AECL-9344

ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

MORTALITY AMONG LONG-TERM CHALK RIVER EMPLOYEES

Statistiques de mortalité du personnel employé à long terme de Chalk River

M.M. WERNER and D.K. MYERS

Chalk River Nuclear Laboratories
Laboratoires nucléaires de Chalk River

Chalk River, Ontario

December 1986 décembre

ATOMIC ENERGY OF CANADA LIMITED

MORTALITY AMONG LONG-TERM CHALK RIVER EMPLOYEES

by

M.M. Werner and D.K. Myers

Radiation Biology Branch
Chalk River Nuclear Laboratories
Chalk River, Ontario K0J 1J0
1986 December

AECL-9344

L'ÉNERGIE ATOMIQUE DU CANADA, LIMITÉE

STATISTIQUES DE MORTALITÉ DU PERSONNEL EMPLOYÉ À LONG TERME DE CHALK RIVER

par

M.M. Werner et D.K. Myers

RÉSUMÉ

On a mis à jour les statistiques de mortalité du personnel des LNCR qui est décédé soit au cours du service soit au cours de la retraite jusqu'au 31 décembre 1985. Les données, qui sont présentées sous forme de tableaux, intéressent la mortalité globale du personnel des deux sexes, le personnel ayant participé à la décontamination à la suite de l'accident des réacteurs NRX et NRU et un groupe de membres de personnel de bureaux des LNCR ayant reçu des doses cumulées de durée de vie supérieures à 0,2 Sv. Elles intéressent également les divers types de cancers mortels contractés par le personnel du sexe masculin. On n'a constaté aucune augmentation importante de mortalité due au cancer chez les groupes étudiés du point de vue de la statistique.

Service de Radiobiologie
Laboratoires Nucléaires de Chalk River
Chalk River, Ontario K0J 1J0

1986 décembre

AECL-9344

ATOMIC ENERGY OF CANADA LIMITED

MORTALITY AMONG LONG-TERM CHALK RIVER EMPLOYEES

BY

M.M. Werner and D.K. Myers

Abstract

Mortality among CRNL employees who died during employment or after retirement has been updated to 1985 December 31. Data in tabular form are presented for overall mortality for male and female employees, for the participants in the clean-up for the NRX and NRU accidents and for a group of CRNL staff with lifetime accumulative doses in excess of 0.2 Sv. Data are also presented on the different types of cancer causing death among male employees. No statistically significant increases in cancer deaths were found in any of the groups analyzed.

Radiation Biology Branch
Chalk River Nuclear Laboratories
Chalk River, Ontario K0J 1J0
1986 December

AECL-9344

CONTENTS

1. INTRODUCTION

This report describes the results of the follow-up of long-term employees of the Chalk River Nuclear Laboratories (CRNL) to 1985 December 31. The group monitored includes all retired employees and current employees of CRNL in any one year. Excluded, therefore, are all persons who have terminated employment at CRNL to work elsewhere before being eligible for a pension at CRNL. Mortality among various sub-groups of employees has also been examined. These groups include persons who worked in both NRX and NRU clean-ups in 1953 and 1958 respectively and a group of male employees who have recorded lifetime doses of more than 0.2 Sv.

2. METHODS

Methods have been described in previous papers in detail (1,2,3). Causes of death for deceased employees of CRNL were taken from medical certificates stating cause of death. These certificates are obtained under conditions of strict confidentiality of personal information from the provincial registrars general for deaths occurring in Canada. Several deaths have occurred in other countries. Certain state vital statistics departments have kindly provided us with cause of death information for deaths occurring in the United States.

To calculate person-years at risk for CRNL current and retired employees age distributions by 5 year intervals were prepared for each year and summed over the years being considered. To calculate expected deaths for a specific cause this figure for person-years at risk was then multiplied by the fraction of the population of Ontario of that age grouping and sex who died from the same cause over the same time period (4). Ontario data were only available up to 1983 so expected death rates for 1981-1985 were based on Ontario data from 1981-1983.

