MORTALITY AND CANCER INCIDENCE IN NEW ZEALAND PARTICIPANTS IN UNITED KINGDOM NUCLEAR WEAPONS TESTS IN THE PACIFIC

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ABSTRACT

In 1957 and 1958 Royal New Zealand Navy (RNZN) personnel participated in atmospheric nuclear weapons tests conducted by the United Kingdom at Malden Island and Christmas Island. Mortality and cancer incidence has been investigated in a group of 528 men known to have participated in the tests, and in a control group of 1504 men who were in the RNZN during the same period but were not involved in the tests. Both groups were primarily identified from Ministry of Defence (MOD) records. However, a complete list of test participants was not available, and names were also sought from other sources. Of the 266 potentially eligible names obtained from these sources, it was possible to verify that 235 were eligible for inclusion in the study. Of these, 224 (95%) had already been identified from MOD records, whereas 11 had not previously been identified but were added to the study. Follow-up was carried out for the period 1957- 1987, and was 94% complete in the test participants and 91% complete in the controls.

There were 70 deaths in the test participants and 179 deaths in the controls during the follow-up period yielding a relative risk (RR) for death from any cause of 1.08, with a 90% confidence interval (CI) of 0.85-1.38 (one-tailed p-value=0.29). The relative risk of death from causes other than cancer was 0.96 (90% CI 0.71-1.29, p=0.59), whereas the relative risk of cancer death was 1.38 (90% CI 0.90-2.10, p=0.09) and that of cancer incidence was 1.12 (90% CI 0.78-1.60, p=0.29).

The overall relative risk for death from cancers other than hematologic malignancies was 1.14 (90% CI 0.69-1.83, p=0.31), and the corresponding relative risk for incidence was 1.01 (90% CI 0.67-1.50, p=0.48). However, there were 7 deaths from hematologic cancers in the test participants (RR=3.25, 90% CI 1.12-9.64, p=0.02), including 4 leukemias (RR=5.58, 90% CI 1.04-41.6, p=0.03). The relative risk for incidence of hematologic cancers was 1.94 (90% CI 0.74-4.84, p=0.10), and that for leukemia was 5.51 (90% CI 1.03-41.1, p=0.03). There were no cases of multiple myeloma in the test participants during the follow-up period, but the expected number was only 0.3.

Although the numbers are very small, the leukemia findings are of particular interest due to their consistency with a previously published large study of United Kingdom participants in the atmospheric nuclear weapons test programme. It is concluded that some leukemias, and possibly some other hematologic cancers, may have resulted from participation in the nuclear weapons test programme. There is little evidence of an increased risk for cancers other than hematologic cancers, and there is no evidence of an increased risk for causes of death other than cancer in New Zealand participants in the test programme.

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1. INTRODUCTION

In 1957 and 1958 Royal New Zealand Navy (RNZN) personnel participated in the series of atmospheric nuclear weapons tests, known as Operation Grapple, which was conducted by the United Kingdom at Malden Island and Christmas Island. The New Zealand ships involved, HMNZS Pukaki and Rotoiti, were there to provide meteorological information, to patrol for shipping, and to measure radiation levels.

In recent years, concern has arisen regarding the possible health effects of participation in the tests. This concern apparently first came to public attention with a Television New Zealand report of a study conducted by Dr Alice Stewart at Birmingham University who noted "an abnormally high incidence of leukaemia and other reticuloendothelial system neoplasms" in British servicemen at Christmas Island (Stewart et al, 1983). Following this report, approximately 70 New Zealand participants in the tests, or their next-of-kin, came forward with reports of health problems. In 1984, several of these men contacted Greenpeace. As a result Dr Graham Gulbransen, a general practitioner in Auckland, interviewed a number of test veterans and next-of-kin. The New Zealand Returned Services Association (RSA) also gathered health information on New Zealand test participants.

As a result of further public concern, our research group was contacted by the Ministry of Defence (MOD) and asked to conduct a study of cancer incidence and mortality in RNZN participants in the weapons tests. Following consultations with the RSA and Dr Gulbransen we agreed to undertake the study on an independent basis with funding provided by the Ministry of Defence. At the time that the study was initiated it was known that a much larger study of 22,347 United Kingdom test participants was nearing completion (Darby et al, 1988a, 1988b). Thus, we emphasized that the findings of the New Zealand study should be interpreted cautiously in light of the much larger United Kingdom study.

2. HISTORICAL BACKGROUND

2.1. The tests

Britain conducted 21 atmospheric nuclear weapons tests between 1952 and 1958. Up until 1956 these were conducted in and around Australia. However, Australia apparently became less receptive to hosting tests, and it was decided to seek another site for testing the hydrogen bomb (Gulbransen, 1989). Christmas Island, the largest coral atoll in the Pacific, and Malden Island, a close neighbour, were chosen as locations for further tests during 1957-1958. These were named Operation Grapple and involved seven H-bomb and two atomic bomb explosions. Two RNZN frigates, HMNZS Pukaki and HMNZS Rotoiti participated as supporting vessels in these tests.

Table 2.1 shows the location and dates of the 9 tests in Operation Grapple (the term "Operation Grapple" is also used to refer specifically to the first three tests in the series). Grapple Z1 and Grapple Z4 were in the kiloton range and were airbursts from balloons at approximately 450 metres. The other tests were in the megaton range and were airdrops at altitudes of more than 2,000 metres. Grapple X apparently involved the strongest explosion.

2.2. Participation by New Zealand ships

The main task of the Pukaki and Rotoiti was to act as weather ships. Generally they were to alternate in this task except when tests were actually conducted. Secondary tasks included air/sea rescue, anti-submarine watch, thermal flash monitoring, and water sampling (Crawford, 1989).

Both ships left Auckland to participate in the initial test (Grapple 1) in March 1957, each with a full complement of nearly 150 officers and ratings, and arrived at Christmas Island at the end of March. The ships were based at Christmas Island, but briefly visited other islands, and conducted a series of weather patrols leading up to the first test. In a typical patrol, the area covered was 400 to 500 nautical miles and weather ballons were released at regular intervals throughout each day. The behaviour of the balloons was monitored as they rose to a height of 20,000-34,000 metres.

Both ships were stationed off Malden Island at the time of the first test on 15 May 1957. Official documents describe the men forming a watching party on deck, wearing protective overalls and hoods, and dark glasses with the pre-wetting gear set up (to wash down the upper surfaces to prevent fallout from settling). The men initially faced away from the

explosion, before standing and facing the burst after 15 seconds (Crawford, 1989). The crew remained in their protective clothing (minus the hoods) for a further six hours, during which a weather balloon was launched and the Pukaki sailed to rendezvous with a United Kingdom ship to transfer data and collect supplies (Crawford, 1989).

A similar pattern was followed for the subsequent tests in Operation Grapple in 1957 (Crawford, 1989). Both ships conducted a series of patrols leading up to each test, as well as spells at Christmas Island. The Rotoiti apparently spent more time on patrol (Gulbransen, 1989), whereas the Pukaki spent relatively more time at Christmas Island.

The first three tests in 1957 were conducted off Malden Island, after which the Pukaki and Rotoiti returned to New Zealand. Both ships subsequently returned to Christmas Island for the final 1957 test (Grapple X) which was conducted off Christmas Island.

In 1958 the Pukaki alone returned for further tests in Operation Grapple. These were all conducted at or near Christmas Island. The first test in the series (Grapple Y) was conducted in April 1958, and the Pukaki then returned to New Zealand, before subsequently returning to Christmas Island for the final series of 4 tests (Grapple Z) in August and September. Once again, the Pukaki conducted weather patrols, interspersed with spells at Christmas Island.

2.3. Radiation exposure

In an airburst at a height of more than 2,000 metres the fireball does not touch the surface of the earth. This minimizes the risk of surface material being sucked up into the fireball and subsequently being deposited as fallout. Thus, theoretically, there should be little or no fallout in the vicinity of the test (Crawford, 1989), although it has been hypothesized that subsequent exposure could occur due to rainout and concentration in the food chain (Gulbransen, 1989).

The Pukaki and Rotoiti were stationed at varying distances of 20 to 150 miles from ground zero throughout the series of tests (table 2.1). However, the Pukaki passed within six nautical miles of ground zero about 5-6 hours after Grapple 1, and passed through ground zero one day after Grapple Y (Crawford, 1989).

As noted above, official reports describe fairly careful precautions and use of protective clothing in the initial tests. However, use of protective clothing declined, or even ceased, with latter tests in the series, apparently because it was considered that no significant radiation exposure was occurring (Crawford, 1989). There have been media reports of various possible sources of contamination, including rain showers following certain tests (Gulbransen, 1989), and these have been supported by some responses to the postal questionnaire used in the current study.

External radiation exposure was monitored throughout each test, and most men apparently had film badges available. It has been stated that Ministry of Defence records indicate that ship crews received no significant radiation exposures (McEwan, 1988). Certainly, official documents indicate that geiger counters encountered radiation levels which were very low or unmeasurable after each test, even when the ships passed close to ground zero, and that no evidence of radioactive contamination of fish was reported (Crawford, 1989). These claims have been supported by one respondent to the current study who stated that he had used a meter which gave a large deflection near a luminous watch, but showed much smaller deflections during the tests. Nevertheless, the accuracy of the recording of the official data has been disputed by some men who participated in the tests (Gulbransen, 1989).

Data derived from the film badges of the New Zealand participants in the tests are not available. Some film badge data have been reported for the British participants in the same series of tests (Darby et al, 1988a). These only involve gamma external radiation exposure, although data on gamma plus beta aggregate are available in some cases. Of the 22,347 test participants in the United Kingdom study, only 1804 (8%) are believed by the Ministry of Defence to have been liable to radiation exposure (Darby et al, 1988a). Of these, film badge data are available for 1,373 men, who received a mean dose of 7.5 mSv per man per test. The total estimated gamma radiation dose was 16,641 millisieverts (mSv), a mean dose of 12.1 mSv per man with data recorded, or less than 1 mSv per man overall. However, by far the biggest dose was received by RAF personnel who were involved in cloud sampling (mean dose 50.5 mSv per man per test).

