter on the southern and SW edges near the ISIS accelerator is protected by a massive earthworks, constructed to provide passive shielding from the beam ends. In these directions, and also to the east of the Rutherford laboratory complex perimeter dose rates were reported as indistinguishable from natural background levels. However along the boundaries with the Harwell site, and the area close to the Fermi Gate access to the Harwell site, elevated signals were detected. Between fence numbers 511 and 579, approximately opposite buildings R45 and R52, elevated dose rates were observed with two maxima, the first of approximately 100 nSv h^{-1} more or less opposite the end of building R55 - the main accelerator target hall, the second a broad peak reaching a maximum of about 600 nSv h^{-1} slightly to the east of the main control room entrance. A third, very localised, peak was observed on a single fence post (no. 596) of approximately 350 nSv h^{-1}. This last feature was located quite close to the Fermi gate.

The overall pattern appears to be spatially consistent with the profiles detected from the airborne survey, which showed two peaks in approximately the same relative intensities. The highly structured signal near the Fermi gate was not spatially resolved in the airborne survey data set.

It is understood that the highest and most strongly collimated signals are believed to be associated with the pre-injector to the accelerator - which is less heavily shielded than other machine parts.

4.3 HMIP Perimeter Monitoring (1989-1994)

Perimeter monitoring was conducted by Tracerco under contract to Her Majesty's Inspectorate of Pollution annually between 1989 and 1994, when it was discontinued in recognition of the NII role on the Harwell site. These consisted of measurements of dose rate at 64 locations around the perimeter of the main Harwell site, the Liquid Effluent Treatment Plant and the Southern Storage Area. These readings were not published at the time, but have been made available for this study by the Environment Agency, and are given in table 4.1. The sequence of measurements proceeds essentially clockwise around the main perimeter. It appears that the data have not been subject to subtraction of the detector background and cosmic ray response, therefore the readings of 70-80 nGy hr^{-1} probably represent the combination of natural gamma ray background and cosmic ray exposure.

The survey data are valuable in drawing attention to the changeable nature of individual features. Moreover these data have responded at times to some of the features detected by the airborne survey, which appear not to have been represented in other contemporary data sets.

Examples of this can be seen in the area between the ISIS and HELIOS accelerators, where position 18 has recorded dose rates of 950 nGy h^{-1} (1989), 1200 nGy h^{-1} (1990), 330 nGy h^{-1} (1992) and 670 nGy h^{-1} (1994). Similarly to the west side of the B462 complex position 35, ground level dose rates of 200-260 nGy h^{-1} were recorded in 1993 and 1994; levels for the previous two years were similar to natural background, and 160 nGy h^{-1} levels were recorded in 1989 and 1990. This position corresponds to the area where airborne features D,I and P were detected in September 1996. The monthly health physics monitoring on-site has shown that dose rates associated with stored materials had reduced between September 1996 and the March 1997 ground based survey. The check monitoring conducted on behalf of HMIP however shows that there have been periods before 1996 when ground level perimeter dose rates have both increased and decreased in this location, presumably as a result of waste movements on site. Results from the LETP area are generally consistent with other data sets.

Table 4.1 Results of HMIP commissioned perimeter monitoring programme 1989-1994.

Position	Dose Rate (μGy hr^{-1})						Location
	4/6/89	11/4/90	29/5/91	6/5/92	18/4/93	19/4/94	
1	0.05	0.08	0.073	0.07	0.06	0.08	Main Gatehouse
2	0.10	0.10	0.081	0.08	0.09	0.07	South of Main Gatehouse
3	0.09	0.10	0.072	0.09	0.08	0.06	Near Hangers 7 and 8
4	**0.11**	0.10	0.076	0.08	0.09	0.07	Near Roundabout
5	**0.11**	**0.11**	0.077	0.07	0.08	0.09	East of Tandem
6	0.10	**0.18**	0.072	0.07	0.08	0.08	West of Tandem
7	**0.25**	0.10	**0.204**	**0.12**	0.09	0.06	North Bus Park
8	0.10	0.10	0.068	0.08	0.08	0.06	North of Atlas Building
9	0.10	0.10	0.077	0.07	0.07	0.07	NW of Atlas Building
10	**0.12**	0.10	0.090	0.08	0.08	0.07	North of NRPB
11	0.10	0.10	0.077	0.08	**0.11**	0.07	NW of NRPB
12	0.10	0.10	0.079	0.07	**0.12**	0.06	East of B462
13	**0.11**	**0.11**	0.090	0.09	**0.12**	**0.23**	East of B462
14	**0.14**	**0.14**	**0.243**	**0.24**	0.10	**0.16**	East of B462
15	0.10	0.10	0.094	0.09	0.07	0.08	East of B462
16	0.09	0.10	0.072	0.07	0.07	0.08	HELIOS
17	**0.18**	**0.19**	0.080	0.08	0.09	0.08	HELIOS/ISIS
18	**0.95**	**1.2**	**0.209**	**0.33**	**0.24**	**0.67**	ISIS
19	**0.12**	**0.60**	**0.117**	**0.14**	0.09	0.10	Between RAL and MTRs
20	**0.25**	**0.15**	0.077	0.08	0.08	0.10	East of DIDO
21	**0.11**	**0.20**	0.076	0.08	0.09	0.07	East of DIDO
22	0.07	**0.15**	0.078	0.09	0.08	0.07	East of DIDO
23	0.09	0.10	**0.180**	**0.11**	0.07	0.08	East of DIDO
24	0.10	0.10	0.088	**0.13**	0.08	0.07	East of DIDO
25	0.10	0.10	0.083	**0.11**	0.08	0.06	East of DIDO
26	**0.12**	**0.12**	**0.104**	**0.34**	0.09	0.09	East of DIDO
27	0.08	**0.15**	**0.124**	**0.18**	0.08	0.06	South of MTRs
28	**0.12**	**0.12**	0.068	0.07	0.08	0.07	South of MTRs
29	0.10	**0.12**	0.076	0.08	0.08	0.07	West of PLUTO
30	0.10	**0.12**	0.075	0.07	0.09	0.08	West of PLUTO
31	0.10	0.10	0.091	**0.11**	0.08	0.08	West of PLUTO
32	0.10	0.10	0.067	0.07	0.08	0.09	W Perimeter of Main Site

33	0.10	**0.12**	0.065	0.07	0.08	0.07	W Perimeter of Main Site
34	0.10	**0.14**	0.072	0.07	**0.11**	0.10	W Perimeter of Main Site
35	**0.16**	**0.16**	0.080	0.08	**0.20**	**0.26**	West of B462 ISO Compound
36	0.10	**0.12**	0.087	0.08	0.09	0.08	WNW of B462
37	0.09	**0.12**	0.090	0.08	0.08	0.08	NNW of B462
38	**0.15**	**0.12**	0.091	0.08	0.09	0.08	NNE of B462
39	0.10	**0.12**	0.082	0.08	0.07	0.07	N Perimeter of Main Site
40	0.09	0.10	0.074	0.08	0.08	0.07	N Perimeter of Main Site
41	0.10	0.10	0.090	0.08	0.08	0.07	N Perimeter of Main Site
42	0.10	**0.12**	0.078	0.09	0.07	0.08	N Perimeter of Main Site
43	**0.12**	**0.15**	0.083	0.09	0.08	0.07	N Entrance of Main Site
44	**0.4**	**0.3**	0.072	0.08	**0.17**	0.09	N Perimeter of Main Site
45	**0.2**	**0.35**	0.066	0.09	**0.11**	0.09	N Perimeter of Main Site
46	**0.16**	**0.2**	0.078	0.10	**0.13**	0.10	S of Sports Field
47	**0.6**	**0.6**	0.076	0.08	**0.13**	**0.22**	West of LETP
48	**0.14**	**0.2**	**0.175**	**0.11**	**0.15**	**0.19**	West of LETP
49	**0.14**	**0.15**	**0.121**	**0.14**	0.10	0.10	West of LETP
50	0.10	**0.15**	**0.346**	**0.39**	0.10	**0.11**	West of LETP
51	**0.12**	**0.20**	**0.158**	**0.19**	0.09	0.08	West of LETP
52	**0.12**	**0.15**	**0.123**	**0.12**	0.08	0.07	West of LETP
53	0.10	**0.15**	**0.104**	0.10	0.10	0.09	East of LETP
54	0.10	**0.12**	**0.101**	0.10	0.08	0.07	East of LETP
55	**0.11**	0.10	**0.103**	0.09	0.08	0.07	East of LETP
56	0.10	**0.11**	0.075	0.07	0.08	0.07	E of Southern Storage Area
57	0.09	0.10	0.070	0.08	0.07	0.07	N of Southern Storage Area
58	0.10	**0.12**	0.077	0.08	0.08	0.07	N of Southern Storage Area
59	0.08	0.10	0.074	0.08	0.08	0.07	N of Southern Storage Area
60	0.10	0.10	0.076	0.08	0.08	0.07	W of Southern Storage Area
61	0.10	0.10	0.070	0.08	0.09	0.07	S of Southern Storage Area
62	0.10	0.10	0.081	0.07	0.08	0.08	S of Southern Storage Area
63	0.10	0.10	0.075	0.07	0.07	0.07	S of Southern Storage Area
64	0.08	0.09	0.067	0.08	0.08	0.08	E of Southern Storage Area

4.4 Vehicular Survey Details (June 1997 by SURRC)

The vehicular survey was designed to provide further detail of the radiation fields projected beyond the perimeter fence to supplement the existing ground based information described in the previous sections. Particular points of interest were to investigate the area to the south of the Tandem accelerator in off-site locations, to investigate the area to the W and NW of the site, and to attempt to separate the ground level contributions of the ISIS and HELIOS accelerators. Other areas of interest were the northern housing area, where the local authority had a particular interest in reviewing the relationship between the LETP source and housing, and areas of the former airfield. Of these the area surrounding feature "O" near the sports field to the east of the Rutherford laboratory had shown a small local anomaly from the airborne data. The local authority and UKAEA also asked for exploratory measurements to be taken at the surface of the old catapult pit on the airfield, and in the vicinity of the former southern housing area, where new housing developments are planned.

The survey dates, the 19th and 20th June 1997, were planned to coincide with a period immediately following ISIS maintenance, when it was hoped to be able to make measurements at a fraction of normal power, and thereafter at full power. In the event however the maintenance period had already ended at the start of survey, and apart from a few short periods when operation was temporarily interrupted in response to faults, this did not prove to be possible.

Approximately 7000 NaI spectra and 2900 Ge spectra were recorded in the course of the survey. Of these 1200 NaI and 600 Ge spectra were recorded just inside the perimeter fence, 340 NaI and 170 Ge spectra were recorded just outside the perimeter fence, and 5500 NaI and 2100 Ge spectra were recorded at other locations. The results from this survey are described in section 5.

4.4.1 The Vehicular Survey Area

The vehicular survey area consisted of inner and outer perimeter drives around the main Harwell site. In addition, the vehicle was driven along roads around the northern housing area near the Liquid Effluent Treatment Plant (LETP) and on the grass to the east of the LETP complex. Open areas to the south of the Tandem Van de Graaff accelerator and the RAL sports field were surveyed by driving parallel routes approximately 10 m apart. Additional attention was given to roads near the B462 Complex (Active Handling facility), between HELIOS 1&2 (B418) and ISIS R55 (RAL) accelerator buildings, and to the south west of the Research Reactors Division (DIDO, PLUTO). Measurements were also taken, with the vehicle stationary for short periods, at routine thermoluminescence dosimeter (TLD) stations. Figure 4.1 shows the perimeter survey routes and survey areas.

A summary of the route taken by the vehicular team is shown in Appendix C. This includes details of filenames, times of measurement, notes and observations made during the two day period 19-20th June 1997.

4.4.2 Equipment and Installation

The vehicular survey was conducted using a long wheel base Vauxhall Frontera 4x4 car.

The detector system deployed in this instance consisted of an 8 litre NaI scintillation unit securely installed on the car roof rails and a pair of HPGe GMX semiconductor detectors (50% relative efficiency) securely mounted on the rear spare wheel, in a downwards orientation. Differential GPS technology was used for positional information, using a NavStar XR-4G and Aztec RDS 3000v3 receiver. Positional accuracy was found to be variable (10 m - 100 m) depending upon prevalent satellite constellation and reception interference by nearby buildings.

The radiometric rack, containing data logging PC and power supplies was installed within the rear passenger compartment, and two new lead acid batteries provided continuous power operation for at least 6 hours use before recharge. Differential GPS and radio antenna's were placed on the vehicle roof. Liquid nitrogen for the semiconductor detectors was provided by RAL ISIS staff. Each GMX detector was attached to a 3 litre dewar, providing sufficient capacity for 24 hours use.

4.4.3 Survey Parameters

The vehicular survey was conducted at approximately 5-10 mph (8-16 kph), and where measurements were taken across accessible parts, at line spacings of about 10 m and consistent with a field of view of about 30 m for complete coverage. Radiometric readings were recorded in 5 and 10 second intervals by the NaI and GMX pair respectively. The gain of the ^{40}K peak (1461 keV) was continuously monitored for thermal gain shifts and adjusted accordingly.

At the start of each survey day, the energy resolution of the 8 litre NaI detector was checked. On the 19th June it was 9.9% at 661 keV; on the 20th June it was 9.7%. The combined energy resolution of the GMX pair was 2.3 keV at 661 keV. The Ge detectors were later found to be slightly mis-matched at energies above 1 MeV, this has no appreciable effect on the results.

4.4.4 Data Recording and Processing

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

The data reduction procedures follow a sequence of isolation and quantification of signals corresponding to individual radionuclides, and estimation of dose rate. Initial processing comprises extraction of count rate data from selected energy regions corresponding to the full-energy peaks for individual radionuclides. This takes place in real time during the survey, for predefined nuclides, and can be supplemented by full spectral analysis afterwards if required. The resulting summary includes individual count rates, positional information and time of measurement which are then processed through a sequence of stages and calibrated with estimates of ground radionuclide inventory. Firstly net count rates are obtained by subtraction of background values from recorded gross count rates. Secondly spectral interferences between nuclides are separated using a matrix stripping procedure. The data are then converted to calibrated activity per unit area, activity concentrations and dose rate values as appropriate. Data can be mapped rapidly at any stage of this procedure.

For this survey, spectral windows corresponding to ^{137}Cs (661 keV), ^{60}Co (1172 keV), ^{40}K (1461 keV), ^{214}Bi (1764 keV), ^{208}Tl (2615 keV) and total count rate 450-3000 keV (for estimation of dose rate) were predefined. A re-integration of the spectral data provided additional information in the region 40-3000 keV. Stripping coefficients used were measured at SURRC using a set of doped concrete blocks, a planar source of ^{137}Cs and point source of ^{60}Co, representing the likely spectral components measured at the detector heights utilised for this survey. Background rates used were those measured during the Newbury District airborne survey over water for a 16 litre NaI, and halved. This method provided count rates consistent with 8 litre NaI readings recorded during previous airborne surveys at Sellafield and in Nigeria (Sanderson *et al*, 1990; Sanderson & Allyson, 1991).

Radiometric maps were prepared from the calibrated data and positional information was transformed from latitude and longitude (WGS84 datum to OSGRS80 grid) to OS coordinate system by a reliable algorithm recommended by the Ordnance Survey. This gave a transformation to within 5-10 m accuracy, assuming that the original DGPS positional information was in itself accurate. During the survey DGPS signal degradation was observed, especially when near high structures or dense woodland. Local topography or poor satellite constellation coverage on occasions also reduced the DGPS accuracy.

Dose rate measurements were made using the NaI spectrometer and Type 680 Mini-monitor environmental radiation meters, owned by UKAEA Harwell and SURRC, near the Tandem accelerator on the afternoon of the 20th June 1997 in order to check the dose rate calibration.

Scottish Universities Research and Reactor Centre

Harwell Vehicular Survey
19-20 June 1997

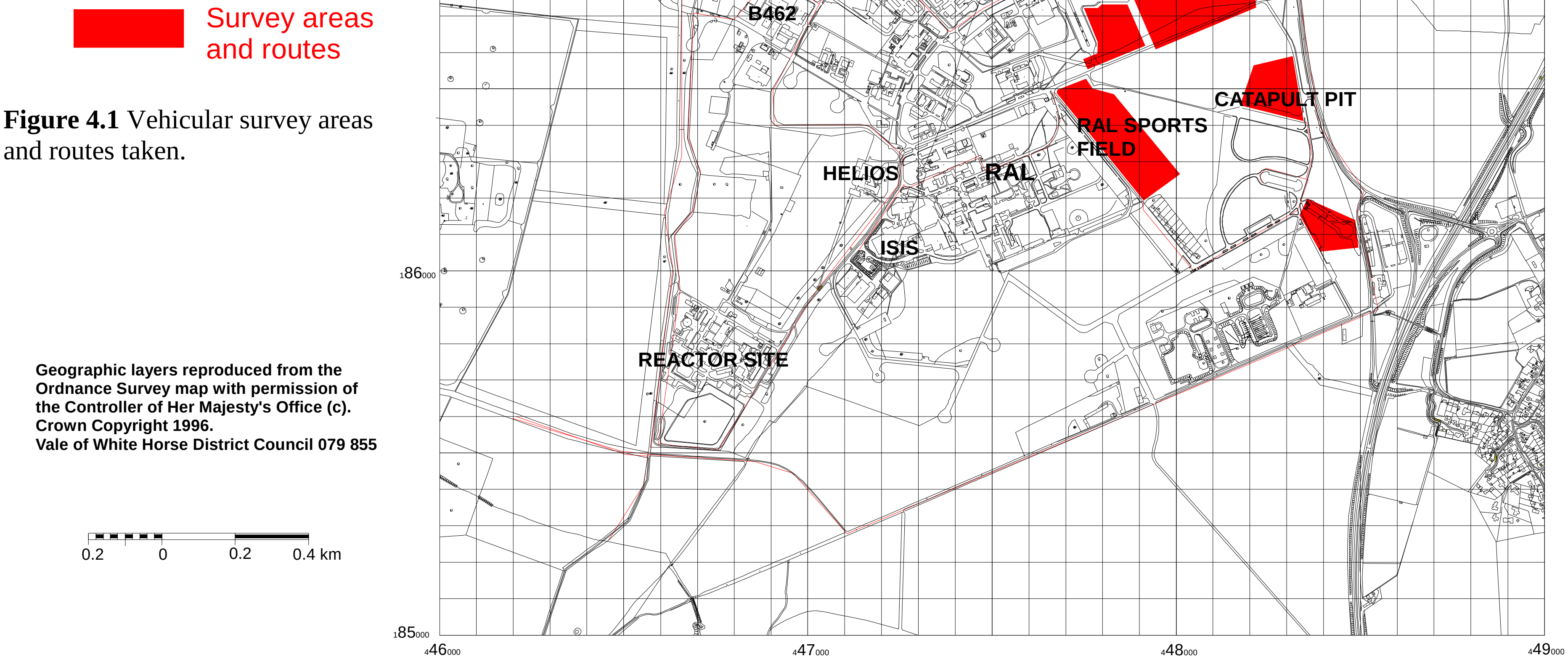


Figure 4.1 Vehicular survey areas and routes taken.

5. RESULTS AND DISCUSSION

This section presents the results of the vehicular survey, and compares them with the results of the other radiometric surveys that have previously been outlined. This data has been used to characterize the nature, extent and any potential radiological implications for the various radiometric features observed.

5.1 Discussion of Features

5.1.1 Liquid Effluent Treatment Plant (LETP)

The vehicular survey covered the readily accessible areas to the south and east of the LETP, which were potentially influenced by the known signals observed from airborne and ground based measurements. The results were consistent with expectations, in that readily detectable ^{137}Cs and ^{60}Co signals were observed in the vicinity of the facility falling off rapidly with increasing distance from the plant. The gamma ray dose rates determined from the vehicular survey are shown in figure 5.1. Maximum recorded levels measured by the vehicular survey near the LETP reached 285 nGy h^{-1} which are consistent with previously recorded levels. The vehicular survey also included extensive areas within the northern housing estate, where the dose rate due to the LETP was considerably lower (60-70 nGy h^{-1}), approximately the upper range of local background levels. A few small areas of enhanced activity were noticed in this area, which will be discussed further in section 5.1.7.

Previous UKAEA reports show that the levels at the TLD monitoring stations to the north and north west of the LETP to be vary between 170 and 480 nSv h^{-1} in recent years, but with levels up to 2200 nSv h^{-1} before 1987. The routine health physics survey conducted in September 1996 recorded levels between 150 and 300 nSv h^{-1}. The HMIP commissioned perimeter monitoring programme measured similar levels around the perimeter fence after 1991; one location having activities of 600 nGy h^{-1} in 1989 and 1990. The radiation levels recorded in the vicinity of the LETP have been falling over the course of recent years. As expected the airborne and vehicular results are highly consistent with the more recent of these observations.

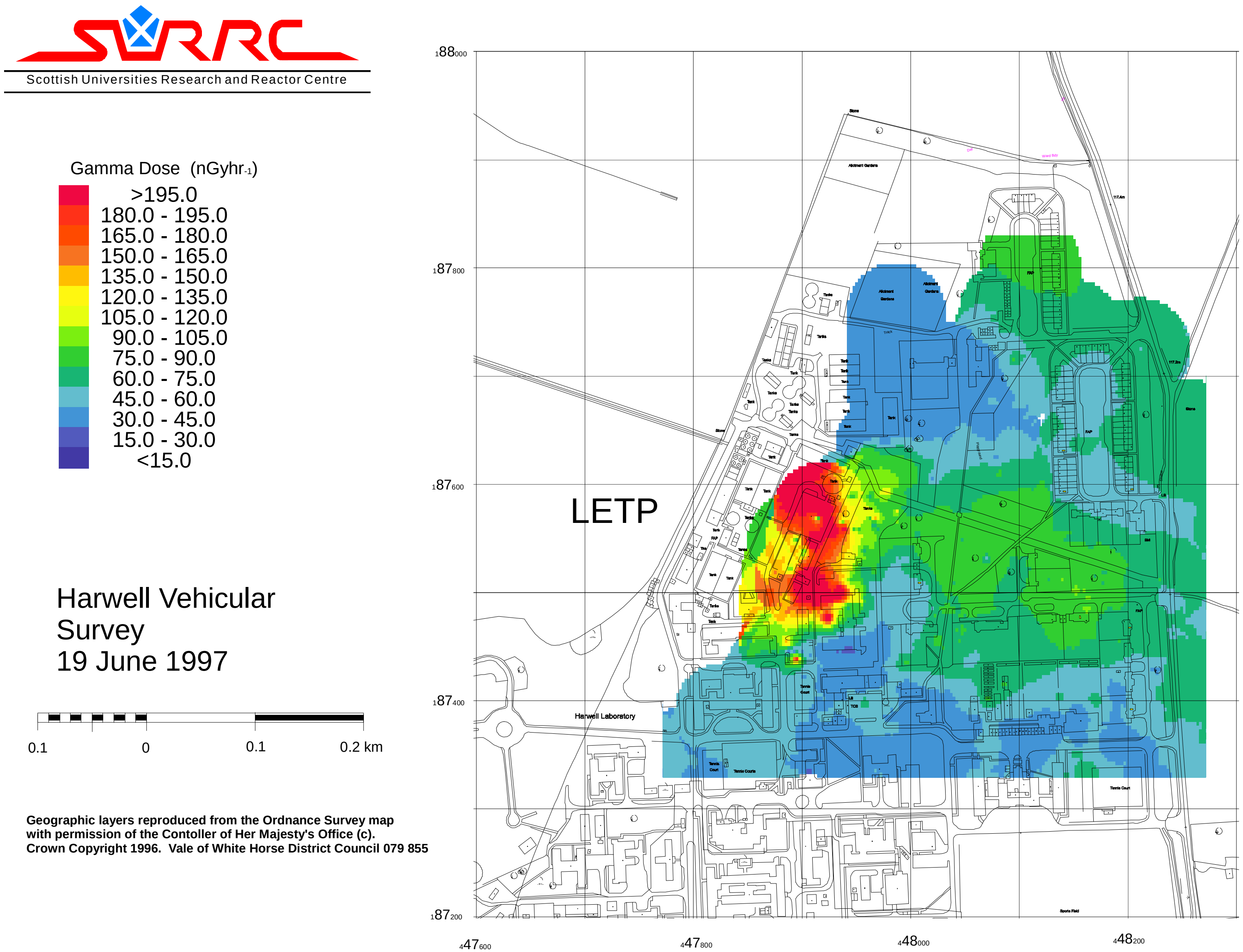


Figure 5.1 Vehicular gamma-ray map at the LETP.

5.1.2 Tandem Van de Graaff Accelerator

Vehicular measurements were conducted in the areas to the south and east of the Tandem accelerator on the 19th June, when the machine was operating at high power, and late in the afternoon of 20th June after the machine had been switched off.

The spectra recorded on 19th June showed a combination of scattered radiation and 511 keV annihilation radiation, consistent with the interactions from high energy photons. Examination of spectra up to 3 MeV produced evidence that the full energy distribution extended beyond the upper limits for these data sets. It has been estimated that 25-30% of the total gamma-dose is in the region 3-10 MeV. Data were corrected for this underestimate using the procedure described in appendix B. With this the maximum (corrected) result on the 19th June was 180 nGy h^{-1} (approx. ±25% uncertainty). With the Tandem operating, the dose rate levels were between 80 and 180 nGy h^{-1}. With the Tandem not operating the dose rate was around 40-50 nGy h^{-1}, corresponding essentially to the local gamma ray background from natural sources.

Gamma dose rate maps are shown in figures 5.2 and 5.3 for the operational and shutdown conditions, with the measurement position of each spectrum indicated. The measurement position is the calculated mid-point between where the spectrum was started and finished. The maps show variations in off site dose rate which appear to reflect the structure of the external shield wall behind the accelerator. It is notable that whereas the highest levels of off-site radiation occur in the southerly directions, the influence of the machine being readily detected out to 200-300 m, lower levels are seen in the easterly directions. This corresponds with directions where the curtain wall behind the machine is significantly thicker. It is moreover notable that the site boundary fence has been moved inwards recently on the eastern side, following demolition of light buildings originally positioned in the areas the SE of Hangar 8. It appears that one effect of the thicker part of the shield wall was to protect these older buildings from radiation arising from the accelerator.

Figure 5.4 shows the variation of dose rate with distance from the Tandem for segments to the south south east (100^o-160^o) and south (160^o-200^o) of the accelerator, and the dose rate for the area including both of these segments with the Tandem not operating. With the Tandem off the average dose rate was 46±7 nSv h^{-1}, the upper and lower limits being shown by the solid lines on the plot. The plots with the Tandem operating show the mean background and fits to inverse square functions, the dose rates for these plots having been corrected to account for the high energy component of the spectra.