Little data on age distributions of current employees of CRNL is available before 1973 when employee records were computerized, with the exception of 1971. On the basis of this information for the year 1971 and the fact that total numbers of staff at this time were reasonably constant, it was decided that age distributions could be extrapolated back to 1966 without introducing a large error. Previous to 1966 only total number of staff in any one year is available.

Causes of death are grouped by ICD code (9th revision) into 3 major categories: ICD 140-239 cancer, ICD 390-459 cardiovascular diseases and ICD E800-E999 violent causes (5). All other ICD codes were placed in the "all other causes" category. Results are presented as standard mortality ratios (SMR): the number of observed deaths in any category divided by the number of expected deaths. For most of the data 95% confidence intervals for the observed SMR's are also provided and have been calculated by the methods of Bailer and Ederer (6).

The lists of employees who took part in the clean-up of NRX and NRU were prepared from CRNL internal documents and dose records. All records relating to recorded doses were obtained from the Dosimetric Research Branch files.

3. RESULTS

3.1 OVERALL MORTALITY

Causes of death among CRNL staff who died before 1965 cannot be analyzed in any detail because of the lack of data on age distribution. Death certificates for deaths of current and retired employees prior to 1966 are, however, available. Table 1 shows the mortality of male employees prior to 1965. On the basis of proportional mortality ratios (i.e. percentage of cancer deaths in total deaths at CRNL to 1965 compared to the percentage in the general population of Ontario for the same period of time), the mortality of male CRNL employees in that period does not differ from that of the general population with the exception of violent causes. The only two on-site industrial accidents occurred in these years, otherwise the excess accidental deaths are related to lifestyles (eg. drownings) and motor vehicle usage. Similar excesses of non-occupational violent deaths were found in other studies involving personnel living in frontier communities such as Elliot Lake, Ontario (7) and Beaverlodge, Saskatchewan (8).

Table 1

CAUSES OF DEATH AMONG RETIREES AND CURRENT EMPLOYEES OF CRNL BEFORE 1966

CAUSES OF DEATH	OBSERVED	EXPECTED	PMR*
Cancer	22	22.19	0.99
Cardiovascular Diseases	72	79.73	0.90
Violent Causes	20	11.64	1.72
All Other Causes	20	22.33	0.89
Unknown Causes	3		

* Proportional mortality ratio.

Table 2 shows the numbers of observed and expected deaths together with SMR's for male current and retired employees between 1966 and 1985. An additional 83 deaths have occurred since the last report covering mortality to the end of 1982 was issued. All SMR's were less than 1.0; however, only values for all causes, all other causes and for violent causes were significantly less than 1.0 at the 95% statistical confidence limits. Causes of death have not been obtained for 2 individuals who died while on holiday in other countries. They are included only in the all causes mortality in the appropriate age category (Table 2). SMR's for major causes by 5 year intervals for males is shown in Table 3. The SMR for cardiovasular diseases increased substantially

Table 2

MORTALITY AMONG MALE CRNL EMPLOYEES WHO DIED DURING EMPLOYMENT OR AFTER RETIREMENT 1966-1985

CAUSES OF DEATH	OBSERVED	EXPECTED	SMR*
Cancer	119	127.7	0.93 (0.77-1.11)
Cardiovascular Diseases	237	262.7	0.90 (0.79-1.02)
Violent Causes	28	46.7	0.60** (0.40-1.0)
All Other Causes	68	90.8	0.75** (0.59-0.96)
Unknown	2		
All Causes	454	527.9	0.86** (0.78-0.94)

* Standard mortality ratio. The numbers in brackets represent the 95% confidence limits on the SMR.

** Value is significantly lower than 1.0 as judged by the 95 percent confidence limits.

Table 3

STANDARD MORTALITY RATIOS FOR MAJOR CAUSES OF DEATH, MALES, 1966-1985 BY 5 YEAR INTERVALS

CAUSES OF DEATH	1966-1970	1971-1975	1976-1980	1981-1985
Cancer	0.95	0.72	0.89	1.07
Cardiovascular Diseases	0.85	0.78	1.15	0.81
Violent Causes	0.59	0.68	0.61	0.52
All Other Causes	0.36	0.80	0.87	0.84
All Causes	0.76	0.76	0.99	0.88

between 1971-1975 and 1976-1980 (1, Appendix A), but this increase did not continue in 1981-1985. SMR's for cancer have shown similar fluctuations by 5 year intervals. The existence of these fluctuations emphasizes the importance of long term follow-up in order to obtain statistically significant mortality ratios.

