Committee on Medical Aspects of Radiation in the Environment (COMARE)

THIRD REPORT

Report on the Incidence of Childhood Cancer in the West Berkshire and North Hampshire area, in which are situated the Atomic Weapons Research Establishment, Aldermaston and the Royal Ordnance Factory, Burghfield.

Chairman: Professor M Bobrow

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List of Abbreviations used in the text

AERE	Atomic Energy Research Establishment
AWE (A)	Atomic Weapons Establishment (Aldermaston)
AWE(B)	Atomic Weapons Establishment (Burghfield)
AWRE	Atomic Weapons Research Establishment (Aldermaston)
BNFL	British Nuclear Fuels plc
CCRG	Childhood Cancer Research Group, Oxford
CEGB	Central Electricity Generating Board
COMARE	Committee on Medical Aspects of Radiation in the Environment
DHA	District Health Authority
DOE	Department of the Environment
HA	Health Authority
HSE	Health and Safety Executive
IARC	International Agency for Research into Cancer
MAFF	Ministry of Agriculture Fisheries and Food
MoD	Ministry of Defence
MR	mortality ratio
NRPB	National Radiological Protection Board
OPCS	Office of Population Censuses and Surveys
RD	Rural District
ROF	Royal Ordnance Factory (Burghfield)
RR	registration ratio
SMR	standardised mortality ratio
SRR	standardised registration ratio
UKAEA	United Kingdom Atomic Energy Authority
YTV	Yorkshire Television

FOREWORD

i) The Committee on Medical Aspects of Radiation in the Environment (COMARE) was established in November 1985 in response to the final recommendation of the report of the Independent Advisory Group chaired by Sir Douglas Black.[1] The Black Advisory Group had been commissioned by the Minister for Health in 1983 to investigate reports of a high incidence of leukaemia occurring in young people living in the village of Seascale in West Cumbria. As Seascale is only 3km from the Sellafield nuclear site this led to the suggestion that there might be an association between the leukaemia incidence in Seascale and the radioactivity from Sellafield discharges.

ii) The Black report confirmed that there was a "higher incidence of leukaemia in young people resident in the area" than the average for England and Wales. They also concluded that the estimated radiation dose received by the local population from the Sellafield discharges and from other sources could not account for the observed leukaemia incidence on the basis of current knowledge. The uncertainties involved in the calculations and conclusions led the advisory group to make a number of recommendations for further investigation, which included the formation of COMARE.

iii) Our terms of reference are "to assess and advise Government on the health effects of natural and man-made radiation in the environment and to assess the adequacy of the available data and the need for further research". Our first report[2] dealt with the implications of some further information on Sellafield discharges which came to light after the publication of Sir Douglas Black's report.

iv) Our second report investigated the incidence of leukaemia in young people near the Dounreay Nuclear Establishment in Caithness, Scotland.[3] We found evidence of an increased incidence of leukaemia in young people living in the area. Although the conventional radiation dose and risk estimates suggested that neither the authorised nor accidental discharges could have been responsible, we pointed out that the evidence of a raised incidence of leukaemia at both Sellafield and Dounreay tended to support the hypothesis that some feature of these two nuclear plants leads to an increased risk of leukaemia in young people living in the vicinity. The report considered other possible explanations and recommended that these needed to be investigated further.

v) We were asked to advise, in this our third report, on whether the incidence of childhood cancer was unusually high in an area which included the Atomic Weapons Research Establishment at Aldermaston, and the Royal Ordnance Factory at Burghfield; if childhood cancer levels were elevated then what, if any, association there could be with environmental radioactivity originating from the nuclear sites in the area; and whether further studies were needed to assess the situation. Many of the basic scientific arguments and problems are set out in detail in our second report[3] and are not discussed again at length in this report.

vi) We asked questions of, and made requests for further information from, a number of organisations and individuals and we thank them for their co-operation. The views expressed in the report are those of the Committee and not necessarily those of the Secretariat, the Assessors or those providing evidence.

vii) A list of Members, Secretariat and Assessors is provided in the Appendix. To explain some of the more technical terms which are unavoidably used in this report, there is also a Glossary of terms. Words included in the Glossary are underlined the first time they appear in the text. However, such a Glossary cannot provide a complete picture of the scientific background to this report and we would draw readers' attention to the references for further information on the scientific material that is currently available.

CHAPTER 1

INTRODUCTION

1.1 This report from the Committee on Medical Aspects of Radiation in the Environment (COMARE) is the result of the Committee's investigations into the allegations of an increased incidence of childhood cancer near two Ministry of Defence (MoD) establishments in Berkshire, namely the Atomic Weapons Research Establishment at Aldermaston and the Royal Ordnance Factory at Burghfield.* Given that both these establishments handle and discharge radioactive materials, we have considered whether there is any possible association between the local childhood cancer incidence and exposure to radioactivity originating from these sites.

1.2 In 1985, Dr Carol Barton, a consultant haematologist at the Royal Berkshire Hospital in Reading, contacted epidemiologists at the Epidemiological Monitoring Unit of the London School of Hygiene and Tropical Medicine, to evaluate her observations that she was seeing more cases of childhood leukaemia at her clinic than she might have expected. Dr Barton and her colleagues published their preliminary findings in a letter to the Lancet at the end of November 1985.[4]

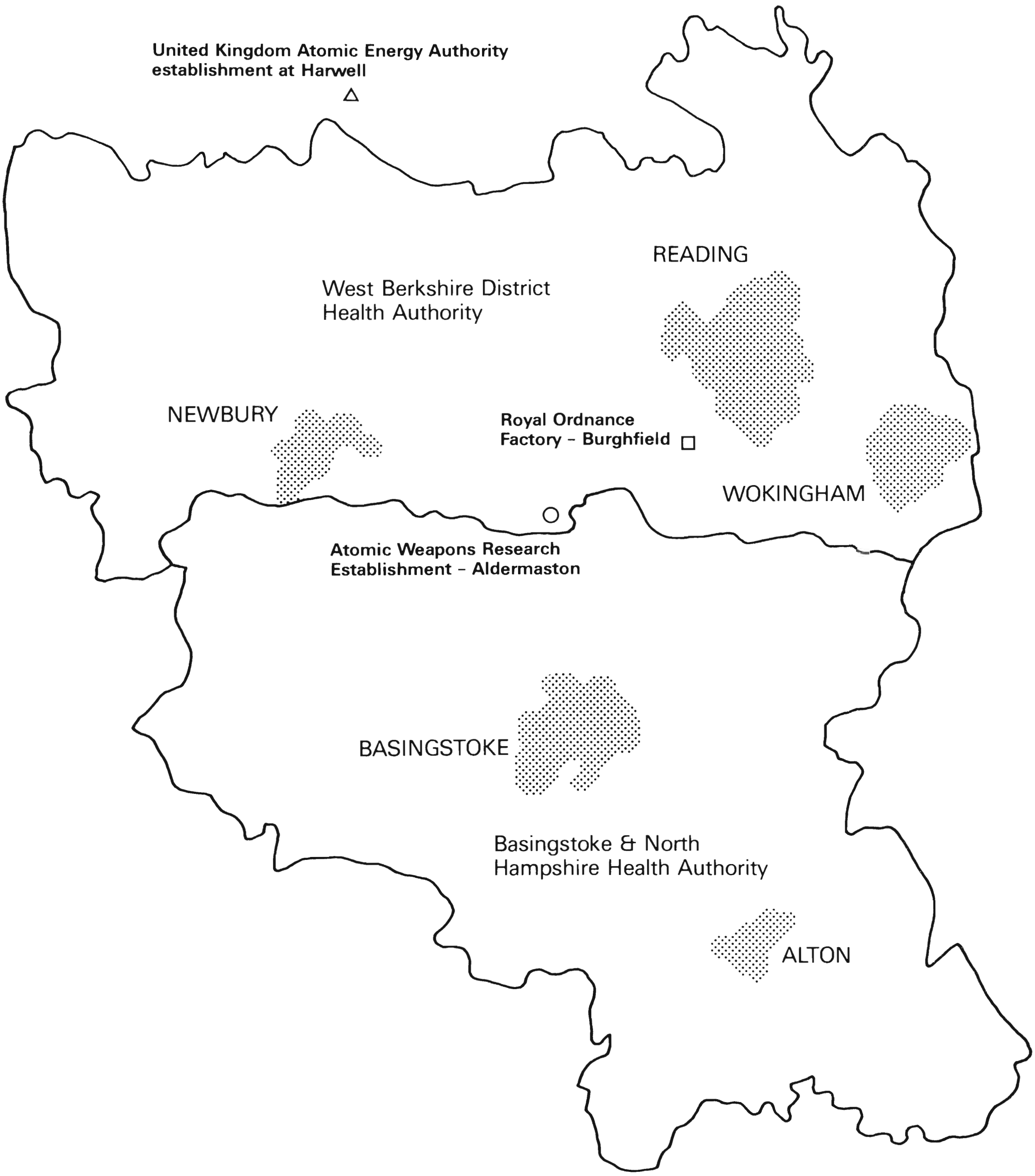
1.3 In December 1985, a Yorkshire Television programme entitled "Inside Britain's Bomb" alleged that there was a raised incidence of leukaemia and "lymphatic cancer" in young people under 25 years of age around the Atomic Weapons Research Establishment (AWRE) at Aldermaston and the Royal Ordnance Factory (ROF) at Burghfield in Berkshire. These establishments are situated in West Berkshire not far from the Hampshire border between six and ten miles southwest of Reading. (Fig 1.1)

1.4 At the time these findings were referred to us, the epidemiological data were still at a preliminary stage, in the form of two letters to the Lancet: one from Barton *et al*[4], and the other from Urquhart *et al*[5], the YTV television researchers. The results from these surveys needed to be treated with caution since both studies were carried out after concern had already been expressed that there might be an excess incidence of childhood cancer in the area, and it is difficult to make an objective statistical assessment of such studies.

1.5 It was therefore clear to us at the outset that more information was needed before we could reach any conclusions on local childhood cancer rates. We considered the relevant studies that were either underway or planned and agreed that it was essential that we wait for these to be completed before reaching any conclusions and formulating any advice.

* During the time when this report was being prepared AWRE Aldermaston and ROF Burghfield have, along with several other sites, been reorganised into the Atomic Weapons Establishment (AWE). Thus, AWRE Aldermaston is now known as AWE(A) and ROF Burghfield as AWE(B). However, the previous titles have been retained in this report.

Figure 1.1
Map of West Berkshire & Basingstoke & North Hampshire District Health Authorities:
showing main urban and nuclear establishments in the area.



1.6 Dr Barton's group and members of the Epidemiological Monitoring Unit at the London School of Hygiene and Tropical Medicine published their more detailed study of childhood leukaemia in March 1987.[6] The large study of the incidence of, and mortality from, cancer around 15 nuclear establishments in England and Wales carried out by Paula Cook-Mozaffari and the Office of Population Censuses and Surveys (OPCS) was also published in March 1987.[7] In addition, the Childhood Cancer Research Group (CCRG) in Oxford have provided the committee with further unpublished data and analyses. These three studies form the main evidence which we have considered.

1.7 MoD have supplied us with information on the discharge data for AWRE Aldermaston and ROF Burghfield, together with their environmental monitoring data, and the National Radiological Protection Board (NRPB) have used this information to assess radiation doses to the general public in the vicinity of these sites. In their assessment, NRPB also considered the impact of the radioactive discharges from the Atomic Energy Research Establishment (AERE) Harwell,* a research establishment which lies just north of the Berkshire boundary (see Fig 1.1). Their report (NRPB-R202) has now been published.[8] Just as NRPB have considered the Harwell discharges, we have also considered the incidence of childhood cancer in the vicinity of Harwell.

1.8 We have considered the evidence relating to Aldermaston and Burghfield within the context of the previous findings of increased leukaemia incidence in young people near both Sellafield and Dounreay. However, it must be stated at the outset that there are considerable differences between the sites at Sellafield and Dounreay and those at Aldermaston and Burghfield, in terms of site activities, in the population and geography of the surrounding areas, and the age groups considered in the studies.

1.9 Dounreay and Sellafield are both nuclear reprocessing sites situated on the coast in sparsely populated rural areas where there are few industrial activities other than those operating on the sites. Thus, attention is naturally focused on these reprocessing facilities as potential sources of pollution or contributors to health problems, whether by a route involving radiation or by some other means. In contrast, West Berkshire and North Hampshire, the area around Aldermaston and Burghfield, is a more populated area containing the large town of Reading, other large towns, several large hospitals, and a University. There is also a large coal-fired power station at Didcot, not far from Harwell, and industrial development around Oxford. In addition to these socio-economic differences, there are considerable differences between the on-site activities and the nature and scale of the radioactive discharges from the establishments at Aldermaston and Burghfield and those at Sellafield and Dounreay. AWRE Aldermaston and ROF Burghfield are not reprocessing sites; the form of the radioactive materials "handled" and the nature of the work performed are different and the radioactive discharges are considerably less than those from Sellafield and Dounreay.

1.10 These are all important differences which mean that care is needed when making comparisons between the results of the previous reports around Sellafield and Dounreay and our findings from the present investigation.

* AERE Harwell is now known as the United Kingdom Atomic Energy Authority (UKAEA) Harwell Laboratory, but the previous title has been retained in this report.

CHAPTER 2

SUMMARY OF DATA

EPIDEMIOLOGICAL EVIDENCE

2.1 The main epidemiological evidence we have used for our assessment of the incidence of childhood cancer in the area surrounding AWRE Aldermaston and ROF Burghfield was provided by Roman *et al*[6] and the OPCS study[7]. In addition, we were presented with unpublished data from a study being carried out by Paula Cook-Mozaffari in collaboration with the Childhood Cancer Research Group. This study considered "other cancers" in 0–14 year olds in the region using the same boundaries as the Roman *et al* study. The epidemiological data are detailed in Annex 1, summarised briefly here and will be discussed in Chapter 3.

Roman *et al*

2.2 The study by Roman *et al*[6] considered the incidence of childhood leukaemia in the West Berkshire Health Authority and Basingstoke and North Hampshire Health Authority during the period 1972–1985. Forty eight of the 143 electoral wards in the two District Health Authorities (DHAs) had at least half their area lying within circles of 10 kilometres radius around the nuclear establishments at Aldermaston and Burghfield. Another two electoral wards in the two DHAs lay within 10 km of Harwell. In those 50 electoral wards, 41 children aged 0–14 were registered with leukaemia, whereas 28.6 registrations would have been expected on the basis of leukaemia registration rates for England and Wales (registration ratio = 1.4, $p < 0.05$), (Table A1.1). The excess was confined to children aged 0–4. In this age group there were 29 registrations of leukaemia whereas 14.4 would have been expected on the basis of national rates (registration ratio = 2.0, $p < 0.001$).*

2.3 In the remaining 93 electoral wards in the two DHAs, that is, those with at least half their area outside the 10 kilometre circles, there was a small but statistically non-significant increase in the number of registrations of leukaemia at age 0–14, compared with that which would have been expected on the basis of leukaemia registration rates for England and Wales.

2.4 When all the electoral wards in the two DHAs were combined there was a statistically significant increase in the number of registrations of leukaemia in 0–14 year olds over the period 1972–1985, compared with national rates. The excess was again confined to the 0–4 year age group.

2.5 Within the two DHAs, the registration ratio for leukaemia in children aged 0–14, within the 10 kilometre circles, was not statistically significantly

* Roman *et al* used two sided significance tests and we have quoted these p-values as originally given. In general our conclusions as to the significance of their results would not be altered if one sided tests were used and we have used the latter approach in our own analyses.

different from the registration ratio for leukaemia in children aged 0–14, outside the 10 kilometre circles, but still in the same 2 DHAs.

2.6 The authors also compared the observed number of cases in the 10 km circles with the numbers expected from leukaemia registration rates for the local cancer registration regions ie Wessex and Oxford. The registration ratios were virtually identical to those based on national rates, as the registration rates in the Wessex and Oxford regions were similar to the national rates.

2.7 From all the data the authors concluded that "there was an excess incidence of childhood leukaemia during 1972–1985 in the vicinity of the nuclear establishments".

CCRG data

2.8 We have also considered the incidence of childhood cancers other than leukaemia for the years 1971–1982 and the age group 0–14, using unpublished data from the National Registry of Childhood Tumours maintained by the Childhood Cancer Research Group (CCRG) in Oxford. The same geographical boundaries and methods were used to analyse the data as for the Roman *et al* study. This analysis shows that for childhood cancers other than leukaemia, occurring within 10 km of AWRE Aldermaston and ROF Burghfield, there were 61 cases observed compared with 47.5 expected on the basis of national rates for England and Wales (registration ratio = 1.28, $p<0.05$, one sided test). For the age group 0–4, there were 30 cases observed, compared with 19.4 expected, on the basis of national rates (registration ratio = 1.55, $p<0.05$), (Table A1.2).

2.9 In the remaining 93 electoral wards in the West Berkshire and the Basingstoke and North Hampshire HAs, there is a small statistically non-significant excess of other cancers in the age group 0–14. When all the electoral wards in the two DHAs were combined, the registration rate for other cancers for the 0–14 age group was significantly raised with the excess being largely confined to the 0–4 age group.

2.10 These data indicate that for the period 1971–1982 there is also an excess of other childhood cancer in the same areas and age groups as those defined by Roman *et al*.

Roman *et al* & CCRG data combined

2.11 The data from Roman *et al*[6] and CCRG are compatible in terms of geographical boundaries and age group, and the time periods largely overlap. We have therefore combined the leukaemia data from Roman *et al* for the period 1972–1985 and the "other cancer" data from CCRG for the period 1971–1982, to give the registration ratio for "total cancers" in children aged 0–14, for the West Berkshire and the Basingstoke and North Hampshire Health Authorities.

2.12 The "leukaemia and other cancers" combined registration rates for the two DHAs are significantly raised for 0–14 year olds based on comparison with rates in England and Wales (registration ratio 1.25, $p<0.001$ one sided test), (Table A1.3). Within this age group, the excess is greater for 0–4 years (registration ratio 1.45, $p<0.0001$) but is not significantly elevated for 5–14 year olds (registration ratio 1.10). These data indicate that the West Berkshire and the Basingstoke and North Hampshire Health Authorities have had higher registration rates of childhood cancer than nationally.

2.13 We have also analysed the combined leukaemia and other cancer data for ages 0–14, 0–4 and 5–14 for the West Berkshire and the Basingstoke and North Hampshire Health Authorities by distance of the electoral ward of residence from a nuclear establishment (Table A1.4). There is a tendency for the registration ratios for leukaemia, "other cancers" and "total cancer" for the ages 0–14 to be higher in electoral wards within 10 km of a nuclear establishment, than in those wards outside this radius, but still within the same 2 DHAs. This difference just reaches statistical significance for total cancer, and for leukaemia, in the age group 0–4 on a one sided test.

OPCS Study

2.14 The OPCS study[7] provides data on cancer incidence and mortality around many nuclear installations in England and Wales, including the incidence of childhood cancer around AWRE Aldermaston, but not ROF Burghfield. Data from the report (Table A1.5) showed that neither the incidence nor the mortality for childhood leukaemia or other cancers were significantly raised in the area with two thirds of its population within 8 miles of Aldermaston. On the other hand, in the local authority areas defined as having one third of their population resident within 16 km (10 miles) of Aldermaston (Table A1.6), the registration ratio for leukaemia for the period 1971–1980, for the age group 0–9, was significantly raised compared with regional rates (registration ratio 1.47, $p<0.05$, two sided test).*

2.15 The results for total cancers, including leukaemia, in the area defined as having one third of the population resident within 10 miles of Aldermaston, also showed significantly raised registration rates for the 0–9, 10–24 and the combined 0–24 year age groups, compared with regional rates, for the period 1961–1980. This was due to excesses in each age group for the later time period, 1971–1980.

2.16 For purposes of comparison, control areas were chosen by matching, as far as possible, for urban and rural status, population size and cancer registration region. We note that the control areas for the areas with one third of their population within 10 miles of Aldermaston, also showed a significant excess in total childhood cancers for the 0–24 year age group for the time period 1971–1980 compared with regional rates. Within the age group 0–24, the excess was mainly due to the excess in the age group 0–9.

2.17 The interpretation of the OPCS data will be discussed further in the next chapter. However, the findings of this study are broadly consistent with the Roman *et al* study of childhood leukaemia incidence and the CCRG analysis of other cancers.

Harwell

2.18 Roman *et al*[6] considered the two electoral wards in the West Berkshire Health Authority which lay within 10 km of Harwell, but no data were examined for the District Health Authority in which Harwell is located. We therefore asked the CCRG to analyse the registration rates for childhood leukaemia and other cancers in the vicinity of AERE Harwell. CCRG considered the period 1971–1982, the area defined as having all wards with at least half their area within 10 km of Harwell, and the age group 0–14 (Table A1.8). Their results show that there is no evidence of an increased incidence of childhood leukaemia in this area compared with national rates. The registration ratio for other cancers in the age group 0–14 is

* For the data obtained from the OPCS report, we have used the same approach as the authors and all p values quoted are two sided.

raised (O=15, E=11.47, registration ratio = 1.31) but is not statistically significant. For the age group 10–14 the registration ratio for other cancers is significantly raised (O=8, E=3.53, registration ratio 2.26, $p<0.05$). However, no weight can be attached to this result as it was obtained by inspection of the data and there was no prior reason to believe that this particular sub-group would show an excess rate. There is no evidence of an excess of other cancers in the age groups 0–4 or 5–9.

ASSESSMENT OF RADIATION DOSES TO THE GENERAL PUBLIC IN WEST BERKSHIRE AND NORTH HAMPSHIRE

2.19 In our assessment of the doses and possible risks to the general public in West Berkshire and North Hampshire, we have considered both the authorised discharges and accidental releases of radioactivity from the three nuclear establishments of AWRE Aldermaston, ROF Burghfield and AERE Harwell.

2.20 The NRPB have estimated the possible doses to the public from the atmospheric radioactive discharges[8] and we have investigated whether the public could be exposed to radioactivity via other routes, such as the authorised liquid discharges. We have also examined the environmental monitoring data that are available, to check the levels of radioactivity present in the environment. We have considered the NRPB's assessment of the likely risks of leukaemia from their dose estimates. The detailed analyses from our investigations are given in Annex 2, are summarised briefly here and will be discussed further in Chapter 3.

Atmospheric Discharges

2.21 Radioactive waste has been discharged to the atmosphere from AWRE Aldermaston since 1952. These discharges have been essentially continuous and consisted mainly of uranium and plutonium. Since 1960, the discharges have also included measured amounts of tritium, (Table A2.1). The levels of discharges have usually been very low and, on occasions, measurements could not distinguish the activity in them from naturally occurring radioactivity. In 1978, during the course of an enquiry by Sir Edward Pochin into site practices, it was discovered that 5 of the stack discharge monitors were incorrectly mounted. However, the report[9] concluded this would only result in a small under-estimation of discharges.

2.22 Atmospheric discharges from ROF Burghfield began in 1970 and consist principally of tritium. The principal radionuclides discharged from AERE Harwell are argon-41, carbon-14, plutonium-239 and tritium. Details of these discharges are given in the annex, (Table A2.2).

2.23 At a late stage, MoD informed the Committee that small amounts of the radioactive noble gas krypton-85 have been, and continue to be, used for testing the integrity of sealed systems at both AWRE Aldermaston and ROF Burghfield. MoD regards the amounts released as insignificant for recording and reporting purposes, so that they were not included in the discharge information supplied earlier. The amount discharged at AWRE Aldermaston since 1981 was roughly constant at 0.3 terabecquerels (TBq) per annum. The amount discharged from ROF Burghfield was 0.5 TBq per annum, but it should be noted that krypton-85 has only been used at Burghfield since 1987 which is after the period considered in this report. The resulting radiation doses to individuals assessed by NRPB on the same basis as those given in NRPB-R202,[8] are several orders of magnitude less than those calculated for the vicinity of AWRE Aldermaston, and around one order of magnitude less than the much smaller doses calculated for the vicinity of ROF Burghfield.

Liquid Discharges

2.24 The discharge points (D1, D2, D3) for liquid effluents from these sites are shown in Fig 2.1. Since 1952, low level radioactive waste from Aldermaston has been piped, after treatment, into the River Thames at Purley, downstream from Pangbourne, (D2). These discharges have contained low levels of alpha emitters (mainly plutonium) with tritiated materials being discharged since 1965, (Table A2.3). In addition, very low levels of radioactive waste are released as trade waste to the local sewage works, where the waste is treated before being discharged (D3) into the River Kennet, which then joins the River Thames at Reading, (Table A2.4). Liquid waste from ROF Burghfield is treated in a similar fashion and also discharged from the station sewage works into a stream which then flows into the Kennet. Liquid discharges from AERE Harwell are released, after treatment, into the River Thames at Sutton Courtney (D1), (Table A2.5).

Accidental Releases

2.25 At our request, AWRE carried out a survey of all reported incidents at Aldermaston and a similar survey was carried out at Burghfield. MoD have assured us that no incidents had significant off-site consequences and such releases had been included in total discharge data.

2.26 UKAEA and NRPB have reviewed the discharge data used for Harwell in the NRPB assessment of radiation doses to members of the public around Aldermaston, Burghfield and Harwell. A number of small releases of radioactive materials were identified which had not been included in the NRPB assessment. NRPB have concluded that the overall radiological impact on the local population from these additional discharges is very small.