Published data are not available specifically for the Royal Navy personnel involved in Operation Grapple. However, in the overall United Kingdom series of 21 tests, the mean total gamma dose for the 194 Royal Navy personnel who were considered to have significant radiation exposure was 5.2 mSv per man. By contrast, the external dose from natural sources is now generally estimated to be about 2.5 mSv per year (Cardis, 1990). No Royal Navy personnel were recorded with gamma doses of greater than 50 mSv, the current legal annual dose limit for radiation workers in the United Kingdom (Darby et al, 1988a).

Exposure may have been higher in RNZN test participants, since they attended 3.6 tests on average compared to about 1.2 tests for the British test participants. The applicability of the United Kingdom data to the RNZN test participants is questionable, since the duties of the ships were different, but we have no reason to believe that the RNZN duties involved more exposure per test. Furthermore, Operation Grapple accounted for only 9 of the 21 tests covered by the United Kingdom study; the other 12 tests were mostly conducted at Maralinga in the Australian desert, and therefore may have involved different exposures. If the available United

Kingdom data are substantially correct, and are applicable to RNZN personnel who participated in Operation Grapple, then the gamma radiation doses they received were very small.

However, two qualifications should be considered before it is concluded that RNZN personnel in Operation Grapple received negligible radiation exposures.

First, the film badge data relate to gamma external radiation, and no data are available on neutron radiation exposure (Darby et al, 1988a). Although the neutron dose is usually much lower than the gamma dose, a given dose of neutrons is generally assumed to have a relative biological effectiveness (carcinogenic potential) of ten times that of the same gamma dose (Beebe, 1981). Higher multipliers may be appropriate at low doses (Beebe, 1981), and various regulatory agencies are now considering raising their estimate of the quality factor for neutrons from 10 to 20 (Cardis, 1990).

Second, no data are available on internal radiation exposure, occurring due to inhalation or ingestion of radioactive particles. The Pukaki and Rotoiti visited Christmas Island on a number of occasions following the tests. Gulbranson (1989) has reported that the crews frequently swam in the lagoon and ate fish caught in the area and this has also been reported by respondents to the current study.

The possibility of significant exposure through inhalation or ingestion has previously been raised for United States Army participants in the Smoky nuclear weapons tests (Caldwell et al, 1980, 1983), who experienced an increased incidence of leukemia. Their mean gamma dose was 0.5 rem (5 mSv), but Beebe (1982) has suggested that there was almost certainly biologically significant exposure to the radioactive isotope iodine-131 through the food chain, and that there may have been other significant internal radiation exposure.

Thus, although currently available data indicate that the RNZN personnel in Operation Grapple probably received very low gamma radiation doses, the possibility cannot be excluded that there could have been significant exposure to neutrons, or internal contamination due to inhalation or ingestion. However, there are currently no data available to confirm or refute these hypotheses.

TABLE 2.1

United Kingdom nuclear weapons tests in the Pacific 1957-1958
in which RNZN ships participated

Operation	Date	Island	Height (metres)	Yield range	Distance from ground zero in nautical miles: Pukaki	Rotoiti
Grapple 1	15/ 5/57	Malden	2400	Megaton	50	150
2	31/ 5/57	Malden	2300	Megaton	50	150
3	19/ 6/57	Malden	2300	Megaton	150	50
Grapple X	8/11/57	Christmas	2250	Megaton	132	60
Grapple Y	28/ 4/58	Christmas	2350	Megaton	80	-
Grapple Z1	22/ 8/58	Christmas	450	Kiloton	28	-
Z2	2/ 9/58	Christmas	2850	Megaton	35	-
Z3	11/ 9/58	Christmas	2650	Megaton	35	-
Z4	23/ 9/58	Christmas	450	Kiloton	20	-

Source: Crawford (1989)

3. GENERAL STUDY DESIGN

As in the United Kingdom study (Darby et al, 1988a), there were several reasons for restricting the New Zealand study to deaths and cancer incidence. Firstly, death can be ascertained with certainty, recording is compulsory and unbiased, and records are routinely available. Secondly, although mortality rates do not reflect morbidity from non-fatal diseases, they are often regarded as the best available indicator of the health of a population. Thirdly, with the exception of cancer, for which a national register exists, it is very difficult to ascertain the occurrence of non-fatal diseases in a large population. Finally, studies of atomic bomb survivors have not generally shown marked increases in risk for diseases other than cancer (Beebe, 1982). The few non-neoplastic diseases which have been shown to be caused by ionizing radiation, such as cataracts or benign skin cancers, are generally non-fatal and difficult to ascertain in follow-up studies, and have only been found to occur at very high doses (Beebe, 1982; Bowker, 1987).

Cancer incidence and mortality are thus the major outcomes of interest in studies of low dose radiation exposure.

The general study design involved ascertaining subsequent deaths and cancer incidence in RNZN personnel who participated in Operation Grapple aboard the HMNZS Pukaki and Rotoiti during 1957- 1958. However, radiation is not the only cause of cancer, and all persons are exposed to radiation from sources other than atmospheric nuclear weapons tests (Darby et al, 1988a). Thus, it is not sufficient to show that cancer and other diseases have occurred in the test participants. It is also necessary to compare their disease experience with that which would have been expected if they had not participated in the tests.

For this purpose, a comparison group was identified. One option would have been to compare the mortality and cancer incidence in the study population with that of all New Zealand males. However, RNZN personnel are selected on the basis of being fit and healthy enough for employment, whereas the general population of New Zealand males includes persons who are too ill to work. This phenomenon, which is commonly referred to as the "healthy worker effect" in occupational studies (Fox and Collier, 1976; McMichael et al, 1976), means that national mortality rates may overestimate the expected mortality in the study population. On the other hand, differences in exposure to other factors (e.g. other occupational hazards, cigarette smoking, general lifestyle, or various socioeconomic factors) could mean that national mortality rates might underestimate the expected mortality in the study population.

Thus, a control group was identified of men who served in the RNZN during the same period

but did not participate in the weapons tests. This group comprised regular RNZN personnel serving on the HMNZS Lachlan, Royalist and Kaniere during 1957- 1958. The study thus involved comparing the mortality of both the test participants and controls with that expected from New Zealand national mortality rates, as well as making a direct comparison of the mortality in the two groups. A similar comparison was made for cancer incidence.

4. STUDY SUBJECTS

4.1. Identification of test participants

All RNZN personnel who participated in the United Kingdom atmospheric nuclear weapons tests in 1957-1958 aboard the RNZN ships HMNZS Pukaki and HMNZS Rotoiti were eligible for inclusion in the study. This group will be referred to as the test participants.

The initial list of RNZN personnel on these two ships at the time of the tests was compiled by vacation workers, employed by the Ministry of Defence, who searched through all of the available RNZN service record cards. These cards list the ships on which each serviceman served. Once identified as having served on either the HMNZS Pukaki or HMNZS Rotoiti, the full name, service number, period of service on either ship, and date of birth were recorded. The personal file held by the Ministry of Defence for each servicemen was then located in order to record further relevant data (see section 4.3). This information was recorded on an index card and entered by Ministry of Defence clerical staff on to a computer word processing programme.

The RNZN service record cards only included enlisted men and therefore a separate procedure was necessary for officers who participated in the tests. The "Navy Lists" which are produced annually detail information as to the ships and times served by each naval officer. These lists for the years 1957 and 1958 were searched and were then checked informally with RNZN personnel in case of any omissions (one omission was found). A further 28 test participants were found by this procedure.

The data were transferred to the Wellington School of Medicine and were checked by comparing the index card, on which the original data had been recorded and the word-processing printout. The data were then transferred to a SAS computer file (SAS, 1982).

It was later discovered that a separate series of RNZN service record cards existed for those servicemen who were not discharged from the RNZN until 1970 or later. The same searching procedure was then carried out for these men, and a further 17 test participants were identified.

4.2. Selection of controls

A control group of RNZN personnel who served during the same period (1957-1958) but did not participate in the weapons tests was identified. It was determined that in order to obtain

a reasonable number of controls it would be necessary to use servicemen from three ships - the HMNZS Kaniere, HMNZS Royalist and HMNZS Lachlan - which were in service during this period, but were not involved in operation Grapple.

The control group was restricted to regular RNZN personnel. The three ships in this group also included a number of men who had been conscripted for a short period of compulsory military training. Since the test participants did not include any conscripts, these were excluded from the controls.

The searching procedure for the controls was conducted simultaneously and in the same manner as for the test participants. Once again, the initial list was compiled by vacation workers employed by the Ministry of Defence, but a further 66 officers were subsequently identified by a search of the annual "Navy Lists", and a further 57 servicemen who were discharged during or after 1970 were also identified separately.

4.3. Characterization of study subjects

All study subjects were male. If available from official records, information was collected on: date of birth, period served on relevant ship(s), service number, rank, place of birth, education at entry into the RNZN, occupation at entry into the RNZN, date of entry into the RNZN, date of discharge out of the RNZN, and current (or most recently known) address. In cases where the RNZN had been notified of a death, this was also recorded (see section 5.5).

4.4. Validation of MOD information

The procedures described above identified 521 test participants and 1512 comparison subjects (table 4.1). As discussed above, there had already been some publicity in the media about the nuclear tests and two other groups had been collecting data from men who had served at Christmas and Malden Islands. This information was used to check the completeness and validity of the list of test participants collected from the Ministry of Defence.