Table 4 presents the data on the different types of cancer causing death in males between 1966 and 1985. Because numbers of deaths in many of the categories are low (less than 10) only general observations can be made. The 95% confidence intervals indicate that none of the observed numbers of deaths are statistically higher or lower than expected. Lung cancer accounts for 30% of all cancer deaths (40 observed, 42.3 expected). Cancers of the lymphatic and haematopoietic tissues which have been associated with radiation exposure in certain studies are not higher than expected (8 observed, 11.2 expected). There were 12 deaths from cancer of the prostate where 8.05 were expected. The 19 cancers in the "other and unspecified sites" category included 8 cancers of unspecified location, 2 brain cancers, 2 bladder cancers, 1 each of thyroid, bile ducts, testes, kidney, nasal passages, a soft tissue sarcoma and a mesotheliomia.

Some authors have questioned the validity of cause of death information on death certificates (9,10). Supplementary information was available to us for about half the death certificates received. The likelihood of one error in a death certificate was thus established (11). However, no corrections were made for this error which would have increased the number of oesophageal cancers from 2 to 3. Any correction would invalidate direct comparison with the uncorrected provincial vital statistics.

Females comprise 12% of the current workforce. A much smaller percentage of the workforce are long-term employees. There have only been 23 deaths among current and retired female employees between 1966 and 1985. Causes of death by major cause for female employees are shown in Table 5.

3.2 NRX CLEAN-UP

On December 12, 1952 a brief power surge caused by a combination of human error and a design fault damaged the NRX reactor so extensively that the reactor vessel was replaced and the reactor rebuilt (2). AECL staff and Canadian and American military personnel did most of the clean-up work. Of the 850 AECL male staff who participated in the clean-up, 288 were lost to follow-up as they left employment with AECL; 562 remained with AECL and were still traceable in 1985. Of this group only 51 were still employed with AECL at the end of 1985; 175 had died and the remainder were retired. Causes of death for this group are shown in Table 6. SMR's were all below 1.0, with deaths from all causes and all other causes significantly lower than expected.

3.3 NRU CLEAN-UP

In May 1958 the NRU reactor building was badly contaminated when a piece of damaged fuel rod fell from the fueling machine as it was being removed from the reactor (3). Highest exposures during the clean-up were to CRNL staff who had to deal with the immediate fire and then remove the highly radioactive remains of the burned fuel rod. The dose rate in the immediate vicinity of the fuel rod debris was well over 1000 rads (10 Gy) per hour. The entire building then had to be decontaminated. Canadian servicemen and a number of short-term employees helped with the later phase of the clean-up.

Table 4

TYPES OF CANCER CAUSING DEATH AMONG MALE CRNL EMPLOYEES AND RETIREES, 1966-1985

TYPE OF CANCER	OBSERVED	EXPECTED	SMR
Buccal Cavity and Pharynx	4	3.92	1.02 (0.28-2.61)
Oesophagus	2	3.42	0.58 (0.07-2.09)
Stomach	7	8.11	0.86 (0.35-1.77)
Intestines	9	11.81	0.76 (0.35-1.44)
Rectum	7	5.11	1.37 (0.55-2.82)
Larynx	0	1.91	-- --
Lung	40	42.30	0.94 (0.67-1.29)
Bone	0	0.42	-- --
Skin	1	1.89	0.53 (0.01-2.94)
Breast	1	0.19	5.26 (0.13-29.22)
Prostate	12	8.05	1.49 (0.77-2.60)
Pancreas	9	7.35	1.22 (0.56-2.31)
Lymph & Blood-Forming System:			
Leukemia	1	4.43	0.22 (0.005-1.25)
Multiple Myeloma & Immunoproliferative System	1	1.77	0.56 (0.01-3.11)
Other (Lymphoma, etc.)	6	4.92	1.22 (0.45-2.66)
Other & Unspecified Site	19	21.31	0.89 (0.54-1.39)
Benign & Unspecified Nature	0	0.86	-- --
TOTAL	119	127.77	0.93 (0.77-1.11)