Environmental Monitoring Data

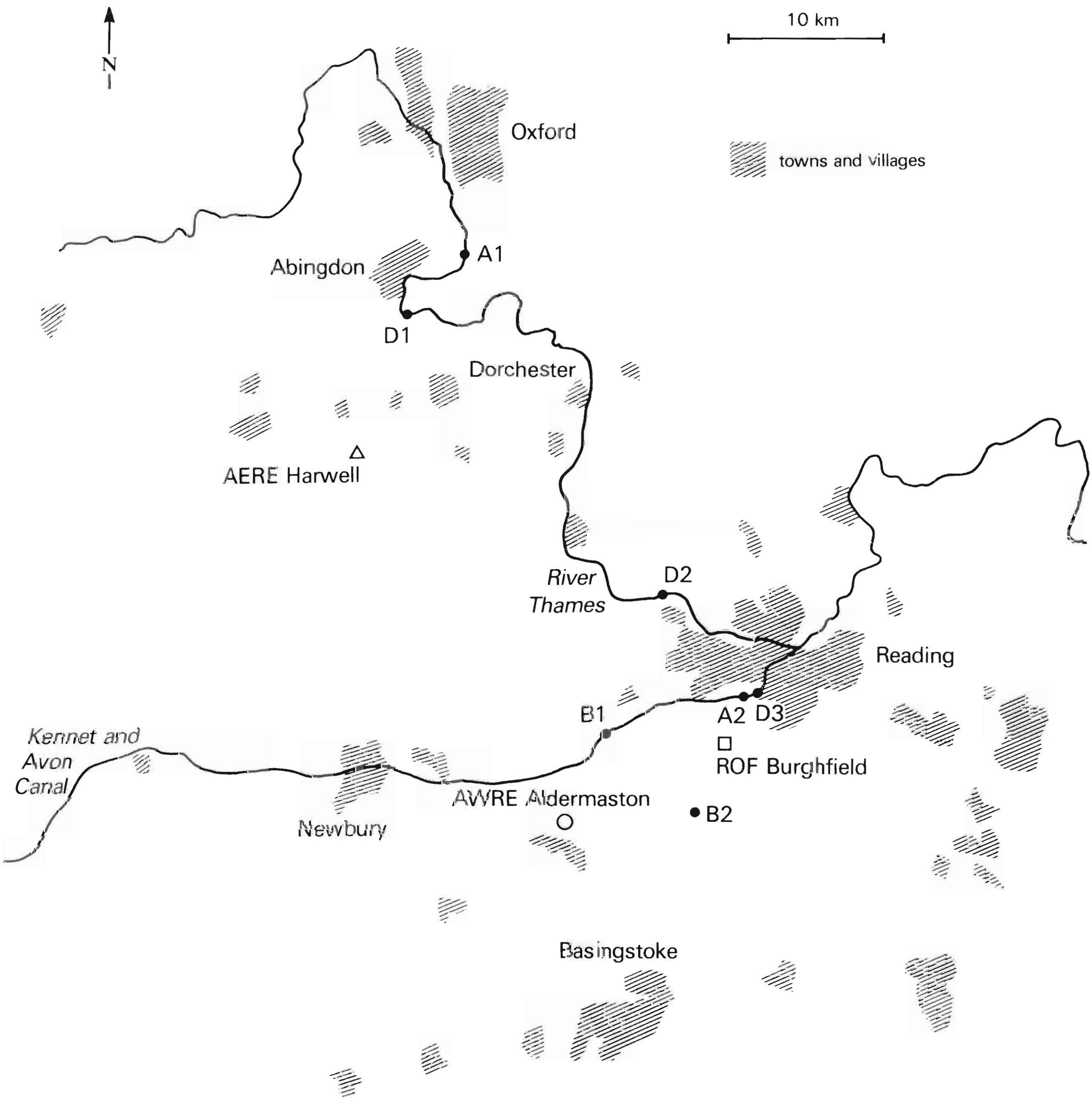
2.27 MAFF have carried out a monitoring programme around Aldermaston and Burghfield to detect airborne levels of radioactivity since 1972. MAFF also monitor the aquatic environment. In addition, MoD have carried out a monitoring programme since 1978. They have monitored surface water, soil and vegetation at regular intervals. Examples of the results are shown in Annex 2, (Tables A2.6 and A2.7). From the results of these programmes, we concluded that there were no environmental measurements of radioactivity significantly above those expected from natural background or nuclear weapons test fall-out.

2.28 Before 1972 there had only been episodic environmental monitoring; thus data for years prior to this were incomplete. As a check, we asked the Department of Health to commission a soil survey to measure the accumulated deposition of radionuclides near Aldermaston and Burghfield. Scientists from AERE Harwell measured these soil samples and the results are given in Annex 2, (Table A2.8). In general, the levels of radionuclides in the soil in the area were low and were sometimes below detectable threshold levels. However, elevated levels of tritium and slightly raised levels of actinides were measured at several points near Aldermaston and at the one distant point (5 km). There were also elevated levels of tritium at some points near Burghfield and slightly elevated levels of plutonium-238 at one point near Burghfield. None of these elevated levels were considered to be of radiological significance.

Estimation of Doses Received by the Local Population

2.29 NRPB have estimated the doses to representative individuals in the local population from the atmospheric discharges. They did not consider that liquid discharges represented a potential route of exposure, as the local population do not obtain their drinking water from river water into which discharges are made.

Figure 2.1
Locations of nuclear sites



A1 Culham, A2 Fobney — Surface water abstraction for Abingdon and Dorchester (A1), Reading (A2)

B1 Ufton Nervet pumping station
B2 Mortimer pumping station

D1 AERE Harwell, D2 AWRE Aldermaston — pipeline discharge point

D3 AWRE Aldermaston and ROF Burghfield discharge point via sewage point

2.30 NRPB have calculated doses received by representative individuals in the local population in the vicinity of each of the three sites separately and independently of each other. For each site, doses were calculated for representative members of four age groups of the population (the fetus, children aged 1 and 10 years, and adults) at a number of distances from the site, (5 km, 10 km, 20 km). The results are described in detail in the NRPB report R2O2[8] and are summarised in Annex 2, (Tables 2.9–2.16). They show that the estimated peak annual doses to adults living 5 km from Aldermaston, Burghfield and Harwell were 0.0017%, 0.0000003% and 0.03% of natural background radiation, respectively. The doses delivered to the fetus and infant were even lower.

2.31 Coal-fired boilers and power stations also release radioactivity into the atmosphere. NRPB have therefore assessed the possible doses from the neighbouring power station at Didcot and the coal-fired plants at Aldermaston and Harwell, (Table 2.19). NRPB have compared the peak doses from these sources with the average annual dose from natural background radiation and fallout from nuclear weapons testing. The doses from the atmospheric radioactive discharges from Aldermaston are lower than the doses from the radioactive discharges from natural uranium coming from the coal-fired plants at Aldermaston and those from the coal-fired station at Didcot. However, the discharges from these nuclear establishments, and the coal-fired plants, make a very small contribution to the total radiation doses received by the population living in the area, when compared to the doses received from natural background radiation or fallout.

2.32 We have also considered whether the population could have received radiation exposure via other routes. We identified some possible routes of exposure from liquid discharges which could theoretically give higher doses to a few selected individuals. NRPB have estimated doses to these hypothetical individuals using pessimistic assumptions; however, actual measurements of radionuclides in fish and river sediment by MAFF[10] show these theoretical doses are considerable overestimates.

2.33 On the basis of NRPB estimates of dose, we have made an estimate of the possible increase in risk of childhood leukaemia from the authorised radioactive discharges using the atmospheric discharges from Aldermaston as an example. The predicted number of cases due to Aldermaston discharges in the 14 year period 1972–1985, for the 0–14 year age group, was estimated to be between 6×10^{-5} and 6×10^{-4} ie 0.00006 and 0.0006. This represents a very low level of risk from the atmospheric discharges from the nuclear plants in the area.

2.34 In the preceding section we have summarised the main evidence presented to us. Further details of the epidemiology and dosimetry are attached in the annexes. In the next chapter we assess the evidence and discuss the difficulties in interpretation.

CHAPTER 3

DISCUSSION

EPIDEMIOLOGY

3.1 The increased incidence of childhood leukaemia around the Sellafield installation in West Cumbria[1], generated the hypothesis that there may be an increased risk of childhood leukaemia around nuclear installations, and, in particular, nuclear reprocessing plants. In our second report[3] we confirmed that there was also a raised incidence of leukaemia around the Dounreay Nuclear Establishment in Scotland, which is the only other nuclear reprocessing plant in the UK. Although no cause could be identified, this finding tended to support the specific hypothesis relating to nuclear reprocessing sites.

3.2 Aldermaston and Burghfield are very different from the nuclear installations at Dounreay and Sellafield. They are not reprocessing sites for reactor fuel, the quantities and type of radioactivity "handled" are different and the discharges are considerably lower. In addition, there are differences between the local circumstances in West Berkshire and those in West Cumbria and Caithness. Aldermaston and Burghfield therefore cannot be considered as tests of the specific hypothesis relating to nuclear reprocessing sites. They could, however, be considered as testing a more general hypothesis concerning "other nuclear installations".

3.3 This more general hypothesis, relating to all nuclear installations, can be tested by examining the incidence of childhood leukaemia around other nuclear installations. Any test of such a hypothesis requires that the geographical area, temporal boundaries and age groups be defined at the outset for the test to be valid.

3.4 Both Barton *et al*[4] and the YTV researchers[5] collated their data in response to concern about a possible increase in cancer incidence in the area and defined their groups for analysis after their initial observations. Therefore these studies cannot be considered as valid tests of the general hypothesis. The study of Roman *et al*[6] on childhood leukaemia around Aldermaston and Burghfield was also done in response to a suspected increased incidence of leukaemia in the area. However, the data were not analysed until geographical and temporal boundaries and age groups had been defined. The OPCS[7] and CCRG studies are valid in both these respects, making it unlikely that the raised childhood cancer registration rates noted in these studies were due to biased selection of the data to be studied.

The Evidence
Roman et al

3.5 Roman *et al*[6] concluded that in the areas within 10 km of AWRE Aldermaston and ROF Burghfield, during the period 1972–1985, there was an increase in childhood leukaemia incidence compared with national rates, which reaches statistical significance (incidence ratio=1.4, $p<0.05$). We have noted that the incidence ratio is small, compared with the excesses at

Seascale and Dounreay, but because the population studied is larger, there are more cases, and this results in a statistically significant excess.

3.6 At Dounreay and Sellafield there were too few cases to permit separate analyses for different age groups, but inspection of the data shows that cases occurred throughout the age range 0–24. However, at Aldermaston and Burghfield, Roman *et al* have noted that the excess is confined to 0–4 year olds. There was no excess in the 5–9 year age group or the 10–14 year age group. The excess leukaemia registration in the 0–14 year age group overall, is almost entirely due to the excess in the 0–4 year age group. However, there was no prior expectation that the excess would be confined to this age group; it is an observation made by inspection of the data and must therefore be treated with caution.

Data from Childhood Cancer Research Group (CCRG)

3.7 The CCRG analysis of childhood cancer other than leukaemia, used the same geographical boundaries and age groups as Roman *et al*,[6] but considered the slightly earlier time period 1971–1982. This analysis shows that within 10 km of Aldermaston and Burghfield there is also an excess of "other cancers" in the age group 0–14, compared with national rates, which reaches statistical significance (incidence ratio = 1.28, $p<0.05$). We conclude from these data that for the period 1971–1982 there is an excess of "other childhood cancers" in the same area and age group as that defined by Roman *et al*. As in the Roman *et al* study, the excess is almost entirely due to an excess in the age group 0–4.

Combined Roman et al *and CCRG data*

3.8 The combined leukaemia data from Roman *et al* and the "other cancers" data from CCRG indicate that the West Berkshire and the Basingstoke and North Hampshire Health Authorities have had higher registration rates for childhood cancer than nationally. These higher ratios are unlikely to be chance phenomena. They could represent real differences in incidence but we cannot rule out the possibility that they are due, at least in part, to artefacts of registration.

3.9 The combined leukemia and other cancer data indicate that the area comprising electoral wards within 10 km of the nuclear establishments at Aldermaston and Burghfield has had higher registration rates of total childhood cancer at age 0–14, than the area comprising wards beyond 10 km but still within the West Berkshire and the Basingstoke and North Hampshire HAs. However, the differences between these areas are only statistically significant, on a one sided test, in the age group 0–4 years for total cancer and for leukaemia. These findings should be interpreted with caution since this age group was separately selected after inspection of the original data. If these findings represent a real difference in incidence this would strengthen an association with the establishments. We consider it unlikely that this is entirely due to an artefact of registration.

OPCS Study

3.10 The OPCS study[7] provides incidence and mortality data on childhood leukaemia, and all childhood cancer, around many nuclear sites in England and Wales, including AWRE Aldermaston but not ROF Burghfield. The OPCS report showed that in the local authority areas with at least one third of their population resident within 16 km (10 miles) of Aldermaston, the registration ratio for leukaemia for the age group 0–9 was significantly raised compared with regional rates for the period 1971–1980. The registration ratio based on regional rates for the control area was also raised and was similar in magnitude but was based on smaller numbers and was not statistically significant.

3.11 The OPCS study also considered cancers other than leukaemia and showed that in the same areas the results for total cancers show significant excesses for the 0–24 year age group. The excess was noted for 1959–1980 but this is due to a significant excess for the time period 1971–1980. We have noted that the control areas also showed a significant excess in total cancers for the later time period which makes interpretation of the results for the "installation areas" difficult.

3.12 We have some reservations about the OPCS data, which the authors themselves expressed:

i Each of the districts selected as an area containing a nuclear installation covers a relatively large geographical area, and these "installation areas" are not necessarily centred on the site. For instance, AWRE Aldermaston is situated in the extreme south west corner of Bradfield RD, which was defined as the area with ⅔ of the population within 8 miles of AWRE Aldermaston. (See Fig A2.2 in Annex 1.)

ii Control areas were chosen by matching, where possible, for urban and rural status, population size and cancer registration region. However, for some installation areas, particularly Aldermaston, there was difficulty in selecting control areas which met these requirements.

Nonetheless, the findings of this study are consistent with the Roman *et al* study and the CCRG results.

3.13 A recent paper by Cook-Mozaffari *et al*[11] analyses, *inter alia*, the mortality rates from all leukaemia and lymphoid leukaemia in 0–24 year olds in 400 county districts throughout England and Wales over the period 1969–1978, examining the associations with proximity to nuclear installations and four other variables which may influence these rates. There are several differences in methodology between this recent study and the OPCS study:

i The problem of selecting specific matched control areas has been overcome by including all county districts in England and Wales and classifying them according to the percentage of their population within 10 miles of a nuclear installation. A comparison of mortality rates was then made between areas where this percentage was more than 0.1%, and the remaining areas.

ii Differences in mortality associated with urban/rural status, population size, social class structure, and health authority region have been taken into account by regression analysis.

iii Larger geographical areas have been used, namely county districts rather than local authority areas.

iv Mortality data only were used.

3.14 After allowing for any effects of the four factors outlined above, the authors concluded that there were significant excesses of mortality in the age group 0–24 from all leukaemia (about 15%). and particularly lymphoid leukaemia (about 20%), in county districts with more than 0.1% of their population near nuclear installations, in the period 1969–1978. However, there appeared to be no direct relationship between the magnitude of the excess and the percentage of the population living near an installation.

3.15 When the installation districts were grouped according to the categories of installation used in the OPCS study (namely BNFL Sellafield, other pre-1955 installations, UKAEA Winfrith and CEGB installations), there was a significant excess mortality from all leukaemia in the age group 0–24 around BNFL Sellafield (about 85%) and for the pre-1955 installations other than Sellafield (about 15%). This group of installations includes AWRE Aldermaston. When individual installations were considered, the relative risk for AWRE Aldermaston was raised (by 18%) but did not reach statistical significance. Nevertheless, the results for Aldermaston in this study are not inconsistent with the other data analysed in this report. The fact that there is evidence of increased mortality from leukaemia in the combined areas around other nuclear installations suggests to us that it is less likely that the results for the area around Aldermaston are due to biased selection of this particular nuclear site.

3.16 It should be noted that this study used mortality data rather than registration data. This has the disadvantage that increasing success in the treatment of childhood cancer can lead to mortality data being an unreliable indicator of incidence. On the other hand, it overcomes the problems of regional variations in the completeness of cancer registrations.

Cancer Registration

3.17 We consider that the results of Roman *et al*,[6] the OPCS study[7] and the CCRG data provide evidence of raised registration rates for childhood leukaemia and other childhood cancers in the vicinity of Aldermaston and Burghfield and that these are unlikely to be due to random variation or biased selection. These elevated rates could represent a real increase in incidence or be due to diagnostic or registration artefact. In our second report[2] we discussed diagnostic problems in some detail. There is a close association between some forms of leukaemia and some of the non-Hodgkins's lymphomas of childhood which can lead to problems when retrospectively reviewing cases registered in past years. This is an important factor when considering leukaemia registrations only, as was the case at Dounreay. However, at Aldermaston and Burghfield the registration rates for other childhood cancers are also elevated and follow a similar pattern to childhood leukaemia rates. The fact that registration rates for all childhood cancers are elevated means that diagnostic artefact is unlikely to provide an explanation for the elevated rates. However, we cannot exclude the possibility that unusually complete registration of both childhood leukaemia and other childhood cancers in the area could play a role in producing artificially raised registration rates.

3.18 Registration data were used in preference to mortality data as a measure of incidence by both Roman *et al* and CCRG, because increasing success with the treatment of childhood cancers can lead to mortality data being an unreliable indicator of incidence. There is also evidence that leukaemia survival rates may depend on the quality of the treatment centre.[12] These factors are a major disadvantage of studies which use mortality data as a measure of incidence. However, cancer registration must be complete and accurate if it is to be used as a measure of incidence, and it must be uniform across the country if one area is to be compared with another. In our second report we considered that registration artefact was unlikely to provide an explanation for elevated childhood leukaemia rates in the vicinity of Dounreay, because a validation procedure had been carried out to check the accuracy of leukaemia registration data throughout Scotland. However, such a procedure has not been carried out for England

and Wales, and the completeness and accuracy of cancer registration may therefore vary across the country.

3.19 We have therefore considered whether the elevated registration rates for childhood leukaemia and other childhood cancers in the vicinity of Aldermaston and Burghfield could be due to more complete registration in this area than the rest of the country. In England and Wales cancer registration is organised on a regional basis. There are twelve regional cancer registries which work independently and collect differing amounts of information, though all include a standard data set that is forwarded to the OPCS. There are differences in cancer registration rates between regions, at least part of which is due to differences in the completeness of registration.[13,14]. It is therefore possible that differences in cancer registration rates in particular areas could reflect this rather than a real difference in incidence.

3.20 The studies outlined above addressed this problem in different ways:

i The OPCS study tried to overcome this problem by using, as far as possible, controls from the same cancer registry region, but they did not manage to do this for all control areas.

ii Roman *et al* compared local incidence with regional as well as national rates and found that regional rates for Oxford and Wessex did not differ from national rates. However, this would not exclude the possibility of more complete and efficient registration at hospital level.

iii The CCRG used the National Registry of Childhood Tumours which is based mainly on the National Cancer Registration Scheme, but with a greater degree of validation to remove incorrectly diagnosed cases and duplicate registrations. Both observed and expected numbers were based on these data.

3.21 We have considered in some detail the effects that over- and under-registration might have on the data. The cancer registration rates used by CCRG are lower than those published by the OPCS, because the OPCS data include some duplicate registrations and incorrect diagnoses,[15] whereas the CCRG data have removed these. For the CCRG analysis this does not matter since the cases and the expected rates were both derived from the CCRG data. However, Roman *et al* included only cases known to be registered with the CCRG, and these therefore contained no duplicates, but the expected values are derived from national and regional incidence rates, based on OPCS data, which do contain duplicates. The effect of duplicate registration would therefore be to overestimate the expected numbers and hence duplicate registration would tend to underestimate the excess around Aldermaston and Burghfield.

3.22 As the observed excess cannot be explained by duplicate registration, we considered whether it could be caused by very accurate and complete registration in the Aldermaston and Burghfield area. In theory, it is possible that the "expected" numbers used as a basis for comparison are too low, because of incomplete registration in the remainder of the Oxford and Wessex regions and nationally. However, it seems extremely unlikely that the whole of the discrepancy could be accounted for by such under-registration, since this would imply that, for all childhood cancer, registration is only about 75% as complete over these larger areas as it is for the area within 10 km of Aldermaston and Burghfield (and only 70% as complete if leukaemia alone is considered). The available data suggest that for childhood leukaemia 90% of cases are registered nationally.[16] It therefore seems unlikely that registration differences can entirely explain the increased registration rate.

3.23 We have noted that there is a tendency for the registration rates for leukaemia, other cancers and total cancer for the ages 0–14, to be higher in electoral wards within 10 km of Aldermaston or Burghfield, than those further away but still in the same two DHAs. For total cancer and for leukaemia in the age group 0–4 there is a significant difference in registrations between areas within and without 10 km ($p<0.05$ one sided test). If registration differences were the explanation this would imply that cancer registration is more complete near the nuclear installations and less efficient further away from the installations, which seems unlikely. Thus, although unusually complete registration cannot be ruled out, it is unlikely to provide the entire explanation for the increased registration rates.

Comparison with other Areas

3.24 The interpretation of the increased registration rates for childhood cancer and leukaemia in the vicinity of Aldermaston and Burghfield is difficult, because it is not possible to demonstrate the degree to which the childhood leukaemia (or cancer) incidence around Aldermaston and Burghfield is unusual, compared with other areas of similar size throughout England and Wales. For the Black Report,[1] data from the Northern Children's Cancer Registry were used to compare the leukaemia incidence rates for Seascale with those for each of 765 electoral wards in the region. Leukaemia mortality data were also used to compare the leukaemia mortality rates in the Rural District in which Sellafield is situated, with that in other similar Rural Districts in England and Wales. For our second report[3] we were able to compare the local leukaemia incidence around Dounreay with the distribution of leukaemia cases in similar small areas throughout Scotland. Thus, we could rank the local incidence in question within the distribution of leukaemia incidence in similar areas. However, there is limited knowledge about local variations in registration rates for childhood cancer in England and Wales since, in contrast to Scotland, the data are not yet available in the appropriate form, namely classified according to precise place of residence.

3.25 Some information of this sort, though for mortality rather than incidence, is available from the recent paper by Cook-Mozaffari *et al*,[11] which was shown to us in advance of publication. This paper considers mortality data for leukaemia, including that for the age group 0–24, for 400 county districts in England and Wales and thus provides national data on local variations in leukaemia mortality rates. After adjustments for social class structure, population size, urban/rural status and health authority region, this study shows significant excess mortality from leukaemia (of about 15%) in the age group 0–24 in districts with more than 0.1% of their population near nuclear installations compared with the remainder. However, the authors note that there appeared to be no direct relationship between the magnitude of the excess and the percentage of the population living near the nuclear installations. We have not had an opportunity to study this paper in detail but the results of this study overall appear to strengthen the evidence for an association between increased leukaemia rates and the areas surrounding nuclear installations. However, these data do not provide evidence as to the possible causes of the increase in leukaemia mortality. Furthermore, this study does not provide a basis for ranking an individual installation area such as AWRE Aldermaston, nor does it give incidence data in small areas. It is therefore not possible to undertake a ranking procedure for the area around Aldermaston and Burghfield, similar to that performed for the areas around Sellafield and Dounreay, because the detailed analysis of childhood cancer cases required to describe the variation in incidence in small geographical areas has not yet been done for England and Wales.

RADIATION EXPOSURE AND RISK ASSESSMENTS

3.26 Public interest in the epidemiology initially arose because the YTV programme "Inside Britain's Bomb" drew attention to the presence of AWRE Aldermaston and ROF Burghfield in the area. We have therefore first considered whether authorised or accidental radioactive discharges from these sites could be responsible for the increased incidence of childhood cancer. When making the estimate of dose to the general population, NRPB also included discharges from Harwell for the purpose of comparison. Separate estimates of dose to the local population have been calculated by NRPB[8] from discharge data for each of the three sites, at various distances from 0.5 to 20 km, and for a range of age groups from the fetus to the adult.

3.27 The dosimetry data show that the estimated doses to representative individuals in the general population of the surrounding districts, from the atmospheric discharges, are extremely small and could not account for the increased incidence of childhood leukaemia or other cancers. The estimated doses to the local adult population are 0.0017%, 0.0000003% and 0.03% of natural background radiation for adults living 5 km from Aldermaston, Burghfield and Harwell respectively. The estimated doses for the fetus and infant were even lower. It can be seen that the doses from Harwell are greater than those from Aldermaston and considerably greater than those from Burghfield, but all are very small compared with natural background radiation.

3.28 However, the dose received by individual members of the local population cannot be measured directly and therefore indirect methods have been used to provide an estimate of dose. These dose estimates can either be calculated from the information on nuclear site discharges or from environmental monitoring data. Environmental monitoring data have the advantage that if unauthorised discharges have occurred, they should be reflected in the environmental monitoring data. In addition, the use of environmental monitoring data removes one stage of the assumptions made in the modelling process required to estimate doses to the population from radioactive discharges in the environment.

Limitations of Environmental Monitoring Data

3.29 In spite of these advantages, environmental monitoring data were not used to estimate radiation doses to the local population for the reasons discussed below:

i The extent of environmental monitoring around Aldermaston and Burghfield has varied over the years. Although MAFF has conducted some monitoring around these sites since they were first established, no environmental monitoring was carried out by AWRE between 1960 and 1978.

ii The Pochin report,[9] in 1978, recommended that more monitoring should be undertaken. Therefore in recent years, the level of environmental monitoring around Aldermaston has been much more extensive. However, the measured activity has been extremely low compared with background levels and in some cases has been indistinguishable from background. Where measurements have been undertaken for individual radionuclides, levels have often been lower than the threshold level for detection. When this was the case, the threshold levels have been quoted as the environmental level, but this would be an overestimate.

3.30 Because of the limitations of the environmental monitoring data in the early years, COMARE asked, as a further check, for a soil survey to be undertaken in the vicinity of the two sites. These confirmed the concentrations in soil of plutonium and uranium measured by the MoD environmental monitoring programme. These levels were, in general, low and were sometimes below detectable threshold levels. However, there were raised levels of tritium and slightly raised levels of actinides measured at several points close to the Aldermaston site (within 0.5 km), and at the one distant point measured (5 km). There were also slightly elevated levels of tritium at some points, and plutonium-238 at one point, near Burghfield. We cannot draw firm conclusions as to whether the elevated levels of radionuclides found in the soil near the nuclear installations could be attributable to the operations at these two nuclear sites for the reasons discussed in para A2.30. However, in terms of soil concentration of radioactivity, the highest concentrations of plutonium and americium-241 were not considered to be of radiological significance. This additional information on environmental monitoring data obtained by COMARE is not sufficient to enable dose estimates to be calculated, nor can it be used to verify the NRPB models. Further, more detailed sampling programmes around the sites would be needed to address the questions outlined above.