Dr Gulbransen had begun collecting data in 1984 from men who had participated in the nuclear tests and responded to media coverage of this issue, and in 1988 he sent out a postal questionnaire. A list of these men was provided by Dr Gulbransen to our research group. Of the 279 men on Dr Gulbransen's list, 45 were not eligible for this study (most had served with the Royal Navy rather than the RNZN). It was not possible to confirm participation in the tests for a further 27 men, either by examination of Ministry of Defence records or by a postal questionnaire; the information was very limited for some of these, and it is possible that there were some duplicates. Of the remaining 207 men, 199 (96%) had already been identified from

MOD records, and the other 8 were added to the study (table 4.1).

A list of men who had responded to an advertisment in the RSA's monthly journal was provided by the RSA. The RSA had received responses from 137 men, 22 of whom were not eligible for the study (most of these had not participated in the tests, or had participated as members of the United Kingdom Armed Forces). Of the remaining 115 men, it was possible to verify that 107 were eligible for the study, whereas there were 8 men whose participation in the tests could not be confirmed either in MOD records or with a postal questionnaire. Of the remaining 107 men, 103 (96%) had already been identified from MOD records, one had been newly identified from Dr Gulbransen's list and the other 3 were added to the study (table 4.1).

There was some duplication in the lists provided by Dr Gulbransen and the RSA. Overall, these sources yielded 323 names, of which 57 were not eligible. Of the remaining 266 men, it was possible to verify that 235 were eligible for the study, and 224 (95%) of these had already been identified from the MOD list whereas 11 were added to the study.

As a final check on the completeness of the study, our research group issued press statements in an attempt to contact men who had served in the RNZN in the late 1950's but who had not been included in the study. A further 8 study subjects were identified in this manner (as well as one subject who had already been identified through Dr Gulbransen). They were added to the study (4 in the test participants and 4 in the controls) once a completed questionnaire was received and this information was confirmed from Ministry of Defence records.

These alternative sources of study subjects were primarily intended as a check on the MOD information. Theoretically, the study subjects who were initially identified from these alternative sources should not be included in the analysis, since this could result in bias. Specifically, inclusion of these subjects could increase the apparent risk if these other sources tended specifically to identify men who had died or developed cancer, or could decrease the apparent risk if these other sources only had responses from the living. However, these other sources only identified a further 15 test participants (including one death from heart disease and one lung cancer registration) and a further 4 controls (no deaths or cancer registrations). Thus, it made only a trivial difference to the study findings if these extra subjects were included or excluded. It was decided to include them so that the test participant group could be as complete as possible.

4.5. Study subjects

The above procedures identified 536 test participants and 1516 controls (table 4.1). Of these,

the date of births were not known for 8 test participants and 12 controls (making vital status ascertainment impossible), leaving 528 men test participants and 1504 controls.

Tables 4.2-4.4 describe the basic characteristics of the test participants and controls, as well as details of the ships on which the men served and their participation in the tests. The majority of test participants served on the Pukaki, which attended all tests, whereas the majority of comparison subjects served on the Royalist (table 4.2). The first four tests involved both ships and nearly 300 men, whereas the subsequent five tests involved only the Pukaki with nearly 150 men (table 4.3). There were 13 men whose participation in the tests was confirmed, but the exact number of tests could not be determined (table 4.3). The remaining 515 men attended an average of 3.6 tests, with 129 men (24%) attending 5 or more tests.

Table 4.4 shows that the test participants and controls were similar with respect to the proportion of officers, year of enlistment (mean year was 1953 for both groups), year of discharge (means were 1965 and 1964 respectively), and length of service (means were 12.2 and 11.1 years respectively). The two groups were also very similar with respect to age at start of follow-up, which is the age at the time of the tests in the test participants and the age at the equivalent date in the controls (means were 24.8 and 24.9 years respectively). In both groups, the year of enlistment (and hence the length of service) was not known for 12-14% of study subjects. The year of discharge was also unknown for a smaller proportion of study subjects (2-4%).

Some information on cigarette smoking was obtained from those men who returned postal questionnaires (see below). The proportions of current smokers and of ex-smokers were similar in the two groups, although the test participants contained a slightly higher proportion of current smokers (25% versus 21%). The main reason for smoking data to be missing was that a questionnaire was not received because a subject was deceased, lost to follow- up, or had emigrated (see section 5.6 below). Approximately 85% of the respondents were reported to be current or ex-smokers, but this figure is likely to be an underestimate because of attenuation of the study populations by the relatively high death rates in smokers. A figure of about 70% might had been expected on the basis of 1976 New Zealand Census data for all men aged 45-49 (the average age of the study subjects in 1976), or about 80% for manual workers aged 45-49 (unpublished data from Pearce et al, 1985). Thus, the proportion of smokers may have been relatively high in both the test participants and the controls.

TABLE 4.1

Sources of study subjects and reasons for exclusions

Source		Test participants	Controls
MOD list		521	1512
Dr Gulbransen:	Ineligible	(45)	(-)
	Eligibility not confirmed	(27)	(-)
	On MOD list	(199)	(-)
	Added to study	8	(-)
RSA list:	Ineligible	(22)	(-)
	Eligibility not confirmed	(8)	(-)
	On MOD list	(103)	(-)
	On Gulbransen list	(1)	(-)
	Added to study	3	(-)
Media release:	On MOD list	(0)	(0)
	On Gulbransen list	(1)	(-)
	Added to study	4	4
Total		536	1516
Date of birth not known		8	12
Included in study		528	1504

TABLE 4.2

Distribution of study subjects by ships in 1957-1958

Ships	Test participants	Controls
Pukaki	308 (58%)	0
Rotoiti	211 (40%)	0
Pukaki/Rotoiti	9 (2%)	0
Royalist	0	943 (63%)
Kaniere	0	228 (15%)
Lachlan	0	191 (13%)
Royalist/Kaniere	0	75 (5%)
Royalist/Lachlan	0	61 (4%)
Lachlan/Kaniere	0	6 (0%)
Total	528(100%)	1504(100%)

TABLE 4.3

Distribution of test participants by tests attended

Tests	No of men
Grapple 1	278 (53%)
Grapple 2	278 (53%)
Grapple 3	286 (54%)
Grapple X	297 (56%)
Grapple Y	149 (28%)
Grapple Z1	149 (28%)
Grapple Z2	147 (28%)
Grapple Z3	147 (28%)
Grapple Z4	147 (28%)
Total number of tests	
Unknown	13 (3%)
1	90 (17%)
2	21 (4%)
3	98 (19%)
4	177 (34%)
5	86 (16%)
6	18 (3%)
7	9 (2%)
8	1 (0%)
9	15 (3%)
Total	528(100%)

TABLE 4.4

Characteristics of test participants and controls

Characteristic		Test participants	Controls
Rank:	Officers	29 (5%)	66 (4%)
	Other ranks	499 (95%)	1438 (96%)
Year of enlistment:	1900-1929	2 (0%)	0 (0%)
	1930-1939	5 (1%)	16 (1%)
	1940-1949	38 (7%)	108 (7%)
	1950-1959	419 (79%)	1166 (78%)
	Unknown	64 (12%)	214 (14%)
	Mean	1953	1953
Year of discharge:	1950-1959	84 (16%)	286 (19%)
	1960-1969	343 (65%)	954 (63%)
	1970-1979	69 (13%)	172 (11%)
	1980-1989	19 (4%)	28 (2%)
	Unknown	13 (2%)	64 (4%)
	Mean	1965	1964
Length of service: (years)	<10	246 (47%)	779 (52%)
	10-19	145 (28%)	356 (24%)
	20-29	51 (10%)	122 (8%)
	30+	18 (3%)	19 (1%)
	Unknown	66 (13%)	228 (15%)
	Mean	12.2	11.1
Age at start of follow-up: (years)	<20	156 (30%)	427 (28%)
	20-29	257 (49%)	732 (49%)
	30-39	97 (18%)	292 (19%)
	40+	18 (3%)	53 (4%)
	Mean	24.8	24.9
Cigarette smoking:	Current	129 (25%)	314 (21%)
	Ex-smoker	160 (30%)	473 (31%)
	Non-smoker	60 (11%)	147 (10%)
	Unknown	179 (34%)	570 (38%)

5. FOLLOW-UP

5.1. Start of follow-up

Follow-up of test participants started on the date of the first test in which they participated. The controls had all served on the Royalist, Kaniere or Lachlan at some time during 1957-1958. For these subjects, follow-up generally started at the date of the first test in the series (Grapple 1) which occurred on 15 May 1957. However, controls who served on one of the ships earlier in 1957, but were discharged from the RNZN prior to 15 May 1957, were followed from the date of discharge. Similarly, controls who first joined one of these three ships later in 1957 or 1958 were followed from the date they joined the relevant ship.

It was attempted to follow all study subjects until 31 December 1987. This date was chosen because the study was carried out during 1988-1989, and 1987 was the last year for which complete death registration information, and reasonably complete cancer registration information, were available.

All follow-up was conducted blind, i.e. the test participants and controls were combined into a single file, and all information which indicated the group to which each person belonged was deleted. This combined file was then used in the follow-up of cancer incidence, mortality, and other vital status.

5.2. Mortality follow-up

The mortality follow-up involved searching through death records at the Births, Deaths and Marriages section of the Justice Department and the National Health Statistics Centre in order to ascertain which study subjects had died during the period 1957- 1987.

The mortality lists kept by the Justice Department are held separately for each year, and separately for Maori and non-Maori prior to 1962. It was assumed that each serviceman was alive until their recorded date of discharge. Therefore searching was only done for the years on or after the date of discharge from the RNZN.