Assuming the dose rate due to the Tandem follows an inverse square function of the form fitted to the plots in figure 5.4 it is possible to normalize the dose rates for the data to a single distance from the Tandem. Figure 5.5 shows the dose rate normalized to 100 m for all the readings within 200 m of the Tandem plotted as a function of bearing from the Tandem. It can be seen that there is a maximum dose at about 160^o.

The two TLD stations near the Tandem (numbers 27 and 28) have recorded dose rates between 40 and 100 nSv h^{-1} in recent years. These stations can be seen to be placed too far to the east and west of beam centre to have recorded maximum dose rates. Their measured values are however consistent with vehicular results for those positions. As noted in section

4.1.2 the health physics survey conducted by UKAEA after the airborne survey showed dose rate levels between 100 and 200 nSv h^{-1} at the fence which appear to be consistent with these recent vehicular results, thus confirming that the accelerator does indeed irradiate areas close to the perimeter fence. These locations are relatively accessible to the public, and are in an area where it is understood that light industrial developments are planned, with the potential that occupancy may increase in future. Radiation exposure to members of the public in this location seems unnecessary, and would have to be justified in terms of ICRP60. Therefore recommendations are made in section 6 for consideration of steps to avoid or minimise such exposure.

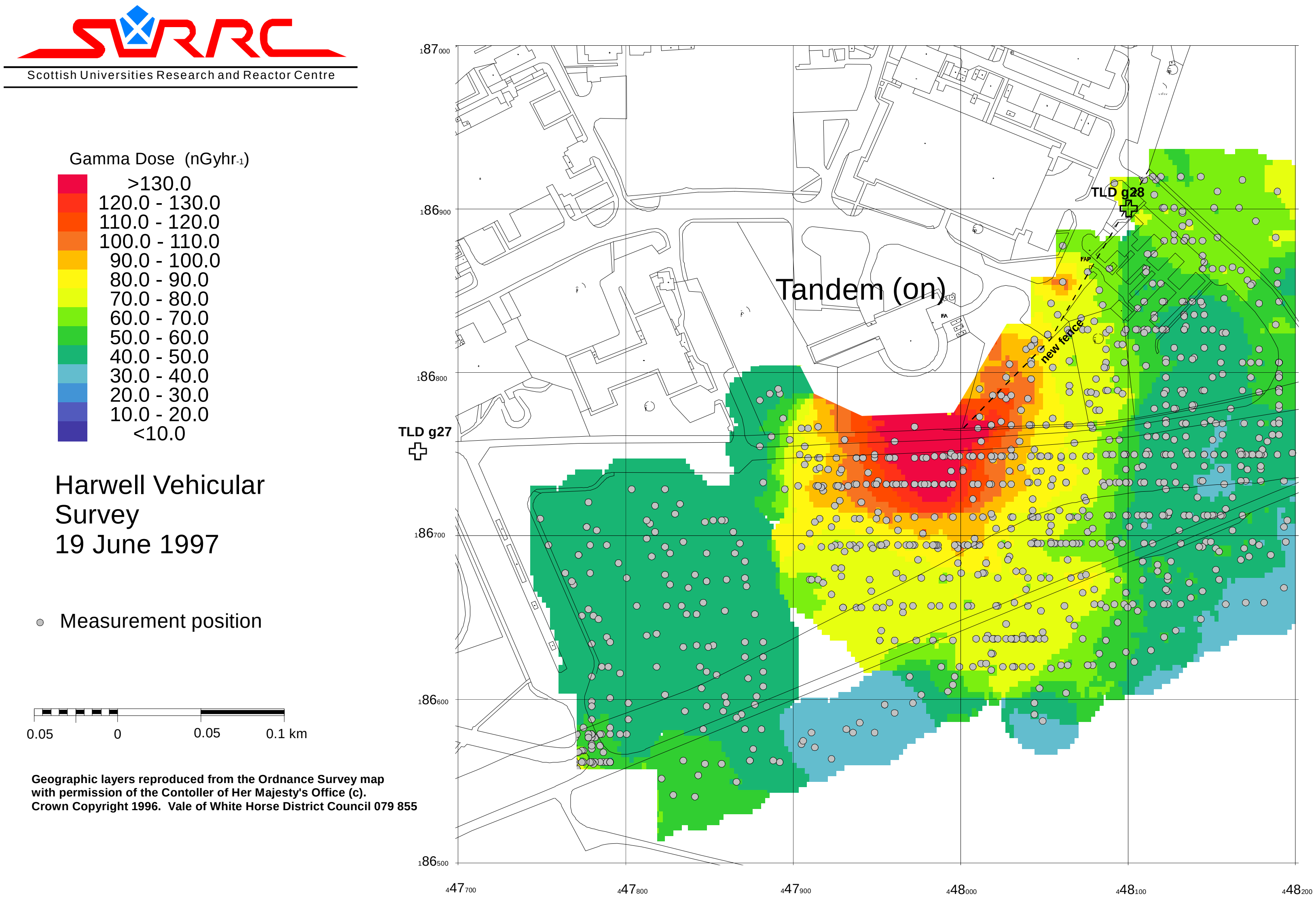


Figure 5.2 Vehicular gamma-ray map at the Harwell Tandem Van de Graaff (B477) on the 19th June 1997.

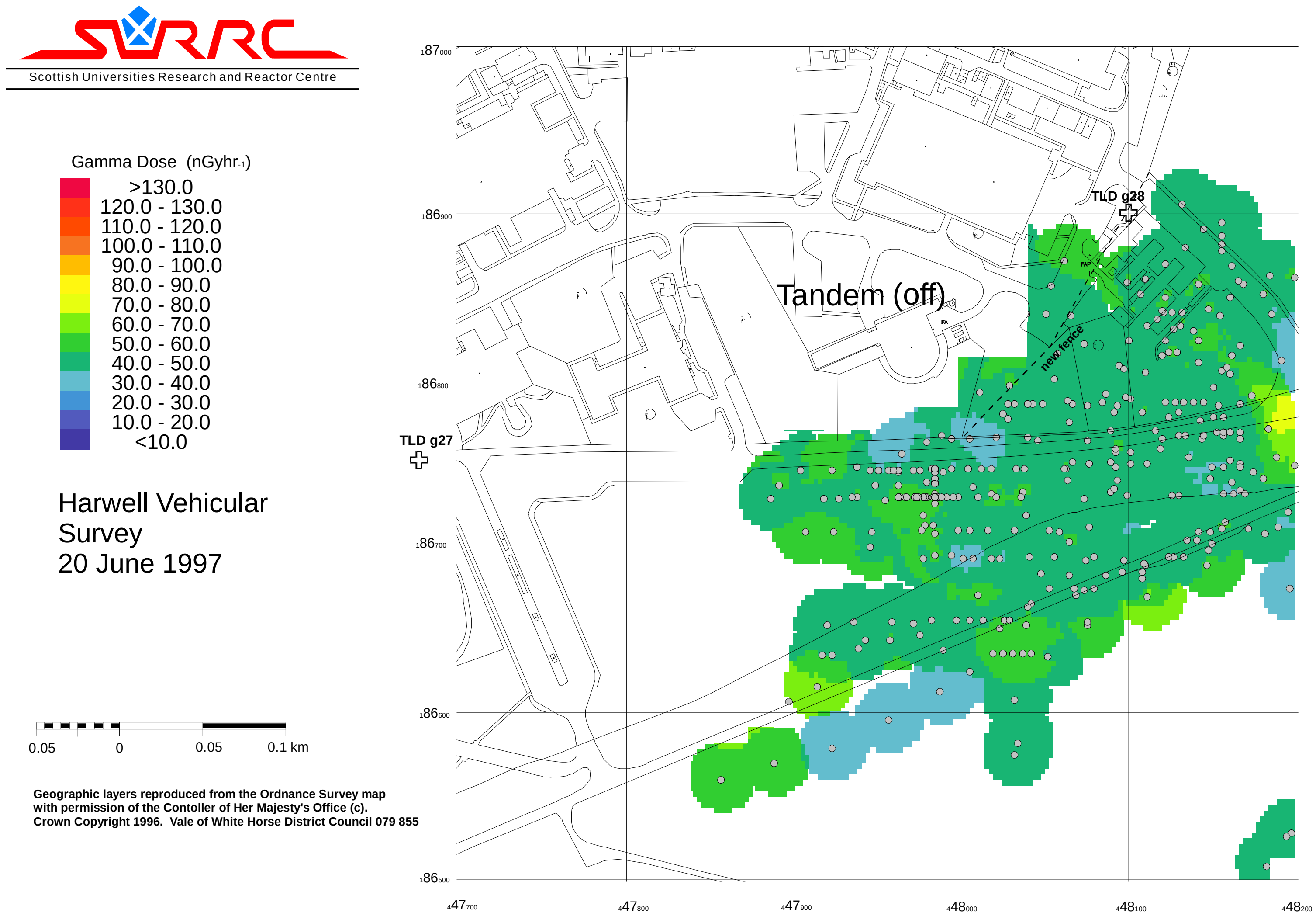


Figure 5.3 Vehicular gamma-ray map at the Harwell Tandem Van de Graaff (B477) on the 20th June 1997.

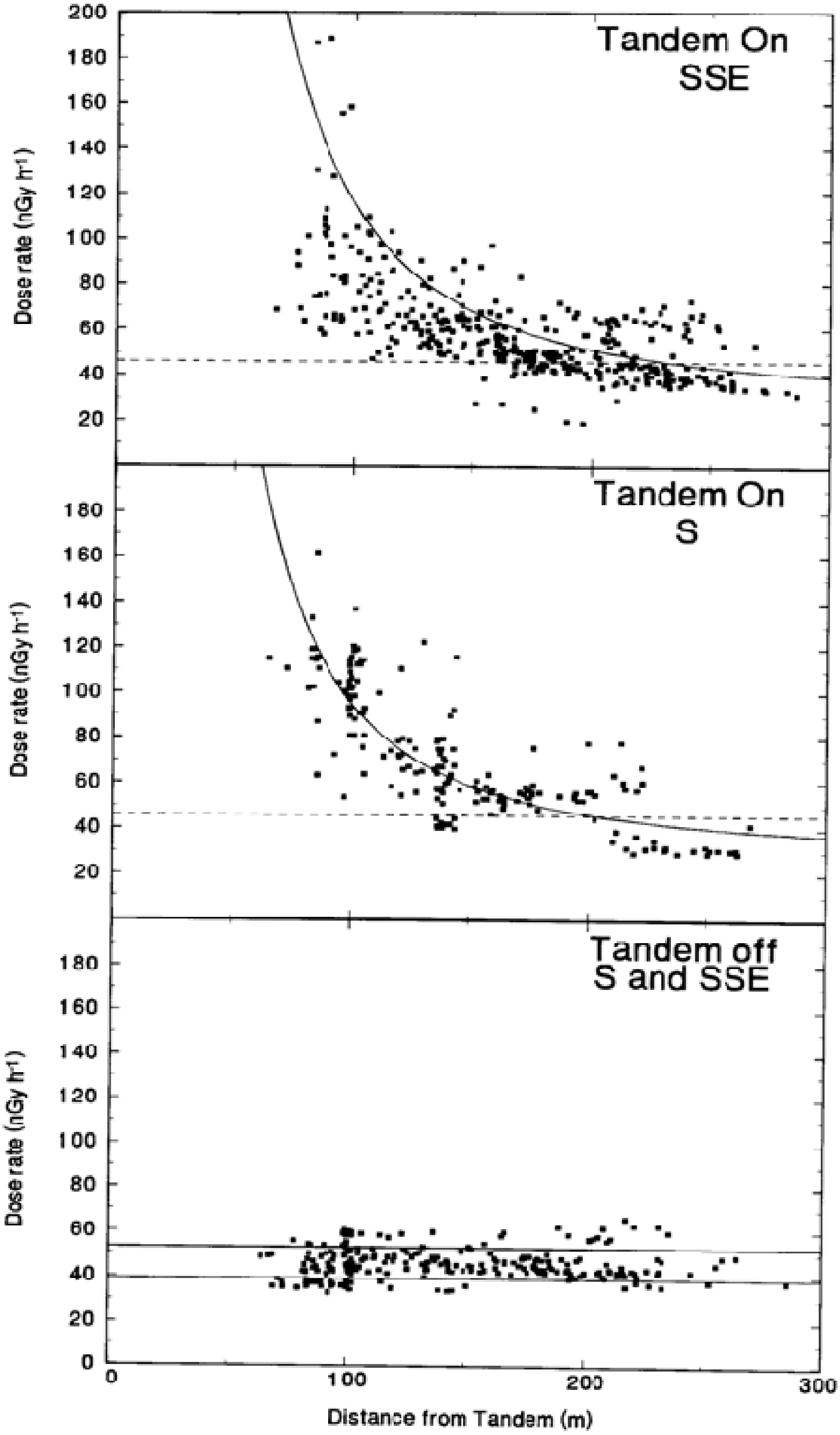


Figure 5.4 Variation of dose rate with distance from the Tandem.

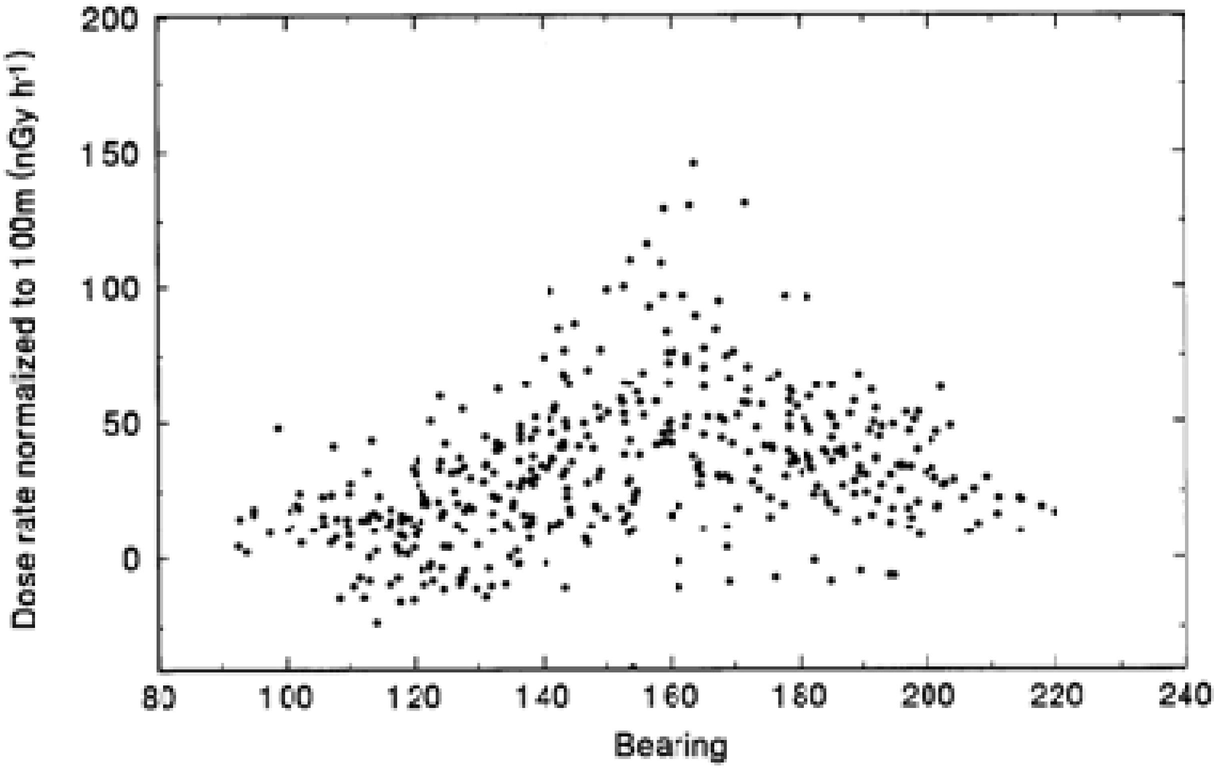


Figure 5.5 Variation of dose rate normalized to 100m from the operating Tandem with bearing.

5.1.3 ISIS (RAL) and HELIOS (Harwell, B418) Accelerators

The ISIS accelerator in the RAL and the HELIOS accelerators in Harwell are located adjacent to each other, separated by the site fences and a site access road. HELIOS 2 is operated virtually continuously, but HELIOS 1 and ISIS function in a less continuous operating cycle. While operating, ISIS and the HELIOS accelerators all contribute significantly to the dose rate along the road.

The two TLD stations (numbers 3 and 4) located near the HELIOS accelerators have recorded dose rates of between 40 and 110 nSv h^{-1} in recent years. Routine health physics monitoring in 1997 showed dose rates up to 240000 nSv h^{-1} in close proximity to the HELIOS accelerators, and the UKAEA March perimeter survey identified areas along the boundary fence with RAL with dose rates of 800 and 300 nSv h^{-1}. Measurements by RAL in March 1997 showed dose rates up to 600 nSv h^{-1}. One of the locations monitored in the HMIP commissioned perimeter monitoring programme recorded levels of between 210 and 1200 nGy h^{-1}.

The vehicular survey took measurements along the perimeter between the ISIS and HELIOS accelerators on three occasions, during the period 18:45-18:51 on the 19th June and twice between 10:57-11:08 and 17:26-17:55 on the 20th June. Figure 5.6 shows the dose rate line profiles for these data sets (using the 8 l NaI detector, corrected to account for the high energy component of the accelerator sources, Appendix B). The measured dose rate was between 70 and 600 nGy h^{-1}, with the highest dose rates corresponding to a location west of the accelerator inside the RAL site. However the measurements within these data sets on the UKAEA side of the boundary do not apparently respond to the major signal recorded opposite the ISIS Control Entrance by UKAEA and RAL in their March 1997 surveys. It was noted (Stonell pers. comm.) that a Mini-series 680 survey meter carried in the vehicle also failed to detect this major peak. Further analysis of the data from both NaI and Ge detectors, together with the RAL observations, have been undertaken to explore this apparent anomaly.

Figure 5.7 shows plots of data sets recorded along the boundary separating UKAEA and the RAL sites, against distance from an origin located at the western corner of the RAL site. Figure 5.7 (a) shows dose rates based on the 8 l NaI detector recorded on 20th June 1997 at around 1740 when the ISIS accelerator was running at a very low beam current, and at around 1103 when ISIS was running at full power. With ISIS on the NaI detector records a peak in excess of 100 nGy h^{-1} 100m from the working origin, which is consistent both in position and magnitude with the values recorded by RAL shown in figure 5.7 (b). However, between 200 and 300m from the origin, opposite the ISIS Control Entrance, the NaI system has recorded lower signals with ISIS on than observed when the accelerator was off. Examination of spectra and spectral colour plots has shown that strong annihilation radiation peaks were observed at 200m and 300m positions on either side of this feature, but that the NaI system has been overloaded in intermediate positions by the high intensity pulsed radiation field associated with this position. Figure 5.7 (c) shows the high energy events recorded in the pile-up channels (>2 MeV) of the Ge spectrometer across the same section, after subtraction of an estimated natural background component between 2 and 3 MeV. This data set shows both the smaller feature at 100m from the origin and the large peak at 200m. There is a suggestion of a small signal at position 400m which may correspond with the highly collimated signal detected by RAL at a single fence post near the Fermi Gate.

This further investigation of the vehicular data set was conducted following consultation with RAL. The reasons why the NaI system, and the 680 survey meter, failed to record the major radiation signal are related to the pulsed nature of the radiation fields associated with ISIS. The ISIS accelerators operate on a 50 pulse per second frequency, with approximate pulse duration of 10^{-6} seconds. During an individual pulse the peak radiation field is thus some 20000 times stronger than average levels. The high volume detector is unable to resolve individual gamma rays at these high peak count rates. Apparently the less efficient gas filled survey meters may also have difficulty resolving these signals. The observations that the "missing" signal could be detected in high energy channels of the Ge detector, and also the associated presence of 511 keV annihilation radiation in adjacent NaI spectra are indicative of a high energy photon component in the major radiation field near ISIS. This may have implications for identification of the origins; whereas part of the fence signals recorded by RAL have been associated with the first stage ISIS pre-injector (maximum energy 665 keV) the higher energies inferred from these spectrometric observations imply additional sources.

Further investigation would be required to determine which aspects of machine operation are responsible for these signals. In any event the survey and this study have drawn attention to the cross-boundary issues surrounding machine sources, and identified areas which had not been fully represented in routine measurements, and where continuing attention is clearly appropriate.

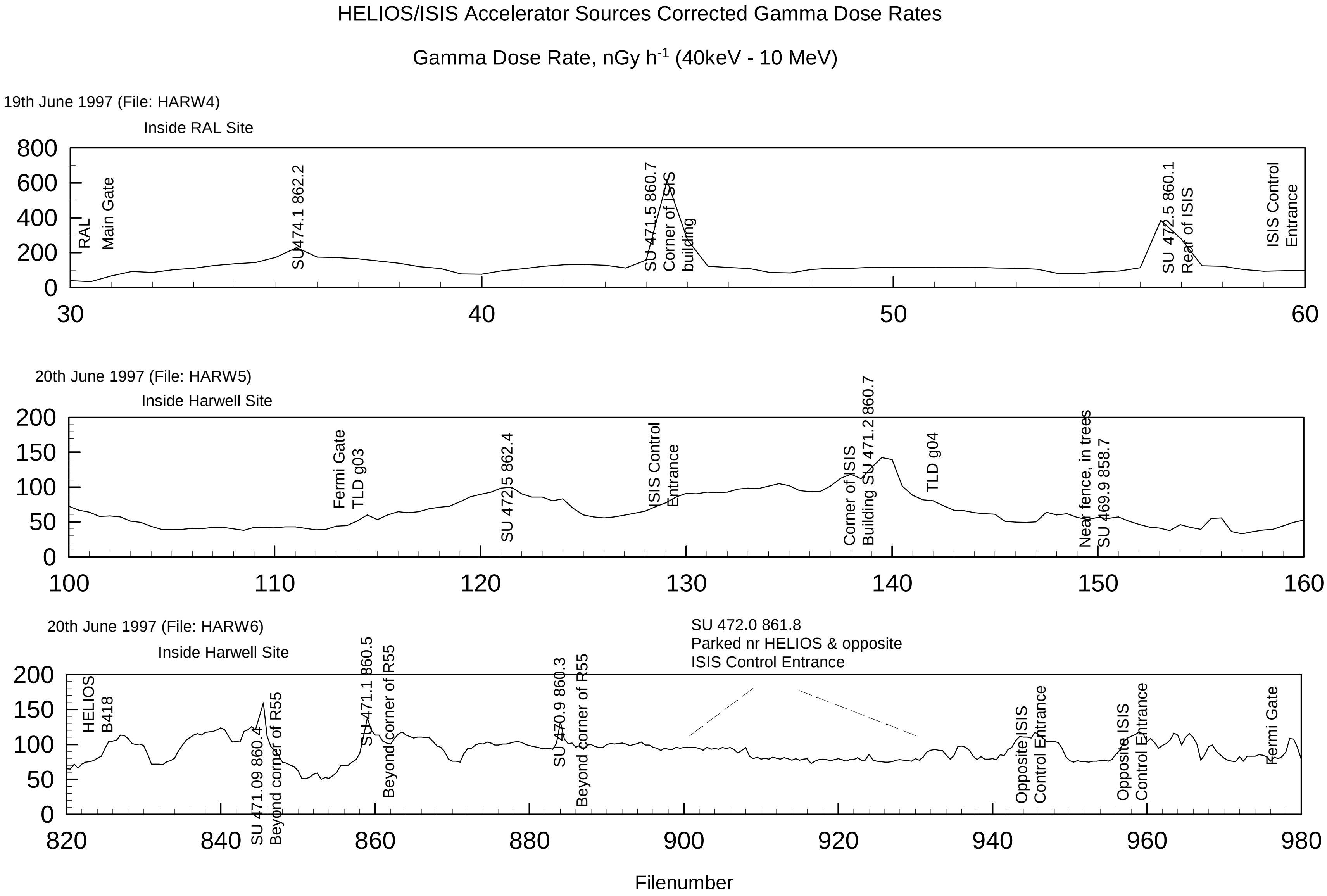


Figure 5.6 Dose rate line profiles for the data sets recorded along the perimeter between the ISIS and HELIOS accelerators.

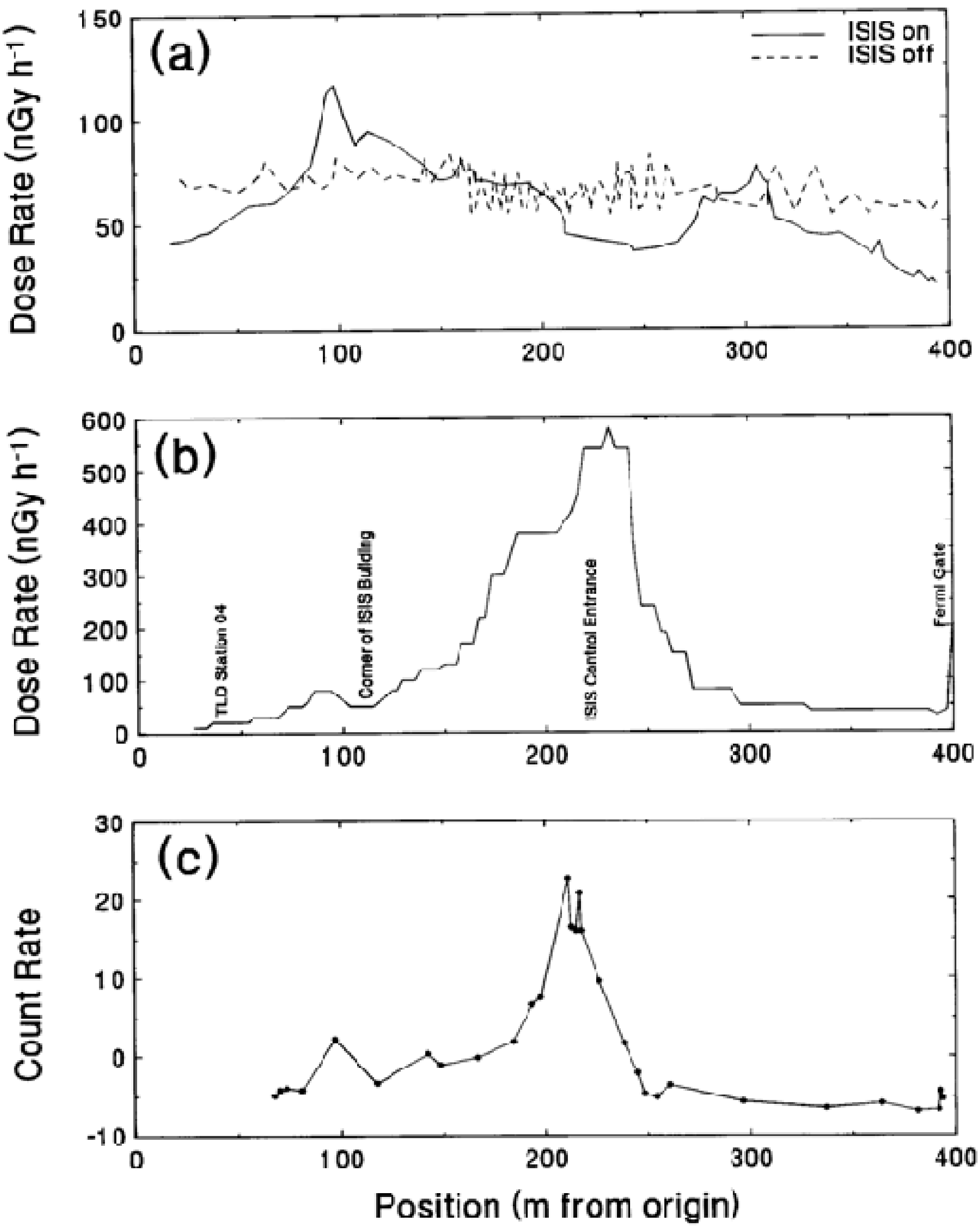


Figure 5.7 Plots of data sets recorded along the road between the ISIS and HELIOS accelerators, with distance from an origin at the western corner of the RAL site; (a) dose rates recorded with an 8 l NaI detector on 20/6/97 with ISIS on and off, (b) dose rates determined by RAL in March 1997, (c) the net count rate in pile-up channels (>2 MeV) of from Ge detectors on the 20th June. The high volume NaI system is evidently overloaded by peak count rates within a pulsed radiation field responsible for the main dosimetric signal opposite the ISIS Control Entrance.