Use of Discharge Data for Dose Assessment

3.31 Despite the extensive environmental monitoring around Aldermaston and Burghfield since 1978, discharge data have been used for calculation of dose estimates. There are detailed discharge data for Aldermaston and Burghfield for atmospheric and liquid discharges and for accidental releases. Discharges from Aldermaston and Burghfield have been measured rather than estimated. In some cases the discharges have been overestimated because when the discharges are undetectable, levels are assumed to be equal to the minimum level of detection. In general, discharges from Harwell have been measured but for certain years atmospheric discharges have been estimated.

3.32 Estimated doses to the local population were calculated by NRPB from the atmospheric discharge data and were calculated separately for each site. No allowance was made for overlap for individuals living between the sites. The population living in the areas of overlap between the sites could receive the radiation dose from each site and these doses have not been combined in the dose estimates. However, because there is a considerable fall off in dose with distance from the source, people living at any distant point of overlap between the three sites would receive a smaller dose than people living close to any one site. In particular, the dose from Burghfield, at such points of overlap with Aldermaston, is so small as to be negligible.

3.33 It should be noted that only atmospheric discharges have been used to calculate the estimated doses. NRPB assumed that the liquid discharges from the three sites do not represent a potential route of exposure because the local population do not obtain their drinking water from stretches of the River Thames, into which the liquid wastes are discharged.

3.34 Calculation of estimated doses from discharge data is a complicated process involving the use of mathematical models. There are inevitably some uncertainties in this process and these have been discussed at length in our second report.[3] However, although we have a general reservation that such a complex process must always be associated with some margin of uncertainty, the atmospheric discharges from Aldermaston and Burghfield are so low that the magnitude of this uncertainty would have to be particularly large to make any appreciable difference in the estimated dose.

Risk Assessment

3.35 We have estimated the possible risks of radiation induced leukaemia to the local population by two methods. The first method was by making a comparison of the dose estimates for Sellafield and Dounreay with those for Aldermaston and then by scaling the risk estimates from the former to the latter. The second method was to assume that all leukaemia is caused by background radiation and then to calculate the increment that would result from the doses due to Aldermaston discharges. This second approach is similar to that performed in the Black report.[1] The expected number of cases of leukaemia in the local population of 54,617 children aged 0–14 years, due to Aldermaston atmospheric discharges for 1972–1985, was calculated to be either 6×10^{-5} (ie approximately 0.000001 per 1000) by the first method or 6×10^{-4} by the second method. Both of these methods of risk estimation demonstrate that the risks from the Aldermaston discharges are extremely low and could not account for the leukaemia incidence in the area. For comparison, the risks calculated for Sellafield in the 0−20 year olds to 1980, were 0.016 per 1225 (0.013 per 1000) and in Thurso, in the 0–24 year olds, from the Dounreay discharges to 1985, were 0.004 per 4,550 (0.00088 per 1000).

Uncertainties in Dose and Risk Assessment

3.36 As at Sellafield and Dounreay, a proportion of the population exposure around Aldermaston, and to a considerably lesser extent Burghfield, comes from the discharge of actinides such as plutonium which emit alpha particles which have a high Linear Energy Transfer (LET). There are a number of uncertainties with regard to high LET radiation which have been discussed at length in our second report.[3] Despite these uncertainties in the dose and risk calculations, the risks from the estimated doses from Aldermaston and Burghfield are so low, that we consider that the authorised and accidental atmospheric discharges are most unlikely to provide an explanation for the raised registration rate for childhood cancer.

Unrecognised Pathways in the Environment

3.37 It should be noted that no estimates are available of doses received by atypical individuals or population groups and the magnitude of the heterogeneity of dose amongst individuals is not known. We have considered whether some section of the community or scattered individuals could receive substantially higher doses of radiation due to unrecognised pathways in the environment. There is some evidence that other pathways in the environment might exist[17] and we have considered whether this could be a possibility at Aldermaston and Burghfield.

3.38 Aldermaston and Burghfield are situated in an inland region, and liquid wastes are discharged into a river first and then to the sea. In the calculation of dose estimates, NRPB has assumed that the liquid discharges from Aldermaston and Burghfield do not represent a potential route of exposure, because the local population do not obtain their drinking water from river water into which discharges are made. Dose estimates have therefore been based on atmospheric discharge data only.

3.39 The local population obtain the bulk of their water supply from the Mortimer and Ufton Nervet pumping stations which are borehole supply points. Smaller amounts are taken from the Fobney Water Treatment Works, which takes water from the river Kennet, but this is upstream of the point of discharge. (See Fig 2.1.) In order to confirm that public drinking water was not a source of exposure, the Department of the Environment (DOE), at COMARE's request, measured the levels of radioactivity in samples of water from each of these three sources and it was confirmed that the levels of radioactivity are within the normal environmental range.

3.40 We have noted that the levels of certain radionuclides, particularly the actinides, in the liquid discharges are often much greater than those in the atmospheric discharges. Although Thames water is not used as a public drinking water supply for the local population, there are large numbers of other listed underground water abstraction points and licensed surface water abstraction points. It is possible that Thames water could be used for purposes of irrigation which could lead to increased levels of radioactivity in meat from animals grazed on irrigated pasture and vegetables grown on irrigated land. Consumption of fish caught in the River Thames could also be relevant.

3.41 These possibilities suggested to us that some individuals could theoretically be exposed via other pathways in the environment resulting from the liquid discharges. At COMARE's request, NRPB have therefore calculated the dose to individuals exposed to some of these pathways, namely drinking river water, eating locally caught fish and pursuing recreational activities on the river bank. Calculation of these doses is based on pessimistic assumptions for a small number of hypothetical individuals and NRPB consider they are overestimates. MAFF have made measurements on fish and river sediment[10] which confirm that the NRPB calculations result in an overestimate of dose. We therefore conclude from these results that an unknown pathway in the environment involving the liquid discharges is most unlikely to cause an increase in radiation levels sufficient to explain the observed increase in childhood cancer.

Harwell

3.42 NRPB calculated the estimated doses to the local population around AERE Harwell from the Harwell discharge data, for purposes of making comparisons with Aldermaston and Burghfield. These show that the estimated doses to the local population around Harwell from the atmospheric discharges from Harwell, are greater than those to the population around Aldermaston and Burghfield from the atmospheric discharges from Aldermaston or Burghfield. However, our analysis shows no evidence of an increased incidence of childhood leukaemia in the area around AERE Harwell. The finding that there is no excess of childhood leukaemia in the vicinity of Harwell, which has higher levels of atmospheric discharges than Aldermaston or Burghfield, tends to support our view that the authorised and accidental atmospheric discharges from Aldermaston and Burghfield are most unlikely to provide an explanation for the raised incidence of childhood leukaemia around these two sites.

3.43 We have also considered data for "other cancers" in the vicinity of Harwell. There is a statistically significant excess of other cancers in the age group 10–14 compared with national rates, but no great weight can be attached to this observation as it has been made by inspection of the data and there was no prior expectation that an excess would be found in this age group. There is no evidence of an excess of other cancers in the vicinity of Harwell in the age group 0–4, which is the age group which shows an excess of other cancers (and leukaemia) in the vicinity of Aldermaston and

Burghfield. For the age group 0–14 the registration ratio for other cancers is 1.31; this excess is not statistically significant.

3.44 We have also considered whether the discharges from Harwell could affect the local population around Aldermaston and Burghfield. The liquid wastes from Harwell are discharged into the River Thames at Sutton Courtney (DI in figure 2.1). The River Thames then flows south-east to be joined by the River Kennet at Reading. Therefore the liquid discharges from Harwell, which are greater than those from Aldermaston or Burghfield, flow into the area of interest. It has been found that levels of uranium are higher upstream of the Aldermaston discharge point than downstream, which could be attributable to Harwell or other industrial sources. However, for the reasons stated in para 3.41 above we conclude that any effect from liquid discharges would be insufficient to account for the observed excess of childhood cancer around Aldermaston and Burghfield.

RELATIONSHIP TO OTHER INVESTIGATIONS

3.45 We have noted that the Roman *et al*[6] and the CCRG data show that the incidence of childhood leukaemia and other childhood cancers is raised in the ten kilometre circles around Aldermaston and Burghfield in children aged 0–14. An increased incidence of leukaemia in young people has already been documented around Sellafield[1] and Dounreay.[3] The Seascale birth and school cohort studies,[18,19] carried out to implement the second and third recommendations of the Black report, showed that the leukaemia excess at Seascale, near Sellafield, was seen in those children born to mothers resident in Seascale, but no excess was observed in children born elsewhere who attended school in Seascale. The Seascale birth cohort also showed an increased incidence of cancer other than leukaemia in young people. An excess of both leukaemia and other cancers at Aldermaston and Burghfield is therefore consistent with the Sellafield findings. There is also evidence from studies of the offspring of women who had diagnostic x-rays during pregnancy that radiation exposure may cause not only leukaemia but also other cancers.[20] However, the increased incidence of "other cancers" in the vicinity of Aldermaston and Burghfield neither strengthens nor negates the possibility that radiation has a causative role, as most alternative explanations of an increased incidence of leukaemia could equally affect other cancers.

3.46 In our judgement, the estimated doses to the population from the authorised or accidental radioactive discharges to atmosphere from Aldermaston, Burghfield or Harwell are much too low to provide an explanation of the epidemiological findings around Aldermaston and Burghfield. We also consider that an unknown pathway in the environment involving the liquid discharges is most unlikely to provide an explanation for these findings. However, some other mechanism of radiation exposure cannot be excluded. We have therefore considered what factors the Sellafield, Dounreay, Aldermaston and Burghfield sites have in common. Sellafield and Dounreay are both reprocessing sites with similar activities and similar discharges, although on a smaller scale at Dounreay than Sellafield. Aldermaston and Burghfield are not reprocessing plants, but it should be noted that plutonium is "handled" at Sellafield, Dounreay, Aldermaston and Harwell, and the potential exposure of workers to plutonium may be a relevant common factor.

3.47 The nuclear installations operate radiological protection regimes which are specifically designed to limit worker's exposure to radiation to internationally accepted levels. However, there are possible mechanisms by which occupational exposure in adults could theoretically be relevant to the induction of childhood cancer, such as a preconception effect in workers or unrecognised pathways of exposure via workers. Both of these mechanisms, which were discussed in our second report, are highly speculative. However, in view of the difficulty in accounting for the childhood cancer and leukaemia excess, the possibility that parents occupationally exposed to this type of radiation may be at above average risk of having children with leukaemia or cancer, needs to be explored, if only to be excluded.

3.48 The published body of knowledge of the conditions, agents and mechanisms which may result in leukaemias in children is meagre, but in addition to radiation exposure, it is possible that exposure to particular chemical agents may be important, although there is little evidence for this and it relates to adults.[21] We have considered the possibility that there could be some type of carcinogenic exposure, associated with the nuclear establishments, other than radiation; for instance the use of some classes of chemicals could be important. However, the use of such chemicals at Aldermaston and Burghfield seems to be on a small scale and under the usual controls to limit exposure.

3.49 We have also considered whether environmental factors such as the use of chemicals in other industries in the area could be implicated. There are major differences between the areas surrounding Aldermaston and Burghfield compared with those surrounding Sellafield and Dounreay. Sellafield and Dounreay are situated in remote, sparsely populated coastal areas where there are few industrial activities other than those operating on the two sites. In contrast, Aldermaston and Burghfield are situated in an inland area which is relatively densely populated, with large towns and a number of other industries nearby, including a large coal-fired power station. Although attention was drawn to this area by the existence of the nuclear establishments at Aldermaston and Burghfield, the industrial complexity of the area makes it difficult to draw firm conclusions about the relationship of childhood cancer to any particular aspect of the local environment.

3.50 Nuclear establishments, which are large employers of specialised labour forces, could have indirect effects on cancer incidence by influencing the demographic characteristics of the local population. In our second report we noted various factors which could be relevant such as the influx of a specialised workforce into a previously isolated community, the possible movement of staff between nuclear sites, the social class distribution of the local population and possible viral causes of leukaemia. Kinlen[22] has recently examined a specific hypothesis of this nature, namely that population influx associated with industrial development, in a previously remote rural area, could be associated with changes in leukaemia rates, as such situations may be conducive to epidemics of leukaemogenic viruses. The author has demonstrated the possibility of such an effect in the new town of Glenrothes in Scotland. This hypothesis is of considerable interest and clearly worthy of further research. However, the area around Aldermaston and Burghfield does not fulfil Kinlen's criteria of isolation and sudden population influx.

3.51 The possibility that the social class structure of the local population may be important was examined in the recent paper by Cook-Mozaffari *et al*[11] which has been discussed earlier. This study concluded that there were significant excesses of mortality in the age group 0–24 from leukaemia, and particularly lymphoid leukaemia, in districts near nuclear installations although there appeared to be no direct relationship between the magnitude of the excess and the percentage of the population living near the installations. This study also found that the mortality from all leukaemia and in particular lymphoid leukaemia, was greater in areas where there is a greater proportion of the population in the higher social classes. When the authors allowed for the social class distribution of the population, and other factors, leukaemia mortality in the age group 0–24 remained significantly elevated in areas near nuclear installations. Therefore the increase in leukaemia mortality around nuclear installations could not be accounted for by the social class composition of these areas. However, it is possible that there is some other feature of the type of area in which nuclear installations are situated, which is relevant to the aetiology of childhood leukaemia.

3.52 In this chapter we have discussed whether the increased registration rates for childhood leukaemia and other cancers in West Berkshire and North Hampshire could be due to random variation, biased selection of data, or local variation in completeness of cancer registration. We have also discussed possible causes for any increased childhood cancer incidence. These include possible direct effects of radiation exposure from the atmospheric discharges; the possibility of unrecognised pathways in the environment involving the liquid discharges; and the possible relevance of parental occupational exposure to radiation. We have also considered other types of carcinogenic exposure from either the nuclear plants or other local industry; and indirect effects from the presence of nuclear plants in the vicinity or the type of area in which they are situated. On the basis of the evidence presented to us and our subsequent considerations we have reached the conclusions set out in the next chapter.

CHAPTER 4

CONCLUSIONS

Childhood Cancer Incidence

4.1 There is a small but statistically significant increase in registration rates for childhood leukaemia in the age group 0–14 over the period 1972–1985, in the areas within 10 km of AWRE Aldermaston and ROF Burghfield, compared with both the national rates, and the regional rates for Oxford and Wessex.

4.2 In the same areas, there is also a small but statistically significant increase in registration rates for other childhood cancers in the age group 0–14 over the period 1971–1982, compared with national rates.

4.3 These areas lie within the West Berkshire and the Basingstoke and North Hampshire Health Authorities. The registration rates for leukaemia and other cancers in the age group 0–14 in the whole of the West Berkshire and the Basingstoke and North Hampshire Health Authorities also show a statistically significant increase compared with national rates.

4.4 Within the age group 0–14, the elevated registration rates for leukaemia and other cancers, whether considered separately or combined, are confined to the 0–4 year age group. This result applies to the areas within 10 km of the installations and also to areas covered by the whole of these two district health authorities. However, this result needs to be interpreted with caution as the observation was not predicted in advance and only came to light following inspection of these data.

4.5 There is evidence that areas within 10 km of AWRE Aldermaston and ROF Burghfield have had higher registration rates of total childhood cancer in the age group 0–14 than those areas beyond 10 km, but still within the same two district health authorities. However, this is only statistically significant in the age group 0–4 for leukaemia and for total cancers.

4.6 We have considered the possibility that these increased registration rates could be explained by local variation in the completeness of cancer registration; in our judgement this is unlikely to provide the entire explanation.

4.7 We are unable to assess the precise extent to which the increased registration rates for childhood cancer in the area within 10 km of AWRE Aldermaston and ROF Burghfield are unusual, because comparable registration data for childhood cancer in similar small areas in the rest of England and Wales are not yet available.

4.8 In the area within 10 km of AERE Harwell, the available evidence shows no increase in registration rates for childhood leukaemia in the age group 0–14, over the period 1971–1982 compared with national rates. In the same area and for the same time period, there is a statistically significant excess of other cancers in the age group 10–14, compared with national rates, but this result should be treated with caution as it has been obtained by inspection of the data. For the age group 0–14 the registration rates for other cancers in this area are not significantly raised above national rates.

Radiation Exposure and Dose Assessment

4.9 We have considered the estimated radiation doses to the local population from authorised and accidental atmospheric discharges from AWRE Aldermaston, ROF Burghfield and AERE Harwell. We judge that these atmospheric discharges are much too low to account for the increase in childhood cancer incidence in the area, even allowing for the uncertainties involved in any estimation of radiation dose. The estimated doses from the liquid discharges have, as far as we can ascertain, also been extremely low. We consider it most unlikely that the liquid discharges could cause a sufficient increase in radiation levels to account for the observed increase in childhood cancer incidence in the area.

4.10 We cannot exclude completely the existence of some hitherto unknown and unexpected route by which some individuals could be exposed to increased levels of radiation. Such speculative pathways, including those involving radiation workers, should be explored.

Other Factors

4.11 We have also considered factors other than radiation exposure, including chemical carcinogens, demographic phenomena and viruses. Although we recognise the considerable importance of these factors we are not aware of any specific evidence that these are responsible for the increased incidence of childhood cancer in this area.

MAIN CONCLUSION

4.12 There is a small but statistically significant increase in the incidence of childhood leukaemia and other childhood cancers in the vicinity of AWRE Aldermaston and ROF Burghfield. In our judgement, the authorised and accidental radioactive discharges from AWRE Aldermaston, ROF Burghfield and AERE Harwell are far too low to account for the observed increase in childhood cancer incidence in the area. We have considered a number of possible explanations for these findings, including other mechanisms by which radiation may be involved, but we do not have sufficient evidence to point to any one particular explanation and it is possible that a combination of factors may be involved.

4.13 The findings set out in this report, taken with those in previous reports[1,3] indicate that there is a statistically significant increase in the incidence of childhood leukaemia in the vicinities of Sellafield, Dounreay, and Aldermaston and Burghfield. We cannot exclude completely the possibility that these observations are a consequence of chance or due to the selection of the sites referred to us for our enquiries. However, if there is a link between these nuclear installations and childhood leukaemia, it follows that there must be a mechanism for such an association, which should be potentially discoverable and remediable. The findings of this report, together with those of our previous reports, warrant further investigation to clarify the situation.

4.14 We have now completed three reports to Government. Our experience so far leads us to the conclusion that the distribution of cases of childhood leukaemia, or other childhood cancer, around individual nuclear installations cannot be seen in a proper context in the absence of comparable information about the general pattern throughout the rest of the UK. We will therefore make recommendations for further work on the geographical distribution of childhood cancer on a nationwide basis and urge that high priority be given to their implementation.

CHAPTER 5

RECOMMENDATIONS TO GOVERNMENT

5.1 We make the following specific recommendations to Government in addition to those already made in our second report.[3]

Recommendation 1

We have already recommended that case control studies of young people registered as cases of childhood cancer, in the vicinity of those nuclear installations which we have studied, should be undertaken. We have recommended that in these studies particular attention should be paid, where possible, to: the occupations of all members of the relevant households; the history of the exposure of the parents and the children to radiation and potentially carcinogenic chemicals; the children's place of birth; and details of any change of residence.

We now recommend that:

i Around Aldermaston and Burghfield, a sample survey of the levels of radionuclides in household dust should be carried out in association with the case control study.

ii In association with the case control studies, consideration should be given to the feasibility of monitoring radionuclides in whole body or specific tissues of leukaemic children and appropriate controls. Such studies, where practicable, should be directed towards the determination of the presence or absence of radiologically significant quantities of radionuclides.

Recommendation 2

We reiterate Recommendation 3 of our second report that epidemiological studies should be set up to consider any possible effects on the health of the offspring of parents occupationally exposed to radiation. We recommend that consideration be given to broadening the scope of such studies to include the health of children of all employees at the nuclear installations we have studied.

Recommendation 3

The OPCS report on cancer and nuclear installations[7] and our own enquiries, have highlighted a number of problems with the National Cancer Registration Scheme. We recommend that urgent consideration should be given to the validity of cancer registration data, the form and completeness of which is currently variable in quality. In addition, the following specific improvements which we urged in our second report, should be made:

i We recommend that high priority be given to the completion of the postcoded childhood cancer registration database for England and Wales, and to ensuring that this database is accurate and complete. As the survival rate for leukaemia and other cancers continues to improve, accurate registration data are becoming an increasingly important part of the information required for the analysis of childhood cancer incidence.

ii We recommend that high priority be given to the work already underway to enable data on childhood cancer to be analysed by place of birth of the child, as well as by place of residence at time of diagnosis.

Recommendation 4

We recommend that studies of the geographical distribution of childhood cancer incidence on a nationwide basis be carried out as the data in Recommendation 3 become available. These studies will provide essential information on the distribution of cases of childhood cancer throughout the UK, thus enabling the patterns found around nuclear sites to be seen in the context of patterns in the rest of the UK.

Recommendation 5

We consider it unlikely that useful information will emerge from further detailed investigations of alleged increased childhood cancer incidence around individual nuclear installations. Such investigations will be difficult to interpret until the results of the studies outlined in Recommendation 4 are available. We recommend that once the results of these national studies are available, this Committee should be asked to participate in a review of the evidence relating to the incidence of childhood cancer around nuclear installations. In the meantime, priority should be given to the recommendations set out in this report, completion of the outstanding recommendations in the Black report[1] and the recommendations in our second report.

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THE ANNEXES

CANCER AMONG YOUNG PEOPLE IN WEST BERKSHIRE AND NORTH HAMPSHIRE

ROMAN *ET AL* — Childhood Leukaemia Incidence

A1.1 Dr Roman and her colleagues at the London School of Hygiene and Tropical Medicine, collaborated with Dr Barton and her colleagues at the Royal Berkshire Hospital and Basingstoke General Hospital, in producing the study "Childhood Leukaemia in the West Berkshire and Basingstoke and North Hampshire District Health Authorities in relation to nuclear establishments in the vicinity".[6] Two nuclear establishments, AWRE Aldermaston and ROF Burghfield lie within West Berkshire Health Authority (HA) and AERE Harwell lies in neighbouring Oxfordshire.

A1.2 In this study, all children with leukaemia were identified who were under 15 years of age at time of diagnosis and were registered as living in either West Berkshire HA or Basingstoke and North Hampshire HA. Diagnoses were confirmed histologically and ascertainment checked for completeness. From their registered addresses, each case was allocated to the appropriate electoral ward. To study the relationship between residence near a nuclear establishment and leukaemia risk, these electoral wards were divided into two groups: those with half or more of their area within one of the circles of 10 km radius around each of the three establishments and those with less than half their area within any of these 10 km circles. The 10 km radius was chosen before the geographical distribution of leukaemia was examined.

A1.3 Forty eight of the one hundred and forty three electoral wards covered by the two health authorities lay within (or at least half their area lay within) a 10 km radius of either AWRE Aldermaston or ROF Burghfield in Berkshire. Only two electoral wards of the two DHAs lie within 10 km of AERE Harwell sited in nearby Oxfordshire (See Fig.A1.1). A total of eighty nine children aged between 0 and 14 years were registered with leukaemia between 1972 and 1985 in the two DHAs. In the fifty electoral wards within 10 km of the three establishments, forty one children aged 0–14 were registered with leukaemia between 1972 and 1985 whereas 28.6 cases were expected on the basis of national rates as shown in Table A1.1 (Registration ratio 1.4, $p<0.05$). The observed excess was confined to children aged 0–4 years (29 observed, 14.4 expected, registration ratio 2.0, $p<0.001$).

A1.4 The authors also compared the observed cases in the 10 km circles with the numbers expected from leukaemia registration rates in the Oxford and Wessex regions. The registration ratios are virtually identical to those based on national rates as the registration rates in the Wessex and Oxford regions did not differ from the national rates.[6]

A1.5 In the remaining 93 wards in West Berkshire and North Hampshire ie those outside the 10 km circles, there was a small but non-significant increase in registrations for leukaemia in children aged 0–14 compared with leukaemia registration rates in the whole of England and Wales.

Figure A1.1
Electoral wards divisions in the District Health Authorities of West Berkshire and Basingstoke and North Hampshire

Table A1.1 Leukaemia registrations in West Berkshire and Basingstoke and North Hampshire by age and by distance of the electoral ward of residence from a nuclear establishment.

Age	Electoral wards ≤10 km from a nuclear establishment			Electoral wards >10 km from a nuclear establishment			Electoral wards combined		
	No of children with cancer			No of children with cancer			No of children with cancer		
	Obs	Exp[1]	Regn.[2] Ratio	Obs	Exp[1]	Regn.[2] Ratio	Obs	Exp[1]	Regn.[2] Ratio
0–4	29	14.4	2.0***	24	19.6	1.2	53	34.0	1.6**
5–9	9	8.3	1.1	12	12.5	1.0	21	20.7	1.0
10–14	3	5.9	0.5	12	8.7	1.4	15	14.6	1.0
0–14	41	28.6	1.4*	48	40.8	1.2	89	69.3	1.3*

1. Expected numbers are based on leukaemia registration rates in England and Wales.
2. Ratio of observed to expected number of registrations.

* Significant at $p<0.05$
** Significant at $p<0.01$
***Significant at $p<0.001$

All tests of significance are two sided

A1.6 In addition, the authors compared all the observed cases of childhood leukaemia in the 143 electoral wards in West Berkshire HA and Basingstoke and North Hampshire HA with expected numbers based on national rates. This analysis showed a significant excess in leukaemia registrations in these two DHAs in the 0–14 year olds for the period 1972–1985 (89 observed, 69.3 expected, registration ratio 1.3, $p<0.05$). The observed excess was again confined to the 0–4 age group (53 observed, 34 expected, registration ratio 1.6, $p<0.01$).

A1.7 The authors noted, that within the two DHAs, the registration ratios for leukaemia in children in the age groups 0–4 and 0–14 living within the 10 km boundary were not significantly different from those in children living outside the 10 km boundary, using a two sided significance test at the conventional 5% level. The authors pointed out that within the study area there was no obvious trend with time for leukaemia incidence nor did the geographical distribution of the cases depart from a random distribution.

A1.8 Roman *et al* used two sided significance tests and we have quoted these p-values as originally given. We have used one sided tests in our own analyses but with one exception, discussed in para A1.21, the two approaches lead to the same statements regarding the significance levels of the results.