As discussed above, a further list of 74 ex-servicemen, who had left the RNZN after 1970, was found after the first death searching procedure had been completed. The mortality follow-up for these men differed from that of other study subjects, in that for men for whom the Ministry of Transport had found a relevant record (see section 5.4), searching was only done for the years on or after the most recent time that either the application for a driver's licence or car

registration had taken place.

One difficulty in the death search was that the lists prior to 1972 only included the age at death and not the date of birth. Where necessary, confirmation of death was established by examining other recorded data such as place of birth or names of parents.

Having ascertained the year of death the precise date and cause of death were established from either the death certificate, for years prior to 1970, or from mortality listings held by the National Health Statistics Centre. Deaths which had been coded according to revisions prior to the 9th International Classification of Diseases (ICD) revision (WHO 1977) were recoded to the 9th revision.

When follow-up was virtually completed, a second search of the death records was conducted for 228 men whose vital status was still unknown at that stage. This second search was extended back in time to cover years before the recorded date of discharge in case this was incorrect. A further 7 deaths were found which had not been identified in the initial search of mortality records.

5.3. Cancer incidence follow-up

The cancer incidence follow-up involved searching through records of the New Zealand Cancer Registry to ascertain which of the study participants had been registered with cancer during 1957- 1987. The New Zealand Cancer Registry was established in 1948. Registration is believed to have been more than 90% complete since the late 1950s, and virtually 100% complete since 1972 (Foster, 1977). During 1985-1987 there were some problems with registration of cancers diagnosed in private hospitals, but registration is believed to have still been more than 90% complete. Apart from malignant melanoma (which is often fatal), the Cancer Registry does not include skin cancers since these are almost always benign.

The Registry holds all registrations in a national listing sorted in alphabetical order. Follow-up involved taking the complete study list and searching the records manually. When a relevant cancer registration was found, the ICD code and date of admission were noted. All but 4 of the 78 men who died of cancer had been reported in the Cancer Registry prior to death.

Subjects were recorded as having only one type of cancer, due to the difficulties of distinguishing multiple independent primary cancers from single tumours recurring at multiple sites. Essentially the same coding rules were used as in the United Kingdom study (Darby et al, 1988a). Namely:

1. For men who had died of cancer (i.e. cancer was the underlying cause of death and the death ICD code was for a tumour), registrations were ignored unless: (a) leukemia appeared as a registration in a man who had died of another type of cancer (there were actually no instances of this); (b) if the death ICD code was for a tumour of unspecified site the information on site and date of diagnosis was obtained from the cancer registration data (this occurred in one instance).

2. For men who had been diagnosed with cancer, but who had not died of cancer, the site and date of diagnosis was recorded from the Cancer Registry. For men with multiple registrations, the first registration was used (there were actually no instances of this).

5.4. Further vital status follow-up

The next stage was to confirm that those subjects who were not known to have died during the period 1957-1987 were actually alive and resident in New Zealand as of 31/12/87. The vacation workers employed by the Ministry of Defence provided possible current addresses obtained from one or more of the personnel files, New Zealand electoral rolls and telephone directories. Additional sources used in tracing study subjects included driver's licence records, and car registration records.

Each subject who had not been found in the death search and for whom a possible current address had been found was sent a brief postal questionnaire (see Appendix). This was intended to: confirm that he was alive: confirm the information already collected from MOD records; and gain new information on factors such as cigarette smoking. If no reply had been received after three letters, an attempt was made to contact the subject by telephone.

Where it was not possible to establish contact with the subject by correspondence or telephone, the last known date of follow up used was the most recent of the following, where applicable: date of discharge from the RNZN, the hospital discharge date (where it was known that an admission had occurred), or the date of application for driver's licence or car registration.

It was not possible to gain access to emigration information. Thus, although it is likely that a number of the study subjects emigrated from New Zealand after leaving the RNZN, it was difficult to verify this in many instances. However, in some instances an overseas address was supplied to us by the Ministry of Defence, or the postal questionnaire was returned by the current resident of the address, or by a neighbour, with a comment that the subject had emigrated. In this situation, the date of emigration was ascertained by writing to the subject's overseas address, or by writing back to the person who had informed us that the subject had

emigrated. In this situation, the date of emigration was ascertained by writing to the subject's overseas address, or by writing back to the person who had informed us that the subject had emigrated. The last date of follow-up was then set to the date of emigration.

5.5. Further validation of vital status information

The information obtained in the mortality and cancer incidence follow-up was compared to that recorded by the Returned Servicemen's Association, Dr Gulbransen, and postal questionnaires returned by study subjects.

The survey previously conducted by Dr Gulbransen had yielded 279 replies, 41 of which (usually completed by the next-of-kin) had noted that the subject was deceased. Of these, 8 were for men who were from the United Kingdom Armed Forces and were ineligible for the current study, and 9 were for men whose eligibility could not be confirmed. The other 24 deaths had all been identified in the mortality follow-up. The survey had also identified a further 9 persons with cancer, but one of these had occurred after 31/12/87, and one had occurred overseas (both were therefore ineligible). Of the remaining 7 cancers, 6 had been identified in the Cancer Registry search. A recheck of the Cancer Registry verified that the other reported cancer was not in the Registry (and therefore was not included in the study).

The RSA survey had yielded 137 replies, 9 of which (usually completed by the next-of-kin) noted that the subject was deceased. Of these, 1 subject's eligibility for the study had not been confirmed, 1 death occurred in 1988 after follow-up had finished, and the other 7 deaths had all been identified in the mortality follow-up. The RSA survey also reported 9 cancer cases; 2 of these were in subjects who were not eligible for the study, 1 occurred in 1988, 1 occurred overseas, and the other 5 had all been identified in the Cancer Registry search.

A further 104 study subjects (42 test participants and 62 controls) had been classified as deceased on MOD records. Of these, 6 were found to be alive, and 3 had died overseas. Of the remaining 95 men, 92 were identified as deceased in the mortality follow-up. A recheck of the death records verified that the other 3 men had not been recorded as having died during the follow-up period of 1957-1987, or during the period 1988-1989 (for which the death records were incomplete). These 3 men were thus classified as being of unknown vital status.

Finally, 45 respondents to the postal questionnaire reported that they had been diagnosed with cancer. Of these, 13 were first diagnosed after 31/12/87, and 25 had already been identified in the Cancer Registry search. A recheck of the Cancer Registry confirmed that the remaining 7 cancers were not listed in the Registry (and therefore were not included in the study). These included one occurrence of Hodgkin's disease in a control.

5.6. Completeness of follow-up

At the end of follow-up (31/12/87), 10% of the test participants and 11% of the controls were of unknown vital status (table 5.1). Thus, the overall vital status ascertainment was 90% and 89% respectively.

However, there are two considerations which modify these estimates of the completeness of vital status ascertainment.

First, an additional 6% of the test participants and 5% of the controls had emigrated during the period of the study. These men were known to be alive at time of emigration, but their subsequent vital status is generally unknown.

Second, for all of the men of unknown vital status at 31/12/87, their vital status was known at some time previous to this date. Thus, their vital status was known for at least a portion of the follow-up period, and these men thus contributed some person- years to the analysis.

The appropriate response to these two considerations is to estimate the completeness of follow-up as the ratio of the total person-years of follow-up actually achieved to that of the total number of person-years which theoretically could have been achieved (Checkoway et al, 1989). For men who died, emigrated, or who were known to be alive as of 31/12/87, these two figures are identical. However, for those of unknown vital status, the actual length of follow-up was compared to that which would have been achieved if follow-up had continued until 31/12/87. For the test participants, there were 13,923 person-years of follow-up, compared to a total of 14,883 person-years which theoretically could have been achieved. This indicates a follow-up completeness of 94%. The corresponding figures for the controls are 38,937 and 42,598 person-years, with a follow-up completeness of 91%.

Table 5.2 shows that the mean length of follow-up was similar in the test participants and controls (means of 26.4 and 25.9 years respectively), as was the distribution of length of follow-up.

TABLE 5.1

Vital status at end of follow-up (31/12/1987)

Vital status	Test participants	Controls
Alive	377 (71%)	1085 (72%)
Deceased	70 (13%)	179 (12%)
Emigrated	31 (6%)	69 (5%)
Unknown	50 (10%)	171 (11%)
Total	528 (100%)	1504 (100%)

TABLE 5.2

Length of follow-up in test participants and controls

Characteristic		Test participants	Controls
Length of follow-up: (years)	<10	56 (11%)	184 (12%)
	10-19	26 (5%)	73 (5%)
	20-29	131 (25%)	395 (26%)
	30+	315 (60%)	852 (57%)
	Mean	26.4	25.9

6. STATISTICAL ANALYSIS

As noted above, test participants were followed from the date of the first test in which they participated. Controls were followed from 15 May 1957, date of discharge if this occurred before 15 May 1957, or date of enlistment if this occurred after 15 May 1957. Follow-up ceased on the date of death, the date of emigration, or 31 December 1987 (in those who had not died or emigrated). For those subjects whose vital status on 31 December 1987 was unknown, follow-up ceased on the last date on which vital status was known.

For the analysis of cancer incidence, the last date of follow-up was the date of cancer registration for those who had developed cancer. For all other subjects the last date of follow-up was the same as used in the mortality analyses.

Each subject contributed person-years at risk from the first date of follow-up until the last date of follow-up, subdivided into 5- year age-groups and calendar periods. For example, a subject for whom follow-up started on 1/1/58 at age 28 would contribute 2 years to the 25-29 age-group/1955-1959 calendar period. He would then contribute 5 years to the 30-34 age-group/1960-1964 calendar period, 5 years to the 35-39 age-group/1965-1969 calendar period, and so on. Thus, a subject who was followed for 25 years would contribute 25 person-years of follow-up, each of which was allocated to one of the age/calendar period strata. These calculations were performed for each of the study subjects, and the data were summed to yield the total number of person-years contributed to each age/calendar period stratum.