5.1.4 Active Handling Facility (B462)

During the airborne survey of September 1996, dose rates of up to 70 nGy h^{-1} were measured along the perimeter north west of the Active Handling Facility (B462), the most significant component being Th-series activity. The TLD station nearest this location recorded a dose rate of 83 nSv h^{-1} at that time, with the TLD station south east of the facility recording a dose rate of 60 nSv h^{-1}. Routine health physics surveys during this period recorded dose rates between 100 and 7000 nSv h^{-1} close to the building. Both of these sets of readings have varied significantly over time, with TLD readings between 40 and 120 nSv h^{-1} at both locations, and at one location health physics monitoring recording a change from 1000 to 20000 nSv h^{-1} in the course of one month. The perimeter monitoring programme commissioned by the HMIP recorded dose rates of 60 to 240 nGy h^{-1} along the fence south and east of the complex, and doses of 70 to 260 nGy h^{-1} along the fence north and west of the facility.

The vehicular survey in June 1997 recorded dose rates of 60 to 400 nGy h^{-1} along the perimeter south and east of the facility, and 30 to 60 nGy h^{-1} along the perimeter to the north and west. The radiometric map from the vehicular survey along the north and west perimeter is shown in figure 5.8. There is no evidence of the strong Th-series signal in this area previously recorded by the airborne survey in September 1996. It is known that in September 1996 approximately 60 tonnes of thorium material were stored in an ISO container inside the Active Handling Complex pending transfer to an on-site storage facility.

The frequent movement of active material to, from and within the Active Handling Facility is reflected in the routine monitoring programmes conducted by UKAEA and others. However it is not clear whether the routine health physics monitoring is sufficiently adaptive to deal with such circumstances, and particularly the off-site aspects of this problem. Given that the HMIP commissioned surveys and the airborne survey had both identified periods in the past when off-site radiation could be measured in the W and NW directions, this possibility should be borne in mind. It is desirable that radioactive materials are stored in a manner which does not cause significant off-site radiation fields. If this is not practicable, it is certainly desirable that off-site implications are considered as an integral part of the operations which move such materials around.

5.1.5 Reactor Feature

It became apparent after the airborne mapping that a low level radiation field was present at the south western corner of the Harwell site, in the vicinity of the PLUTO reactor building. Figure 5.9 shows airborne survey gamma dose-rates and estimates of ^{137}Cs deposition. Results from the vehicular survey are shown in figure 5.10, and colour encoded plots from the NaI detectors and HPGe detectors are shown in figures 5.11 and 5.12 respectively. The only nuclide other than natural sources identified in the vehicular survey was ^{137}Cs, with signal levels close to fallout levels. The airborne survey showed scattered signals consistent with a shielded source, possibly on site, or with activity with a well mixed distribution in soil. The presence of stored materials containing ^{137}Cs in the vicinity of the reactors was not expected at this stage of decommissioning (Stonell, pers comm). Nor was it possible to infer from the vehicular results whether the radiometric signals were the result of projected radiation or low level off-site contamination.

A small scale investigation was thus conducted by the Geosciences Advisory Unit of Southampton University to determine whether any contamination was present (Croudace and Warwick, 1997). This consisted of in-situ gamma spectrometry and soil sampling along two transects oriented normally to the axis of the radiometric feature, at increasing distances from the site boundary. The sampling results showed a ^{137}Cs distribution which was broadly consistent with the radiometric anomaly, with maximum activity at the higher end of the range expected from global weapons testing fallout. Such a feature has no significant radiological implications, although the reasons for this particular distribution of activity are not clear.

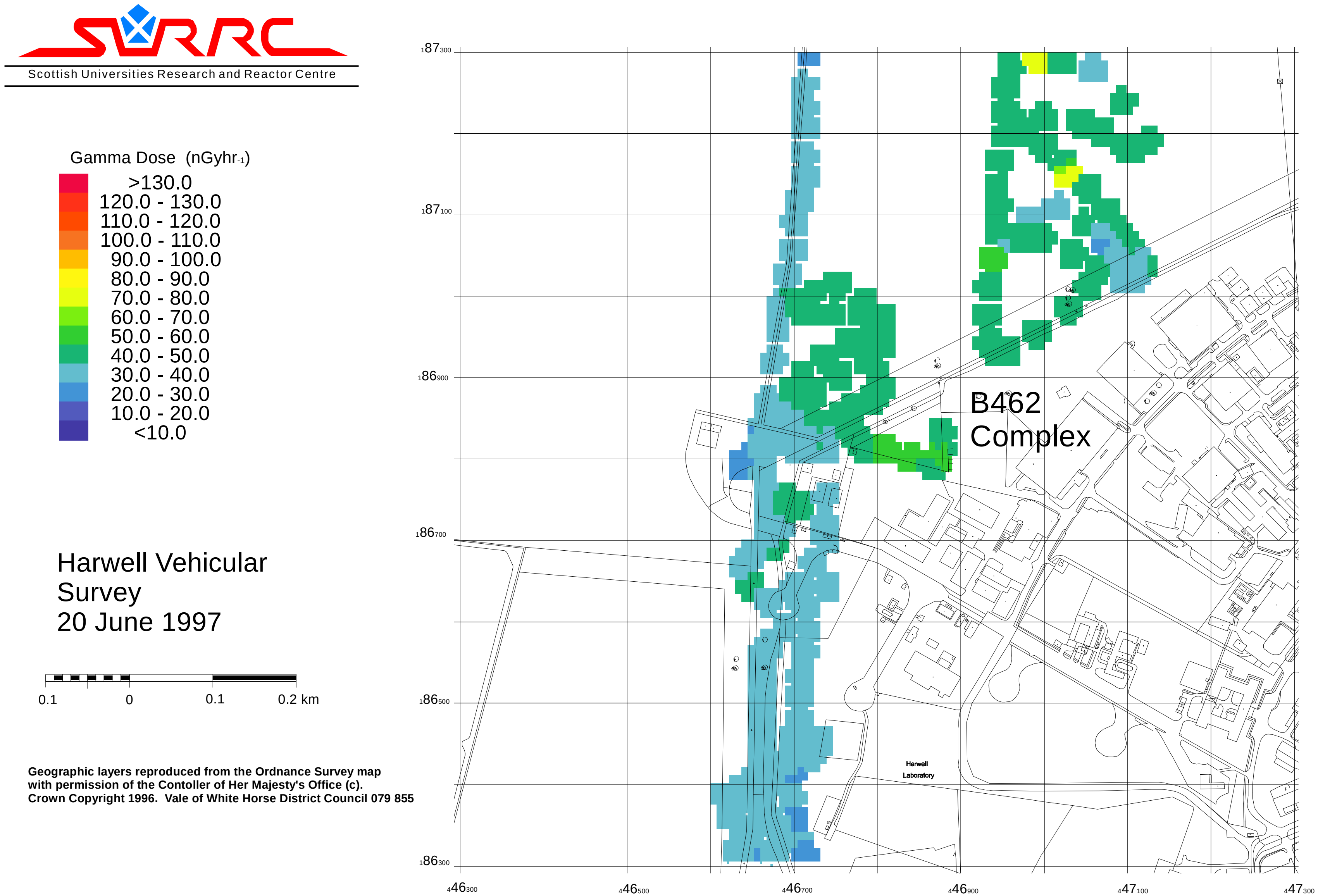
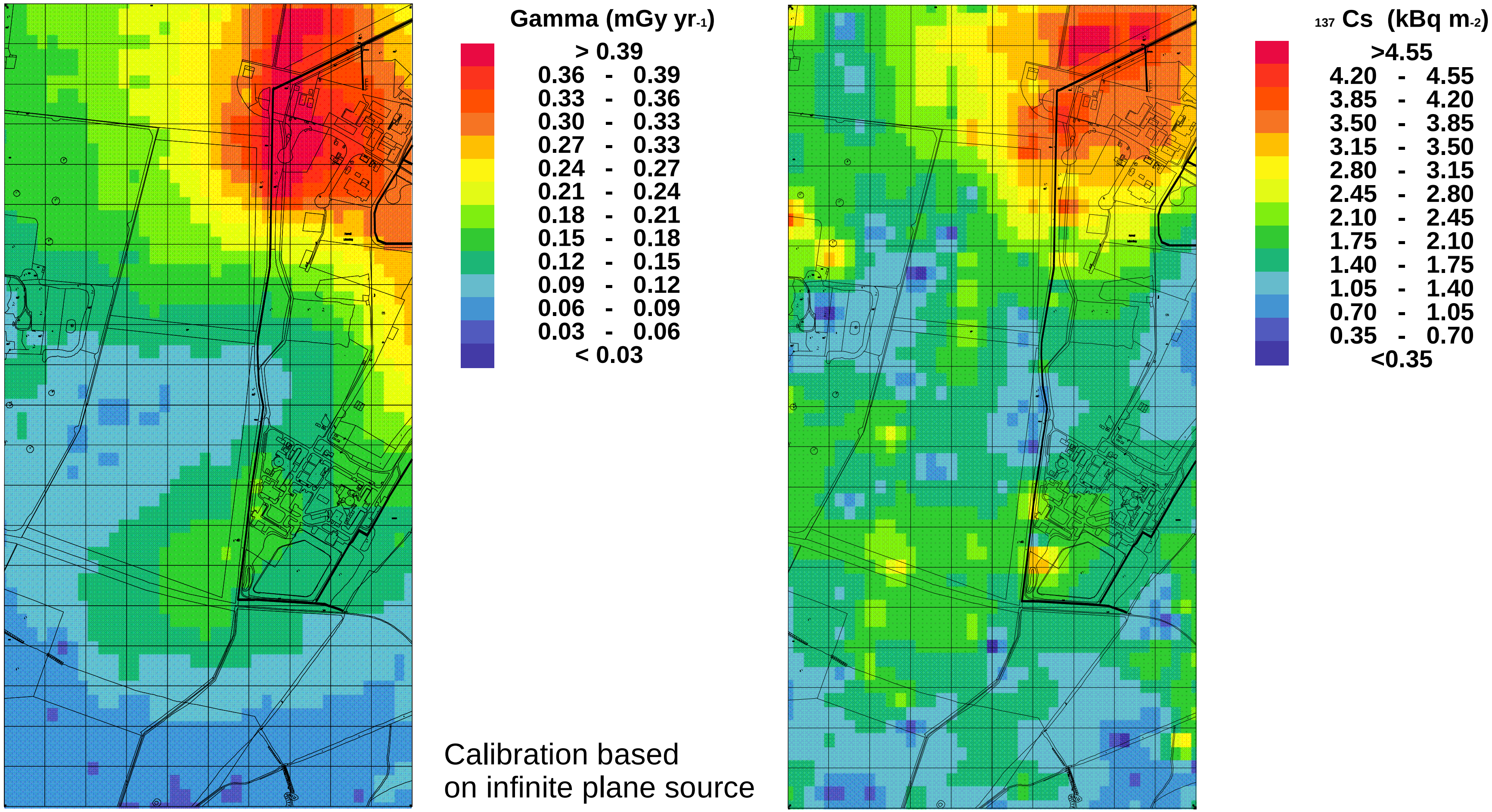


Figure 5.8 Vehicular gamma-ray map at B462 Active Handling Complex.



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0.25 0.125 0 0.25 0.5 km

Figure 5.9 Airborne survey contour maps at SW corner of Harwell site.

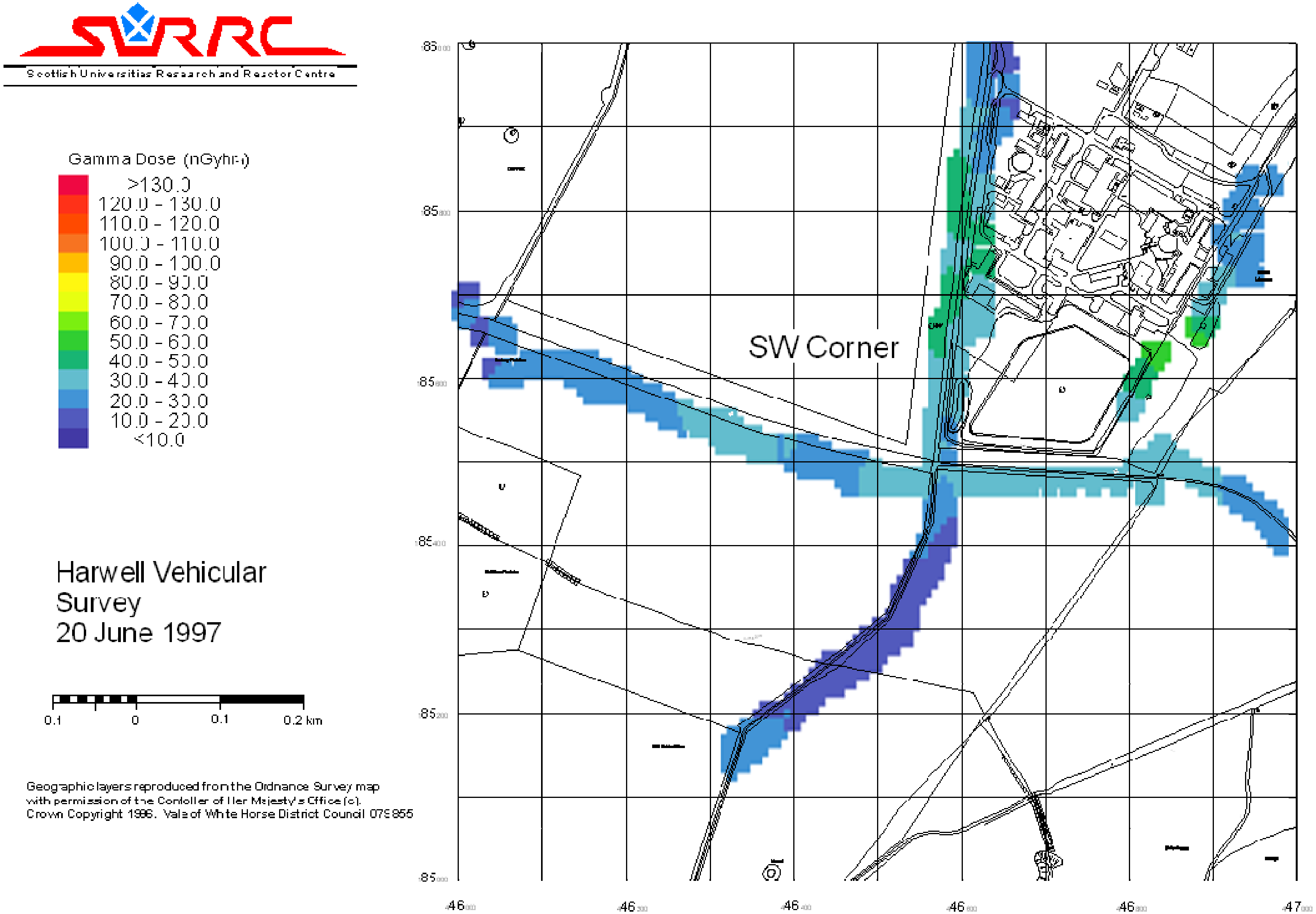

Figure 5.10 Vehicular gamma ray map of SW corner of Harwell site.

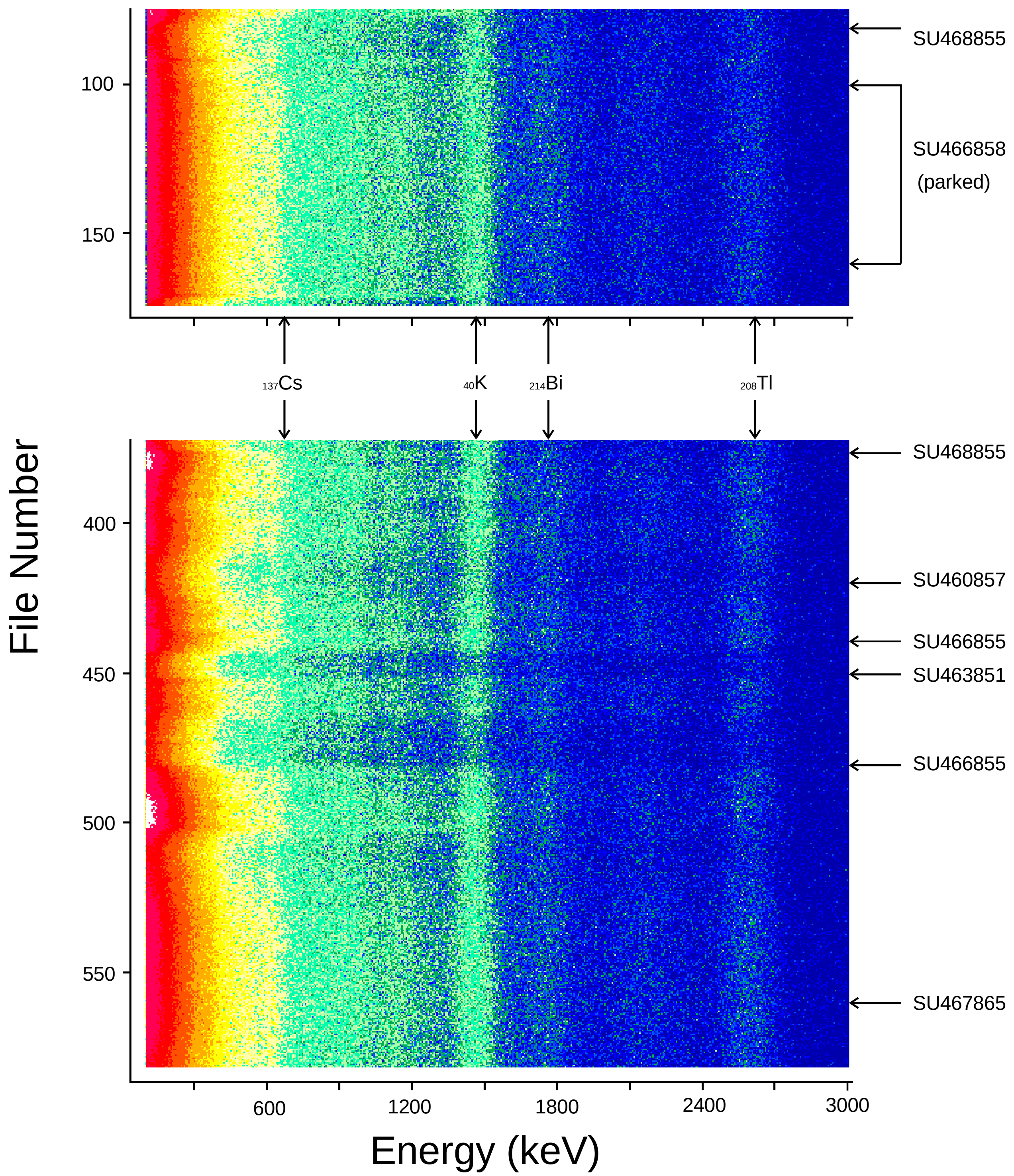

Figure 5.11 Colour encoded spectral plot using NaI detector near SW Fence.

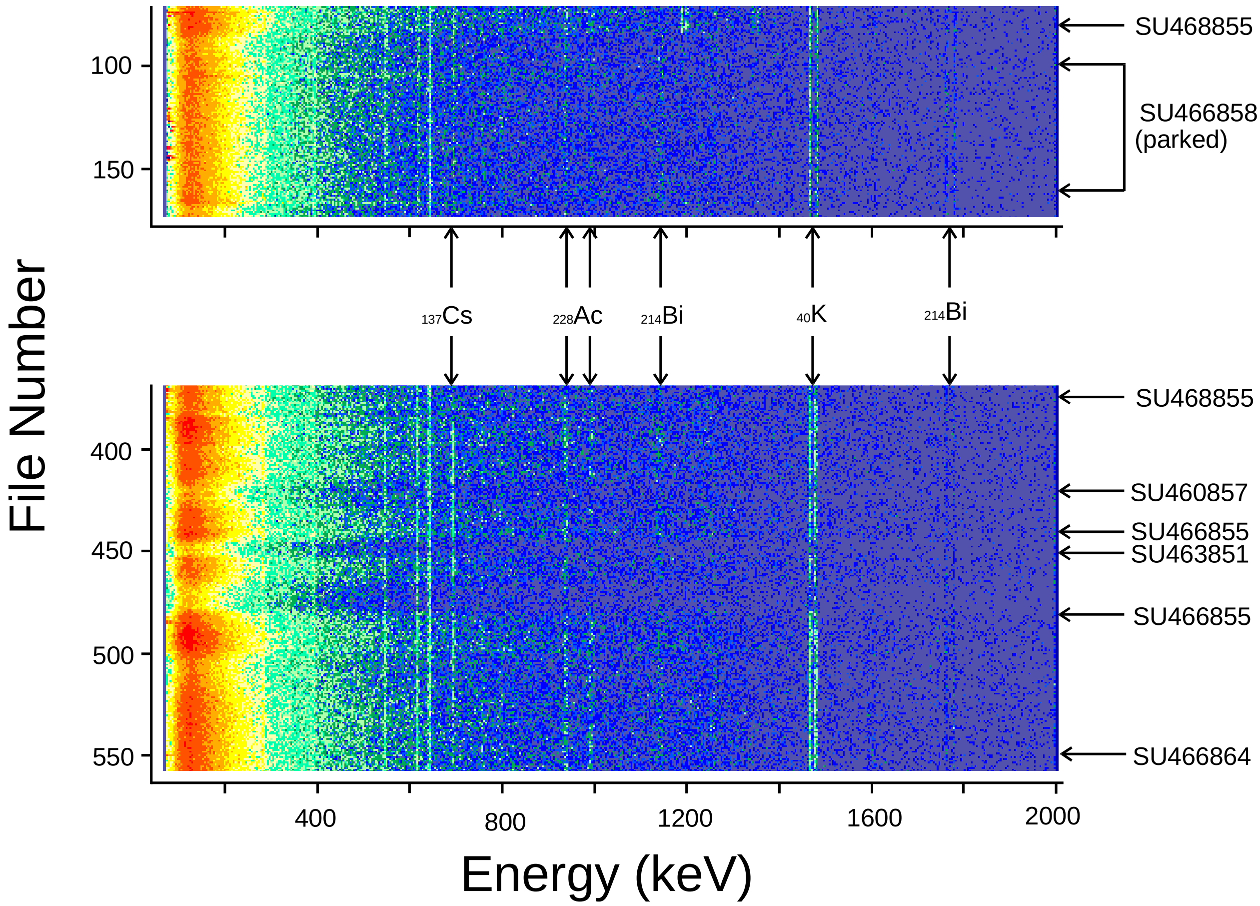

Figure 5.12 Colour encoded spectral plot using GMX detectors near SW Fence.

5.1.6 RAL Sports Field (Feature "O")

Evidence of a small feature from airborne survey measurements, on the sports field adjacent to the RAL site was brought to attention immediately prior to the vehicular survey. The opportunity was therefore taken to further investigate this feature (feature "O") at ground level. A series of slow speed, parallel tracks were taken by the vehicle over the sports field at about 10 m spacing and close to the previously identified feature. The results show that rather than having a local focus, the general area has slightly higher levels of natural radionuclides than the surroundings. The most likely explanation for this is that the sports fields may have been based on imported soil with a higher natural radioactivity than the local chalks. Figure 5.13 shows the contoured vehicular gamma-ray map.

5.1.7 Additional and Unresolved Features

A number of additional features were identified by the vehicular survey, which were not observed during the airborne survey. An enhanced source of natural uranium or radium was located near the southern end of the Harwell bus park (feature 1). This corresponded to a small earthwork adjacent to a link road (51°34.727N, 1°18.727W, ±7m). The vehicle was parked at this site, and a long live time spectrum was obtained using the Ge detectors. Figure 5.14 shows the resulting spectrum, after subtraction of a suitable local background, with a representative local background spectrum for comparison.

During the course of the survey six other features were also observed (features 2-7), and it was recommended that UKAEA staff sample these areas for further analysis. Subsequent examination of the data revealed another six small features (features 8-13), five of which were outside the site perimeter. The locations of all these features are shown in figure 5.15.

Spectra from the other small areas of enhanced activity were also examined. Figure 5.16 shows the background subtracted Ge spectra for the other sixes features identified during the survey (2-7). Figure 5.17 shows the spectra from the six features identified during later analysis (8-13). Table 5.1 gives the count rates for various gamma ray peaks in the GMX spectra, after subtraction of a suitable local background, for radioisotopes in the U-series, Th-series and for ^{137}Cs, for the 13 locations and the calibration site at Greenham Common. Due to the geometry associated with small localized sources these count rates can not be readily converted to calibrated activity concentrations for these isotopes, the relative intensity of the peaks can, however, provide the relative composition of these sources.