A1.9 The authors concluded that an excess incidence of childhood leukaemia was evident in electoral wards within 10 km of both Aldermaston and Burghfield (there were no cases in the two wards within 10 km of Harwell); however, the effect was not large. They illustrated this point with the example that within the population that live within 10 km of the two nuclear installations (around 60,000 children under 15), two cases of leukaemia would be expected per year according to the national average, with the observed incidence adding a single case per year.

CCRG — Incidence of Childhood Cancer other than Leukaemia

A1.10 The Childhood Cancer Research Group (CCRG) considered the incidence of childhood cancer other than leukaemia in the areas defined by Roman *et al*. This unpublished data has been taken from a study being carried out by Paula Cook-Mozaffari in collaboration with CCRG. The ascertainment of cases for the analysis has been made through the National Registry of Childhood Tumours maintained by the Childhood Cancer

Research Group (CCRG) in Oxford. This is based mainly on the National Cancer Registration Scheme but with a greater degree of validation and checking than is possible for adult tumours. The allocation to wards of residence was carried out as part of a more comprehensive study.

A1.11 Population estimates for the areas defined in the analysis are based on electoral ward populations from the 1981 census, and yearly estimates of populations for District Health Authorities, obtained from Dr Eve Roman; Dr Roman also provided a list of wards at various distances from the nuclear installations. The analysis is therefore directly comparable with the analysis of leukaemia rates carried out by Roman *et al* except that the period covered is 1971–1982 rather than 1972–1985.

A1.12 The incidence rates used in the analysis are based on CCRG data published in the IARC Volume "International Incidence of Childhood Cancer".[23] These rates are rather lower than those published by OPCS since the process of validation includes the removal of incorrectly diagnosed cases and duplicate registrations. This does not affect the comparisons discussed below since both observed and expected numbers are based on CCRG data. CCRG data are not available for separate cancer registration regions but it appears that the cancer registry rates for Oxford at ages 0–14 do not differ materially from those for England and Wales generally.[6,24,25a,25b]

A1.13 The results for cancers other than leukaemia are given in Table A1.2. In this table observed and expected numbers of cases are compared for each five year age group and for the areas defined by Roman *et al*.[6] One sided tests of significance are used.

Table A1.2 Registrations of cancers other than leukaemia in West Berkshire and Basingstoke and North Hampshire by age and by distance of the electoral ward of residence from a nuclear establishment.

Age	Electoral wards ≤10 km from a nuclear establishment			Electoral wards >10 km from a nuclear establishment			Electoral wards combined		
	No of children with cancer			No of children with cancer			No of children with cancer		
	Obs	Exp[1]	Regn.[2] Ratio	Obs	Exp[1]	Regn.[2] Ratio	Obs	Exp[1]	Regn.[2] Ratio
0–4	30	19.4	1.55*	33	26.3	1.25	63	45.7	1.38**
5–9	16	13.4	1.19	23	20.3	1.13	39	33.8	1.15
10–14	15	14.7	1.02	26	21.6	1.20	41	36.3	1.13
0–14	61	47.5	1.28*	82	68.3	1.20	143	115.8	1.23**

1. Expected numbers are based on Childhood Cancer Research Group incidence rates for England and Wales, 1971–1980.
2. Ratio of observed to expected number of registrations.

* Significant at $p<0.05$
** Significant at $p<0.01$

Tests of significance are one sided

A1.14 Table A1.2 shows a similar pattern to Table A1.1. For childhood cancer other than leukaemia there is an overall excess of Observed to Expected cases, in the 0–14 age group in wards at distances less than 10 km from an installation. ($O=61$, $E=47.5$, $O/E=1.28$, $p<0.05$). The excess is largely confined to the age group 0–4 in which there were 30 cases observed compared with 19.4 expected ($O/E=1.55$, $p<0.05$).

A1.15 In the remaining 93 wards within the two DHAs there was a small but non-significant excess of childhood cancer other than leukaemia for the 0–14 age group.

A1.16 Table A1.2 also shows that when all the electoral wards in West Berkshire HA and Basingstoke and North Hampshire HA are considered together, there is a significant excess of childhood cancer other than leukaemia in 0–14 age group (O=143, E=115.8, O/E=1.23, $p<0.01$). The excess is again largely confined to the age group 0–4 (O=63, E=45.7, O/E=1.38, $p<0.01$).

A1.17 These data indicate that there has been an excess of childhood cancer other than leukaemia in the areas defined by Roman *et al*[6] for the period 1971–1982. The CCRG have also considered childhood leukaemia incidence for the same period 1971–1982 and these results are similar to those given by Roman *et al*.

SUMMARY OF RESULTS FROM ROMAN *ET AL* AND CCRG

A1.18 The data from Roman *et al* and the CCRG are compatible in terms of geographical boundaries and have considerable overlap for the temporal limits. We have, therefore, combined the data to give an overall view of childhood cancer registration in the West Berkshire and the Basingstoke and North Hampshire Health Authorities (Table A1.3). We have also analysed the results by distance from a nuclear installation (Table A1.4).

A1.19 Table A1.3 shows the results from Roman *et al* for leukaemia registrations (1972–1985) and from CCRG for other cancer registrations (1971–1982), at ages 0–4, 5–14 and 0–14 in West Berkshire and Basingstoke/North Hampshire HAs. In each case, the observed numbers are compared with expected numbers from England and Wales rates. For the age group 0–14, both for leukaemia and other cancers registrations,

Table A1.3 Leukaemia and other cancers at ages, 0–4, 5–14 and 0–14 years in West Berkshire and Basingstoke/North Hampshire District Health Authorities compared to expected numbers based on England and Wales rates.

Age	Source	Diagnosis and Time Period	Number of registrations		Registration[2] ratio
			Observed	Expected[1]	
0–4	Roman *et al*	Leukaemia 1972–85	53	34.0	1.56**
	CCRG	Other cancers 1971–82	63	45.7	1.38**
	Combined Data[3]	Total cancer	116	79.7	1.45****
5–14	Roman *et al*	Leukaemia 1972–85	36	35.3	1.02
	CCRG	Other cancers 1971–82	80	70.1	1.14
	Combined Data	Total cancer	116	105.4	1.10
0–14	Roman *et al*	Leukaemia 1972–85	89	69.3	1.28*
	CCRG	Other cancers 1971–82	143	115.8	1.23**
	Combined Data	Total cancer	232	185.2	1.25***

1. Expected numbers based on age-specific registration rates in England and Wales
2. Ratio of observed to expected number of registrations
3. Combined data includes leukaemia registrations from 1972–1985 and registrations for other cancers from 1971–1982.

* $p<0.05$
** $p<0.01$
*** $p<0.001$
****$p<0.0001$

Tests of significance are one sided.

separately and also combined, the observed numbers are significantly in excess of the numbers expected (leukaemia registration ratio 1.28, $p<0.05$, other cancers registration ratio 1.23, $p<0.01$, combined registration ratio 1.25 $p<0.001$ one sided tests). This excess is largely confined to the 0–4 year olds (leukaemia registration ratio 1.56, $p<0.01$, other cancers registration ratio 1.38, $p<0.01$, combined registration ratio 1.45, $p<0.0001$ one sided tests). There is a non-significant excess of other cancers in the 5–14 year olds (registration ratio 1.14)

A1.20 Table A1.4 compares the registration ratios for leukaemia, other cancers and total cancers for the age groups 0–4, 5–14 and 0–14 in electoral wards within 10 km of a nuclear installation, with those for wards beyond 10 km but still within the West Berkshire and Basingstoke/North Hampshire HAs. Over the full age range 0–14 there is a tendency for the registration ratios for both leukaemia and other cancers to be higher in areas within 10 km of a nuclear establishment than in those outside this radius, but this is not significant (ratio of registration ratios for leukaemia 1.22, ratio of registration ratios for other cancers 1.07). The excesses are greater in the age group 0–4 years both for leukaemia and for leukaemia and other cancers combined (ratio of registration ratios 1.64 and 1.41 respectively). These results for the 0–4 year age group are significant at the

Table A1.4 Leukaemia and other cancers at ages 0–4, 5–14, and 0–14 in West Berkshire and Basingstoke/North Hampshire District Health Authorities by distance of the electoral ward of residence from a nuclear establishment.

Age	Source	Diagnosis and Time Period	Distance of electoral wards from a nuclear establishment						Comparison of ≤10 km with >10 km	
			≤10 km			>10 km			Ratio of Registration ratios[4]	95% confidence interval
			Number of registrations		Registration ratio[2]	Number of registrations		Registration ratio[2]		
			Observed	Expected[1]		Observed	Expected[1]			
0–4	Roman *et al* CCRG	Leukaemia 1972–85	29	14.4	2.01	24	19.6	1.23	1.64*	0.92 to 2.94
		Other cancers 1971–82	30	19.4	1.55	33	26.3	1.25	1.24	0.73 to 2.09
	Combined Data[3]	Total Cancer 1971–85	59	33.8	1.75	57	45.9	1.24	1.41*	0.96 to 2.06
5–14	Roman *et al* CCRG	Leukeamia 1972–85	12	14.2	0.85	24	21.2	1.13	0.75	0.34 to 1.56
		Other cancers 1971–82	31	28.1	1.10	49	42.0	1.17	0.94	0.58 to 1.51
	Combined Data	Total Cancer 1971–85	43	42.3	1.02	73	63.1	1.16	0.88	0.59 to 1.30
0–14	Roman *et al* CCRG	Leukaemia 1972–85	41	28.6	1.43	48	40.8	1.18	1.22	0.78 to 1.89
		Other cancers 1971–82	61	47.5	1.28	82	68.3	1.20	1.07	0.75 to 1.51
	Combined Data	Total Cancer 1971–85	102	76.1	1.34	130	109.1	1.19	1.12	0.86 to 1.47

1. Expected numbers based on age-specific registration rates in England and Wales
2. Ratio of observed to expected number of registrations
3. Combined data includes leukaemia registrations from 1972 to 1985 and registration for other cancers from 1971–1982
4. Ratio of registration ratios for ≤10 km and >10 km electoral wards

* $P<0.05$, one sided test

5% level using a one sided test but are not significant at the conventional 5% level if a two sided test is used; the latter statement is implied by the 95% confidence intervals given in table A1.4.

A1.21 Roman *et al* used two sided tests for this analysis of their leukaemia data and on this criterion stated that the differences were not significant (see para A1.7). The reason for the apparent discrepancy is that a result just significant using a one sided test will not be significant using a two sided test. The wide confidence limits for the ratios of the registration ratios indicate the degree of uncertainty in comparing the leukaemia and other cancer rates inside and outside the 10 km circles.

OPCS — Childhood Cancer Incidence and Mortality
General Methods

A1.22 In 1987, the OPCS published a study on "Cancer Incidence and Mortality in the Vicinity of Nuclear installations in England and Wales, 1959–80".[7] It dealt with cancer statistics around all nuclear sites in England and Wales using OPCS data. The study was therefore partly dependent on, and affected by, the varying quality of cancer registration in different parts of the country. However, it had the advantages that it concerned itself with mortality as well as with incidence; that it examined "control" as well as "exposed" areas; and its concern with the whole country meant that the authors could set any locally observed concentrations of incidence within the broader context of geographical variability. Because it covered a period of twenty years, this investigation also measured trends in incidence and mortality with time and then compared them for different parts of the country.

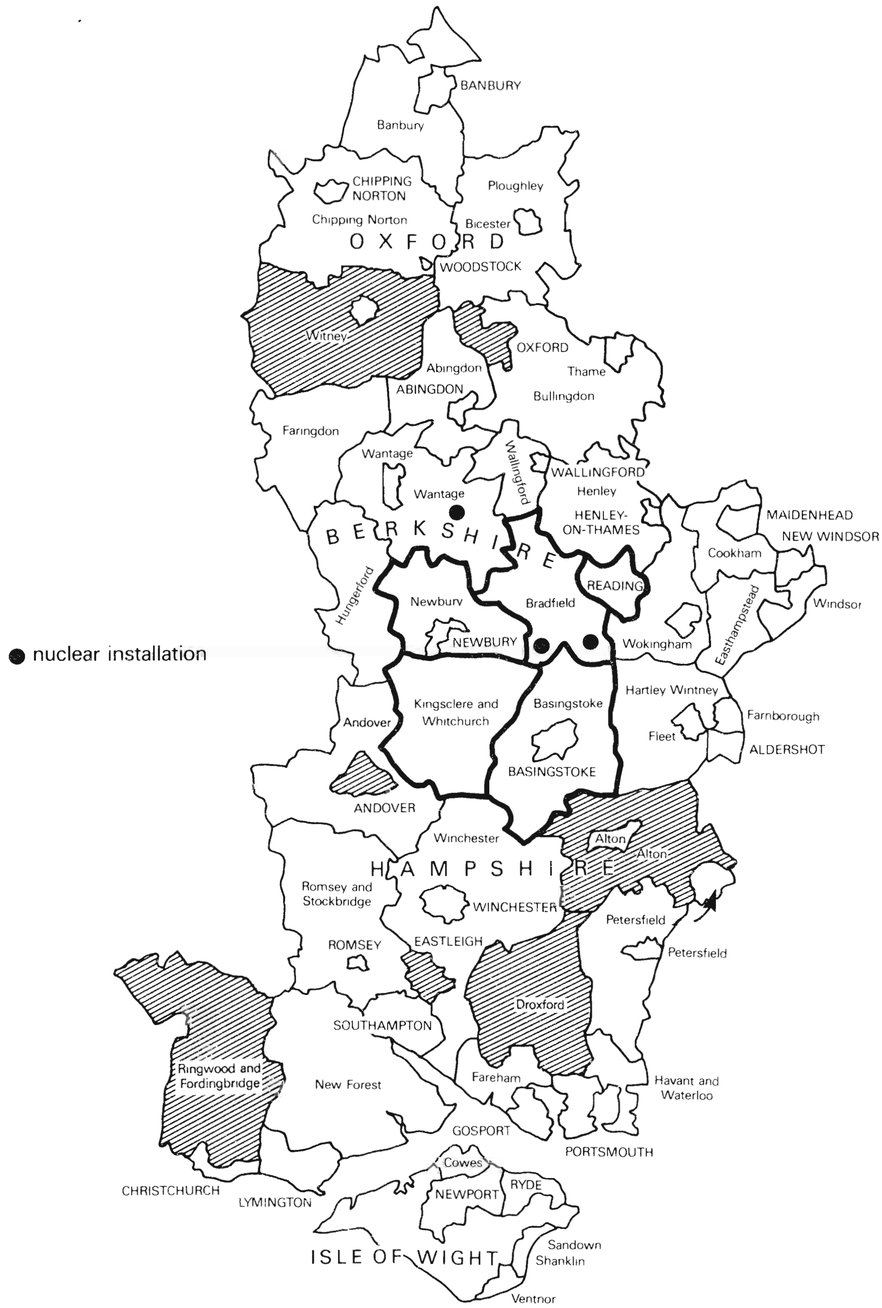
A1.23 This large study covered 15 nuclear installations and for each location, cancer registrations and deaths were recorded for up to seventeen disease classifications grouped into five year time periods between 1959 and 1980. Although the data were collected in five year age bands, the age groupings have been simplified to 0–24, 25–75 and 75+ in the published tables, with other groupings available on microfiche. Three groups of location were studied, the CEGB sites, pre-1955 sites (including Aldermaston) and Sellafield and neighbouring coastal areas.

A1.24 The investigation has been based on local authority areas which existed before the major boundary revisions in 1974, ie rural and urban districts and municipal and county boroughs. Local authority areas were classified according to the proportion of the population living within various distances of the installation. The categories were as follows: two thirds of the population within 6 miles, two thirds of the population within 8 miles, two thirds of the population within 10 miles and one third of the population within 10 miles.

A1.25 For comparison, control areas were chosen for each area by matching, as far as possible, for urban and rural status, population size and, where possible, for cancer registration region. Unfortunately, for one fifth of the installation areas it was not possible to match controls from within the same registration region. This problem particularly affected the control areas for Aldermaston so that for the distance zone "between one third and two thirds of the population within ten miles", the installation area had 68% in the Oxford RHA whereas the control area had 48%.[7]

A1.26 The authors calculated standardised registration ratios (SRRs) and standardised mortality ratios (SMRs) for the periods subsequent to the start up of the installations within the ranges for which the relevant data were

Figure A1.2
Map showing the geographical boundaries for both the installation and control areas for MOD Aldermaston as used in the Cook-Mozaffari/OPCS study.



Definition of distance areas	Installation areas	Control Areas
At least two-thirds of the population within eight miles but not within six miles	Bradfield RD	Witney RD
At least two thirds of the population within ten miles but not within eight miles	Newbury MB Newbury RD Basingstoke MB Basingstoke RD Reading CB	Andover MB Ringwood & Fordingbridge Eastleigh MB Droxford RD Oxford CB
With between one third and two-thirds of the population within ten miles	Kingsclere & Whitchurch RD	Alton RD

available ie 1959–1980 for mortality and 1961–1980 for incidence. Expected values, for the numbers of deaths or registrations, were derived using regional rates (excluding conurbations) for each individual year and summing for each time period. The authors carried out tests for significant deviations of the incidence and mortality rates near installations, from both the chosen control locations and from the respective standard regions. They also looked for trends with distance from the establishment and over time.

A1.27 Consideration of the entire study is outside the scope of this report. For the purposes of this review, we have confined ourselves to the data on childhood cancer around AWRE Aldermaston. ROF Burghfield, together with UKAEA Risley and UKAEA Culcheth, were not included in the OPCS study because discharges from these establishments had been deemed to be negligible; they were several orders of magnitude below those from CEGB nuclear power stations and these in turn were much lower than the discharges from the pre–1955 installations.

Data for AWRE Aldermaston

A1.28 The local authority areas classified in the report as near AWRE Aldermaston are shown in Fig. A1.2 together with the control areas. Bradfield RD is the installation area for the local authority areas with "at least two-thirds of the population within eight miles" and Witney RD is the corresponding control. For the largest and most distant definition "with one third of the population within 10 miles" all the local authority areas listed in figure A1.2 are included. There was no local authority area which could be classified as having "two thirds of the population within 6 miles" of AWRE Aldermaston.

A1.29 The results presented in Tables A1.5 and A1.6 have been calculated from data presented in the OPCS study. In this report, in order to facilitate comparison with the other studies considered, we have expressed the comparison between observed and expected numbers simply as their ratio; the SRRs and SMRs are these numbers multiplied by 100. We have followed the approach used by the authors and have used two sided tests of significance. Table A1.5 shows the results for Bradfield RD and the control area Witney for leukaemia, other cancers and total cancer for the ages 0–9, 10–24, and the combined age range 0–24. Registration data are considered for the time periods 1961–1970, 1971–1980 and for the total 1961–1980. Mortality data are considered for the slightly earlier period 1959–1970, 1971–1980 and the total 1959–1980. For each category the observed and expected values and either the registration ratio (RR) or the mortality ratio (MR) are shown. Similar data for the local authority areas with one third of the population within 10 miles (16 km) of AWRE Aldermaston are shown in Table A1.6.

A1.30 Table A1.5, shows that neither the incidence nor the mortality for childhood leukaemia, or for other cancers, were significantly raised in Bradfield RD, for the whole period 1959/61–1980 for any age group. There were no significantly raised childhood cancer rates in the control area — Witney RD.

A1.31 Table A1.6 shows that in the areas with one third of the population within 10 miles of Aldermaston, the incidence ratios for leukaemia for the total time period, 1961–1980, for the age groups 0–9, 10–24 and 0–24 were not significantly raised. However, the incidence ratio for leukaemia for the period 1971–1980 for the age group 0–9 was significantly raised (incidence ratio 1.47 $p=0.05$). The incidence ratio for the control area away from any nuclear installation was similar for the same time period 1971–1980 for the age group 0–9 (incidence ratio 143) but was not significant.

Table A1.5 Observed and Expected Cancer Registration and Mortality in the Area with two thirds of the Population within 8 miles of AWRE Aldermaston (ie Bradfield RD) and the corresponding control area (ie Witney).

Installation area											
Age	Diagnosis		1961[2]–1970			1971–1980			TOTAL[3]		
			Obs	Exp[1]	Ratio	Obs	Exp[1]	Ratio	Obs	Exp[1]	Ratio
0–9	Leuk.	Reg.	3	2.29	1.31	5	3.20	1.56	8	5.49	1.46
		Mort	0	2.65	—	5	2.18	2.30	5	4.83	1.04
	Other Cancers	Reg	2	5.24	0.38	9	5.02	1.79	11	10.27	1.07
		Mort	1	3.59	0.27	5	2.86	1.75	6	6.45	0.93
	Total Cancer	Reg	5	7.54	0.66	14	8.25	1.70	19	15.77	1.21
		Mort	1	6.25	0.16	10	5.03	1.99	11	11.28	0.98
10–24	Leuk	Reg	3	1.30	2.31	3	2.01	1.49	6	3.32	1.81
		Mort	2	1.81	1.10	1	1.77	0.56	3	3.59	0.84
	Other Cancers	Reg	8	8.80	0.91	10	11.22	0.89	18	20.00	0.90
		Mort	1	4.32	0.23	6	4.33	1.39	7	8.64	0.81
	Total Cancer	Reg	11	10.09	1.09	13	16.20	0.80	24	23.32	1.03
		Mort	3	6.13	0.49	7	6.11	1.15	10	12.23	0.82
0–24	Leuk	Reg	6	3.59	1.67	8	5.21	1.53	14	8.81	1.59
		Mort	2	4.46	0.45	6	3.95	1.52	8	8.42	0.95
	Other Cancers	Reg	10	14.04	0.71	19	16.24	1.17	29	30.27	0.96
		Mort	2	7.91	0.25	11	7.19	1.53	13	15.09	0.86
	Total Cancer	Reg	16	17.63	0.91	27	21.45	1.26	43	39.09	1.10
		Mort	4	12.38	0.32	17	11.14	1.53	21	23.51	0.89
Control areas											
Age	Diagnosis		1961[2]–1970			1971–1980			TOTAL[3]		
			Obs	Exp[1]	Ratio	Obs	Exp[1]	Ratio	Obs	Exp[1]	Ratio
0–9	Leuk	Reg	2	2.08	0.96	6	2.78	2.16	8	4.86	1.65
		Mort	1	2.42	0.41	2	1.90	1.05	3	4.32	0.70
	Other Cancers	Reg	6	4.77	1.26	7	4.34	1.61	13	9.12	1.43
		Mort	5	3.27	1.53	3	2.48	1.21	8	5.75	1.37
	Total Cancer	Reg	8	6.86	1.17	13	7.12	1.83	21	13.98	1.50
		Mort	6	5.68	1.06	5	4.39	1.14	11	10.09	1.09
10–24	Leuk	Reg	1	1.28	0.78	3	1.88	1.60	4	3.17	1.26
		Mort	1	1.77	0.56	3	1.68	1.79	4	3.45	1.16
	Other Cancers	Reg	7	8.98	0.78	8	11.01	0.73	15	19.98	0.75
		Mort	1	4.40	0.23	4	4.30	0.93	5	8.69	0.58
	Total Cancer	Reg	8	10.24	0.78	11	12.90	0.85	19	23.16	0.82
		Mort	2	6.19	0.32	7	5.96	1.17	9	12.13	0.74
0–24	Leuk	Reg	3	3.36	0.89	9	4.66	1.93	12	8.03	1.50
		Mort	2	4.19	0.95	5	3.58	1.40	7	7.77	0.90
	Other Cancers	Reg	13	13.75	0.95	15	15.35	0.98	28	29.10	0.96
		Mort	6	7.67	0.78	7	6.78	1.03	13	14.44	0.90
	Total Cancer	Reg	16	17.10	0.94	24	20.02	1.20	40	37.14	1.08
		Mort	8	11.87	0.67	12	10.35	1.16	20	22.22	0.90

1 Expected numbers (Exp) to 2 decimal places.
2 1959 for mortality data
3 Total time period=1961–1980 for registration; 1959–1980 for mortality

Table A1.6 Observed and Expected Cancer Registration and Mortality in Areas with one third of the Population within 10 miles of AWRE Aldermaston.

Installation area											
Age	Diagnosis		1961[2]–1970			1971–1980			TOTAL[3]		
			Obs	Exp[1]	Ratio	Obs	Exp[1]	Ratio	Obs	Exp[1]	Ratio
0–9	Leuk	Reg	16	18	0.88	35	24	1.47*	51	42	1.21
		Mort	10	22	0.46	19	16	1.16	29	28	0.77
	Other Cancers	Reg	38	42	0.91	61	37	1.63**	99	79	1.25*
		Mort	20	29	0.68	33	21	1.55*	53	61	0.87
	Total Cancer	Reg	54	60	0.90	96	61	1.57**	150	121	1.24*
		Mort	30	51	0.59	52	38	1.38*	82	89	0.93
10–24	Leuk	Reg	12	11	1.06	19	16	1.16	31	28	1.11
		Mort	15	16	0.94	11	15	0.76	26	30	0.86
	Other Cancers	Reg	92	77	1.18	127	95	1.35**	219	172	1.27**
		Mort	34	45	0.89	34	33	0.93	68	79	0.86
	Total Cancer	Reg	104	89	1.17	146	111	1.32**	250	200	1.25**
		Mort	49	61	0.80	45	48	0.99	94	109	0.86
0–24	Leuk	Reg	28	30	0.95	54	40	1.34	82	70	1.17
		Mort	25	38	0.67	30	31	0.98	55	68	0.81
	Other Cancers	Reg	130	120	1.09	188	132	1.42**	318	251	1.27*
		Mort	54	67	0.80	67	58	1.16	121	126	0.96
	Total Cancer	Reg	158	150	1.06	242	172	1.41**	400	321	1.25**
		Mort	79	105	0.75	97	89	1.09	176	194	0.91
Control areas											
Age	Diagnosis		1961[2]–1970			1971–1980			TOTAL[3]		
			Obs	Exp[1]	Ratio	Obs	Exp[1]	Ratio	Obs	Exp[1]	Ratio
0–9	Leuk	Reg	8	16	0.52	27	19	1.43	35	34	1.01
		Mort	16	19	0.85	20	13	1.53	36	32	1.13
	Other Cancers	Reg	40	35	1.13	47	30	1.58**	87	65	1.34**
		Mort	32	25	1.28	19	17	1.12	51	42	1.21
	Total Cancer	Reg	48	51	0.94	74	49	1.52**	122	99	1.23**
		Mort	48	44	1.09	39	30	1.30	87	74	1.18
10–24	Leuk	Reg	9	12	0.76	17	15	1.14	26	27	0.97
		Mort	11	17	0.64	18	13	1.35	29	30	0.96
	Other Cancers	Reg	105	87	1.21	101	89	1.14	206	175	1.17
		Mort	38	44	0.86	27	34	0.79	65	78	0.83
	Total Cancer	Reg	114	99	1.16	118	104	1.14	232	203	1.14
		Mort	49	61	0.80	45	48	0.94	94	109	0.87
0–24	Leuk	Reg	17	27	0.62	44	34	1.30	61	62	0.99
		Mort	27	36	0.75	38	26	1.44	65	62	1.05
	Other Cancers	Reg	145	122	1.19	148	119	1.25	293	240	1.22
		Mort	70	69	1.01	46	51	0.90	116	120	0.96
	Total Cancer	Reg	162	149	1.09	192	153	1.26**	354	302	1.17**
		Mort	97	105	0.93	84	78	1.08	181	182	0.99

1. Expected numbers (Exp) rounded to two significant figures
2. 1959 for mortality data
3. Total time period: 1961–1980 for registration, 1959–1980 for mortality

* $p<0.05$ (two sided test)

** $p<0.01$ (two sided test)

A1.32 Table A1.6 also gives the results for "total cancer" (including leukaemia) in the same area. These results show significant excesses for incidence for both the 0–9, 10–24 and combined 0–24 year age groups in the installation area for the total period 1961–1980; this is due to excesses in the 0–9, 10–24, and 0–24 year age groups for the later time period 1971–1980. However, the controls for this area also show significant incidence ratios for the later time period (1971–1980) for the 0–24 year age groups; this is due to an excess in the 0–9s.

