Mortality and Cancer Incidence in UK Participants in UK Atmospheric Nuclear Weapon Tests and Experimental Programmes

S C Darby*, G M Kendall, T P Fell,
J A O'Hagan, C R Muirhead, J R Ennis,
A M Ball, J A Dennis and R Doll*

*Imperial Cancer Research Fund, Oxford

National Radiological Protection Board

Chilton, Didcot, Oxon OX11 0RQ

January 1988

NRPB-R214

The National Radiological Protection Board was established by the Radiological Protection Act 1970 and is responsible for carrying out research and development and providing information, advice and services to those with responsibilities for radiological protection.

Any questions relating to this report should be addressed to the Publications Officer, National Radiological Protection Board, Chilton, Didcot, Oxfordshire, England.

Further copies of this report are available from Her Majesty's Stationery Office

---

UNITS

As from 1 April 1978 NRPB adopted the International System of Units (SI). The relationships between the new SI units and those previously used are shown in the table below.

Quantity	New named unit and symbol	In other SI units	Old special unit and symbol	Conversion factor
Exposure	–	$C\ kg^{-1}$	röntgen (R)	$1\ C\ kg^{-1} \sim 3876\ R$
Absorbed dose	gray (Gy)	$J\ kg^{-1}$	rad (rad)	1 Gy = 100 rad
Dose equivalent	sievert (Sv)	$J\ kg^{-1}$	rem (rem)	1 Sv = 100 rem
Activity	becquerel (Bq)	s^{-1}	curie (Ci)	$1\ Bq \sim 2.7 \times 10^{-11}\ Ci$

NRPB-R214

MORTALITY AND CANCER INCIDENCE IN UK PARTICIPANTS IN UK ATMOSPHERIC NUCLEAR WEAPON TESTS AND EXPERIMENTAL PROGRAMMES

S C Darby*, G M Kendall, T P Fell, J A O'Hagan,
C R Muirhead, J R Ennis, A M Ball, J A Dennis and R Doll*

*Imperial Cancer Research Fund
Cancer Epidemiology & Clinical
Trials Unit,
University of Oxford,
Radcliffe Infirmary,
Oxford OX2 6HE.

National Radiological Protection Board
Chilton,
Didcot,
Oxon OX11 ORQ.

Approved for publication: January 1988

Publication date: January 1988

HMSO : Price £8.00 ISBN 0 85951 297 5

ABSTRACT

A follow-up study has been carried out of the health of men who participated in the UK atmospheric nuclear weapon tests and experimental programmes that were carried out in Australia and the Pacific between 1952 and 1967. The names of participants were identified from archives of the Ministry of Defence (MOD) and a matched control group was selected from the same archives. The study groups defined totalled 22,347 participants and 22,326 controls, of which 99.6% were traced to 1 January 1984 and the rates of mortality and cancer incidence (as determined from death certificates and national records of cancer registration) were compared in the two groups. The numbers of deaths observed were also compared with those that would have occurred if the men had experienced the death rates recorded for all men of the same ages over the same years in England and Wales.

No comprehensive list of participants had been compiled at the time and it could not be assumed that all participants had been identified. Names of participants and identifying details were, therefore, also sought from many other sources. Reports were received of 2161 individuals who were apparently eligible for inclusion and who were adequately identified, and these 'independent respondents' were followed as a separate group. Of these, 1707 had been included in the main study group, 414 were accepted as participants but had not been included, and 7 could not be traced in MOD records.

Altogether 3198 deaths were recorded in the two main study groups and the certified cause of death was determined for 3134 (98.0%). Mortality rates in the two groups were closely similar, the relative risk (RR) in the participants compared with the controls being 0.96 for neoplasms, 1.00 for other known non-violent causes, 1.07 for accidents and violence, and 1.01 for all causes. In both groups the mortality was less than expected from national rates, the standardised mortality ratios (SMRs) being, respectively, 80 and 83 for neoplasms and 80 and 79 for all causes. In the main analyses, 38 causes of death were examined. In 6 cases the mortality rates in participants and controls differed significantly (by one-sided tests). Mortality from leukaemia ($p=0.004$), multiple myeloma ($p=0.009$) and 'other injury and poisoning' ($p=0.04$) was higher in the participants and mortality from cancer of the prostate ($p=0.01$), cancer of the kidney ($p=0.007$) and chronic bronchitis, emphysema, and chronic obstructive lung disease ($p=0.02$) was higher in the controls. Examination of cancer incidence rates showed similar differences for leukaemia ($p=0.009$), multiple myeloma ($p=0.0007$) and cancer of the kidney ($p=0.01$), but different results for cancer of the prostate, for which the rates were about equal in both groups, and for cancer of the lung, for which the rate was higher in the controls ($p=0.03$). Examination of the rates from cancer in different groups of participants, divided according to measured doses of external irradiation and different types of participation, failed to show any relationship between leukaemia, multiple myeloma, or all neoplasms and the recorded doses of external radiation, and it showed very little difference between the experience of different groups of participants. The highest RRs and SMRs for leukaemia and multiple myeloma were observed in men who were not present at a major test or involved in minor trials at Maralinga. A study of the 11 participants in this group who developed multiple myeloma or leukaemia (other than chronic lymphatic leukaemia) and 66 other participants in the same group matched for age failed to indicate any specific risk factor.

The difference between the two groups in the mortality from leukaemia and multiple myeloma (22 deaths from leukaemia and 6 from multiple myeloma in participants, against 6 from leukaemia and 0 from multiple myeloma in controls) was largely due to extraordinarily low rates from these diseases in the controls (SMRs, respectively, of 32 and 0), while the mortality in the participants was only slightly greater than expected from national rates (SMRs, respectively, of 113 and 111) and much of these differences seems likely to have been due to chance. The low relative risk in the participants from both chronic bronchitis and lung cancer suggests that participants may have smoked less than the controls

and this is supported by the finding that the mortality from the other principal diseases related to smoking, but not from other diseases, was also lower in the participants. The relatively high mortality in the participants from 'other injury and poisoning' and the relatively low mortality from cancer of the kidney seem likely to be the chance findings that must be expected when so many different causes of death are examined.

The low mortality in both study groups from neoplasms and other non-violent causes of death compared with that expected from national mortality rates is largely explained by the fact that both groups contained a high proportion of officers and men whose occupations would be classified in social class I by the Office of Population Censuses and Surveys, particularly in the older age groups in which most deaths occurred, and that both groups were selected for physical fitness.

Comparison of the mortality rates of the independent respondents who were, respectively, included in and omitted from the main study showed that the results were not substantially biased by the omission of some participants, but that the mortality rates observed might be slightly underestimated.

It is concluded that small hazards of leukaemia and multiple myeloma may well have been associated with participation in the nuclear weapons programme, but that such participation has not otherwise had a detectable effect on the participants' expectation of life or on their total risk of developing cancer.

CONTENTS

		Page No.
1.	INTRODUCTION	1
2.	METHOD OF INVESTIGATION	2
3.	STUDY POPULATION AND DATA COLLECTION	4
	3.1 Definition of a test participant	4
	3.2 Listing of suspected test participants	4
	3.3 Enumeration and characterisation of confirmed test participants	6
	3.4 Radiation exposure of participants	8
	3.5 Listing of possible controls	10
	3.6 Enumeration and characterisation of selected controls	12
	3.7 Comparability of test participants and controls	13
4.	FOLLOW-UP	27
	4.1 Determination of mortality	27
	4.2 Determination of cancer incidence	28
5.	VALIDATION	31
	5.1 Accuracy of personal data	31
	5.2 Completeness of ascertainment of mortality and emigration data	31
	5.3 Completeness of ascertainment of cancer incidence	32
	5.4 Accuracy of diagnoses	33
	5.5 Completeness of coverage of test participants	33
	5.6 Conclusions from validation procedures	38
6.	METHOD OF ANALYSIS	42
7.	RESULTS	45
	7.1 Introduction	45
	7.2 Comparison of mortality in test participants and controls	46
	7.3 Cancer incidence in test participants and controls	50
	7.4 Mortality and cancer incidence within test participants by type and degree of exposure	52
	7.5 Mortality and cancer incidence in independent respondents	55
8.	DISCUSSION	72
	8.1 General considerations	72
	8.2 Cancers of lymphatic and haematopoietic tissue	75
	8.3 Other cancers	78
	8.4 Other diseases	79
	8.5 Possible differences between participants and controls	80
9.	CONCLUSIONS	85
10.	RECOMMENDATIONS	86
11.	ACKNOWLEDGEMENTS	87
12.	REFERENCES	88
13.	ABBREVIATIONS AND ACRONYMS USED	91

		Page No.
Appendix A	Form completed by Service Record Offices for suspected test participants in the Services	92
Appendix B	Form completed by Service Record Offices for controls in the Services	95
Appendix C	Sources of information on independent respondents	101
Appendix D	Form completed by Service Record Offices for independent respondents	102
Appendix E	Comparison of data in NRPB and Birmingham University series	103
Appendix F	Supplementary tables to accompany Section 7	105
Appendix G	Estimation of relative risk after adjustment for men not included in the main study	123
Appendix H	Observed deaths and standardised mortality ratios among test participants and controls by time since entry to the study, for neoplasms and other non-violent causes of death	124

TABLES

The tables associated with each section of the report are grouped at the end of that section for the convenience of the reader.

1. INTRODUCTION

Between 1952 and 1958, the United Kingdom Ministry of Supply (MOS) conducted a series of 21 atmospheric nuclear weapon tests in South and Western Australia and at Malden Island and Christmas Island in the Pacific Ocean. Other experiments in which radioactive materials were dispersed into the environment were also carried out by the MOS at the same sites in South Australia between 1953 and 1963. Survey and clean-up operations continued until 1967, when the sites were returned to Australian control. UK personnel also participated in a series of American tests based at Christmas Island in 1962, finally vacating the Island in 1964.

The Ministry of Defence (MOD) has always believed that only a small proportion of the UK participants could have been exposed specifically to ionising radiations by virtue of their participation and that those who were exposed received only a small radiation dose. Some participants, however, have expressed concern about the effects that their participation may have had on their health. No firm conclusion could be drawn from the studies of small groups of self-identified participants (Knox et al, 1983) nor from the increased incidence of leukaemia that had been reported in the participants in the US shot Smoky in the Plumbob series in Nevada (Caldwell et al, 1980; 1983) except that further research was desirable. MOD, therefore, commissioned the National Radiological Protection Board (NRPB) to undertake a study of the health of the participants, investigating whether it showed any correlation with radiation exposure (Reissland, 1983). The study now reported was designed and carried out by the authors, under the general direction of NRPB, and with the assistance of MOD and other NRPB and Imperial Cancer Research Fund (ICRF) staff, to provide the desired information.

The study was not easy to carry out as no complete list of participants was available for reference. A wide variety of sources were consulted and well over 100,000 records of various kinds had to be examined individually. Many of them, moreover, had to be examined two or three times to eliminate error, explain discrepancies, and make sure that no groups had been overlooked. The description of the methods used to make sure that the information had been accurately transcribed and was free of bias is necessarily long, but it has been included for the benefit of professional epidemiologists and statisticians who may wish to form independent opinions about the reliability of our results. The general reader, who is interested in the nature of our results rather than in the method by which they were obtained, may prefer to omit Section 3, apart from Sections 3.1 and 3.4, and Section 5 as they deal with these aspects, and perhaps also Section 6, which describes the mathematical techniques used to analyse the results.

2. METHOD OF INVESTIGATION

The authors sought first to identify as large a group as practicable of those UK servicemen and civilians who took part in the tests, including UK personnel who participated in the American tests at Christmas Island in 1962, and then to determine:

(i) whether they subsequently suffered a greater incidence of cancer, or mortality from cancer or other causes, than would normally be expected, and

(ii) if they did, whether the increase could be attributed to their participation and related to the level of exposure to ionising radiations that had been recorded.

The authors have chosen to rely primarily on the mortality from specific diseases and from all causes as indicators of the health of the participants for three reasons. Firstly, death is unequivocal, its recording is compulsory and unbiased, and information that it has occurred can be obtained efficiently and rapidly from national records. Secondly, mortality rates are believed to be the best available general indicators of the health of a community, even though they provide no information about the incidence of non-fatal diseases like cataract and eczema. Despite much thought, no better indicators have been suggested and the Department of Health and Social Security continues to use mortality rates for determining the health needs of different parts of the country in the allocation of funds (DHSS, 1976; 1986). Thirdly, any attempt to obtain reliable information about the incidence of a wide range of diseases would have required personal contact with each individual or his general practitioner and a subsequent approach to hospitals for access to many thousands of sets of hospital notes, many of which would prove to have been destroyed. Such an attempt was, in the authors' opinion, both impracticable and unnecessary. It was possible, however, to obtain incomplete but unbiased information about the incidence of cancer through the national cancer registration scheme and, as cancer is certainly the most serious, if not the only, likely effect of low doses of ionising radiations, this information was sought as well.

It could not, of course, be assumed that the mortality and incidence of cancer in the participants, in the absence of any effect of participation, would be identical with that of others in the UK population of the same sex and age. Firstly, participants were selected as fit and healthy for employment, either by the Services or by their civilian employers, and they were further selected as fit for deployment overseas to participate in the tests. Secondly, all participants experienced at least a short period of life in a tropical or desert environment and service personnel experienced a lifestyle that differed materially from that of the majority of the population for the period of their engagement. To overcome these difficulties, an approximately equal number of individuals who did not participate in the tests, but who otherwise had similar characteristics, was also identified from MOD archives to form a control group.

The test participants and controls were then followed up through service records or the records of their civilian employers, and national registers maintained by the Office of Population Censuses and Surveys (OPCS) and the Department of Health and Social Security (DHSS). The authors were thus able to compare cancer and other mortality rates in the test participants not only with the corresponding national rates, but also with those of a control group with a comparable service history.

For the study to be definitive, either all participants needed to be included or the authors needed to be able to show that those who were included were fully representative of all those who had participated. At the time of the test programme, no comprehensive list of participants was compiled, and this made it unlikely that after so many years the authors could be certain to identify every person eligible for the study. Therefore, names and identifying details of participants were sought from many sources other than MOD. People identified in this way include individuals who notified themselves as test participants, or who were notified by a third party. The identification may have been made by contacting a government department or some other public body (for example, NRPB, the BBC or the University of Birmingham), or through one of the organisations of test veterans who have assisted NRPB. A list of the sources from which this further information was obtained is given in Appendix C. The service or personnel records of those individuals who had not previously been identified by our searching of the MOD archives have been examined wherever possible and all for whom there is reason to think that they were eligible have been followed up as a separate group. These individuals are referred to subsequently as independent respondents, and are discussed further in Sections 5 and 7.

3. STUDY POPULATION AND DATA COLLECTION

3.1 Definition of a test participant

The 21 UK atmospheric nuclear weapon tests are listed in Table 3.1. The tests and associated experimental programme took place at the Monte Bello Islands in Western Australia, Emu Field and Maralinga Range in South Australia, and at Malden Island and Christmas Island in the Pacific Ocean. Visits to these five locations in connection with the testing programme were spread over 15 years, as is shown in Table 3.2. All UK servicemen and male employees of the Atomic Weapons Research Establishment, Aldermaston (AWRE) (now part of the Atomic Weapon Establishment (AWE)) and the Atomic Energy Research Establishment, Harwell (AERE), and of their preceding organisations, who were known to have visited any of these five locations during the periods indicated in Table 3.2 were included in the study population as test participants. Also included were UK personnel who worked at two other locations, RAAF Pearce in Western Australia and RAAF Edinburgh Field in South Australia, where the work included cloud sampling and dealing with contaminated aircraft. Men were not included if they had been involved only with peripheral activities associated with the test programme, such as weather forecasting or the handling of non-radioactive stores and supplies, at other locations.

With this definition, 22,347 individuals were identified as test participants, and these constitute the group of test participants in this study. Some individuals are included in it who are thought not to have been exposed to more radiation than the general public. These include, for example, individuals who left the test locations before the first detonation and those who worked at RAAF Edinburgh Field or RAAF Pearce but were not involved in cloud sampling or handling contaminated aircraft. To eliminate the dilution effect caused by their inclusion, the study group has been divided according to the dates when the locations were visited and the nature of the individual's participation in the programme (see Section 7.4).

A few civilians employed by organisations other than AWRE and AERE are also known to have participated in the tests. They have been excluded, however, because of the difficulty of compiling a list of those involved and of obtaining detailed information about them within the timescale of the present study. The small number of women who participated in the tests and all non-UK nationals, other than those with regular engagements in the UK Services or who were permanent employees of AWRE or AERE, have also been excluded in order to simplify and expedite the analysis. Australian and Canadian nationals excluded from this investigation have been studied separately (Commonwealth Department of Health, 1983; Raman et al, 1984).

3.2 Listing of suspected test participants

Provisional lists of service and civilian personnel believed to have participated in the tests had been compiled by AWRE before NRPB was commissioned

to carry out the present study. These lists, collectively known as "the Blue Book", had been compiled by a search of archival material held by AWRE and the Services historical branches. When the Blue Book was examined, two or more entries were sometimes found for men with the same surname and service number. These were regarded as referring to the same individual and the later entries were eliminated. The resulting lists contained the names of approximately 13,000 potential participants. MOD advised, however, that the Blue Book did not provide a complete list, apart from employees of AWRE or AERE and men in the Services whose personal film badges showed exposures greater than the minimum recordable. MOD also advised that the information in the Blue Book had not been checked and might contain transcription errors especially as individuals named in planning documents had been included, some of whom did not, in the event, attend the tests. The Blue Book was, therefore, used only as the starting point for determining the list of participants and extensive searches of MOD archival material were made to identify additional service personnel who had taken part in the tests.

Identification of Royal Navy participants was simpler than for the other Services because most naval participants had been attached to ships for which ledgers, listing the crew, were kept. A number of HM ships had been identified as being involved in the tests by the Blue Book compilers but naval archives provided evidence that several additional ships had visited the test locations during the period covered by the study and the names of those on board at the time were extracted from the ships' ledgers. Extra names were also obtained by searching the ledgers of naval holding units for men on detached duties.

Army archives caused the greatest problem, as no special records had been kept which would have shown precisely who had participated. Personnel records of men who have been discharged from the Army are stored in groups, known as discharge collations, according to (a) the unit to which the man belonged (for example, corps or regiment), (b) whether or not he is currently receiving a pension, and, if not, (c) his year of discharge from Reserve liability. A complete search of all the collations would have taken at least 6 person-years of work and was, therefore, impracticable in the time available. Fortunately, however, the great majority of Army participants were Royal Engineers and the relevant collations for Royal Engineers could be, and were, searched systematically for evidence of test participation using the deployment information provided in each service record. Further names of Army personnel were identified from ships' ledgers, lists of Army honours awards, and security vetting records.

RAF archives contained squadron operational record books that related to test activities and several books were found that had not been examined when the original Blue Book lists were compiled. These yielded further names of RAF officers and some airmen.

Additional participants from all three Services were identified from day passes issued by the Australian authorities for the Maralinga range and from archival material discovered during the general search. A substantial number of soldier and airman participants were identified directly from service records when searching for the records of known test participants and in the search for controls. Altogether, these procedures identified approximately 17,000 men who might have been participants in addition to the 13,000 already included in the Blue Book.

3.3 Enumeration and characterisation of confirmed test participants

For each individual recorded in the Blue Book and for all other servicemen discovered from other sources, identifying data were recorded on NRPB's computerised data-base together with the relevant operation or test location, the dates present, and the man's ship, unit, squadron or other organisational group during the tests. For each individual on the data-base, NRPB produced a form, divided into two sections. (The form used is reproduced in Appendix A.) Section A was completed by NRPB and gave the details necessary for the man's identification and the information suggesting possible involvement in the tests, while Section B was for completion by the Service Record Offices.

There were altogether 28,580 forms for servicemen suspected of being test participants. This total is shown in Table 3.3 divided by service branch and the original source of information.

The forms for servicemen were then sent to Service Record Offices with detailed notes for guidance, and the record custodians of the three Services were asked to trace the record for each suspected participant and to find out whether the deployment information in the service record matched the information already recorded on the form and to complete Section B accordingly, including details of any additional test involvements mentioned in the service record. When the deployment and information on the form did not conflict but the deployment information was insufficient to confirm presence in the test area unequivocally, the source material that had suggested that the individual might have been involved in the tests was re-examined to see if it was clear enough to confirm test participation. In cases where the service record did not match the information given on the form, the source material was checked for transcription errors. When doubt persisted, all available information relating to the individual was examined by NRPB staff. If doubt still persisted, the individual was excluded.

When test participation was confirmed, service record custodians were asked to record in Section B of the form information showing characteristics of his service (National or Regular service, job in service, dates of first enlistment and last discharge, and reason for discharge) and information that would help in tracing the man (full forenames, any previous surnames, date and place of birth, nationality at birth, civilian addresses and dates, National Insurance Number,

and National Registration or Health Service Number). If the man was discharged dead, information was also requested about the date and place of death. Completed forms were then returned to NRPB and the additional information transferred to the NRPB data-base.

For AWRE and AERE test participants, forms were not produced but computer listings were made of the identification and test participation details that had been notified to NRPB. NRPB staff then examined the AWRE overseas travel registers and health physics records to confirm that each individual had actually visited a test location on the stated dates. Where neither of these two sources provided definite confirmation of participation, confirmation was sought from any other archival source. All employees of AERE and AWRE and their preceding organisations are included in follow-up studies of radiation-exposed workers being carried out by the Medical Research Council's (MRC) Epidemiological Monitoring Unit (Fraser et al, 1985; Beral et al, 1985) and the Unit's help was sought to obtain the necessary information about those who had been test participants.

The results of these checks are shown in Table 3.4. (Over 95% of the civilians in the study were employees of AWRE rather than AERE. For brevity they are all referred to as AWRE employees in the tables.) No relevant records could be traced for 897 (3.1%) of the servicemen and 5 (0.5%) of the civilians. The traced records confirmed that 22,347 individuals had participated in the tests (75.3% of the servicemen and 80.8% of the civilians), and showed that the remainder were ineligible for inclusion according to study criteria or were duplicate entries.

Of the suspected participants whose records were untraced, 640 (71%) were thought to have been in the RAF, some 217 (24%) were thought to have been in the Army, 40 (4%) in the Royal Navy, NAAFI, Royal Marines or RNVR, and 5 (0.6%) civilian employees of AWRE or AERE. The great majority of untraced individuals were associated with the tests on Christmas Island (47%) or Maralinga (40%) but some had been thought to be possibly associated with each operation and location except Pearce Field. The failure to trace records of suspected participants was often due to the lack of sufficient information for precise identification. It was possible that 243 (27%) were identical with men accepted as participants and 45 (5%) with men known to have been overseas visitors. There were 15 who were identified as probably being Canadians (and so ineligible), but regulations prevented the Canadian authorities from revealing their names. A further 3 individuals were identified as New Zealand citizens by the New Zealand authorities.

The reasons for which suspected test participants were regarded as ineligible are shown in Table 3.5. Out of a total of 2342, 954 (41%) were in the RAF, 905 (39%) in the RN and 296 (13%) in the Army. For 779 (33%), the man's name had been obtained from the ledger of HMS *Newfoundland* and so included in the

original Blue Book listings; but it was later established that HMS *Newfoundland* had not visited any of the test locations. For 459 (20%), the records revealed that the individuals were ineligible because they were not UK nationals (283) or because they were civilians not employed by AWRE or AERE (159) or female (17). For the remaining 1104 (47%) participation could neither be excluded nor confirmed. The majority of these men had visited Australia, but the records did not specify the task or the location.

For 10 test participants the service record was incomplete and information about date of birth, date of enlistment, date of discharge, or type of engagement was missing. One possible reason for the incompleteness of the record is that the man later developed a disease that he or his dependents attributed to his service, the consequent removal of the record for investigation causing the record to be mislaid. For this reason these men have been retained in the study population, with the value of the missing variable assumed to be equal to the average value of that variable for other men in the study with similar values for the remaining variables, and similar rank, service, and test participation details.

3.4 Radiation exposure of participants

The numbers of attendances at different operations and different locations that were made by the test participants are shown in Table 3.6. Men in the RM, the RNVR and the NAAFI have been grouped with those in the RN, under the heading RN, etc. Almost 60% of the attendances were at Christmas Island and just under a quarter were at the Maralinga Range. Overall more than 40% of visits were made by RAF personnel, but the distribution of visits between the three Services and AWRE varied from operation to operation. For Hurricane and Mosaic at the Monte Bello Islands, about 80% of visits were by men in the RN, etc, while for Totem at Emu Field, over 80% of visits were by AWRE personnel. Over half the attendances at the Maralinga Range and almost all at Edinburgh Field were by RAF personnel, and RAF personnel also contributed nearly 40% of the attendances at Christmas Island.

The distribution of the number of attendances made by each participant is shown in Table 3.7. In each of the three Services the majority of men were recorded as attending only once. In contrast, more than half the AWRE personnel were recorded as attending more often, and a few individuals were recorded as attending on 10 or more occasions.

At the start of the study NRPB were informed by MOD that only a small proportion of test participants were liable to have been exposed to radiation as a consequence of their test participation. The relevant groups of personnel were:

(i) the members of the crew of HMS *Diana* which sailed through the fallout plumes in Operation Mosaic;

(ii) the members of the Buffalo Indoctrinee Force, a group of volunteer officers assembled to observe at first-hand the effects of a nuclear explosion;

(iii) RAF aircrews involved in radioactive sampling from the clouds of the explosions;

(iv) the RAF active handling flight, who decontaminated aircraft used in cloud sampling, and

(v) individuals not in groups (i)-(iv) but who had recorded radiation doses greater than zero.

The numbers of attendances at each operation by the members of these special groups, together with estimates of the total collective doses are shown in Table 3.8.

The numbers of individuals involved in the special groups are shown in Table 3.9 by Service. Of the 22,347 test participants included in the study, only 1804 (8%) are believed by MOD to have been liable to exposure to radiation. The proportion was very much higher for AWRE personnel, 409 (50%) of whom were included in a special group.

Explicit exposure data for 1373 men are recorded in the Blue Book listings. These were in the form of gamma exposure stated in millirem (mrem). In some cases surface exposures in the form of gamma plus beta aggregate or localised doses were also available. For operations listed in Table 3.1, exposures were given as totals for the operation, while for staff deployed for a period at the Maralinga range they were given as annual totals. The exposure data had been compiled by AWRE staff from original film badge records and summaries of radiation exposures recorded at the tests that had been prepared by the AWRE Health Physics Group in the early 1960s. Dosemeters at the tests had been calibrated in terms of roentgen but, in collating the data, AWRE staff made the conventional approximation that an exposure of 1 roentgen delivered a dose equivalent to the whole body of 10 mSv. In what follows the term "dose" will be used rather than "exposure". This both avoids confusion between the technical and general senses of the latter term and is more consistent with the units used (sieverts). NRPB were informed that the listings included doses from every personal film badge dosemeter issued that had registered a dose greater than the minimum recordable level. At the end of the test programme in the 1960s the minimum recordable level was 0.1 mSv but the normal figure in Australia was 0.2 mSv, though, on occasions, 0.3 mSv or 0.5 mSv were used. For the Buffalo Indoctrinee Force at Buffalo Round 1, the minimum recordable level was 4 mSv as low sensitivity emulsion film badges had been issued which did not record lower doses. Exposures to neutrons and from internal contamination by radioactive materials will not have been recorded on personal film badge dosemeters. This complication was recognised from the outset and its impact is considered later (see Section 8.2).