It can be seen that all these features have count rates for U-series isotopes enhanced by factors of approximately 10-100 above expected natural background levels. Some of the locations also have count rates from Th-series isotopes enhanced by factors of about 10. The ^{137}Cs count rates are all consistent with weapons testing fallout levels. Some of these locations (1, 5, 7, 9 and 11-13) are due to enhanced levels of U-series isotopes, others (3, 4 and 10) have enhanced levels of U and Th-series isotopes in approximately natural proportions. The remaining locations have enhanced activities from U and Th-series isotopes, but with the U/Th ratio greater than that present in natural materials.

The energy deposited in the Ge detectors can be found by forming an energy integral, the sum of the energy of each channel multiplied by the number of counts in that channel. Table

5.2 gives the rate of energy deposition in the Ge detectors for each location and the Greenham Common calibration site, along with an equivalent dose rate. The equivalent dose rate is that which would give the energy integral assuming a uniform planar source, and is produced by comparison with the calibration site. The table also gives the OS grid reference of each location and summarises the information on source composition.

Samples of road surface taken from seven locations identified during the course of the survey were collected by UKAEA staff, and analysed by gamma spectrometry in the laboratory. The activity concentrations for ^{214}Bi and ^{208}Tl determined from these measurements are given in table 5.3. There are some discrepancies between these measurements and the measurements made during the vehicular survey. There is agreement for locations 1, 4, 5 and 7. However, for location 2 the UKAEA measurement is of enhanced natural material, whereas the vehicular survey has U and Th-series, with excess U-series isotopes. For locations 3 and 6 the UKAEA measurements only show U-series enhancements, whereas the vehicular survey shows enhanced levels of Th-series isotopes as well. These discrepancies may be a result of inhomogeneity within the material on the road surface, with the samples removed for testing not being entirely representative.

These features consist of material that is significantly enriched in U-series isotopes, with some evidence for segregated Th series activities. The activity is located at or near the surface at various locations around the Harwell site. These produce significant, though highly localized, enhancements to external dose rates, and their superficial nature may result in potential suspension, and possible internal exposure pathways. The material appears to be typical of uranium mineralisation or low grade ores. The reasons for it's presence in these locations, and the precise physical and chemical forms of the activity have not yet been determined. Nevertheless it appears to be a low level radioactive contaminant associated with historic use of the site.

5.1.8 Catapult Pit

An aircraft catapult pit established by the RAF on the former airfield at grid reference SU483865 (approx.) was filled with industrial waste by AERE around 1949/50. Although this area had been examined by AEA within recent years, without revealing any signs of radioactivity, more recent measurements of samples taken at depth discovered low level radioactive material amongst the waste. It is understood that some of this material was removed recently, and the pit backfilled. The Vale of the White Horse District Council asked for surface measurements to be made to ensure that there was no surface activity.

The vehicular survey in the vicinity of the Catapult Pit comprised a series of parallel tracks traversing the known location of this buried feature (figure 5.18). There is no enhancement of radiation levels above local background values.

Table 5.1 The count rates (after subtracting a local background) of full energy peaks for isotopes in the U and Th-series and ^{137}Cs for locations in and around Harwell with higher localized dose rates (nd=not detected).

Location		U-series					Th-series				^{137}Cs
		^{226}Ra	^{214}Pb		^{214}Bi		$^{212/214}Pb$	^{208}Tl	^{228}Ac		
	keV	186.0	295.2	351.4	609.3	1120.3	238.6/241.9	583.2	911.3	969.2	661.6
1. Near Bus Park		11.9±0.3	24.3±0.3	43.3±0.3	39.2±0.3	9.0±0.2	11.1±0.3	0.66±0.13	<0.4	<0.5	1.24±0.14
2. Road near LETP		1.8±0.5	5.1±0.4	7.4±0.4	7.0±0.4	1.3±0.2	10.4±0.5	4.1±0.2	2.7±0.2	2.3±0.2	nd
3. Road near LETP		1.1±0.3	2.7±0.2	3.2±0.2	3.0±0.2	0.59±0.10	9.0±0.3	3.7±0.2	2.50±0.14	2.20±0.13	nd
4. Road near LETP		<0.7	1.7±0.3	2.4±0.3	2.4±0.2	0.7±0.2	5.5±0.4	2.0±0.2	1.3±0.2	1.5±0.2	0.13±0.2
5. Near roundabout		1.2±0.6	3.9±0.5	6.1±0.6	5.5±0.5	1.5±0.4	1.6±0.6	<0.2	<0.2	<0.2	nd
6. Near former prefabricated housing		<0.5	2.5±0.3	5.0±0.3	4.6±0.3	1.56±0.15	5.8±0.3	1.78±0.15	1.25±0.15	0.5±0.2	nd
7. Near road junction		<0.8	3.9±0.5	4.5±0.5	4.1±0.5	1.4±0.4	<1.7	<0.2	<0.2	<0.2	nd
8. Near former prefabricated housing		<0.6	2.0±0.3	3.0±0.4	1.1±0.4	0.6±0.2	9.0±0.5	3.5±0.2	2.3±0.2	2.0±0.2	nd
9. Near road junction		<0.4	1.1±0.3	2.8±0.3	1.8±0.3	0.6±0.3	<1.0	<0.5	<0.5	<0.1	nd
10. Near Southern Storage Area		0.8±0.2	1.9±0.2	2.0±0.2	2.1±0.2	0.87±0.06	7.6±0.3	3.05±0.13	2.1±0.10	1.46±0.12	nd
11. Near roundabout		3.0±0.3	4.7±0.3	9.5±0.3	8.2±0.2	1.82±0.15	1.6±0.2	<0.3	<0.1	<0.1	0.94±0.08
12. On road west of Tandem		<3	3.3±1.1	7.6±0.9	7.8±0.9	2.2±0.5	<3	<0.5	<0.5	<0.5	nd
13. Near Harwell restaurant		<1.5	<1.0	3.5±0.7	3.1±0.7	1.0±0.5	<2	<0.3	<0.5	<0.7	0.6±0.5
Greenham		<0.05	0.20±0.08	0.37±0.07	0.41±0.06	0.03±0.05	0.97±0.10	0.44±0.04	0.30±0.04	0.21±0.05	1.13±0.05

Table 5.2 Positions, energy integrals and equivalent dose rates for areas of enhanced localized activity.

Location	Position (OSGB)	Energy Integral (pJ s^{-1})	Equivalent dose rate (nGy h^{-1})	Comments
1. Near Bus Park	$^{4}47^{760}$ $^{1}86^{560}$	59.1±0.1	113±10	Enhanced U
2. Road near LETP	$^{4}48^{020}$ $^{1}87^{520}$	28.3±0.2	54±5	Enhanced U and enhanced natural material
3. Road near LETP	$^{4}48^{150}$ $^{1}87^{470}$	16.7±0.1	32±3	Enhanced natural material
4. Road near LETP	$^{4}48^{220}$ $^{1}87^{450}$	10.9±0.1	21±2	Enhanced natural material
5. Near roundabout	$^{4}48^{190}$ $^{1}86^{790}$	13.5±0.2	26±3	Enhanced U
6. Near former prefabricated housing	$^{4}48^{350}$ $^{1}86^{220}$	16.8±0.1	32±3	Enhanced U and enhanced natural material
7. Near road junction	$^{4}48^{420}$ $^{1}85^{980}$	11.8±0.2	23±2	Enhanced U
8. Near former prefabricated housing	$^{4}48^{150}$ $^{1}86^{090}$	12.9±0.2	25±2	Enhanced U and enhanced natural material
9. Near road junction	$^{4}48^{420}$ $^{1}85^{980}$	5.6±0.1	10.7±1.0	Enhanced U
10. Near Southern Storage Area	$^{4}48^{270}$ $^{1}85^{950}$	12.2±0.1	23±2	Enhanced natural material
11. Near roundabout	$^{4}48^{200}$ $^{1}86^{800}$	15.6±0.1	30±3	Enhanced U
12. On road west of Tandem	$^{4}47^{760}$ $^{1}86^{870}$	23.7±0.4	45±4	Enhanced U
13. Near Harwell restaurant	$^{4}47^{680}$ $^{1}86^{740}$	15.1±0.3	29±3	Enhanced U
Greenham		8.45±0.04	16.2±1.5	Calibration site

Table 5.3 Activity concentrations determined by UKAEA for sources located during the vehicular survey.

Location	Position	^{214}Bi (Bq kg^{-1})	^{208}Tl (Bq kg^{-1})
1. Bus Park	$^{4}47^{760}$ $^{1}86^{550}$	1800±100	<8
2. Near LETP	$^{4}48^{020}$ $^{1}87^{520}$	84±5	77±3
3. Near LETP	$^{4}48^{150}$ $^{1}87^{470}$	1500±100	<9
4. Near LETP	$^{4}48^{220}$ $^{1}87^{450}$	82±6	66±4
5. Roundabout	$^{4}48^{190}$ $^{1}86^{790}$	1600±100	<8
6. Near former prefabricated housing	$^{4}48^{350}$ $^{1}86^{220}$	1400±100	<6
7. Near road junction	$^{4}48^{420}$ $^{1}85^{980}$	750±100	<6

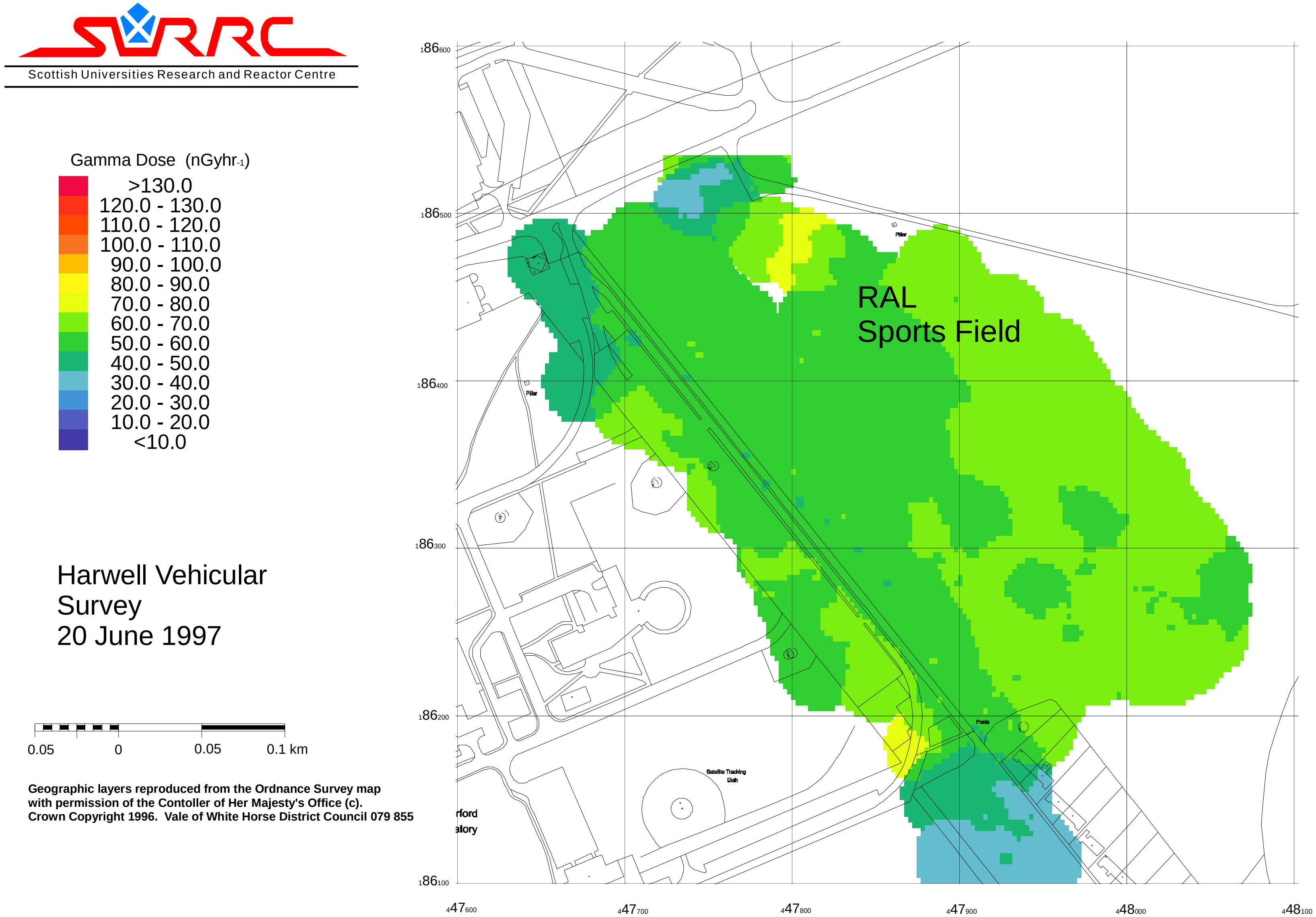

Figure 5.13 Vehicular gamma-ray map at RAL Sports Fields (Feature "O").

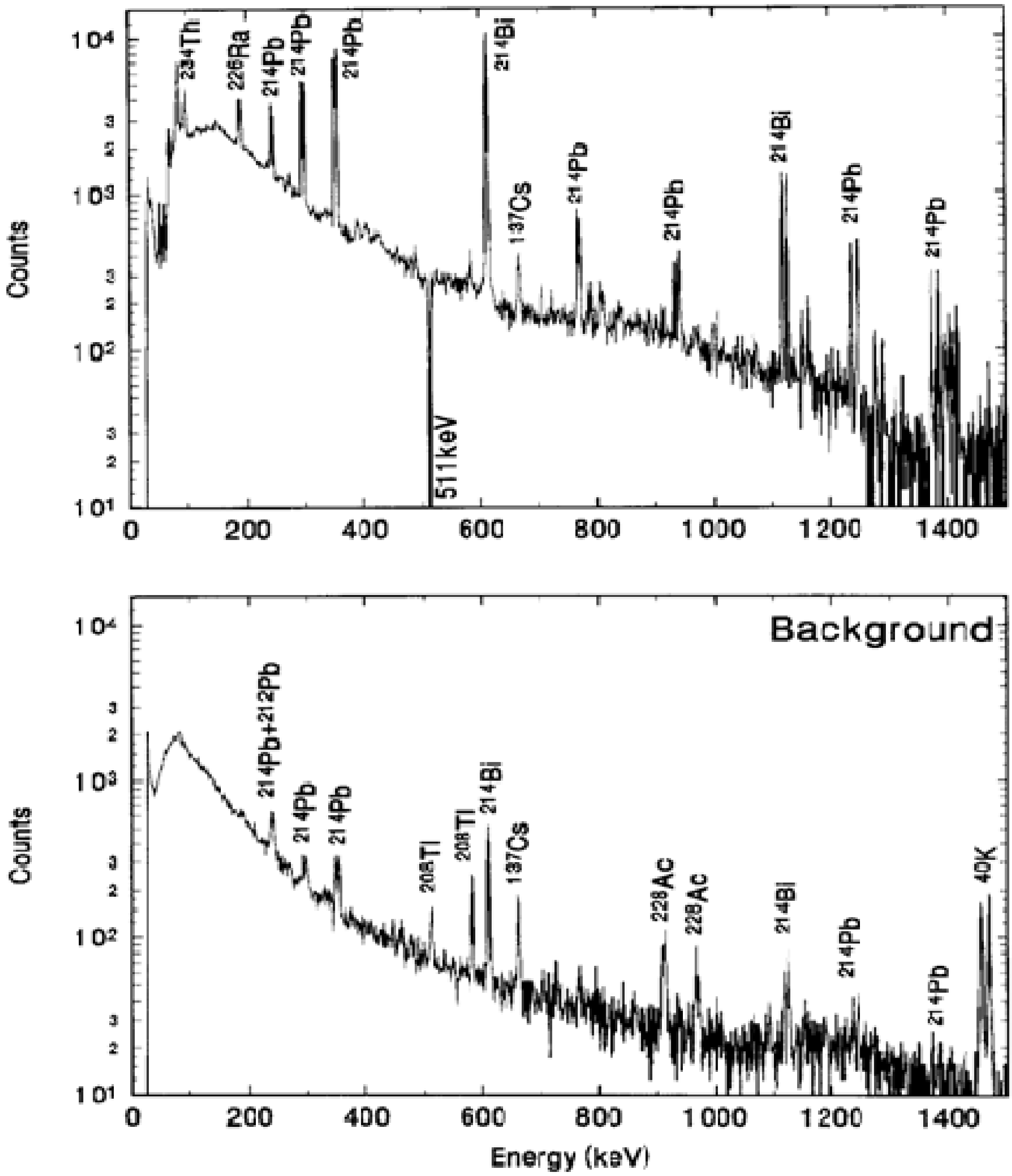

Figure 5.14 Background subtracted spectrum recorded with the Ge detectors (livetime 783s) at the south end of the bus park, with a local background spectrum for comparison.

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Harwell Vehicular Survey
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Localised enhanced radioactivity

Figure 5.15 Map showing the location of the small features observed in the vehicular survey.

0.2 0 0.2 0.4 km

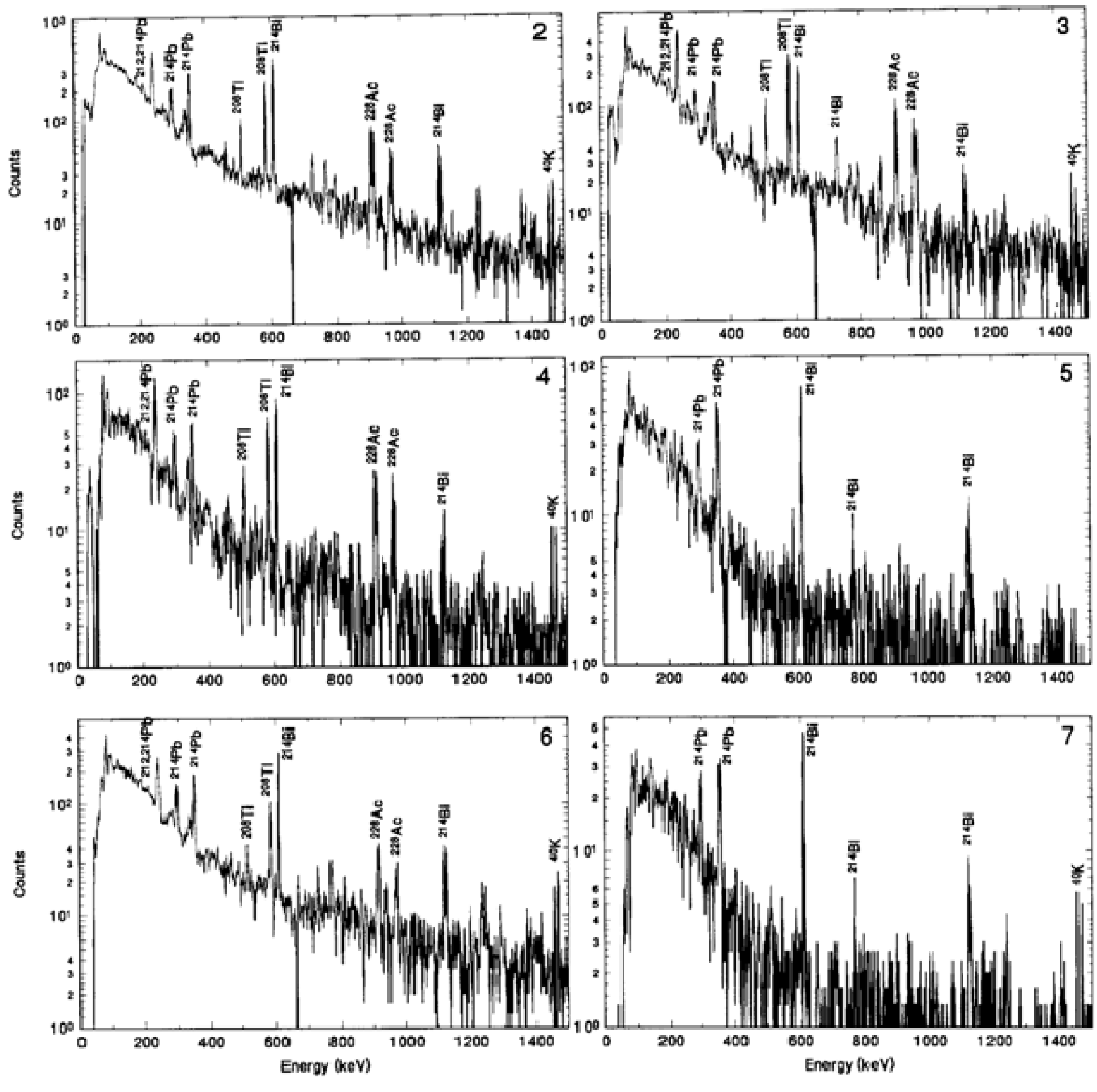

Figure 5.16 Background subtracted spectra recorded with the Ge detectors for six features identified during the vehicular survey.

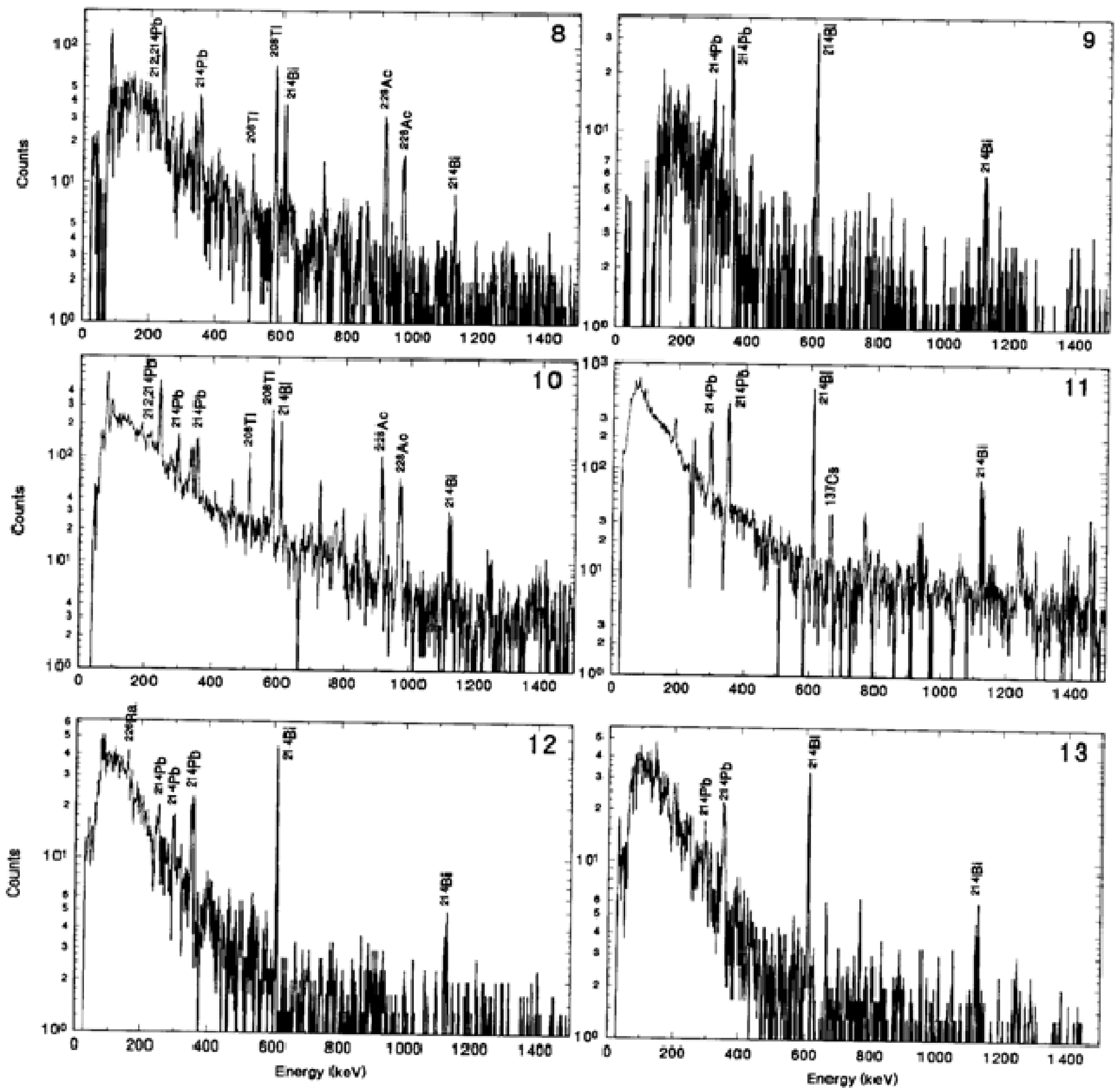

Figure 5.17 Background subtracted spectra recorded with the Ge detectors for six features identified after the vehicular survey.

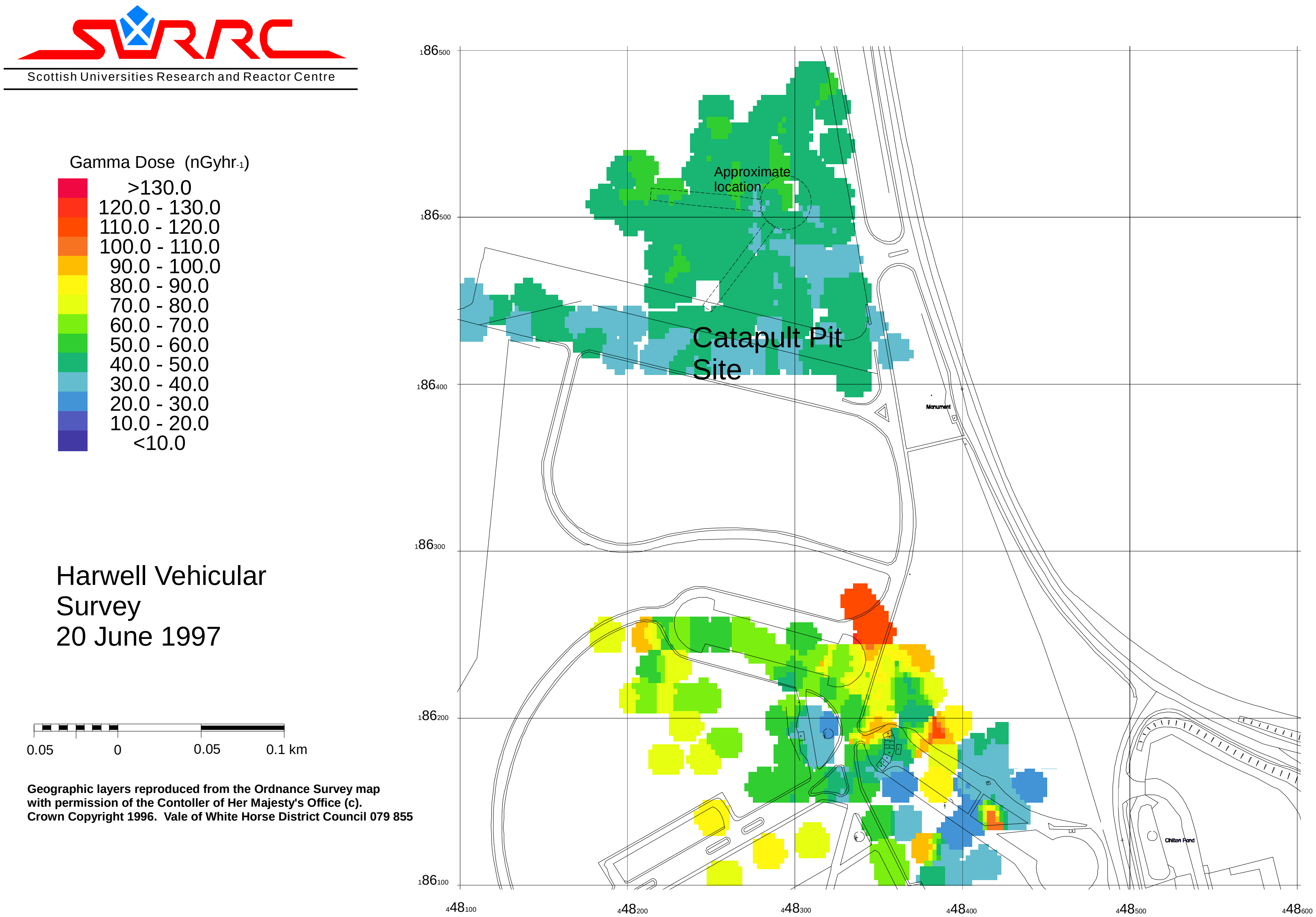

Figure 5.18 Vehicular gamma-ray map at Catapult Pit Site.

