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

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SUMMARY

This is a supplementary report on the follow-up of 528 Royal New Zealand Navy men who took part in the United Kingdom nuclear weapons tests at Christmas Island and Malden Island during 1957-1958. We have studied the numbers of deaths and cancer cases in these men since they took part in the tests, and we have compared them with a control group of 1504 men who were in the Navy at the same time, but who did not take part in the tests.

Previous follow-up: We previously followed both groups of men from 1957 until 1987. We found that during that time 13.3% (70 out of 528) of the test participants had died, and that 11.9% (179 out of 1504) of the control group had died. Thus, the overall death rates in the two groups were very similar, but slightly higher for the test participants. We then looked separately at cancer deaths and at other causes of death. For causes of death other than cancer we found that the death rates were very similar in the two groups (8.7%) in the test participants and 8.4% in the controls). However, cancer deaths were more common in the test participants than in the controls: in particular, 7 of the test participants (1.4%) had died from hematologic cancers (including leukemia and non-Hodgkin's lymphoma), which was more than three times the risk in the controls.

New follow-up: We have now followed these men for a further five years, up until the end of 1992. We did this by searching national death registrations and cancer registrations to find out who had died and who had developed cancer. The following table shows the findings for the entire follow-up period of 1957-1992:

Cause of death	Test participants	Controls	Relative risk
Causes other than cancer	61 (11.6%)	171 (11.4%)	1.0
Cancer deaths	36 (6.8%)	85 (5.7%)	1.2
Total deaths	97 (18.4%)	256 (17.0%)	1.1

The table shows that 97 (18.4%) of the test participants had died by the end of 1992, compared with 256 (17.0%) of the controls. Thus, a slightly higher percentage of the test participants had died; this was entirely due to an excess of cancer deaths in the test participants. The death rates were about the same in the two groups for causes of death other than cancer (11.6% in the test participants and 11.4% in the controls).

When we looked at the types of cancer that the test participants were dying from. We were particularly concerned about hematological cancers, because this is the group of cancers that is known to be most strongly caused by radiation exposure:

Cause of death	Test participants	Controls	Relative risk
Hematological cancer deaths	8 (1.5%)	6 (0.4%)	3.9
Other cancer deaths	28 (5.3%)	79 (5.3%)	1.0
Total cancer deaths	36 (6.8%)	85 (5.7%)	1.2

The table shows that the test participants and the controls had exactly the same risk of dying from cancers that did not belong to the group known as "haematological cancers". However, the test participants had nearly four times the risk of developing a hematological cancer (1.5% in the test participants and 0.4% in the controls).

When we looked separately at each type of hematological cancer we found the following results:

Cause of death	Test participants	Controls	Relative risk
Non-Hodgkin's lymphoma	2 (0.4%)	1 (0.1%)	5.7
Hodgkin's Disease	1 (0.2%)	1 (0.1%)	2.8
Multiple myeloma	1 (0.2%)	2 (0.1%)	1.4
Leukemia	4 (0.8%)	2 (0.1%)	5.7
Hematological cancer deaths	8 (1.5%)	6 (0.4%)	3.9

Thus, 8 of the test participants died from haematological cancers (a relative risk of 3.9): 4 of these were leukemias (a relative risk of 5.7), and 2 of these were Non-Hodgkin's lymphomas (a relative risk of 5.7).

Conclusions: From this further follow-up to the end of 1992, we concluded that the evidence is still consistent that some hematological cancers (including some leukemias and some non-Hodgkin's lymphomas) may have been caused by participation in the nuclear weapons test programme. However, this further follow-up strengthens the evidence that there is no increased risk for non-hematological cancers or for causes of death other than cancer in the test participants.

INTRODUCTION

In 1957 and 1958 Royal New Zealand Navy 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 in the Pacific [1]. The main task of HMNZS Pukaki and Rotoiti was to act as weather ships; secondary tasks included air/sea rescue, anti-submarine watch, thermal flash monitoring, and water sampling; the ships were stationed at varying distances of 20 to 150 miles from ground zero throughout the series of tests [2,3].