The expected numbers of deaths from various causes among the exposed group and the controls were calculated on the basis of New Zealand national mortality rates during the period 1957-87. A file of New Zealand national mortality rates, broken down by age (in five-year groupings), and calendar period (in five-year groupings), was assembled with the aid of the International Agency for Research on Cancer. A similar file of New Zealand cancer incidence rates was also assembled with the help of the International Agency for Research on Cancer. However, incidence rates were not available for 1967 and it was assumed that these were the same as the 1962-1966 rates. Similarly, incidence rates were not available for 1983-1987 and it was assumed that these were the same as the 1978-1982 rates.

The expected numbers of deaths (or cancer registrations) were calculated by multiplying the national mortality (or cancer incidence) rates by the person-years at risk in each category of age and calendar year, using a FORTRAN computer program (Coleman et al, 1986). For each outcome, the observed mortality was then divided by the expected mortality to yield the standardized mortality ratio (SMR). The relative risk for each outcome was then estimated by

taking the SMR in the test participants and dividing it by the SMR in the controls. A similar procedure was followed for cancer incidence to estimate the standardized incidence ratio (SIR).

It is known that problems can arise from comparing SMRs in this manner (Rothman, 1986) since they are not mutually standardized. However, this theoretical problem is trivial when the age/calendar period distributions of the two groups are similar. This applies to the current study since the two groups had very similar age distributions at start of follow-up (table 4.4), follow-up started in the same years, and extended over the same time periods. In fact, it was found that there was very little confounding by age and calendar period, and the crude (non-standardized) relative risks were virtually identical to the standardized relative risks.

Similarly, it was initially intended to adjust for various potential confounding factors in the analysis, such as rank, year of enlistment, year of discharge, length of service, and length of follow-up. However, the two groups were found to be so similar with respect to these factors (tables 4.4, 5.2), that adjustment for these factors was not necessary. Thus, all relative risks were calculated as the ratios of the SMRs (standardized for age and calendar period) in the two groups.

There has been considerable debate concerning the appropriateness of calculating p-values in epidemiological studies (e.g. Gardner and Altman 1989; Pearce and Jackson, 1988). In general, these have not been included in this study, but they have been presented for some key findings as an aid to reviewers who find them useful in interpreting study findings. As in the United Kingdom study (Darby et al, 1988a), we were specifically interested in testing the hypothesis that mortality and cancer incidence were greater in the test participants than in the controls. Thus, one-tailed p-values and 90% confidence intervals have been calculated.

The confidence intervals for the relative risk estimates were calculated by the method of Ederer and Mantel (1987) with the aid of a computer program developed by Gardner and Altman (1989). P- values were calculated using the uncorrected Mantel-Haenszel chi- square adapted for person-time data (Mantel and Haenszel, 1959; Rothman, 1986), but the mid-p form of Fisher's exact test (Rothman, 1986) was used for the hematologic cancer and leukemia findings due to the small numbers involved.

7. RESULTS

7.1. Mortality

Table 7.1 shows the findings for total mortality, and mortality for major disease groupings. Unlike the United Kingdom study (Darby et al, 1988a), which contained a relatively high proportion of officers, there was apparently no "healthy worker effect" and the mortality in the controls was close to that expected on the basis of national mortality rates (observed deaths=179, expected deaths=168.6, SMR=1.06). There was a modest elevation in total mortality in the test participants (SMR=1.15). Consequently, the relative risk was also modestly elevated (RR=1.08), but the confidence interval (0.85-1.38) indicated that the modest elevation in risk was within the range of normal statistical variation (one-tailed p-value=0.29).

Of the 6 disease categories other than cancer, 3 had relative risks very close to 1.0, 1 showed an elevated relative risk and 2 showed decreased relative risks. All of the findings are within the range of normal statistical variation. The only noteworthy elevation was for deaths from diseases of the genitourinary system, but this was based on only 2 deaths. This disease category was not of a priori interest as it has not previously been linked to radiation exposure. Thus, it is likely that this is a chance finding. Overall, there was actually a slight deficit for causes of death other than cancer in both the test participants (Obs=44, Exp=46.4, SMR=0.95), and the controls (Obs=127, Exp=128.6, SMR=0.99), and the relative risk was 0.96 (90% CI 0.71-1.29, p=0.59). Thus there was essentially no difference between the test participants and the controls for causes of death other than cancer.

The findings for cancer are less straightforward. Both the test participants and the controls had an elevated death rate for cancer when compared with national mortality rates. However, the elevation in risk was stronger in the test participants, yielding a relative risk of 1.38 (90% CI 0.90-2.10, p=0.09).

The site-specific cancer mortality findings are presented in table 7.2. Of the 16 non-hematologic cancer sites examined, 4 had no deaths in either group. Of the remaining 12 sites, 6 had relative risks greater than 1.0 and 6 had relative risks less than 1.0. However, many comparisons involved very small numbers of deaths, and the relative risk estimates were accordingly unstable with very wide confidence intervals. The overall relative risk for non-hematologic cancers was 1.14 (90% CI 0.69- 1.83, p=0.31).

The two sites of strong a priori interest were multiple myeloma and leukemia, since it was these two sites which showed elevated relative risks in the United Kingdom study. These two

sites both belong to the general category of hematologic cancers (Hodgkin's disease, non-Hodgkin's lymphoma, multiple myeloma, and leukemia). Overall, there were 7 deaths from hematologic cancers in the test participants compared with 6 deaths in the controls, yielding a relative risk of 3.25 (90% CI 1.12-9.64, p=0.02).

This excess risk for hematologic cancers was primarily due to the occurrence of 4 deaths from leukemia in the test participants compared with only 2 in the controls, a relative risk of 5.58 (90% CI 1.04-41.6, p=0.03).

There were no deaths from multiple myeloma in the test participants, and the relative risk was consequently 0.00 (90% CI 0.00-9.50). However, the number of expected multiple myeloma deaths was only 0.2, and the relative risk estimate was accordingly very unstable. In fact, one case of multiple myeloma was identified in a test participant, but this was diagnosed in 1988 and death occurred in 1989; thus, the multiple myeloma did not occur during the period under study (1957-1987) and was not included in the analysis.

7.2. Cancer incidence

The relative risk of cancer incidence in the test participants and controls was also estimated for 12 cancer sites (table 7.3). There were an additional 7 cancer registrations in the test participants (in addition to the cancer deaths) and 29 in the controls. The overall relative risk for cancer incidence of 1.12 (90% CI 0.78-1.60, p=0.29) was lower than that for cancer mortality. Of the 7 non-hematologic cancer sites with at least one death, 3 showed elevated risks in the test participants, 2 showed elevated risks in the controls, and 2 relative risks were very close to 1.0. The overall relative risk for non-hematologic cancers was 1.01 (90% CI 0.67-1.50, p=0.48).

There were 7 hematologic cancers in the test participants, compared to 10 in the controls (RR=1.94, 90% CI 0.74-4.84, p=0.10). The Cancer Registry search yielded an additional 2 multiple myelomas in the controls, but none in the test participants. However, the expected numbers were still very low, and the relative risk estimates were accordingly unstable. Of the 4 multiple myelomas in the controls, 3 occurred in officers.

No further leukemias were identified in the Cancer Registry search, apart from the 4 men who died of leukemia, all of whom had been registered prior to death. Consequently, the relative risk estimate for the cancer incidence analysis was virtually identical to that for the mortality analysis (RR=5.51, 90% CI 1.03-41.1, p=0.03).

The two non-Hodgkin's lymphoma deaths in test participants were coded as a mycosis

fungoides and a malignant histiocytosis. The one death and one registration for non-Hodgkin's lymphoma in the controls were both reticulosarcomas.

Of the six leukemia deaths, four were confirmed by examination of the relevant hospital notes, and two were confirmed by contacting the deceased patient's physician.

The two leukemia deaths in controls included an acute lymphocytic leukemia (diagnosed as acute lymphoblastic leukemia on bone marrow examination two years before death) and a chronic myeloid leukemia (diagnosed on peripheral blood and bone marrow examination two years before death).

The four leukemia deaths in the test participants included an acute myeloid leukemia (diagnosed on peripheral blood and bone marrow examination two months before death), a chronic myeloid leukemia (diagnosed on blood screen and bone marrow examination three years before death), and an acute unspecified leukemia (diagnosed 15 months before death as myelodysplastic syndrome, which progressed to a blood picture of acute myeloid leukemia after one year).

The greatest problem of interpretation is presented by the test participant who died of chronic lymphocytic leukemia. Two years before death peripheral blood and bone marrow examination showed markers consistent with chronic lymphocytic leukemia but a lymph node biopsy showed diffuse poorly differentiated lymphocytic lymphoma and he was registered in this category. Shortly before death he was registered again with acute myeloid leukemia (which was listed as a contributing cause on the death certificate). He received chemotherapy for the non-Hodgkin's lymphoma, and it was possible that the leukemia was a result of therapy, or that he suffered a relapse of his non-Hodgkin's lymphoma with a leukemic blood picture. In the current analysis, the rules outlined above were adhered to, and this subject was classified as a leukemia in both the mortality and the cancer incidence analysis. If he had been classified as a lymphoma (instead of a leukemia) in the cancer incidence analysis, then the non-Hodgkin's lymphoma relative risk would have increased to 4.15 (90% CI 0.65-33.4, p=0.07) and the leukemia relative risk would have decreased to 4.11 (90% CI 0.64-33.2, p=0.07). However, the overall findings for hematologic cancers would have remained unchanged.