The total collective gamma dose recorded for test participants in the study was 16,641 man mSv (see Table 3.8). All the operations listed in Table 3.1 contributed, but the largest contribution was for operation Grapple Z for which a collective dose of 3814 man mSv was recorded. Table 3.10 shows the distribution of doses to individuals by Service or employer together with the collective dose in each dose category. Only 483 individuals received 5 mSv or more. Eighty test participants were recorded as having received 50 mSv or more, the current legal annual dose limit for radiation workers, though the doses referred to here are totals for the entire test programme and so may be spread over several years. A large majority (80%) of these 80 individuals were the crew of aircraft which sampled the radioactive cloud from the explosions. These aircrew received half the collective dose (8334 man mSv out of a total of 16,641 man mSv). AWRE employees received the next largest fraction of the collective dose (3723 man mSv).

In addition to the members of the special groups, there were 2928 more individuals mentioned in a series of Health Physics Documents held by AWRE. These were men who had had a dosemeter issued for which no detectable dose was recorded. Their distribution by Service or employer was RN, etc: 1253; Army:469; RAF:902; AWRE:304. NRPB were informed by MOD that the high proportion of naval personnel in this group reflected a greater propensity to monitor individuals at the first test, Hurricane, where there was a high proportion of naval personnel. It did not imply that men involved in Operation Hurricane were more likely to be exposed compared with men attending other tests.

A total of 1503 test participants were included in the study who are unlikely to have been exposed to more radiation than the general public. These were individuals whose only visits to test locations were in the following categories:

(i) Edinburgh Field or Pearce Field, with no evidence of any involvement in cloud sampling or the decontamination of aircraft;

(ii) Monte Bello Islands, but departing before 3 October 1952, the date of Hurricane;

(iii) Christmas Island but departing before 15 May 1957, the date of the first Grapple explosion;

(iv) the crew of HMS *Comus* or HMS *Concord*, both of which visited the Monte Bello Islands briefly in March and April 1956 before the first explosion of Mosaic.

Their distribution between the Services was RN, etc:396, Army:515, RAF:592. These individuals are considered as a separate subgroup in the analysis of the results.

3.5 Listing of possible controls

The criteria used for selecting controls varied between different categories of test participants, according to the differing information and record systems available.

For test participants in the Services, controls were chosen from servicemen who did not participate in the Weapon Test Programme, but who had served in tropical or sub-tropical areas other than the test locations while the tests were being carried out. Controls were selected by the service record custodians according to criteria laid down by NRPB. For the Royal Navy, the dates of visits made by each ship to the test locations were noted and the Naval Historical Branch was asked to identify a ship of similar size that was deployed on the same dates in tropical waters (including the Persian Gulf) away from the test locations. The names of those on board for the corresponding period were extracted from the ships' ledgers, excluding visitors and short stay personnel who were on board for less than 10 days.

For officers in the Army and in the RAF, control personnel were identified from the monthly Army strength returns and RAF operational record books for selected units and squadrons deployed in tropical or sub-tropical areas on dates at which test participants were deployed in test locations.

For airmen and soldiers no lists of individuals deployed in tropical areas were available and controls had to be selected directly from the service records using matching procedures. For airmen, the place in which an individual's service record was stored was not affected by premature death or ill-health. For each airman test participant, neighbouring service records were searched until an eligible control was found. For eligibility the control had to have the same type of service (National Service or Regular) as the test participant and a date of birth within 18 months, and he needed to have commenced a period of tropical service starting no earlier than 5 years before and ending no later than 5 years after the year of the test participant's first test participation. In a few instances these stringent criteria could not be met and National Servicemen were chosen as controls for regular airmen or vice versa (10% of cases) or the period of tropical service of the control lay slightly outside the specified limits (0.5% of cases).

For each soldier test participant, who had been discharged from the Army other than on medical grounds, who was not a current pensioner and had remained alive until the end of his period of Reserve liability, a control was selected from the same discharge collation (see Section 3.2), with the same type of service (National Service or Regular) as the test participant, whose year of birth and year of first enlistment were within 2 years of those of the test participant, who had commenced a period of tropical service within 2 years of the test participant's first participation in the test programme, who had been discharged from the Army on other than medical grounds, and who had remained alive until the end of his period of Reserve liability. In 27% of cases these stringent criteria could not be met and a slightly weaker set of criteria was used. It was still required that the year of discharge collation should be the same as that of the participant, that the control had been discharged from the

Army for reasons other than medical grounds, and that he had remained alive until the end of his period of liability for Reserve Service, but other corps or regiments could be used, the year of birth was matched as closely as possible, and the calendar requirement for the period of service in the tropics was relaxed. The service records for soldiers who died in service or during their period of liability for Reserve Service, or who were discharged from the Army on medical grounds, are stored in different discharge collations from the ones in which they would have appeared if the man had been discharged alive and well, and the records of serving soldiers, pensioners and others still liable for Reserve Service are stored separately. It was, therefore, impossible to use the collations of service records to select appropriate controls for test participants in these categories. Allowance for the lack of controls for these groups has been made in the analysis (see Section 6).

For employees of AWRE, AERE or their forerunners, controls were selected from AWRE employees who had not visited a test location or attended tests at a test site in the USA. Controls were selected from the data-base of AWRE employees compiled for the MRC's study of the health of nuclear energy workers. For each test participant, a control was selected who started work at AWRE in the same year as the test participant had started work at AWRE or AERE, and had the same social class (Office of Population Censuses and Surveys, 1970) and radiation worker status (defined as whether or not required to wear regularly for their work with AWRE a film badge that would measure the dose received). For 29 test participants, all of whom started work at AWRE in 1951 or earlier and who were radiation workers, no control could be found who satisfied these criteria exactly, and for these few, control radiation workers were selected using a slightly relaxed set of criteria, in which social classes 1 and 2 and the years 1946-49 for commencement of employment were each grouped together.

3.6 Enumeration and characterisation of selected controls

For each serviceman selected as a possible control, NRPB produced a form (see Appendix B) equivalent to the forms used for possible test participants. Altogether 22,186 forms were produced for servicemen. This total is shown in Table 3.11 divided by service branch. The forms were sent to the service record custodians, accompanied by detailed notes for guidance. The custodians were asked to provide corresponding personal data from the service record in Section B as they had been asked to do for test participants, and to make a careful study of the deployment information in the service record to ensure that there was no evidence that the man had participated in the test programme. For each individual identified via a ship's ledger, Army strength return, or RAF operational record book, the custodians were also asked to confirm that the individual was indeed deployed in the tropics as had been indicated in the original source material.

The results of these checks are shown in Table 3.12. No relevant records could be traced for 0.1% of the servicemen. The traced records confirmed that 97.0% of the servicemen and 98.7% of the civilians could appropriately serve as controls and showed that the remainder were ineligible or duplicate entries.

Of the 20 untraced controls, 8 were in the NAAFI, 6 in the RM, 3 in the RN, and 3 were officers in the Army. Controls for soldiers, airmen, and civilians were selected directly from the stored service records and the Harwell data-bases; consequently there were no untraced controls in these groups.

The reasons for which potential controls were excluded from the study are summarised in Table 3.13 by Service or employer. Out of a total of 302 exclusions, 124 (41%) were in the Royal Navy, 103 (34%) in the Army, and 54 (18%) in the RAF. The most common reason for exclusion, accounting for over half the exclusions, was that further investigation revealed that they were, in fact, test participants. Ten men identified from ships' ledgers were found to be short stay personnel or visitors to the ship and 98 men were found to have emigrated and 27 to have died before their nominal dates of entry to the study (see Section 6).

3.7 Comparability of test participants and controls

The distributions of test participants and of controls by Service or employer, rank or social class and, for servicemen, whether on National Service is given in Table 3.14. Of test participants, 39% were in the RAF, 30% in the group RN, etc, 28% in the Army, and only 4% employed by AWRE; the corresponding distribution among the controls was similar, except that there were relatively fewer controls in the Army (see Section 3.5). Overall, 14% of test participants and 15% of controls were either officers or in social class I; but the distribution varied between the Services. In the RN, etc, and the Army about one-tenth of personnel were officers, while in the RAF the proportion was about a quarter, and nearly half the AWRE personnel were in social class I. Some 12% of test participants and 13% of controls were on National Service, the majority being in the Army.

The distributions of test participants and of controls by year of birth, year of enlistment (servicemen) or commencement of employment (civilians), and year of discharge (servicemen) or termination of employment (civilians) are given in Tables 3.15-3.17. For all three variables the distribution is almost identical in the two groups, indicating that the control selection procedures had succeeded in identifying a group of individuals with closely similar characteristics to the test participants.

Table 3.1
UK atmospheric nuclear weapon tests in Australia and the Pacific, 1952-1958[1]

Operation	Round	Location	Date of firing[2]	Yield	Explosion conditions
Hurricane		off Trimouille Island, Monte Bello Islands, Western Australia	3 Oct 1952	25 kt	Ocean surface burst
Totem	1	Emu Field, S. Australia	14 Oct 1953	10 kt	Tower mounted
Totem	2	Emu Field, S. Australia	26 Oct 1953	8 kt	Tower mounted
Mosaic	1	Trimouille Island, Monte Bello Islands, Western Australia	16 May 1956	15 kt	Tower mounted
Mosaic	2	Alpha Island, Monte Bello Islands, Western Australia	19 Jun 1956	60 kt	Tower mounted
Buffalo	1	One Tree, Maralinga Range, S. Australia	27 Sep 1956	15 kt	Tower mounted
Buffalo	2	Marcoo, Maralinga Range, S. Australia	4 Oct 1956	1.5 kt	Ground surface burst
Buffalo	3	Kite, Maralinga Range, S. Australia	11 Oct 1956	3 kt	Air dropped - high air burst over land
Buffalo	4	Breakaway, Maralinga Range, S. Australia	21 Oct 1956	10 kt	Tower mounted
Grapple	1	off Malden Island, Pacific Ocean	15 May 1957	megaton[3]	Air dropped - high air burst over ocean
Grapple	2	off Malden Island, Pacific Ocean	31 May 1957	megaton[3]	Air dropped - high air burst over ocean
Grapple	3	off Malden Island, Pacific Ocean	19 Jun 1957	megaton[3]	Air dropped - high air burst over ocean
Antler	1	Tadje, Maralinga Range, S. Australia	14 Sep 1957	1 kt	Tower mounted
Antler	2	Biak, Maralinga Range, S. Australia	25 Sep 1957	6 kt	Tower mounted
Antler	3	Taranaki, Maralinga Range, S. Australia	9 Oct 1957	25 kt	Balloon suspended - high air burst over land
Grapple X		off Christmas Island, Pacific Ocean	8 Nov 1957	megaton[3]	Air dropped - high air burst over ocean
Grapple Y		off Christmas Island, Pacific Ocean	28 Apr 1958	megaton[3]	Air dropped - high air burst over ocean
Grapple Z	1	Christmas Island, Pacific Ocean	22 Aug 1958	kiloton[4]	Balloon suspended - high air burst over ocean
Grapple Z	2	off Christmas Island, Pacific Ocean	2 Sep 1958	megaton[3]	Air dropped - high air burst over ocean
Grapple Z	3	off Christmas Island, Pacific Ocean	11 Sep 1958	megaton[3]	Air dropped - high air burst over ocean
Grapple Z	4	Christmas Island, Pacific Ocean	23 Sep 1958	kiloton[4]	Balloon suspended - high air burst over land

Notes:

1. A series of 25 US tests, part of US Operation Dominic and known as Operation Brigadoon, took place off Christmas Island between April and July 1962 (Carter and Moghissi, 1977). UK personnel known to have attended are also included in the present study.

2. Dates according to Greenwich Mean Time.

3. Megaton - yield range (few hundred kiloton to several megaton).

4. Kiloton - yield range (1-1000 kiloton).

Table 3.2

Locations and periods for the UK atmospheric nuclear weapon testing programme*

Location	Period	Comment
Monte Bello Islands, Western Australia	Apr 1952-Jun 1956	The first ships of the Royal Naval Task Force for Operation Hurricane arrived in April 1952. The last ships of the Royal Naval Task Force for Operation Mosaic left in June 1956.
Emu Field, South Australia	Aug 1953-Aug 1967	The first members of the Radiological Hazards Group for trials at Emu Field arrived in August 1953. The UK clearing-up operation was completed in August 1967.
Maralinga Range, South Australia	Apr 1955-Aug 1967	The first scientific personnel for activities involving the dispersal of radioactive material into the environment arrived at Maralinga in April 1955. The UK clearing-up operation was completed in August 1967.
Christmas Island, Pacific Ocean	Jun 1956-Jun 1964	The first UK personnel for Grapple arrived on Christmas Island in June 1956. The final clearing-up exercise finished in June 1964.
Malden Island, Pacific Ocean	Oct 1956-Jun 1964	The first UK personnel for Grapple arrived on Malden Island in October 1956. The evacuation of Malden Island was completed by June 1964.
RAAF Pearce, Western Australia	May 1956-Aug 1956	UK personnel involved with cloud sampling for operation Mosaic were based at RAAF Pearce during this period, including some who remained there for 2 months after June 1956 when the Royal Navy Task Force left the Monte Bello Islands.
RAAF Edinburgh Field, South Australia	Aug 1956-Nov 1960	UK personnel involved with cloud sampling for Operation Buffalo were based at RAAF Edinburgh Field from August 1956. The RAF Holding Unit was withdrawn from RAAF Edinburgh Field in November 1960.

* Only locations where there was a possibility of radiation exposure to UK personnel as a result of the weapon tests are included.

Table 3.3

Numbers of servicemen who were possible test participants, by Service and original source of information

Service	Number of possible test participants		
	Listed in Blue Book	Added from other sources	Total
Royal Navy (RN)	5,487	2,180	7,667
Army	2,263	4,944	7,207
Royal Air Force (RAF)	3,789	9,441	13,230
Navy, Army & Air Force Institute (NAAFI)	27	18	45
Royal Marines (RM)	288	120	408
Royal Naval Volunteer Reserve (RNVR)	17	6	23
Total	11,871	16,709	28,580

Table 3.4

Results of checking information about possible test participants against official records

Records	Number of forms issued for possible test participants who were servicemen	Number of names listed for possible test participants who were AWRE employees	Total
Untraced	897 (3.1)*	5 (0.5)	902 (3.0)
Traced			
Participation confirmed	21,531 (75.3)	816 (80.8)	22,347 (75.5)
Duplicate entry	3,986 (13.9)	13 (1.3)	3,999 (13.5)
Ineligible	2,166 (7.6)	176 (17.4)	2,342 (7.9)
Total	28,580 (100.0)	1,010 (100.0)	29,590 (100.0)

* Percentages are shown in parentheses.

Table 3.5

Numbers of possible test participants excluded by Service or employer and reason for exclusion

Reason for exclusion	Service/employer							
	RN	Army	RAF	RM	RNVR	NAAFI	AWRE	Total
HMS Newfoundland	770	0	0	9	0	0	0	779
Ineligible								
Non UK national	17	197	63	0	0	1	5	283
Civilian not employed by AWRE or AERE	1	7	4	0	0	0	147	159
Female	0	0	17	0	0	0	0	17
No firm evidence of participation	117	92	870	1	0	0	24	1,104
All reasons	905	296	954	10	0	1	176	2,342

Table 3.6

Numbers of attendances at different operations and test locations, by Service or employer

Location and operation	Service or employer				
	RN, etc	Army	RAF	AWRE	Total
Monte Bello Islands:					
Hurricane	1,074	205	21	95	1,395
Mosaic	1,507	72	127	49	1,755
Other	12	0	0	0	12
Emu Field:					
Totem	1	11	9	86	107
Maralinga Range:					
Buffalo[1]	5	194	846	203	1,248
Antler[2]	60	122	1,129	196	1,507
Minor trials	5	212	61	569	847
Other	546	1,195	2,361	80	4,182
Christmas Island:					
Grapple	1,720	634	1,000	117	3,471
Grapple X	595	618	926	108	2,247
Grapple Y	850	1,319	1,301	113	3,583
Grapple Z	738	1,414	1,901	181	4,234
Brigadoon	63	225	344	47	679
Other	672	2,303	1,716	44	4,735
Edinburgh Field[3]	0	11	2,070	0	2,081
Total	7,848	8,535	13,812	1,888	32,083

Notes:

1. Includes 66 visits to Maralinga at the time of Buffalo for which there was no mention of Buffalo or the minor trials on the source document or the service record.

2. Includes 302 visits to Maralinga at the time of Antler for which there was no mention of Antler or the minor trials on the source document or the service record.

3. Includes 2 visits to Pearce Field.

Table 3.7

Distribution of test participants by number of recorded visits to test locations and Service

Number of visits	Service or employer				
	RN, etc	Army	RAF	AWRE	Total
1	5,700	4,282	5,387	367	15,736
2	854	1,691	2,026	187	4,758
3	125	167	630	114	1,036
4	15	58	432	59	564
5	1	19	88	35	143
6	0	6	34	25	65
7	0	1	10	8	19
8	0	0	4	11	15
9	0	0	1	3	4
10	0	0	0	5	5
11	0	0	0	1	1
12	0	0	0	1	1
Total number of test participants	6,695	6,224	8,612	816	22,347
Total number of visits	7,848	8,535	13,812	1,888	32,083

Table 3.8

Numbers of test visits believed by MOD to have been liable to exposure to radiation, by group and operation together with collective gamma dose recorded[1]

Location and operation	Special group						
	Crew of HMS Diana (i)	Buffalo Indoctrinee Force[2] (ii)	Aircrew involved in cloud sampling (iii)	Active handling flight (iv)	Other non-zero dose record (v)	Total number of visits	Total collective gamma dose (man mSv)
Monte Bello Islands:							
Hurricane	-	-	-	-	205	205	2,426
Mosaic	282	-	19	16	159	476	1,274
Emu Field:							
Totem	-	-	3	-	56	59	1,133
Maralinga Range:							
Buffalo	-	172	31	22	138	363	2,156
Antler	-	-	28	34	251	313	1,865
Minor trials	-	-	-	-	234	234	775
Other[3]	-	-	-	-	36	36	111
Christmas Island:							
Grapple	-	-	23	28	28	79	1,018
Grapple X	-	-	14	25	88	127	1,081
Grapple Y	-	-	13	35	48	96	981
Grapple Z	-	-	34	44	145	223	3,814
Brigadoon	-	-	-	-	3	3	6
Other	-	-	-	-	9	9	1
Total number of test visits	282	172	165	204	1,400	2,223	-
Total collective dose (man mSv)[4]	0.2	360[2]	8,334	672	7,275	-	16,641

Notes:

1. For each operation any individual has been allocated to at most one special group, however individuals may be mentioned twice on this table, for different operations.

2. 64 members of the Buffalo Indoctrinee Force were exposed to low levels of neutron radiation. There were no direct measurements of neutron doses to these individuals and estimates are based on calculations. MOD have estimated that, although there must be some uncertainty, the collective dose from neutrons to the Buffalo Indoctrinee Force was approaching 1 man mSv. This is not included in the figure of 360 man mSv total collective dose.

3. Including Edinburgh Field.

4. The collective dose, that is the sum of the doses received by all the individuals in a group, is commonly used in radiobiology as an indicator of the frequency with which harmful effects might be expected to occur in the group as a whole. It is preferred to the mean dose to individual members as different individuals will have received different doses and been exposed, in consequence, to different risks. It can, however, be replaced by the mean dose to individuals by dividing the collective dose by the number of individuals exposed.

Table 3.9

Numbers of individuals believed by MOD to have been liable to exposure to radiation, by group and Service

Service or employer	Special group						
	Crew of HMS Diana (i)	Buffalo Indoctrinee Force (ii)	Aircrew involved in cloud sampling (iii)	Active handling flight (iv)	Other non-zero dose record[1] (v)	Total number of indiv-iduals	Total collective gamma dose (man mSv)
RN, etc	282	2	0	0	193	477	1,008
Army	0	170	0	0	300	470	2,137
RAF	0	0	98	129	221	448	9,773
AWRE	0	0	0	0	409	409	3,723
Total	282[2]	172[2]	98	129	1,123	1,804	16,641

Notes:

1. Individuals are included in this group only if they are not in groups (i)-(iv).

2. Very few men in these groups had doses above the threshold of detection recorded.

Table 3.10

Number of individuals (and collective dose) in different gamma dose categories by Service or employer

Dose category (mSv)	Service or employer									
	RN, etc		Army		RAF		AWRE		Total	
	No	(Dose) (man mSv)	No	(Dose) (man mSv)	No	(Dose) (man mSv)	No	(Dose) (man mSv)	No	(Dose) (man mSv)
0.01-0.99	88	(30)	191	(92)	160	(68)	151	(71)	590	(261)
1.00-4.99	45	(126)	68	(177)	81	(176)	106	(250)	300	(730)
5.00-9.99	25	(184)	49	(297)	33	(233)	53	(378)	160	(1092)
10.00-49.99	36	(668)	49	(1296)	69	(1589)	89	(2014)	243	(5567)
50.00-99.99	0		4	(275)	32	(2349)	8	(627)	44	(3251)
>100.00	0		0		34	(5358)	2	(384)	36	(5742)
Total	194	(1008)	361	(2137)	409	(9773)	409	(3723)	1373	(16641)

Note:

Doses have been rounded to the nearest man mSv and individuals have been assigned to dose classes based on their total dose in the whole test programme (this accounts for some apparent minor discrepancies in the totals).

Table 3.11

Numbers of servicemen who were selected as possible controls, by Service group

Service	No of possible controls
Royal Navy (RN)	7,071
Army	5,584
Royal Air Force (RAF)	8,999
Navy, Army and Air Force Institute (NAAFI)	35
Royal Marines (RM)	486
Royal Naval Volunteer Reserve (RNVR)	11
All servicemen	22,186

Table 3.12

Result of checking information on forms about men selected as controls against official records

Records	Number of forms issued for servicemen selected as controls	Number of AWRE employees selected as controls	Total
Untraced	20 (0.1)*	0 (0.0)	20 (0.1)
Traced			
Duplicate entry	354 (1.6)	0 (0.0)	354 (1.5)
Ineligible	291 (1.3)	11 (1.3)	302 (1.3)
Acceptable, no evidence of participation	21,521 (97.0)	805 (98.7)	22,326 (97.1)
Total	22,186 (100.0)	816 (100.0)	23,002 (100.0)

* Percentages as shown in parentheses.

Table 3.13

Reasons for which men selected as controls were deemed ineligible and excluded

Reason for exclusion	Service or employer							Total
	RN	Army	RAF	RM	RNVR	NAAFI	AWRE	
Man initially selected as control found to have participated in tests	111	1	45	7	0	2	1	167
Short stay	9	-	-	1	0	0	-	10
Emigrated before nominal date of entry to study	1	90	1	0	0	0	6	98
Died before nominal date of entry to study	3	12	8	0	0	0	4	27
Total	124	103	54	8	0	2	11	302

Table 3.14

Test participants and controls by Service or employer, rank or social class and, for servicemen, whether on national service

Service or employer	Rank	Test participants			Controls		
		National servicemen	Others	Total no. (%)	National Servicemen	Others	Total no. (%)
RN, etc	Officers	59[1]	458[2]	517 (2%)	22[3]	559[4]	581 (3%)
	Other ranks	355[5]	5,823[6]	6,178 (28%)	261[7]	6,498[8]	6,759 (30%)
	Total	414	6,281	6,695 (30%)	283	7,057	7,340 (33%)
Army	Officers	27	566	593 (3%)	173	485	658 (3%)
	Other ranks	1,783	3,848	5,631 (25%)	1,727	3,092	4,819 (22%)
	Total	1,810	4,414	6,224 (28%)	1,900	3,577	5,477 (25%)
RAF	Officers	16	1,690	1,706 (8%)	43	1,757	1,800 (8%)
	Other ranks	405	6,501	6,906 (31%)	765	6,139	6,904 (31%)
	Total	421	8,191	8,612 (39%)	808	7,896	8,704 (39%)
AWRE	Social class I	-	380[9]	380 (2%)	-	361	361 (2%)
	Other social classes	-	436	436 (2%)	-	444	444 (2%)
	Total	-	816	816 (4%)	-	805	805 (4%)
All Services and employers	Officers/social class I	102	3,094	3,196 (14%)	238	3,162	3,400 (15%)
	Other ranks/social classes	2,543	16,608	19,151 (86%)	2,753	16,173	18,926 (85%)
	Total	2,645	19,702	22,347 (100%)	2,991	19,335	22,326 (100%)

Notes:

1. Includes 22 RNVR officers.
2. Includes 10 RM officers.
3. Includes 11 RM officers.
4. Includes 11 RNVR officers.
5. Includes 62 RM other ranks.
6. Includes 313 RM other ranks and 31 NAAFI personnel.
7. Includes 28 RM other ranks.
8. Includes 431 RM other ranks and 22 NAAFI personnel.
9. Includes 23 AERE employees.

Table 3.15

Distribution of test participants and controls by year of birth

Year of birth	Test participants		Controls	
	No	%	No	%
Before 1900	5	0	27	0
1900-04	31	0	45	0
1905-09	155	1	219	1
1910-14	550	2	636	3
1915-19	1,240	6	1,210	5
1920-24	2,157	10	2,065	9
1925-29	2,104	9	2,139	10
1930-34	4,566	20	4,433	20
1935-39	10,220	46	10,214	46
1940-44	1,235	6	1,275	6
1945-49	84	0	63	0
Total	22,347	100	22,326	100

Table 3.16

Distribution of test participants and controls by year of enlistment (servicemen) or commencement of employment (civilians)

Date of enlistment or employment	Test participants		Controls	
	No	%	No	%
1900-04	1	0	0	0
1905-09	0	0	0	0
1910-14	1	0	1	0
1915-19	4	0	3	0
1920-24	21	0	44	0
1925-29	149	1	199	1
1930-34	347	2	386	2
1935-39	1,669	7	1,817	8
1940-44	1,840	8	1,581	7
1945-49	2,994	13	3,141	14
1950-54	6,023	27	6,321	28
1955-59	8,764	39	8,277	37
1960-64	513	2	545	2
1965-69	21	0	11	0
1970-74	0	0	0	0
Total	22,347	100	22,326	100

Table 3.17

Distribution of test participants and controls by year of discharge (servicemen) or termination of employment (civilians)

Date of discharge or termination	Test participants		Controls	
	No	%	No	%
1945-49	0	0	9	0
1950-54	501	2	440	2
1955-59	5,687	25	6,660	30
1960-64	6,233	28	6,136	27
1965-69	4,383	20	4,325	19
1970-74	2,177	10	1,969	9
1975-79	1,840	8	1,466	7
1980-83	769	3	649	3
Still in Service or employment on 1.1.84	757	3	672	3
Total	22,347	100	22,326	100

4. FOLLOW-UP

4.1 Determination of mortality

An attempt was made to follow all men who were accepted as test participants or controls to 1 January 1984. Details sufficient to identify the men were submitted to the National Health Service (NHS) central registers at Southport and Edinburgh (Office of Population Censuses and Surveys (OPCS), 1982), where searches were made to see if there was a record that the individual had emigrated or died, and the results were notified to NRPB. For individuals who were recorded as having died, both the underlying and the contributory causes of death, as stated on the death certificate, were coded according to the 9th revision of the International Classification of Diseases (ICD) (World Health Organisation, 1977) by OPCS staff. After coding, the particulars were returned to NRPB and reviewed by one of the authors (RD).

For servicemen who could not be traced on the NHS central registers, further attempts were made to trace the men with the help of health departments in Belfast, the Isle of Man, and Jersey. If there was any indication that the men might have died on Guernsey or in the Republic of Ireland, copies of death certificates were sought from the relevant offices. For individuals who remained untraced, the forms were returned to MOD for the personal data to be re-checked and to see if any additional information could be found that would be useful in tracing. Revised details (if any) were then resubmitted to the NHS central registers.