5.2 Radiological Consequences

The survey has clearly shown that the LETP is not the only source associated with the Harwell complex with localised off-site dose rates in excess of 200 nGy h^{-1}. Whether such signals actually cause exposure to members of the public depends on local habits and occupancy. Exposure from machine sources is dependent upon the operating conditions at times when members of the public are present. In general terms one would not expect a benefit to accrue to an exposed member of the public, and therefore there must be doubts in the area of justification of such exposure.

Exposure of this sort may be largely unnecessary, given that public access could in principle be limited or controlled. There may be scope for construction or deployment of additional local shielding around critical features, or for arranging the storage of radioactive wastes in a manner which does not lead to off-site radiation.

The range of dose rates, determined from all available measurements, along the perimeter fences near features with significant radiological signatures are shown in table 5.2 below. For each feature, the range of the number of hours required to reach an annual dose of 0.3 mSv (the NRPB recommended dose constraint for members of the public), 1 mSv (the NRPB recommended dose limit for a member of the public) and 5 mSv (the statutory dose limit for a member of the public) is given. The equivalent number of hours per day to reach these annual limits are given in parentheses.

The areas of highest dose rate are along the road separating the RAL and Harwell sites, particularly between the ISIS and HELIOS accelerators with ISIS operating, and along the perimeter between the MRC and B462 Active Handling Facility. In both of these cases exposure in excess on average of 1 hour per day could result in an annual dose in excess of the dose constraint of 0.3 mSv. However, public access to these areas is limited by the need to pass through the RAL or MRC areas to reach them, so these areas are only of concern to

Table 5.4 Range of dose rates and exposure times to reach annual dose levels of 0.3, 1 and 5 mSv at the site perimeter near various identified site features.

Feature	Perimeter dose rate (nGy h^{-1})	Hours to reach annual dose constraints or limits (hours per day)		
		0.3 mSv	1 mSv	5 mSv
LETP	100-300	1000-3000 (2.7-8.2)	3300-10000 (9.0-27)	16500-50000 (>24)
Tandem	70-200	1500-4300 (4.1-11.8)	5000-14300 (13.7-39)	25000-71500 (>24)
ISIS/HELIOS	100-1200	250-3000 (0.7-8.2)	850-10000 (2.4-27)	4150-50000 (>11)
B462	50-800	400-6000 (1.1-16.4)	1300-20000 (3.7-55)	6500-100000 (>18)

staff at Harwell, the RAL or the MRC who may enter these areas during their working day. It is highly relevant in this context to note that the dose constraint concept was developed to deal with situations where more than one exposure pathway applied. The unusual situation of two machine sources operated by different institutions affecting the same area provides an interesting example of this situation. There are still unresolved questions about the relative contributions of the two sources. Moreover there may be aspects of the application of dose constraints across inter-institutional boundaries which would merit further attention.

Other areas around the perimeter are more accessible to the general public. In particular, the area near the Tandem and the North Housing Estate near the LETP are both accessible to the public. Spending a few hours each day on average in these areas could result in an annual dose approaching the NRPB recommended dose constraint.

A recent NRPB report (Robinson *et al*, 1994) defined two critical groups who may be exposed to direct radiation from the Harwell site. The first of these are inhabitants of a local housing estate, who spend 2000 h yr^{-1} working in a local town, 1000 h yr^{-1} working an allotment near the site, 30 h yr^{-1} on the river bank near Sutton Courtenay with the remainder of their time at home. The second critical group is a combination group of individuals with outdoor activities and eating habits likely to enhance exposure. Members of this group were assumed to live in a nearby village, spend 1000 h yr^{-1} in their garden, 2000 h yr^{-1} working near the Harwell site, walk close to the site for 1 h day^{-1} and spend 30 h yr^{-1} on the river bank near Sutton Courtenay. The annual doses due to direct radiation for these two groups were calculated by NRPB to be 38 and 7.9 μSv respectively.

These annual doses were calculated using measurements in the local environment where available, or from fence monitoring data collected in July 1992, with the dose rate at the point of interest obtained using an inverse square law corrected for attenuation. It has been shown in this study that the routine monitoring programmes conducted by UKAEA and others may have overlooked or underestimated the perimeter dose rates for some of the sources of off-site radiation. Improvements in monitoring strategy of these dose rates may require a reassessment of the annual doses to critical groups.

5.3 Airborne Surveys of other Nuclear and Non-Nuclear Sites

The airborne survey of licensed nuclear sites in the UK, Europe and USA has become a recognised assessment and monitoring technique, in addition to regular health physics and environmental management. The airborne survey of the UKAEA Harwell site and the RAL facilities is therefore not unique. To put the results of the present report further into context, the following section summarises some comparative data arising from other airborne surveys.

The SURRC airborne survey team has, since 1988, conducted measurements at nuclear and non-nuclear sites, in the UK, Europe and Africa for a number of purposes including baseline studies, environmental research, radiation assessment, emergency response, source searches, epidemiological studies and European standardisation exercises. Table 5.5 tabulates airborne surveys conducted near UK nuclear sites, indicating those sites where perimeter radiation signals have and have not been detected and an approximate estimate of the associated environmental dose rates.

Table 5.5 Airborne surveys of Nuclear Sites

Nuclear Sites	Radionuclides observed at the fence	Reference
Trawsfynydd Nuclear Power Station	$^{41}Ar + ^{16}N$	Sanderson *et al*, 1989b
Calder Hall Nuclear Power Station, Sellafield	$^{41}Ar + ^{16}N$ (410 nGy h^{-1})	Sanderson *et al*, 1990d
Chapelcross Nuclear Power Station	$^{41}Ar + ^{16}N$ (120 nGy h^{-1})	Sanderson *et al*, 1992
Hinkley Point Nuclear Power Station	$^{41}Ar + ^{16}N$ (100 nGy h^{-1})	Sanderson *et al*, 1993a
Springfields Fuel Fabrication Plant	U and ^{234m}Pa (150 nGy h^{-1})	Sanderson *et al*, 1993b
Hunterston Nuclear Power Station	$^{60}Co + ^{137}Cs$ (90 nGy h^{-1})	Sanderson *et al*, 1994e
Sizewell Nuclear Power Station	$^{41}Ar + ^{16}N$ (150 nGy h^{-1})	Sanderson *et al*, 1997d
HMNB Devonport	none	Sanderson *et al*, 1993a
Torness Nuclear Power Station	none	Sanderson *et al*, 1994d
HMNB Clyde (Faslane), North Perimeter	none	Sanderson *et al*, 1996b

The nuclear fuel reprocessing plant at Sellafield has discharged a variety of radionuclides into the environment of the Irish Sea. Airborne surveys conducted in the vicinity of coastal margins, saltmarshes and estuaries in the Solway Firth and River Ribble, have revealed the extent and level of radiocaesium and other radionuclides in these environments (Sanderson *et al*, 1990c,1990d,1992,1993b,1994c). Gamma dose rates of a saltmarsh near Sellafield varied between 60-230 nGy h^{-1} (Sanderson et al, 1990d), mainly due to radiocaesium. Similar levels have been observed in salt marshes in the Ribble Estuary (Sanderson et al, 1993b), which have been considered in critical group dose assessments for the Springfields site.

An international exercise was conducted in Finland in 1995 involving 8 airborne survey teams from France, Germany, Sweden, Finland, Denmark, Norway, Canada and the UK (Sanderson *et al*, 1997b). The survey area included ^{137}Cs deposition from the 1986 Chernobyl nuclear accident, at levels of up to 100 kBq m^{-2}, which, when added to the natural gamma ray background of an area of predominantly granitic and granidioritic origins produced overall gamma dose rates of approximately 150 nGy h^{-1}.

Across Europe, a number of airborne survey teams have conducted nuclear site assessments. An airborne survey of Kozlodui nuclear power station in Bulgaria was performed by the

Bulgarian airborne geophysics group, in collaboration with the Finnish Geological survey and Geological Survey of Canada (Hetu *et al*, 1992). It showed average total dose rates of 75 nGy h^{-1}, and up to 160 nGy h^{-1} in some areas. Radiocaesium contamination corresponding to the same areas where these dose rates occurred, were found to be comparable with large areas of Sweden and Finland due to Chernobyl fallout (about 80 kBq m^{-2} ^{137}Cs).

In France, HELINUC of the Commissariat a L'Energie Atomique (CEA) have performed a large number of airborne surveys, including a request by the IAEA and the Marine Environmental Laboratory (Monaco) to investigate nine industrial and nuclear plants along the Danube between Budapest and the Black Sea (Bourgeois *et al*, 1995). The Radiation and Nuclear Safety Authority of Finland (STUK) and Finnish Defence Forces Research Centre have conducted extensive airborne surveys in Finland and Estonia between 1994-1997 (Nikkinen *et al*, 1997). These included power plants and environmental monitoring of Chernobyl fallout.

In the USA, an airborne survey team operated by EG&G Energy Measurement Remote Sensing Laboratory has extensive experience in conducting monitoring and assessments at nuclear facilities. Measurements taken directly over the Brookhaven National Laboratory have shown at least 1 milli-Roentgen per hour (9000 nGy h^{-1}) due to the presence of ^{58}Co, ^{60}Co and ^{137}Cs (EG&G, 1984). Elsewhere, dose rates of about 90 nGy h^{-1} were measured.

The airborne survey technique has developed from uranium prospecting applications and gamma dose rates from the natural environment show variations reflecting the underlying geology of the area being investigated. In SW England, there are variations in dose rate of 10-80 nGy h^{-1} (Sanderson *et al*, 1993a), related to the native geological features. In SW Scotland, granite masses contribute 10-100 nGy h^{-1} to the local dose rate. The airborne survey of Newbury District in 1996 (Croudace *et al*, 1997a; Sanderson *et al*, 1997a), which included the Harwell area, showed that the region as a whole had a relatively lower natural radiation environment than most parts of the UK. In Switzerland, airborne radiometric mapping has been used by the Swiss Geophysical Commission in regions of high natural radioactivity (Schwarz *et al*, 1992).

Enhanced gamma dose rates from non-nuclear, industrial sites have been recognised for some time as contributing to the natural radiation environment. Airborne surveys which have included the Delta Steel Works in Nigeria (Sanderson and Allyson, 1991), and fly ash settling pits at Longannet coal fired power station on the Firth of Forth (Sanderson *et al*, 1991) have revealed local enhancements of comparable magnitude to those observed near nuclear sites.

With the exception of the accelerator sources, the signals and features discussed in this report are similar to those found by airborne surveys at the perimeter of other UK nuclear facilities and in some instances, comparable with levels found in coastal environments of the Irish Sea due to discharges from nuclear fuel reprocessing. However specific conclusions and recommendations with respect to the Harwell site are made in the following section.

6. CONCLUSIONS AND RECOMMENDATIONS

The aim of the study was to investigate the series of radiometric features identified in the vicinity of the Harwell site during the airborne survey conducted for Newbury District Council in 1996. The airborne results have been re-analysed and associated with known sources of ionising radiation on the Harwell and Rutherford laboratory sites. Published environmental monitoring data have been reviewed, together with the results of existing unpublished data sets supplied by UKAEA, the Environment Agency and NRPB. Supplementary measurements have been made by UKAEA and RAL between March and May 1997, and a vehicular survey was conducted by SURRC in June 1997.

The work has confirmed that there are a number of additional radiation sources, apart from the liquid effluent treatment plant, which generate off-site radiation fields at ground level, in the vicinity of the signals detected in the airborne survey. The main additional sources identified include the Tandem accelerator, the ISIS/HELIOS accelerators, and radiation fields associated with licensed radioactive wastes stored on the Harwell site in building 462 and its surrounding ISO container compound. These machine sources, and the wastes produce dynamic radiation fields, whose implications vary, but are of comparable or greater strength to those associated with the LETP, which had previously been identified.

The significance of these features has been examined relative to ICRP and NRPB recommended criteria. In particular the dose constraint concept is relevant to individual sources of direct radiation. It has been recognised that the direct radiation pathways have received less attention in past radiological assessments than doses due to radioactive discharges. However the decommissioning of the Harwell materials testing reactors and other changes to the nature of work on the site have resulted in lower radioactive waste discharges over the last decade, these render the direct pathways more significant. Changes to the licensing, management and site boundaries have also taken place within recent years, and the nature and quantities of radioactive wastes stored on site are clearly undergoing changes. The peripheral areas of the site are undergoing re-development as part of the process of diversification from previous nuclear interests. Against this background it is clear that direct radiation exposure close to the site perimeter represents a more significant exposure pathway than recognised in past radiological assessments.

The features discussed in this study would be capable of delivering dose constraint exposures to individuals spending 1-2 hours on average per day in the most affected areas, when machine sources are operating. It is recognised that it is unlikely that the actual occupancy of these areas is as high as this. Moreover it is recognised that the dose constraint level of 300 $\mu Sv\ yr^{-1}$ represents a radiation dose increment which is within the range of variations of natural radiation exposure, and which corresponds to a very small level of risk to an individual. Nevertheless current recommendations at both international and national levels are clear that such radiation exposure should be avoided where possible or at least minimised, and any significant residual radiation justified.

The Harwell and RAL sites maintain both statutory and non-statutory radiation monitoring programmes. These programmes consist primarily of measurements using TLD's in fixed locations, which are replaced and analysed on a monthly or bi-monthly basis, and measurements at fixed locations using portable dose rate meters. This report has identified some areas in which the routine monitoring programmes have failed to fully identify and characterise radiation sources with off-site radiation consequences. This is also true of the monitoring conducted independently by NRPB in 1992 in support of the most recent published dose assessment. Independent monitoring commissioned by HMIP between 1989 and 1994 as a regulatory check identified more of these features; however these results were neither published nor communicated to UKAEA, and therefore their potential for influencing site assessments may have been limited.

Supplementary monitoring conducted as a result of the airborne survey, and the vehicular survey conducted for this study have indicated where improvements could be made in routine monitoring, and confirmed the existence of the main features. In addition the vehicular survey identified a number of small areas outside the licensed site boundary with low level uranium contamination. More work is needed to identify the source and extent of this material, and to ensure that its presence does not present hazards to the redevelopment of areas of the former airfield which have been used by AERE in the early years of the nuclear programme.

It became apparent after the airborne mapping that a low level radiation field was present at the south western corner of the Harwell site, in the vicinity of the PLUTO reactor building. The soil sampling results showed a ^{137}Cs distribution which was broadly consistent with the radiometric anomaly, with activity corresponding with that expected from global weapons testing fallout. Such a feature has no significant radiological implications, although the reasons for this particular distribution of activity are not clear. The airborne data may additionally appear to include a scattering component from the ISIS facility.

On the basis of this study a number of recommendations are made for consideration. It is suggested that the Vale of White Horse District Council raise these points with the site operators and their regulators, and follow up the responses:

1) Steps should be taken to prevent or minimise public radiation exposure resulting from on-site activities including those identified here. Consideration should be given to limiting public access to the affected areas, to provision of supplementary shielding around radiation sources on-site, and to re-arranging the locations of radioactive materials to minimise off-site dose rates.

2) Justification for radiation levels remaining after such work should be reviewed subject to the normal process of consultation.

3) The additional radiation features discussed in this report, principally the Tandem Van de Graaff accelerator, the ISIS and HELIOS accelerators and the B462 complex with the associated ISO storage compound, should form part of future dose assessments.

4) Routine monitoring programmes conducted by the site operators should be adapted to respond more positively to perimeter dosimetry and its changes. In this respect consideration should be given to the location of fixed monitoring stations, to the use of instrumental methods which respond to dynamic situations in addition to integrating dosimetry, and to conducting periodic

perimeter surveys to ensure that critical areas are being kept under review.

5) Consideration be given to incorporating monitoring and assessment of off-site consequences into operational procedures for moving radioactive materials on-site.

6) Any revisions to the routine perimeter monitoring programme be published in annual reports, but that the practice of reporting a "site average" based on a partial set of monitoring data be discontinued.

7) The site regulators consider the re-instatement of an independent programme of perimeter monitoring, to replace that which was discontinued by HMIP in 1994. The results of such monitoring should be published, and action taken to ensure that any gaps in the operators routine monitoring are identified and corrected.

8) The nature, extent and origins of patches of low level Uranium contamination on the former airfield should be identified. The presence of other similarly contaminated areas should be investigated, and consideration should be given to removing such material from areas outside the current licensed site.

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9. APPENDICES

APPENDIX A. Airborne Survey Flight Details and Profile Plots

The airborne survey commenced at 16:00 on 25th September 1996. Four circuits of the Harwell perimeter were flown in a clockwise direction starting from the eastern side of the site, at increasing distances from the perimeter. The first circuit, including approach to the site from the north, took 8 minutes, and comprised 76 files (152 NaI spectra) and the second took 6 minutes (48 files, 96 NaI spectra), both of these flights passed between the main site and the LETP compound. The third circuit took 5 minutes (52 files, 104 NaI spectra) and the fourth 5 minutes (46 files, 92 NaI spectra).

General infilling of the surrounding area at approximately 50m linespacing was then carried out. First, north of the site (10 minutes, 89 files, 178 NaI spectra), then the east (6 minutes, 58 files, 116 NaI spectra), the south east (5 minutes, 43 files, 86 NaI spectra), the south and west (10 minutes, 78 files, 156 NaI spectra).

Figures A.1 and A.2 show profile plots for spectral windows corresponding to: ^{137}Cs (661 keV), ^{60}Co (1172 keV), ^{40}K (1461 keV), ^{214}Bi (1764 keV), ^{208}Tl (2615 keV), total gamma dose (450-3000 keV) for the first 500 spectra and the entire data set. The data have been calibrated with respect to an equivalent plane deposition (eg. ^{137}Cs) and uniform depth distribution in the case of the natural radionuclides.

Low energy spectral windows which have been demonstrated to be useful in interpreting scattered gamma radiation have also been used. An additional dose rate profile was calculated over a much larger range (40-3000 keV), from energy deposition in the detector crystals (in pJ s^{-1}). Profile plots for these parameters are shown in figures A.3 and A.4, again for the first 500 spectra and the entire data set.

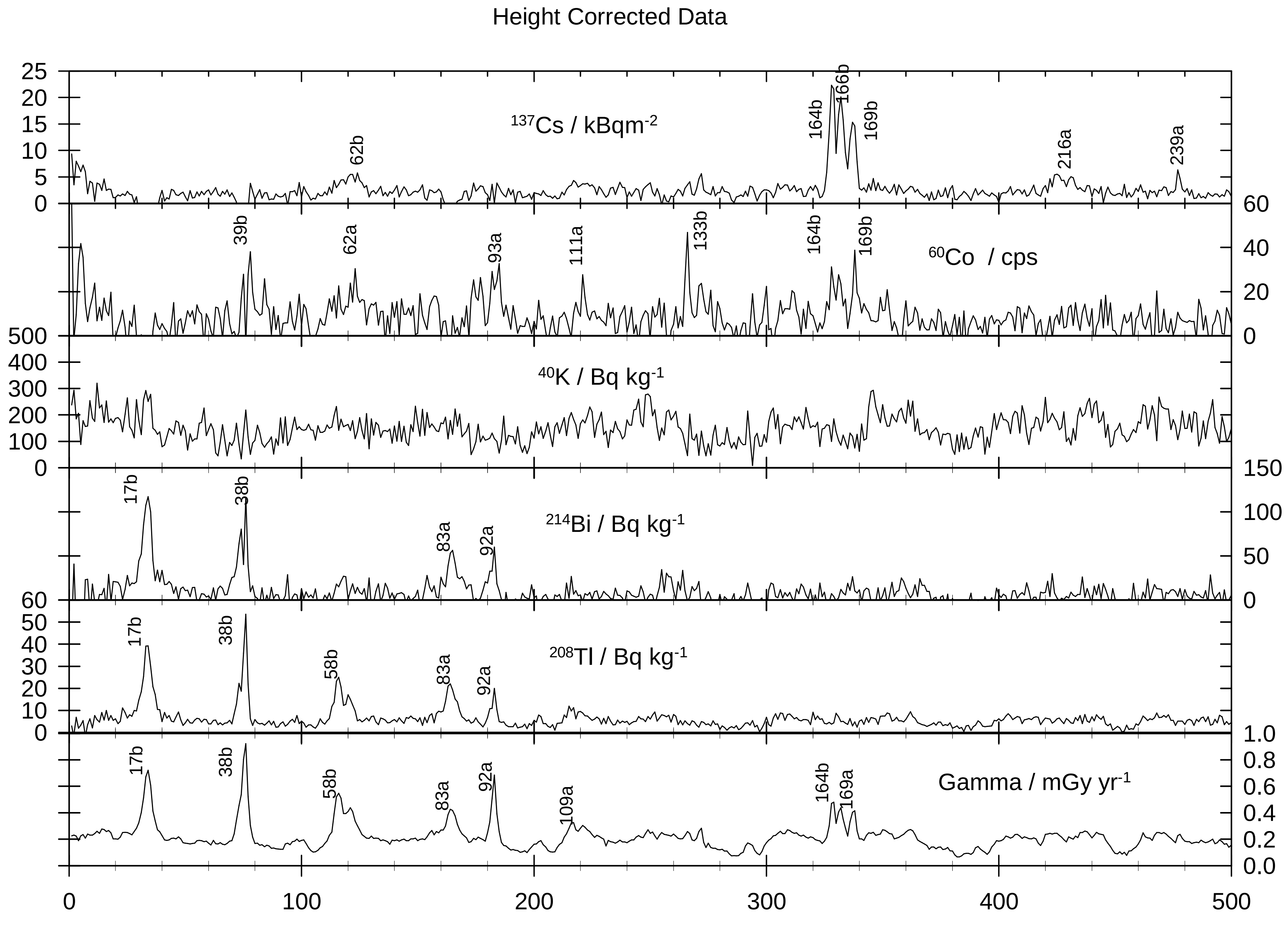


Figure A.1 Airborne survey profile plot.

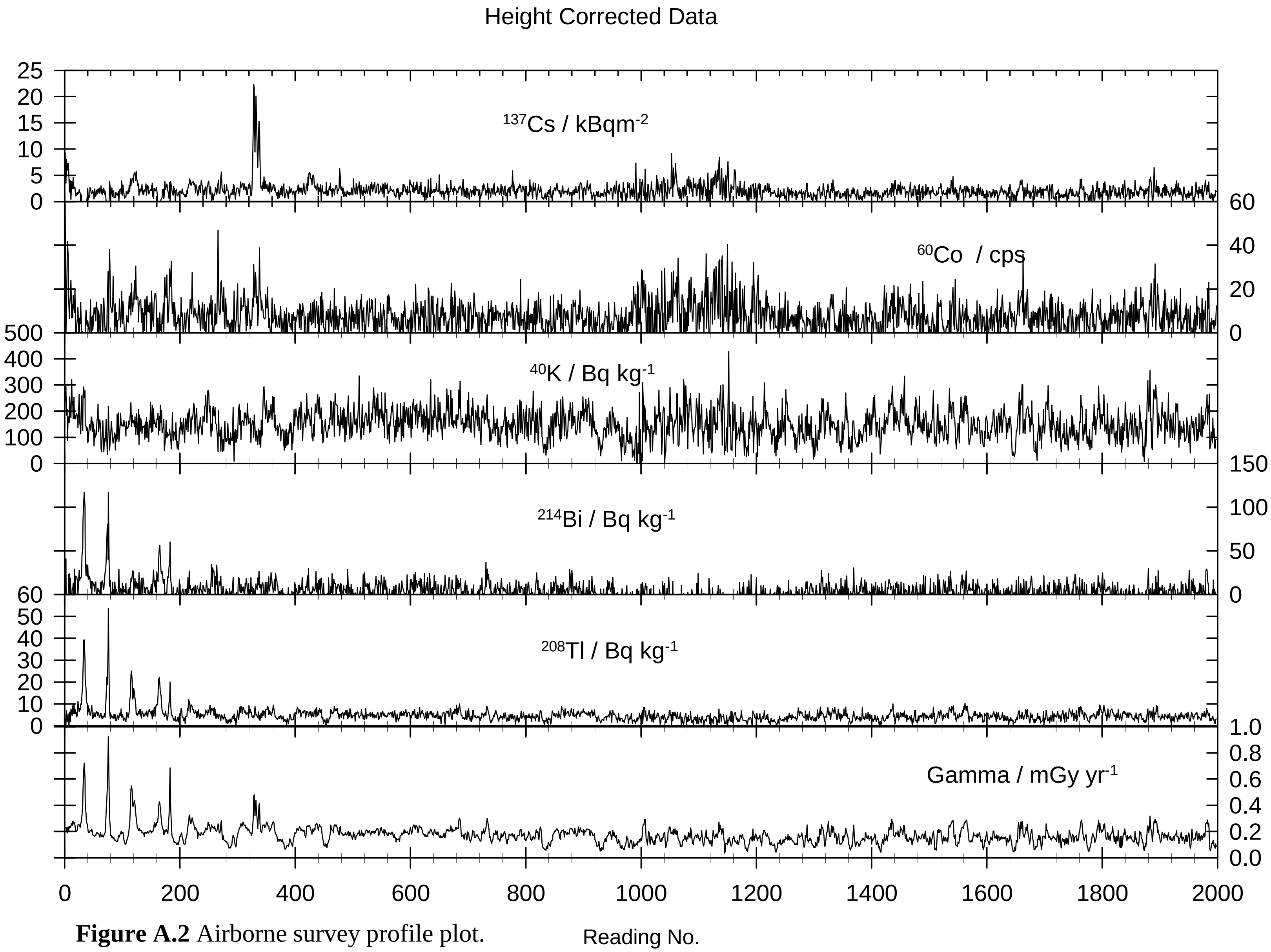


Figure A.2 Airborne survey profile plot.