In 1988 a study was published of 22,347 servicemen and civilians from the United Kingdom who participated in 21 United Kingdom atmospheric nuclear weapons tests (including the 9 tests of Operation Grapple) and a control group of 22,326 non-participants [4]. The risk of death in the test participants relative to the controls was 1.01 for all causes and 0.96 for all cancers. However, the most noteworthy finding was that mortality from leukaemia and multiple myeloma in the test participants was only slightly higher than expected on the basis of national mortality rates (standardized mortality ratios of 1.11 and 1.13 respectively), but was substantially higher than in the controls. Thus, the relative risks were strongly elevated for both neoplasms (relative risks of infinity and 3.45 respectively). The authors noted [4] that these findings were of particular interest, since leukaemia is the cancer type which has been most consistently elevated among populations exposed to relatively high doses of ionizing radiation. Furthermore, multiple myeloma is the one cancer type for which a dose-related association has been shown in two large groups of nuclear industry workers [5,6]. The authors thus noted [4] that the increases for multiple myeloma and leukaemia "cannot therefore be lightly dismissed as chance findings". However, there were considerable problems of interpretation, since the excess risks for these two cancer types were primarily due to decreased risks in the controls, and the excesses were not characteristic of men with measured doses, or even of men present at the time of the tests. The authors therefore cautiously concluded [4] that "there may well have been small hazards of both diseases associated with participation in the programme but that this has not been proved". An accompanying editorial [7] 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".

In 1990 we published a report on 528 Royal New Zealand Navy personnel who were involved in Operation Grapple and 1504 men who were in the New Zealand Navy during the same period but did not participate in the tests [2]. We found that total mortality was greater in the test participants than in the controls, but the elevation in risk was very small. There was little evidence of an increased risk for non-haematological cancers or for non-cancer deaths. However, there was an excess risk of haematological cancer deaths in the test participants, which was largely due to the occurrence of four leukaemia deaths but also included two non-Hodgkin's lymphomas and one case of Hodgkin's Disease.

The test participants and controls have now been followed for an additional five years to further assess these hypotheses and to examine the long-term effects of participation in the tests. We here report the findings of the extended follow-up and compare them with those of the extended follow-up of the United Kingdom cohort [8].

This further report should be read as a supplement to our previous report, which includes details on the historical background, the identification of test participants and controls, the validation of information, the ascertainment and validation of vital status, and the methods of data analysis. In this report, we briefly refer to the study methods used, but we concentrate on presenting and discussing the new findings from the extended follow-up.

METHODS

As noted above, the study methodology and characteristics of the study subjects have been presented in detail in previous reports [2,3] and will only be summarized briefly here. The Royal New Zealand navy test participants (on the Pukaki and Rotoiti) were identified from Royal New Zealand Navy service record cards and annual "Navy Lists" of officers. The controls comprised Royal New Zealand Navy personnel from three ships - HMNZS Kaniere, Royalist and Lachlan - which were in service during 1957-1958, but were not involved in Operation Grapple. Since the test participants did not include any conscripts, these were excluded from the controls. The test participants and controls were similar with respect to the proportion of officers, year of enlistment, year of discharge, length of service, age at start of follow-up, length of follow-up, and tobacco smoking [2,3].

Follow-up

The tests were conducted in 1957 and 1958 and the study participants were previously followed from the time of their first test (or the corresponding date in the controls) until 31 December 1987 [3]. Follow-up has now been extended to 31 December 1992. All follow-up was conducted blind, i.e. information on the groups to which study subjects belonged was deleted. Deaths which had been coded according to revisions other than the 9th International Classification of Diseases revision [9] were recoded to the 9th revision.

Study participants were also followed in the New Zealand Cancer Registry which has been more than 90% complete since the late 1950s, and virtually 100% complete since 1972 [10]. During 1985-1992 there were some problems with registration of cancers diagnosed in private hospitals, but registration is believed to have still been more than 90% complete (J Fraser, personal communication). Apart from malignant melanoma, the Cancer Registry does not include skin cancers.