Table 5

CAUSES OF DEATH AMONG FEMALE CRNL EMPLOYEES WHO DIED DURING EMPLOYMENT OR AFTER RETIREMENT 1966-1985

CAUSES OF DEATH	OBSERVED	EXPECTED	SMR
Cancer	6	7.0	0.86 (0.31-1.87)
Cardiovascular Diseases	10	9.1	1.10 (0.53-2.02)
Violent Causes	2	2.0	1.00 (0.12-3.61)
All Other Causes	4	4.0	1.00 (0.27-2.56)
Unknown	1		
All Causes	23	22.1	1.04 (0.66-1.56)

Table 6

MORTALITY AMONG AECL PARTICIPANTS IN THE NRX CLEAN-UP

CAUSES OF DEATH	OBSERVED	EXPECTED	SMR
Cancer	38	47.8	0.79 (0.57-1.10)
Cardiovascular Diseases	101	109.2	0.92 (0.75-1.12)
Violent Causes	14	16.2	0.86 (0.47-1.44)
All Other Causes	22	35.0	0.63** (0.39-0.95)
All Causes	175	208.3	0.84** (0.72-0.98)

** Statistically significant (see Table 2)

Of the 537 CRNL traceable staff, 108 were still current employees, 135 had died and the remainder had retired from AECL as of 1985 December 31. Causes of death are shown in Table 7. All SMR's except that for cancer are below 1.0. There were 37 cancer deaths where 33.9 were expected. Interestingly all SMR's for this group were lower than those observed in follow-up to the end of 1982 (1).

Table 7

MORTALITY AMONG AECL PARTICIPANTS IN THE NRU CLEAN-UP

CAUSES OF DEATH	OBSERVED	EXPECTED	SMR
Cancer	37	33.9	1.09 (0.78-1.53)
Cardiovascular Diseases	68	75.2	0.90 (0.71-1.15)
Violent Causes	9	13.0	0.69 (0.32-1.30)
All Other Causes	21	24.5	0.86 (0.53-1.31)
All Causes	135	146.6	0.92 (0.77-1.09)

3.4 0.2 Sv AND OVER GROUP

In AECL-8183 (1), causes of death were reported for a group of 436 CRNL male employees who had lifetime accumulated doses of more than 0.2 Sv (20 rem). This number represented the total number of employees who had recorded accumulated doses of that amount to the end of 1982. For this follow-up no additional persons were added to this group. Of this group 412 are easily traceable, that is, they are either current or retired employees of AECL or have died. This is one less than in the last report as one person has left CRNL for other employment. Table 8 shows the mortality pattern of this group by major cause to the end of 1985. All SMR's for this group are still below 1.0, with the SMR's for all causes and all other causes being statistically significantly lower than 1.0. We have anecdotal evidence that 22 of the 24 persons who left CRNL are still alive; the two deaths which have occurred are not due to cancer.

Table 8

MORTALITY AMONG 412 CRNL EMPLOYEES WITH ACCUMULATED LIFETIME DOSES ≥ 0.2 Sv

CAUSES OF DEATH	OBSERVED	EXPECTED	SMR
Cancer	19	22.8	0.83 (0.50-1.30)
Cardiovascular Diseases	45	49.3	0.91 (0.66-1.22)
Violent Causes	5	10.8	0.46 (0.15-1.07)
All Other Causes	7	16.4	0.43** (0.17-0.89)
All Causes	76	99.3	0.76** (0.60-0.96)

** Statistically significant (see Table 2)

4. DISCUSSION

The data presented in this report indicate that the mortality from all causes among CRNL male current and retired employees is well below that of the general male population of Ontario. This could be interpreted as a "healthy worker effect". The factors that lead to this "healthy worker effect" do not act to the same extent on mortality from cancer (12). Although observed deaths from cancer are below the expected level, the average decrease is not so striking as in other major categories. When mortality by major categories is examined over 5 year intervals (Table 3), SMR's for cancer have increased over the last three 5 year intervals until in 1981-1985 the SMR was slightly above 1.0. The increase is far from significant and may reflect only the size of the population under investigation. There is no obvious trend when the comparison is extended to include all four 5 year intervals since 1966.