Identifying details of four groups of men were submitted to the Department of Health and Social Security (DHSS) Records Branch at Newcastle: namely

(i) men who were not satisfactorily traced on the NHS central registers (that is, men who were untraced or who were traced but found not to be currently registered with a Family Practitioner Committee (FPC)),

(ii) men who had been reported, either by MOD or by the NHS central registers, as having died, but for whom OPCS were unable to supply copies of the death certificate,

(iii) men who were reported by the NHS Central Registers as living in Northern Ireland, the Isle of Man or Jersey, but who were untraced by the relevant local health department, and

(iv) all remaining men who were born before 1916 (that is, thought to be over 70 years of age at the time of completion of the follow-up).

At Newcastle a search was made to see if a death grant had been claimed for the individual. DHSS were also requested to carry out additional searches to see if extra information, such as an additional address or evidence that the man had emigrated, could be found. When the DHSS searches gave new information about an individual the details were resubmitted to the central registers together with the new information. The DHSS searches altogether led to an increase of 8% in the number of deaths discovered.

For servicemen who still remained untraced and for servicemen who were traced on the NHS central registers, but who were not registered with an NHS doctor, the forms were re-examined by NRPB staff. In a few cases the individual was found to be still in the Services, or discharged from the Services after the final follow-up date for the study (31 December 1983). In other cases, addresses outside the UK were given after discharge from the Services and these men were assumed to have emigrated, the approximate date of emigration being determined from the service record. In a few remaining cases the form itself indicated that the man had died - usually abroad. For these men, information regarding the cause of death was sought from MOD. Information was obtained in this way for 15 test participants and 13 controls. It was subsequently examined and coded by one of the authors (RD).

For civilians, the mechanism of follow-up was similar to that for servicemen, except for AWRE ex-employees who had left AWRE before 1 January 1983, as these men had recently been followed-up by the MRC's Epidemiological Monitoring Unit as part of the cohort study of AWRE employees. With the Unit's consent, OPCS kindly provided NRPB with mortality and emigration data compiled for this study (both test participants and controls).

The results are shown in Table 4.1. Some 8% of test participants and 6% of controls were found to have emigrated; 92% of test participants and 93% of controls were found to be alive and resident in the UK at the end of 1983 or to have died; and less than 1% of each group were lost to follow-up after discharge from full-time service or leaving employment at AWRE or AERE. Follow-up to determine mortality was, therefore, satisfactory and comparable in both groups.

4.2 Determination of cancer incidence

Less than half the cancers that occur in the UK prove to be fatal and only a small proportion of the rest are referred to on death certificates as having contributed to death in an ancillary way. Nearly all are, however, now registered in regional cancer registries and the fact of their occurrence is recorded nationally in Southport and Edinburgh, where the information has been linked, since 1971, with the NHS central registers. Some, however, still fail to be registered and, to obtain information about all the cases that have occurred in the test participant and control series, we should have had to correspond personally with the general practitioners on whose lists the men were registered, with the men themselves, or with the informants who reported the death of those who had died. This was impracticable and the study of cancer "incidence" has been limited to the information that could be obtained from death certificates (including both the underlying and contributory causes of death) and from the registrations recorded since 1971 on the NHS central registers.

Due to the difficulty of distinguishing multiple primaries from single tumours that have recurred, individuals have been recorded as having only one type of cancer in the analysis of cancer incidence. For individuals who had more

than one type of cancer mentioned as an underlying or contributory cause of death or in cancer registration, cancers were chosen for analysis as follows:

(i) for individuals who had died and whose underlying cause of death was a tumour, registrations and contributory causes were ignored unless either a leukaemia appeared as a registration or a contributory cause but not as the underlying cause or the underlying cause was a tumour of unspecified site or a secondary cancer, in which case information on site and date of diagnosis was sought from cancer registration data;

(ii) for other individuals, preference was given to tumours other than non-melanomatous skin cancer, to malignant rather than benign conditions, and, in other circumstances, to the first type of tumour reported.

Table 4.1

Results of follow-up of test participants and controls at 1 January 1984

Status	Test participants		Controls	
	No	%	No	%
Emigrated	1,705	8	1,410	6
Living in United Kingdom or known to have died	20,567	92	20,828	93
Lost to follow-up after date of last discharge from full-time Service or date of leaving employment at AWRE or AERE	75	0.3	88	0.4
Total	22,347	100	22,326	100

5. VALIDATION

5.1 Accuracy of personal data

In order to verify that the Service Record Offices had completed the forms for service personnel in accordance with the guidance notes that had been supplied, NRPB staff visited the Service Record Offices and completed forms for a 1% sample of test participants and controls. Comparison with the forms previously completed by MOD staff showed that the guidelines had been observed and that the initial transcription of the data had been satisfactory. For AWRE and UKAEA personnel, similar 1% sample checks of data collected for the MRC studies had already been carried out by staff of the Epidemiological Monitoring Unit, as part of the validation procedure for those studies.

Further checks on the accuracy of the data were carried out at NRPB using computer checks for errors, omissions, and inconsistencies. To reduce transcription errors during computerisation of the data-base, all the important items of information obtained on participants and controls were entered into the computer twice and the resulting data files compared. All information on deaths and cancer registrations was also entered into the computer twice. Whenever an error could not be rectified after reference to the documents held at NRPB, details were returned to MOD, OPCS, or DHSS for re-checking against the original data source. Extensive computer checks were also carried out to search for duplicate entries on the data-base, including a cross-check of the controls against the test participants.

A 1% sample of records for all those participants with "health physics" recorded as a data source was examined in order to check the accuracy of transcription of dose data. In one instance it was found that a dose recorded as 13 mSv should have been 0.9 mSv. A detailed check of the original health physics material was, therefore, carried out for all the 349 individuals whose total recorded dose, as given in the Blue Book, exceeded 10 mSv or appeared unusual in other respects. In one instance a dose of 110 mSv recorded in the Blue Book as having been incurred by a pilot could not be confirmed as no reference to the individual could be found in the health physics records. Neither the squadron's operational record book nor the individual's record of service indicated that he took part in the test in question so the Blue Book entry was assumed to be an error. There were 18 other instances where discrepancies of more than 0.5 mSv in the recorded dose were identified. The largest discrepancy was that described above, in which a dose of 0.9 mSv had been recorded as 13 mSv. Other discrepancies were trivial; for example, the same doses being recorded, but in different years. The collective dose recorded in the Blue Book for the 18 individuals was 354.1 man mSv; on checking it was reduced by 5% to 335.1 man mSv.

5.2 Completeness of ascertainment of mortality and emigration data

The efficiency of the techniques used to follow-up men to ascertain their vital status was tested by submitting to the DHSS records branch a 1% sample of

all men who were reported by the NHS central registers as being currently registered with an FPC and who were thought to be under 70 years of age. Men over 70 years were not included in the sample as all such men had been submitted previously as part of our routine enquiries. A total of 391 individuals were included in the sample and in no case was there evidence that a claim for a death grant had been received by DHSS. It appears, therefore, that the techniques used to ascertain vital status in those men who had remained in Britain were satisfactory.

DHSS were also requested to search for evidence of emigration among all those for whom details were submitted (ie, both the 1% sample and those submitted as part of the regular follow-up procedures; a total of 5746 men), but they were able to carry out the search for only about three-quarters of them, within the timescale of the study. Among these men a total of 136 emigrations were reported that had not previously been taken into account. Thus, if the men for whom DHSS were able to carry out the search were typical of all for whom details were submitted, it must be assumed that approximately 45 more emigrations (one-third of 136) are likely to have been missed. However, 4 of the emigrations reported were among the 1% sample of men submitted to the DHSS records branch who were reported by the NHS central registers as being currently registered with an FPC and this implies that our follow-up procedures may have missed approximately 400 more emigrations in this group making 445 in all. This would have led to an overestimate of the person-years at risk in the study (see Section 6) of just under 1%. The follow-up procedures were, however, identical for test participants and controls so that the effect is likely to have been of comparable magnitude in each group.

5.3 Completeness of ascertainment of cancer incidence

Of the men who died, 886 were recorded on their death certificates as having cancer as the underlying or contributory cause of death; 1008 were reported as having a registered diagnosis of cancer since the beginning of 1971. The total numbers recorded, the numbers recorded annually since 1970, and the overlap between registration and death certification is shown in Table 5.1. Of the 1008 with a registered diagnosis, 496 were men whose death certificates made some reference to cancer in the years 1971-83 (70% of the 706 deaths). The registration details, therefore, provided information about an additional 512 men who developed cancer (ie, an additional 73% in the years 1971-83).

From Table 5.1 it is evident that the cancer registration data do not provide information about all the fatal cancers and it must also be presumed that they do not provide information about all the non-fatal cancers (Hunt and Coleman, 1987). Nor is it the case that they provide such information for the last five years of the study (1979-83), when registration is likely to have been most complete, as registration data were received for only 279 (72%) of the 386 men whose death certificates made some reference to the disease.

This failure to obtain information on all the non-fatal cancers that occurred since 1970 was only to be expected, as there are substantial regional variations in the completeness of cancer registrations throughout Great Britain (Swerdlow, 1986) and some of the men have lived in parts of the country where there was no automatic system for tracing cancer cases available for our use (Northern Ireland, the Isle of Man, and the Channel Islands). The data that have been obtained do not therefore provide figures for the total incidence of cancer that can be compared with any expected figures derived from external sources. They do, however, provide substantially more data than is obtained in the study of mortality (1396 cases against 840 considering cancers recorded as underlying cause of death and 886 considering all death certificates with a mention of cancer), and can all be used for a direct comparison of the experience of the test participants and their controls.

5.4 Accuracy of diagnoses

The diagnoses recorded on death certificates or cancer registration forms have been accepted for the comparisons between the mortality and incidence rates in the test participants and controls and between the observed number of deaths and the expected numbers estimated from national mortality rates. When, however, any information raised the suspicion that an individual in either series might have developed leukaemia, an attempt was made to confirm the diagnosis with the assistance of the relevant hospital records. These were reviewed by one of the authors (RD) and, if the diagnosis was not abundantly clear, the evidence was referred to a haematological consultant (Professor Sir David Weatherall). In no case was the recorded diagnosis clearly wrong. The few changes and qualifications that seemed desirable are noted in Section 7.

5.5 Completeness of coverage of test participants

Failure to obtain information about all the men who were eligible for inclusion in the study by the methods described in Sections 3.2 and 3.3 could have a serious impact on the validity of the results, if there was any reason to suppose that there could have been differential failure in the coverage of men who had died or developed cancer. We therefore sought evidence about the completeness of the coverage in three ways: (a) by further checks of service records, (b) by seeking information from organisations that had compiled lists of participants independently of MOD archival material, and (c) by examining a sample of the service claims for disabilities that had been received by DHSS. These are described below.

(a) As a check on service records, NRPB staff first inspected the official planning documents (known as Pink Lists) compiled by the MOD detailing the proposed movements of RN ships for the Far East Station for the entire period 1956–1964 to ensure that no RN ships had been omitted from the study. In addition, for each RN ship known to have participated in the tests, NRPB staff inspected the ship's log for the entire period that the ship was in the vicinity

of the test location and noted all dates of arrival and departure and recorded sitings of other ships. These investigations did not reveal any ships that had been omitted from the study, although it was discovered that HMS *Newfoundland,* whose crew had been included in the original Blue Book listings, had not, in fact, visited any of the test locations in Table 3.1. Individuals on HMS *Newfoundland* were therefore excluded from the study (as shown in Table 3.5) unless they were known to have made other visits to test locations.

A series of checks were then carried out to ensure that individual names had not been omitted from source documents containing lists of names of test participants where the original search of the material had been carried out by MOD staff. A new search was carried out, by NRPB staff, of the most important sources, including all the available original health physics material, the summaries of individual's recorded radiation exposures, the AWRE overseas travel registers, and approximately 40 AWRE Trials Series Reports. These searches revealed an additional 29 test participants out of a total of over 6000 individuals, an omission rate of less than 0.5%. In addition, there was a total of 118 names that appeared in the original Blue Book listings with health physics records given as the source of the information, but which could not be found in the available records. The majority of these entries relate to operations at the Maralinga range, and confirmed, as MOD had indicated, that a few health physics records relating to individuals with no recorded dose at the Maralinga range had been discarded.

For other sources, including Army unit records, ship's ledgers, and RAF squadron operational record books, 10% of documents were selected for a fresh search by NRPB staff. No extra test participants were found in the Army unit records, but some omissions were revealed among certain categories of ship's ledgers and in the RAF operational record books. The number of omissions was unacceptably high, and so NRPB staff searched again all the relevant ship's ledgers, while MOD were requested to carry out another search of all the operational record books listed as having been used in the compilation of the original Blue Books; all these additional searches identified a further 178 test participants. In order to check that names had not been omitted from the systematic search of Royal Engineers' service records, NRPB staff selected a 1% sample of the boxes in which the records were stored and searched them again. This cross-check revealed the name of only one test participant who had been omitted in the original systematic search.

Lastly, MOD were requested to provide information regarding total numbers of participants at each series of tests wherever possible. Only limited information was available, but for the Army a series of quarterly strength returns for Christmas Island was found and for the RAF monthly strengths for Christmas Island could be compiled from the operational record books of units and squadrons known to be involved in the tests. These are summarised in Table 5.2. For the Army

the number of attendances for Grapple exceeded the posted strength by 14%, while the number of attendances enumerated for Grapple X was only about two-thirds of the posted strength. It seems likely that this fluctuation is at least partly due to a tendency in the archival material to use the term Grapple both for Grapple and for Grapple X. As the two operations occurred in the same year the available date information would often not be sufficient to enable the two to be distinguished. This finding indicates a limitation to the ability of the available data to distinguish between attendances at particular operations in the Pacific. It is highly likely that a similar problem applies to the activities at the Maralinga range. For Grapple Y and Grapple Z the comparison with posted strength indicated coverages of 83% and 85% for the Army. For the RAF a similar pattern was seen for the Grapple operations, except that the level of coverage appeared to be slightly lower at just over 70%. For Operation Brigadoon slightly more test attendances were enumerated than the posted strength. However this was to be expected as Operation Brigadoon lasted for several months and the posted strength refers only to a single date.

(b) In its second check, NRPB requested information about test participants from all other organisations which, it was believed, had compiled lists of participants independently of MOD archival material. These are shown in Appendix C. All those approached granted the request. Any additional test participants identified from these sources could not be included directly in the main study as in most cases the lists were made up of individuals who had themselves contacted the organisation concerned or whose relatives had done so on their behalf. They thus form a selected group (subsequently referred to as "independent respondents") and their mortality cannot be assumed to be representative of test participants as a whole. They can, however, be used to test the completeness and representativeness of the group of test participants enumerated for the main study.

All independent respondents notified to NRPB before the general closing date of 1 April 1986 were included in this check. The first step was to examine the available information for each man. Any men who were ineligible, for example because they had served in the Merchant Navy or another civilian organisation not included in the study, or because their test involvement did not involve a visit to one of the test locations listed in Table 3.2, were excluded. Also excluded were any for whom there was very sparse information (namely (i) no Service Number, nor (ii) an indication that the man was a DHSS claimant, nor (iii) full forename or second initial plus a statement that the man was an officer, served in the RM, RNVR or NAAFI or was employed by AWRE). For the 2161 remaining well-identified individuals who appeared eligible, identification details were compared with those of the 22,347 test participants enumerated for the main study who had been traced at the Service Records Offices and whose test participation had been confirmed (see Table 3.3), noting instances where there was good

evidence that the independent respondent had already been included in the main study. For those 454 independent respondents who did not appear to have been included in the main study, forms similar to those used for participants in the main study were prepared (see Appendix D). These were then forwarded to MOD for completion, with a specific request for full details of postings that might have involved test participation. As a check on the quality of the search at MOD an additional 76 dummy forms for individuals previously notified by MOD were also included, 65 of which related to individuals that had been listed as test participants and 11 to individuals listed as controls.

The results of the check using dummy forms are shown in Table 5.3. For all 11 individuals from the control database MOD reported that test participation was highly unlikely, given the information on the individual's service record, while for 60 out of the 65 known test participants their test participation was confirmed, thus validating the overall results obtained for the other independent respondents. Of the remaining 5, one was a naval officer and it was reported that there was no trace of an officer with that surname serving in the Navy (despite the fact that a form had already been completed for him in the main study) and 4 were individuals (3 RAF officers and 1 Army officer) for whom there was a mention of postings that would have been compatible with test involvement, such as a posting to Australia without precise details as to location or a posting to a unit known to have been involved in some way with the tests, but without positive indication of a visit to a test site. For these 4 individuals, definite confirmation of test participation had previously come from sources other than the service record, such as an operational record book, and they indicate a limitation to the checks involving independent respondents.

The outcome of the submission of the forms for the 454 independent respondents not included in the main study are shown in Table 5.4. For 397 individuals, three-quarters of whom were in the RAF, test participation was confirmed. For 7 individuals the service records could not be traced. For 33 men, over half of whom were in the RN, examination of the service record gave no indication that the man had visited a test location during the period included in the study or been posted with a ship or unit known to have participated in the tests at an appropriate period. For only 7 (21%) of these did the initial notification come from the man himself, while for 26 (79%) it came from a third party such as a relative or friend; this contrasts strongly with the 397 individuals whose test participation was confirmed, for two-thirds of whom the notification came from the man himself. There is a second Christmas Island in the Indian Ocean that is known to have been visited by HM Forces personnel during the period of the tests, and in some cases service on this other island may have led to mistaken reporting of test participation by relatives or friends. It was therefore concluded that these individuals were unlikely to have been test

participants. For 17 individuals, examination of the service record was compatible with test involvement, although the evidence was inconclusive.

To estimate the percentage of all eligible test participants covered by the main study, the number of independent respondents who had not already been included, but whose test participation was confirmed or inconclusive, was compared with the number of independent respondents who had been included. The results are shown in Table 5.5. For AWRE employees all had been included in the main study and for the category RN, etc, almost all. For the Army and RAF, the proportions were 84%, with 95% confidence interval 81% to 87%, and 69%, with 95% confidence interval 66% to 72%, respectively. The low figure, particularly for RAF personnel reflects the fact that the system for monitoring of movements and postings at the time of the tests makes it difficult to reconstruct now, from the records currently held within MOD, a comprehensive listing of those who may have been present. From these data the overall proportion was estimated to be 83% after standardising service or employment category to the proportions observed in the main study.

A separate analysis of the results obtained for the 1152 men whose names were provided by Professor Knox and Drs Sorahan and Stewart of Birmingham University's Department of Social Medicine is reported in Appendix E.

(c) In its third check, NRPB sought the help of DHSS archives at Nelson where records are held of all servicemen who had ever claimed a disability pension or for whom a claim had been made by a dependent. Altogether about a million records are held in the department of which about 300,000 relate to claims made since 1953. A one in 1000 sample of these claims was selected from the ledgers and inquiries were then made to the various Service Record Offices to see if the man's record was currently at that office. There were 44 claims for officers or men serving in the RN or RM, and for all of these the service record was in its correct place. There were 71 claims classed by DHSS as 'RAF'; for 69 the service record was in its correct place and the remaining 2 were found to relate to men who had served only in the Royal Australian Air Force. For the Army there were 172 claims and for 135 the record was in its correct place. Twenty records, however, could not be traced, of which 6 were subsequently found to be at DHSS following a claim or appeal. In a further 17 some information was available, but the main record of service including details of postings was at DHSS and missing from the Service Record Office. These missing and incomplete records included both officers and other ranks. It was therefore established that there was a problem of potential bias but that it was confined to the Army.

All these missing and incomplete records were found to relate to individuals in the Army who had made claims (or appeals) before 1976 and enquiries showed that before that date it had been the practice to allow records to be sent to DHSS without keeping a note of their removal or seeking their return. This was

not known to current MOD staff and is contrary to current practice, so that it had not been taken into account when the study was designed.

5.6 Conclusions from validation procedures

The evidence obtained in these various ways gives confidence that the listings of participants used in this study are likely to be complete (or nearly complete) for the RN and civilian employees of AWRE, but that an appreciable number of individuals who served in the Army and the RAF may have been missed. Moreover, there is evidence to suggest that the omission of some of those who served in the Army may have been biased by the differential exclusion of a small number for whom claims had been lodged. The possible effect of these omissions is taken into account in the presentation of the results (see Sections 7.5 and 8.1).

Table 5.1

Numbers of cancer registrations and numbers of deaths with mention of cancer, with and without cancer registration by calendar year
(Numbers are for test participants and controls combined)

Calendar year	Number of cancer registrations	Numbers of deaths with cancer mentioned on the death certificate:			Total number of men known:	
		For whom cancer registration details were also received	For whom no cancer registration details were received	Total	To have developed cancer	To have died with cancer as underlying cause
1971	45	9 (25)*	27 (75)	36	62	36
1972	40	18 (69)	8 (31)	26	42	26
1973	48	20 (56)	16 (44)	36	56	33
1974	54	19 (73)	7 (27)	26	46	26
1975	51	29 (81)	7 (19)	36	59	33
1976	65	37 (70)	16 (30)	53	71	47
1977	73	38 (83)	8 (17)	46	82	40
1978	91	47 (77)	14 (23)	61	100	57
1979	85	42 (76)	13 (24)	55	94	53
1980	92	51 (70)	22 (30)	73	114	70
1981	107	47 (67)	23 (33)	70	144	69
1982	119	62 (75)	21 (25)	83	147	77
1983	138	77 (73)	28 (27)	105	199	97
1971-1983	1,008	496 (70)	210 (30)	706	1216	664
Before 1971	0	0 (0)	180 (100)	180	180	176
All years	1,008	496 (56)	390 (44)	886	1396	840

* Percentage of deaths in parentheses.

Table 5.2

Comparison of posted strengths at Christmas Island derived from monthly or quarterly reports with numbers of attendances enumerated for this study

Operation	Army			Royal Air Force		
	Date of available information	Posted strength	Number of attendances enumerated*	Date of available information	Posted strength	Number of attendances enumerated*
Grapple	June 1957	556	634	May 1957	1,073	1,000
Grapple X	Dec. 1957	953	618	Nov. 1957	1,564	926
Grapple Y	March 1958	1,597	1,319	May 1958	1,819	1,301
Grapple Z	Sept. 1958	1,659	1,414	Sept. 1958	2,504	1,901
Brigadoon	-			June 1962	229	344

* From Table 3.6

Table 5.3

Summary of outcome for 76 dummy forms included with batch of 454 independent respondents whose details were submitted to MOD

Outcome of search for test participation using dummy forms	Status in main study	
	Test participant	Control
Untraced	1	0
Test participation unlikely	0	11
Test participation inconclusive	4	0
Test participation confirmed	60	0
Total	65	11

Table 5.4

Summary of outcome of examination of service record for independent respondents not already included in main study

	RN	Army	RAF	NAAFI	Other or not known	Total
Untraced	1	3	2	0	1	7
Test participation unlikely	18	8	7	0	0	33
Test participation inconclusive	1	1	12	3	0	17
Test participation confirmed	3	90	298	6	0	397
Total	23	102	319	9	1	454

Table 5.5

Numbers (and percentages) of independent respondents not included in the main study and those included, by Service

Service or employer	Independent respondents		
	Not included in main study	Included in main study	Total
RN	4 (1%)	442 (99%)	446
Army	91 (16%)	479 (84%)	570
RAF	310 (31%)	694 (69%)	1004
AWRE	0 (0%)	50 (100%)	50
NAAFI	9 (82%)	2 (18%)	11
RM	0 (0%)	40 (100%)	40
Crude total	414 (20%)	1707 (80%)	2121
Total standardised to Service or employer distribution of main study	(17%)	(83%)	

6. METHOD OF ANALYSIS

Test participants were entered into the study on the date of their first test involvement. For test participants who were present at a test location on the date of firing of one or more of the operations listed in Table 3.1 this was taken to be the first date of firing at the earliest such operation, while for other test participants it was taken to be the date of their first visit to a test location. For controls, the date of entry to the study was calculated differently for each of the principal groups. Controls in the Royal Navy were entered into the study on the last day in the ledger period of the ledger from which the name was taken. RAF officer and airman controls were entered 6 months and 2 months, respectively, after the date of start of tropical service as recorded on the proforma, as these were the minimum lengths of stay required in selecting controls for these two groups. Army officer controls were selected from lists of Army officers in tropical postings on particular dates. Only the date of commencement of overseas service was recorded on the proforma. A typical length of stay overseas was, however, about 2 years and Army officer controls were, therefore, entered into the study 1 year after their start of overseas service. Soldier controls were entered on termination of their Reserve liability, to take account of the fact that only individuals who survived until this time were selected as controls (see Section 3.5). Civilian controls were entered on the date of the first test involvement of the participant with whom they were matched.

For the analyses of mortality, individuals were removed from the study on their date of death or emigration, or on 31 December 1983, whichever of these came earliest. For the analysis of cancer incidence, the date of death was used for those individuals who had died and for whom there was a mention of cancer on the death certificate, and for others the date of cancer registration. Individuals were removed from the study on emigration because we were unable to ascertain reliably the vital status of those living abroad. Individuals were also removed from the study if they reached age 85 years. This was for two reasons. First, the description of the cause of death as given on the death certificate is unreliable at very old ages. Second, the death rate over 85 years of age is so high and increases so rapidly with age that substantial bias would be introduced into the comparison of mortality rates in the study populations with the national rates if even a few deaths have been missed in individuals who were thought to have reached 85 years of age before the study period ended, or if the age distribution of the test participants and controls in this open-ended age group differs from that of the nation as a whole. A total of 4 deaths were excluded for this reason: 2 among test participants were attributed to heart failure and atherosclerosis (ICD codes 428.0 and 440.9) and 2 among controls were attributed respectively to cerebral atherosclerosis and chronic renal failure (ICD

codes 437.0 and 585.0). No cancer registrations occurred in individuals aged more than 85 years.

In the analyses, each individual contributed person-years at risk from the date of his entry to the date of his removal from the study sub-divided, as appropriate, by service, rank, 5-year age group, and calendar year. To compare mortality rates in test participants and controls with those of the nation generally, the numbers of deaths expected in each group were calculated by multiplying the person-years at risk in each age and calendar year group by the corresponding specific mortality rates for men in England and Wales and the results summed. Standardised mortality ratios (SMRs) were then calculated for each disease or group of diseases by dividing the numbers of deaths observed by the corresponding numbers expected and multiplying by 100. The national mortality rates in 5-year age groups were calculated for each calendar year in the study for each cause of death of interest, from computer tapes supplied by OPCS. For years in which the national data were coded to revisions of the ICD earlier than the ninth, disease groups were constructed that approximated as closely as possible to those based on the ninth revision. For the years prior to 1968 national rates for the sub-types of leukaemia were calculated using data published by Court Brown and Doll (1959), and unpublished data based on a review of leukaemia death certificates for England and Wales from 1958 to 1967, made available by Dr L J Kinlen. The statistical significance of the SMRs was calculated by assuming that the number of deaths observed from any cause had a Poisson distribution. Two-sided tests were used for calculating the statistical significance of the SMRs, as both increases and decreases compared with the national rates were of interest.

To compare the mortality rates of the test participants directly with those of the controls, the deaths and person-years at risk were stratified by age and calendar year into 5-yearly groups, by Service or employer into four groups (RN etc, Army, RAF, AWRE) and within each of the three Services by rank into officers and men and within AWRE employees into social class I and others. The relative risk (RR) or proportional increase in the rate of mortality in test participants relative to controls was then estimated by the method of maximum likelihood. Here it was assumed that within each stratum the number of deaths among test participants, given the total number of deaths among participants and controls, had a binomial distribution. Where there was at least one death among both the participants and the controls, significance levels for the RR were based on the score statistic using a continuity correction (Breslow and Day, 1987). When the total number of deaths observed was less than 30, these values were checked using 1000 simulations and always found to be satisfactory. When the observed deaths were all among the test participants or all among the controls, exact significance levels were calculated. Confidence intervals for the RRs were based on the score statistic using a continuity correction. The same method was used for the

analysis of cancer incidence. One-sided tests were used to calculate the statistical significance of the RRs, as there was specific interest in testing the hypothesis that rates of mortality and cancer incidence were greater among test participants than among controls. When the RR was less than unity, one-sided tests of the hypothesis that rates of mortality and cancer incidence were greater among controls than among test participants were also carried out, so that the number of significant excesses and deficits could be compared.