Study participants were recorded as having at most one type of cancer, due to the difficulties of distinguishing multiple independent primary cancers from single tumours recurring at

multiple sites. For men who had died of cancer, registrations were ignored, except in two instances where the death was coded as a tumour of unspecified site and more detailed information was obtained from cancer registration. 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.

In the previous follow-up a postal questionnaire was used to ascertain whether those men who were not known to have died during 1957-1987 were alive and resident in New Zealand as of 31/12/87. This was not done for the extended follow-up, but in many instances it was possible to confirm that study subjects were alive and living in New Zealand on 31/12/92 (or some date between 1/1/88 and 31/12/92) using information previously collected, and new information from electoral rolls, driver's licence or car registrations, and hospital discharges.

Data analysis

Test participants were followed from the date of the first test in which they participated. Controls were followed from 15 May 1957, the date of discharge from the Navy if this occurred before 15 May 1957, or the 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 1992 for those known to be live at that date. For study participants of unknown vital status, follow-up ceased on the last date on which vital status was known. However, study participants for whom the last known date of follow-up was later than 31/12/87 (i.e. the end of the previous follow-up) but prior to 31/12/92, continued to contribute person-years until 31/12/92 (but were withdrawn at the last known date of follow-up for estimating the completeness of follow-up). This was done to avoid underestimating the person-years of follow-up and the expected number of deaths, since it was almost certain that these study participants were still alive at end of follow-up (in our previous follow-up we sent a postal questionnaire to all study participants, and also consulted independently prepared lists of deaths in the test participants, and we did not find any additional deaths that had not already been identified from national death records). For the analysis of cancer incidence, the last date of follow-up was the date of cancer registration for those who had developed cancer.

Expected deaths were calculated with the computer program PYRS [11], using New Zealand mortality and cancer incidence rates during 1957-1992, broken down by age (in five-year groupings), and calendar period. For mortality, the calendar periods were: 1957-1959, 1960-1963, 1964-1967, 1968-1972, 1973-1978, 1979-1982, 1983-1985, 1986-1991; national mortality data were not available for 1992 so it was assumed that the 1992 rates were the same as the 1986-1991 rates. Incidence rates were available for six calendar periods: 1960-1961, 1962-1966, 1968-1971, 1972-1976, 1978-1982, 1983-1987; the rates for 1960-1962 were applied to cover 1957-1961, rates for 1967 were assumed to be the same as the 1962-1966 rates, and the 1983-1987 rates were applied to cover 1988-1992.

For each outcome, the observed deaths or cancer cases were divided by the expected number to yield the standardized mortality ratio (SMR) or standardized incidence ratio (SIR). The relative risk (RR) for each outcome was then estimated by taking the ratios of the SMRs (or SIRs) in the test participants and controls. Problems can arise from comparing SMRs (or SIRs) in this manner [12] since they are not mutually standardized, but this theoretical problem is trivial when, as in the current study, the age/calendar period distributions of the two groups are very similar [2,3]. Confidence intervals were calculated by the method of Ederer and Mantel [13] with the aid of a computer program developed by Gardner and Altman [14]. As in the previous study [3], we were specifically interested in testing the hypothesis that mortality and cancer incidence were greater in the test participants than in the controls. Therefore, 90% confidence intervals (corresponding to one-tailed p-values) were used throughout.

RESULTS

For the test participants, there were 14,158 person-years of follow-up, compared to a total of 16,953 person-years which theoretically could have been achieved; a follow-up completeness of 84%. The corresponding figures for the controls are 39,651 and 48,695 person-years; a follow-up completeness of 81%. However, as noted above, in the analysis study participants for whom the last known date of follow-up was later than 31/12/87 (i.e. the end of the previous follow-up), but prior to 31/12/92, continued to contribute person-years until 31/12/92 since it was considered that they were almost certainly alive at the end of follow-up; this increased the total person-years of follow-up to 15742 in the test participants (93% of that theoretically achievable) and 44311 in the controls (91% of that theoretically achievable).