Epidemiological studies of persons exposed to high levels of radiation have found an association between certain types of cancer and the radiation exposure (13,14). For the survivors of the bombings of Hiroshima and Nagasaki these types now include leukemia, lung, breast, stomach, esophagus, colon, urinary tract and multiple myeloma (15). The report on Hanford workers (16) indicates a dose related increase in deaths from multiple myeloma, with no significant increases in deaths from leukemia, prostate cancer or all other cancers. A recent report (17) on the staff of the United Kingdom Atomic Energy Authority (UKAEA) documents an increase in prostate cancer with no significant

increase in deaths from leukemia, multiple myeloma or other types of cancer in the group of staff with radiation records. This increase in prostate cancer deaths was strongest in employees who had been monitored for tritium exposure. When the results of these two studies on Hanford and UKAEA workers are combined, the correlations of incidence of multiple myeloma and prostate cancer with dose are no longer significantly different from zero (18). This suggests that the associations observed in one or other of the two studies taken separately are both due to chance (18). The CRNL cancer mortality data when viewed in the light of these statements yields some interesting details although it must be remembered that numbers of cancers in many of the categories is very low (less than 10 in most categories). Fatal cancers of the lymph and blood-forming systems (including leukemia and multiple myeloma) are below the expected - 8 observed, 11.1 expected. There were 12 deaths from prostate cancer in 1966-1985 where only 8.05 were expected (SMR = 1.49, 95% confidence limits 0.77 - 2.60). Table 9 indicates whole body and tritium exposures for these 12 individuals. Seven had been monitored for tritium. Tritium monitoring at Chalk River is done on a routine basis for all persons working in locations where significant tritium exposure is possible. Two were in the group with whole body doses greater than 0.2 Sv. The tritium doses for these individuals and for the others (Table 9) are only a small fraction of their whole body doses. It is thus most improbable that these prostate cancers were associated with tritium exposures.

Table 9

RECORDED LIFETIME WHOLE BODY AND TRITIUM DOSES FOR PERSONS DYING FROM PROSTATE CANCER

	WHOLE BODY DOSE Sv		TRITIUM DOSE Sv	
Case 1	0.396	(39.6)[a]	0.0042	(0.4)[a]
2	0.253	(25.3)	0.0191	(1.9)
3	0.055	(5.5)	*	
4	0.021	(2.1)	*	
5	0.014	(1.4)	0	
6	0.013	(1.3)	0.0005	(0.05)
7	0.012	(1.2)	0	
8	0.005	(0.5)	0	
9	0.003	(0.3)	*	
10	0.002	(0.2)	0	
11	0	0	*	
12	0	0	*	

[a] doses in rem
* not monitored for tritium

Analysis of the combined experience of the UKAEA and Hanford workers provides risk estimates for all fatal cancers which are very similar to those suggested by the ICRP and other scientific committees after analysis of data on persons exposed to high radiation doses (18). The 95% confidence limits on the risk estimates obtained from follow-up of the UKAEA and Hanford workers are extremely wide, which is inevitable if the true risks of radiation exposure are as low as appears and the number of workers with relatively high exposures is so small (18). Similar results were observed in a recent study of the mortality of workers at the Sellafield plant of British Nuclear Fuels. The findings on death rates from all cancers in these radiation workers were compatible with the ICRP estimates of the carcinogenic risk of low doses of radiation (19), although it was impossible to exclude with confidence either a 10-fold higher risk or the absence of any risk at all (i.e. zero risk).