In the analyses comparing cancer incidence and mortality rates in test participants with different levels of recorded gamma dose, incident cancers or deaths and person-years were stratified as for comparison of mortality rates in test participants with controls. The number of incident cancers or deaths expected in each dose category (E_I) was then calculated internally assuming that within any stratum the death rate was the same in each dose category, and a one-sided test for trend with increasing dose was carried out using the score test (Breslow and Day, 1987). In this analysis, the participants entered the study on the first date for which a dose was recorded. This involved a slight approximation; for example a man who received his recorded gamma dose in two parts, some in 1957 at Grapple and the remainder in 1958 at Grapple Z, would have been classed as having received all his dose in 1957. A similar approximation arises in the analyses by type and degree of exposure, for which the same dates of entry to the study were used as for the main analyses. Investigation revealed, however, that the effect on the results of this approximation was negligible.

7. RESULTS

7.1 Introduction

One way of seeking to discover whether or not test participants suffered any deleterious effect from their exposure would be to compare their subsequent mortality with that of the general population of the United Kingdom. The results of any such comparison would, however, be extremely difficult to interpret. First, test participants included a high proportion of officers* or AWRE employees, who would be allocated on the basis of their occupation to social class I. The proportion was particularly high in the older age groups, amounting to 40% at age 30 years and over at their time of entry to the study, and these groups would have contributed a disproportionately high number of deaths. It would, therefore, be essential to make some allowance for the social class distribution of the participants, as mortality rates in the UK have been substantially lower in social class I than in the population as a whole (OPCS, 1978). Second, servicemen who served abroad were selected for physical fitness, so that their mortality would be expected to be substantially less than average, at least for the first five years of observation and possibly for much longer (Fox and Collier, 1976). Third, life in the services involved specific hazards, apart from any that might arise from participation in the tests, most notably hazards of accidents in the air in the case of RAF officers, but also from some other causes in all the services (Darby et al, 1988).

These difficulties are avoided by comparing the mortality and cancer incidence in test participants directly with that in the control subjects who were chosen specifically for this purpose and were matched to the participants with respect to service status (officers and other ranks) as well as with respect to service abroad, date of service and age. The results of the study are, therefore, presented in the form of a comparison between these two series and national mortality rates in England and Wales have been used only to calculate "expected" numbers of deaths that would help to decide whether the differences observed between the two groups were due to peculiarities in the experience of the test participants or their controls. This comparison between participants and selected controls is certainly the most appropriate for examining the mortality rate from common conditions that give rise to large numbers of deaths and are known to be affected by social factors; but for the study of rare diseases, when the number of deaths in the control series is small and therefore subject to proportionately large effects of random variation, the results may be difficult to interpret.

---

* *Members of HM Forces are normally excluded from the classification scheme (OPCS, 1978). Officers, however, may be regarded as closely comparable to social class I.*

7.2 Comparison of mortality in test participants and controls

The total mortality in the two groups and that from three broad groups of causes (namely, neoplasms, other diseases, and accidents and violence) are shown in Table 7.1.

This table and Tables 7.2 - 7.6 and 7.8 are set out in the same way and show the numbers of deaths observed from different causes in the two groups along with standardised mortality ratios (SMRs) calculated from the experience of all men in England and Wales, and relative risks (RRs) of mortality in the test participants compared to that in the controls, both SMRs and RRs being calculated by the methods described in Section 6. RRs that are so much greater or less than unity that as big or bigger differences would have occurred by chance less often than once in 20, 100, or 1000 times (corresponding to p-values of 0.05, 0.01 and 0.001) are designated by asterisks. Similar indications are not given routinely for the "statistical significance" of the level of the SMRs because of the difficulties referred to in Section 7.1. When, however, this is thought to be of interest, it is given in the text. The expected numbers from which the SMRs are derived are not shown in the tables, but are given in Appendix F, as are the ICD codes used to define the disease groups and explicit significance levels for the SMRs and RRs and 90% confidence intervals for the RRs.

In Table 7.1 and in many other tables, some deaths are shown for which no cause could be obtained. Many of these occurred abroad and they are, therefore, more likely to have been due to accident or disease of sudden onset, such as myocardial infarction, than to disease that runs a prolonged course, such as many types of cancer. So long as the proportions are small and similar in both groups, they are unlikely to have affected the RRs and they have generally been ignored. The fact that the cause of death was not obtained for 2% of the participants and 2% of the controls could, however, be taken to imply that all the SMRs for specific causes are too low. The reader may, therefore, wish to multiply the SMRs by a factor derived from the percentages of deaths due to unknown causes, namely 1.02, on the assumption that the distribution of causes of death is the same irrespective of whether the cause is known or not.

From Table 7.1 it appears that the mortality from all neoplasms and from all other diseases was substantially lower in both groups than in men of the same ages in England and Wales, but that the mortality from accidents and other violence was considerably higher. Very little difference was observed between the experience of the test participants and the controls ($p>0.10$ in all cases) and, in so far as there was any difference in the mortality from neoplasms, it was lower in the participants.

Table 7.2 shows that in officers (including AWRE employees in social class I) the mortality from neoplasms and all other diseases was relatively much lower than in other ranks, but that the mortality from accidents and other violence was relatively much higher and that this was true in both test participants

and controls. In officers, the mortality from neoplasms was slightly lower in the test participants than in the controls, while among other ranks it was almost identical.

Table 7.3 shows the results for the same four cause of death groups separately for the Army and for the other two services and AWRE employees combined. For cancer, the mortality rate in test participants relative to controls was lower in the Army than in the other two Services and AWRE employees. However, exclusion of the Army still leaves the mortality from cancer slightly lower in the test participants than in the controls. For diseases other than cancer and for accidents and violence, exclusion of the Army increases slightly the relative mortality in test participants. It is evident, therefore, that any bias that may have been introduced into the results by the failure to obtain controls for other rank participants in the Army who died before discharge from Reserve liability (see Section 3.5) or from the retention of some Army records by DHSS that pertained to individuals for whom disability claims were made (see Section 5.5) may have resulted in a slight underestimate of the RR of the test participants but that it is not responsible for the fact that the mortality from cancer in the test participants is slightly lower than in the controls.

Not all organs are equally susceptible to the induction of cancer by ionising radiations, particularly if there is any possibility that they may have been irradiated as a result of the inhalation or ingestion of radionuclides which might lead to some organs of the body receiving much greater doses than others, and Table 7.4 provides a comparison of the mortality from cancer of 23 different types. For some types, mortality in the test participants exceeded that in the controls, while for others the reverse was true. The relative risk in test participants was significantly greater than unity at the 5% level or less only for leukaemia and multiple myeloma. For leukaemia there were 22 deaths among test participants compared with only 6 among controls, giving a mortality rate in test participants 3.45 times that in controls ($p=0.004$; 90% confidence interval 1.50, 8.37). For multiple myeloma there were 6 deaths in test participants compared with 0 among controls ($p=0.009$; 90% confidence interval 1.67, ∞). For both these diseases the numbers of deaths observed among test participants were slightly greater than those expected from national rates, although the differences were not statistically significant (leukaemia: SMR=113, $p=0.57$; multiple myeloma: SMR=111, $p=0.83$). Among controls the numbers of deaths observed were substantially less than would be expected from national rates for both diseases (leukaemia: SMR=32, $p<0.001$; multiple myeloma: SMR=0, $p=0.006$). For bladder cancer the mortality rate in test participants was estimated to be greater than that of the controls by a factor of 2.79; but the increase did not quite reach statistical significance ($p=0.06$). In contrast, the relative risk in test participants was significantly less than unity at the 5% level for cancers of the prostate and kidney, while for cancers of the trachea, bronchus, lung and pleura

the RR was 0.82 but the deficit did not quite reach statistical significance (p=0.07). For the remaining types of cancer shown in Table 7.4 there was little evidence that the mortality rate experienced by the test participants was different from that of the controls (p>0.10 in all cases) and there was practically no difference in the rate for all cancers or for all cancers other than leukaemia.

The four disease categories of Hodgkin's disease, non-Hodgkin's lymphoma, multiple myeloma, and leukaemia, which are shown separately in Table 7.4, together constitute the broad group of "cancers of lymphatic and haematopoietic tissue". Altogether there were 51 deaths from this group of cancers in the test participants and 28 in the controls, and the relative risk was estimated to be 1.65, which is significantly increased (p=0.02; 90% confidence interval 1.08, 2.51). The difference was not, however, due to a high mortality in the test participants in whom the number of deaths was equal to that expected from national rates (SMR 100) but to a low mortality in the controls in whom the number was only just over half that expected (SMR 56, p<0.001).

When the analysis was repeated excluding the Army, the results were similar. For leukaemia, multiple myeloma, and all cancers of lymphatic and haematopoietic tissue, the relative risks were slightly lower, but still significantly increased (RR=2.64, p=0.03; RR=∞, p=0.02, and RR=1.89, p=0.01, respectively). In no case was the SMR in test participants significantly increased in comparison with the mortality observed nationally, even if an allowance is made for the number of deaths due to cancer that might have been included in the 36 deaths for which the cause was unknown (SMRs of 104, 117 and 98, respectively, after adjustment; p in all cases >0.10). As in the previous analysis, the relative risk in test participants was significantly less than unity for cancer of the prostate and kidney (RR=0.35, p=0.01, and RR=0.23, p=0.003, respectively) while the deficit for cancers of the trachea, bronchus, lung and pleura did not reach statistical significance (RR=0.83, p=0.09). For all other types of cancer shown in Table 7.4 there was no clear evidence that the mortality rate experienced by the test participants was either greater or less than that of the controls when those in the Army were excluded (p>0.10 in all cases, with as many deficits as excesses).

Table 7.5 shows data similar to those in Table 7.4, except that they are limited to the period when any cancers attributable to ionising radiations are most likely to have occurred. For leukaemia this is assumed to have been from 2 - 25 years after first exposure as the induction period for leukaemia may be short and the experience of the survivors of the Hiroshima and Nagasaki nuclear bomb explosions and of patients irradiated for ankylosing spondylitis shows that the risk is greatly reduced (though not completely eliminated) more than 25 years after exposure (Preston et al, 1987; Darby et al, 1987). For other types of cancer, the induction period is generally longer and few induced cancers have been shown to cause death in less than 10 years. Whether the risk is reduced beyond 25 years after exposure is, however, uncertain and for these other cancers

we have examined the mortality at all times after the first 10 years. The results are very similar to those shown in Table 7.4. Only for leukaemia and multiple myeloma was the mortality rate among test participants significantly greater than that among controls (leukaemia: RR=3.51, p=0.008; multiple myeloma: RR=∞, p=0.03). For cancer of the bladder the relative risk was estimated to be 2.51, but this increase did not reach statistical significance (p=0.10). In contrast, the relative risk in test participants was significantly less than unity at the 5% level for cancers of the trachea, bronchus, lung and pleura, prostate, and kidney. For the remaining types of cancer shown in Table 7.5 there was no clear evidence that the mortality rate of test participants was different from that of controls (p>0.10 in all cases).

Although leukaemia is the disease that has been most closely associated with exposure to ionising radiation in studies of individuals known to have been exposed to ionising radiation at high doses, not all types of leukaemia are thought to be equally easily induced by ionising radiation. Chronic lymphatic leukaemia, in particular, has not been shown to be increased in any irradiated population. The deaths attributed to the four major types of leukaemia have, therefore, been examined separately to see if the pattern expected from exposure to ionising radiation is apparent. The results are shown in Table 7.6. For each of the three major types that have been observed in excess in irradiated populations (acute myeloid, chronic myeloid, and acute lymphatic) the number of deaths observed in the test participants exceeded that expected from national rates and, when comparison is made with the controls, the RR among test participants was greater than unity. However, only for chronic myeloid leukaemia was the increase in RR statistically significant (p=0.04). Only 2 deaths, both among test participants, were attributed to chronic lymphatic leukaemia and this number was approximately equal to that expected from national rates. If chronic lymphatic leukaemia is excluded the RR among test participants for the remaining types of leukaemia combined was estimated to be 3.12, which is still statistically significant (p=0.01).

Table 7.7 shows the distribution of deaths from leukaemia by type of leukaemia and time since commencement of first test participation. Apart from the first 5-year period, the number of observed deaths exceeded that expected from national rates in every period both for acute myeloid leukaemia and when all types are considered together. Otherwise there are no clear time trends, either when all types are considered together or when the different types are considered individually.

Review of the evidence on which the diagnoses of leukaemia were based had no material effect on these results. No information could be obtained about 12 deaths (9 in test participants and 3 in controls) as the hospital records had been destroyed or mislaid. In two instances the diagnoses were changed from acute monocytic leukaemia to acute myeloid leukaemia (in a test participant), and

to acute leukaemia, unspecified (in a control). In all the others, the diagnoses were confirmed (acute lymphatic leukaemia, 2 test participants and 1 control; acute myeloid leukaemia, 7 test participants and 1 control; chronic myeloid leukaemia, 2 test participants; and chronic lymphatic leukaemia, 1 test participant).

Table 7.8 shows the results for specific causes of death other than neoplasms. For most of the individual causes mortality was lower than in men of the same ages in England and Wales in both test participants and controls, and sometimes much lower. Not surprisingly the mortality from air and space transport accidents was raised in both groups by more than a factor of 10, and mortality from drowning and water transport accidents was raised by 22% in test participants and 47% in controls. When the mortality of test participants was compared with that of controls, the RR was in some cases less than unity and in some cases greater. Only for the category 'other injury and poisoning' was the RR significantly greater than unity with a RR of 1.34 ($p=0.04$). Inspection of the individual causes of death involved revealed that this was due to a slightly greater number of deaths from a wide variety of accidents and injuries in test participants than in controls. Only for chronic bronchitis, emphysema, and chronic obstructive lung disease was the relative risk statistically significantly less than unity, the mortality among test participants being less than 60% of that in the controls ($RR=0.55$, $p=0.02$). For no other non-violent cause did either the increase or the deficit reach statistical significance ($p>0.10$ in all other cases).

7.3 Cancer incidence in test participants and controls

Table 7.9 shows the numbers of known incident cancers in test participants and controls and the relative risk of incident cancer in the two groups. The patterns are very similar to those for mortality. When all neoplasms are considered together the incidence rate in test participants was slightly less than in controls, although the difference is not significant statistically ($RR=0.95$, $p>0.10$). This slight deficit is chiefly due to cancers of the trachea, bronchus, lung and pleura for which the incidence rate in test participants is approximately 20% lower than in the controls ($RR=0.81$, $p<0.05$), but it is also contributed to by lower incidence rates for cancers of the kidney and cancers of the skin other than melanoma ($p=0.01$ and $p=0.10$, respectively). Neoplasms with notably higher incidence rates in the participants, other than leukaemia and multiple myeloma, were tumours of the central nervous system and cancers of the bones, but neither difference was statistically significant ($p=0.08$ and $p=0.25$, respectively).

Despite the small numbers, the bone tumours are potentially of interest because of their production by bone-seeking radioactive isotopes. Review of the information recorded on death certificates and registration records showed, however, that two of the so-called tumours of bone arose in the mucosa lining the

ethmoid sinus and the mucosa covering the gum, and the third, in a control, arose in the soft tissues of the leg. The two remaining tumours, which were both in participants, appeared to have genuinely arisen from bone, as they were described as being an osteosarcoma of the leg and a fibrosarcoma of the right maxilla.

For none of the other cancers shown in Table 7.9 was there any clear evidence of a difference between the incidence rates in the test participants and the controls. For prostate cancer the incidence rates were almost identical (RR 1.01) despite the fact that the mortality rate was shown in Section 7.2 to be significantly higher in the controls.

For both leukaemia and multiple myeloma, the increased relative risks that were reported in Section 7.2 for mortality persist. Altogether, 28 cases of leukaemia were reported in test participants with 12 in controls. In one control, however, the diagnosis of leukaemia was not confirmed (see below) and this case has been ignored. The incidence in test participants was, therefore, 2.43 times greater than in controls ($p=0.009$; 90% confidence interval 1.27, 4.70). Four further cases of multiple myeloma were reported in test participants making 10 in all compared with 0 in controls ($p=0.0007$; 90% confidence interval $2.75,\infty$). For the whole group of cancers of lymphatic and haematopoietic tissue there were 74 reported cases in test participants compared with 49 in controls, leading to an estimated relative risk of 1.42 ($p=0.04$; 90% confidence interval 1.03, 1.97).

No information could be obtained from hospital records about 5 of the 12 additional incident leukaemias not certified as the cause of death (3 in test participants and 2 in controls). In 6 of the others, the diagnoses were confirmed (acute myeloid leukaemia, 2 controls; chronic lymphatic leukaemia, 3 test participants, 1 control). In one control the leukaemia (described on the death certificate as aleukaemic leukaemia) was clearly the terminal stage of an associated lymphosarcoma and not an independent disease. In Table 7.10 the numbers of incident cases of leukaemia are reported by type, taking into account the revisions suggested by review of the hospital records here and in Section 7.2. For each of the four types the RR was greater than unity, but the increase reached statistical significance only for chronic myeloid leukaemia ($p=0.01$). If chronic lymphatic leukaemia is excluded the RR among test participants is estimated to be 2.64 (90% confidence interval 1.25, 5.75) which is still significantly increased ($p=0.01$).

When the analyses of cancer incidence shown in Tables 7.9 and 7.10 were repeated first excluding test participants in the Army and then considering only the period when any cancers attributable to ionising radiations are most likely to have occurred (2 - 25 years after first exposure for leukaemia, more than 10 years after exposure for other types of cancer) very similar results were obtained.

7.4 Mortality and cancer incidence within test participants by type and degree of exposure

As indicated in Section 3.4, gamma doses greater than the threshold of detection were available for 1373 men, and for 3080 others a dosemeter had been issued on which no detectable dose was recorded. To see whether the risk of cancer was related to dose, all incident cases can be used as the comparisons to be made are entirely within the participant group and no comparison with the numbers expected from national rates is required. Table 7.11 shows, therefore, the number of incident cases of all neoplasms and of eight types of cancer in each of six groups of men receiving either no detectable dose (classed as <0.01 mSv) or five levels of dose ranging up to 50 mSv or more and have compared the observed numbers with the numbers expected for the experience of the group as a whole (see Section 6). In some cases the trend is negative (including leukaemia), and in others it is positive (including multiple myeloma and all neoplasms), but in no case does the trend approach statistical significance ($p>0.25$ for all types). The confidence intervals for the trend in the relative risk per mSv, as given in Appendix Table F11, are very wide. When the analysis was limited to mortality data very similar results were obtained.

Among the 64 members of the Buffalo Indoctrinee Force who were exposed to neutron radiation nine had died. One death was attributed to cancer and this arose in the lung. Three more men had been registered with cancer but had not died. One of these occurred in the maxillary sinuses and the remaining two were non-melanomatous skin cancers (both basal cell carcinomas).

Before the results of the study were available, two groups of test participants had been selected by MOD as being those in which any effect of exposure to radiation would, if present, be expected to be concentrated: namely,

(a) men liable to have been exposed to radiation as a consequence of their test participation (see Section 3.4 and Tables 3.8 and 3.9); and

(b) all participants employed by AWRE or known to be directly involved with the programme of minor trials at Maralinga.

This second group was identified by MOD as that in which undocumented inhalation or ingestion of radionuclides, if any, was most likely to have occurred. Table 7.12 shows the numbers of deaths from eight types of cancers in these two groups, separately and combined, the SMRs and the RRs compared with the total control group and the corresponding figures for all other test participants. In the two pre-selected groups there was a total of 2314 men among whom there were four deaths from cancers of lymphatic and haematopoietic tissue, including two deaths from leukaemia and one from multiple myeloma; the relative risks for these three disease groups were all greater than unity (RRs 1.18, 3.67 and ∞, respectively) but none of them reached statistical significance ($p>0.10$ in all three diseases). The mortality rate in the two pre-selected groups did not stand out as being higher than that of other test participants when compared either with

the national mortality rates or with mortality among the controls and, for all neoplasms combined, both the SMR and the RR were, in fact, slightly lower for the selected groups than for other test participants.

A second division of the test participants that it had been decided to examine before the results of the follow-up were available, comprised:

(A) the 15,211 men who were thought to have been present for a major test, (that is, one of those listed in Table 3.1) or to have been present and directly involved in the programme of minor trials at Maralinga;

(B) the 10,712 men in group A who were thought to have been present at the tests on Christmas and Malden Islands in the Pacific and who had been in the subjects of previous enquiry (Knox et al, 1983, and see Appendix F); and

(C) the 1503 participants who were unlikely to have been exposed to more radiation than the general public (see Section 3.1).

Mortality data for these three categories, similar to those given previously for the two groups selected for special examination by MOD, are shown in Table 7.13, together with the corresponding data for the 5633 other test participants (group D). For those who were unlikely to have received more radiation than the general public (group C), the RR for some of the individual types of cancer, including leukaemia, was greater than unity and for others it was less; but in no case did the difference reach statistical significance ($p>0.10$ for all types shown). For those who were present for a major test or involved in the minor trials at Maralinga (group A) the mortality from leukaemia was significantly greater than in the controls (RR=2.54, $p=0.05$), while the mortality from multiple myeloma approached statistical significance (RR=∞, $p=0.06$). For both of these diseases, however, the mortality rate was somewhat lower than expected by comparison with that of the general population (SMRs 95 and 78, respectively). For the participants who were thought to have been present at the tests at Christmas or Malden Islands (group B), the mortality from leukaemia was slightly greater than for men in group A, both in comparison with the controls (RR=3.35, $p=0.02$) and in comparison with the general population (SMR 123) and so was the mortality from multiple myeloma in comparison with the latter (SMR 86). In contrast, the mortality from all neoplasms was lower than in group A and provided the only instance in which the difference from the controls was statistically significant for this disease group being, in this case, significantly lower (RR=0.85, $p=0.05$). For the remaining group of 'other' test participants (group D) mortality was increased by comparison with the controls for leukaemia, multiple myeloma, and, largely as a consequence of the increases in these two diseases, the RR for the broad group of neoplasms of lymphatic and haematopoietic tissue was also raised. For all three disease categories, the increases were significant statistically (RRs 6.55 ($p=0.0002$), ∞ ($p=0.009$) and 2.64 ($p=0.001$), respectively). Moreover, in comparison with the mortality for the whole country the rates were also raised (SMRs 181, 250 and 164, respectively) and for the

group of neoplasms of lymphatic and haematopoietic tissue as a whole, the increase was statistically significant (p-values: 0.15, 0.12 and 0.05, respectively).

When the analysis was repeated for incident cancers broadly similar results were obtained. For the men who were unlikely to have received more radiation than the general public (group C) there were no significant increases in comparison with the controls for leukaemia, multiple myeloma, and all cancers of the lymphatic and haematopoietic tissue (RRs 3.13 (p=0.17), ∞ (p=0.08) and 1.83 (p=0.13), respectively based on 2, 1 and 6 cases). In group A (men exposed to a major test or involved in tests at Maralinga), there were 17 cases of leukaemia, 6 of multiple myeloma, and a total of 46 cancers of the lymphatic and haematopoietic tissue (RRs 1.93 (p=0.07), ∞ (p=0.008) and 1.19 (p=0.24), respectively). In group B (men exposed only at Christmas and Malden Islands), there were 15 cases of leukaemia, 3 of multiple myeloma, and a total of 34 cancers of the lymphatic and haematopoietic tissue (RRs 2.66 (p=0.01), ∞ (p=0.03) and 1.32 (p=0.14), respectively), while the most highly significant differences for leukaemia and cancers of the lymphatic and haematopoietic tissue continued to be observed in the 'other' men in group D (9 leukaemias, RR 3.44, p=0.005; 3 multiple myelomas, RR ∞, p=0.009; 22 cancers of the lymphatic and haematopoietic tissue, RR 1.78, p=0.02). As with mortality, none of the four groups showed a statistically significant excess of all neoplasms, but the men exposed at Christmas and Malden Islands showed a statistically significant deficit (group A: 456 neoplasms, RR=0.90, p=0.05; group B: 263 neoplasms, RR=0.85, p=0.01; group C: 49 neoplasms, RR=1.11, p=0.27; group D: 166 neoplasms, RR=1.06, p=0.25).

It would appear, therefore, that there was no material evidence of any increase in the mortality or incidence of cancer in the men who were thought unlikely to have been exposed to more radiation than the general public and that the increases in leukaemia and multiple myeloma that were observed are principally concentrated in the 'other' men who were not present for a major test or known to have been involved with the programme of minor trials at Maralinga.

To see if there was any feature related to their participation which distinguished men in this group who developed leukaemia or multiple myeloma from other members of the group, their records were re-examined and the information compared with that of other participants in the same group (group D in Table 7.13) who did not develop either disease. For this purpose, one man who developed chronic lymphatic leukaemia was omitted, as this disease is certainly less likely to be produced by ionising radiation than other types of leukaemia, and may not be produced by it at all, and six men were randomly selected to serve as controls for each of the remaining 11 men, who were in the same broad group of participants (group D in Table 7.13) and who were born in the same year as the corresponding affected man. The results failed to suggest any feature that

distinguished the affected men from the unaffected. In particular, all three Services were represented (RN, etc — 2 affected, 19 controls; Army — 5 affected, 16 controls; RAF — 4 affected, 31 controls) and approximately equal proportions had visited Christmas Island (6 affected, 35 controls) and Maralinga (5 affected, 24 controls). Thus no particular feature of the programme could be identified which distinguished those who developed leukaemia (other than chronic lymphatic leukaemia) or multiple myeloma.

7.5 Mortality and cancer incidence in independent respondents

To test whether there was any evidence that the failure to achieve complete coverage of the study population, as described in Section 5, had led to any bias in the findings, enquiries were made about the status of all independent respondents who were not already included in the main study and who had not been excluded for the reasons given in Section 5.5.

The method described in Section 4 for following the participants in the main study group was used to follow-up the 414 men for whom participation was confirmed or inconclusive; 98% were successfully followed. The results are shown in Table 7.14 in comparison with those obtained for the 1707 independent respondents who had been included in the main study. It was predicted that both categories would have a high mortality from cancer which the respondents might attribute to their participation, and this was found to be so. In both categories the SMRs for cancer were more than three times that expected from national mortality rates and the increases were statistically highly significant ($p<0.001$ in both categories). Comparison of the mortality from neoplasms and from other non-violent causes of death showed that it was higher in the participants not included in the main study than in those who had been included (RRs 1.18 and 1.38) but that the mortality from accidents was lower. For leukaemia and for all cancers of lymphatic and haematopoietic tissues the relative risks (1.09 and 1.08, respectively) were similar to those for all cancers. For multiple myeloma no extra deaths were found. None of the relative risks observed, either for all causes of death or for any of the causes listed in Table 7.14, was significantly greater or less than unity. When the analysis was repeated excluding respondents who had been notified to NRPB by the Ministry of Defence (groups 11-13 in Appendix C) similar results were obtained.

Two other incident cases of leukaemia were also recorded in the 414 independent respondents who had not been included in the main study against two in the 1707 who had been. When these are also taken into account the relative risk of leukaemia in the former group is increased to 1.83 ($p=0.23$) (see Table 7.15).