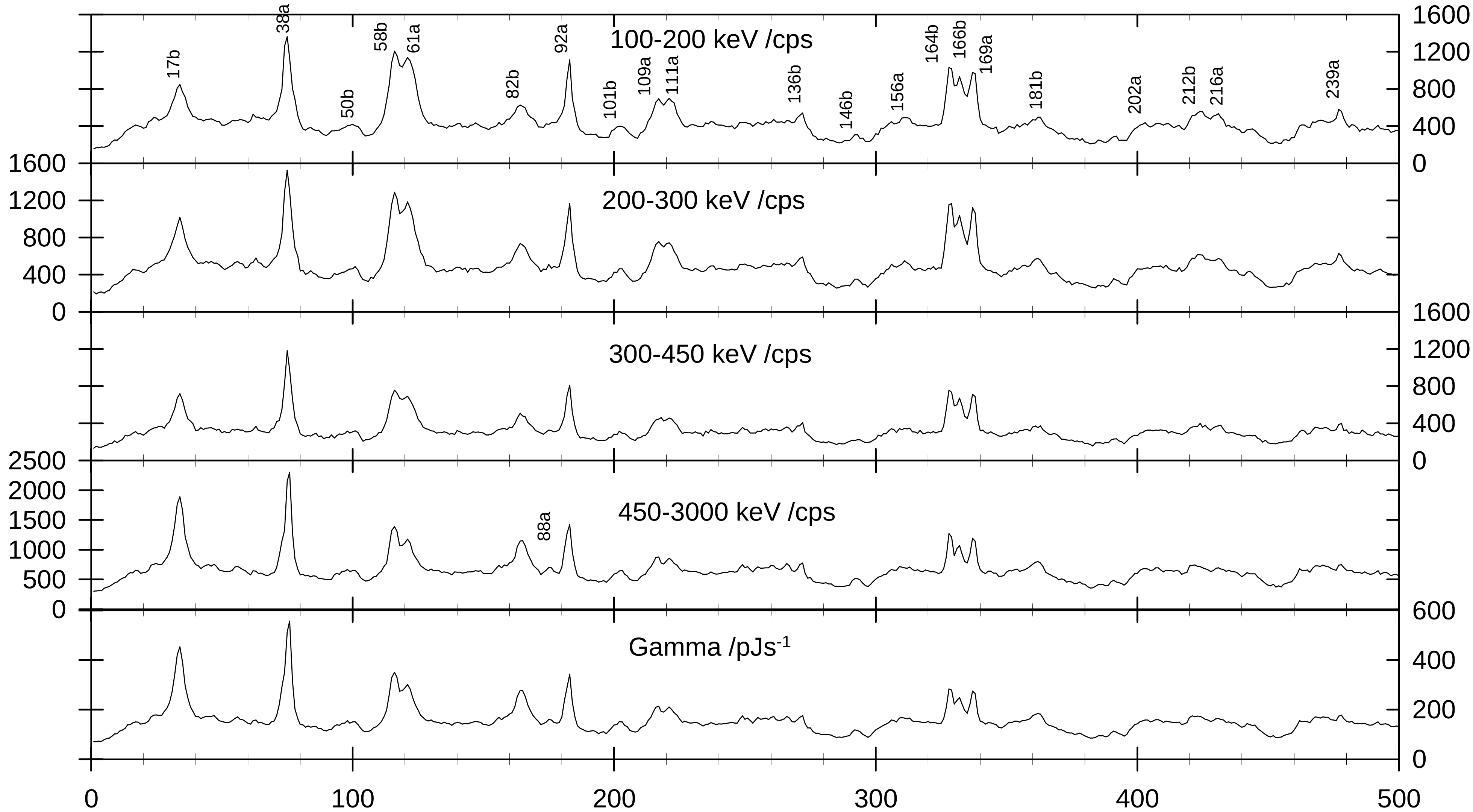


Figure A.3 Airborne survey profile plot.

Reading No.

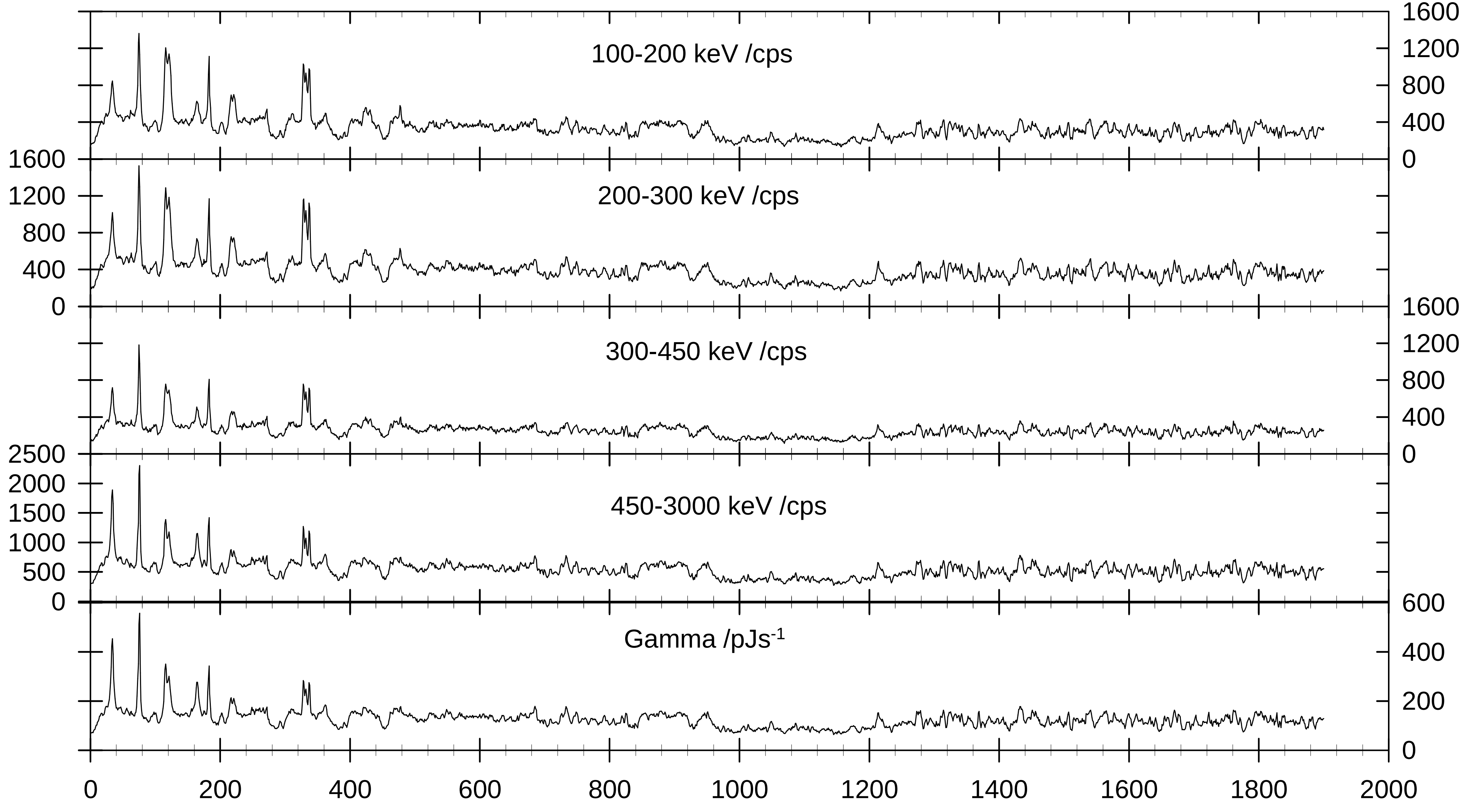


Figure A.4 Airborne survey profile plot.

APPENDIX B. Summary of Detector Calibration and Data Processing for the Vehicular Survey

1) Detector and Data Collection System

8 litre NaI(Tl) detector array (2 crystal pack):
Serial numbers: IN356, JA895
EHT: 1000V (nominal)

Pair of GMX Semiconductor detectors operated in parallel with scintillation detector:
Serial number: 32-TN30665A Pop Top (EHT: -3000V)
Serial number: 32-TN40320A Pop Top (EHT: -3000V, previously -3500V)

Table B.1 16 litre NaI system performance check

Date	Resolution at 661 keV / %	Detector * Sensitivity (Gross) /cps	Detector * Sensitivity (Net) /cps
16/06/97	11.1	972±3	541±2
19/06/97	9.9	839±3	572±2
20/06/97	9.7	-	519±5

***** 1 ^{137}Cs calibration sheet (#1, number up)

486PC logging computer. SURRC 19" rack and NIM. DPS MkII power supply
NavStar GPS operated in conjunction with RDS3000v3 to enable DGPS operation (10 m accuracy, 4800 Baud)

Garmin GPS 89 provided additional information to the operator

24 Vdc battery power supply

Recording software: GREN1.BAT/.BAS/.EXE (twin MCB, NaI and GMX detectors)

Summary software: NDSM1.BAS, NDSM2.BAS (.SM1 AND .SM2 respectively)
Data analysis software: AERONW16/17.BAS

Time differential: 19:12:08 (PC), 19:09 (DCWS)

Table B.2 Filenames

Filenames	Filenumbers	Logging Programme	Counting Times /s
HARW1	1,312	GREN1	5,10
HARW2	1,201	GREN1	5,10
HARW3	1,768	GREN1	5,10
HARW4	1,167	GREN1	5,10
HARW5	1,930	GREN1	5,10
HARW6	1,999	GREN1	5,10
HARW7	1,83	GREN1	5,10

2). Spectral Windows

Table B.3 NaI measurement windows

Channel	Original Windows			Reintegrated Windows		
	Radio-nuclide	Channel Number	Back-ground /cps	Energy Range	Channel Number	Back-ground /cps
1	^{137}Cs 661 keV	95-128	27.31	40-100 keV	7-16	0
2	^{60}Co 1172 keV	170-208	10.21	100-299 keV	17-33	48.4
3	^{40}K 1461 keV	220-270	10.61	200-300 keV	34-50	62.4
4	^{214}Bi 1764 keV	270-318	5.8	300-450 keV	51-75	47.3
5	^{208}Tl 2615 keV	390-480	4.87	450-3000 keV	75-500	103
6	Total >450 keV	75-500	103	pJ s^{-1} in 40-3000 keV	7-500	23.54 pJ s^{-1}

Table B.4 HPGe measurement windows

Window	Radionuclide	GMX Pair	
		Channel Number	Background /cps
1	^{241}Am (59.5 keV)	62-66	0
2	^{234}Th (63 keV)	66-70	0
3	^{208}Tl (583 keV)	578-590	0
4	^{214}Bi (609 keV)	604-615	0
5	^{137}Cs (661 keV)	655-666	0
6	^{40}K (1461 keV)	1450-1463	0

3) 8 litre NaI Stripping Ratios

Stripping ratios were measured on the 9th July 1997 using doped concrete calibration pads, a ^{137}Cs plane source and a ^{60}Co point source, at ground level within the SURRC Calibration Facility.

Table B.5 Stripping ratios

	^{137}Cs	^{60}Co	^{40}K	^{214}Bi	^{208}Tl
^{137}Cs	1	0	0	0	0
^{60}Co	0.304	1	0.606	0	0
^{40}K	0.456	0.420	1	0.008	0
^{214}Bi	3.23	1.47	0.905	1	0.082
^{208}Tl	2.58	0.682	0.594	0.446	1

4) Calibration Constants

b: slope of calibration line
c: calibration intercept

Table B.6 Calibration factors

Window	Radionuclide	b	c	Notes
1	^{137}Cs	0.133 kBq m^{-2}/cps	0	Fieldwork based
2	^{60}Co	1	0	cps
3	^{40}K	9.87 Bqkg^{-1}/cps	0	Fieldwork based
4	^{214}Bi	2.92 Bqkg^{-1}/cps	0	Fieldwork based
5	^{208}Tl	0.853 Bqkg^{-1}/cps	0	Fieldwork based

5) Gamma Ray Dose Rate

Gamma ray dose rate as measured by scintillation detectors has commonly been estimated by using the integration of count rate above an energy threshold (for example >450 keV and terminating at 3000 keV). This has been demonstrated to provide a satisfactory basis for conversion to total gamma ray dose rate for environmental radionuclides. However in the presence of machine sources and low energy sources, the use of a broader energy range (for example 40-3000 keV) may be preferable. In view of this, gamma dose rate was estimated by re-integrating the Harwell survey data set (forming HARW1-7.SMR files; counting period 5,10 seconds), and similarly the Greenham Common vehicular survey (Sanderson *et al*, 1997a) data set (forming GRN01-05.SMR; counting period 15,30 seconds). The Greenham Common data provided a control since extensive soil sampling and radionuclide inventory was undertaken at the designated calibration site (51°22.731N, 1°17.390W, ±10 m). The re-integrated data was then converted to the equivalent energy absorbed in the detector (in pJ/s). Both data sets were related to the total count rate 450-3000 keV to observe the correlation.

The NaI spectrometer system used in the ground and airborne surveys was configured to record spectra up to 3 MeV. However, it is expected that machine sources would generate gamma rays at energies in excess of this. Thus a small number of high energy gamma rays may be missed by the spectrometry system used, and this could result in a significant underestimate of the gamma ray dose rate measured from machine sources when the system is calibrated to a natural radiation field. Figure B.3 shows a plot of the log of counts against log of energy for a spectrum recorded near the ISIS accelerator, it is noted that a straight line is produced at energies above the peak due to annihilation gamma rays at 511 keV. An extrapolation of this line beyond 3 MeV can be used to estimate the dose unaccounted for by integration of the measured spectrum. This extrapolation indicates that approximately 25% of the total dose is accounted for by the region from 3-10 MeV, with upper and lower values of 50% and 10% for the 1 sigma limits of the parameters for the straight line fit.

Corrected dose rates were estimated by taking the dose rate value derived for a natural energy distribution, subtracting a fixed 40 nGy h^{-1} background, scaling up by 1.3, and adding in the fixed 40 nGy h^{-1} background again.

Figure B.1

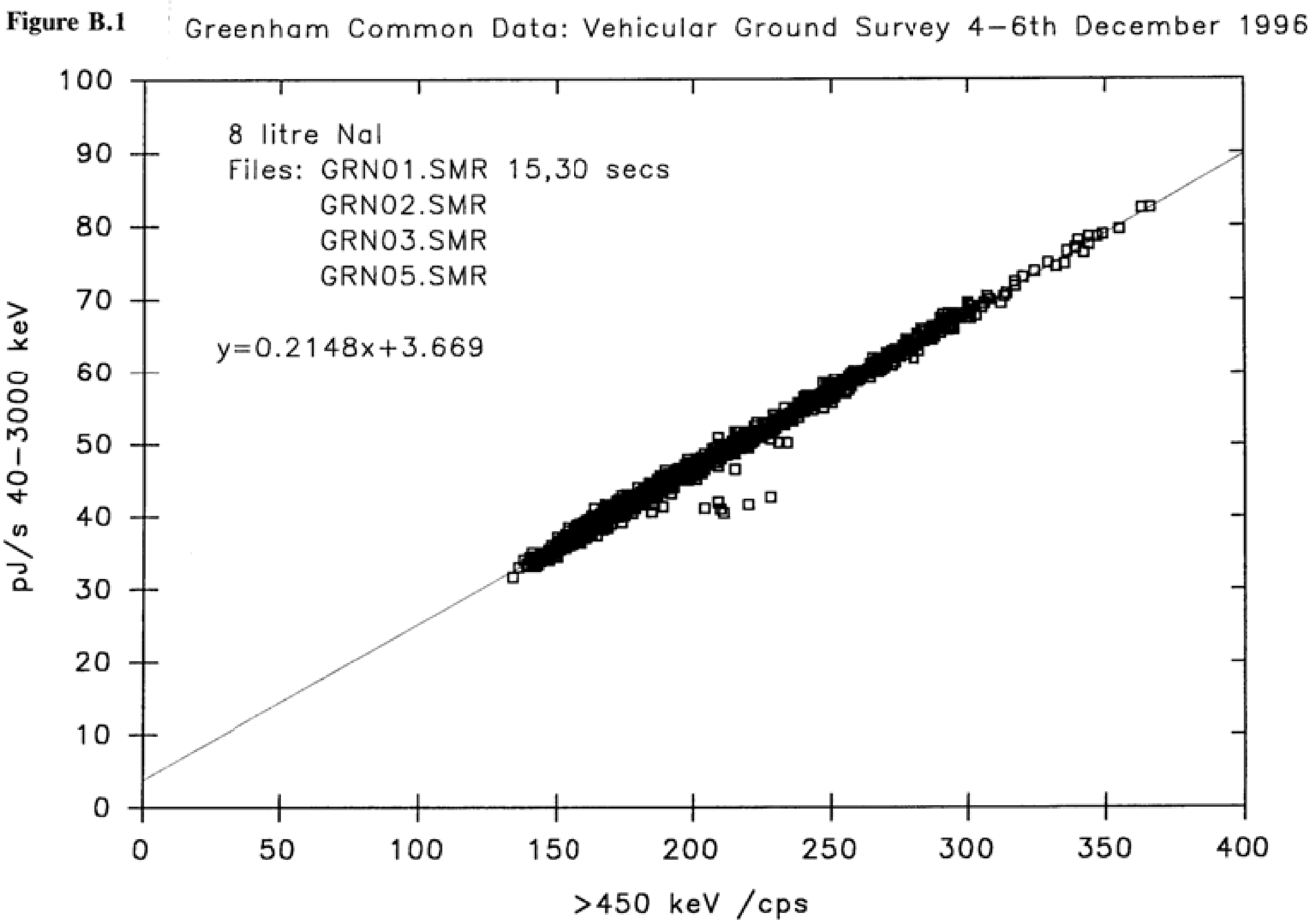

Greenham Common Data: Vehicular Ground Survey 4–6th December 1996
8 litre NaI
Files: GRN01.SMR 15,30 secs
GRN02.SMR
GRN03.SMR
GRN05.SMR
y=0.2148x+3.669
pJ/s 40–3000 keV
>450 keV /cps
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
400

Figure B.2 Harwell Data: Vehicular Ground Survey 19–20th June 1997

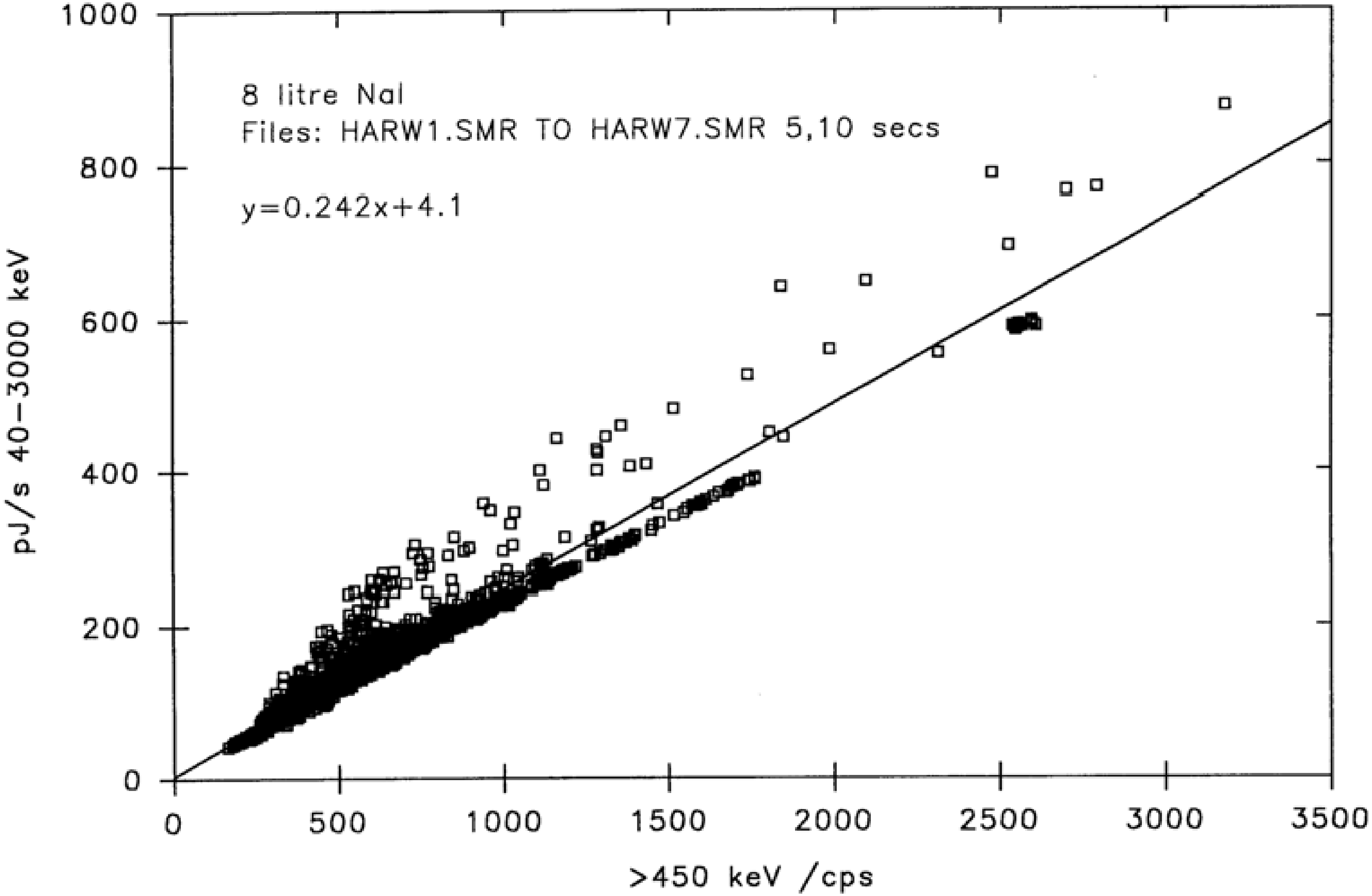
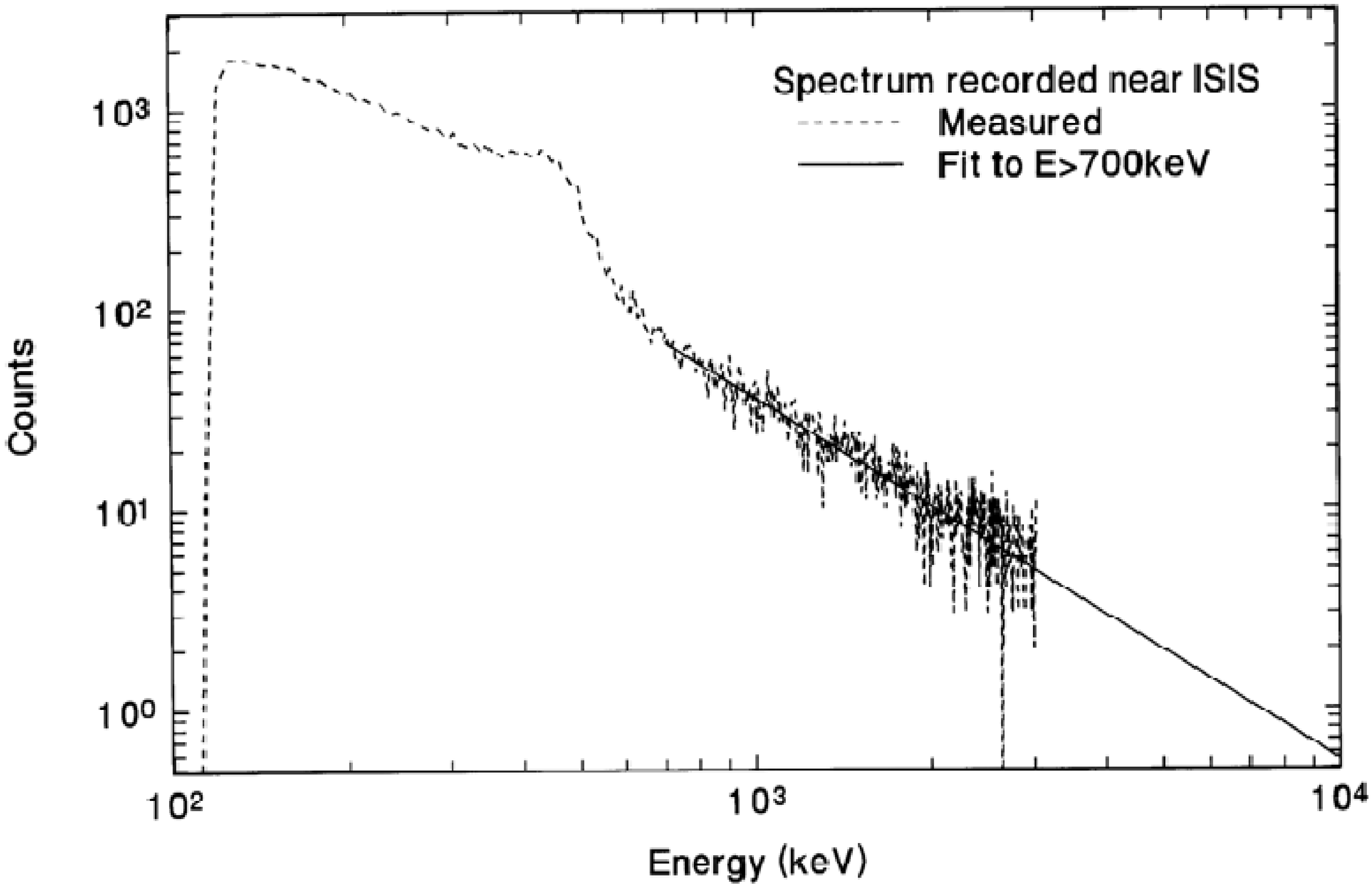


Figure B.3 Correction of high energy component



APPENDIX C. Summary of Vehicular Route

Thursday 19th June 1997

Filename HARW1, recorded 10:52:53 - 11:52:57.