Table 1 shows that mortality in the controls was close to that expected on the basis of national mortality rates, but there was a modest elevation in mortality in the test participants. Consequently, the relative risk was also modestly elevated (relative risk=1.06, 90% confidence interval 0.87-1.30). For causes of death other than cancer the relative risk was 1.00 (90% confidence interval 0.77-1.29).

TABLE 1

Observed deaths, expected deaths and standardized mortality ratios by general cause of death categories

		Test participants			Controls				
Cause of death	ICD-9	Obs	Exp	SMR	Obs	Exp	SMR	Relative risk	90% CI
Cancer	140-208	36	22.0	1.63	85	62.0	1.37	1.19	0.84-1.67
Circulatory	390-459	34	35.9	0.95	90	100.5	0.90	1.06	0.74-1.49
Respiratory	460-519	4	5.1	0.79	12	14.1	0.85	0.92	0.28-2.61
Digestive	520-579	2	2.4	0.85	15	6.6	2.27	0.38	0.06-1.36
Genitourinary	580-629	2	0.8	2.39	2	2.3	0.86	2.79	0.30-25.8
Accidents,etc	800-999	16	12.7	1.26	41	35.6	1.15	1.10	0.64-1.83
Other causes		3	5.9	0.51	11	16.7	0.66	0.77	0.18-2.45
Total non-cancer		61	62.8	0.97	171	175.8	0.97	1.00	0.77-1.29
Total deaths		97	84.8	1.14	256	237.8	1.08	1.06	0.87-1.30

The findings for cancer are less straightforward. Both the test participants and the controls had elevated death rates for cancer, but the elevation in risk was slightly greater in the test participants, yielding a relative risk of 1.19 (90% confidence interval 0.84-1.67). Table 2 shows that the relative risk for non-haematological cancers was 1.00 (90% confidence interval 0.67-1.45). Overall, there were 8 deaths from haematological cancers in the test participants compared with 6 deaths in the controls, yielding a relative risk of 3.75 (90% confidence interval 1.36-10.8). This excess risk was mainly due to 4 deaths from leukaemia in the test participants (relative risk=5.59, 90% confidence interval 1.04-41.7).

TABLE 2

Cancer deaths, expected deaths, and standardized mortality ratios by site

		Test participants			Controls				
Cancer site	ICD-9	Obs	Exp	SMR	Obs	Exp	SMR	Relative risk	90% CI
Buccal/pharynx	140-149	3	0.6	5.25	3	1.6	1.85	2.84	0.51-15.7
Oesophagus	150	2	0.7	3.01	2	1.9	1.07	2.83	0.31-26.2
Stomach	151	1	1.3	0.78	10	3.6	2.80	0.28	0.01-1.60
Small intestine	152	0	0.1	0.00	0	0.2	0.00	-	-
Colon	153	2	2.3	0.88	7	6.4	1.09	0.80	0.12-3.44
Rectum	154	1	1.5	0.69	5	4.1	1.22	0.56	0.02-3.91
Larynx	161	0	0.2	0.00	0	0.6	0.00	-	-
Lung	162	9	6.0	1.51	27	16.8	1.61	0.94	0.45-1.84
Bone	170	0	0.1	0.00	0	0.3	0.00	-	-
Connective tissue	171	0	0.1	0.00	1	0.4	2.55	0.00	0.00-52.9
Prostate	185	1	1.0	1.04	8	2.7	3.01	0.35	0.02-2.08
Testis	186	0	0.3	0.00	1	0.8	1.26	0.00	0.00-53.6
Bladder 188	2	0.4	4.86	0	1.1	0.00	-	-	
Kidney	189	2	0.6	3.53	3	1.6	1.88	1.87	0.23-12.0
Brain/nervous	191,192	2	1.0	1.92	2	2.9	0.68	2.83	0.31-26.1
Thyroid	193	0	0.0	0.00	0	0.1	0.00	-	-
Other cancer		3	4.0	0.75	10	11.3	0.89	0.84	0.20-2.75
Total non-haematological		28	20.0	1.40	79	56.3	1.40	1.00	0.67-1.45
Non-Hodgkin's lymphoma	200,202	2	0.7	3.02	1	1.9	0.54	5.67	0.44-165
Hodgkin's disease	201	1	0.2	4.17	1	0.7	1.48	2.83	0.07-109
Multiple myeloma	203	1	0.3	3.11	2	0.9	2.21	1.41	0.05-18.0
Leukaemia	204-208	4	0.8	5.07	2	2.2	0.90	5.59	1.04-41.7
Total haematological		8	2.0	3.97	6	5.7	1.06	3.75	1.36-10.8
Total cancer		36	22.0	1.63	85	62.0	1.37	1.19	0.84-1.67