7.3. Further analyses

Further analyses were performed for incidence of total cancer, hematologic cancers, and leukemia. Tables 7.4 shows the findings by length of follow-up (i.e. time since start of follow-up, which is the same as time since first exposure for the test participants). Table 7.5 shows the findings by various ships, and table 7.6 shows the findings by tests attended. Generally,

the numbers are far too small, particularly for leukemia, to draw valid inferences. However, one point of note is that 3 of the 4 leukemias in test participants occurred 20-29 years (in fact 25- 29 years) after exposure occurred. Another point of note (not shown in the tables) is that 3 of the 4 multiple myelomas occurred in officers.

TABLE 7.1

Observed deaths, expected deaths and SMRs
by general cause of death categories

Cause of death	ICD	Test participants			Controls			Relative risk	90% CI
		Obs	Exp	SMR	Obs	Exp	SMR		
Cancer	140-209	26	14.4	1.80	52	40.0	1.30	1.38	0.90-2.10
Circulatory	390-459	21	24.9	0.84	58	68.7	0.84	1.00	0.63-1.55
Respiratory	460-519	2	3.5	0.57	8	9.6	0.84	0.69	0.11-2.82
Digestive	520-579	2	1.7	1.18	13	4.7	2.77	0.43	0.07-1.58
Genitourinary	580-629	2	0.6	3.17	1	1.8	0.57	5.56	0.44-162
Accidents,etc	800-999	14	11.3	1.24	38	31.5	1.21	1.03	0.58-1.77
Other causes		3	4.3	0.69	9	12.1	0.74	0.93	0.22-3.11
Total non-cancer		44	46.4	0.95	127	128.6	0.99	0.96	0.71-1.29
Total deaths		70	60.9	1.15	179	168.6	1.06	1.08	0.85-1.38

TABLE 7.2

Cancer deaths, expected deaths, and SMRs by site

Cancer site	ICD	Test participants Obs	Exp	SMR	Controls Obs	Exp	SMR	Relative risk	90% CI
Buccal/pharynx	140-149	2	0.4	5.26	1	1.0	0.96	5.47	0.43-159
Oesophagus	150	1	0.4	2.56	1	1.1	0.93	2.77	0.07-107
Stomach	151	1	0.9	1.11	6	2.5	2.42	0.46	0.02-2.99
Small intestine	152	0	0.1	0.00	0	0.2	0.00	-	-
Colon	153	2	1.5	1.32	6	4.2	1.42	0.93	0.14-4.18
Rectum	154	1	0.9	1.06	3	2.6	1.16	0.92	0.04-8.33
Larynx	161	0	0.2	0.00	0	0.4	0.00	-	-
Lung	162	4	3.8	1.05	13	10.5	1.23	0.85	0.26-2.36
Bone	170	0	0.1	0.00	0	0.2	0.00	-	-
Connective tissue	171	0	0.1	0.00	0	0.3	0.00	-	-
Prostate	185	1	0.4	2.27	3	1.2	2.54	0.89	0.03-8.11
Testis	186	0	0.3	0.00	1	0.8	1.33	0.00	0.00-52.8
Bladder	188	1	0.2	4.36	0	0.6	0.00	-	-
Kidney	189	2	0.4	5.00	3	1.1	2.73	1.83	0.23-11.8
Brain/nervous	191,192	1	0.8	1.30	2	2.1	0.94	1.39	0.05-17.8
Other cancer		3	2.6	1.15	7	7.3	0.96	1.19	0.27-4.28
Total non-hematologic		19	13.1	1.46	46	36.1	1.27	1.14	0.69-1.83
Non-Hodgkin's	200,202	2	0.4	5.13	1	1.1	0.92	5.59	0.44-163
Hodgkin's disease	201	1	0.2	4.35	1	0.6	1.56	2.78	0.07-107
Multiple myeloma	203	0	0.2	0.00	2	0.5	3.85	0.00	0.00-9.50
Leukemia	204-208	4	0.6	7.02	2	1.6	1.26	5.58	1.04-41.6
Total hematologic		7	1.4	5.07	6	3.8	1.56	3.25	1.12-9.64
Total cancer		26	14.4	1.80	52	40.0	1.30	1.38	0.90-2.10

TABLE 7.3

Cancer incidence, expected incidence, and SIRs by site

Cancer site	ICD	Test participants Obs	Exp	SIR	Controls Obs	Exp	SIR	Relative risk	90% CI
Stomach	151	1	1.2	0.81	10	3.4	2.94	0.27	0.01-1.57
Colon	153	3	2.9	1.05	6	8.0	0.76	1.39	0.30-5.26
Rectum	154	2	1.8	1.12	4	5.0	0.81	1.38	0.19-7.43
Lung	162	6	4.6	1.30	16	12.6	1.27	1.03	0.40-2.42
Connective tissue	171	0	0.3	0.00	0	0.9	0.00	0.00	-
Testis	186	0	1.0	0.00	3	2.7	1.12	0.00	0.00-4.80
Bladder	188	2	1.0	1.98	0	2.8	0.00	-	-
Thyroid	193	0	0.2	0.00	0	0.5	0.00	-	-
Endocrine	194	0	0.1	0.00	0	0.2	0.00	-	-
Other cancer		12	9.9	1.21	32	27.3	1.17	1.03	0.55-1.87
Total non-hematologic		26	22.9	1.13	71	63.2	1.12	1.01	0.67-1.50
Non-Hodgkin's	200,202	2	0.8	2.44	2	2.3	0.88	2.77	0.30-25.6
Hodgkin's disease	201	1	0.5	1.96	2	1.4	1.41	1.39	0.05-17.8
Multiple myeloma	203	0	0.3	0.00	4	0.7	5.56	0.00	0.00-3.09
Leukemia	204-208	4	0.7	5.48	2	2.0	1.00	5.51	1.03-41.1
Total hematologic		7	2.3	3.02	10	6.4	1.56	1.94	0.74-4.84
Total cancer		33	25.2	1.31	81	69.6	1.16	1.12	0.78-1.60

TABLE 7.4

Observed and expected cancer incidence by length of follow-up

Length of follow-up (years)	Total cancer			Hematologic cancers			Leukemia		
	Obs	Exp	SIR	Obs	Exp	SIR	Obs	Exp	SIR
Test participants									
0- 9	0	2.9	-	0	0.5	-	0	0.2	-
10-19	6	6.5	0.93	2	0.7	2.99	1	0.2	5.05
20-29	24	15.1	1.59	5	1.1	4.47	3	0.4	8.65
30+	3	0.8	3.58	0	0.1	-	0	0.0	-
Controls									
0- 9	3	8.0	0.38	0	1.3	-	0	0.5	-
10-19	15	17.7	0.85	2	1.8	1.09	0	0.6	-
20-29	60	41.1	1.46	8	3.1	2.61	2	0.9	2.12
30+	2	2.9	1.04	0	0.2	-	0	0.1	-

TABLE 7.5

Observed and expected cancer incidence by ship

Tests	Total cancer			Hematologic cancers			Leukemia		
	Obs	Exp	SIR	Obs	Exp	SIR	Obs	Exp	SIR
Pukaki	22	14.6	1.50	5	1.4	3.71	2	0.4	4.72
Rotoiti	11	10.3	1.07	2	0.9	2.12	2	0.3	6.79
Both	0	0.3	-	0	0.0	-	0	0.0	-
Controls	81	69.6	1.16	10	6.4	1.56	2	2.0	1.00

TABLE 7.6

Observed and expected cancer incidence by tests participated in

Tests	Total cancer			Hematologic cancers			Leukemia		
	Obs	Exp	SIR	Obs	Exp	SIR	Obs	Exp	SIR
Grapple 1	17	13.5	1.26	3	1.2	2.43	2	0.4	5.20
Grapple 2	17	13.5	1.26	3	1.2	2.43	2	0.4	5.20
Grapple 3	19	13.9	1.37	4	1.3	3.13	3	0.4	7.54
Grapple X	13	13.1	1.00	0	1.2	-	0	0.4	-
Grapple Y	9	7.2	1.25	0	0.7	-	0	0.2	-
Grapple Z1	9	7.0	1.28	3	0.7	4.62	1	0.2	4.83
Grapple Z2	9	6.9	1.30	3	0.6	4.69	1	0.2	4.90
Grapple Z3	9	6.9	1.30	3	0.6	4.69	1	0.2	4.90
Grapple Z4	9	6.9	1.30	3	0.6	4.69	1	0.2	4.90
Total number of tests									
7-9	0	1.1	-	0	0.1	-	0	0.0	-
4-6	17	13.0	1.31	3	1.2	2.49	1	0.4	2.64
1-3	15	10.4	1.44	4	0.9	4.26	3	0.3	10.21
Unknown	1	0.8	1.20	0	0.1	-	0	0.0	-
Controls	81	69.6	1.16	10	6.4	1.56	2	2.0	1.00

8. DISCUSSION

8.1. General considerations

The aim of this study has been to investigate mortality and cancer incidence in RNZN personnel who participated in the United Kingdom atmospheric nuclear weapons tests and in a control group of men who were in the RNZN during the same period but were not involved in the tests. In the protocol for the study it was noted that the number of deaths and cancer registrations would be relatively small, and that the findings should be interpreted in light of the much larger study of United Kingdom Armed Forces personnel involved in the same series of tests (Darby et al, 1988a, 1988b). However, as noted above, Operation Grapple represented only 9 of the tests in the series of 21 tests covered by the United Kingdom study; thus the exposures may not be directly comparable.

In the United Kingdom study the relative risk for mortality in test participants compared to the controls was 1.01 for all causes and 0.96 for all neoplasms. There was little evidence of an increased relative risk for other disease groupings or for specific cancer sites. However, the most noteworthy finding was that mortality from multiple myeloma and leukemia in the test participants was only slightly higher than that expected on the basis of national mortality rates (SMRs of 1.11 and 1.13 respectively), but was substantially higher than in the controls. Thus, the relative risks were markedly elevated for mortality from these two neoplasms (RRs of infinity and 3.45 respectively).