Survey commenced at B151, Harwell. The detectors were confirmed to be operational. The route taken was inside site from B151 to B462 complex, Fermi Gate, Research Reactors Division (DIDO, PLUTO), south east corner of site along perimeter fence, south west corner, water recovery plant, Tandem Van de Graaff accelerator (B477). The Tandem was operational.

Filename HARW2, recorded 13:56:50 - 14:33:51.

Survey begun at Tandem (B477), outside Harwell site near perimeter fence. Proceeded with parallel line spacing of approximately 10 m , in north-south direction in the area immediately facing B477 (features "A" and "F"). Areas to the east of B477, along access road and Harwell playing fields was monitored with a similar survey pattern.

Filename HARW3, recorded 16:03:25 - 18:22:29.

The battery pair were replaced to extend duration. Further Tandem monitoring work, and extension towards bus park was made, behind Harwell canteen and current road construction area. The area near southern end of bus park was noted to have elevated levels of gamma radiation in uranium windows. A return route was taken past Harwell nursery and NIREX building towards Liquid Effluent Treatment Plant (LETP) and features previously noted as "N, Q and R" inspected. Measurements were then made close to the TLD monitoring point at the LETP. Elevated levels were observed within the housing estate (no.10 South Drive) and at "Keep Clear" sign on garage door (no.3 South Drive). The rear of the LETP was then monitored. A return route was taken to the bus park for closer inspection of previously noted feature. A small earthwork (51°34.727N, 1°18.727W, ±7 m) appeared to be the source of enhanced natural uranium.

Filename HARW4, recorded 18:40:27 - 19:11:14.

Route to RAL for liquid nitrogen supplies. Measurements were made near the inside fence of RAL, and up to ISIS Control entrance.

Friday 20th June 1997

Filename HARW5, recorded 10:39:15 - 13:25:18.

Detector checks were completed and confirmed. The first route chosen was inside the Harwell perimeter track near Tandem B477, and around side of Harwell canteen towards B551. High levels were recorded near B462 complex and a number of passes were made. The survey route headed towards Fermi Gate and B418. A slow run was made along inside Harwell perimeter fence adjacent to RAL site and TLD badge locations. ISIS status was variable throughout the day (features "B, G and K"). Further measurements were made at the south east, south west and north west corners of site. An exit was made at the Harwell main gate and a route chosen towards local garden centre, and along past Chilton School, Upper Farm, reactor site perimeter fence (south west corner, outside site), and features "C, H and L". Measurements were made at Meeshill Plantation, B462 (features "E, D, I, J, M and P) and Aldfield Farm.

Filename HARW6, recorded 14:59:05 - 17:59:16.

A cross calibration between Harwell and SURRC 680 mini-monitors was made at the Tandem accelerator. The Tandem was then brought off-line. Further measurements were made in the vicinity to compare recorded signals with the previous day. A route was then taken to RAL playing fields to inspect for evidence of feature "O". Parallel line spacings were made to enable saturation coverage. The survey then headed towards the nearby housing estate and old "prefab" locations. Some observations were noted on the roadway, showing elevated levels. A slow run was made between trees, grass areas and Chilton School. Slow parallel runs were made at the location of the old Catapult Pit. The survey file was completed with further measurements inside Harwell site along perimeter fence adjoining RAL, near ISIS buildings.

Filename HARW7, recorded 18:55:59 - 19:11:07.

Final measurements were made within RAL site at ISIS Control entrance and RAL car park.

Line profile plots for the files HARW1 to HARW6 are shown in Figures B.1-B.6. Six channels 1 to 6 from the original data set, equivalent to ^{137}Cs (kBq m^{-2}), ^{60}Co (cps), ^{40}K (Bq kg^{-1}), ^{214}Bi (Bq kg^{-1}),^{208}Tl (Bq kg^{-1}) and gamma dose rate >450 keV (mGy yr^{-1}). Figures B.7-B.12 show channels 2 to 6 from a re-integrated data set (see Appendix A, section 4), corresponding to count rates in energy ranges 100-200 keV, 200-300 keV, 300-450 keV, 450-3000 keV and 40-3000 keV (calibrated in mGy yr^{-1} from pJ s^{-1}).

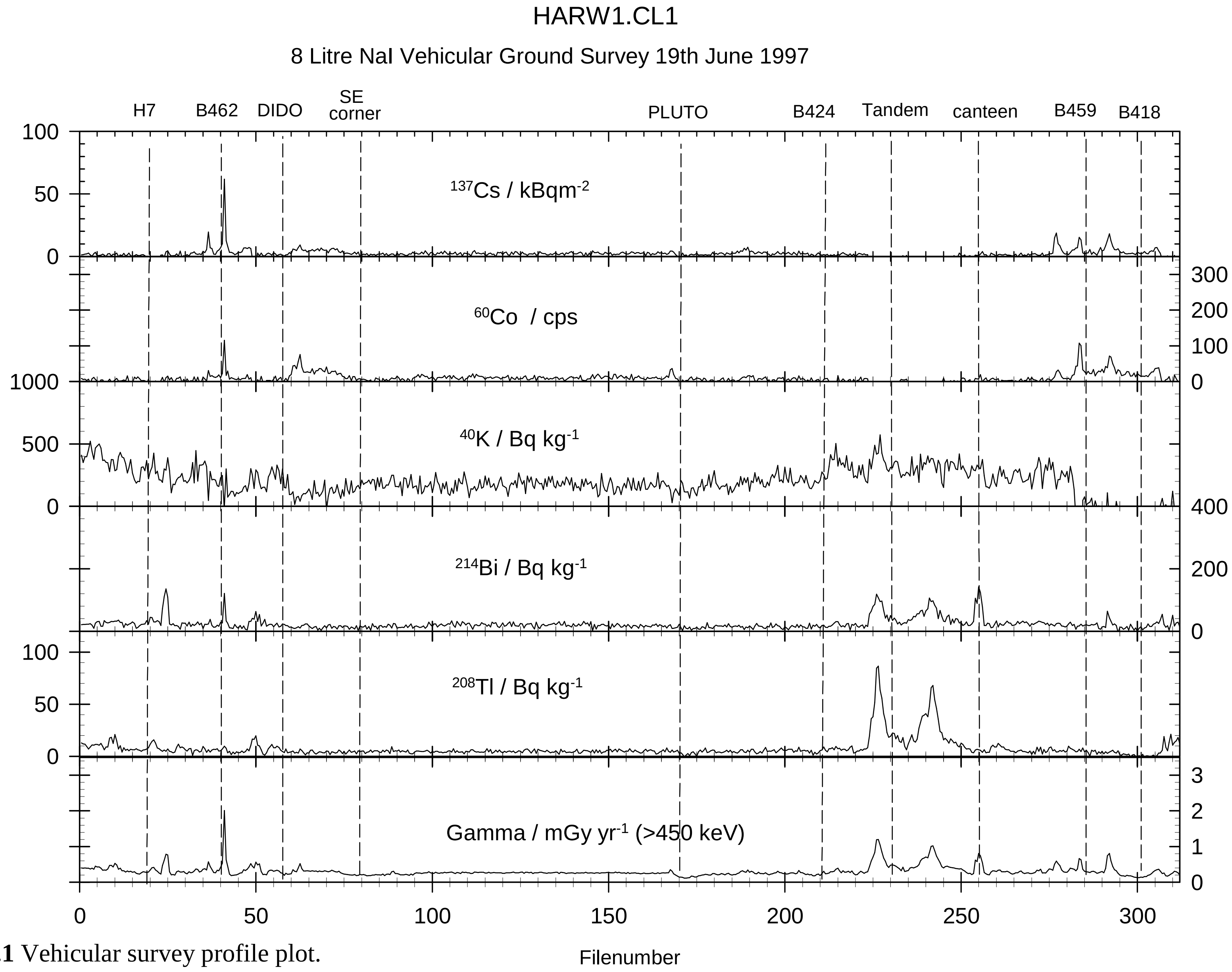


Figure C.1 Vehicular survey profile plot.

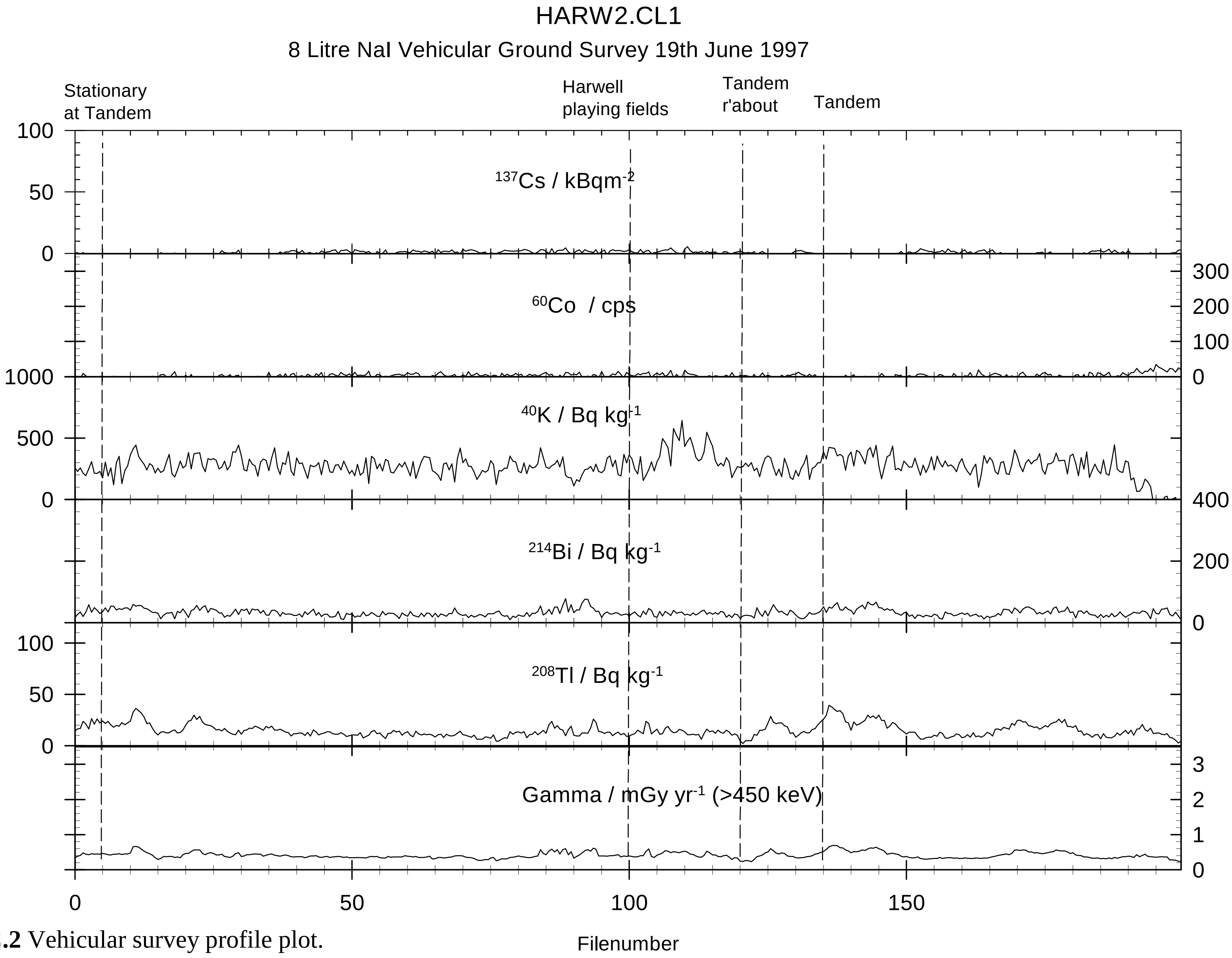


Figure C.2 Vehicular survey profile plot.

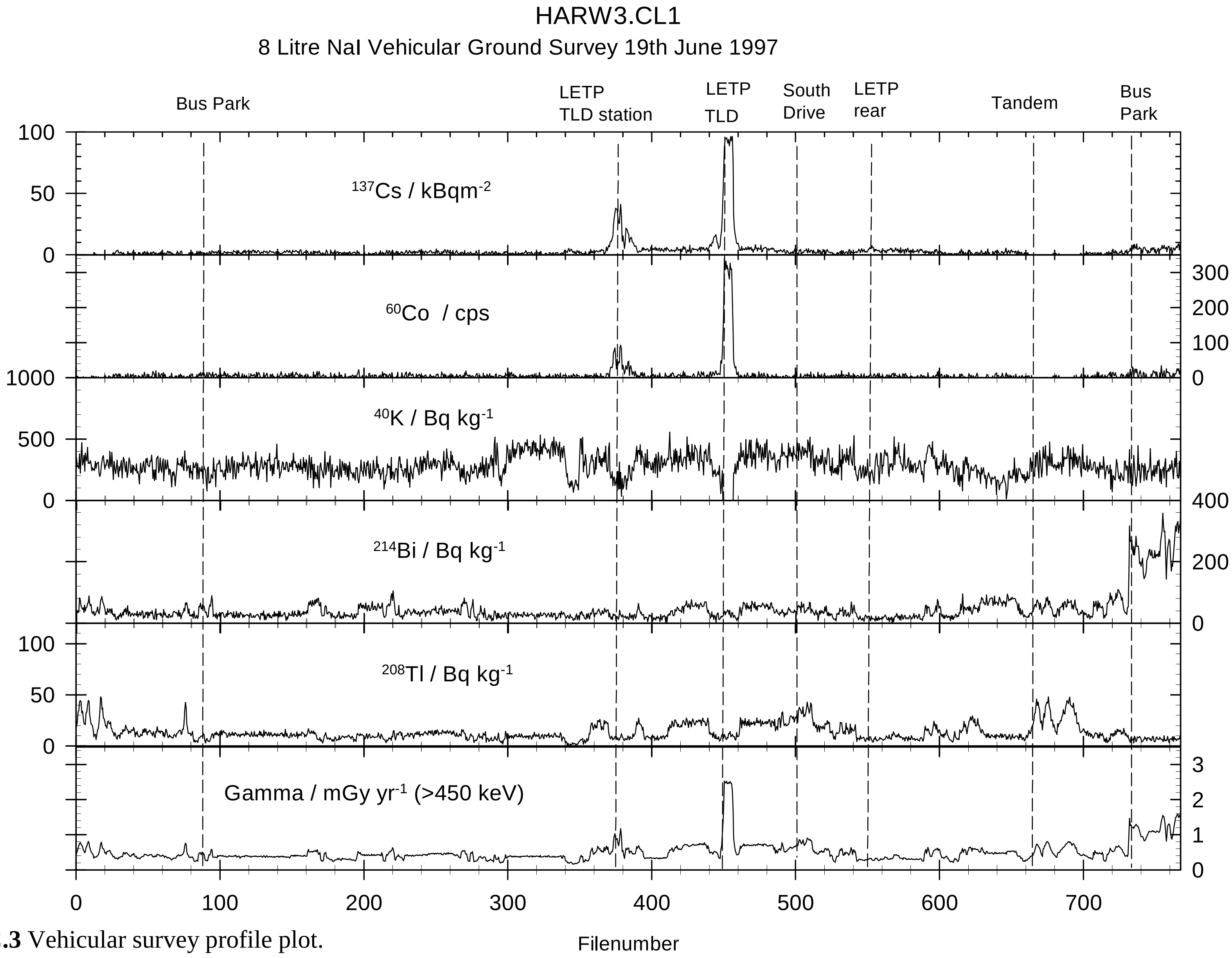


Figure C.3 Vehicular survey profile plot.

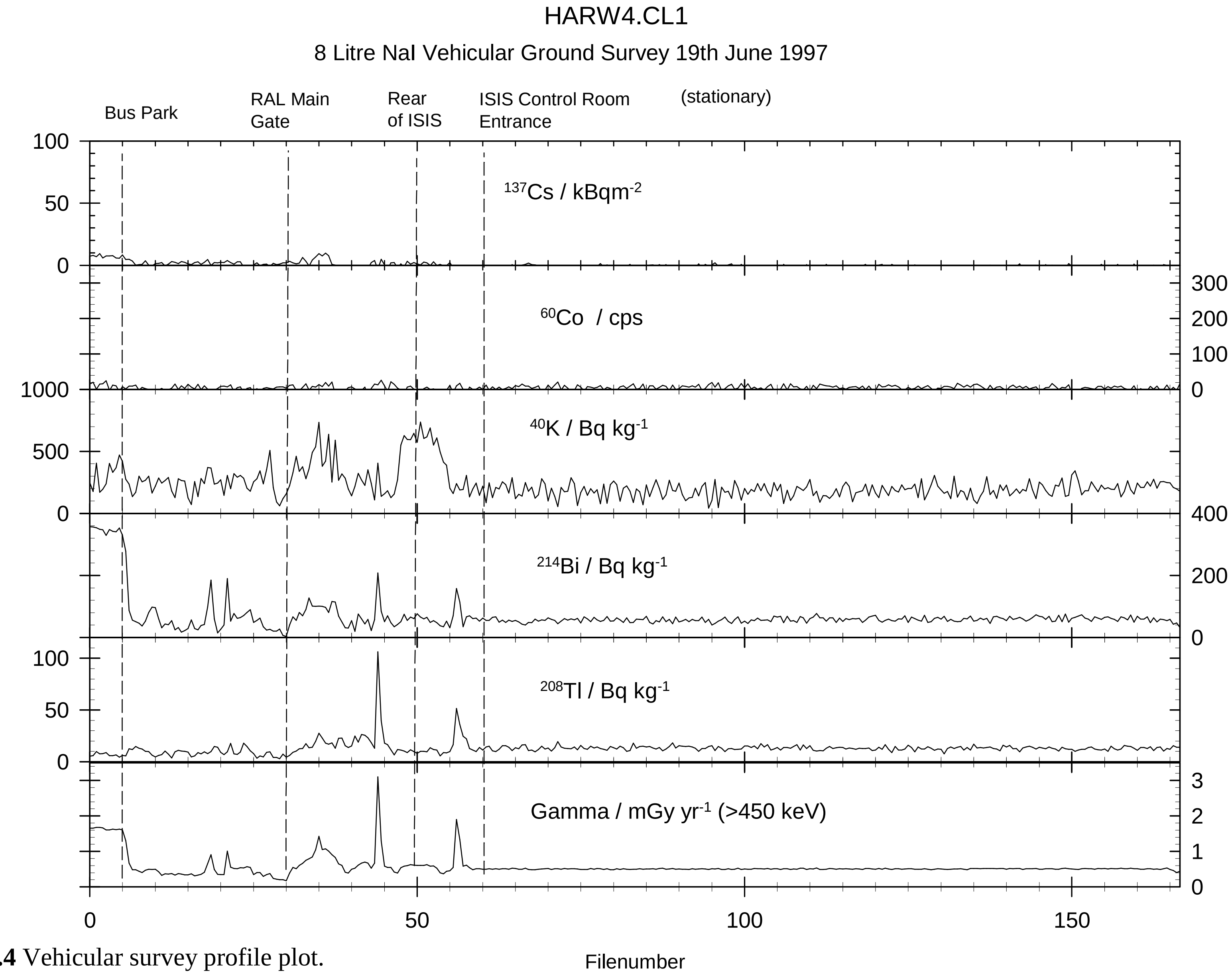


Figure C.4 Vehicular survey profile plot.

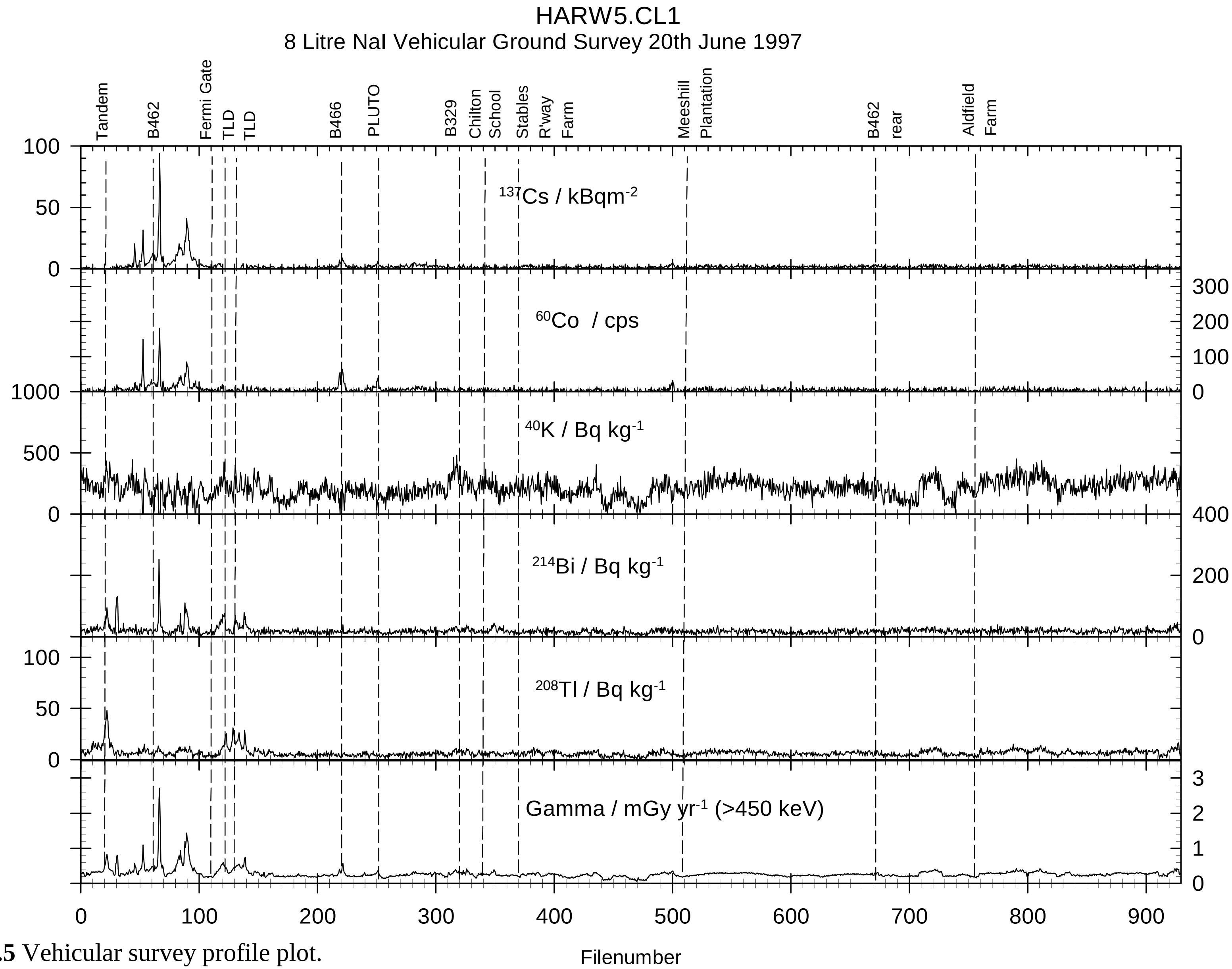


Figure C.5 Vehicular survey profile plot.

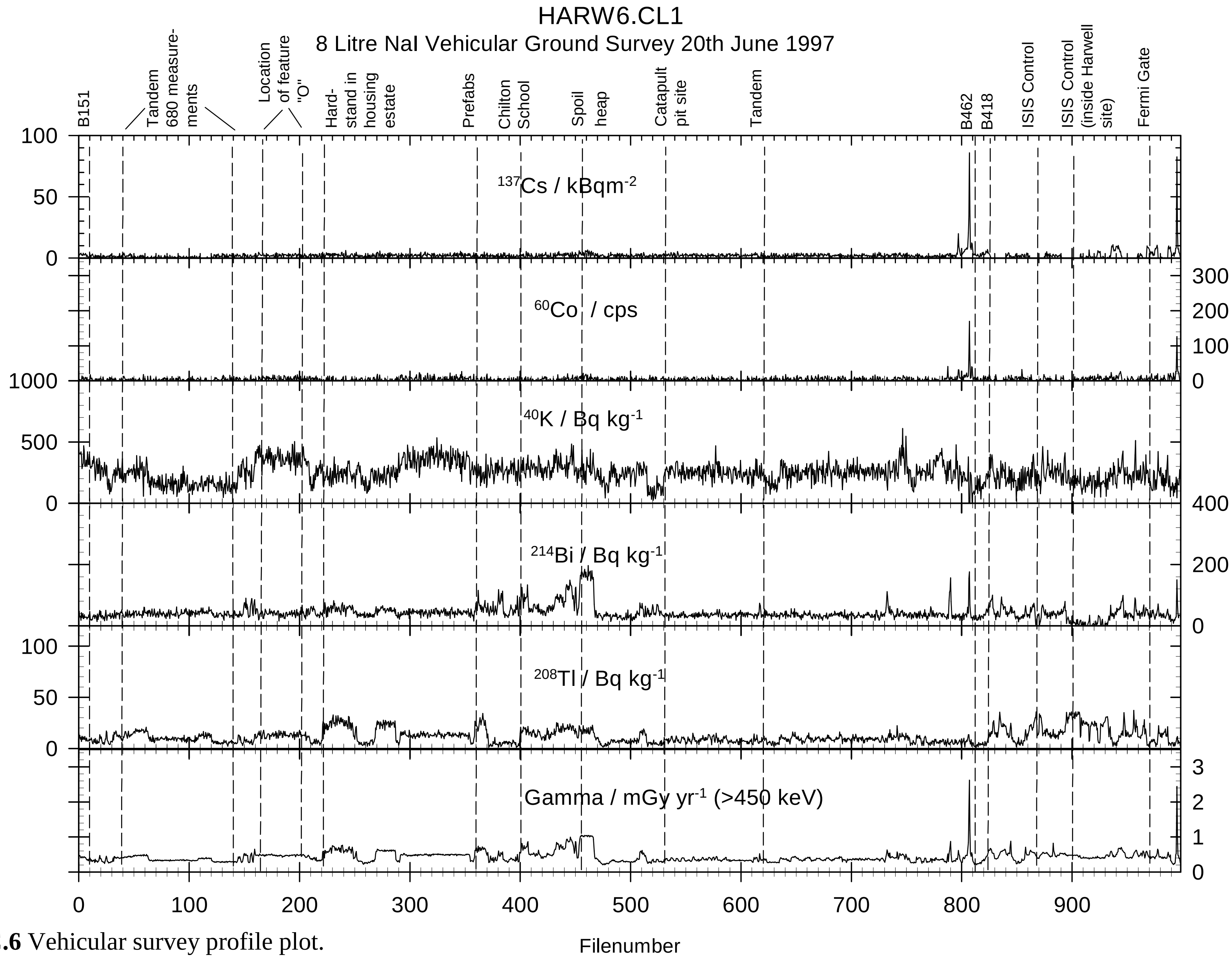


Figure C.6 Vehicular survey profile plot.