Subgroup analyses were of limited value due to the small numbers involved. The only information which was available on surrogates for radiation exposure was the number of tests attended: 3 of the leukaemia cases in test participants had attended 1-3 tests (expected=0.3, SMR=9.23); 1 had attended 4-6 tests (expected 0.4, SMR=2.46) and none had attended 7 or more tests (expected=0.03). The corresponding numbers for total hematological cancers were 4 (expected=0.8, SMR=4.79), 4 (expected=1.0, SMR=3.89) and 0 (expected=0.1). Table 3 shows the mortality findings according to length of follow-up, i.e. the length of time since the first nuclear test attended by the test participants, and the length of time since the corresponding date in the controls. Seven of the 8 haematological cancer deaths in test participants, and all of the four leukaemia deaths, occurred 10-29 years after participation in the tests. Total cancer deaths showed relative risks close to 1.0 throughout the follow-up period.

TABLE 3

Observed deaths, expected deaths and SMRs by length of follow-up

Cancer site	Length follow-up (years)	Test participants Obs	Exp	SMR	Controls Obs	Exp	SMR	Relative risk	90% CI
Haematological cancers	0-9	0	0.3	0.00	0	0.8	0.00	-	-
	10-19	2	0.4	4.89	1	1.1	0.88	5.51	0.43-160
	20-29	5	0.7	7.28	5	1.9	2.64	2.74	0.78-9.57
	30+	1	0.6	1.61	0	1.8	0.00	-	-
Leukaemia	0-9	0	0.1	0.00	0	0.4	0.00	-	-
	10-19	1	0.2	6.01	0	0.5	0.00	-	-
	20-29	3	0.3	10.98	2	0.8	2.66	4.17	0.65-33.5
	30+	0	0.2	0.00	0	0.6	0.00	-	-
Non-Haematological cancers	0-9	0	1.0	0.00	1	2.9	0.35	0.00	0.00-53.0
	10-19	3	3.2	0.95	10	8.7	1.15	0.82	0.19-2.68
	20-29	14	8.3	1.68	36	22.9	1.57	1.07	0.60-1.86
	30+	11	7.5	1.46	32	21.8	1.47	1.00	0.52-1.84
All cancers	0-9	0	1.3	0.00	1	3.7	0.27	0.00	0.00-52.9
	10-19	5	3.6	1.40	11	9.8	1.12	1.25	0.42-3.33
	20-29	19	9.0	2.11	41	24.8	1.65	1.28	0.77-2.07
	30+	12	8.1	1.48	32	23.7	1.35	1.09	0.58-1.97

Further to the observed cancer deaths, there were an additional 13 cancer registrations in the test participants and 47 in the controls (Table 4). The relative risk for cancer incidence was 1.04 (90% confidence interval 0.77-1.38), and that for non-haematological cancers was 0.95 (90% confidence interval 0.69-1.30). There were 8 haematological cancers in the test participants (i.e. the same number as for deaths), compared to 12 in the controls (relative risk=1.86, 90% confidence interval 0.77-4.30). The cancer incidence findings by length of follow-up were generally similar to those shown for mortality in Table 3, except that the relative risks were generally slightly lower for incidence than for mortality (e.g. the relative risks for incidence for all cancers were 0.00, 1.10, 1.06, and 1.06 for the time periods 0-9, 10-19, 20-29 and 30+ years after tests, compared with the corresponding mortality relative risks of 0.00, 1.25, 1.28 and 1.09 (Table 3)).