A1.33 If leukaemia is excluded from all cancers to give "other cancers" the incidence ratios for the installation area are still significantly raised for the 0–9, 10–24 and combined 0–24 years for the whole time period but again this is due mainly to excesses in each age group in the later period 1971–1980. The control areas show significant incidence ratios for other cancers in the age group 0–9 for the total time period; this is largely due to an excess in the later time period 1971–1980.

COMPARISON OF ROMAN *ET AL* AND OPCS RESULTS

A1.34 The time limits of the OPCS investigation (1961–1980) were quite different from that of Roman *et al*, so case by case collation was not possible. However, at the Committee's request, Roman *et al* rearranged their data according to the geographical boundaries and age limits used by OPCS. It was then possible to compare leukaemia registratioin rates for the age group 0–9 in the 1971–1980 OPCS data, with the Roman *et al* results for 1972–85. The registration ratios within 10 miles of the nuclear installations were similar; 1.46 from OPCS and 1.40 from Roman *et al* (see table A1.7.)

Table A1.7 Registrations of leukaemia in children aged 0–9 in the local authority areas having at least one third of their population living within 10 miles of AWRE Aldermaston.

Source	Time period	No. of leukaemia registrations			
		Observed	Expected	Registration ratio	95% confidence interval
OPCS	1971–1980	35	23.9	1.46	1.0–2.0
Roman *et al*	1972–1980	31	22.1	1.40	1.0–2.1

A1.35 The findings of the OPCS studies are consistent with those of Roman *et al* and also those of the CCRG data although different areas, time periods and age groups were considered.

VALIDITY OF THE DATA

A1.36 These three studies compared leukaemia and other childhood cancer registrations in the vicinity of the two nuclear installations, with registration rates measured elsewhere. We must therefore consider the accuracy of the local registration data, the accuracy and appropriateness of the population figures used to calculate the rates and the accuracy and suitability of the national and regional registration rates with which the local measures were compared.

i. Registration

A1.37 In the Roman *et al* study, the cases of leukaemia identified in the West Berkshire, and the Basingstoke and North Hampshire Health Authorities, during the years 1972 to 1985, were exhaustively cross-checked. The Roman *et al* study included 89 children aged 0 to 14 registered with leukaemia during this time and within the boundaries of the two DHAs, from a total of 93 cases identified by the researchers. Fifty-eight were first diagnosed at the Royal Berkshire Hospital (56 living in West Berkshire and 2 in the Basingstoke and North Hampshire Districts) while 27 were first diagnosed at Basingstoke District Hospital (25 living in

Basingstoke and North Hampshire and 2 in the West Berkshire District Health Authorities). Eight additional children (6 resident in West Berkshire and 2 in Basingstoke and North Hampshire) were identified through enquiries at clinics in adjacent areas. This brought the total to 93. However, cross-checking with the national registration scheme showed that 4 of the 93 had not been registered for inclusion within national statistics and these 4 cases were therefore excluded. This left 89 registered cases of leukaemia as the basis of the comparison with national and regional registration rates.

A1.38 It should be noted that this extensive cross-checking had not been done for the national and regional registration rates based on OPCS data used to derive "expected" values, neither could there be such cross-checking in the OPCS study.

A1.39 The CCRG used the National Registry of Childhood Tumours which is based on the National Cancer Registration Scheme but has a greater degree of validation and cross-checking than is possible for the majority of tumours included in the scheme. Both the observed and expected numbers are based on these data. Thus a comparison of these values will be more consistent than comparing cross-checked observed rates with general rates based on OPCS data.

ii. Population Data

A1.40 For the Roman *et al* study and the CCRG analysis, the estimated numbers of children in successive 5–year age-bands in the two Health Districts, and the distribution of these numbers across the 85 electoral wards of West Berkshire and the 58 electoral wards of Basingstoke and North Hampshire, were based primarily on the 1981 census. OPCS also supplies inter-censal annual population estimates for each district. These can be used to derive annual estimates for individual wards. These results are thought to be sufficiently accurate for the purposes of making comparisons between groups of electoral wards.

iii. Allocation of Cases

A1.41 For the OPCS study, cases were allocated to local authority areas. The whole local authority area was then allocated to the relevant zone but without knowledge whether the actual residences of the cases were within the zone. For the purposes of this analysis, the CCRG allocated the cases in the same way as the Roman *et al* study. Allocation of cases in the Roman *et al* study and for the CCRG analysis could not be made on an individual basis; instead the whole population within an entire electoral ward was regarded as being inside or outside the drawn circles.

HARWELL

A1.42 Harwell is just beyond the northern boundary of the West Berkshire Health Authority. In the Roman *et al* study electoral wards in West Berkshire that had half or more of their area within 10 km of Harwell were included as electoral wards "within 10 km of a nuclear installation". Roman *et al* explained in their report that they did not extend their area northwards, to include the whole of the area around Harwell because they knew that other investigators were studying this area. The authors concluded that the inclusion or the exclusion of the Harwell sector which falls within West Berkshire makes no material difference to their conclusions.

A1.43 At our request the CCRG have provided us with data on the incidence of leukaemia and other tumours in the age group 0–14 in the vicinity of Harwell. CCRG considered the area defined as having all wards with at least half the area within 10 km of Harwell, and the time period 1971–1982. These data are shown in Table A1.8. It can be seen that for the age group 0–14 the observed number of cases of childhood leukaemia near Harwell does not differ from the expected value derived from national rates (O=4, E=5.87, registration ratio 0.68.) For childhood cancer other than leukaemia in the age group 0–14, there were 15 cases observed, compared with 11.47 expected on the basis of national rates (registration ratio 1.31, $p>0.05$). For other cancers in the age group 10–14 there were 8 cases observed compared with 3.53 expected (registration ratio 2.26, $p<0.05$). In the age groups 0–4 and 5–9 the observed cases of other cancers did not differ from expected values.

Table A1.8 Registration of leukaemia and other cancers in the wards with at least half their area within 10 km of AERE Harwell for 1971–1982.

Age	Diagnosis	Number of registrations		Registration Ratio
		Observed	Expected[1]	
0–4	leukaemia	3	3.05	0.98
	other cancers	5	4.75	1.05
	Total cancer	8	7.80	1.03
5–9	leukaemia	0	1.68	—
	other cancers	2	3.19	0.63
	Total cancer	2	4.86	0.41
10–14	leukaemia	1	1.13	0.88
	other cancers	8	3.53	2.26*
	Total cancer	9	4.67	1.93*
0–14	leukaemia	4	5.87	0.68
	other cancers	15	11.47	1.31
	Total cancer	19	17.34	1.10

1. The expected numbers are based on Childhood Cancer Research Group incidence rates for England and Wales 1971–1980.

* $P<0.05$ (one sided tests)

MEASURED DISCHARGES OF RADIOACTIVITY AND ESTIMATES OF THE DOSES RECEIVED BY THE LOCAL POPULATION LIVING AROUND AWRE ALDERMASTON, ROF BURGHFIELD AND AERE HARWELL

INTRODUCTION

A2.1 This Annex summarises the data considered by COMARE on the levels of discharge of radionuclides from the Atomic Weapons Research Establishment (AWRE) at Aldermaston, the Royal Ordnance Factory (ROF) at Burghfield and the Atomic Energy Research Establishment (AERE) at Harwell. Monitoring data on levels of radionuclides in the environment around these three sites are also examined. Finally, it considers estimated doses, calculated from the discharge data, that may be received by members of the public living near each of the sites.

A2.2 In order to obtain this information COMARE asked the National Radiological Protection Board (NRPB) to provide estimates of the radiation doses to members of the public living in the area surrounding the sites. The Ministry of Defence (MoD) and United Kingdom Atomic Energy Authority (UKAEA) have informed us that they have provided the NRPB with complete records, on an annual basis, of the airborne and liquid radioactive discharges from AWRE Aldermaston, ROF Burghfield and AERE Harwell since they were established. NRPB have used this information to estimate doses to members of the public living at various distances up to 20 kilometres (20 km) from each site. These dose estimates have been published in full detail in the NRPB report R202.[8]

A2.3 We are grateful to the NRPB for undertaking this work for us and also to the MoD and UKAEA for making their data available. The NRPB have also carried out calculations of the estimates of radiation doses received by the general population around AWRE Aldermaston, ROF Burghfield and AERE Harwell from sources other than discharges of radionuclides from these sites. These sources are

(i) natural radiation
(ii) nuclear fallout from atmospheric testing of atomic weapons and
(iii) medical procedures.

The methods of dose assessment have been described in detail in the NRPB report R202.[8]

A2.4 Some of our members visited AWRE Aldermaston on two occasions, on 14th September and 30th November 1987. This enabled us to see the geographical area and the operations on the site. We would like to thank the Ministry of Defence for enabling us to make these visits.

A2.5 COMARE was informed by the Ministry of Defence (MoD) that the research and development section of the UK nuclear defence programme was established at AWRE Aldermaston following the Second World War and that radionuclides have been discharged from the site since 1952. The majority of these discharges arise from work on the design and development of warheads for nuclear weapons. There are also very small amounts of radioactive material discharged from a small research reactor at the site.

A2.6 The Royal Ordnance Factory at Burghfield is used for the assembly of nuclear weapons. This site has given rise to low levels of atmospheric discharges since 1970 and to liquid discharges since 1962. Discharge data have been provided for each year since this time by MoD. The discharges of radioactive materials from this site are considerably lower than those arising from the AWRE site at Aldermaston.

A2.7 The Atomic Energy Research Establishment (AERE) Harwell has discharged radioactive material to the air and to the River Thames since 1947. This has arisen from a number of research facilities including research reactors. Discharge data were provided to NRPB by AERE Harwell.

DISCHARGE DATA

Atmospheric Discharges

Atomic Weapons Research Establishment (AWRE) Aldermaston

A2.8 Atmospheric discharges of radioactive material arise from 73 of the 81 ventilation stacks at Aldermaston. These discharges are essentially continuous and consist mainly of uranium and plutonium, both giving rise to high LET alpha particles, and tritium (a low energy beta emitter). Annual discharges of plutonium and uranium have been in the ranges 2.5 x 10^{-2} to 1.0×10 Megabecquerels (MBq) and 1.5×10^{-1} to 2×10^{2} MBq

Table A2.1 Airborne radioactive material discharged from AWRE Aldermaston 1952–1986

	Alpha emitters		*Beta emitters*			
	Pu[1]	U	Other alpha	Beta[2]	Tritiated material	Krypton-85[3]
Year	MBq	MBq	MBq	MBq	TBq	TBq
1952	0.025	0	0.03	0	0	
1953	0.5	0.15	0.1	0	0	
1954	0.5	4	0.25	0	0	
1955	1	80	0.5	0	0	
1956	2	150	1.5	0	0	
1957	4	150	0.8	10	0	
1958	5	200	1	15	0	
1959	8	200	0.6	30	5	
1960	4	200	0.2	8	80	
1961	2.5	100	0.03	10	30	
1962	2	80	0.02	25	20	
1963	2	40	0.03	50	40	
1964	1.5	150	0.1	15	25	
1965	2.5	150	0.01	5	80	
1966	2.5	80	0.06	20	60	
1967	3	40	0.01	400	100	
1968	5	60	0.02	25	150	
1969	5	50	0.01	20	200	
1970	2.5	30	0.01	20	250	
1971	2.5	30	0.01	20	300	
1972	2.5	50	0.01	20	500	
1973	3	60	0.01	20	400	
1974	1.5	40	0.01	20	500	
1975	2.5	30	0.01	20	400	
1976	1.5	30	0.01	20	400	
1977	10	30	0.02	20	400	
1978	0.6	6	0.03	20	400	
1979	1.5	10	0.01	20	250	
1980	1.5	15	0.01	20	200	
1981	1	15	0.02	20	150	0.3
1982	1.5	30	0.01	20	200	0.3
1983	0.6	10	0.02	20	150	0.3
1984	0.8	6	0.01	20	150	0.3
1985	0.4	1.5	0.006	50	100	0.3
1986(*)	0.3	1	0.004	30	80	0.3

[1] Excluding ^{241}Pu
[2] Excluding tritium
[3] First released 1981.
(*) Interim data

respectively. The corresponding values for tritium were 5×10^6 to 5×10^8 MBq. Since 1981 approximately 0.3 Terabecquerels (TBq) per annum of krypton-85 have been released to atmosphere. Full details are given in Table A2.1.

Table A2.2 Annual discharges of radionuclides to atmosphere from AERE, Harwell

	Discharge, MBq y^{-1}			
Year	^{3}H	^{14}C	$^{41}Ar^{1}$	^{239}Pu
1947	0.0	0.0	1.1 10^7	3.7 10
1948	0.0	0.0	1.0 10^{10}	3.7 10
1949	0.0	0.0	1.0 10^{10}	3.7 10
1950	0.0	0.0	1.0 10^{10}	3.7 10
1951	0.0	0.0	1.0 10^{10}	3.7 10
1952	0.0	0.0	1.0 10^{10}	3.7 10
1953	0.0	0.0	1.0 10^{10}	3.7 10
1954	0.0	0.0	1.0 10^{10}	3.7 10
1955	0.0	0.0	1.0 10^{10}	3.7 10
1956	3.7 10^6	1.1 10^5	1.0 10^{10}	3.7 10
1957	7.4 10^6	2.2 10^5	1.0 10^{10}	3.7 10
1958	7.4 10^6	2.2 10^5	1.0 10^{10}	3.7 10
1959	7.4 10^6	2.2 10^5	1.0 10^{10}	3.7 10
1960	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1961	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1962	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1963	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1964	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1965	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1966	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1967	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1968	7.4 10^6	2.2 10^5	1.6 10^{10}	3.7 10
1969	7.4 10^6	2.2 10^5	1.3 10^8	3.7 10
1970	7.4 10^6	2.2 10^5	1.2 10^8	3.7 10
1971	7.4 10^6	2.2 10^5	1.2 10^8	3.7 10
1972	7.4 10^6	2.2 10^5	1.2 10^8	3.7 10
1973	7.4 10^6	2.2 10^5	1.2 10^8	3.7 10
1974	7.4 10^6	2.2 10^5	1.2 10^8	3.7 10
1975	7.4 10^6	2.2 10^5	1.2 10^8	3.7 10
1976	7.4 10^6	2.2 10^5	7.3 10^7	3.7 10
1977	2.1 10^7	2.2 10^5	1.7 10^8	3.7 10
1978	3.7 10^7	2.2 10^5	1.4 10^8	3.7 10
1979	3.5 10^7	2.2 10^5	9.6 10^7	3.7 10
1980	1.6 10^7	2.2 10^5	1.3 10^8	3.7 10
1981	2.1 10^7	2.2 10^5	1.6 10^8	3.7 10
1982	2.4 10^7	2.2 10^5	2.0 10^8	3.7 10
1983	1.2 10^8	2.2 10^5	1.3 10^8	3.7 10
1984	8.8 10^7	2.2 10^5	1.9 10^8	3.7 10
1985	8.8 10^7	2.2 10^5	1.9 10^8	3.7 10

[1] Includes 1.0 10^{10}MBq y^{-1} in 1948–59 and 1.6 10^{10}MBq y^{-1} in 1960–1968 from the BEPO reactor at a stack height of 60m.

A2.9 The levels of discharges were frequently very low and on occasions they were indistinguishable from the levels of background radiation. When this was the case, the reported level of discharge would be over-estimated as the level of detection was always recorded as having been discharged. In 1978, Sir Edward Pochin carried out an investigation into on site practices in the context of radiation protection.[9] During the course of his enquiry it was discovered that five of the stack discharge monitors were incorrectly mounted, resulting in a small under-estimation of releases. However, the Pochin Report concluded that this would not have resulted in an appreciable under-estimate of the total discharge data, since the affected stacks contributed very little to the total airborne discharges from the site.

A2.10 It was noted at the site visit that air discharges from the main depleted uranium plants were not filtered until recently; even so the discharges were well within the authorised limits and the use of filters has reduced these discharges even further. The highly enriched uranium plant discharges have always been filtered. The figures provided to COMARE on uranium discharges included these unfiltered discharges.

ROF Burghfield

A2.11 Atmospheric discharges arise from two stacks and consist of the low energy beta emitter tritium. MoD assured COMARE that up to 1987 no alpha or beta emitting materials other than tritium could be detected in the monitored discharges. Annual discharges of tritium were in the range 4×10^3 to 6×10^4 MBq. Since 1987 approximately 0.5 TBq of krypton-85 has been discharged to the atmosphere.

AERE Harwell

A2.12 The principal radionuclides discharged to the atmosphere from this site are argon-41, carbon-14, plutonium-239 and tritium. The annual amounts discharged are approximately 10^8 MBq argon-41 (10^{10} MBq before 1968), 2.2×10^5 MBq carbon-14, 37 MBq of plutonium-239 and 10^7 MBq of tritium. Details of atmospheric discharges are given in table A2.2.

Liquid discharges

AWRE Aldermaston

A2.13 Liquid waste is discharged after treatment from AWRE Aldermaston via an 11 km pipeline which enters the River Thames at Purley, downstream from Pangbourne. The discharge point from this pipeline is shown in Figure A2.1 and is marked D2. Annual discharges of alpha emitters (mostly plutonium) have been in the range of 6.0×10 to 8.0×10^3 MBq. Tritiated material was first released in 1965 and the annual discharge levels of tritiated material have been in the range of 8×10^4 to 8×10^5 MBq. Annual discharges of other beta emitters have been in the range 1×10^2 to 1×10^4 MBq.

A2.14 In addition, there is some release of material as "trade waste" to the local sewage works which after dilution and further treatment, is discharged to a river section of the Kennet and Avon navigational system which flows into the River Thames. The discharge point, D3 is shown in Figure A2.1. These releases have been in the ranges 3 x 10 to 3 x 10^2 MBq per year for alpha emitters and 8 x 10 to 8 x 10^2 MBq per year for beta emitters. Full details are given in Tables A2.3 and A2.4. COMARE have been informed that the local population do not obtain their drinking water from the River Thames into which discharges are made and the Department of the Environment (DoE) have assured the Committee that there had been no changes in the sources of water throughout the period of interest (i.e. since 1952). The principal points of water abstraction for the local population are shown in Figure A2.1 and marked as A1, A2, B1 and B2. B1 and B2 are borehole pumping stations.

Figure A2.1
Locations of nuclear sites

A1 Culham } Surface water abstraction for { Abingdon and Dorchester
A2 Fobney } { Reading

B1 Ufton Nervet pumping station
B2 Mortimer pumping station

D1 AERE Harwell } pipeline discharge point
D2 AWRE Aldermaston }

D3 AWRE Aldermaston and ROF Burghfield discharge point via sewage point

Table A2.3 Treated radioactive liquidborne effluent to R Thames near Pangbourne from AWRE Aldermaston 1952–1986

Year	Alpha (MBq)	Beta[1] (MBq)	Tritiated material (GBq)
1952	60	100	0
3	1000	400	0
4	3000	1000	0
5	6000	1500	0
6	5000	1500	0
7	8000	2500	0
8	6000	400	0
9	5000	500	0
1960	2500	400	0
1	3000	300	0
2	3000	500	0
3	2000	1000	0
4	2000	3000	0
5	2000	5000	800
6	2500	10000	400
7	2000	5000	800
8	4000	5000	500
9	4000	4000	250
1970	3000	2500	150
1	1000	2500	150
2	1000	2500	150
3	500	2500	200
4	400	3000	150
5	300	300	200
6	800	1000	200
7	600	1500	100
8	150	300	80
9	150	300	50
1980	200	500	80
1	150	300	100
2	200	300	800
3	80	500	80
4	100	300	100
5	80	250	200
1986(*)	150	250	100

(*) Interim data
[1] Excluding tritium and ^{241}Pu.

Table A2.4 Treated trade waste radioactive landborne effluent to sewer, thence to Silchester Sewage Works, Foudry Brook, R Kennet and R Thames from AWRE Aldermaston 1952–1986

Year	Alpha[1] (MBq)	Beta[1] (MBq)
1958	30	80 (Sept-Dec)
9	200	300
1960	200	800
1	300	600
2	250	300
3	150	600
4	150	500
5	100	400
6	100	400
7	150	400
8	200	300
9	250	400
1970	250	400
1	300	500
2	200	500
3	100	500
4	150	600
5	100	400
6	80	400
7	100	800
8	100	500
9	80	500
1980	80	400
1	80	400
2	80	400
3	50	300
4	50	300
5	60 [2,3]	300 [2,3]
1986(*)	80	500

Notes:

[1] The activities shown in this Table are those recorded for Discharge Record purposes but actually may be much lower, since they are in most cases at the lower limits of measurement.

[2] A detailed analysis of the raw data used to calculate the official waste disposal returns showed that the average level of radioactivity in the effluent for the whole of 1985 was indistinguishable statistically from the background (see [3] below).

[3] Aliquots of the liquid discharges were bulked on a fortnightly basis during 1985 and more sensitive analysis techniques applied. The results of these analyses, and similar analyses of the local tap water, indicate the amount of additional alpha activity discharged to be about five, and additional beta activity ten, times less than the reported and recorded levels.

[4] Interim data

Liquid Discharges from ROF Burghfield

A2.15 The liquid discharges that occur from ROF Burghfield are from low activity sources such as washing water and are similar to the "trade waste" discharges from AWRE Aldermaston. These are treated in a similar fashion and discharged via the sewage works (D3 on Figure A2.1). The levels of discharge are at the minimum detectable level.

AERE Harwell

A2.16 Discharges of treated liquid wastes are made into the River Thames at Sutton Courtney (D1 in Figure A2.1). These discharges are dealt with under three categories: Low level effluent, tritium and trade wastes (see Table A2.5). Annual discharges of alpha emitters in low level effluent have been in the range 2.6 x 10 to 1.9 x 10^3 MBq and in trade wastes 8.9 x 10 to 2.6 x 10^2 MBq. Detectable levels of tritiated material were first released in 1964 and the annual discharge levels have been in the range of 8.5 x 10^5 to 5.6 x 10^6 MBq. Annual discharges of other beta emitters in low level effluent have been in the range 7.4 x 10 to 8.5 x 10^5 MBq and in trade wastes 9.6 x 10 to 7.4 x 10^3 MBq.

Table A2.5 Discharges to Thames from AERE Harwell

Year	*Low level Effluent*		*Tritium*	*Trade Wastes*	
	Alpha (MBq)	*Beta (MBq)*	*(MBq)*	*Alpha (MBq)*	*Beta (MBq)*
1948	25.9	74	0		
1949	247.9	3256	0		
1950	281.2	7363	0	Included in low level Effluent	
1951	847.3	12062	0		
1952	1343.1	25937	0		
1953	945.6	39997	0		
1954	1287.6	62160	0		
1955	569.8	96348	0	259	4144
1956	810.3	107330	0	88.9	4625
1957	481.0	168979	0	103.6	4477
1958	625.3	411625	0	199.8	5254
1959	743.7	849039	0	159.1	555
1960	477.3	337255	0	173.9	4070
1961	492.1	139416	0	255.3	1813
1962	743.7	55167	0	214.6	1369
1963	754.8	32745	0	251.6	1443
1964	584.6	43438	5624000	288.6	1406
1965	455.1	47730	4255000	481.0	2849
1966	529.1	34669	3071000	414.4	2220
1967	259.0	80697	1776000	203.5	1332
1968	314.5	156842	2849000	144.3	2257
1969	654.9	155622	1665000	136.9	7363
1970	728.9	120324	2294000	270.1	2405
1971	714.1	146520	3034000	185.0	2553
1972	529.1	157324	1721000	222.0	3404
1973	299.7	107411	3256000	185.0	2405
1974	177.6	46139	2627000	159.1	1073
1975	358.9	77441	3626000	218.3	2368
1976	543.9	40811	3145000	155.4	1073
1977	543.9	82769	3515000	114.7	1295
1978	462.5	28860	1850000	166.5	1776
1979	1065.6	35816	1776000	173.9	1665
1980	1853.7	67451	1254000	255.3	2220
1981	643.8	18389	851000	247.9	1295
1982	647.5	11470	1369000	111.0	1036
1983	526.4	12395	3256000	140.6	1073
1984	703.0	8325	1739000	107.3	962

Accidental Releases

AWRE Aldermaston

A2.17 At the request of COMARE, the AWRE have carried out a survey of all reported incidents involving radioactive material which led to any investigation (either a formal enquiry or an internal study or report) at the site since 1956. The Committee was told that the majority of these incidents could only have had on-site effects. In cases where there was any doubt about the possibility of off-site consequences the accident reports were re-examined by AWRE. In all cases the MoD has assured COMARE that they were found to have insignificant off-site consequences. Any estimated discharges arising from such events were included by MoD in the total annual discharge data referred to earlier in this report.