A review of the death attributed to leukaemia in the independent respondents not included in the main study was not possible in one case (attributed to acute myeloid leukaemia) as the hospital records had been destroyed. The other two deaths were attributed to acute lymphatic leukaemia. In one, the hospital

records provided clear evidence of the correctness of the diagnosis. The other presented a number of unusual features and the differential diagnosis lay between acute lymphatic leukaemia and lymphoma. Hospital records confirmed the correctness of the diagnosis of both the additional incident cases, which were respectively cases of acute and chronic myeloid leukaemia.

No service records could be traced for seven other independent respondents. Four had service numbers; two identified other men, one could not be traced, and one identified a man of the correct name, whose record had been mislaid following a police enquiry. For the remaining three no service number was given. One was said to have been an officer in the RN, another was reported by another respondent and said to have been an officer in the Army, and the third, also reported by another respondent, was identified in a photograph of participants, but may not have been a UK citizen. Too little information was available for three of these men to allow successful follow-up; two are alive, and two have died, one of cirrhosis of the liver and one of lung cancer.

Seven other men reported to be participants but not included in any of the groups referred to in this section, were reported to have died of leukaemia. One did not have the minimum information that was required for identification (see Section 5.5). Another was involved in the programme, but did not visit any of the locations listed in Table 3.2. These two men were, therefore, excluded in the same way as other independently notified participants with similar characteristics. The remaining five men (four in the RN and one in the Army) were excluded because inspection of their service records showed that participation in the tests was impossible or very unlikely. In each case the notification had come from a relative or friend rather than from the man himself, and certainly in some cases there is likely to have been a confusion with the Christmas Island in the Indian Ocean referred to in Section 5.5. Review of three of these last cases (one acute myeloid and two acute unspecified leukaemias) was not possible as the hospital records had been destroyed. One case of chronic myeloid leukaemia was confirmed, while in the other the diagnosis of acute unspecified leukaemia was changed to chronic myeloid leukaemia with terminal blast crisis.

The implication of these findings is discussed in Section 8.

Table 7.1

Observed deaths (O) and standardised mortality ratios (SMR) among test participants and controls, and relative risks (RR) of mortality in test participants compared with controls, by broad cause

Cause of death	Test participants		Controls		Mortality rate in test participants relative to controls
	O	SMR	O	SMR	RR
Neoplasms	406	80	434	83	0.96
Other known non-violent causes	828	68	854	68	1.00
Accidents and violence	321	124	291	121	1.07
Unknown[1]	36	-	28	-	-
All causes	1591	80	1607	79	1.01

Note:

1. One death in a test participant was fully investigated and diagnosed only as 'natural causes': 63 causes of death not discovered, of which 27 are known to have occurred abroad.

Table 7.2

Observed deaths (O) and standardised mortality ratios (SMR) among test participants and controls for officers and other ranks, together with relative risks (RR) of mortality in test participants compared with controls, by broad cause

Cause of death	Status[1]	Test participants		Controls		Mortality rate in test participants relative to controls
		O	SMR	O	SMR	RR
Neoplasms	Officers	97	59	117	67	0.88
	Other ranks	309	90	317	91	0.99
Other known non-violent causes	Officers	175	45	201	48	0.92
	Other ranks	653	79	653	78	1.03
Accidents and violence	Officers	68	181	95	231	0.81
	Other ranks	253	114	196	98	1.18
Unknown	Officers	9	-	9	-	-
	Other ranks	27	-	19	-	-
All causes	Officers	349	59	422	67	0.89
	Other ranks	1242	89	1185	85	1.05

Note:

1. Includes AWRE employees in social class I with officers and other employees with other ranks.

Table 7.3

Observed deaths (O) and standardised mortality ratios (SMR) among test participants and controls in the Army and other Services or AWRE, together with relative risks (RR) of mortality in test participants compared with controls, by broad cause

Cause of death	Service	Test participants		Controls		Mortality rate in test participants relative to controls
		O	SMR	O	SMR	RR
Neoplasms	Army	71	69	56	75	0.91
	Other Services or AWRE	335	82	378	84	0.97
Other known non-violent causes	Army	176	72	136	76	0.96
	Other Services or AWRE	652	67	718	67	1.01
Accidents and violence	Army	81	114	46	116	1.06
	Other Services or AWRE	240	128	245	121	1.07
Unknown	Army	9	-	1	-	-
	Other Services or AWRE	27	-	27	-	-
All causes	Army	337	80	239	81	0.99
	Other Services or AWRE	1254	80	1368	79	1.01

Table 7.4

Observed deaths (O) and standardised mortality ratios (SMR) among test participants and controls, and relative risks (RR) of mortality in test participants compared with controls, for 23 specific types of cancer

Type of cancer	Test participants		Controls		Mortality rate in test participants relative to controls
	O	SMR	O	SMR	RR
Cancer of tongue, mouth, pharynx	8	106	9	117	0.87
" " oesophagus	23	156	18	118	1.37
" " stomach	26	58	34	72	0.78
" " large intestine and rectum	49	94	46	85	1.12
" " liver and gallbladder	12	164	6	80	1.90
" " pancreas	20	93	23	103	0.87
" " larynx	3	67	8	172	0.40
" " trachea, bronchus, lung and pleura	119	65	156	81	0.82
" " bone	2	63	1	33	1.34
Malignant melanoma	7	105	6	91	1.25
Other skin cancer	0	0	0	0	-
Cancer of prostate	8	76	22	188	0.38**
" " testis	9	112	9	122	1.01
" " bladder	10	76	4	28	2.79
" " kidney	6	54	20	176	0.30**
Tumours of central nervous system	30	98	22	73	1.33
Cancer of thyroid	1	92	1	90	1.01
Hodgkin's disease	7	58	8	70	0.81
Non-Hodgkin's lymphoma	16	114	14	101	0.90
Multiple myeloma	6	111	0	0	∞ **
Leukaemia	22	113	6	32	3.45**
Other specified neoplasms	6	38	9	56	0.65
Unspecified neoplasms	16	80	12	58	1.47
All neoplasms	406	80	434	83	0.96

**p<0.01 (one-sided test).

Table 7.5

Observed deaths (O) and standardised mortality ratios (SMR) among test participants and controls, and relative risks (RR) of mortality in test participants compared with controls for leukaemia and 22 other specific types of cancer

(For leukaemia only the period 2 to 25 years after first exposure, and for all neoplasms and other specific cancers only the period more than 10 years after first exposure, is considered.)

Type of cancer	Test participants		Controls		Mortality rate in test participants relative to controls
	O	SMR	O	SMR	RR
Cancer of tongue, mouth, pharynx	7	106	9	138	0.66
" " oesophagus	23	168	16	116	1.52
" " stomach	24	63	33	84	0.73
" " large intestine and rectum	46	100	37	80	1.23
" " liver and gallbladder	12	189	6	95	1.82
" " pancreas	19	98	20	102	0.92
" " larynx	3	75	8	197	0.39
" " trachea, bronchus, lung and pleura	107	65	140	84	0.79*
" " bone	1	56	1	58	1.04
Malignant melanoma	6	111	6	120	1.08
Other skin cancer	0	0	0	0	-
Cancer of prostate	8	79	22	199	0.38**
" " testis	4	91	3	79	1.29
" " bladder	9	75	4	32	2.51
" " kidney	5	51	16	166	0.34*
Tumours of central nervous system	22	95	17	77	1.17
Cancer of thyroid	1	110	1	111	1.01
Hodgkin's disease	3	45	5	83	0.65
Non-Hodgkin's lymphoma	12	110	7	67	1.42
Multiple myeloma	5	102	0	0	∞ *
Leukaemia	19	116	5	32	3.51**
Other specified neoplasms	6	46	8	63	0.75
Unspecified neoplasms	13	72	12	66	1.21
All neoplasms	354	82	375	86	0.95

*$p<0.05$, **$p<0.01$ (one-sided test).

Table 7.6

Observed deaths (O) and standardised mortality ratios (SMR) among test participants and controls, and relative risks (RR) of mortality in test participants compared with controls, by type of leukaemia as reported on the death certificate

Type of leukaemia	Test participants		Controls		Mortality rate in test participants relative to controls
	O	SMR	O	SMR	RR
Acute myeloid[1]	12	137	5	58	2.34
Chronic myeloid[1]	5	134	0	0	∞ *
Acute lymphatic	3	129	1	47	2.11
Chronic lymphatic	2	102	0	0	∞
Not fully specified	0	0	0	0	-
All types	22	113	6	32	3.45**
All types other than chronic lymphatic	20	115	6	35	3.12**

Notes:

1. Monocytic leukaemia has been classed with myeloid.

*p<0.05, **p<0.01 (one-sided test).

Table 7.7

Observed deaths (O) and standardised mortality ratios (SMR) among test participants, by type of leukaemia, as reported on the death certificate, and time since commencement of first test participation

Type of leukaemia		Time since commencement of first test participation (years)						
		<5	5-9	10-14	15-19	20-24	25+	Total
Acute myeloid[1]	O	0	3	3	2	3	1	12
	SMR	0	250	202	103	140	123	137
Acute lymphatic	O	1	0	0	0	1	1	3
	SMR	147	0	0	0	279	769	129
Chronic myeloid[1]	O	0	0	1	1	3	0	5
	SMR	0	0	149	117	283	0	134
Chronic lymphatic	O	0	0	0	1	1	0	2
	SMR	0	0	0	215	143	0	102
Not fully specified	O	0	0	0	0	0	0	0
	SMR	0	0	0	0	0	0	0
All types	O	1	3	4	4	8	2	22
	SMR	35	106	123	102	169	111	113
All types other than chronic lymphatic	O	1	3	4	3	7	2	20
	SMR	36	111	134	87	174	137	115

Note:

1. Monocytic leukaemia has been classed with myeloid.

Table 7.8

Observed deaths (O) and standardised mortality ratios (SMR) for specific causes other than neoplasms among test participants and controls, and relative risks (RR) of mortality in test participants compared with controls, for causes other than neoplasms

Cause of death	Test participants		Controls		Mortality rate in test participants relative to controls
	O	SMR	O	SMR	RR
a. Diseases related to smoking:					
Coronary heart disease	460	74	505	78	0.94
Bronchitis, emphysema and chronic obstructive lung disease	20	30	37	51	0.55*
Aortic aneurysm	16	104	15	92	1.20
b. Diseases related to alcohol:					
Cirrhosis of liver, alcoholism and alcoholic psychosis	20	108	20	107	1.05
c. Other diseases:					
Infectious and parasitic diseases	15	71	15	70	1.01
Diseases of nervous system	13	39	14	42	1.03
Other diseases of circulatory system	166	71	153	63	1.13
Other diseases of respiratory system	51	61	42	48	1.31
Other diseases of digestive system	33	81	24	58	1.39
Remaining diseases other than neoplasms	34	44	29	38	1.20
d. Accidents and violence:					
Motor vehicle traffic accidents	92	101	82	100	0.97
Drowning and water transport accidents	17	122	19	147	0.77
Air and space transport accidents	42	1285	54	1796	0.89
Suicide	69	101	62	95	1.12
Other injury and poisoning	101	122	74	94	1.34*
All known causes, other than neoplasms	1149	78	1145	76	1.02

*p<0.05 (one-sided test).

Table 7.9

Numbers of incident cancers (I) among test participants and controls, and relative risks (RR) of incident cancer in test participants compared with controls, for 23 specific types of cancer

Type of cancer	Test participants	Controls	Incidence rate in test participants relative to controls
	I	I	RR
Cancer of tongue, mouth, pharynx	15	15	1.04
" " oesophagus	25	23	1.14
" " stomach	30	42	0.72
" " large intestine and rectum	67	77	0.92
" " liver and gallbladder	12	6	1.90
" " pancreas	21	23	0.90
" " larynx	14	16	0.86
" " trachea, bronchus, lung and pleura	141	186	0.81*
" " bone	4	1	3.38
Malignant melanoma	13	12	1.15
Other skin cancer	75	94	0.81
Cancer of prostate	26	27	1.01
" " testis	18	19	0.95
" " bladder	33	25	1.42
" " kidney	13	29	0.46*
Tumours of central nervous system	41	28	1.47
Cancer of thyroid	2	3	0.65
Hodgkin's disease	13	14	0.89
Non-Hodgkin's lymphoma	23	24	0.84
Multiple myeloma	10	0	∞ ***
Leukaemia	28	11	2.43**
Other specified neoplasms	30	31	0.98
Unspecified neoplasms	17	19	1.00
All neoplasms	671	725	0.95

Notes:

*p<0.05, **p<0.01, ***p<0.001 (one-sided test).

Table 7.10

Numbers of incident leukaemias (I) among test participants and controls, and relative risks (RR) among test participants compared with controls, by type of leukaemia classified after review of all the available evidence

Type of leukaemia	Test participants	Controls	Incidence rate in test participants relative to controls
	I	I	RR
Acute myeloid[1]	12	6	1.92
Chronic myeloid[1]	7	0	∞ **
Acute lymphatic	4	1	3.05
Chronic lymphatic	5	3	1.84
Not fully specified	0	1[2]	0.00
All types	28	11	2.43**
All types other than chronic lymphatic	23	8	2.64*

Notes:

1. Monocytic leukaemia has been classed with myeloid.

2. Unspecified acute leukaemia.

*p<0.05 (one-sided test), **p<0.01 (one-sided test).

Table 7.11

Numbers of incident cancers observed (O) and number expected calculated internally (E_I) for test participants with a recorded gamma dose, by dose category for 8 types of cancer

Type of cancer		Total deaths in test participants with a recorded gamma dose	Dose category (mSv)						Direction of trend[1]	Probability[2]
			<0.01	0.01-0.99	1.00-4.99	5.00-9.99	10.00-49.99	≥50.00		
Cancers of lymphatic and haematopoietic tissue	O	16	9	3	2	1	1	0	+	0.46
	E_I		10.42	2.57	1.46	0.59	0.88	0.07		
Leukaemia	O	6	3	2	1	0	0	0	-	0.32
	E_I		4.10	0.98	0.48	0.16	0.27	0.01		
Multiple myeloma	O	4	1	1	1	0	1	0	+	0.29
	E_I		1.83	0.78	0.62	0.30	0.42	0.05		
Hodgkin's disease	O	3	3	0	0	0	0	0	-	0.35
	E_I		2.48	0.25	0.12	0.05	0.09	0.00		
Non-Hodgkin's lymphoma	O	3	2	0	0	1	0	0	+	0.43
	E_I		2.00	0.57	0.23	0.09	0.10	0.01		
Cancer of trachea, bronchus, lung and pleura	O	40	30	3	1	3	3	0	-	0.47
	E_I		30.35	3.14	2.10	1.27	2.93	0.20		
Alcohol-related cancers	O	14	10	3	0	0	1	0	-	0.28
	E_I		10.07	1.14	1.02	0.47	1.09	0.22		
Remaining neoplasms	O	95	64	10	6	6	8	1	+	0.37
	E_I		65.03	8.99	7.69	5.16	7.23	0.90		
All neoplasms	O	165	113	19	9	10	13	1	+	0.48
	E_I		115.87	15.83	12.28	7.49	12.13	1.40		

Notes:

1. -: tendency for mortality rate to decrease with increasing recorded dose.
   +: tendency for mortality rate to increase with increasing recorded dose.

2. One-sided test that the trend is greater than zero (+), or less than zero (-).

Table 7.12

Observed deaths (O), standardised mortality ratios (SMR) and relative risks compared with total control group (RR) for test participants in two pre-selected groups for 8 different types of cancer

Type of cancer	A. Participants in special groups identified by MOD as liable to be exposed to radiation			B. Test participants employed by AWRE, or directly involved in the minor trials at Maralinga			All test participants in A or B[1]			Other test participants			All test participants		
	O	SMR	RR	O	SMR	RR	O	SMR	RR	O	SMR	RR	O	SMR	RR
All cancers of lymphatic or haematopoietic tissue	3	56	1.17	2	60	1.81	4	57	1.18	47	107	1.65*	51	100	1.65*
Leukaemia	1	49	3.25	1	79	5.54	2	75	3.67	20	119	3.54**	22	113	3.45**
Multiple myeloma	1	138	∞	1	201	∞	1	102	∞	5	113	∞	6	111	∞ **
Hodgkin's disease	0	0	0.00	0	0	0.00	0	0	0.00	7	65	.87	7	58	0.81
Non-Hodgkin's lymphoma	1	67	0.48	0	0	0.00	1	51	0.46	15	125	0.92	16	114	0.90
Cancer of trachea, bronchus, lung & pleura	14	53	0.92	5	27	0.53	17	47	0.85	102	69	0.83	119	65	0.82
Alcohol-related cancers	3	86	0.59	5	206	1.77	5	105	0.68	29	132	1.09	34	127	1.01
Remaining neoplasms	27	86	1.01	13	60	0.75	32	75	0.95	170	83	0.96	202	82	0.96
All neoplasms	47	70	0.95	25	54	0.81	58	64	0.90	348	83	0.97	406	80	0.96

Notes:

1. Some test participants are in both A and B.

*p<0.05, **p<0.01 (one-sided test).

Table 7.13

Observed deaths (O), standardised mortality ratios (SMR), and relative risks compared with total control group (RR) for three groups of test participants for 8 different types of cancer

Type of cancer	A. Participants present at a major test, or present for and directly involved in minor trials at Maralinga			B. Participants present at a Pacific Ocean test			C. Participants unlikely to have been exposed to more radiation than the general public			D. Other test participants not in A or C		
	O	SMR	RR	O	SMR	RR	O	SMR	RR	O	SMR	RR
All cancers of lymphatic or haematopoietic tissue	31	86	1.34	22	94	1.30	1	30	0.46	19	164	2.64***
Leukaemia	13	95	2.54*	11	123	3.35*	1	78	2.42	8	181	6.55***
Multiple myeloma	3	78	∞	2	86	∞	0	0	-	3	250	∞**
Hodgkin's disease	2	23	0.35	0	0	0.00*	0	0	0.00	5	180	2.47
Non-Hodgkin's lymphoma	13	132	1.08	9	141	0.96	0	0	0.00	3	94	0.63
Cancer of trachea, bronchus, lung & pleura	91	69	0.88	51	66	0.85	6	55	0.70	22	54	0.69
Alcohol-related cancers	23	121	0.94	11	95	0.73	3	181	1.58	8	134	1.21
Remaining neoplasms	132	75	0.87	74	68	0.80*	18	118	1.37	52	93	1.14
All neoplasms	277	76	0.91	158	71	0.85*	28	90	1.09	101	88	1.10

*p<0.05, **p<0.01, ***p<0.001 (one-sided test).

Table 7.14

Observed deaths (O) and standardised mortality ratios (SMR) among independent respondents not included and included in the main study, together with relative risks

Cause of death	Independent respondents				Relative risk (included in main study = 1.00)
	Not included in main study		Included in main study		
	O	SMR	O	SMR	
Neoplasms	37	502	134	348	1.18
Cancers of lymphatic and haematopoietic tissue	7	830	27	683	1.08
Leukaemia	3	932	15	998	1.09
Multiple myeloma	0	0	3	735	0.00
Hodgkin's disease	1	463	2	209	1.25
Non-Hodgkin's lymphoma	3	1309	7	648	1.46
Cancer of trachea, bronchus, lung and pleura	13	522	33	239	1.59
Alcohol-related cancers	3	775	8	395	2.05
Other neoplasms	14	384	66	352	0.92
Other known non-violent causes	21	120	68	74	1.38
Accidents and violence	0	0	10	49	0.00
Unknown	1	-	6	-	-
All causes	59	199	218	145	1.22

Table 7.15

Numbers of incident cancers (I) among independent respondents not included and included in the main study, together with relative risks

Type of cancer	Independent respondents		Relative risk (included in main study = 1.00)
	Not included in main study	Included in main study	
	I	I	
Cancers of lymphatic and haematopoietic tissue	12	38	1.59
Leukaemia	5	17	1.83
Multiple myeloma	0	5	0.00
Hodgkin's disease	2	5	1.25
Non-Hodgkin's lymphoma	5	11	2.20
Cancer of trachea, bronchus, lung and pleura	16	41	1.70
Alcohol-related cancers	5	16	2.02
Other neoplasms	25	116	0.94
All neoplasms	58	211	1.26

8. DISCUSSION

8.1 General considerations

The study was designed to discover whether participation in the nuclear weapons test programme had affected the health of the participants and, if so, whether the effects produced were related specifically to exposure to ionising radiation. To answer these questions, mortality and cancer incidence rates have been compared in (i) a large group of participants assembled from MOD records with that in a control group of servicemen and civilians chosen to be as similar in character as possible, and in (ii) groups of participants classed according to their part in the programme and their degree of exposure. The mortality in both the participants and the controls has also been compared with that expected from national mortality rates in England and Wales. The results, on first inspection, suggest that participation has not been associated with any detectable effect on the individuals' expectation of life or on their overall risk of developing cancer, but that it has been associated with an increased mortality from leukaemia, multiple myeloma and 'other injury and poisoning' and a decreased mortality from cancers of the prostate and kidney, and from chronic bronchitis and emphysema. The interpretation of these results is not, however, easy.

One problem, which inevitably arises in any study in which the individuals of interest have been determined retrospectively and in which follow-up to ascertain vital status is not 100% complete, is the possibility of the introduction of bias. Service records of eligible individuals who have made claims for disability may have been differentially mislaid and, conversely, the fact that an individual has made a claim may have ensured that he was successfully followed up and his cause of death obtained. In the present study the low and almost equal proportions of individuals who were not followed beyond their date of discharge in the two principal groups (respectively, 0.3 and 0.4%) makes it unlikely that the latter effect can have been important. The complexity and size of the database, however, made it virtually certain that some participants would be omitted from the main study and the checks that were described in Section 5 confirmed that this had happened. It follows that the possibility that bias may have affected the results has to be considered.

In this respect, the omission of some participants in the Army was particularly worrying, as past practices had allowed the records to be out of place for some of those for whom disability pensions had been sought when the lists were compiled. This, it seemed, might have differentially affected the participant group because of the concern that their health might have been affected, with a consequently greater tendency for claims to have been made for a disability pension by participants (or their relatives) than by the controls (or their relatives). Exclusion of the Army, however, had practically no effect on the results, and this particular feature of the study does not seem to have biased the comparisons between test participants and controls.

Another test of the effect of the omission of some participants is provided by the information obtained about participants from other sources. Most of the information referred to individuals who had already been included in the lists prepared from MOD and AWRE records. Some, however, referred to participants who had been omitted. It was, therefore, possible to test for bias in the construction of the lists by comparing the disease specific mortality and cancer incidence rates in these two groups. Mortality from non-malignant disease and mortality and incidence rates from cancer were all higher in the participants who had not been included in the study than in those who had been included but the number of independent respondents not included in the main study was small and none of the increases was significant statistically.

Further evidence relating to the possibility of bias is provided by the fact that despite extensive enquiries reports were received of only seven individuals who were apparently eligible for whom enough information was available for identification to be possible, but for whom no service records could be found. Four were successfully followed up; only one is known to have developed cancer, and this was in the lung.

It would seem, therefore, that there is no strong evidence of any bias in the findings due to failure to achieve complete follow-up of the population included in the main study, but it is not possible to be sure that a small number of individuals who developed serious disease has not been differentially omitted. The best estimate of the extent of this bias can, the authors suggest, be obtained from the observations on the two groups of independent respondents who were respectively included in the main study and omitted from it. If (i) the proportion of independent respondents who were included is typical of the proportion of all the actual participants who were included in the main study, and (ii) the ratios of the mortality and cancer incidence rates in the two groups of independent respondents are typical of the ratios for all those who were studied and all those who were omitted, the mortality and cancer incidence in test participants relative to controls would then be at the levels shown in Table 8.1. The calculations which lead to these estimates are given in Appendix G. For accidents and violence, the estimated relative risk is lower after adjustment for men not included in the main study than before adjustment but for all causes of death, cancers, and other non-violent causes of death it is increased. The increases are not great and none of the estimated rates in test participants relative to controls is statistically significant.

A second problem that is common to many follow-up studies is the low mortality, especially from non-violent causes of death, that has been observed in comparison with that expected from the corresponding temporal, age, and sex-specific national rates, something which would have been more marked if the pooled rates for the whole of the UK instead of the rates for England and Wales had been used, as the corresponding rates for Scotland and Northern Ireland are

mostly higher. One reason for the finding is the high proportion of officers in whom nearly a quarter of the deaths (24.1%) occurred. To allow for this it would have been necessary to have corrected the expected deaths by factors for social class. An indication of the effect that this would have had is obtained if we multiply the expected deaths in officers by the mortality rates for men aged 15-64 in social class I relative to those for England and Wales as a whole in the 3-year period around the 1971 census (OPCS, 1978), that is, approximately half-way through the study. The SMRs for all officers (both participants and controls) would then have been 83 for all neoplasms instead of 63, and 60 for other known non-violent causes instead of 46, and the corresponding rates for all ranks 87 instead of 81, and 73 instead of 68.

Another reason for the low mortality rates observed in the study is that all ranks who served in the tropics, and sub-tropics were selected for physical fitness. This might have had an effect throughout the study, but it would certainly have had a substantial effect on the mortality from neoplasms and from all non-violent causes of death in the early years. It provides an explanation for the fact that the SMRs for neoplasms rose (for participants and controls combined) from 65 in the first 5 years after the start of observation, through 72 from 5 - 15 years after the start, to 86 for subsequent years and for all non-violent causes of death from 55 through 65 to 76 (see Appendix H).

No other reason is likely to have been of comparable importance in reducing mortality from that expected nationally. Other minor factors, which between them may have resulted in underestimating all the SMRs by about 3%, were the mis-classification of some 445 men as alive who had emigrated (see Section 5.2), the failure to find the cause of 64 (2%) of the deaths, and possibly the failure to follow-up 0.4% of the men.

All these factors will have caused the SMRs for most diseases to be underestimated. For some diseases, however, the reverse will be true and the SMRs will have been overestimated by the failure to take account of social class, while for some others the effect of screening for service abroad will have been negligible.

A third problem is that when so many different causes of disease are examined some differences must be expected to occur by chance alone which, according to normal scientific standards, must be regarded as 'statistically significant'. In this study, when comparing test participants with controls the standard of 'significance' that was chosen was a finding that was so extreme that as great or greater a difference would be expected to occur by chance, if there were truly no difference between the two groups, once in 20 times in the particular direction observed (that is, a 'one-sided' test was used). This, it was thought, was appropriate as the study had been specifically designed to see if participation had an adverse effect on health, not whether it had any effect, adverse or beneficial. The same one-sided test was, however, used irrespective

of whether the mortality was higher in the participants or the controls to simplify the presentation and interpretation of the results.

In the basic analyses summarised in Tables 7.1, 7.4, and 7.6, 38 separate causes of death were examined, and 5 broad categories in which the individual causes were subsumed. If, therefore, there were no real differences in the annual risk of death between the two groups, about two differences might be expected to be found by chance which were so extreme that the observed excess in the participants was statistically significant, and about two more in which the observed excess in the controls was statistically significant. In fact 3 examples of each were found: excesses of leukaemia ($p=0.004$), multiple myeloma ($p=0.009$), and 'other injury and poisoning' ($p=0.04$) in the participants and excesses of cancer of the kidney ($p=0.007$), cancer of the prostate ($p=0.01$), and chronic bronchitis and emphysema ($p=0.02$) in the controls. None of these was, in fact, so extreme that no such difference would be expected to occur by chance once in 20 times when 38 different causes were examined (which would require a probability value of 0.001 or less) and, on purely numerical grounds, it would be reasonable to categorise all the differences as due to the random variation that must inevitably occur with any set of biological observations. The position is different, however, if there was a prior reason for looking particularly for an excess of any of these diseases specifically in the group in which it occurred. For two of the excesses (namely, those of leukaemia and multiple myeloma in the participants) there was such a reason: leukaemia is the type of cancer that has been most consistently increased among populations known to have been exposed to high doses of radiation and an increase in leukaemia has also been observed among participants at the American shot SMOKY, while multiple myeloma is the one type of cancer for which a dose-related association has been demonstrated in two large groups of radiation workers, in addition to being in excess in many groups exposed at high doses (UNSCEAR, 1977; ICRP, 1977; Cuzick, 1981; Gilbert and Marks, 1979; Smith and Douglas, 1986; Robinette et al, 1985). These excesses cannot, therefore, be lightly dismissed as chance findings.