The authors noted (Darby et al, 1988b) that these findings were of particular interest, since leukemia is the cancer type which has been most consistently elevated among populations exposed to relatively high doses of ionizing radiation.

Leukemia has been found to be elevated in at least one study of nuclear industry workers exposed to low doses of ionizing radiation (Checkoway et al, 1985). It was also elevated among participants in the United States nuclear weapons test known as Smoky (Caldwell et al, 1980), which was part of the Plumbob series. However, leukemia was not found to be elevated in four other United States test participant groups (Robinette et al, 1985).

Similarly (Darby et al, 1988b), multiple myeloma is the one cancer type for which a dose-related association has been shown in two large groups of nuclear industry workers (Gilbert and Marks, 1979; Smith and Douglas, 1986), and elevated risks have been shown in many groups exposed to high doses of radiation (Cuzick, 1981; Darby et al, 1985).

The United Kingdom study authors thus noted that the increases for multiple myeloma and leukemia "cannot therefore be lightly dismissed as chance findings". However, there were considerable problems of interpretation, since the elevated relative risks for these two cancer types were primarily due to decreased risks in the controls rather than increased risks in the test participants. A further problem was that the leukemia/multiple myeloma excess was not characteristic of men with measured doses, or even of men present at the time of the tests. The authors of the United Kingdom study therefore cautiously concluded (Darby et al, 1988b) that "there may well have been small hazards of both diseases associated with participation in the programme but that this has not been proved". Professor Martin Gardner, in an accompanying editorial (Gardner, 1988) was prepared to go further and stated that "the preferred conclusion so far must surely be that some leukaemias, and probably multiple myelomas, have resulted from radiation exposure during the tests".

The authors of the United Kingdom study (Darby et al, 1988b) noted three major problems in interpreting their findings.

The first problem is shared by the current study: the possibility of the introduction of bias due to the omission of some participants. In the current study, the completeness of the lists supplied by the Ministry of Defence was checked against information provided from other sources. In some instances, it was not possible to verify that the persons included in lists compiled from other sources had actually participated in the tests. For those men whose participation in the tests was verified, approximately 5% of them had been omitted from the initial list of test participants. These omissions could conceivably have resulted in bias if the mortality of those who were omitted was greater than that of those who were included in the test participants. However, there is no reason to believe that this is the case, and the proportion of apparent omissions was much lower than in the United Kingdom study where the corresponding figure was 17%.

The United Kingdom investigators tested for bias in the construction of the lists by comparing mortality in those initially included and those initially omitted but subsequently identified from other sources. A second check was obtained by omitting test participants from the Army, the group in which the problem of omissions was greatest. In both instances, the authors concluded that the omissions were unlikely to have biased the study findings. In the current study, only 19 additional men were identified from alternative sources, and only one of these had died. Thus, these data do not indicate that serious bias is likely to have occurred due to omissions from the study.

A second problem of the United Kingdom study was the low mortality observed in comparison with national mortality rates. Overall, the mortality in the controls was 79% of that expected

on the basis of national mortality rates. This was attributed (Darby et al, 1988b) to the high proportion of officers who experienced low mortality and the selection of test participants on the basis of physical fitness (analogous to the healthy worker effect). The problem of low mortality rates in the controls was particularly great with regard to multiple myeloma and leukemia. This is puzzling, since the healthy worker effect is usually relatively weak for neoplasms (McMichael, 1976) and it is difficult to think of environmental or behavioural differences which might have influenced the development of these diseases (Darby et al, 1988b).

This problem does not apply to the current study. The SMRs in the controls were 1.06 for all causes mortality, 1.30 for total cancer mortality, 1.56 for mortality from hematologic cancers, 3.85 for multiple myeloma mortality, and 1.26 for leukemia mortality. Thus, if anything, the controls experienced an increased mortality relative to national rates, particularly for multiple myeloma, and to a lesser extent for other hematologic cancers.

A third problem with the United Kingdom study was that 38 separate causes of death were considered, raising the possibility of chance findings (Darby et al, 1988b). However, the authors noted that the position was different with regard to multiple myeloma and leukemia which were of strong a priori interest since they had been found to be elevated in previous studies of low-dose radiation exposure. The findings in the United Kingdom study made these two cancer types of even stronger a priori interest in the current study, and the problem of multiple comparisons consequently does not apply to the leukemia findings in the current study.

8.2. Total mortality

Total mortality was greater in the test participants than in the controls. However, the elevation in risk was very small (RR=1.08) and the 90% confidence interval (0.85-1.38) was consistent with the hypothesis that overall mortality was not elevated (i.e. the true relative risk was 1.0). The elevated risk was due to an increased risk for neoplasms. There was actually a slight deficit in both groups for causes of death other than neoplasms, and the relative risk was 0.96. Thus there was essentially no difference between the test participants and the controls for causes of death other than cancer.

This finding, which is consistent with previous studies of ionizing radiation (Beebe, 1982), is reassuring in terms of both scientific and public health concerns. It is reassuring scientifically since it indicates that it is unlikely that there is any major source of bias in this study, and that the test participants and controls were probably similar in their general lifestyles and their exposure to the major causes of death. It is also reassuring in public health terms, in that it indicates that participation in the test programme has not had a detectable effect on

the overall life expectancy of the test participants.

8.3. Total cancer

The findings for all cancers classed together present greater problems of interpretation. The death rate from cancer was elevated in both groups of men (possibly due to the high smoking rates in both groups, although lung cancer was not particularly elevated). However, the elevation was greater in the test participants. If hematologic cancers are excluded, the overall relative risk of death from other cancers is 1.14 (90% CI 0.69- 1.83). The corresponding relative risk for cancer incidence is 1.01 (90% CI 0.67-1.50).

Thus, the elevation in risk is very weak for cancer mortality and non-existent for cancer incidence. These findings are thus consistent with the hypothesis that the minor differences for mortality from non-hematologic cancers are due to chance. The possibility of an elevated risk for cancer cannot be completely dismissed, since ionizing radiation has been shown to cause almost all types of cancer. In fact, although several reviewers have divided the various cancer sites into the "radiogenic" and "non-radiogenic" cancers, the most comprehensive analysis has indicated that high doses of ionizing radiation can cause virtually every type of cancer with the possible exception of chronic lymphocytic leukemia (Darby et al, 1985).

Nevertheless, the increase in non-hematologic cancers in the current study is very small, if it exists at all, and there was actually a slight deficit of these cancers in the United Kingdom study. Thus, the weight of current evidence is that participation in the test programme has not increased the risk of non- hematologic cancers, or at least that any increase in risk is likely to be very small. Once again, this is reassuring in both the scientific and public health contexts, and is consistent with previous studies of populations exposed to relatively low doses of ionizing radiation.

8.4. Hematologic cancers

The most striking finding in this study is the excess risk of hematologic cancers in the test participants, which was largely due to the occurrence of 4 leukemia deaths.

The findings for other specific hematologic cancers are very difficult to interpret because the numbers are so small: 1 Hodgkin's disease, 2 non-Hodgkin's lymphoma, and no multiple myelomas in the test participants. Lymphomas (i.e. Hodgkin's disease and non-Hodgkin's lymphoma) have been found in excess in atomic bomb survivors and other populations exposed to high doses of radiation (Darby et al, 1985), but the evidence is less persuasive for low-dose exposure (Greene, 1982), and there was actually a slight deficit of non-Hodgkin's

lymphomas in the United Kingdom study (Darby et al, 1988a). Furthermore, some of the lymphomas found in the current study are not known to be strongly radiogenic (Greene, 1982), and some reviewers have questioned whether Hodgkin's disease is in fact radiogenic (Boice and Land, 1982).

Multiple myeloma is unquestionably a radiogenic cancer (Boice and Land, 1982), and increased risks have been observed in several studies of nuclear industry workers with chronic low-dose exposures (Cardis, 1990). Multiple myeloma was of particular interest because of the elevated relative risk found in the United Kingdom study. However, the expected number of multiple myelomas in test participants in the current study is so small (expected = 0.3) as to make interpretation virtually meaningless. It is also noteworthy that one multiple myeloma was identified in a test participant, but this was diagnosed after the end of the follow-up period. Furthermore, the current findings should be considered together with those of the United Kingdom study. Thus, the absence of multiple myelomas in the test participants during the follow-up period in the current study, should not be taken as definitive evidence that participating in the tests did not result in an increase in multiple myeloma in other test participants, or that such an increase will not occur in the future.

Leukemia was of prime a priori interest in the current study, since it is the type of cancer which has been most consistently elevated in populations exposed to high doses of radiation. It has been found to be elevated in a previous study of United States nuclear weapons test participants (Caldwell, 1980), and was found to be elevated in the United Kingdom study (Darby et al, 1988b). The findings of the United Kingdom study were difficult to interpret, since they were primarily due to a deficit of leukemia in the controls, but this problem does not apply to the current study.

The 4 leukemia deaths in test participants included one death from chronic lymphocytic leukemia which has not been associated with radiation exposure in previous studies of either high-dose or low-dose exposure. This subject was also diagnosed as having acute myeloid leukemia prior to death (as well as a previous non- Hodgkin's lymphoma), and this was listed as a contributing cause on the death certificate. As noted above, if this subject had been classified as a non-Hodgkin's lymphoma instead of a leukemia in the cancer incidence analysis, the leukemia findings would not have been so striking, but the non-Hodgkin's lymphoma relative risk would have increased, and the overall findings for hematologic cancers would have remained unchanged.