Integrity of AWRE Discharge Pipeline

A2.18 A leak from the pipeline discharging liquid waste from AWRE Aldermaston could cause contamination of the adjacent land and result in a hazard to those living in the local area. COMARE was concerned to examine this possibility. In response the following information was provided by the MoD.

A2.19 AWRE has a twin pipeline; to allow maintenance to be carried out, the flow can be switched between them. There is a standing head of water in each pipeline and any leak would cause this level to fall. The pipelines are inspected regularly in two ways. They are examined both externally by AWRE staff and internally by an independent company using automated inspection equipment All of these tests indicate that the pipeline has continued in first class condition.

A2.20 No defects in the pipeline causing it to leak have been found. However, in December 1987, faulty completion of a maintenance operation that occurs very infrequently, caused a sampling valve to be left partially open and resulted in discharge of some low level radioactive waste effluent to public land when the adjoining part of the line was being refilled with clean water. The alpha activity dispersed from residual activity within the pipeline was estimated to amount to 0.2MBq, with small amounts of associated tritiated material. These quantities were well below the amount which is required by legislation to be notified to Regulatory Authorities. Nevertheless, action was taken to retrieve much of the discharged material and measurements afterwards of the activity levels in soils and sediments in the area of the release, show that they are close to natural background and have no radiological impact on the public. No further decontamination or restrictive use of the area has been shown to be necessary. Action is being taken to improve the procedures for inspection and sensitivity of leak detection following routine maintenance so as to provide assurance of pipeline integrity before re-use.

ROF Burghfield

2.21 Any potential contribution to the total discharge data from accidental releases has been considered in a similar fashion to those described for the Aldermaston site. All incidents involving radioactive materials which have led to any enquiry have been re-examined by MoD. They found no evidence for any off-site consequences resulting from any on-site incident.

AERE Harwell

A2.22 UKAEA and NRPB have reviewed the discharge data used in the NRPB assessment of doses to the public around Harwell. A number of small releases were identified which were not included in the original assessment. However, NRPB conclude that there is no significant radiological impact of these releases on the local population.

ENVIRONMENTAL MONITORING DATA

A2.23 A monitoring programme to detect airborne levels of radioactivity has been carried out around AWRE Aldermaston since 1972 by the Ministry of Agriculture, Fisheries and Food (MAFF). An array of passive deposition collectors, located at fixed positions around the AWRE site, is used to trap airborne radionuclides. This programme was established to provide an independent monitoring capability, and such detectors are used by MAFF around most UK nuclear establishments. Although these methods are not fully quantitative in that they do not give a precise measurement of the actual levels present, they do provide very useful data for assessing trends and have proved sensitive indicators of airborne activity. The main reason for variations in general levels of radioactivity at a particular site is considered to be due to variations in levels due to nuclear fallout resulting from weapons testing worldwide and peaks due to specific tests can be detected. DoE and MAFF inspectors have access to areas of the site associated with discharges. A formal DoE/MAFF inspection is carried out twice a year. This practice has been in use for 33 years. The site is also subject to inspection by the HSE. Inspectors may visit any part of the establishment. The question of notice and day to day access is subject to agreements with the departments concerned.

A2.24 The NRPB informed us that the activity detected around Aldermaston has not revealed any exceptional pattern. Activity due to gamma radiation followed the pattern seen at other sites in the UK and any variation in gamma activity can be attributed almost entirely to activity from weapons testing. Activity due to alpha emitters was generally very low.

A2.25 In addition, a programme of monitoring of levels of radionuclides in the environment in the vicinity of Aldermaston was initiated by the MoD following the Pochin report in 1978.[9] This, consisted of measuring the levels of alpha, beta and gamma activity and specifically uranium and tritium levels, in surface water, vegetation and soil samples taken from various locations around the AWRE site. Airborne dust levels of radioactivity were measured by detectors placed in fixed positions near the two sites of Aldermaston and Burghfield. The detailed results are given in published AWRE reports. Examples of results for 1984 are given in tables A2.6 and A2.7.

Table A2.6 MoD vegetation and soil survey (activities)*

	Vegetation		Surface Soil		Deeper Soil	
	Average	Range	Average	Range	Average	Range
Less than 500m from AWRE						
Number of samples	15		20		20	
Alpha (kBq/kg)	0.01	0.001-0.02	0.4	0.08–0.7	0.5	0.2–0.7
Beta (kBq/kg)	0.1	0.03–0.2	0.5	0.07–1.1	0.6	0.1–0.9
Uranium (Bq/kg)	0.4	0.03–2.0	30	3–50	40	25–30
Tritium (kBq/m^3)	80	40–190	50	40–170	50	40–160
Surface Activity Alpha (Bq/m^2)	2	0.1–6.0	360	80–640	—	—
Between 500 and 3000m from AWRE						
Number of samples	11		16		16	
Alpha (kBq/kg)	0.01	0.004–0.01	0.4	0.08–0.6	0.4	0.2–0.7
Beta (kBq/kg)	0.1	0.004–0.2	0.4	0.04–0.9	0.5	0.2–0.7
Uranium (Bq/kg)	0.6	0.03–3.0	20	3–40	30	10–50
Tritium (kBq/m^3)	40	40–80	40	40–50	40	40–60
Surface Activity Alpha (Bq/m^2)	2	0.4–4.0	400	110–580	—	—

* No sample indicated gamma activity that was significantly higher than the detection limit.

Table A2.7 MoD passive airborne dust survey

Sample array	Number of Samplers	Gross Alpha		Gross Beta	
		Average	Range	Average	Range
AWRE Boundary	18				
Total Activity (Bq)		0.5	0.3–1.3	2.7	1.0–4.3
Concentration (kBq/kg)		1.1	0.1–1.5	5.0	3.4–6.3

Radiochemical Analysis of Bulked Airborne Dust, (kBq/kg)

	Total Uranium		Total Plutonium	
	Average	Range	Average	Range
AWRE Boundary	0.20	0.09–0.32	0.07	0.002–0.99
Outside AWRE	0.11	0.04–0.16	0.02	0.01–0.07

Notes:
When the result obtained was below the detection limit, the figure given is that of the detection limit.

A2.26 These results did not indicate any significant increase of radioactivity levels above those due to natural background levels and to fallout from nuclear weapons testing, in the vicinity of Aldermaston and Burghfield. No significant trends were observed apart from a slightly higher tritium concentration in air, soil, vegetation and rainwater samples taken near AWRE, compared with those from more distant locations (greater than 10 miles from the site). Toxic material other than radioactive materials were monitored. Levels have been found to be very low. Members of the local rabbit population were also monitored for radiation.

Radionuclides in Soil Around AWRE Aldermaston and ROF Burghfield

A2.27 As a check on the environmental monitoring programme, COMARE asked the Department of Health to instigate a survey to measure the content of the accumulated deposition of radionuclides in the immediate vicinity of the two sites and at locations distant from the establishments. These data were to be compared with those from control sites in the South of England remote from areas close to nuclear installations. This survey was carried out by the Environmental and Medical Sciences Division of the Harwell Laboratory.

A2.28 Twelve sampling sites were chosen within 0.5 km of the boundary fences of both establishments. In addition, soil samples were collected at a single location approximately 5 km to the north-east of each establishment (that is, in the direction of the prevailing wind). Soil samples were obtained from six control grassland sites in central and southern England with rainfall similar to that of the Aldermaston area. During fieldwork around the nuclear installations, staff from AWRE were present. At each sampling site 12 soil cores of 38 mm diameter were removed to a depth of 15 cm. These samples were bulked and then composite samples were used for analysis of tritium. Half of each composite sample was given to AWRE. A further 12 cores were removed for analysis of total alpha activity, total beta activity, uranium and thorium isotopes, plutonium isotopes (Pu-238, 239, 240 and 241) and americium-241. Again half of each composite sample was given to AWRE. The results are summarised in table A2.8.

Table A2.8 Radionuclides in soil samples taken around AWRE Aldermaston and ROF Burghfield: measured by AERE Harwell

Total of 13 sites sampled. 12 within 0.5 km of boundary fences and one at 5 km from the site. Range of soil concentrations of radionuclides (to 15 cm depth) in Bq/kg dry soil§

Radionuclides	AWRE Aldermaston	No. of sites with activity greater than range of baseline sites	ROF Burghfield	No. of sites with activity greater than range of baseline sites	Controls: Baseline sites elsewhere in Great Britain
Pu-238	<0.01–0.08	3	<0.01–0.08	1	<0.01–0.02
Pu-239 + 240	0.15–0.99	2	0.11–0.38	0	0.17–0.41
Pu-241	<3.0–5.6	4	<3	0	<3
Am-241	0.05–0.34	1	<0.01–0.16	1	0.05–0.15
Tritium (Bq/litre soil water)	6–58	12	4.2–37	4	3.5–6.1*
Total No. of sites tested		13		13	6

* Excluding one site where waste disposal activities contributed to the soil concentrations of tritium.
§ The levels of uncertainties for radionuclide analyses are:
Pu-238:- 50%, Pu-239/240:- 12%, Pu-241:- 65%, Am-241:- 30% and Tritium:- 10%.

A2.29 The results confirmed the concentrations in soil of plutonium and uranium measured by the MoD environmental programme. These levels were in general low and were sometimes below the limit of detection. There were, however, several sites close to AWRE Aldermaston (within 0.5 km) and one distant site (5 km), at which the soil concentrations of the plutonium isotopes, americium-241 and tritium were slightly raised above the levels found at the control sites. Similarly, there were some sites near ROF Burghfield at which the levels of tritium were raised, and one site where the levels of plutonium 238 were slightly raised, above the concentration found in soil at the control sites.

A2.30 These results give rise to conflicting observations with regard to the possibility that the elevated levels of radionuclides found in the soil could be attributed to the activities at AWRE Aldermaston and ROF Burghfield.

(i) First, at some of the monitored sites around both installations the ratio of the level of plutonium-238 to plutonium-239/240 is higher than the ratio which would be expected from weapons test fallout. This elevated ratio is due to raised levels of plutonium-238. However, MoD have assured COMARE that no significant quantities of this plutonium isotope are used or processed at Aldermaston or Burghfield.

(ii) Secondly, at some of the sites there were slightly raised levels of plutonium isotopes and americium-241 which are known to be present in the atmospheric discharges. However, the uncertainties associated with measurements of radioactivity at such low levels, means that we cannot assess whether the levels in samples taken from near these nuclear sites are significantly above those measured in control areas remote from the installations.

We therefore cannot draw firm conclusions as to whether the slightly elevated levels of radionuclides found in soil near the nuclear installations could be attributable to the operations at these two nuclear sites. However, in terms of soil concentration and the possible resulting doses to the general public, the levels found are not considered to be of any radiological significance.

A2.31 The gamma radiation background was found to be typical for southern England and was attributable to both natural radioactivity in soil (mainly potassium-40) and weapons fallout levels of caesium-137.

Estimation of doses received by the local population

A2.32 Separate estimates of the doses received by representative individuals in the local populations in the vicinity of each of the three sites (AWRE Aldermaston, ROF Burghfield and AERE Harwell) have been made by NRPB. The results are described in detail in an NRPB report, R-202,[8] and are summarised in the following sections. The doses calculated by NRPB are the effective dose equivalents (measured in sieverts) and red bone marrow dose equivalents from external irradiation in a year and the respective committed dose equivalents from intakes in the same year. For simplicity in this annex the term dose equivalent is taken to include any committed doses from intakes of radionuclides. The effective dose equivalents provide a means of comparing risks of fatal cancers and hereditary defects from various sources of radiation exposure. The dose equivalent to the red bone marrow is considered to be the relevant quantity for comparing sources in terms of their potential to cause leukaemia.

A2.33 The doses from the principal exposure pathways were calculated by the NRPB using models of the dispersion of radionuclides in the environment and information on typical food consumption rates and inhalation rates. The calculations were based on atmospheric discharge data only, as NRPB did not consider that liquid discharges contributed to the estimate of doses to the local population, as the local population did not obtain their drinking water from the River Thames. The calculations are based on discharge data as levels of radioactivity due to discharges monitored in the environment were often indistinguishable from background levels and hence could not be used for dose calculations.

A2.34 For each site, doses were calculated to individuals representative of four age groups of the population (the fetus, children aged 1 and 10 years and adults), at a number of distances (0.5 km, 1 km, 5 km, 10 km and 20 km) from each site.

A2.35 At each of the three sites the inhalation of tritium and the ingestion of locally grown foodstuffs contaminated by tritium were included and for AERE Harwell the doses from inhalation and ingestion of carbon-14 were also assessed. These dose assessments were carried out using a specific activity model. The NRPB believe that this approach will over-estimate the intake and therefore that the calculated doses will also be over-estimates of actual doses. In addition, it was also cautiously assumed that the tritium discharges were all as tritiated water vapour. The NRPB believe that this results in the calculated doses being over-estimates, thus any calculations should err on the safe side.

A2.36 In addition the doses to the population around AWRE Aldermaston from inhalation of uranium and plutonium were also assessed. The doses due to uranium were assumed by NRPB to arise from the isotope uranium-238 and that the doses from plutonium were assumed to arise from plutonium-239. The NRPB believe that these assumptions are likely to lead to over-estimations of doses. It was also assumed that the material deposited in the lungs was absorbed into the body from this site within a few weeks (and is thus described as a "lung class W" compound) rather than over a more prolonged period; this assumption would maximise the dose to the red bone marrow. Thus the NRPB believe that these calculations would tend to produce an over-estimate of dose to the red bone marrow in the exposed population. The doses from inhalation of plutonium-239 from AERE Harwell were calculated using similar assumptions, so that again the dose received by the red bone marrow is believed to be an overestimate. AERE Harwell is the only site of the three which releases argon-41, so the doses received by exposure to argon-41 were also calculated for the Harwell area. The results obtained at the three sites are summarised in the following sections.

A2.37 Discharges of plutonium-241 are not included in table A2.1 and A2.3 of the atmospheric and liquid discharges from AWRE Aldermaston, and are not included in the main dose assessment. Plutonium-241 is predominantly a beta-emitter but decays to the alpha-emitter americium-241. NRPB were provided with data on the plutonium-241 discharges by the MoD in confidence, and considered separately the dose that would have resulted from the discharge of this radionuclide and from its daughter product, americium-241, which grows in following discharge. The NRPB have informed us that they consider that the dose from these two radionuclides would have been a few per cent of the dose from the total plutonium discharges.

Atomic Weapons Research Establishment Aldermaston

A2.38 Full details of the estimated effective dose equivalent and the dose equivalent to the red bone marrow received by the individuals representative of four population groups 5 km from the site, for the period since discharges started, are given in Tables A2.9 and A2.10. The highest estimated doses were for adults, and the lowest for the fetus. The overall trend was of increasing doses during the 1950s and 1960s reaching a peak in the 1970s, followed by a slight decline. The peak level of annual effective dose equivalent received by adults was estimated to be about 0.037 μSv and the dose equivalent to the red bone marrow was estimated as 0.039 μSv. The corresponding annual doses to the fetus and fetal bone marrow were estimated to be 0.027 μSv and 0.029 μSv respectively. In the early years, the principal radionuclides released were plutonium and uranium. However, from 1959 onwards increasing quantities of tritium were released and this was responsible for over 99% of the dose in recent years. These estimated doses may be compared with the average annual effective dose equivalent of 2200 μSv received by the general population from background radiation.

Table A2.9 Committed effective dose equivalents from AWRE, Aldermaston atmospheric discharges, at 5 km

Year	Effective dose equivalent, μSv			
	Fetus	1-year-old	10-year-old	Adult
1952	$1.4\ 10^{-9}$	$1.2\ 10^{-6}$	$2.8\ 10^{-6}$	$3.6\ 10^{-6}$
1953	$2.9\ 10^{-8}$	$2.4\ 10^{-5}$	$5.7\ 10^{-5}$	$7.2\ 10^{-5}$
1954	$2.9\ 10^{-8}$	$3.2\ 10^{-5}$	$6.7\ 10^{-5}$	$7.8\ 10^{-5}$
1955	$5.7\ 10^{-8}$	$2.0\ 10^{-4}$	$3.2\ 10^{-4}$	$2.8\ 10^{-4}$
1956	$1.1\ 10^{-7}$	$3.9\ 10^{-4}$	$6.1\ 10^{-4}$	$5.4\ 10^{-4}$
1957	$2.3\ 10^{-7}$	$4.8\ 10^{-4}$	$8.4\ 10^{-4}$	$8.3\ 10^{-4}$
1958	$2.9\ 10^{-7}$	$6.3\ 10^{-4}$	$1.1\ 10^{-3}$	$1.1\ 10^{-3}$
1959	$2.7\ 10^{-4}$	$1.1\ 10^{-3}$	$1.8\ 10^{-3}$	$1.9\ 10^{-3}$
1960	$4.3\ 10^{-3}$	$5.1\ 10^{-3}$	$6.6\ 10^{-3}$	$6.7\ 10^{-3}$
1961	$1.6\ 10^{-3}$	$2.0\ 10^{-3}$	$2.7\ 10^{-3}$	$2.7\ 10^{-3}$
1962	$1.1\ 10^{-3}$	$1.4\ 10^{-3}$	$1.9\ 10^{-3}$	$1.9\ 10^{-3}$
1963	$2.1\ 10^{-3}$	$2.5\ 10^{-3}$	$3.2\ 10^{-3}$	$3.3\ 10^{-3}$
1964	$1.3\ 10^{-3}$	$1.8\ 10^{-3}$	$2.4\ 10^{-3}$	$2.3\ 10^{-3}$
1965	$4.3\ 10^{-3}$	$5.0\ 10^{-3}$	$6.4\ 10^{-3}$	$6.5\ 10^{-3}$
1966	$3.2\ 10^{-3}$	$3.7\ 10^{-3}$	$4.8\ 10^{-3}$	$4.9\ 10^{-3}$
1967	$5.4\ 10^{-3}$	$5.9\ 10^{-3}$	$7.6\ 10^{-3}$	$7.8\ 10^{-3}$
1968	$8.0\ 10^{-3}$	$8.9\ 10^{-3}$	$1.2\ 10^{-2}$	$1.2\ 10^{-2}$
1969	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$	$1.5\ 10^{-2}$	$1.6\ 10^{-2}$
1970	$1.3\ 10^{-2}$	$1.5\ 10^{-2}$	$1.8\ 10^{-2}$	$1.9\ 10^{-2}$
1971	$1.6\ 10^{-2}$	$1.7\ 10^{-2}$	$2.2\ 10^{-2}$	$2.3\ 10^{-2}$
1972	$2.7\ 10^{-2}$	$2.9\ 10^{-2}$	$3.6\ 10^{-2}$	$3.7\ 10^{-2}$
1973	$2.1\ 10^{-2}$	$2.3\ 10^{-2}$	$2.9\ 10^{-2}$	$3.0\ 10^{-2}$
1974	$2.7\ 10^{-2}$	$2.9\ 10^{-2}$	$3.6\ 10^{-2}$	$3.7\ 10^{-2}$
1975	$2.1\ 10^{-2}$	$2.3\ 10^{-2}$	$2.9\ 10^{-2}$	$3.0\ 10^{-2}$
1976	$2.1\ 10^{-2}$	$2.3\ 10^{-2}$	$2.9\ 10^{-2}$	$3.0\ 10^{-2}$
1977	$2.1\ 10^{-2}$	$2.3\ 10^{-2}$	$3.0\ 10^{-2}$	$3.1\ 10^{-2}$
1978	$2.1\ 10^{-2}$	$2.3\ 10^{-2}$	$2.9\ 10^{-2}$	$3.0\ 10^{-2}$
1979	$1.3\ 10^{-2}$	$1.4\ 10^{-2}$	$1.8\ 10^{-2}$	$1.9\ 10^{-2}$
1980	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$	$1.5\ 10^{-2}$	$1.5\ 10^{-2}$
1981	$8.0\ 10^{-3}$	$8.6\ 10^{-3}$	$1.1\ 10^{-2}$	$1.1\ 10^{-2}$
1982	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$	$1.5\ 10^{-2}$	$1.5\ 10^{-2}$
1983	$8.0\ 10^{-3}$	$8.6\ 10^{-3}$	$1.1\ 10^{-2}$	$1.1\ 10^{-2}$
1984	$8.0\ 10^{-3}$	$8.6\ 10^{-3}$	$1.1\ 10^{-2}$	$1.1\ 10^{-2}$
1985	$5.4\ 10^{-3}$	$5.7\ 10^{-3}$	$7.3\ 10^{-3}$	$7.4\ 10^{-3}$

Table A2.10 Committed dose equivalents to red bone marrow from AWRE, Aldermaston atmospheric discharges, at 5 km

Year	Dose equivalent, μSv			
	Fetus	1-year-old	10-year-old	Adult
1952	$1.9\ 10^{-9}$	$1.7\ 10^{-6}$	$4.2\ 10^{-6}$	$5.1\ 10^{-6}$
1953	$3.9\ 10^{-8}$	$3.5\ 10^{-5}$	$8.4\ 10^{-5}$	$1.0\ 10^{-4}$
1954	$3.9\ 10^{-8}$	$3.5\ 10^{-5}$	$8.4\ 10^{-5}$	$1.0\ 10^{-4}$
1955	$7.8\ 10^{-8}$	$7.7\ 10^{-5}$	$1.8\ 10^{-4}$	$2.2\ 10^{-4}$
1956	$1.6\ 10^{-7}$	$1.5\ 10^{-4}$	$3.6\ 10^{-4}$	$4.4\ 10^{-4}$
1957	$3.1\ 10^{-7}$	$2.9\ 10^{-4}$	$6.9\ 10^{-4}$	$8.5\ 10^{-4}$
1958	$3.9\ 10^{-7}$	$3.7\ 10^{-4}$	$8.7\ 10^{-4}$	$1.1\ 10^{-3}$
1959	$2.9\ 10^{-4}$	$8.7\ 10^{-4}$	$1.8\ 10^{-3}$	$2.1\ 10^{-3}$
1960	$4.6\ 10^{-3}$	$5.0\ 10^{-3}$	$6.7\ 10^{-3}$	$7.1\ 10^{-3}$
1961	$1.7\ 10^{-3}$	$1.9\ 10^{-3}$	$2.7\ 10^{-3}$	$2.9\ 10^{-3}$
1962	$1.1\ 10^{-3}$	$1.3\ 10^{-3}$	$1.8\ 10^{-3}$	$2.0\ 10^{-3}$
1963	$2.3\ 10^{-3}$	$2.5\ 10^{-3}$	$3.3\ 10^{-3}$	$3.5\ 10^{-3}$
1964	$1.4\ 10^{-3}$	$1.6\ 10^{-3}$	$2.1\ 10^{-3}$	$2.3\ 10^{-3}$
1965	$4.6\ 10^{-3}$	$4.9\ 10^{-3}$	$6.4\ 10^{-3}$	$6.8\ 10^{-3}$
1966	$3.4\ 10^{-3}$	$3.7\ 10^{-3}$	$4.9\ 10^{-3}$	$5.2\ 10^{-3}$
1967	$5.7\ 10^{-3}$	$6.1\ 10^{-3}$	$8.0\ 10^{-3}$	$8.4\ 10^{-3}$
1968	$8.6\ 10^{-3}$	$9.1\ 10^{-3}$	$1.2\ 10^{-2}$	$1.3\ 10^{-2}$
1969	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$	$1.6\ 10^{-2}$	$1.7\ 10^{-2}$
1970	$1.4\ 10^{-2}$	$1.5\ 10^{-2}$	$1.9\ 10^{-2}$	$2.0\ 10^{-2}$
1971	$1.7\ 10^{-2}$	$1.8\ 10^{-2}$	$2.3\ 10^{-2}$	$2.4\ 10^{-2}$
1972	$2.9\ 10^{-2}$	$2.9\ 10^{-2}$	$3.8\ 10^{-2}$	$3.9\ 10^{-2}$
1973	$2.3\ 10^{-2}$	$2.4\ 10^{-2}$	$3.0\ 10^{-2}$	$3.2\ 10^{-2}$
1974	$2.9\ 10^{-2}$	$2.9\ 10^{-2}$	$3.8\ 10^{-2}$	$3.9\ 10^{-2}$
1975	$2.3\ 10^{-2}$	$2.4\ 10^{-2}$	$3.0\ 10^{-2}$	$3.2\ 10^{-2}$
1976	$2.3\ 10^{-2}$	$2.4\ 10^{-2}$	$3.0\ 10^{-2}$	$3.1\ 10^{-2}$
1977	$2.3\ 10^{-2}$	$2.4\ 10^{-2}$	$3.2\ 10^{-2}$	$3.3\ 10^{-2}$
1978	$2.3\ 10^{-2}$	$2.3\ 10^{-2}$	$3.0\ 10^{-2}$	$3.1\ 10^{-2}$
1979	$1.4\ 10^{-2}$	$1.5\ 10^{-2}$	$1.9\ 10^{-2}$	$2.0\ 10^{-2}$
1980	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$	$1.5\ 10^{-2}$	$1.6\ 10^{-2}$
1981	$8.6\ 10^{-3}$	$8.8\ 10^{-3}$	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$
1982	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$	$1.5\ 10^{-2}$	$1.6\ 10^{-2}$
1983	$8.6\ 10^{-3}$	$8.8\ 10^{-3}$	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$
1984	$8.6\ 10^{-3}$	$8.8\ 10^{-3}$	$1.1\ 10^{-2}$	$1.2\ 10^{-2}$
1985	$5.7\ 10^{-3}$	$5.9\ 10^{-3}$	$7.5\ 10^{-3}$	$7.9\ 10^{-3}$

A2.39 Data were also used by NRPB to calculate the doses received by the different population groups at various distances from the sites. Estimated dose for a 1 year old child and an adult are given in Tables A2.11 and A2.12. The estimated effective dose equivalents and dose equivalents to the red bone marrow, at a distance of 0.5 km from the site were almost 20 times higher than the doses received at 5 km, whereas the doses received at 20 km from the site were less than a tenth of those received at 5 km.