8.2 Cancers of lymphatic and haematopoietic tissue

The differences between the participant and the control groups in the mortality from leukaemia and multiple myeloma would have been easy to interpret if the mortality in the controls had been close to that expected from the national experience and the mortality in the participants had been substantially raised. This, however, was not so; the mortality in the controls was unusually low (SMRs 32 and 0) and the mortality in the participants was raised only slightly (SMRs 113 and 111). The finding of two such low mortality rates in the controls is most surprising. No social, behavioural, or environmental factor is known that would lead to a low mortality for these diseases (Heath, 1982; Blattner, 1982), nor do any of the general considerations referred to in Section 8.1 suggest that any characteristic of the study could have produced them

artificially. It is, therefore, difficult not to believe that, despite the prior reason for looking for an excess in the participants, some of the differences between the mortality rates for these two diseases was due to the chance occurrence of very low mortality in the controls.

There are, however, several reasons for thinking that the excess in the participants was partly due to their participation in the programme. As was shown in Table 7.6, the leukaemias from which the participants died were mostly the types known to be produced characteristically by exposure to ionising radiations: namely, acute leukaemia (both myeloid and lymphatic) and chronic myeloid leukaemia. For these types of leukaemia combined (including the contribution from those for which the type was not fully specified) the SMR was 115 and the RRs compared with the controls were 3.12 for deaths and 2.64 for incident cancers, while the SMR for chronic lymphatic leukaemia, which previous studies indicate may not be induced by ionising radiations, was lower (102) and the RR for incident cases 1.84. Another reason, as was pointed out in Section 8.1, is the omission of some participants from the main study may have led to an underestimate of the SMR and the real mortality in comparison with national rates may have been somewhat higher. The authors note, too, that in the brief period since the formal follow-up ceased they have been notified of only two further deaths from leukaemia: both were due to acute lymphatic leukaemia and both were in participants.

More detailed examination of the distribution of cases with time and place fails to provide any clear evidence of a relationship with radiation. There was, as Tables 7.5 and 7.7 showed, a slightly higher SMR for leukaemia 2 - 25 years after first exposure when any effects might be most likely to be seen (SMR 116 against 113) but the spread with time shown in Table 7.7 gave no hint of the early peak that might have been expected from studies of populations known to have been exposed to external radiation at a known point in time (Preston et al, 1987; Darby et al, 1987). Nor was there any evidence of an accumulation of cases in the groups which, it had been thought, were most likely to have been exposed to a radiation hazard if any existed. There was no increase in risk with measured external dose (Table 7.11) and no special accumulation of cases in men identified by MOD as liable to be exposed to radiation, in men employed by AWRE or involved with the minor trials at Maralinga, or in men present at one or other of the tests, or specifically at the tests at Christmas and Malden Islands (Table 7.12 and 7.13), who include any men known to have been exposed to neutrons or thought by MOD to be the ones likely to have ingested or inhaled any radionuclides that would have escaped measurement on the dosemeters. Indeed, the greatest (or equal greatest) RR, the most highly significant difference from the controls, and the highest SMRs for both leukaemia and multiple myeloma were all found in the group of 'other test participants' after excluding the small number who, on any assumption, were unlikely to have been exposed to more radiation than

the general public. These 'other' men had been involved in the test programme in a variety of ways: just under 60% of them had visited Christmas Island, but not during one of the operations listed in Table 3.1, and just over 30% had visited Maralinga, but were not known to have been involved in the programme of minor trials or to have been present during one of the major tests. Most of the remaining visits had been to the Monte Bello Islands either before or after tests in the Mosaic series. According to MOD, the experience of men in this group (group D in Table 7.13) is, on all counts, likely to be less than for groups A and B in the same table. A comparison of the 11 men who developed leukaemia (other than chronic lymphatic leukaemia) or multiple myeloma with unaffected participants in the same group, failed, however, to highlight any characteristics that distinguished them.

The part played by men in this group is very different from that played by the one group of American participants in the Nevada tests who experienced an increased risk of leukaemia. These were 3554 men who participated at shot SMOKY in the PLUMBOB series of tests in Nevada in 1957, 10 of whom subsequently died of leukaemia when only 3.97 deaths would have been expected at national rates ($p=0.008$). The greatest excess, however, was of 4 leukaemias in two small groups of 563 and 110 men who also participated in other shots, undertaking special duties which involved above average exposure. These are described in detail in the US National Research Council's report (Robinette et al, 1985).

When the deaths in this study from leukaemia and multiple myeloma were combined with those from Hodgkin's disease and non-Hodgkin's lymphoma, as it is sometimes suggested they should be, the excess mortality in the participants was less marked. The evidence that lymphomas are readily induced by ionising radiations is, however, conflicting. Several studies have shown an excess following exposure, particularly of non-Hodgkin's lymphoma (Darby et al, 1987, and see Finch, 1984 for review) but there is no evidence of an increase in risk with increasing dose in the 128 deaths reported in the survivors of the Hiroshima and Nagasaki bombs (Preston et al, 1987). The failure to observe an increased risk of lymphomas in the participants (RR 0.87 and SMR 88 for Hodgkin's disease and non-Hodgkin's lymphomas combined) does not, therefore, weigh heavily against the idea that some of the participants may have experienced a hazard of leukaemia and multiple myeloma.

If, as the results of this study suggest, there has been an association between participation in the nuclear weapons test programme and the development of leukaemia and multiple myeloma, it must, of course, be borne in mind that an association does not necessarily imply causation. There is always the possibility in a non-experimental study that an association may reflect confounding rather than causality: that is to say in this case it may reflect an association between participation in the programme and some other factor that causes the disease and is nothing to do with the programme as such. That there should be

such a factor here seems, however, to be extremely unlikely. The controls were matched with the participants on so many features, sex, age, Service (or civilian employment), rank (officers and other ranks, or socio-economic class for civilians), service in tropical or sub-tropical areas, and date of entry to the study, that it is difficult to think of any environmental or behavioural difference that might have influenced the development of these two diseases. There is, moreover, no clear difference between the participants and their controls in the mortality from other diseases, unless it is thought that the evidence suggests that participants may have tended to smoke less (see Section 8.4), and if it does this would imply that if anything the participants should have experienced less leukaemia rather than more (Austin and Cole, 1986). A remote possibility may be that the participants were subjected to a greater number of radiological examinations, but the difference would have to be very great and there is nothing to suggest that it was. In one respect only the matching broke down, in that Army other ranks who left the Service before the termination of their Reserve liability could not be matched at all; but this has not had any effect on the results as they are unchanged when the Army is omitted. It is concluded, therefore, that if a real, as opposed to a chance, association exists, it is likely to reflect causality rather than confounding.

8.3 Other cancers

All cancers classed together caused a slightly lower mortality in the participants than in the controls, irrespective of whether the Army was included (RR=0.96) or not (RR=0.97) and irrespective of whether the whole period of follow-up was examined or only the period 10 or more years after entry, when any effect of exposure to ionising radiations would be more likely to be seen (RR=0.95). The inclusion of non-fatal cases, moreover, left the result essentially unchanged (RR=0.95). It follows that the mortality from (and incidence of) cancers other than those of lymphatic and haematopoietic tissue would have been relatively even less in the participants since the latter cancers were so substantially in excess. It is notable, too, that no increase in cancer incidence or mortality was observed with increasing dose in the 4453 subjects to whom dosemeters were issued. Even if allowance is made for a slight underestimation of the mortality in participants due to the omission of some participants from the main study, the results would not suggest that participation in the programme had caused any material increase in the risk of cancer in general. Nor does detailed examination of individual types of cancer suggest that there was a hazard of any particular type other than leukaemia and multiple myeloma.

For two types (cancers of the kidney and prostate) the mortality rates in the two groups were significantly different but in each case the mortality was higher in the controls than in the participants and the differences, as noted in Section 8.1, can reasonably be attributed to chance. This conclusion is strengthened by the finding that when incident cases were also included the diff-

erences diminished and, in the case of cancer of the prostate, disappeared. The data for cancer of the prostate are particularly notable as this was the only type of cancer, other than leukaemia, for which an excess had been observed in the participants of any of the American series of tests (Robinette et al, 1985) and it had also been found in excess in men employed by the UK Atomic Energy Authority (Beral et al, 1985). One other significant difference was recorded when the analysis was limited to the period 10 or more years after entry, but again the excess (of cancer of the lung) was in the controls. This may also be due to chance or it may perhaps be related to the similar difference in the mortality from chronic bronchitis and emphysema that is discussed in Section 8.4.

For cancer of the bladder and cancer of the bone, either the mortality or the incidence in the participants was more than double that in the controls. For cancer of the bladder, the difference, based on only 14 deaths in both of the study groups combined, was not statistically significant ($p=0.06$) and it became less significant when the period 10 or more years after entry was examined and still less when incident cases were also included (Tables 7.9 and F9; $p=0.12$). There is no special reason to think that this disease would be induced by radiation and the difference observed seems most likely to be due to chance. Only two of the five so-called cancers of the bone appear to have been true bone cancers. Both occurred in participants, one in a man who visited Christmas Island before the first explosion in the Grapple series, and the other in a man who paid a brief visit to the Monte Bello Islands in between the two Mosaic explosions.

If, as the results considered in Section 8.4 suggest, participants have smoked less than controls, the data for cancer need to be re-examined, classing the cancers produced by smoking separately from the rest. Those related to smoking include, in additon to cancer of the lung, cancers of the tongue, mouth, and pharynx, oesophagus, larynx, pancreas, bladder, and possibly the kidney (International Agency for Research on Cancer, 1986). The results of separating them off as a group are shown in Table 8.2. For some of the cancers related to smoking, it will be noted, the SMRs in both participants and controls are greater than 100 while for others they are less. The reasons for this difference are presumably unrelated to participation in the test programme and are considered elsewhere (Darby et al, 1988). Considered as two broad groups, the cancers that can be produced by smoking caused a lower mortality in the participants than in the controls ($RR=0.84$, $p=0.05$) while for all other cancers, excluding cancers of lymphatic and haematopoietic tissue, mortality was virtually identical ($RR=1.01$, $p=0.49$). Similar data for incident cases are summarised in Table 8.3. These show lower incidence rates for both groups in the participants than in the controls; but the RR for cancers related to smoking is again lower than that for other cancers.

8.4 Other diseases

Little difference has been observed between the mortality rates in the participants and the controls for most of the other causes of death that were examined or for all other causes combined. In these circumstances, the two differences that were statistically significant (a deficiency of deaths from bronchitis, emphysema, and chronic obstructive lung disease in the participants ($p=0.02$) and an excess of deaths from 'other injury and poisoning' ($p=0.04$)) could reasonably be attributed to chance, as was suggested in Section 8.1 The deficiency of deaths from bronchitis, etc, in the participants combined with the possible deficiency of deaths from cancer of the lung, referred to in Sections 8.1 and 8.3, does, however, suggest that the participants may have smoked less than the controls. The only way this possibility can be examined is by looking at the mortality rates for other causes of death that can be caused by smoking. To the cancers referred to in Section 8.3, it is necessary to add the two other non-malignant diseases that were characterised as related to smoking before the results were analysed: namely, coronary heart disease and aortic aneurysm. The differences in mortality are not statistically significant, neither for other malignant diseases related to smoking (based on 70 and 82 deaths, RR 0.88, $p=0.25$) nor for similar non-malignant diseases (based on 476 and 520 deaths, RR 0.94, $p=0.20$), but in both cases the mortality is lower in the participants, and the possibility that the participants have smoked less than the controls has to be considered seriously. Therefore, the mortality from other non-malignant diseases that had not originally been characterised as related to smoking has been examined separately. Classed as a group, these other non-malignant diseases caused a higher mortality in the participants than in the controls (RR 1.16, based on 332 and 297 deaths) and the difference was statistically significant ($p=0.03$, 90% confidence interval 1.02, 1.34). It seems unlikely, however, that this difference could be due to exposure to ionising radiation in the absence of any greater excess in the participants from the corresponding group of neoplasms, since neoplasms have been the only somatic disease with appreciable fatality produced in adult populations exposed to moderate doses (International Commission on Radiological Protection (ICRP), 1977) and, on this basis, the finding is attributed to chance.

No information has been obtained about the incidence of cataract, as it does not give rise to a recognisable increase in mortality. This, as far as the authors are aware, is the only somatic disease with a very low fatality rate that is liable to be caused by exposure of adults to moderate doses of radiation (ICRP, 1977).

8.5 Possible differences between participants and controls

In considering the results of this study, the possibility must be borne in mind that there may have been differences between the participants and their controls in some features that could have affected their subsequent health, apart

from the fact of their participation in the tests. No such feature seemed capable of affecting their subsequent risk of developing leukaemia or multiple myeloma and, in view of the care taken to select controls that matched the participants with regard to so many personal characteristics, there were not expected to be any major difference between the groups that would have a material effect on any other disease. The finding that the participants had a lower mortality than the controls from two categories of diseases that are generally accepted as being closely related to smoking was, therefore, disturbing. It is not easy to see why participants should have smoked less in the 1950s and early 1960s; but many men have given up smoking in the last 25 years and it is conceivable that the participants may have responded more to subsequent public education about the effects of smoking, if they were selected in part on psychological and personality grounds. If this explanation is true, it is necessary to base the conclusions about the effect of participation principally on the results obtained for diseases that are unrelated to smoking rather than the total risk of disease of all types. The suggestion that participants have smoked less than controls is, however, a tentative hypothesis and without further support the principal conclusions are, perhaps, better based on total mortality from all neoplasms and all other diseases.

Table 8.1

Relative risks of mortality and cancer incidence in test participants compared with controls, after adjustment for men not included in the main study together with 90% confidence intervals (CI)

Cause of death	Relative risk of mortality	90% CI	Relative risk of cancer incidence	90% CI
Neoplasms	0.99	(0.87, 1.13)	0.99	(0.89, 1.10)
Other known non-violent causes	1.07	(0.93, 1.22)	-	-
Accidents and violence	0.89	(0.77, 4.17)	-	-
All causes	1.05	(0.97, 1.13)	-	-

Table 8.2

Observed deaths (O), standardised mortality ratios (SMR) and relative risks (RR) of mortality in test participants compared with controls, for cancers related to smoking and other neoplasms

Cause of death	Test participants		Controls		Mortality rate in test participants relative to controls
	O	SMR	O	SMR	RR
Cancers related to smoking:					
Cancer of trachea, bronchus, lung and pleura	119	65	156	81	0.82
Cancer of tongue, mouth and pharynx	8	106	9	117	0.87
Cancer of oesophagus	23	156	18	118	1.37
Cancer of pancreas	20	93	23	103	0.87
Cancer of larynx	3	67	8	172	0.40
Cancer of bladder	10	76	4	28	2.79
Cancer of kidney	6	54	20	176	0.30**
All cancers related to smoking	189	74	238	89	0.84*
Cancers of lymphatic and haematopoietic tissue	51	100	28	56	1.65*
All other neoplasms	166	82	168	81	1.01
All neoplasms	406	80	434	83	0.96

Notes:

*p<0.05, **p<0.01 (one-sided test).

Table 8.3

Numbers of incident cancers (I) among test participants and controls, and relative risks (RR) of incident cancer in test participants compared with controls, for cancers related to smoking and other neoplasms

Type of cancer	Test participants	Controls	Incidence rate in test participants relative to controls
	I	I	RR
Cancers related to smoking	262	317	0.87*
Cancers of lymphatic or haematopoietic tissue	74	49	1.42*
All other neoplasms	335	359	0.96
All neoplasms	671	725	0.95

*$p<0.05$ (one-sided test).

9. CONCLUSIONS

It is concluded from this study that participation in the nuclear weapons test programme has not had a detectable effect on the participants' expectation of life nor on their total risk of developing cancer, apart from a possible effect on the risks of developing multiple myeloma and leukaemia (other than chronic lymphatic leukaemia).

The evidence relating to multiple myeloma and leukaemia (other than chronic lymphatic leukaemia) is confusing. Some of the differences observed between the mortality and incidence rates in participants and in a control group selected to match the participants in respect of personal and service characteristics seems likely to have been due to a chance finding of unusually low rates of these diseases in the controls. Moreover, the excess observed in the participants is not specifically related to the measured external doses of ionising radiations nor to the individual's presence at the time of the test explosions, nor to any other specific aspect of the programme that it has been possible to define. Some aspects of the results, however, suggest that a real hazard was associated with the programme. The most striking is the very low probability of finding by chance such large differences as those observed specifically for two diseases for which there were prior reasons for thinking might be particularly likely to be produced. Another is the greater mortality from these diseases than would be expected from national rates and the over-representation of leukaemia types that are known to be produced by ionising radiation. On balance it is concluded that there may well have been small hazards of leukaemia and multiple myeloma associated with participation in the programme, but their existence is certainly not proven, and further research is desirable. The only carcinogenic agent that has been shown to cause an increased incidence of both these diseases is ionising radiation, but there is no specific evidence that the test participants who developed these diseases were exposed to unusual amounts.

The interpretation of the results of this study has been complicated by the fact that not all participants were included in the study and that the results suggested that the participants might, as a group, have smoked less than their controls. The former does not appear to have introduced any substantial bias into the results, but it may have resulted in a slight underestimate of the mortality of the participants. The latter has meant that different types of cancer have had to be examined separately. Neither has caused a modification of the main conclusions, but they do point to a need to test the hypotheses that have emerged in this study by further research.

The study was limited to an examination of the incidence of cancer and of mortality from different causes and no evidence has been obtained about the incidence of non-fatal diseases such as cataract.

10. RECOMMENDATIONS

The results of this study have led to three hypotheses: namely that

(i) participation in the UK nuclear weapons test and experimental programmes caused small hazards of multiple myeloma and leukaemia (other than chronic lymphatic leukaemia),

(ii) participation in the programmes did not cause a detectable hazard of any other cancer or of any other disease that has an appreciable fatality rate, and

(iii) participants in the programme have smoked less than other similar men in HM Forces or employed by the Atomic Weapons Research Establishment.

None of these hypotheses is, however, thought to have been proved, and it is recommended that further observations are made to test them. The third hypothesis it should be noted, is not just of academic interest, for it determines the way the effects of participation in the programmes are tested; namely, the decision to examine the total mortality of the participants or the mortality from all diseases other than those closely related to smoking.

Three reasons in particular have militated against the acceptance of proof. First, the differences between the incidence rates of leukaemia and multiple myeloma in the participants and the controls have been mainly due to very low rates in the controls and these, it was thought, were likely to have been due to chance. Second, a small proportion of men who participated in the programme was omitted from the study and it is possible that this has caused some of the mortality and incidence rates in the participants to be slightly underestimated. Third, the finding of a lower mortality from smoking-related diseases in the participants than in the control group was unexpected and the suggestion that the participants have smoked less than the controls was unsupported by any direct evidence of a difference in smoking habits.

Further observations would need to be made for long enough for sufficient data to be obtained to provide substantial new evidence and it is recommended that the observations are continued for 10 years. In this time about 30 deaths would be expected from leukaemia and multiple myeloma and at least a further 20 cases in the participants and a similar number in the controls, if the men experienced the normal national mortality and cancer registration rates in England and Wales. This would be sufficient to show whether our previous experience of the control group was or was not atypical and would provide a 50% chance of showing whether there was a statistically significant difference between the mortality rates in the two groups if the true rates in the participants were 50% greater than in the controls. In addition, the new results will indicate whether the present results were materially affected by bias, as the closing date for identifying test participants and controls occurred in mid-1986, and the large number of observations made between that date and the end of 1993 would be essentially free from bias because the populations observed will

have been defined before that observation period began. Lastly, there will be ample data to test whether the participants have smoked less than the controls, including approximately 1000 deaths in each group from the two diseases most closely related to smoking (lung cancer and chronic obstructive lung disease).

It should be noted, however, that any new evidence relating to the incidence of leukaemia in the participants will be of limited value as the risk of leukaemia following exposure to ionising radiation diminishes appreciably more than 10 years after the exposure has occurred, unless any of the exposure was due to the ingestion or inhalation of long-lived radionuclides. This qualification does not apply to the risk of multiple myeloma nor, in all probability, to the risk of many other cancers.

11. ACKNOWLEDGEMENTS

The work described in this report was made possible only by the cooperation of many organisations and individuals. The authors are grateful for the help of (i) the staff of the Ministry of Defence, the Atomic Weapons Establishment and the Atomic Energy Research Establishment who have assisted in the collection of the data; (ii) the organisations and individuals who helped to provide follow-up information, viz: the National Health Service Central Registers, the Department of Health and Social Security (Records Branch, Newcastle, and Archives Branches at Norcross and Nelson), the Health Departments in Belfast, Dublin, Guernsey, Jersey, and the Isle of Man, the Office of Population Censuses and Surveys, Dr P Fraser and other staff of the Environmental Monitoring Unit of the Medical Research Council, and (iii) all who provided lists of independent respondents. The authors would also like to thank those who provided information about the studies of test veterans in Australia, Canada, and New Zealand, especially Dr J L Symonds and Dr R A Spasoff and co-workers, Professor Sir David Weatherall for assistance with the review of leukaemia diagnoses, the Office of Population Censuses and Surveys for supplying computer tapes enabling national mortality rates to be calculated, and the Oxford Regional Cancer Registry for assistance in coding cancer registrations. Other NRPB and ICRF staff whose help is gratefully acknowledged include Steve Barry, Debbie Belcher, Sharon Bowler, Andrew Brown, Cathy Harwood, Mark Hillier, Gladys Lane, Christine Lees, Thora Mould, Louise Ogden, Carole Pearce, Stewart Rae, Steve Rees, Gill Saw, Lynda Smith, Irene Stratton, Val Weare, and Michael Yeats. Finally, the authors wish to record the contribution made by the late Dr John Reissland during the planning of this study.

12. REFERENCES

1. Austin, H and Cole, P (1986), Cigarette smoking and leukaemia. J. Chron. Dis., 39, 417.

2. Beral, V, Inskip, H, Fraser, P, Booth, M, Coleman, D and Rose, G (1985), Mortality of employees of the United Kingdom Atomic Energy Authority, 1946-1979. Br. Med. J., 291, 440.

3. Blattner, W A (1982), Multiple myeloma and macroglobulinaemia. IN Cancer Epidemiology and Prevention (D Schottenfeld and J F Fraumeni, Jr, Eds.). Philadelphia, W B Saunders, p795.

4. Breslow, N E and Day, N E (1987), Statistical Methods in Cancer Research, Vol. II. The Analysis of Cohort Studies. Lyon, International Agency for Research on Cancer.

5. Caldwell, G G, Kelley, D B and Heath, C W (1980), Leukaemia among participants in military maneuvers at a nuclear bomb test. A preliminary report. J. Am. Med. Assoc., 244, 1575.

6. Caldwell, G G, Kelley, D B, Zack, M, Falk, H and Heath, C, W (1983), Mortality and cancer frequency among military test (Smoky) participants, 1957 through 1979. J. Am. Med. Assoc., 250, 620.

7. Carter, M W and Moghissi, A A (1977), Three decades of nuclear testing. Health Phys., 33, 55.

8. Commonwealth Department of Health (1983), Health of Atomic Test Personnel. Canberra, Australian Government Publishing Service.

9. Court Brown, W M and Doll, R (1959), Adult leukaemia. Trends in mortality in relation to aetiology. Br. Med. J., 1, 1063.

10. Cuzick, J (1981), Radiation-induced myelomatosis. New. Engl. J. Med., 304, 204.

11. Darby, S C, Doll, R, Gill, S K and Smith, P G (1987), Long term mortality after a single treatment course with x-rays in patients treated for ankylosing spondylitis. Br. J. Cancer, 55, 179.

12. Darby, S C, Doll, R, Muirhead, C R, Fell, T P and Kendall, G M (1988), Mortality rates among servicemen who served in the 1950s and 1960s. To be published.

13. Darby, S C, Kendall, G M, Fell, T P, O'Hagan, J A, Muirhead, C R, Ennis, J R, Ball, A M, Dennis, J A and Doll, R (1988), A summary of mortality and incidence of cancer in men from the United Kingdom who participated in the United Kingdom atmospheric nuclear weapon tests and experimental programmes. Br. Med. J., 296.

14. Department of Health and Social Security (1976), Sharing resources for health in England: the report of the Resource Allocation Working Party (RAWP). London, HMSO.

15. Department of Health and Social Security (1986), Review of the Resource Allocation Working Party formula. London, Department of Health and Social Security.

16. Finch, S C (1984), Ionising radiation and drugs in the pathogenesis of lymphoid neoplasms. IN Pathogenesis of Leukaemias and Lymphomas. Progress in Cancer Research, Vol 27 (Magrath, I T, ed). New York, Raven Press.

17. Fox, A J and Collier, P F (1976), Low mortality rates in industrial cohort studies due to selection for work and survival in the industry. Br. J. Prev. Soc. Med., 30, 225.

18. Fraser, P, Booth, M, Beral, V, Inskip, H, Firsht, S and Speak, S (1985), Collection and validation of data in the United Kingdom Atomic Energy Authority mortality study. Br. Med. J., 291, 435.

19. Gilbert, E S and Marks, S (1979) An analysis of the mortality of workers in a nuclear facility. Radiat. Res., 79, 122.

20. Heath, C W, Jr (1982), The leukaemias. IN Cancer Epidemiology and Prevention (D Schottenfeld and J F Fraumeni, Jr, Eds.). Philadelphia, W B Saunders, p728.

21. Hunt, K and Coleman, M P (1987), The completeness of cancer registration in follow-up studies. A cautionary note. Br. J. Cancer, 56, 357.

22. International Agency for Research on Cancer (1986), IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Vol. 38. Tobacco Smoking. Lyon, International Agency for Research on Cancer.

23. International Commission on Radiological Protection (1977), Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. Ann. ICRP, 1, No 3.

24. Knox, E G, Sorahan, T and Stewart, A M (1983), Cancer following nuclear weapon tests. Lancet, 1, 815; 2, 856.

25. Office of Population Censuses and Surveys (1970), Classification of Occupations 1970. London, HMSO.

26. Office of Population Censuses and Surveys (1978), Occupational Mortality. The Registrar General's Decennial Supplement for England and Wales, 1970-72. Series DS no. 1. London, HMSO.

27. Office of Population Censuses and Surveys (1982), The National Health Service Central Register as an Aid to Medical Research. A Guide for Potential Applicants. London, OPCS.

28. Preston, D L, Kato, H, Kopecky, K J and Fujita, S (1986), Life Span Study Report 10. Part I. Cancer mortality among A-bomb survivors in Hiroshima and Nagasaki 1950-82. Hiroshima, Radiation Effects Research Foundation, RERF-TR1-86.

29. Raman, S, Dulberg, C S and Spasoff, R A (1984), Mortality of Canadian military personnel exposed to radiation: Atomic test blasts and Chalk River nuclear reactor clean-ups, 1950s. Ottawa, University of Ottawa Department of Epidemiology and Community Medicine.

30. Reissland, J A (1983), Protocol for a study of the health of UK participants in the UK atmospheric nuclear weapon tests. Chilton, NRPB-R154 (London, HMSO).

31. Robinette, C D, Jablon, S and Preston, D L (1985), Studies of participants in nuclear tests. Final report. Washington, National Research Council Medical Follow-up Agency.

32. Smith, P G and Douglas, A J (1986), Mortality of workers at the Sellafield plant of British Nuclear Fuels. Br. Med. J., 293, 845.