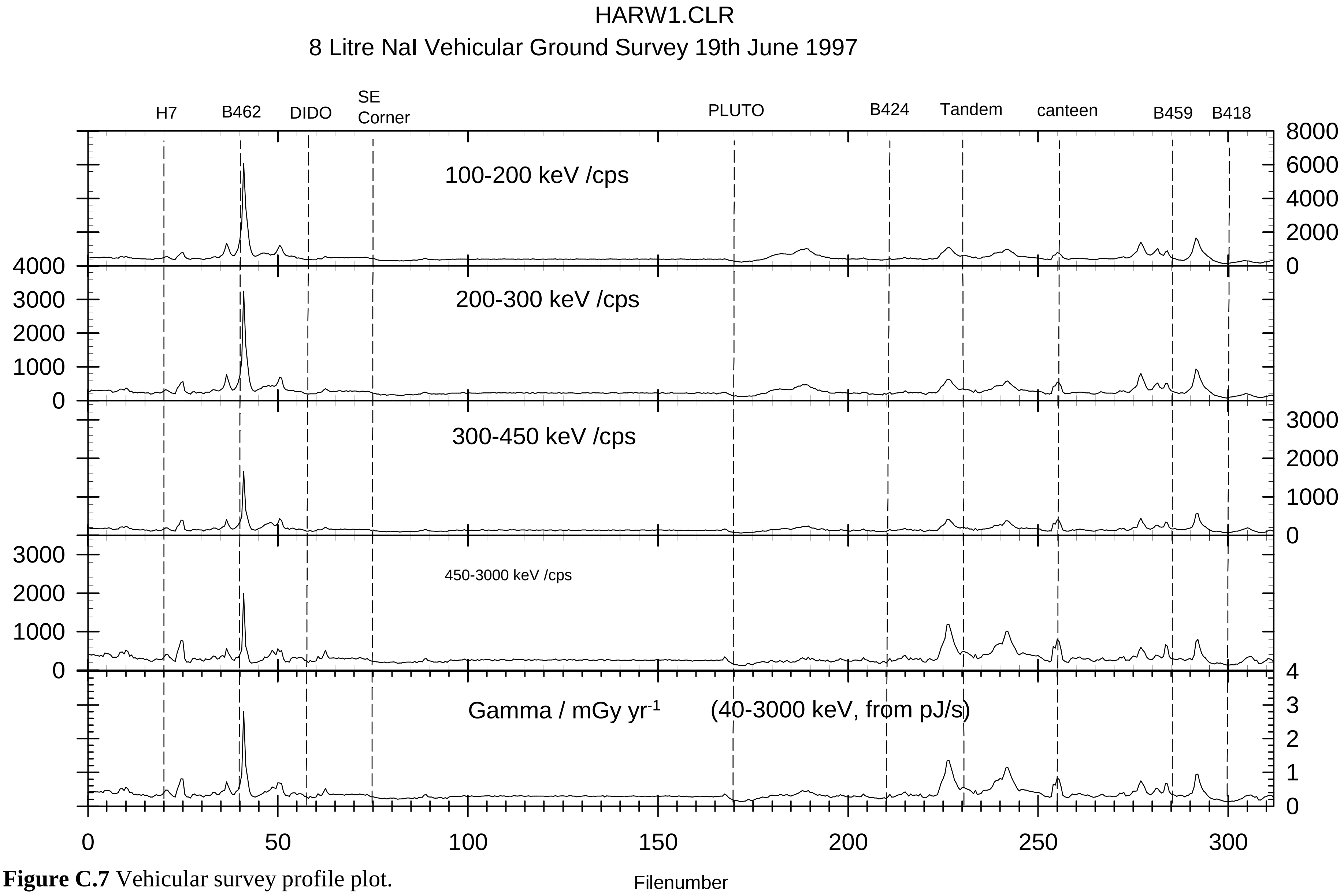


Figure C.7 Vehicular survey profile plot.

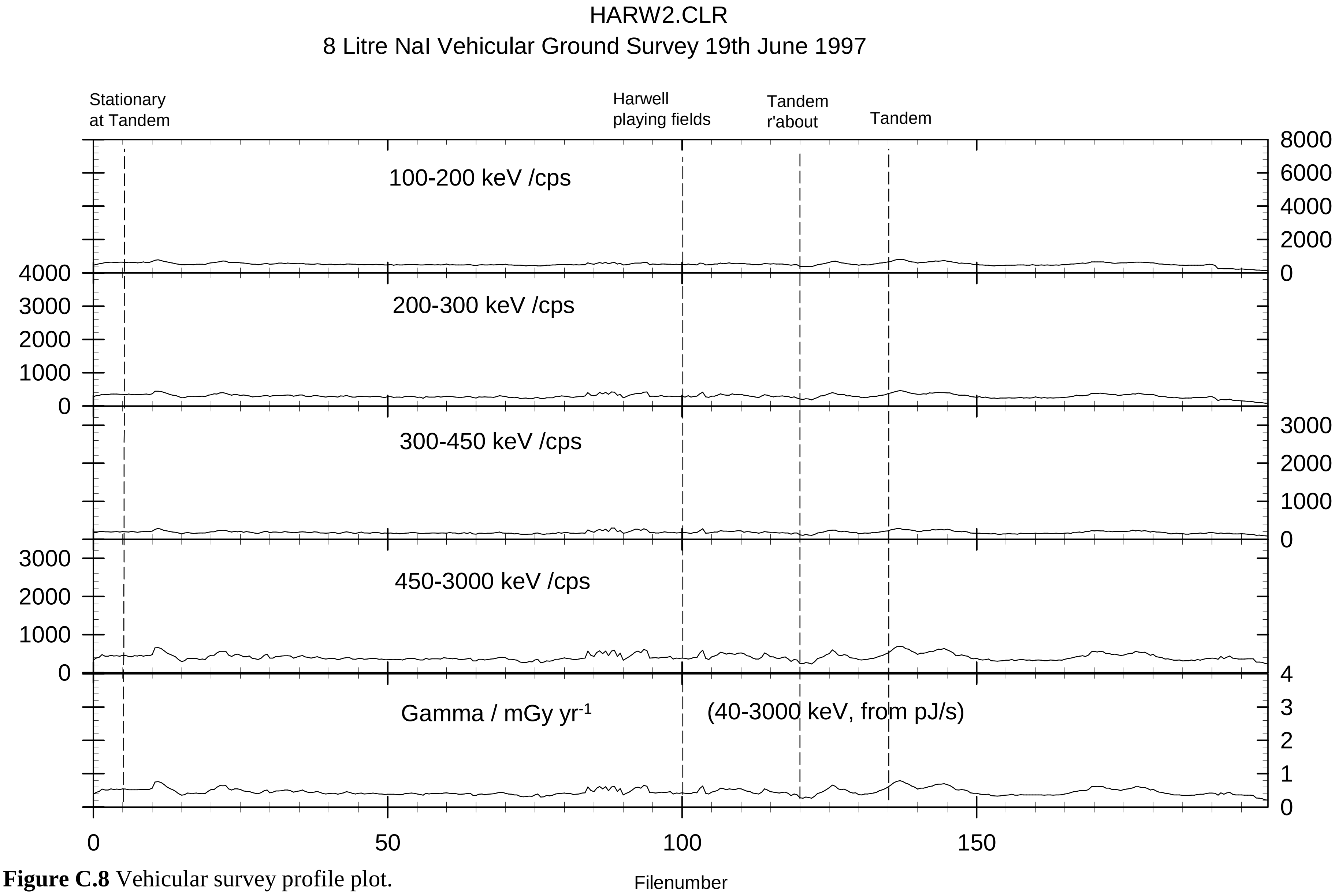


Figure C.8 Vehicular survey profile plot.

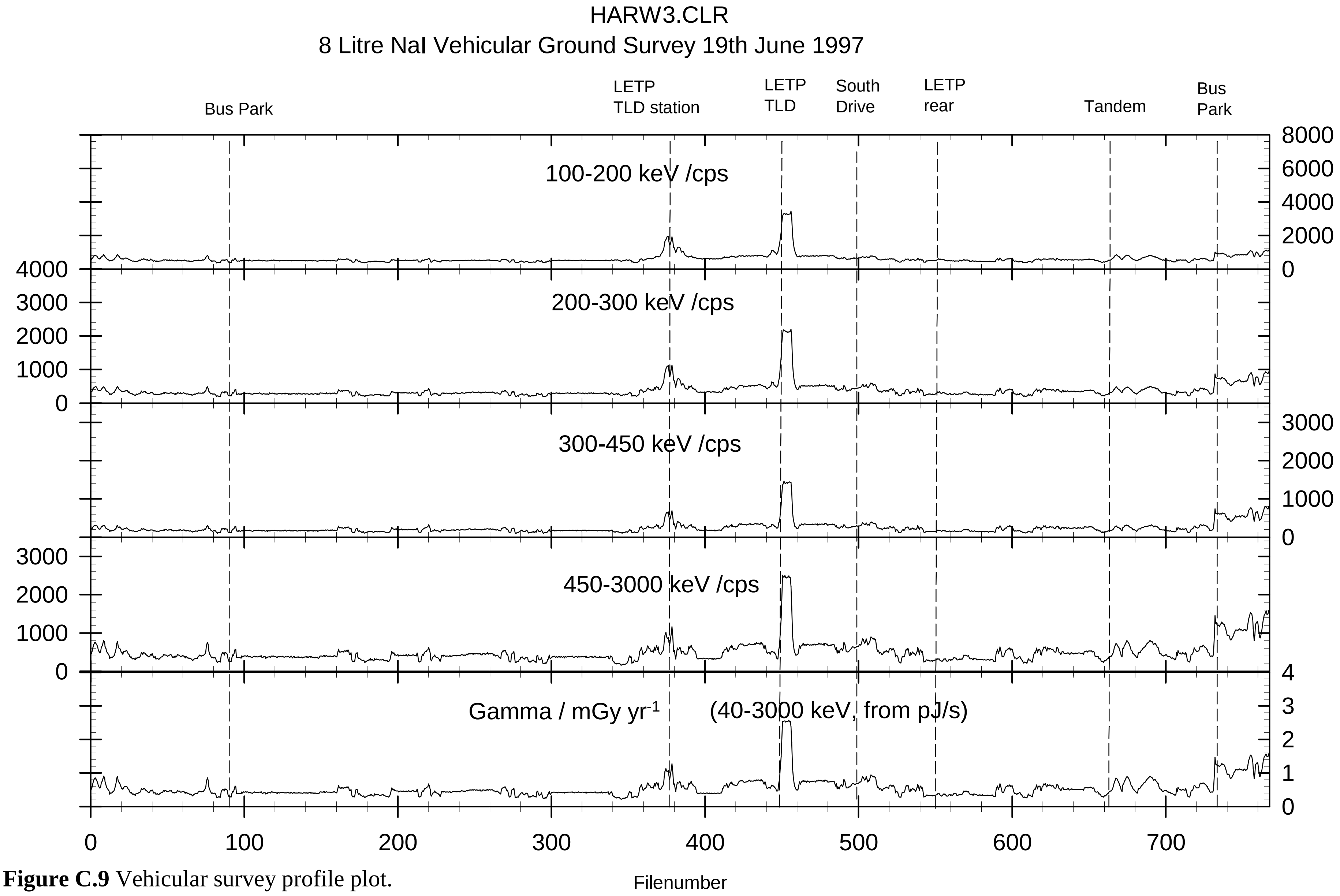


Figure C.9 Vehicular survey profile plot.

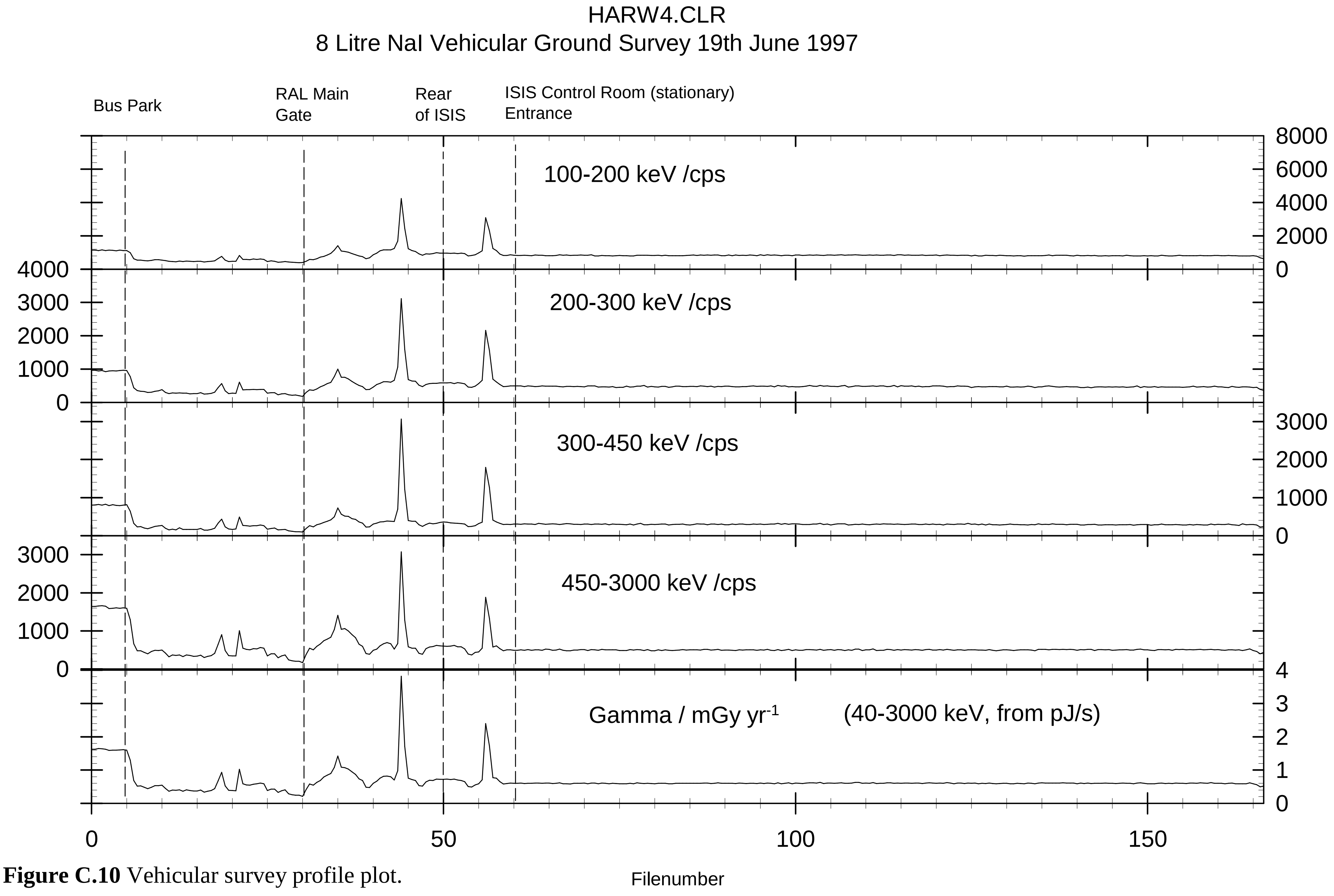


Figure C.10 Vehicular survey profile plot.

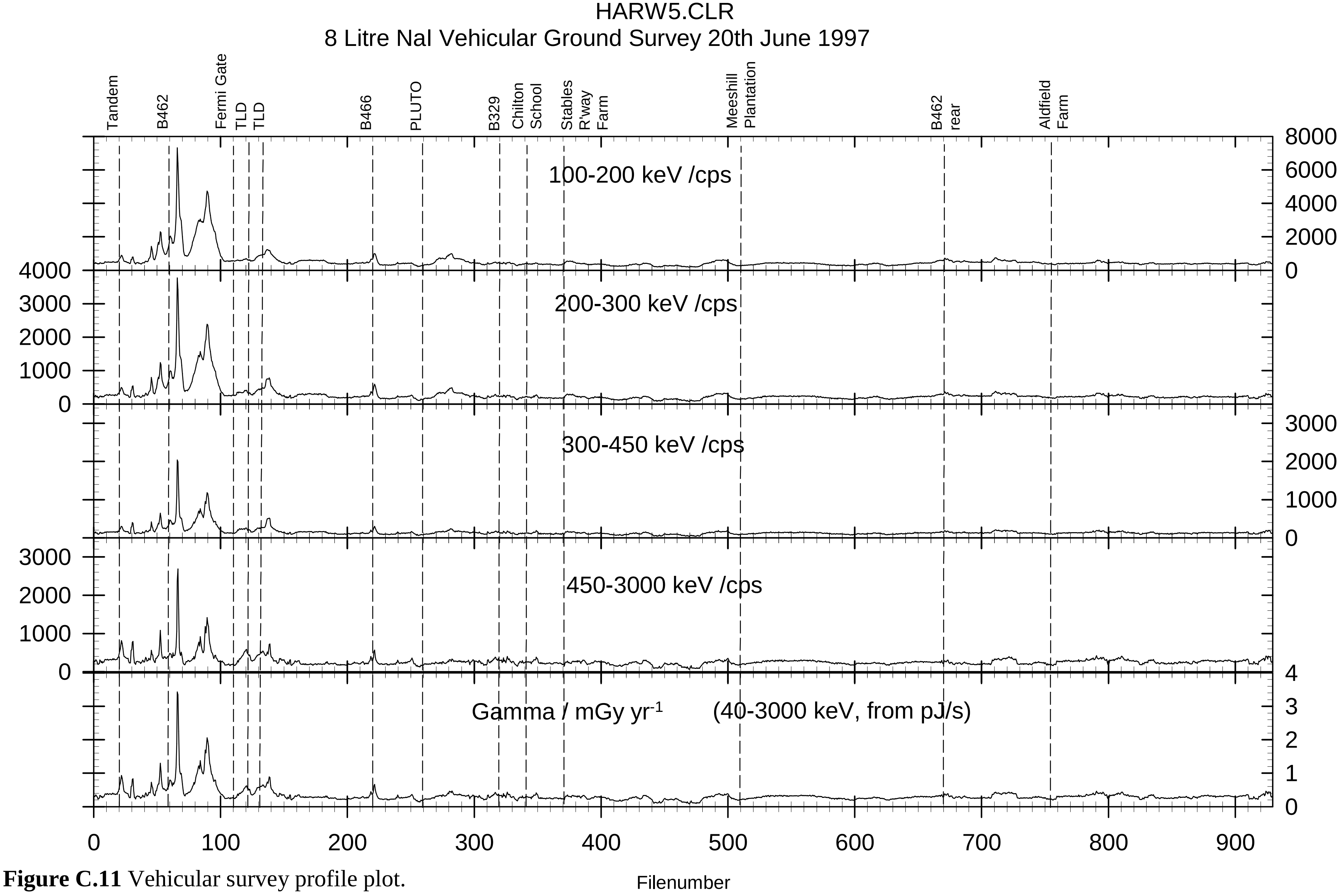


Figure C.11 Vehicular survey profile plot.

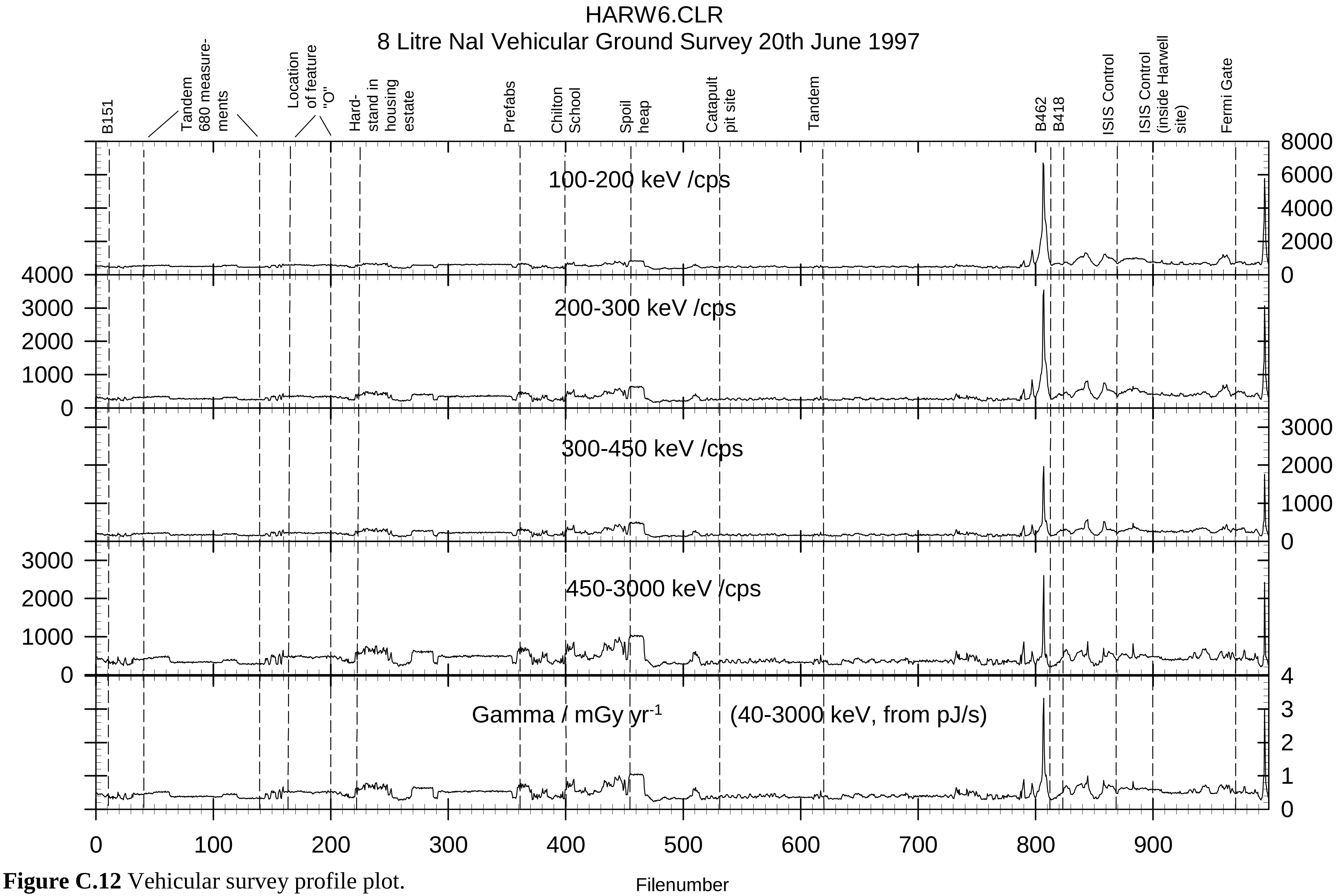


Figure C.12 Vehicular survey profile plot.

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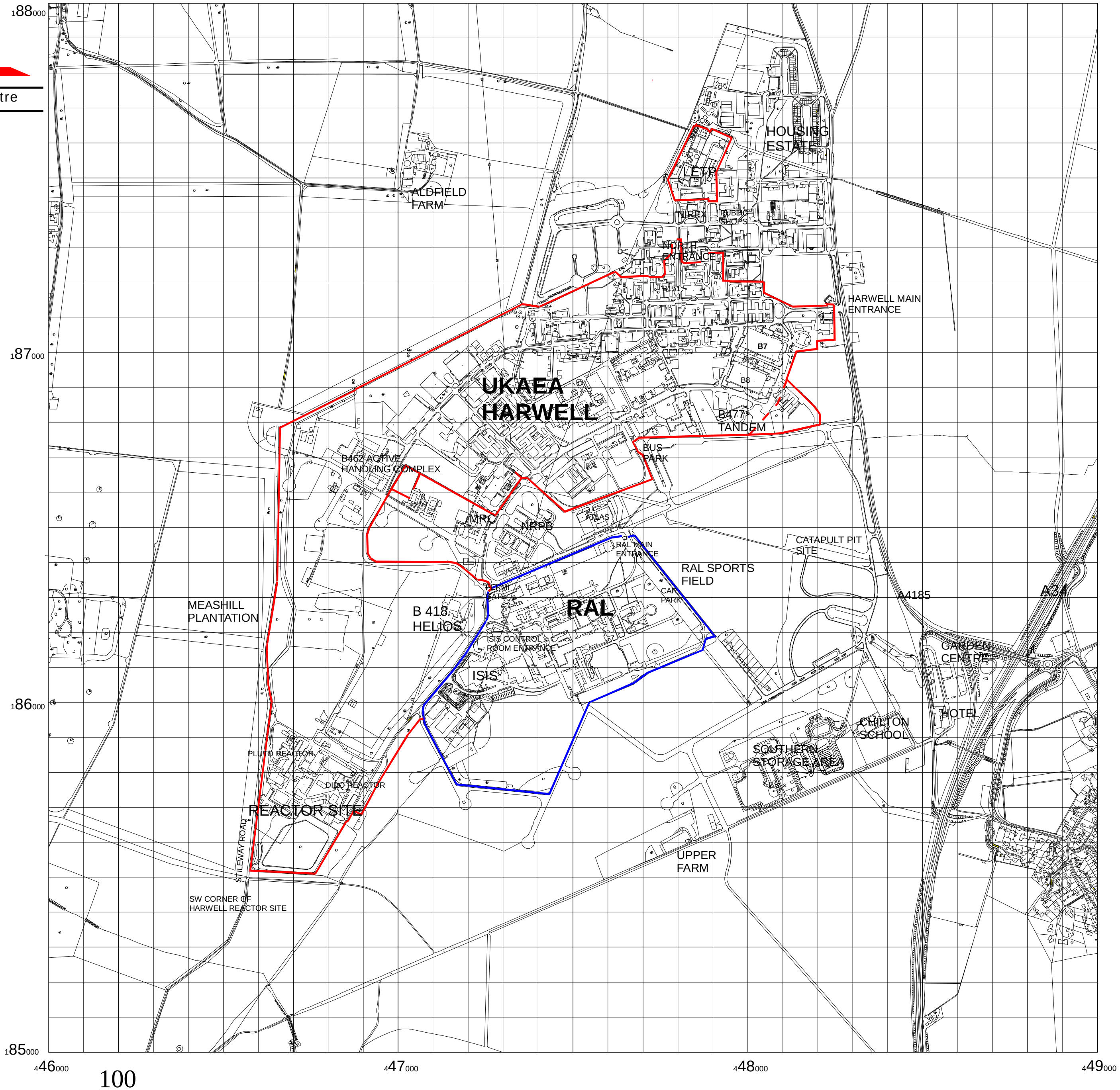

0.2 0 0.2 0.4 km