Table A2.11 Committed effective dose equivalent to 1-year-old child from AWRE, Aldermaston atmospheric discharges, at increasing distances from the site

Year	Effective dose equivalent, μSv				
	0.5 km	1.0 km	5.0 km	10.0 km	20.0 km
1955	$3.5\ 10^{-3}$	$1.7\ 10^{-3}$	$2.0\ 10^{-4}$	$7.7\ 10^{-5}$	$2.9\ 10^{-5}$
1960	$8.4\ 10^{-2}$	$4.1\ 10^{-2}$	$5.1\ 10^{-3}$	$1.9\ 10^{-3}$	$7.0\ 10^{-4}$
1965	$8.3\ 10^{-2}$	$4.0\ 10^{-2}$	$5.0\ 10^{-3}$	$1.8\ 10^{-3}$	$6.9\ 10^{-4}$
1970	$2.4\ 10^{-1}$	$1.2\ 10^{-1}$	$1.5\ 10^{-2}$	$5.3\ 10^{-3}$	$2.0\ 10^{-3}$
1975	$3.8\ 10^{-1}$	$1.8\ 10^{-1}$	$2.3\ 10^{-2}$	$8.4\ 10^{-3}$	$3.2\ 10^{-3}$
1980	$1.9\ 10^{-1}$	$9.2\ 10^{-2}$	$1.2\ 10^{-2}$	$4.2\ 10^{-3}$	$1.6\ 10^{-3}$
1985	$9.5\ 10^{-2}$	$4.6\ 10^{-2}$	$5.7\ 10^{-3}$	$2.1\ 10^{-3}$	$8.0\ 10^{-4}$

Table A2.12 Committed effective dose equivalent to adult from AWRE Aldermaston atmospheric discharges, at increasing distances from the site

Year	Effective dose equivalent, μSv				
	0.5 km	1.0 km	5.0 km	10.0 km	20.0 km
1955	$4.7\ 10^{-3}$	$2.2\ 10^{-3}$	$2.8\ 10^{-4}$	$1.0\ 10^{-4}$	$4.0\ 10^{-5}$
1960	$1.1\ 10^{-1}$	$5.4\ 10^{-2}$	$6.7\ 10^{-3}$	$2.5\ 10^{-3}$	$9.3\ 10^{-4}$
1965	$1.1\ 10^{-1}$	$5.2\ 10^{-2}$	$6.5\ 10^{-3}$	$2.4\ 10^{-3}$	$9.0\ 10^{-4}$
1970	$3.1\ 10^{-1}$	$1.5\ 10^{-1}$	$1.9\ 10^{-2}$	$6.8\ 10^{-3}$	$2.6\ 10^{-3}$
1975	$5.0\ 10^{-1}$	$2.4\ 10^{-1}$	$3.0\ 10^{-2}$	$1.1\ 10^{-2}$	$4.1\ 10^{-3}$
1980	$2.5\ 10^{-1}$	$1.2\ 10^{-1}$	$1.5\ 10^{-2}$	$5.4\ 10^{-3}$	$2.1\ 10^{-3}$
1985	$1.2\ 10^{-1}$	$5.9\ 10^{-2}$	$7.4\ 10^{-3}$	$2.7\ 10^{-3}$	$1.0\ 10^{-3}$

Royal Ordnance Factory, Burghfield

A2.40 The only significant discharges from this site up to 1985 arise from tritiated material and the resulting estimated annual doses are extremely low. Full details of the effective dose equivalents and the red bone marrow dose equivalents for each of the four population groups 5 km from this site are given in Tables A2.13 and A2.14. Adults received the highest estimated dose with levels reaching a peak in 1971. The effective dose equivalent was 0.0000065 μSvy^{-1} and the corresponding dose equivalent to the red bone marrow was 0.0000069 μSvy^{-1}. The estimated doses to the fetus were the lowest of all the groups considered. In 1971 the effective dose equivalent to the fetus was 0.0000048 μSvy^{-1} and the dose equivalent to the bone marrow was 0.0000051 μSvy^{-1}. These doses have not varied substantially throughout the time period since emissions from this site began. The variation of dose with distance from the site showed a similar pattern to that observed around Aldermaston.

Table A2.13 Committed effective dose equivalents from ROF Burghfield atmospheric discharges, at 5 km

Year	Effective dose equivalent, μSv			
	Fetus	1-year-old	10-year-old	Adult
1970	$3.2\ 10^{-7}$	$3.4\ 10^{-7}$	$4.3\ 10^{-7}$	$4.3\ 10^{-7}$
1971	$4.8\ 10^{-6}$	$5.1\ 10^{-6}$	$6.4\ 10^{-6}$	$6.5\ 10^{-6}$
1972	$4.0\ 10^{-6}$	$4.2\ 10^{-6}$	$5.3\ 10^{-6}$	$5.4\ 10^{-6}$
1973	$3.2\ 10^{-6}$	$3.4\ 10^{-5}$	$4.3\ 10^{-6}$	$4.3\ 10^{-6}$
1974	$2.0\ 10^{-6}$	$2.1\ 10^{-6}$	$2.7\ 10^{-6}$	$2.7\ 10^{-6}$
1975	$7.9\ 10^{-7}$	$8.4\ 10^{-7}$	$1.1\ 10^{-6}$	$1.1\ 10^{-6}$
1976	$6.3\ 10^{-7}$	$6.8\ 10^{-7}$	$8.5\ 10^{-7}$	$8.7\ 10^{-7}$
1977	$2.4\ 10^{-6}$	$2.5\ 10^{-6}$	$3.2\ 10^{-6}$	$3.3\ 10^{-6}$
1978	$1.2\ 10^{-6}$	$1.3\ 10^{-6}$	$1.6\ 10^{-6}$	$1.6\ 10^{-6}$
1979	$4.8\ 10^{-7}$	$5.1\ 10^{-7}$	$6.4\ 10^{-7}$	$6.5\ 10^{-7}$
1980	$4.0\ 10^{-6}$	$4.2\ 10^{-6}$	$5.3\ 10^{-6}$	$5.4\ 10^{-6}$
1981	$1.2\ 10^{-6}$	$1.3\ 10^{-6}$	$1.6\ 10^{-6}$	$1.6\ 10^{-6}$
1982	$3.2\ 10^{-6}$	$3.4\ 10^{-6}$	$4.3\ 10^{-6}$	$4.3\ 10^{-6}$
1983	$4.0\ 10^{-6}$	$4.2\ 10^{-6}$	$5.3\ 10^{-6}$	$5.4\ 10^{-6}$
1984	$4.0\ 10^{-6}$	$4.2\ 10^{-5}$	$5.3\ 10^{-6}$	$5.4\ 10^{-6}$
1985	$3.2\ 10^{-6}$	$3.4\ 10^{-6}$	$4.3\ 10^{-5}$	$4.3\ 10^{-6}$

Table A2.14 Committed dose equivalents to red bone marrow from ROF Burghfield atmospheric discharges, at 5 km

Year	Dose equivalent, μSv			
	Fetus	1-year-old	10-year-old	Adult
1970	$3.4\ 10^{-7}$	$3.5\ 10^{-7}$	$4.4\ 10^{-7}$	$4.6\ 10^{-7}$
1971	$5.1\ 10^{-6}$	$5.2\ 10^{-5}$	$6.6\ 10^{-6}$	$6.9\ 10^{-6}$
1972	$4.2\ 10^{-6}$	$4.3\ 10^{-6}$	$5.5\ 10^{-6}$	$5.8\ 10^{-5}$
1973	$3.4\ 10^{-6}$	$3.5\ 10^{-5}$	$4.4\ 10^{-6}$	$4.6\ 10^{-6}$
1974	$2.1\ 10^{-6}$	$2.2\ 10^{-5}$	$2.3\ 10^{-6}$	$2.9\ 10^{-5}$
1975	$8.4\ 10^{-7}$	$8.6\ 10^{-7}$	$1.1\ 10^{-5}$	$1.2\ 10^{-5}$
1976	$6.7\ 10^{-7}$	$6.9\ 10^{-7}$	$8.8\ 10^{-7}$	$9.2\ 10^{-7}$
1977	$2.5\ 10^{-6}$	$2.6\ 10^{-5}$	$3.3\ 10^{-5}$	$3.5\ 10^{-6}$
1978	$1.3\ 10^{-5}$	$1.3\ 10^{-6}$	$1.7\ 10^{-6}$	$1.7\ 10^{-6}$
1979	$5.1\ 10^{-7}$	$5.2\ 10^{-7}$	$6.6\ 10^{-7}$	$6.9\ 10^{-7}$
1980	$4.2\ 10^{-6}$	$4.3\ 10^{-5}$	$5.5\ 10^{-5}$	$5.8\ 10^{-5}$
1981	$1.3\ 10^{-6}$	$1.3\ 10^{-5}$	$1.7\ 10^{-5}$	$1.7\ 10^{-6}$
1982	$3.4\ 10^{-5}$	$3.5\ 10^{-5}$	$4.4\ 10^{-5}$	$4.6\ 10^{-5}$
1983	$4.2\ 10^{-6}$	$4.3\ 10^{-5}$	$5.5\ 10^{-6}$	$5.8\ 10^{-5}$
1984	$4.2\ 10^{-5}$	$4.3\ 10^{-5}$	$5.5\ 10^{-5}$	$5.8\ 10^{-6}$
1985	$3.4\ 10^{-5}$	$3.5\ 10^{-5}$	$4.4\ 10^{-6}$	$4.6\ 10^{-5}$

Atomic Energy Research Establishment, Harwell

A2.41 Full details of the effective dose equivalents received each year and the red bone marrow dose equivalents received by the four population groups 5 km from the site are given in Tables A2.15 and A2.16. The doses were similar for all the four representative groups with the exception that the fetal doses were somewhat lower than those received by the other groups. The highest estimated doses for all groups were received during the 1960s. The effective dose equivalents and the red bone marrow dose equivalents were essentially the same during this period, being 0.6 μSvy^{-1} for adults and children and 0.4 μSvy^{-1} for the fetus.

Table A2.15 Committed effective dose equivalents from AERE Harwell atmospheric discharges, at 5 km

Year	Effective dose equivalent, μSv			
	Fetus	1-year-old	10-year-old	Adult
1947	$3.1\ 10^{-4}$	$1.5\ 10^{-3}$	$2.9\ 10^{-3}$	$3.5\ 10^{-3}$
1948	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1949	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1950	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1951	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1952	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1953	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1954	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1955	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1956	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$
1957	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.9\ 10^{-1}$
1958	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.9\ 10^{-1}$
1959	$2.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.8\ 10^{-1}$	$3.9\ 10^{-1}$
1960	$4.5\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1961	$4.5\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1962	$4.5\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1963	$4.5\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1964	$4.4\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1965	$4.5\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1966	$4.5\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1967	$4.5\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1968	$4.5\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$	$6.1\ 10^{-1}$
1969	$8.6\ 10^{-3}$	$1.6\ 10^{-2}$	$1.9\ 10^{-2}$	$2.0\ 10^{-2}$
1970	$8.2\ 10^{-3}$	$1.5\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$
1971	$8.2\ 10^{-3}$	$1.5\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$
1972	$8.2\ 10^{-3}$	$1.5\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$
1973	$8.2\ 10^{-3}$	$1.5\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$
1974	$8.2\ 10^{-3}$	$1.5\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$
1975	$8.2\ 10^{-3}$	$1.5\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$
1976	$6.3\ 10^{-3}$	$1.2\ 10^{-2}$	$1.6\ 10^{-2}$	$1.6\ 10^{-2}$
1977	$1.1\ 10^{-2}$	$1.9\ 10^{-2}$	$2.3\ 10^{-2}$	$2.3\ 10^{-2}$
1978	$1.1\ 10^{-2}$	$1.9\ 10^{-2}$	$2.3\ 10^{-2}$	$2.3\ 10^{-2}$
1979	$9.4\ 10^{-3}$	$1.6\ 10^{-2}$	$2.0\ 10^{-2}$	$2.1\ 10^{-2}$
1980	$9.3\ 10^{-3}$	$1.6\ 10^{-2}$	$2.0\ 10^{-2}$	$2.1\ 10^{-2}$
1981	$1.1\ 10^{-2}$	$1.9\ 10^{-2}$	$2.3\ 10^{-2}$	$2.3\ 10^{-2}$
1982	$1.3\ 10^{-2}$	$2.1\ 10^{-2}$	$2.5\ 10^{-2}$	$2.5\ 10^{-2}$
1983	$1.8\ 10^{-2}$	$2.5\ 10^{-2}$	$3.1\ 10^{-2}$	$3.2\ 10^{-2}$
1984	$1.8\ 10^{-2}$	$2.6\ 10^{-2}$	$3.1\ 10^{-2}$	$3.2\ 10^{-2}$
1985	$1.8\ 10^{-2}$	$2.6\ 10^{-2}$	$3.1\ 10^{-2}$	$3.2\ 10^{-2}$

Table A2.16 Committed dose equivalents to red bone marrow from AERE Harwell atmospheric discharges, at 5 km

Year	Dose equivalent, μSv			
	Fetus	1-year-old	10-year-old	Adult
1947	3.1 10^{-4}	2.0 10^{-3}	4.2 10^{-3}	4.9 10^{-3}
1948	2.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}
1949	2.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}
1950	2.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}
1951	2.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}
1952	2.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}
1953	2.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}
1954	2.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}
1955	2.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}	3.8 10^{-1}
1956	2.8 10^{-1}	3.8 10^{-1}	3.9 10^{-1}	3.9 10^{-1}
1957	2.8 10^{-1}	3.8 10^{-1}	3.9 10^{-1}	3.9 10^{-1}
1958	2.8 10^{-1}	3.8 10^{-1}	3.9 10^{-1}	3.9 10^{-1}
1959	2.8 10^{-1}	3.8 10^{-1}	3.9 10^{-1}	3.9 10^{-1}
1960	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1961	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1962	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1963	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1964	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1965	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1966	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1967	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1968	4.5 10^{-1}	6.1 10^{-1}	6.1 10^{-1}	6.1 10^{-1}
1969	8.6 10^{-3}	1.7 10^{-2}	2.3 10^{-2}	2.3 10^{-2}
1970	8.2 10^{-3}	1.6 10^{-2}	2.2 10^{-2}	2.2 10^{-2}
1971	8.2 10^{-3}	1.6 10^{-2}	2.2 10^{-2}	2.2 10^{-2}
1972	8.2 10^{-3}	1.6 10^{-2}	2.2 10^{-2}	2.2 10^{-2}
1973	8.2 10^{-3}	1.6 10^{-2}	2.2 10^{-2}	2.2 10^{-2}
1974	8.2 10^{-3}	1.6 10^{-2}	2.2 10^{-2}	2.2 10^{-2}
1975	8.2 10^{-3}	1.6 10^{-2}	2.2 10^{-2}	2.2 10^{-2}
1976	6.3 10^{-3}	1.4 10^{-2}	1.9 10^{-2}	2.0 10^{-2}
1977	1.1 10^{-2}	2.0 10^{-2}	2.6 10^{-2}	2.7 10^{-2}
1978	1.2 10^{-2}	2.0 10^{-2}	2.7 10^{-2}	2.7 10^{-2}
1979	9.5 10^{-3}	1.7 10^{-2}	2.4 10^{-2}	2.4 10^{-2}
1980	9.4 10^{-3}	1.8 10^{-2}	2.4 10^{-2}	2.4 10^{-2}
1981	1.1 10^{-2}	2.0 10^{-2}	2.6 10^{-2}	2.6 10^{-2}
1982	1.3 10^{-2}	2.2 10^{-2}	2.8 10^{-2}	2.9 10^{-2}
1983	1.8 10^{-2}	2.7 10^{-2}	3.5 10^{-2}	3.6 10^{-2}
1984	1.8 10^{-2}	2.7 10^{-2}	3.5 10^{-2}	3.6 10^{-2}
1985	1.8 10^{-2}	2.7 10^{-2}	3.5 10^{-2}	3.6 10^{-2}

A2.42 Up until 1968 when the BEPO reactor was shut down, 99% of the dose received by the population around Harwell from the AERE site was due to the direct, external radiation from argon-41. The contribution due to argon-41 then decreased to about 30–40% of the total effective dose equivalent to an adult, the remainder being due to carbon-14 and plutonium-239, with the contribution from tritium becoming more important in 1985 (contribution to total dose about 30%).

Comparison of Doses Received from the Nuclear Establishments to those Received from Natural Radiation

A2.43 The doses arising from airborne discharges from the AWRE Aldermaston, ROF Burghfield and AERE Harwell sites to populations in the surrounding areas have been compared, by the NRPB, with those doses received by the same population from natural radiation. The effective dose equivalent from natural radiation for adults living in the West Berkshire area has been estimated to be 2140 μSv. This can be compared with the national average figure of 2200 μSv per annum.

A2.44 The peak estimated annual effective dose equivalent for adults (the group receiving the highest dose from the sites) at a distance of 5 km from these sites was only a very small fraction of the doses received from natural radiation, being 0.0017%, 0.0000003% and 0.03% at Aldermaston, Burghfield and Harwell respectively. These proportions become even smaller when the estimated average doses arising from other sources of radiation (nuclear weapons fallout and medical treatment) are considered.

Other possible routes of exposure — liquid discharges

A2.45 Natural surface water leaves the AWRE Aldermaston via the River Kennet. MAFF monitor this water although the radioactivity levels present are negligible. It enters the Thames below the liquid discharge point of the waste pipeline at Pangbourne. The liquid discharges of radioactive material from AWRE Aldermaston and ROF Burghfield are released into the River Thames and the River Kennet. NRPB told us that the liquid discharges were not thought to represent a route of exposure to the local population and therefore they were not included in NRPBs dose assessment. The Department of the Environment informed COMARE that the local population obtain the bulk of their water supply from the Mortimer and Ufton Nervet Pumping Stations which are borehole supply points. Smaller amounts are obtained from the Fobney Water Treatment Works which takes water from the River Kennet, but upstream of the points of discharge. The amounts from this source vary seasonally, but are greatest in the summer. The locations of these supply points are shown in Figure A2.1.

A2.46 In order to check that drinking water was not a current source of any significant exposure, the level of radioactivity in samples of water from these locations was measured by the Department of the Environment at our request. The results are given in table A2.17. These levels of activity are within the normal environmental range as measured by DoE.

Table A2.17 Levels of activity in drinking water

		Bq/Litre	
	Alpha Activity	Beta Activity	Tritium (by electrolysis)
Mortimer supply	0.04(±0.01)	0.34(±0.01)	0.95(±0.39)
Ufton Nervet supply	0.04(±0.01)	0.26(±0.01)	0.56(±0.35)
Fobney Treatment Works	0.06(±0.02)	0.30(±0.01)	2.12(±0.88)
Normal Range	0.04–0.1	0.10–0.50	0.03–12.2

A2.47 Although water from the Thames is not used as a public drinking water supply to the local population, water is abstracted from the Thames for other purposes such as irrigation and industrial use. It is possible therefore, that some individuals are exposed via other pathways such as consumption of meat from animals grazing irrigated pasture and drinking river water, consumption of vegetables, inhalation of resuspended radionuclides as well as external exposure. In addition to the abstraction points for public drinking water supplies to the local populations (see Figure A2.1), there are large numbers of other listed underground water abstraction points and licensed surface water abstraction points. This includes a variety of private uses.

A2.48 Fishing in the Thames is normally carried out for sport but the possibility of some fish being taken for consumption cannot be ruled out. Furthermore, the possibility cannot altogether be dismissed that a few individuals, such as those living on houseboats, might use Thames water for drinking purposes. Some individuals may be exposed via pathways such as using the river for recreational purposes or drinking river water, therefore if these exposure pathways exist, they will apply to a few individuals rather than whole populations. At our request the NRPB have calculated the annual effective dose equivalent for such individuals exposed to these pathways, assuming particular habits for these individuals. (For the purposes of these calculations it was assumed that the consumption rate of fish by adults was 5 kilograms per year and the consumption rate of water by adults was 400 litres per year. It was also assumed that adults spent 100 hours per year standing on river sediment in the pursuit of recreational activities such as fishing.)

A2.49 The highest annual effective dose equivalents were calculated for the liquid discharges from AERE Harwell. The maximum annual dose was from the beta-emitting radionuclides and was about 500 μSv to an adult. About 60% of this was calculated to be from eating fish and about 35% from external exposure from river sediment. Less than 3% was due to drinking water. The maximum annual dose from the beta-emitting radionuclides to 1 year old and 10 year old children was calculated to be 100 μSv and 300 μSv, respectively, again most of the dose resulting from eating fish. The doses to adults from the highest discharges of alpha-emitting radionuclides in liquid wastes from AERE Harwell were about 3 μSv; those from the tritium discharges were about three times smaller.

A2.50 The highest annual effective dose equivalents to adults as a result of liquid alpha discharges from AWRE Aldermaston were calculated to be about 10 μSv. About 85% of the dose was due to drinking water, and the remainder mainly from fish consumption. Doses to 1 year old and 10 year old children were about 9 μSv and 8 μSv respectively. The doses to adults from the highest discharges of beta-emitting radionuclides were about two times lower than those from alpha discharges, doses from tritium discharges were about 50 times lower still. The highest effective dose equivalent to adults from the alpha discharges from ROF Burghfield was about 10^{-2} μSv. As for AWRE Aldermaston about 85% of this dose was from drinking water. Doses to adults from the discharges of beta-emitting radionuclides were about 6 times lower than the alpha doses. Therefore the peak adult individual doses from the liquid discharges from AWRE Aldermaston and ROF Burghfield are about 50 times and 35,000 times lower, respectively, than that from the peak liquid discharges from AERE Harwell. As already stressed, the calculation of these doses was carried out to provide some indication of the maximum dose that an individual might receive from the liquid discharges. They are hypothetical in the sense that they were based on pessimistic assumptions for a small number of individuals since, at the time, no specific data were available to permit more realistic calculations.

A2.51 However the recently published MAFF Aquatic Environment Monitoring Report on Radioactivity in Surface and Coastal Waters of the British Isles (1987)[10] contains results arising from monitoring the discharges of the AERE Harwell laboratory into the River Thames at Sutton Courtenay, and from the AWRE Establishment at Aldermaston into the same river at Pangbourne. For the former, samples of freshwater fish (chub, perch, roach and grayling) were taken for analysis at Sutton Courtenay, Marlow and Staines. The only gamma-emitting nuclides detected were those of caesium nuclides, which were slightly enhanced (98 Bq kg^{-1} wet weight maximum) close to the outfall. Traces of $^{239/240}Pu$ and ^{241}Am (at most 1 mBq kg^{-1} wet weight) are of the level expected from fallout. Other indicator samples analysed (yellow water lily and water crowfoot), plus river sediment samples, also revealed the presence of traces of ^{60}Co. Using fish consumption rates (100 g day^{-1}) and occupancy times (150 h.$year^{-1}$) typical of enthusiastic anglers, it was calculated that dose rates from both internal and external sources would have been less than 10 μSv per year. With regard to the Aldermaston site, a similar range of samples, from Pangbourne, was analysed. Again traces of ^{137}Cs were detectable and transuranium nuclides were less than 1 mBq kg^{-1} wet weight in fish flesh. Dose rates for anglers associated with this site were estimated to be less than 2 μSv per year. These recent results suggest that these pathways for exposure to liquid discharges from Harwell produce levels of exposure much lower than those calculated by NRPB using the hypothetical assumptions given above.

Doses and risks from radiation exposure around AWRE Aldermaston

A2.52 In 1984, the NRPB provided an assessment of the radiation doses and risks of leukaemia induction to children in the Seascale population for the Sir Douglas Black inquiry.[26] The calculations were repeated for COMARE following the revelations about increased radioactive emissions from the Sellafield site in the 1950s.[27] The procedure used in both these sets of calculations was to calculate doses in each year to children born at regular intervals from 1945 to 1975 to age 20 years or to 1980, whichever was sooner. Risk coefficients, which were chosen to ensure that the overall radiation risks were not underestimated, were used to calculate the risks of radiation induced leukaemia and hence the numbers of leukaemias that might be expected to be produced by radiation exposure in the young people that lived in Seascale.

A2.53 This method of calculation was chosen to provide as comprehensive an assessment as possible of the radiation risks. It was feasible because the population of interest was geographically reasonably well defined. A more usual approach to dose assessments in radiological protection is to calculate external radiation doses in a year and internal radiation doses to a specified age (for the public, 70 years would be appropriate) from intakes of radionuclides in the same year. This is a much more straightforward procedure and the doses so calculated can be compared with any appropriate limits; they also provide an indication of the radiation risks but not to the same detail as in the approach adopted for the Seascale assessments.

A2.54 Both approaches were used in the assessments of the doses and risks to the young people living in Thurso from the Dounreay discharges.[28,29] The more comprehensive assessment was feasible because again the population of interest was geographically reasonably well-defined.

A2.55 At the time that the NRPB produced the assessment of doses from emissions from AWRE Aldermaston, the population in the local area in which the incidence of leukaemia was raised was ill-defined. In addition, because the discharges from Aldermaston were so much lower than those from either Sellafield or Dounreay, a detailed assessment of risks seemed unwarranted. For example, the atmospheric discharges of plutonium-239 during the 1970s from Dounreay were at least 10 times higher than those from Aldermaston and from Sellafield they were 100 to 1000 times higher. Atmospheric discharges are the main source of exposure around Aldermaston but a relatively minor component of the exposure of the populations in Seascale and Thurso.

A2.56 Table A2.18 provides a comparison of the doses from the discharges from Sellafield, Dounreay and Aldermaston[30] (the doses from Burghfield are not included to avoid over complicating the table and because they are so minute).[8] The doses given are dose equivalents to the red bone marrow of 1-year-old children and are separated into those from low and high LET except in the case of Thurso where the data are not readily available. Doses to children of other age groups are not substantially different from those in table A2.18. The doses from natural radiation and fallout in both locations are up to a factor of two or so higher due to the greater rainfall in these areas. The doses in this table were calculated using the simpler approach and therefore are directly comparable with each other. The very low doses from the Aldermaston discharges relative to the doses from natural radiation and fallout and the doses in Seascale and Thurso are immediately apparent.