33. Swerdlow, A J (1986), Cancer registration in England and Wales: some aspects relevant to interpretation of the data. J. R. Statist. Soc. A., 149, 146.

34. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (1977), Sources and Effects of Ionizing Radiation. New York, United Nations.

35. World Health Organisation (1977), Manual of the International Statistical Classification of Diseases, Injuries and Causes of Death. 9th Revision. Geneva, World Health Organisation.

13. ABBREVIATIONS AND ACRONYMS USED

AERE	Atomic Energy Research Establishment
AWE	Atomic Weapons Establishment
AWRE	Atomic Weapons Research Establishment
CI	Confidence interval
DHSS	Department of Health and Social Security
E	Number of deaths expected from national rates
E_I	Number of deaths expected calculated internally
FPC	Family Practitioner Committee
I	Incident cancers
ICD	International Classification of Diseases
ICRF	Imperial Cancer Research Fund
MOD	Ministry of Defence
MOS	Ministry of Supply
MRC	Medical Research Council
mSv	Millisievert
NAAFI	Navy, Army and Air Force Institute
NHS	National Health Service
NRPB	National Radiological Protection Board
O	Observed deaths
OPCS	Office of Population Censuses and Surveys
RAAF	Royal Australian Air Force
RAF	Royal Air Force
RE	Royal Engineers
RM	Royal Marines
RN	Royal Navy
RNVR	Royal Naval Volunteer Reserve
RR	Relative risk
SMR	Standardised mortality ratio
Sv	Sievert

APPENDIX A

Forms completed by Service Record Offices for suspected test participants in the Services.

Two slightly different forms were used: one for test participants whose names had been listed in the Blue Book or other source document separate from the service record, and one for individuals whose names were derived directly from the service record, as in the systematic search of Royal Engineers' discharge collations (see Section 3.2).

Registration no._____ IN CONFIDENCE Blue Book no.

STUDY GROUP-SERVICE PERSONNEL

A. INFORMATION FROM BLUE BOOK ON TEST INVOLVEMENT

1 Name 2 Service 3 Rank/Serial no.

4 Organisational group 5 Operation 6 Date 7 Area of operation

8 Confirmation from service record that individual was present in the test area at the specified dates. Yes(Y)/Inconclusive(I)/No(N) ____
If "I" or "N" please note conflicting data or dates present

9 Unit(s) _____

B. INFORMATION FROM SERVICE RECORD

1 Corrected surname (if different from Blue Book) _____

2 Full forenames _____

3 Previous names if any _____

4 Service number (if not in A.3) _____

5 National Service(N) or Regular(R) on discharge _____

6 Officer(O) or Serviceman(S) at time of nuclear weapon tests.See A.6 for dates. _____

7 Job in service.
Officer:Specialisation or Arm/Corps
Serviceman:Branch/Arm/Corps/Trade _____

8 Date of first enlistment (dd/mm/yy) _____

9 Still in service(S) or date of last discharge (dd/mm/yy) from full-time service _____

10 Reason for discharge. _____
(Death(D)/Medical grounds(M)/Other alive(A))
If dead state date and place of death _____

11 Date of birth (dd/mm/yy) _____

12 Place of birth Town: _____
County/Country: _____

13 Nationality at birth.
British(B);state other in full _____

14(i) CIVILIAN address on ENLISTMENT in full _____
(Please supply further addresses _____
(if given) and dates overleaf) _____
_____

(ii) Date of currency _____

15 National Insurance Number _____

16 National Registration/National Health Service no. _____

Registration no._____ IN CONFIDENCE NRPB Ref no.

STUDY GROUP-SERVICE PERSONNEL

A. INFORMATION ON TEST INVOLVEMENT

1 Name	2 Service	3 Rank/Ser no.		
4 Unit	5 Test Area	6 Date on	7 Date off	8 Other info. eg Test nam

B. OTHER INFORMATION FROM SERVICE RECORD

1 Corrected surname (if different from Section A) _____

2 Full forenames _____

3 Previous names if any _____

4 Service number (if not in Section A) _____

5 National Service(N) or Regular(R) on discharge _____

6 Officer(O) or Serviceman(S) at time of nuclear weapon tests.See Section A for dates. _____

7 Job in service.
Officer:Specialisation or Arm/Corps
Serviceman:Branch/Arm/Corps/Trade _____

8 Date of first enlistment (dd/mm/yy) _____

9 Still in service(S) or date of last discharge (dd/mm/yy) from full-time service _____

10 Reason for discharge. _____
(Death(D)/Medical grounds(M)/Other alive(A))
If dead state date and place of death _____

11 Date of birth (dd/mm/yy) _____

12 Place of birth Town: _____
County/Country: _____

13 Nationality at birth.
British(B);state other in full _____

14(i) CIVILIAN address on ENLISTMENT in full _____
(Please supply further addresses _____
(if given) and dates overleaf) _____
_____

(ii) Date of currency _____

15 National Insurance Number _____

16 National Registration/National Health Service no. _____

APPENDIX B

Forms completed by Service Record Offices for controls in the Services

Five slightly different forms were used, for the various Services and ranks.

(i) Control Group for Royal Navy and Royal Marines

(ii) Control Group for Army Officers

(iii) Control Group for Soldiers

(iv) Control Group for Royal Air Force Officers

(v) Control Group for Royal Air Force Airmen

Registration no._____ IN CONFIDENCE NRPB Ref no.

CONTROL GROUP FOR ROYAL NAVY AND ROYAL MARINES

A. INFORMATION FROM SHIP'S LEDGER

1 Name 2 Service 3 Rank

4 Ser. no. 5 Ship 6 Dates

B. INFORMATION FROM SERVICE RECORD

1 Corrected surname (if different from Ship's Ledger) _____

2 Full forenames _____

3 Previous names if any _____

4 Service number (if not in A.4) _____

5 Is there any evidence that this man was involved in the overseas weapon test programme? Yes(Y)/No(N) _____

If yes please give details _____

6 National Service(N) or Regular(R) on discharge _____

7 Officer(O) or Serviceman(S) at time ship's ledger compiled.See above for dates. _____

8 Job in service.
Officer:Specialisation or Arm/Corps
Serviceman: Branch/Arm/Corps/Trade _____

9 Date of first enlistment (dd/mm/yy) _____

10 Still in service(S) or date of last discharge (dd/mm/yy) (excluding reserve service) _____

11 Reason for discharge _____
(Death(D)/Medical grounds(M)/Other alive(A))
If dead date and place of death _____

12 Date of birth (dd/mm/yy) _____

13 Place of birth. Town: _____
County/Country: _____

14 Nationality at birth.
British(B);state other in full _____

15(i) CIVILIAN address on ENLISTMENT in full _____
(Please supply further addresses _____
(if given) and dates overleaf) _____
_____

(ii) Date of currency _____

16 National insurance number _____

17 National Registration/National Health Service no. _____

Registration no._____ IN CONFIDENCE NRPB ref no.

CONTROL GROUP FOR ARMY OFFICERS

A. INFORMATION FROM COMMANDERS DIARY

1 Name _____ 2 Rank _____ 3 Service no._____

4 Overseas posting _____ 5 Dates _____

B. INFORMATION FROM SERVICE RECORD

1 Corrected surname (if different from Commanders diary) _____

2 Full forenames _____

3 Previous names if any _____

4 Service number (if not in A.3) _____

5 National Service(N) or Regular(R) on discharge _____

6 Is there any evidence that this man was involved in the overseas weapon test programme? Yes(Y)/No(N) _____

If yes please give details _____

7 Job in service i.e. specialisation or Arm/Corps _____

8 Date of first enlistment (dd/mm/yy) _____

9 Still in service(S) or date of last discharge (dd/mm/yy) (excluding reserve service) _____

10 Reason for discharge _____
(Death(D)/Medical grounds(M)/Other alive(A))
If dead state date and place of death _____

11 Date of birth (dd/mm/yy) _____

12 Place of birth. Town: _____
County/Country: _____

13 Nationality at birth.
British(B);state other in full _____

14(i) CIVILIAN address on ENLISTMENT in full _____
(Please supply further addresses _____
(if given) and dates overleaf) _____
_____

(ii) Date of currency _____

15 National insurance number _____

16 National Registration/National Health Service no. _____

IN CONFIDENCE

CONTROL GROUP FOR SOLDIERS

A. CORRESPONDING STUDY GROUP MEMBER

1 Name _____ 2 Ser.no. _____ 3 Blue book no. _____

B. ITEMS FOR MATCHING BETWEEN STUDY GROUP MEMBER AND CONTROL

1 Discharge collation _____ 2 National Service(N) or Regular(R) ____ on discharge

3 Year of birth ____ 4 Year of first participation in test (study group)/ start of overseas service (control group) ____

5 Year of first enlistment ____

C. INFORMATION FROM SERVICE RECORD OF CONTROL

1 Reason for discharge (Death(D)/Medical grounds(M)/Other alive(A)) _____
If dead state date and place of death _____

2 Surname _____

3 Full forenames _____

4 Previous names if any _____

5 Service number _____

6 Is there any evidence that this man was involved in the overseas weapon test programme? Yes(Y)/No(N) _____

If yes please give details _____

7 Date of start of overseas service (dd/mm/yy) _____

8 Job in service i.e. Branch/Arm/Corps/Trade _____

9 Date of first enlistment (dd/mm/yy) _____

10 Still in service(S) or date of last discharge (dd/mm/yy) (excluding reserve service) _____

11 Date of birth (dd/mm/yy) _____

12 Place of birth. Town: _____
County/Country: _____

13 Nationality at birth. British(B);state other in full _____

14(i) CIVILIAN address on ENLISTMENT in full _____
(Please supply further addresses _____
(if given) and dates overleaf) _____
_____

(ii) Date of currency _____

15 National insurance number _____

16 National Registration/National Health Service no. _____

Registration no._____ NRPB reference no.

CONTROL GROUP FOR ROYAL AIR FORCE OFFICERS

A. INFORMATION FROM OPERATIONAL RECORDS

1 Name _____ 2 Rank _____ 3 Service no._____

4 Sqn/Org._____ 5 Dates _____

B. INFORMATION FROM SERVICE RECORD

1 Corrected surname (if different from Operational records) _____

2 Full forenames _____

3 Previous names if any _____

4 Service number (if not in A.3) _____

5 National Service(N) or Regular(R) on discharge _____

6 Is there any evidence that this man was involved in the overseas weapon test programme? Yes(Y)/No(N) _____

If yes please give details _____

7 Job in service i.e. specialisation _____

8 Date of first enlistment (dd/mm/yy) _____

9 Still in service(S) or date of last discharge (dd/mm/yy) (excluding reserve service) _____

10 Reason for discharge (Death(D)/Medical grounds(M)/Other alive(A)) _____
If dead state date and place of death _____

11 Date of birth (dd/mm/yy) _____

12 Place of birth. Town: _____
County/Country: _____

13 Nationality at birth. British(B);state other in full _____

14(i) CIVILIAN address on ENLISTMENT in full. _____
(Please supply further addresses _____
(if given) and dates overleaf) _____
_____

(ii) Date of currency _____

15 National insurance number _____

16 National Registration/ National Health Service Number _____

IN CONFIDENCE

CONTROL GROUP FOR RAF AIRMEN

A. CORRESPONDING STUDY GROUP MEMBER

1 Name _____ 2 Ser.no. _____ 3 Blue book no. _____

B. ITEMS FOR MATCHING BETWEEN STUDY GROUP MEMBER AND CONTROL

1 Year of first enlistment ____ 2 National Service(N) or Regular(R) ____ on discharge

3 Year of birth ____ 4 Year of first participation in test (study group)/ start of overseas service (control group) ____

C. INFORMATION FROM SERVICE RECORD OF CONTROL

1 Surname _____

2 Full forenames _____

3 Previous names if any _____

4 Service number _____

5 Is there any evidence that this man was involved in the overseas weapon test programme? Yes(Y)/No(N) _____

If yes please give details _____

6 Date of start of overseas service (dd/mm/yy) _____

7 Job in service i.e. Branch/Arm/Corps/Trade _____

8 Date of first enlistment (dd/mm/yy) _____

9 Still in service(S) or date of last discharge (dd/mm/yy) (excluding reserve service) _____

10 Reason for discharge (Death(D)/Medical grounds(M)/Other alive(A)) _____
If dead state date and place of death _____

11 Date of birth (dd/mm/yy) _____

12 Place of birth. Town: _____
County/Country: _____

13 Nationality at birth. British(B);state other in full _____

14(i) CIVILIAN address on ENLISTMENT in full _____
(Please supply further addresses _____
(if given) and dates overleaf) _____
_____

(ii) Date of currency _____

15 National insurance number _____

16 National Registration/National Health Service no. _____

APPENDIX C

Sources of information on independent respondents

1. British Atomic Veterans Association - list of members.
2. British Nuclear Test Veterans Association - list of members.
3. Royal British Legion - individuals named in cases connected with the tests.
4. British Broadcasting Corporation - test participants named in correspondence following 'Nationwide' television programme.
5. Department of Social Medicine, University of Birmingham - list of test participants.
6. Oxford Eye Hospital - list of test participants with possible or definite diagnosis of cataract.
7. Institution of Professional Civil Servants - list of test participants.
8. Association of Scientific, Technical and Managerial Staffs - list of test participants.
9. National Radiological Protection Board - test participants named in correspondence or inquiries received by NRPB.
10. *Ministry of Defence - test participants named in response to Defence Council Instruction issued in 1985 to the armed forces.
11. *Ministry of Defence - individuals identified as test participants in claims or appeals to DHSS.
12. *Ministry of Defence - test participants named in correspondence or inquiries received by various government departments.

**These three sources comprise individuals who were identified to NRPB independently of MOD archival material, but whose names did not reach NRPB entirely independently of MOD. During the enumeration of test participants, as described in Chapter 3, these sources were deliberately ignored so as to avoid any possible bias due to the fact that they are self-selected. They have been included in the general category of independent respondents and have been specially marked in NRPB records, so that individuals who have been identified by one of these sources but not by any source that is entirely independent of MOD can be easily identified.*

APPENDIX D

Form completed by Service Record Offices for independent respondents

Registration no._____ IN CONFIDENCE NRPB Ref no. SR

SELF RESPONDERS

A. INFORMATION ON TEST INVOLVEMENT

1 Name 2 Service 3 Rank/Service no.

4 Group or unit 5 Operation 6 Dates 7 Area of op.

8 Confirmation from service record that individual was present in the test area at the specified dates. Yes(Y)/Inconclusive(I)/No(N) ____
If "Y" please give full details of test info. from service record.
If "I" or "N" please give service record info. for dates listed above.
Continue on rear or separate sheet if necessary.

9 Has this man already been included in the study ? Y/N ____

10 If "Y" STUDY or CONTROL group ? S/C ____

B. INFORMATION FROM SERVICE RECORD

1 Corrected surname (if different from A.1) _____

2 Full forenames _____

3 Previous names if any _____

4 Service number (if not in A.3) _____

5 National Service(N) or Regular(R) on discharge _____

6 Officer(O) or Serviceman(S) at time of nuclear weapon tests.See A.6 for dates. _____

7 Job in service.
Officer:Specialisation or Arm/Corps
Serviceman:Branch/Arm/Corps/Trade _____

8 Date of first enlistment (dd/mm/yy) _____

9 Still in service(S) or date of last discharge (dd/mm/yy) from full-time service _____

10 Reason for discharge. _____
(Death(D)/Medical grounds(M)/Other alive(A))
If dead state date and place of death _____

11 Date of birth (dd/mm/yy) _____

12 Place of birth Town: _____
County/Country: _____

13 Nationality at birth.
British(B);state other in full _____

14(i) CIVILIAN address on ENLISTMENT in full _____
(Please supply further addresses _____
(if given) and dates overleaf) _____
_____

(ii) Date of currency _____

15 National Insurance Number _____

16 National Registration/National Health Service no. _____

APPENDIX E

Comparison of data in NRPB and Birmingham University series

by

S C Darby, R Doll, E G Knox, T Sorahan and A M Stewart

The need for a comprehensive follow-up of all men involved in nuclear weapons tests was expressed by Knox et al (1983a and b) in two letters to the *Lancet*. This followed a television broadcast on the subject in December 1982, to which many viewers responded. By October 1983, Knox and his colleagues had received information about 594 servicemen and others who were "involved in any of the Pacific tests or clean-up operations (1957-59)", including 27 who had died of a neoplasm of the reticulo-endothelial system (RES). They estimated that, among 14,000 men thought to have taken part in the tests, the expected number of deaths from an RES neoplasm would have been about 30. The question then arose as to how complete the ascertainment of RES neoplasms had been. They also reported an excess cumulative incidence of RES neoplasms in the younger age-groups, but concluded that a confident interpretation was not possible.

When NRPB was awarded a research contract to carry out a full study of servicemen participating in the UK nuclear weapon test programme, there was seen to be advantage in pooling and collating the data sets collected by NRPB and by Knox and his colleagues at Birmingham University.

By May 1985, the Birmingham list contained the names of 1152 men, including some men who had participated in the tests in Australia. Forty-five men (one of whom had died of an RES neoplasm) were ineligible for inclusion within the NRPB data set obtained from MOD, having been either civilians not employed by AWRE, or else members of the Royal Fleet Auxiliary, Merchant Navy, or Commonwealth Services. Another 116 had insufficient identifying information to enable MOD to be sure of finding their service record, 91 (78%) of whom were probably included in the NRPB population, while 8 men were too incompletely identified for any hope of finding them. None of these last two groups were known to have died of an RES neoplasm.

An intensive search through the service and AWRE records for the remaining 983 men resulted in (a) confirmation that 974 men had certainly participated, (b) evidence that 7 were very unlikely to have participated, and (c) failure to find any records for 2 men. Two of the 7 men who were unlikely to have participated had died from an RES neoplasm. In each instance, participation had been reported by a relative or friend and not by the man himself, and in five instances the report had been of 'Service on Christmas Island'. There is another Christmas Island in the Indian Ocean on which men served and we suspect that knowledge that the men had served on this other Christmas Island had in some cases led to a mistaken report of participation in the tests.

Of the 974 men whose participation was confirmed, 758 (78%) were included in the group studied by NRPB, a proportion similar to the 83% for other NRPB-respondents with adequate identifying information (see Section 5). This proportion is also similar to that among NRPB-eligible 'Birmingham' men who were classed in October 1983 as having died of an RES neoplasm (19 out of 24, or 79%). These proportions together provide an estimate of completeness of the MOD study population available to NRPB. By the above date voluntary reporting had notified 17 of the 31 men who had died of an RES neoplasm and had been involved with the Pacific Island tests, with which Knox and his colleagues were chiefly concerned.

A further comparison of the two lists showed that 51% of all men on the NRPB list who were certified as having died from an RES neoplasm were included on the Birmingham list. This was greater than the figure of 23% for those who had died of other cancers and the 5% of those who had died of other conditions.

In conclusion, this comparison has:

(1) confirmed the existence of a selective voluntary reporting effect for men who had developed or died of a disease that was thought to be induced by ionising radiation;

(2) shown that among servicemen participating in the Pacific Island tests, the ascertainment of deaths attributable to RES neoplasms had been 55% complete;*

(3) shown that the study population available to NRPB was approximately 80% complete.

REFERENCES

Knox, E G, Sorahan, T and Stewart, A M (1983a), Cancer following nuclear weapons tests. Lancet, 1, 815.

Knox, E G, Sorahan, T and Stewart, A M (1983b), Cancer following nuclear weapons tests. Lancet, 2, 856.

**61% complete (17 out of 28) for deaths occurring before the end of 1982.*

APPENDIX F

Supplementary tables to accompany Section 7

The tables in this appendix give information that supplements the tables in Section 7 including the expected numbers from which the standardised mortality ratios are derived, the ICD codes used to define the disease groups, and explicit significance levels and 90% confidence intervals for the relative risks.

Table F1

Observed deaths (O) and deaths expected from national rates (E) among test participants and controls, and relative risks (RR) and 90% confidence intervals (CI), at ages less than 85 years, by broad cause together with significance levels

Cause of death (ICD codes (9th revision))	Test participants			Controls			Mortality rate in test participants relative to controls		
	O	E	Probability[1]	O	E	Probability[1]	RR	Probability[2]	90% CI
All neoplasms (140-239)	406	509.59	<0.001	434	525.20	<0.001	0.96	0.31	(0.86, 1.08)
Other known non-violent causes (001-139, 240-799.8)	828	1214.62	<0.001	854	1259.09	<0.001	1.00	0.49	(0.92, 1.09)
Accidents and violence (E800-E999)	321	259.34	<0.001	291	241.46	0.002	1.07	0.23	(0.93, 1.23)
Unknown cause	36	-	-	28	-	-	-	-	-
All causes	1591	1983.57	<0.001	1607	2025.77	<0.001	1.01	0.41	(0.95, 1.07)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

2. One-sided test that the RR is greater than unity (RR≥1.00), or less than unity (RR<1.00).

Table F2

Observed deaths (O) and deaths expected from national rates (E) among test participants and controls for officers and other ranks, and relative risks (RR) and 90% confidence intervals (CI) at ages less than 85 years by broad cause

Cause of death	Status[1]	Test participants			Controls			Mortality rate in test participants relative to controls		
		O	E	Probability[2]	O	E	Probability[2]	RR	Probability[3]	90% CI
Neoplasms	Officers	97	164.78	<0.001	117	175.73	<0.001	0.88	0.21	(0.70, 1.12)
	Other ranks	309	344.81	0.05	317	349.47	0.08	0.99	0.47	(0.86, 1.14)
Other known non-violent causes	Officers	175	390.88	<0.001	201	416.91	<0.001	0.92	0.24	(0.77, 1.11)
	Other ranks	653	823.74	<0.001	653	842.18	<0.001	1.03	0.33	(0.93, 1.13)
Accidents and violence	Officers	68	37.59	<0.001	95	41.10	<0.001	0.81	0.12	(0.61, 1.08)
	Other ranks	253	221.75	0.04	196	200.36	0.78	1.18	0.05	(1.00, 1.39)
Unknown	Officers	9	-	-	9	-	-	-	-	-
	Other ranks	27	-	-	19	-	-	-	-	-
All causes	Officers	349	593.25	<0.001	422	633.74	<0.001	0.89	0.07	(0.79, 1.01)
	Other ranks	1242	1390.32	<0.001	1185	1392.03	<0.001	1.05	0.13	(0.98, 1.12)

Notes:

1. Includes AWRE employees in social class I with officers and other employees with other ranks.

2. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

3. One-sided test that the RR is greater than unity ($RR \geq 1.00$), or less than unity ($RR < 1.00$).

Table F3

Observed deaths (O) and deaths expected from the national rates (E) among test participants and controls in the Army and other Services or AWRE, and relative risks (RR) and 90% confidence intervals (CI) at ages less than 85 years, by broad cause

Cause of death	Service	Test participants			Controls			Mortality rate in test participants relative to controls		
		O	E	Probability[1]	O	E	Probability[1]	RR	Probability[2]	90% CI
Neoplasms	Army	71	102.54	0.001	56	75.02	0.02	0.91	0.33	(0.66, 1.25)
	Other Services or AWRE	335	407.04	<0.001	378	450.18	<0.001	0.97	0.37	(0.86, 1.10)
Other known non-violent causes	Army	176	245.06	<0.001	136	179.61	<0.001	0.96	0.40	(0.79, 1.17)
	Other Services or AWRE	652	969.56	<0.001	718	1079.48	<0.001	1.01	0.43	(0.92, 1.11)
Accidents and violence	Army	81	71.28	0.26	46	39.57	0.34	1.06	0.43	(0.74, 1.50)
	Other Services or AWRE	240	188.06	<0.001	245	201.90	0.004	1.07	0.24	(0.92, 1.25)
Unknown	Army	9	-	-	1	-	-	-	-	-
	Other Services or AWRE	27	-	-	27	-	-	-	-	-
All causes	Army	337	418.89	<0.001	239	294.20	0.001	0.99	0.47	(0.85, 1.15)
	Other Services or AWRE	1254	1564.68	<0.001	1368	1731.57	<0.001	1.01	0.38	(0.95, 1.08)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

2. One-sided test that the RR is greater than unity (RR≥1.00), or less than unity (RR<1.00).

Table F4

Observed deaths (O) and deaths expected from national rates (E) among test participants and controls, and relative risks (RR) and 90% confidence intervals (CI) at ages less than 85 years for 23 specific types of cancer

Type and site of neoplasm (ICD codes (9th revision))	Test participants			Controls			Mortality rate in test participants relative to controls		
	O	E	Prob-ability[1]	O	E	Prob-ability[1]	RR	Prob-ability[2]	90% CI
Cancer of tongue, mouth, pharynx (141, 143-149)	8	7.53	0.85	9	7.70	0.72	0.87	0.49	(0.35, 2.18)
Cancer of oesophagus (150)	23	14.75	0.05	18	15.27	0.52	1.37	0.20	(0.78, 2.41)
Cancer of stomach (151)	26	44.90	0.003	34	47.22	0.05	0.78	0.20	(0.49, 1.23)
Cancer of large intestine and rectum (153, 154 excl 154.3, 159.0)	49	52.17	0.68	46	54.06	0.28	1.12	0.33	(0.78, 1.61)
Cancer of liver and gallbladder (155, 156)	12	7.30	0.14	6	7.47	0.72	1.90	0.15	(0.76, 4.95)
Cancer of pancreas (157)	20	21.62	0.75	23	22.42	0.92	0.87	0.38	(0.50, 1.50)
Cancer of larynx (161)	3	4.47	0.64	8	4.66	0.15	0.40	0.13	(0.10, 1.37)
Cancer of trachea, bronchus, lung and pleura (162, 163)	119	184.34	<0.001	156	193.15	0.006	0.82	0.07	(0.67, 1.02)
Cancer of bone (170)	2	3.19	0.60	1	3.05	0.28	1.34	0.66	(0.09, 31.38)
Malignant melanoma (172)	7	6.69	1.00	6	6.56	0.85	1.25	0.45	(0.44, 3.59)
Other skin cancer (173)	0	1.31	0.42	0	1.35	0.41	-	-	-
Cancer of prostate (185)	8	10.54	0.45	22	11.73	0.008	0.38	0.01	(0.17, 0.80)
Cancer of testis (186)	9	8.03	0.72	9	7.36	0.58	1.01	0.59	(0.41, 2.46)
Cancer of bladder (188)	10	13.20	0.41	4	14.05	0.003	2.79	0.06	(0.94, 8.94)
Cancer of kidney (189)	6	11.12	0.13	20	11.37	0.02	0.30	0.007	(0.12, 0.71)
Tumours of central nervous system (191, 192, 225, 239.6)	30	30.60	0.93	22	30.25	0.15	1.33	0.19	(0.81, 2.21)
Thyroid cancer (193)	1	1.09	1.00	1	1.11	1.00	1.01	0.76	(0.04, 27.70)
Hodgkin's disease (201)	7	12.14	0.15	8	11.37	0.38	0.81	0.45	(0.31, 2.15)
Non-Hodgkin's lymphoma (200, 202.0-202.3, 202.5-202.9)	16	13.98	0.59	14	13.84	1.00	0.90	0.47	(0.45, 1.81)
Multiple myeloma (203 excl 203.1, 238.6)	6	5.40	0.83	0	5.58	0.006	∞	0.009	(1.67, ∞)
Leukaemia (202.4, 203.1, 204-208)	22	19.40	0.57	6	19.03	<0.001	3.45	0.004	(1.50, 8.37)
Other specified neoplasms (140-239 excl. above, 196-199 and 239)	6	15.89	0.008	9	16.02	0.08	0.65	0.29	(0.24, 1.72)
Unspecified neoplasms (196-199, 239, excl. 239.6)	16	20.07	0.38	12	20.70	0.05	1.47	0.21	(0.73, 2.96)
All neoplasms (140-239)	406	509.59	<0.001	434	525.20	<0.001	0.96	0.31	(0.86, 1.08)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.
2. One-sided test that the RR is greater than unity (RR≥1.00), or less than unity (RR<1.00).