A further problem with interpretation of the leukemia findings is that 3 of the leukemias in the test participants (as well as both of the leukemias in the controls) occurred more than 25 years after the tests, and only one occurred less than 15 years after the tests. The usual

"latency period" (also known as the "empirical induction time") between exposure and diagnosis of leukemias caused by ionizing radiation is about 2-25 years (Darby et al, 1985). However, longer latency periods have been observed in Hiroshima survivors aged less than 35 at time of exposure (Kato and Schull, 1982; Beebe, 1984), and might in fact be expected if exposure were due to ingestion or inhalation of long- lived radionuclides (Darby et al, 1988a). Thus, the leukemia findings cannot be dismissed simply on the basis that some leukemias were diagnosed more than 25 years after exposure occurred.

8.5. Interpretation of observed differences

Thus, despite the small numbers, the findings of the current study are consistent with the hypothesis that participation in the testing programme increased the risk of leukemia, and possibly some other hematologic cancers. The excess of multiple myelomas in the control group illustrates the potential for chance findings in studies of multiple cancer sites. However, the leukemia findings in particular cannot be lightly dismissed on this basis when they are considered together with those of the United Kingdom study.

Apart from chance, there are three other possible explanations for the leukemia findings: they could reflect either bias, confounding, or a causal relationship.

It is unlikely that the findings are due to serious bias in the study design. Virtually all of the potential biases that can be hypothesized (such as biases due to incomplete identification of study subjects, or shortcomings in the vital status follow-up) would be expected to bias the results for all causes of death, rather than just those for hematologic cancers. Thus, the findings for non-cancer deaths, and those for non-hematologic cancers, indicate that serious bias is unlikely to have occurred.

Of more major concern, in the interpretation of the leukemia findings, is the possibility of diagnostic bias, i.e. that leukemias may have been more readily diagnosed in the test participants because of the well-known association between radiation exposure and leukemia. Although there is no evidence of this occurring, it remains a possibility.

In any non-experimental study there is always the possibility that an association may reflect confounding rather than a causal relationship, i.e. it may reflect an association between participation in the test programme and some other factor (other than ionizing radiation or other exposures intrinsic to the programme) which causes disease. However, the existence of such a factor in the current study appears unlikely. The test participants may have been exposed to asbestos used in lagging of pipes on RNZN ships. However, we have no reason to believe that asbestos exposure differed between test participants and controls, and any

differences which did occur would not explain the findings for leukemia and other hematologic cancers. In fact, the test participants and controls appear very similar in most respects, which is to be expected given the manner in which the groups were selected.

Although it is possible that the test participants may have smoked cigarettes more than the comparison subjects, the association between cigarette smoking and leukemia is relatively weak (Austin and Cole, 1986) and could not account for the associations observed here. It is difficult to think of other lifestyle factors which can cause leukemia and which could have differed between the two groups, particularly since relatively few causes other than ionizing radiation have been established for leukemia or other hematologic cancers (Heath, 1982; Savitz and Pearce, 1987).

The preferred conclusion is therefore that if the findings for leukemia and other hematologic cancers are real, and not due to chance, then they are likely to reflect a causal relationship rather than bias or confounding. Apart from exposure to ionizing radiation, no other aspects of the test programme have been suggested which could cause an increased risk of leukemia. Thus, the most obvious question is whether the radiation exposure received by the test participants could account for these findings.

As discussed above (section 2.3) no information is currently available on the gamma radiation doses received by the RNZN participants in the test programme, but published information on the British participants in the same programme suggests that the gamma radiation doses they received were very small. In general, low doses of gamma radiation, similar to those which have been hypothesized for the test participants, might only be expected to lead to a leukemia risk of 1.01 or at most 1.1 (Boice and Land, 1982), even allowing for recent revisions in risk estimates based on new radiation dosimetry (Lancet, 1987). Thus, the leukemia relative risks observed in this study (and in the United Kingdom study) are not explicable in terms of the reported gamma radiation doses.

However, no data are available on neutron radiation exposure, and no data are available on internal radiation exposure due to inhalation or ingestion of radioactive particles. The latter may be relevant since the Pukaki and Rotoiti visited Christmas Island following the tests, and it has been hypothesized that rainout into the lagoon could have occurred (Gulbranson, 1989).

The possibility of significant exposure through inhalation or ingestion has previously been raised for United States Army participants in the Smoky nuclear weapons tests (Caldwell et al, 1980), who experienced an increased incidence of leukemia with relative risks similar to those reported here. Their mean gamma dose was 0.5 rem (5 mSv), which is also similar to that indicated by published data on United Kingdom participants in the Pacific test programme.

A gamma dose of this size in the Smoky nuclear weapons tests study is not large enough to account for their increased leukemia risk on the basis of studies of A-bomb survivors (Beebe, 1982). However, Beebe (1982) has suggested that there was almost certainly biologically significant exposure to radioactive isotopes through the food chain, and that there may have been other internal radiation exposure.

However, in the United Kingdom study it was noted (Darby et al, 1988a) that the part played by the United Kingdom test participants was very different from that of the United States participants in the Smoky tests, since the excess of leukemia in the latter group of men primarily occurred in men who had also participated in other tests and had undertaken special duties.

Nevertheless, although currently available data indicate that the RNZN personnel in Operation Grapple probably received negligible gamma radiation doses, the possibility cannot be excluded that there could have been significant external exposure to neutron radiation, or internal exposure due to inhalation or ingestion. However, there is currently no data available to confirm or refute these hypotheses.

9. CONCLUSIONS AND RECOMMENDATIONS

This study was restricted to examining mortality from various causes, and cancer incidence. No evidence has been obtained regarding the occurrence of non-fatal diseases such as cataracts or benign skin cancers.

The findings presented here indicate that New Zealand participants in the United Kingdom nuclear weapons test programme have not experienced any detectable increase in risk of death for causes other than cancer. There is little evidence of an increased risk for cancers other than the group of relatively rare cancers known as hematologic cancers, and there is no evidence of an increased risk for causes of death other than cancer. These findings are reassuring, and indicate that there has not been a detectable effect on overall life expectancy resulting from participation in the programme.

However, it is concluded that some leukemias, and possibly some other hematologic cancers, may have resulted from participation in the nuclear weapons test programme. These findings should be interpreted with caution since they are based on very small numbers. However, if the findings reflect a real association, rather than chance, then they are most likely to be causal rather than being due to bias or confounding. The strongest reason for concluding that the leukemia findings may reflect a causal relationship is that a similar excess was found in the previously published study of British participants in the same nuclear weapons testing programme. Thus, the preferred conclusion must be in favour of the causal interpretation, despite the absence of evidence of significant radiation exposure.

The results of this study thus indicate three hypotheses, which are similar to those produced by the United Kingdom study. Namely, participation in the test programme: (1) did not cause a detectable hazard for deaths from causes other than cancer; (2) did not cause a detectable hazard for cancers other than hematologic cancers; (3) caused an increase in risk for leukemia and possibly some other hematologic cancers.

None of these hypotheses has been proven. Hypothesis 1 is unlikely to be changed with further observations, since the findings are relatively stable, and highly consistent with the United Kingdom findings. However, hypotheses 2 and 3 warrant further investigation. Further follow-up would be increasingly valuable, since the study subjects are reaching the age at which cancer unfortunately becomes relatively common. The excess risk of leukemia might be expected to diminish with increasing follow- up, but this qualification may not apply if exposure was due to ingestion or inhalation of long-lived radionuclides and certainly does not apply to other cancers (Darby et al, 1988a). Thus, it is recommended that follow-up is

continued.

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APPENDIX

Postal questionnaire

QUESTIONNAIRE

THIS INFORMATION IS STRICTLY CONFIDENTIAL

Where there is a choice of answers please **circle** your answer.

1. What is your full name?

2. What is your address?

3. What is your age in years?

4. What is your race of origin? | **MAORI** | **EUROPEAN** | **OTHER** |

5. Did you serve in the Royal N.Z.Navy during the 1950's

| **YES** | **NO** |

If **YES** please continue.

If **NO** stop and return questionnaire in enclosed envelope.

6. What years did you serve in the Navy? **19____- 19____**

7. What ships did you serve on during 1957 and 1958?

8. What was your service number?

9. What was your rank in 1958?

10. Were you aboard the HMNZS Pukaki or HMNZS Rotoiti when these ships participated in the atmospheric tests conducted at Malden or Christmas Islands?

| **YES** | **NO** |

If **YES** please continue.

If **NO** go straight to question 17.

11. Which tests did you participate in?

12. Were you on deck during any of these tests? | YES | NO |

If **YES** which ones?

How long did you spend on deck?

13. Did it rain within 2 days after any of the tests?

| YES | NO |

If **YES** which one(s)

14. What were your duties aboard the naval vessel during the actual tests.

15. Did you go ashore? | YES | NO |

If **YES** please provide details.

16. During the nuclear testing programme did you serve on any ship apart from HMNZS Pukaki or HMNZS Rotoiti or with a Royal Air Force or British Army Unit?

YES	NO

If **YES** please provide details.

17. We are interested in your full occupational history and would be grateful if you could list the jobs you have held and indicate where and when you were employed on each job

EMPLOYER POSITION HELD DATES

---

18. Are you a

current smoker
ex - smoker
non - smoker

If you are a current smoker or ex-smoker continue Q19

If you are a non-smoker go to Q21.

19. Over what period have you smoked? 19__ to 19__

20. What do/did you smoke?

cigarettes	YES	NO
cigar	YES	NO
pipe	YES	NO

21. Have you ever been diagnosed as having cancer or leukemia?

YES	NO

If **YES** please give details :-

Type

When diagnosed.

22. Are there any comments you wish to make on your health.

Please return this questionnaire in the enclosed envelope.

THANKYOU FOR YOUR CO-OPERATION IN ANSWERING THIS QUESTIONNAIRE.