Table A2.18 Comparison of dose equivalents, μSv, to red bone marrow of 1-year-old children

Year	In Seascale from BNFL, Sellafield		In Thurso from Dounreay	In Thurso from Sellafield	At 5 km from Aldermaston		Fallout		Natural	
	Low LET	High LET	Low + High LET	Low + High LET	Low LET	High LET	Low LET	High LET	Low LET	High LET
1955	1100	17	0	not calculated	4.8×10^{-7}	7.6×10^{-5}	50	3.6	840	144
1960	98	17	3.5	0.19	4.7×10^{-3}	3.0×10^{-4}	88	1.7	840	144
1965	52	13	15	0.37	4.7×10^{-3}	1.9×10^{-4}	250	4.4	840	144
1970	81	34	8.9	0.94	1.5×10^{-2}	1.8×10^{-4}	84	0.6	840	144
1975	270	62	3.1	4.8	2.3×10^{-2}	1.8×10^{-4}	42	0.3	840	144
1980	140	34	0.3	4.2	1.2×10^{-2}	1.1×10^{-4}	27	0.07	840	144
Average of 5-year values since 1955	330		5.1	1.8	0.01		93		990	
Average of 5-year values since 1960	160		6.2	2.1	0.012		100		990	

A.2.57 Some idea of the risks posed by the discharges from Aldermaston can be obtained by two methods. The first involves scaling the risks calculated for the Seascale and Thurso young people in proportion to the doses. The doses used here are the average of the 5-year values shown in the last two lines of the table. The number of radiation induced leukaemias due to discharges from Sellafield in 0–20 year olds in Seascale to 1980 was calculated to be 0.013 per 1000 children (0.016 per 1225). That due to discharges from Dounreay in 0–25 year olds in Thurso to 1985 was calculated to be 0.00088 per 1000 children (0.004 per 4550) and 0.0002 per 1000 (0.0009 per 4550) due to discharges from Sellafield. Thus, for example, the average risk to a Seascale child from the Sellafield discharges is about 15 times higher than that to a Thurso child from the Dounreay discharges. This, of course, ignores the different age ranges considered.

A2.58 From the average of the 5-year doses since 1955 given in Table A2.18 one would expect the risk of leukaemia induction due to radiation exposure to be about 65 times higher in Seascale from the Sellafield discharges than in Thurso from the Dounreay discharges. If the relatively high dose in Seascale and the zero dose in Thurso in 1955 are ignored, the factor reduces to about 25 (data from last line of Table A2.18). In view of the crudity of the comparison this number agrees reasonably well with the actual factor of 15 and this provides justification for scaling the risks in proportion to the doses.

A2.59 On this basis, the approximate risk of radiation-induced leukaemia in children to about 20 years of age at 5 km from AWRE Aldermaston due to the discharges is given by;

1955–1980 data: $\frac{0.01}{5.1} \times 0.00088 = 1.7 \times 10^{-6}$ per 1000
using the Dounreay/Thurso data

or $\frac{0.01}{330} \times 0.013 = 4.0 \times 10^{-7}$ per 1000
using the Sellafield/Seascale data

1960–1980 data: $\frac{0.012}{6.2} \times 0.00088 = 1.7 \times 10^{-6}$ per 1000
using the Dounreay/Thurso data

or $\frac{0.012}{160} \times 0.013 = 9.8 \times 10^{-7}$ per 1000
using the Sellafield/Seascale data

Thus the risk is calculated to be of the order of 10^{-6} per 1000 children. In a population of about 55,000 children, the total number of radiation-induced leukaemias would therefore be expected to be about 6×10^{-5} due to Aldermaston discharges.

A2.60 The second way of considering the situation is to assume that all leukaemias are caused by radiation and to calculate the increment that would result from the doses from the Aldermaston discharges. This is similar to the calculations performed in the Black report and the recent COMARE report on Dounreay. The calculation was performed using the data below:

(a) Population of 0–14 year old children living within a circle of 10 km radius from AWRE Aldermaston is 54,617 (from 1981 census figure).

(b) The regional rate of leukaemia incidence in 0–14 year olds is 3.4×10^{-5} per year.

(c) Assuming all these cases are caused by a "background" radiation (natural radiation, fallout and medical) level of 1071 μSv in 1975 to the red bone marrow of 1 year old children,[8] we obtain an estimate of risk of radiation-induced leukaemia of 3.17×10^{-2} per sievert per year. This compares with the figure of 2.28×10^{-2} per sievert per year in the Black report; the somewhat higher value in the case here being due to a slightly higher leukaemia rate and lower background dose.

(d) The average dose from these discharges to the red bone marrow of a 1 year old child living 5 km from Aldermaston in the 1970s, the period of highest discharges, was about 2.4×10^{-2} μ Sv each year.

A2.61 The number of cases due to the Aldermaston discharges was calculated, using this approach, to be 4.16×10^{-5} per year in the population of 54,617. For the 14 year period from 1972 to 1985, we would therefore expect about 6 x 10^{-4} leukaemia cases due to radiation exposure resulting from AWRE Aldermaston atmospheric discharges.

A2.62 The value calculated by this second approach is in reasonable agreement with that obtained by the first. Both demonstrate that the radiation risks are extremely low.

Chemical discharges from AWRE Aldermaston and ROF Burghfield

A2.63 Some chemicals are potentially leukaemogenic so COMARE asked MoD for information on the usage and discharge of the following chemicals:

Benzene
Epichlorohydrin
Ethylene oxide
Medicinal-type alkylating agents (including bis (chloromethyl) ether and dimethyl sulphate)
Certain hydrazides and hydrazine derivatives

AWRE Aldermaston

A2.64 Three of the chemicals listed are currently used in small quantities at laboratory reagent scale:

(i) benzene: used as a laboratory solvent in trivial quantities in research tasks.

(ii) dimethyl sulphate: used as a reagent in trivial quantities in small research laboratory projects.

(iii) hydrazine: used in very small quantities in small propellant research projects in a research laboratory.

None of the materials have been discharged to atmosphere or to liquid wastes. Waste disposal of these substances where they are not decomposed harmlessly during usage, is by incineration if explosive, or otherwise via the specialist chemical disposal service at UKAEA/AWRE.

ROF Burghfield

A2.65 None of the specified chemicals are in use at present but in the past, two chemicals were used in small quantities in laboratory work.

(i) benzene: prior to 1980 used as a solvent in a small laboratory experiment in trivial amounts: the waste solvent was recovered and incinerated. Surplus stock went to a specialist chemical disposal contractor.

(ii) methylene bis-ortho chloraniline: used prior to 1977 in small quantities in a solvent.

A2.66 The research quantities used are no more than those found in many university and college laboratories and less than the quantities in many commercial laboratories and works. Typically, 5 Winchester quarts of the liquids were drawn from stores in 1986 and the contents can still be accounted for, illustrating the very limited usage. AWRE and ROF Burghfield do not use any of the listed chemicals in larger quantities for their fabrication, process and manufacturing tasks; none is discharged to the atmosphere, to drains, or to surface waters.

Workers safety

A2.67 During the course of the second site visit members visited a uranium and plutonium handling facility, where the party had to undergo the changing and monitoring procedures for staff entering and leaving controlled areas. It was noted specifically that a member of the Health and Safety Unit supervises staff leaving controlled areas to ensure that procedures are correctly followed.

A2.68 All workers in uranium and plutonium areas must wear individual air sampling monitors, and plutonium workers are measured by a whole body monitor once or twice a year. Monitoring of staff households has been carried out as and when necessary. Other areas of general usage on site are monitored and no abnormal levels have been found.

A2.69 Women of reproductive age and those known to be pregnant are subject to special regulatory dose limits. These were quoted to us as: "Not more than 13 mSv in any three month period for the former and not more than 10 mSv in total from the time that the pregnancy is declared." Pregnant women may opt to work away from exposure risk areas and are encouraged to do so, but cannot be required to do so because of equal opportunity legislation.

Assessment of radiation doses from coal-fired plants in Oxfordshire and Berkshire

A2.70 Coal-fired boilers and power stations release radioactivity to the atmosphere as a waste product of coal combustion. This radioactivity is present in the form of natural sources in coal and can be released in the fly ash in a more concentrated form following combustion. Because both AWRE Aldermaston and AERE Harwell operate coal-fired boilers and because a major 2000 MW coal-fired power station is situated at Didcot at a site between the two nuclear installations, we asked the NRPB to assess the level of radiation dose to the general public from these coal-fired plants.

A2.71 Coal contains many natural radionuclides, principally those in the decay series of uranium-238, uranium-235 and thorium-232, and also potassium-40. Many of the natural radionuclides released by burning coal, such as radium-226, polonium-210 and lead-210 are members of the decay series of uranium-238 and many are alpha emitters.

A2.72 In their report[31] NRPB calculated the effective dose equivalents and dose equivalents to red bone marrow for three age groups (1 and 10 year old children and 20 year old adults) living at distances of 0.5, 1, 5, 10 and 20 km from each site.

A2.73 Table A2.19 summarises the effective dose equivalents in a year from discharges from these coal-fired plants for the three age groups, at a distance of 5 km. The effective dose equivalents for the year of peak airborne discharge from the three nuclear installations are given for comparison.

A2.74 The discharges from the coal-fired plants can be seen to make a very small contribution to the total radiation doses received by the population living around the sites. However, it is worth noting that the dose from the annual discharges from the coal-fired plant at AWRE Aldermaston are slightly higher than the doses from the airborne radioactive discharges from the site. Adults living at 5 km from Didcot power station receive an annual dose from the activity in the fly ash, which is approximately ten times the dose received by an adult, living at a distance of 5 km from AWRE Aldermaston, from the peak year of airborne radionuclide discharge.

Table A2.19 Effective dose equivalents in a year from discharges from coal-fired plants, given as μSv, compared with peak discharge year doses from AWRE Aldermaston and AERE Harwell.

Age Group	Effective Dose Equivalent, μSv						
	AWRE, Aldermaston at 5 km		AERE, Harwell at 5 km		Didcot at 5 km	Natural Radiation	Fallout Peak Dose
	Peak Discharge Dose	Coal-fired Plant	Peak Discharge Dose	Coal-fired Plant			
1 year-old children	$2.9\ 10^{-2}$ (1972)*	$4.2\ 10^{-2}$	$6.1\ 10^{-1}$ (1960–1968)*	$4.7\ 10^{-3}$	$1.6\ 10^{-1}$	$1.6\ 10^{3}$	$21.\ 10^{2}$ (1963)[1]
10 year-old children	$3.6\ 10^{-2}$ (1972)*	$5.8\ 10^{-2}$	$6.1\ 10^{-1}$ (1960–1968)*	$8.5\ 10^{-3}$	$2.9\ 10^{-1}$	$1.5\ 10^{3}$	$1.9\ 10^{2}$ (1963)[1]
Adults	$3.7\ 10^{-2}$ (1972)*	$5.8\ 10^{-2}$	$6.1\ 10^{-1}$ (1960–1968)*	$1.0\ 10^{-2}$	$3.4\ 10^{-1}$	$1.5\ 10^{3}$	$1.5\ 10^{2}$ (1963)[1]

* Year(s) of peak discharge.

[1] Year of peak discharge from fallout.

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GLOSSARY

ACTINIDES

These are a series of fifteen elements beginning with actinium. They are all radioactive and many of them decay by the emission of alpha particles. Some of the actinides can also decay by spontaneous fission or can be made to undergo fission by bombardment with neutrons, and hence are used in the nuclear power industry as nuclear fuels.

ALPHA EMITTER (α)

A radionuclide that emits alpha particles.

ALPHA PARTICLE

A charged particle emitted during the radioactive decay of many heavy radionuclides. It is identical to the nucleus of a helium atom, consisting of two protons and two neutrons. It has low penetrating power and a high linear energy transfer (LET).

AMERICIUM-241

A radionuclide with a half-life of 460 years, which decays with the emission of alpha particles and gamma rays. It is formed as a daughter product of the decay of plutonium-241.

ARGON-41

This is a radioactive form of the noble gas argon. Argon-41 is a beta and gamma emitter with a half-life of about two hours.

BACKGROUND RADIATION

The radiation level to which the general population is exposed. It consists of radiation from outer space, rocks, air, soil and substances within our bodies and from food. It also consists of radiation from nuclear weapons fallout, medical radiation and radiation from occupational exposures and nuclear discharges.

BECQUEREL (Bq)

The International (SI) unit for the number of nuclear disintegrations occurring per unit time, in a quantity of radioactive material.

1 Bq = 1 radioactive disintegration per second.

Because this is an extremely small unit, levels of activity are often quoted in terms of Megabecquerels (MBq) and Terabecquerels.

1 Megabecquerel (1 MBq) = one million becquerels (10^6Bq).

1 Terabecquerel (1 TBq) = one billion becquerels (10^{12}Bq).

The old unit of activity was the curie (Ci).

1 Bq = 27×10^{-12} Ci. Thus 1 MBq = 27×10^{-6} Ci and 1 TBq = 27 Ci.

BETA EMITTER (β)

A radionuclide that emits beta particles.

BETA PARTICLE

A particle emitted from a nucleus during the radioactive decay of certain types of radionuclides. It has a mass and charge similar to that of an electron. It is a low linear energy transfer (LET) radiation.

CAESIUM-134

This is a radionuclide which has a half-life of about 2 years. It decays with the emission of beta particles and gamma rays.

CAESIUM-137

This radionuclide has a half-life of about 30 years and decays with the emission of beta particles and gamma rays.

CANCER REGISTRATION

In the UK, formally co-ordinated but non statutory schemes whereby all cases of cancer should be notified to regional registries, in agreed detail, as soon as possible after diagnosis.

CARBON-14

A beta emitting radionuclide with a half-life of nearly 6000 years.

COMMITTED EFFECTIVE DOSE EQUIVALENT

The dose equivalent to the tissues resulting from a radionuclide that has been incorporated into the body will be spread out in time and will be delivered gradually as the radionuclide decays. To take account of this the ICRP defined the quantity committed effective dose equivalent which is the effective dose equivalent integrated over fifty years following an uptake. In this report, for convenience, the term is used to represent the dose integrated over the lifetime of an individual which is taken to be seventy years. For example, the committed effective dose equivalent for intakes at ages 1 year (infant), 10 year (child) and 20 years (adult) would involve integrating the dose over 69, 60 and 50 years, respectively. In a similar way the dose equivalents to various individual body organs (eg red bone marrow) can be integrated over the same time period. The resulting quantity would be the committed "organ" dose equivalent.

CONFIDENCE INTERVAL

A confidence interval indicates the (im)precision of the study result as a measure of the real size of any risk. In this way a confidence interval conveys the effects of sampling variation on the precision of, for example, a standardised registration ratio calculated from a limited time period, etc. Specifically, the true registration ratio is likely to be inside the 95% confidence interval on 95% of occasions, although the study registration ratio remains the best estimate of the true value.

DOSE

The amount of energy absorbed per unit mass of a given tissue. It is measured in grays (or, in old units, rads). In the main text of this report the term dose is taken to mean the sum of effective dose equivalent from external irradiation in each year and the committed effective dose equivalents from intakes of radionuclides in the same year.

EFFECTIVE DOSE EQUIVALENT

Is the sum of the quantities obtained by multiplying the dose equivalent for individual tissues by the risk weighting factor for each particular tissue. Effective dose equivalent is then related to the dose from uniform whole-body exposure. The risk weighting factor reflects the fact that the risk of fatal malignancy and genetic defects due to radiation exposure for any individual tissue, is only a fraction of the total risk for uniform whole-body exposure and that this fraction is different for different tissues. For example, the risk to the thyroid is lower than the risk to the lungs from the same dose of radiation and both of these constitute only a part of the whole body risk. The unit of effective dose equivalent is the sievert.

EXTERNAL AND INTERNAL EXPOSURES

External exposure arises from sources which are outside the body. Internal exposure arises from radioactive materials which are taken inside the body. An alpha particle has a very short range, so that if it were to come from an external source it would be unlikely to penetrate the surface of the skin, giving up most of its energy in the dead surface skin layers and causing little or no damage. If, however, an alpha particle was emitted from a source which had been inhaled into the lung its closer proximity to living cells could result in damage to those cells. Internal exposures are generally received from sources that have been inhaled or ingested. Beta and gamma radiation sources can give rise to either internal or external exposures.

GAMMA RAYS

Are high energy photons emitted from the nucleus of a radionuclide following radioactive decay, as an electromagnetic wave. They are very penetrating and have a low linear energy transfer.

GRAY (Gy)

The International (SI) unit of absorbed dose. 1 gray is equivalent to 1 joule of energy absorbed per kilogram of matter such as body tissue.

HALF-LIFE

The time for the activity of a radionuclide to decay to half of its original value; during each subsequent half-life its activity is halved again so its activity decays exponentially.

INCIDENCE

The number of new cases of a disease in a defined population within a defined period of time.

IONISING RADIATION

Radiation which is energetic enough to remove electrons from atoms in its path. This results in the formation of highly reactive particles (known as free radicals) which can cause damage to the individual components of living cells and tissues. The term is restricted to radiation at least as energetic as X-rays and includes gamma rays and charged particles such as alpha and beta particles. In this report the term radiation is used rather loosely to mean ionising radiation.

KRYPTON-85

A radioactive form of the noble gas krypton. It has a half-life of about ten years and decays by the release of beta particles and gamma rays.

LEAD-210

A radionuclide with a half-life of 25 years. It emits beta particles and gamma rays, and it is a member of the natural uranium radioactive decay series.

LEUKAEMIA

Is the name given to a group of malignant diseases caused by abnormal white blood cells which divide in a manner outside the control of the body.

LINEAR ENERGY TRANSFER (LET)

Is a measure of the density of the energy deposition in the track of radiation in biological tissue or other material. Particles or rays of radiation are generally described as having a high linear energy transfer (high LET) or low linear energy transfer (low LET). That is their tracks leave high or low density deposits of energy in the tissue they pass through. High LET radiation is more damaging to body tissue than low LET radiation.

LUNG CLASS

The term applied to describe the length of time for a substance to be removed from the lung. Thus, lung class W is a type of substance which is removed from the lungs in a matter of weeks. Similarly lung class D and lung class Y are substances removed from the lungs in days or years respectively.

LYMPHATIC CANCER see LYMPHOMA

LYMPHOMA

A tumour of the lymphoid tissue.

MORTALITY RATIO see STANDARDISED MORTALITY RATIO

NATURAL BACKGROUND RADIATION

Natural radiation pervades the whole environment. Radiation reaches the earth from outer space. The earth itself contains radionuclides and natural radionuclides are present in the food we eat and in some of the elements contained in our body. Everyone is exposed to such radiation, which is frequently referred to as background radiation. The principal sources of background radiation are as follows:

a **Cosmic rays:** High energy ionising radiations from outer space. Most of such radiation is absorbed as it penetrates the earth's atmosphere, and thus the resulting dose decreases as the altitude decreases. The average annual effective dose equivalent for the UK population from this source is about 0.25 mSv.

b **Terrestrial gamma rays:** All materials in the earth's crust contain radionuclides (eg potassium-40 and radionuclides in the uranium-238 and thorium-232 series) and the population is continuously exposed externally to gamma radiation resulting from this decay. The average annual effective dose equivalent for the UK population from this source is about 0.35 mSv.

c **Radon decay products:** The decay of the naturally occurring radionuclides thorium-232 and uranium-238 results in the production of radon gas which can move through rocks, soils or building material in which it is generated and be released from the surface. Out of doors radon is soon dispersed but indoors it can accumulate as a result of limited ventilation, the concentrations varying widely and being dependent on such factors as local geology and the degree of ventilation. The average annual effective dose equivalent for the UK population from this source is about 1.3 mSv.

d **Internal radiation:** There are a variety of radionuclides naturally present in air, food and water which irradiate the body internally after ingestion or inhalation. The principal radionuclide is potassium-40, which is always present in natural potassium. Other contributions to internal dose are from lead-210, polonium-210 and radium-226. The average annual effective dose equivalent for the UK population from this source is about 0.30 mSv.

NUCLEAR SITE, ESTABLISHMENT OR PLANT

A site which includes a nuclear reactor and/or the facility for handling radionuclides associated with the nuclear fuel cycle.

NUCLEAR WEAPONS TEST FALLOUT

Radioactive material is injected high into the atmosphere following an atmospheric nuclear explosion. After a time this material is deposited. The term nuclear fallout is used to describe this material. It can be inhaled or ingested resulting in internal radiation exposure to the body. Nuclear fallout can also cause external radiation exposure.

NUCLEAR REACTOR

A structure in which neutron-induced nuclear fission can be sustained and controlled in a self-supporting chain reaction. In a thermal reactor the fission is brought about by slow or thermal neutrons which are produced by slowing fast neutrons by the use of a moderator such as carbon or water. In a fast reactor most of the fission is produced by fast neutrons and therefore requires no moderator. Most thermal reactors use uranium as a fuel, in which the uranium-235 content has been artificially raised. (This fuel is known as enriched uranium.) Fast reactors use fuel which is a mixture of plutonium and uranium dioxide.

NUCLEAR REPROCESSING

The processing of spent nuclear fuel from a nuclear reactor, to remove fission products and to recover fissile material for further use.

ONE-SIDED TEST see P-VALUES

PASSIVE DEPOSITION COLLECTORS

These are sometimes known as tacky shade or dry cloth detectors. They consist of two poles with a cloth stretched between them. The cloths are made of material which has small pores in it. Particles which fall or are blown onto these cloths adhere to them and after a period of time the cloths are analysed to determine what type of material has been collected. They are used to monitor the dust and particle debris in the air, including particulate radioactive material that may be present in the air.

PLUTONIUM

Is an element which exists in several different isotopic forms. The five main isotopes are listed below:

Plutonium-238 an alpha emitter with a half-life of about 86 years.
Plutonium-239 an alpha emitter with a half-life of about 24,000 years.
Plutonium-240 an alpha emitter with a half-life of about 6,600 years.
Plutonium-241 a beta emitter with a half-life of about 13 years which decays to americium-241 which is an alpha emitter with a half-life of about 460 years.
Plutonium-242 an alpha emitter with a half-life of about 379,000 years.

POLONIUM-210

Is a radioactive element with a half-life of 140 days. During its decay it emits alpha particles and gamma rays. Polonium is a member of the natural uranium radioactive decay series.

POTASSIUM-40

A naturally occurring radionuclide with a half-life of 1.27×10^9 years, which decays with the emission of beta particles and gamma rays.

P-VALUE

The probability that, if a specified ("null") hypothesis is true, the value of some statistic will be at least as extreme as that actually observed. In calculating this probability it will sometimes be appropriate to consider deviations in only one direction (one sided significance tests); in other cases deviations in either direction may be appropriate (two sided tests). Conventionally, if p is less then 5% "significant at the 5% level", we take it to be unlikely that the deviation has arisen simply by chance and are inclined to "reject the null hypothesis", ie to seek some alternative hypothesis to explain the observations. Similarly if p is less then 1% (significant at the 1% level) we are more persuaded that such an alternative hypothesis is necessary.

QUALITY FACTOR

The factor by which the absorbed dose of a given radiation is multiplied in order to obtain its dose equivalent for radiation protection purposes. For example, the quality factor for X-rays is 1 and for alpha particles it is 20, as defined by the International Commission on Radiological Protection (ICRP).

RADIOACTIVITY

The number of nuclear disintegrations occurring per unit of time in a quantity of a radioactive substance. Activity is measured in becquerels (Bq).

RADIONUCLIDE

A type of atomic nucleus which is unstable and which may undergo spontaneous decay to another atom by emission of ionising radiation (usually alpha, beta or gamma).

RADIUM-226

This is a naturally occurring radionuclide with a half-life of 1620 years, which emits alpha particles and gamma rays. It decays through a series of daughter products which emit alpha, beta and gamma rays. Radium is a member of the natural uranium radioactive decay series.

RADON

The heaviest known naturally occurring gas. Two radioactive isotopes of radon give rise to a large percentage of the radiation dose received from natural background radiation. These are radon-222 and radon-220. Radon-222 is the first daughter product of the decay of radium-226, and has a half-life of 3.8 days and emits alpha particles. It decays through a series of daughter products which emit alpha, beta and gamma rays. Radon-220 also occurs in the natural environment and is a decay product of thorium and hence it is often known as thoron. It has a half-life of 54.5 seconds and emits alpha particles.

RED BONE MARROW

Is the cellular material found in certain bones (eg the ribs) and is the organ responsible for producing the cells of the blood.

REGISTRATION—See CANCER REGISTRATION

REGISTRATION RATIO—See STANDARDISED REGISTRATION RATIO.

RISK

A probability that an individual will become ill, or that other untoward event will occur, within a stated period. The risk of a disease occurring in the individuals in a population in the future, is commonly assessed from the incidence of that disease in the past but "risk" and "incidence" are conceptually different.

SIEVERT (Sv)

The International (SI) unit of dose equivalent and effective dose equivalent is the sievert. The sievert is obtained by multiplying the absorbed dose in grays by the quality factor for the particular type of radiation. Because the sievert is a large unit, dose equivalents are commonly expressed in millisieverts (mSv). There are a thousand millisieverts in one sievert.

SPECIFIC ACTIVITY MODEL

This is a straightforward way of calculating doses from atmospheric releases of tritium and carbon-14. The basic assumption is that the radionuclide is in equilibrium with the stable form of its element. For example with tritium the concentration of the radionuclide in water taken into the body by ingestion and inhalation is assumed to be the same as that in atmospheric water vapour.

STANDARDISED MORTALITY RATIOS (SMR)

Defined analogously to the Standardised Registration Ratio, using deaths and death rates.

STANDARDISED REGISTRATION RATIOS (SRR)

The ratio of the observed number of registrations in a particular area (or occupation, etc) to that expected if each age/sex group in the area had experienced the registration rate for that age/sex group in some standard population, eg that of England and Wales. Often, but not in this report, expressed as a percentage.

THORIUM-232

A naturally occurring radionuclide with a half-life of 1.3×10^{10} years, which decays with the emission of alpha particles and gamma rays.

TRITIUM

Is a radioactive isotope of hydrogen which emits beta particles, and has a half-life of twelve and a half years.

TWO SIDED SIGNIFICANCE TEST - See P-VALUE

URANIUM

Is an element which exists in several different isotopic forms. The principal two isotopes being uranium-235 and uranium-238. Both isotopes decay through a series of daughter products which emit alpha, beta and gamma rays.

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