Table F5

Observed deaths (O) and deaths expected from national rates (E) among test participants and controls, and relative risks (RR) and 90% confidence intervals (CI) at ages less than 85 years for leukaemia and 22 other specific types of cancer.

(For leukaemia only the period 2 - 25 years after first exposure, and for all neoplasms and other specific cancers only the period more than 10 years after first exposure is considered.)

Type and site of neoplasm	Test participants			Controls			Mortality rate in test participants relative to controls		
	O	E	Probability[1]	O	E	Probability[1]	RR	Probability[2]	90% CI
Cancer of tongue, mouth, pharynx	7	6.60	0.84	9	6.54	0.32	0.66	0.30	(0.24, 1.75)
Cancer of oesophagus	23	13.67	0.02	16	13.74	0.59	1.52	0.13	(0.84, 2.74)
Cancer of stomach	24	38.20	0.02	33	39.09	0.34	0.73	0.15	(0.45, 1.17)
Cancer of large intestine and rectum	46	45.90	1.00	37	46.04	0.19	1.23	0.21	(0.83, 1.81)
Cancer of liver and gallbladder	12	6.36	0.04	6	6.33	1.00	1.82	0.17	(0.72, 4.75)
Cancer of pancreas	19	19.47	1.00	20	19.59	0.91	0.92	0.47	(0.52, 1.64)
Cancer of larynx	3	4.02	0.65	8	4.06	0.07	0.39	0.13	(0.10, 1.36)
Cancer of trachea, bronchus, lung and pleura	107	163.46	<0.001	140	167.45	0.03	0.79	0.04	(0.63, 0.98)
Cancer of bone	1	1.80	0.73	1	1.72	0.74	1.04	0.75	(0.04, 28.39)
Malignant melanoma	6	5.39	0.83	6	5.02	0.65	1.08	0.56	(0.36, 3.25)
Other skin cancer	0	1.07	0.44	0	1.09	0.43	-	-	-
Cancer of prostate	8	10.09	0.54	22	11.07	0.004	0.38	0.01	(0.17, 0.80)
Cancer of testis	4	4.39	1.00	3	3.78	0.81	1.29	0.52	(0.29, 6.03)
Cancer of bladder	9	11.92	0.47	4	12.45	0.01	2.51	0.10	(0.83, 8.19)
Cancer of kidney	5	9.74	0.15	16	9.64	0.07	0.34	0.02	(0.12, 0.85)
Tumours of central nervous system	22	23.27	0.84	17	22.08	0.29	1.17	0.38	(0.64, 2.14)
Thyroid cancer	1	0.91	1.00	1	0.90	1.00	1.01	0.76	(0.04, 27.70)
Hodgkin's disease	3	6.62	0.18	5	6.06	0.70	0.65	0.40	(0.15, 2.55)
Non-Hodgkin's lymphoma	12	10.88	0.76	7	10.44	0.35	1.42	0.32	(0.57, 3.61)
Multiple myeloma	5	4.88	1.00	0	4.91	0.01	∞	0.03	(1.23, ∞)
Leukaemia	19	16.44	0.54	5	15.77	0.003	3.51	0.008	(1.41, 9.34)
Other specified neoplasms	6	13.01	0.05	8	12.66	0.21	0.75	0.40	(0.27, 2.06)
Unspecified neoplasms	13	18.17	0.24	12	18.24	0.16	1.21	0.39	(0.58, 2.56)
All neoplasms	354	433.47	<0.001	375	435.99	0.003	0.95	0.26	(0.84, 1.08)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.
2. One-sided test that the RR is greater than unity (RR≥1.00), or less than unity (RR<1.00).

Table F6

Observed deaths (O) and deaths expected from national rates (E) among test participants and controls, and relative risks (RR) and 90% confidence intervals (CI), at ages less than 85 years by type of leukaemia as reported on the death certificate

Type of leukaemia (ICD codes (9th revision))	Test participants			Controls			Mortality rate in test participants relative to controls		
	O	E	Probability[1]	O	E	Probability[1]	RR	Probability[2]	90% CI
Acute myeloid[3]	12	8.77	0.31	5	8.56	0.24	2.34	0.09	(0.87, 6.63)
Chronic myeloid[3]	5	3.73	0.60	0	3.70	0.04	∞	0.04	(1.08, ∞)
Acute lymphatic	3	2.32	0.74	1	2.15	0.54	2.11	0.48	(0.19, 44.12)
Chronic lymphatic	2	1.95	1.00	0	2.06	0.19	∞	0.25	(0.33, ∞)
Not fully specified	0	2.62	0.12	0	2.55	0.12	-	-	-
All types	22	19.40	0.57	6	19.03	<0.001	3.45	0.004	(1.50, 8.37)
All types other than chronic lymphatic	20	17.44	0.55	6	16.96	0.004	3.12	0.01	(1.33, 7.64)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

2. One-sided test that the RR is greater than unity (RR≥1.00), or less than unity (RR<1.00).

3. Monocytic leukaemia has been classed with myeloid.

Table F7

Observed deaths (O) and deaths expected from national rates (E) at ages less than 85 years by type of leukaemia as reported on the death certificate and time since commencement of first test participation

Type of leukaemia		Time since commencement of first test participation (years)						
		<5	5-9	10-14	15-19	20-24	25+	Total
Acute myeloid[1]	O	0	3	3	2	3	1	12
	E	1.19	1.20	1.49	1.95	2.15	0.81	8.77
	Probability[2]	0.42	0.12	0.19	1.00	0.48	1.00	0.31
Acute lymphatic	O	1	0	0	0	1	1	3
	E	0.68	0.44	0.39	0.31	0.36	0.13	2.32
	Probability[2]	0.49	1.00	1.00	1.00	0.30	0.12	0.74
Chronic myeloid[1]	O	0	0	1	1	3	0	5
	E	0.31	0.51	0.67	0.85	1.06	0.34	3.73
	Probability[2]	1.00	0.69	0.49	1.00	0.09	1.00	0.60
Chronic lymphatic	O	0	0	0	1	1	0	2
	E	0.07	0.13	0.26	0.46	0.70	0.34	1.95
	Probability[2]	1.00	1.00	1.00	0.37	1.00	1.00	1.00
Not fully specified	O	0	0	0	0	0	0	0
	E	0.62	0.57	0.45	0.34	0.45	0.19	2.62
	Probability[2]	0.67	0.68	1.00	1.00	1.00	1.00	0.12
All types	O	1	3	4	4	8	2	22
	E	2.87	2.84	3.25	3.91	4.72	1.80	19.40
	Probability[2]	0.38	1.00	0.78	1.00	0.16	1.00	0.57
All types other than chronic lymphatic	O	1	3	4	3	7	2	20
	E	2.80	2.71	2.99	3.45	4.02	1.46	17.44
	Probability[2]	0.38	1.00	0.55	1.00	0.20	0.66	0.55

Notes:

1. Monocytic leukaemia has been classed with myeloid.

2. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

Table F8

Observed deaths (O) and deaths expected from national rates (E) among test participants and controls, and relative risks (RR) and 90% confidence intervals (CI) at ages less than 85 years, for causes other than neoplasms

Cause of death (ICD codes (9th revision))	Test participants			Controls			Mortality rate in test participants relative to controls		
	O	E	Probability[1]	O	E	Probability[1]	RR	Probability[2]	90% CI
a. Diseases related to smoking:									
Coronary heart disease (410-414)	460	623.11	<0.001	505	646.03	<0.001	0.94	0.17	(0.84, 1.05)
Bronchitis, emphysema and chronic obstructive lung disease (491, 492, 496, 519)[3]	20	66.40	<0.001	37	72.56	<0.001	0.55	0.02	(0.34, 0.91)
Aortic aneurysm (441)	16	15.43	0.90	15	16.36	0.81	1.20	0.37	(0.62, 2.32)
b. Diseases related to alcohol:									
Cirrhosis of liver, alcoholism and alcoholic psychosis (303, 305.0, 291, 571)	20	18.57	0.73	20	18.71	0.82	1.05	0.50	(0.60, 1.85)
c. Other diseases:									
Infectious and parasitic diseases (1-139)	15	21.24	0.19	15	21.58	0.16	1.01	0.56	(0.52, 1.96)
Diseases of nervous system (320-389)	13	33.56	<0.001	14	33.03	<0.001	1.03	0.55	(0.50, 2.08)
Other diseases of circulatory system (390-459, excl. 410-414, 441)	166	234.07	<0.001	153	244.74	<0.001	1.13	0.17	(0.93, 1.37)
Other diseases of respiratory system (460-519, excl. 491-2, 496, 519)	51	83.50	<0.001	42	87.17	<0.001	1.31	0.12	(0.91, 1.90)
Other diseases of digestive system (520-579 excl. 571)	33	40.72	0.24	24	41.62	0.004	1.39	0.14	(0.86, 2.25)
Remaining diseases other than neoplasms (001-799.8 excl. above diseases in a. and b. and 140-239)	34	77.71	<0.001	29	76.99	<0.001	1.20	0.28	(0.76, 1.90)
d. Accidents and violence:									
Motor vehicle traffic accidents (E810-819)	92	91.49	0.96	82	81.89	1.00	0.97	0.45	(0.74, 1.27)
Drowning and water transport accidents (E830-838, E910, E984)	17	13.94	0.42	19	12.93	0.12	0.77	0.29	(0.40, 1.47)
Air and space transport accidents (E840-845)	42	3.27	<0.001	54	3.01	<0.001	0.89	0.32	(0.61, 1.28)
Suicide (E950-959)	69	68.10	0.90	62	65.13	0.71	1.12	0.29	(0.83, 1.52)
Other injury and poisoning (E800-999 excl. above)	101	82.56	0.05	74	78.52	0.61	1.34	0.04	(1.02, 1.76)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

2. One-sided test that the RR is greater than unity (RR≥1.00), or less than unity (RR<1.00).

3. Code 519 (other diseases of respiratory system) is included as it is impossible to separate deaths attributed to this cause from those attributed to 496 (chronic airways obstruction, not elsewhere classified) in calculating expected deaths prior to 1979.

Table F9

Numbers of incident cancers (I) among test participants and controls, and relative risks (RR) and 90% confidence intervals (CI) in test participants compared with controls, at ages less than 85 years, for 23 specific types of cancer

Type of cancer	Test participants	Controls	Incidence rate in test participants relative to controls		
	I	I	RR	Probability[1]	90% CI
Cancer of tongue, mouth, pharynx	15	15	1.04	0.53	(0.53, 2.02)
" " oesophagus	25	23	1.14	0.38	(0.68, 1.91)
" " stomach	30	42	0.72	0.11	(0.47, 1.10)
" " large intestine and rectum	67	77	0.92	0.33	(0.68, 1.23)
" " liver and gallbladder	12	6	1.90	0.15	(0.76, 4.95)
" " pancreas	21	23	0.90	0.42	(0.52, 1.55)
" " larynx	14	16	0.86	0.40	(0.44, 1.66)
" " trachea, bronchus, lung and pleura	141	186	0.81	0.03	(0.67, 0.98)
" " bone	4	1	3.38	0.25	(0.42, 62.03)
Malignant melanoma	13	12	1.15	0.44	(0.55, 2.39)
Other skin cancer	75	94	0.81	0.10	(0.62, 1.06)
Cancer of prostate	26	27	1.01	0.54	(0.62, 1.66)
" " testis	18	19	0.95	0.51	(0.53, 1.73)
" " bladder	33	25	1.42	0.12	(0.88, 2.28)
" " kidney	13	29	0.46	0.01	(0.25, 0.83)
Tumours of central nervous system	41	28	1.47	0.08	(0.95, 2.27)
Cancer of thyroid	2	3	0.65	0.49	(0.10, 3.84)
Hodgkin's disease	13	14	0.89	0.46	(0.44, 1.79)
Non-Hodgkin's lymphoma	23	24	0.84	0.34	(0.49, 1.44)
Multiple myeloma	10	0	∞	0.0007	(2.75, ∞)
Leukaemia	28	11	2.43	0.009	(1.27, 4.70)
Other specified neoplasms	30	31	0.98	0.52	(0.62, 1.55)
Unspecified neoplasms	17	19	1.00	0.56	(0.55, 1.84)
All neoplasms	671	725	0.95	0.18	(0.87, 1.04)

Note:

1. One-sided test that the RR is greater than unity ($RR \geq 1.00$), or less than unity ($RR < 1.00$).

Table F10

Numbers of incident cancers (I) among test participants and controls, and relative risks (RR) and 90% confidence intervals (CI), at ages less than 85 years in test participants compared with controls, by type of leukaemia classified after review of all the available evidence

Type of leukaemia	Test participants	Controls	Incidence rate in test participants relative to controls		
	I	I	RR	Probability[1]	90% CI
Acute myeloid[2]	12	6	1.92	0.15	(0.75, 5.05)
Chronic myeloid[2]	7	0	∞	0.01	(1.51, ∞)
Acute lymphatic	4	1	3.05	0.30	(0.36, 57.38)
Chronic lymphatic	5	3	1.84	0.31	(0.46, 7.96)
Not fully specified	0	1[3]	0.00	0.52	(0.00, 13.73)
All types	28	11	2.43	0.009	(1.27, 4.70)
All types other than chronic lymphatic	23	8	2.64	0.01	(1.25, 5.75)

Notes:

1. One-sided test that the RR is greater than unity ($RR \geq 1.00$), or less than unity ($RR < 1.00$).

2. Monocytic leukaemia has been classed with myeloid.

3. Unspecified acute leukaemia.

Table F11

Estimated trends in relative risk of incident cancer per mSv for 8 types of cancer, together with 90% confidence intervals (CI) and standardised test statistics (ratio of trend to standard error); see Table 7.11

Type of cancer	Trend[1]	90% CI	Standardised test statistic
Cancers of lymphatic and haematopoietic tissue	0.003	(-0.047, 0.053)	0.09
Leukaemia	-0.028	(-0.123, 0.068)	-0.48
Multiple myeloma	0.023	(-0.047, 0.093)	0.55
Hodgkin's disease	-0.042	(-0.214, 0.131)	-0.40
Non-Hodgkin's lymphoma	0.017	(-0.127, 0.161)	0.20
Cancer of trachea, bronchus, lung and pleura	-0.001	(-0.031, 0.028)	-0.07
Alcohol-related cancers	-0.013	(-0.051, 0.025)	-0.58
Remaining neoplasms	0.003	(-0.013, 0.020)	0.33
All neoplasms	0.0004	(-0.013, 0.014)	0.05

Note:

1. The estimated change in the relative risk of cancer associated with an additional gamma dose of 1 mSv.

Table F12

Observed deaths (O), deaths expected from national rates (E) and relative risks compared with total control group (RR) together with 90% confidence intervals (CI) in two pre-selected groups of test participants, at ages <85 years for 8 different types of cancer

Type of cancer	A. Participants in special groups identified by MOD as liable to be exposed to radiation						B. Test participants employed by AWRE, or involved with the minor trials at Maralinga					
	O	E	Probability[1]	RR	Probability[2]	90% CI	O	E	Probability[1]	RR	Probability[2]	90% CI
All cancers of lymphatic or haematopoietic tissue	3	5.33	0.39	1.17	0.55	(0.28, 4.09)	2	3.33	0.60	1.81	0.49	(0.19, 14.06)
Leukaemia	1	2.03	0.55	3.25	0.39	(0.19, 21.93)	1	1.27	1.00	5.54	0.61	(0.05, 428.93)
Multiple myeloma	1	0.72	1.00	∞	0.30	(0.18, ∞)	1	0.50	0.39	∞	0.48	(0.09, ∞)
Hodgkin's disease	0	1.09	0.43	0.00	0.69	(0.00, 10.82)	0	0.61	0.67	0.00	0.95	(0.00, 94.28)
Non-Hodgkin's lymphoma	1	1.49	1.00	0.48	0.44	(0.02, 4.25)	0	0.95	0.63	0.00	0.73	(0.00, 17.47)
Cancer of trachea, bronchus, lung & pleura	14	26.41	0.01	0.92	0.45	(0.54, 1.56)	5	18.72	<0.001	0.53	0.16	(0.19, 1.40)
Alcohol-related cancers	3	3.50	0.81	0.59	0.29	(0.16, 1.91)	5	2.42	0.19	1.77	0.32	(0.45, 7.30)
Remaining neoplasms	27	31.50	0.43	1.01	0.52	(0.68, 1.50)	13	21.58	0.07	0.75	0.26	(0.39, 1.42)
All neoplasms	47	66.75	0.01	0.95	0.41	(0.71, 1.27)	25	46.06	<0.001	0.81	0.24	(0.51, 1.27)

Table F12 (contd)

Type of cancer	All test participants in A or B						Other test participants					
	O	E	Prob-ability[1]	RR	Prob-ability[2]	90% CI	O	E	Prob-ability[1]	RR	Prob-ability[2]	90% CI
All neoplasms of lymphatic or haematopoietic tissue	4	6.99	0.34	1.18	0.53	(0.33, 3.79)	47	43.94	0.65	1.65	0.03	(1.08, 2.55)
Leukaemia	2	2.66	0.78	3.67	0.25	(0.36, 21.59)	20	16.74	0.46	3.54	0.004	(1.51, 8.68)
Multiple myeloma	1	0.98	1.00	∞	0.48	(0.09, ∞)	5	4.42	0.81	∞	0.02	(1.49, ∞)
Hodgkin's disease	0	1.38	0.41	0.00	0.67	(0.00, 9.86)	7	10.76	0.29	0.87	0.49	(0.33, 2.28)
Non-Hodgkin's lymphoma	1	1.97	0.73	0.46	0.41	(0.02, 3.90)	15	12.01	0.38	0.92	0.49	(0.45, 1.86)
Cancer of trachea, bronchus, lung & pleura	17	36.09	<0.001	0.85	0.33	(0.51, 1.39)	102	148.25	<0.001	0.83	0.08	(0.66, 1.04)
Alcohol related cancers	5	4.74	1.00	0.68	0.32	(0.23, 1.87)	29	21.97	0.16	1.09	0.42	(0.69, 1.73)
Remaining neoplasms	32	42.55	0.11	0.95	0.45	(0.65, 1.38)	170	205.05	0.01	0.96	0.37	(0.80, 1.15)
All neoplasms	58	90.37	<0.001	0.90	0.28	(0.69, 1.18)	348	419.21	<0.001	0.97	0.38	(0.86, 1.10)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

2. One-sided test that the RR is greater than unity (RR≥1.00) or less than unity (RR<1.00).

Table F13

Observed deaths (O), deaths expected from national rates (E) and relative risks compared with total control group (RR) together with 90% confidence intervals (CI), for three groups of test participants for 8 different types of cancer

Type of cancer	A. Participants present for a major test, or directly involved in minor trials at Maralinga						B. Participants present at a Pacific Ocean Test					
	O	E	Probability[1]	RR	Probability[2]	90% CI	O	E	Probability[1]	RR	Probability[2]	90% CI
All neoplasms of lymphatic or haematopoietic tissue	31	35.96	0.45	1.34	0.17	(0.83, 2.16)	22	23.48	0.84	1.30	0.23	(0.76, 2.23)
Leukaemia	13	13.70	0.89	2.54	0.05	(1.01, 6.64)	11	8.96	0.50	3.35	0.02	(1.27, 9.06)
Multiple myeloma	3	3.87	0.81	∞	0.06	(0.91, ∞)	2	2.32	1.00	∞	0.09	(0.74, ∞)
Hodgkin's disease	2	8.52	0.02	0.35	0.14	(0.06, 1.44)	0	5.79	0.006	0.00	0.03	(0.00, 0.94)
Non-Hodgkin's lymphoma	13	9.86	0.33	1.08	0.51	(0.51, 2.25)	9	6.41	0.32	0.96	0.56	(0.40, 2.23)
Cancer of trachea, bronchus, lung & pleura	91	132.50	<0.001	0.88	0.19	(0.70, 1.11)	51	77.61	0.002	0.85	0.18	(0.64, 1.13)
Alcohol-related cancers	23	19.08	0.42	0.94	0.47	(0.58, 1.52)	11	11.54	0.89	0.73	0.23	(0.39, 1.36)
Remaining neoplasms	132	176.46	<0.001	0.87	0.12	(0.72, 1.05)	74	108.37	<0.001	0.80	0.05	(0.63, 1.01)
All neoplasms	277	364.01	<0.001	0.91	0.13	(0.80, 1.04)	158	221.01	<0.001	0.85	0.05	(0.72, 1.00)

Table F13 (contd)

Type of cancer	C. Participants unlikely to have been exposed to more radiation than the general public						D. Other test participants not in A or C					
	O	E	Probability[1]	RR	Probability[2]	90% CI	O	E	Probability[1]	RR	Probability[2]	90% CI
All neoplasms of lymphatic or haematopoietic tissue	1	3.38	0.28	0.46	0.34	(0.03, 2.58)	19	11.59	0.05	2.64	0.001	(1.52, 4.54)
Leukaemia	1	1.29	1.00	2.42	0.47	(0.14, 16.18)	8	4.41	0.15	6.55	0.0002	(2.37, 18.49)
Multiple myeloma	0	0.33	1.00	-	-	-	3	1.20	0.12	∞	0.009	(2.29, ∞)
Hodgkin's disease	0	0.84	0.64	0.00	0.51	(0.00, 5.92)	5	2.77	0.21	2.47	0.11	(0.79, 7.38)
Non-Hodgkin's lymphoma	0	0.92	0.63	0.00	0.36	(0.00, 3.74)	3	3.20	1.00	0.63	0.34	(0.17, 2.07)
Cancer of trachea, bronchus, lung & pleura	6	10.82	0.17	0.70	0.25	(0.32, 1.47)	22	41.02	0.002	0.69	0.07	(0.46, 1.03)
Alcohol-related cancers	3	1.65	0.42	1.58	0.35	(0.46, 4.66)	8	5.97	0.41	1.21	0.39	(0.58, 2.47)
Remaining neoplasms	18	15.26	0.52	1.37	0.13	(0.88, 2.12)	52	55.87	0.64	1.14	0.22	(0.87, 1.50)
All neoplasms	28	31.13	0.59	1.09	0.37	(0.77, 1.53)	101	114.45	0.21	1.10	0.21	(0.91, 1.34)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

2. One-sided test that the RR is greater than unity (RR≥1.00), or less than unity (RR<1.00).

Table F14

Observed deaths (O) and deaths expected from national rates (E) among independent respondents not included and included in the main study, and relative risks (RR) and 90% confidence intervals (CI), at ages less than 85 years

Cause of death	Independent respondents						Relative risk (included in main study = 1.00)		
	Not included in main study			Included in main study					
	O	E	Probability[1]	O	E	Probability[1]	RR	Probability[2]	90% CI
Neoplasms	37	7.37	<0.001	134	38.49	<0.001	1.18	0.24	(0.82, 1.67)
Cancers of lymphatic and haematopoietic tissue	7	0.84	<0.001	27	3.95	<0.001	1.08	0.53	(0.46, 2.45)
Leukaemia	3	0.32	0.004	15	1.50	<0.001	1.09	0.59	(0.27, 3.89)
Multiple myeloma	0	0.08	1.00	3	0.41	0.008	0.00	0.46	(0.00, 6.74)
Hodgkin's disease	1	0.22	0.19	2	0.96	0.25	1.25	0.68	(0.06, 14.32)
Non-Hodgkin's lymphoma	3	0.23	0.002	7	1.08	<0.001	1.46	0.45	(0.34, 5.86)
Cancer of trachea, bronchus, lung and pleura	13	2.49	<0.001	33	13.79	<0.001	1.59	0.14	(0.81, 3.08)
Alcohol-related cancers	3	0.39	0.007	8	2.02	0.001	2.05	0.31	(0.42, 9.41)
Other neoplasms	14	3.65	<0.001	66	18.73	<0.001	0.92	0.46	(0.52, 1.62)
Other known non-violent causes	21	17.54	0.40	68	91.68	0.01	1.38	0.15	(0.85, 2.23)
Accidents and violence	0	4.71	0.01	10	20.39	0.02	0.00	0.52	(0.00, 9.07)
Unknown	1	-	-	6	-	-	-	-	-
All causes	59	29.62	<0.001	218	150.56	<0.001	1.22	0.13	(0.92, 1.60)

Notes:

1. Two-sided test that the difference between the number of deaths observed and that expected could have occurred by chance.

2. One-sided test that the RR is greater than unity ($RR \geq 1.00$), or less than unity ($RR < 1.00$).

Table F15

Numbers of incident cancers (I) among independent respondents not included and included in the main study, together with relative risks (RR), and 90% confidence intervals (CI), at ages less than 85 years

Type of cancer	Independent respondents		Incidence rate in those not included relative to those included		
	Not included in main study	Included in main study			
	I	I	RR	Probability[1]	90% CI
Cancers of lymphatic and haematopoietic tissue	12	38	1.59	0.14	(0.81, 3.08)
Leukaemia	5	17	1.83	0.23	(0.60, 5.32)
Multiple myeloma	0	5	0.00	0.43	(0.00, 6.27)
Hodgkin's disease	2	5	1.25	0.58	(0.19, 6.74)
Non-Hodgkin's lymphoma	5	11	2.20	0.16	(0.68, 6.91)
Cancer of trachea, bronchus, lung and pleura	16	41	1.70	0.08	(0.93, 3.08)
Alcohol-related cancers	5	16	2.02	0.19	(0.64, 6.15)
Other neoplasms	25	116	0.94	0.45	(0.62, 1.43)
All neoplasms	58	211	1.26	0.09	(0.95, 1.67)

Note:

1. One-sided test that the RR is greater than unity (RR≥1.00), or less than unity (RR<1.00).

APPENDIX G

Estimation of relative risk after adjustment for men not included in the main study

Let the proportion of test participants included in the main study be denoted by p, the relative risk among test participants in the main study compared with controls by RR_I, and the relative risk among test participants excluded from the main study compared with those included by RR_E. The relative risk among test participants compared with controls adjusting for those not included in the main study, RR_A, is then given by

$$RR_A = pRR_I + (1-p)RR_IRR_E$$

Under the assumptions given in Section 8.1, an estimate of RR_A can be obtained by substituting the estimates of p, RR_I and RR_E obtained from the study.

If any error in the estimation of p is ignored, as is the covariance between the estimates of RR_I and RR_E, then an approximate formula for the variance of the logarithm of RR_A is given by

$$\text{Var}(\log RR_A) = \text{Var}(\log RR_I)+(1-p)^2RR_E^2\text{Var}(\log RR_E)$$

This formula can be used to derive an approximate confidence interval for RR_A when the estimate of RR_E is greater than zero.

If the estimate of RR_E was equal to zero, the following approximate formula was used:

$$\text{Var}(\log RR_A) = \text{Var}(\log RR_I) + (1-p)^2\text{Var}(RR_E)$$

In constructing the upper limit of an approximate 90% confidence interval for RR_A based on this formula, Var (RR_E) was chosen so that

$$RR_E + 1.64 \{\text{Var } (RR_E)\}^{\frac{1}{2}}$$

coincides with the upper limit of the corresponding confidence interval for RR_E based on the score statistic; similarly for the lower limit.

APPENDIX H

Observed deaths (O) and standardised mortality ratios (SMR) among test participants and controls by time since entry to the study, for neoplasms and other non-violent causes of death

Cause of death		Time since entry to the study (years)			
		<5	5-14	15+	Total
Neoplasms	O	42	183	615	840
	SMR	65	72	86	81
Other known non-violent causes	O	82	382	1218	1682
	SMR	50	62	72	68
All non-violent causes	O	124	565	1833	2522
	SMR	55	65	76	72