TABLE 4

Cancer incidence, expected incidence, and standardized incidence ratios by site

		Test participants			Controls				
Cancer site	ICD-9	Obs	Exp	SIR	Obs	Exp	SIR	Relative risk	90% CI
Oral cavity & pharynx	140-149	4	1.8	2.23	8	5.0	1.59	1.40	0.39-4.37
Oesophagus	150	2	0.7	2.73	2	2.1	0.98	2.81	0.30-26.0
Stomach	151	1	1.7	0.58	13	4.8	2.69	0.21	0.01-1.17
Small intestine	152	0	0.1	-	0	0.4	-	-	-
Colon	153	3	4.5	0.67	12	12.6	0.95	0.70	0.17-2.19
Rectum	154	3	3.0	1.00	8	8.4	0.96	1.05	0.24-3.62
Larynx	161	0	0.7	-	2	1.9	1.06	0.00	0.00-9.79
Lung	162	13	7.3	1.78	35	20.4	1.72	1.04	0.56-1.83
Bone	170	0	0.2	-	0	0.5	-	-	-
Soft tissue	171	0	0.4	-	1	1.2	0.85	0	0-53.4
Prostate	185	2	2.2	0.89	13	6.1	2.14	0.42	0.07-1.55
Testis	186	0	1.1	-	3	3.0	1.01	0.00	0.00-4.79
Bladder	188	3	1.5	2.01	2	4.1	0.48	4.16	0.65-33.5
Kidney	189	2	1.2	1.73	3	3.2	0.93	1.88	0.23-12.1
Brain & nervous system	191-192	2	1.2	1.61	2	3.5	0.57	2.82	0.31-26.1
Thyroid	193	0	0.2	-	0	0.6	-	-	-
Other cancers		6	7.1	0.84	16	20.0	0.80	1.05	0.40-2.47
Total non-haematological		41	35.0	1.17	120	97.6	1.23	0.95	0.69-1.30
Non-Hodgkin's	200,202	2	1.2	1.64	4	3.4	1.17	1.40	0.19-7.53
Hodgkin's	201	1	0.6	1.80	2	1.6	1.28	1.39	0.05-17.8
Multiple myeloma	203	1	0.5	2.05	4	1.4	2.95	0.69	0.03-5.33
Leukaemia	204-208	4	1.0	3.99	2	2.8	0.72	5.58	1.04-41.6
Total haematological		8	3.3	2.45	12	9.1	1.32	1.86	0.77-4.30
Total cancer		49	38.2	1.28	132	106.7	1.24	1.04	0.77-1.38

DISCUSSION

In our previous report [3] it was noted that the number of deaths and cancer registrations was 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 [4]. The same caveat applies to this extended follow-up. However, it should be emphasized that 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 our previous report we concluded that: (a) New Zealand participants in the United Kingdom nuclear weapons test programme had not experienced any detectable increase in risk of death for causes other than cancer; (b) there was little evidence of an increased risk for non-haematological cancers; but (c) some leukaemias, and possibly some other haematological cancers may have resulted from participation in the nuclear weapons test programme.

The extended follow-up provides further evidence that the New Zealand nuclear test participants did not experience an increased risk of death for causes other than cancer. There were 17 extra non-cancer deaths in the cases (expected = 16.4) and 44 in the controls (expected = 47.2). The relative risk of non-cancer death for the entire follow-up period was 1.00 (90% confidence interval 0.77-1.29) compared with 0.96 (90% confidence interval 0.71-1.29) in the previous follow-up.

The extended follow-up also provides further evidence that there is no increased risk of non-haematological cancers. There were 9 extra non-haematological cancer deaths in the test participants (expected = 6.9) and 33 in the controls (expected = 20.2). This gives a relative risk for the entire follow-up period of 1.00 (90% confidence interval 0.67-1.45) compared with 1.14 (90% confidence interval 0.69-1.83) in the previous follow-up. The relative risk of incidence of non-haematological cancers for the entire follow-up period was 0.95 (90% confidence interval 0.69-1.30) compared with 1.01 (90% confidence interval 0.67-1.50) for the previous follow-up period. Thus the small increased risk of non-haematological cancer death in the test participants has disappeared with the further follow-up and there is now no

evidence of an increased risk for either mortality or incidence. It should be noted that both the test participants and controls showed small increased risks of non-haematological cancers compared with the general population rates (SMRs of 1.40 for mortality for both groups and SIRs of 1.17 and 1.23 respectively), but this was largely due to increased risks of tobacco-related cancers, which might be expected because of the high smoking rates in both groups [3]).

The greatest problems of interpretation apply to the findings for leukaemia and other haematological cancers. The additional five years of follow-up yielded only one extra haematological cancer death in the test participants (expected = 0.6) and no extra cases in the controls (expected = 1.9), resulting in a strengthening of the relative risk for the entire follow-up period for all haematological cancers (relative risk = 3.75 compared with 3.25 in the previous follow-up) but with virtually no change in the leukaemia relative risk. In the incidence findings, there was one extra haematological cancer case in the test participants (expected = 1.0) and two extra cases in the controls (expected = 2.7) resulting in virtually no change in the relative risk (1.86 compared with 1.94 in the previous follow-up).

Following the initial findings of the United Kingdom study [4] and because leukaemia is among the cancer types which is most strongly radiogenic, haematological cancers, and particularly leukaemia, were of prime *a priori* interest in the previous follow-up of the New Zealand test participants [3]. The findings of the United Kingdom study were difficult to interpret, since they were primarily due to a deficit of leukaemia and multiple myeloma in the controls, but this problem did not apply to the New Zealand data. The further follow-up of the United Kingdom cohort [8] found no increased risk of leukaemia (relative risk 0.57) or multiple myeloma (relative risk 0.57) and in both instances the mortality rates in the controls were close to that expected from national mortality rates. The authors therefore concluded that the excess of multiple myeloma in participants compared with controls in the previous follow-up was likely to have been a chance finding. However, they noted that the possibility of a small risk in the first 25 years after the tests could not be ruled out, and it remains possible that a genuine increased risk did occur during the previous period of follow-up but that this excess risk has now receded with continued follow-up. Similar considerations apply to the New Zealand findings. In our previous analysis we noted that our data showed a

genuinely increased risk in the test participants rather than a deficit in the controls. The further follow-up still supports these conclusions although it should be noted that the findings for the further follow-up period are generally consistent with the United Kingdom study findings that the increased risk (if it is real) appears to have receded. In fact, one criticism of the previous findings was that the latency period was too long (3 of the 4 leukaemias occurred more than 25 years after the tests) so is perhaps not surprising that any increased risk in the New Zealand cohort may have also receded.

If the findings for leukaemia and other haematological cancers are real, this raises the question as to what exposures could be responsible for the observed increased risks. In our previous report we noted that no information was available on the gamma or neutron radiation doses received by the Royal New Zealand Navy participants in the test programme, and that no data were available on internal radiation exposure due to inhalation or ingestion of radioactive particles. It appears that during Operation Grapple most film badges, including those from the New Zealand frigates, were not processed. Available information on the British participants in Operation Grapple whose film badges were processed suggests that the gamma radiation doses they received were very small. We have previously noted [3] that internal radiation exposure may have been relevant since the Pukaki and Rotoiti visited Christmas Island following the tests, and it has been hypothesized that rainout into the lagoon and concentration in the food chain could have occurred. However, the United Kingdom authors have argued [8] that visits to the lagoon were unlikely to have caused any increased risk because little or none was seen in staff from the United Kingdom serving at Christmas Island. Nevertheless, although currently available data indicate that the Royal New Zealand Navy personnel in Operation Grapple probably received very low 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, but there is little or no data available to confirm or refute these hypotheses.

In summary, the evidence from this extended follow-up is still consistent with the hypothesis that some leukaemias and other haematological cancers may have resulted from participation in the nuclear weapons test programme. However, the extended follow-up strengthens the

evidence that there is no increased risk for non-haematological cancers or for causes of death other than cancer in the New Zealand test participants.

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