In the past 3 years, two reports have been prepared on Canadian service personnel who participated in the clean-ups after the NRX accident in late 1952 and the NRU accident in 1958. The first report (20) was prepared by the Department of Epidemiology and Community Medicine at the University of Ottawa under a contract from the Canadian Pension Commission. The second (21) was a report prepared by the Health Division at Statistics Canada for the Department of National Defence (DND). Both studies were of mortality only and relied mainly on the Canadian Mortality Data Base at Statistics Canada. The cohort in both cases included the Chalk River clean-up service personnel and the atom bomb test observers. The University of Ottawa cohort was larger (954 vs. 908) than the DND cohort, probably due to an advertising campaign which elicited a number of additional personnel, some of whom were confirmed by examination of personnel records. The University of Ottawa group analyzed the data in 2 ways; firstly by comparison with the U.S. (white) male population for the appropriate years, and secondly, by comparison with other Canadian service personnel matched by age and rank who were not exposed to radiation. The DND study compared mortality in the service personnel to that of the Canadian male population. Both reports conclude that there was no increase in cause-specific mortality for those causes, i.e. cancer, which are thought to be associated with radiation. The University of Ottawa group could find "no demonstrable association between radiation dosage and mortality". They also note that the documentation of dose was very poor because of the insensitivity of recording procedures available in the 1950's. However, the dosimeters used at CRNL in 1953 were capable of overestimating radiation doses, and it is thought that the actual whole body doses received by people in the NRX clean-up were somewhat less than the recorded amounts (22).

The results of these 2 studies agree with the findings of our follow-up of AECL clean-up personnel. The exposures to the clean-up personnel were, with very few exceptions, within the allowable yearly limit so it would not be expected that the exposures were large enough to yield positive results. These results were similar to those found among American military observers of Nevada bomb tests as well (23).

Recorded annual cumulative exposures at AECL have decreased by a factor of three in the last 30 years - from 20.1 person-Sv in 1956 to 6.77 person-Sv in 1985 (24). Recorded cumulative exposures for all CRNL employees combined for the years 1966 to 1985 are 170 person-Sv (24). On the basis of the risk estimates prepared by the International Commission on Radiological Protection (ICRP) of one induced fatal cancer per 100 person-Sv (25) it could be expected that there may have been about two fatal cancers and an equal number of curable cancers induced by the occupational exposures at CRNL in those twenty years. During the same period a total of 125 employees have died from cancer from other "normal" causes. Since cancers induced by exposure to radiation cannot be distinguished from those due to other causes, it is reassuring to note that the numbers of cancer deaths among CRNL employees is lower than expected. The absence of an excess of leukemia deaths in the high exposure group is particularly reassuring.

The studies reported above have failed to provide evidence for any major detrimental health effects, whether from radiation, chemicals, or any other source, associated with employment at CRNL. However, because of the long latent period between the exposure to a carcinogen (i.e. radiation) and the appearance of an overt cancer, continued surveillance of employees exposed to radiation is necessary to provide continued assurance that nuclear industry standards of worker safety are in line with those for other safe industries.

5. ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of the provincial Vital Statistics Departments particularly those of Ontario, British Columbia, Quebec, Alberta and Nova Scotia and also of the State of Florida who provided us with cause of death information. CRNL staff who assisted us included Mr. J.H. Collins, Mrs. M. Myers, Mrs. N. Oelke, Mrs. M. Edwards, Mrs. M. TerHuurne, Dr. R.M. Holford and Mrs. C. Thibeau. We are especially grateful to Mr. D.W. Dunford for computer programming assistance.

6. REFERENCES

1. M.M. Werner, D.K. Myers and D.P. Morrison, "Updated follow-up of long-term Chalk River employees". Atomic Energy of Canada Limited, Report AECL-8183 (1983).

2. M.M. Werner, D.K. Myers and D.P. Morrison, "Follow-up of CRNL employees involved in the NRX reactor clean-up". Atomic Energy of Canada Limited, Report AECL-7760 (1982).

3. M.M. Werner, D.K. Myers and D.P. Morrison, "Follow-up of AECL employees involved in the decontamination of NRU in 1958". Atomic Energy of Canada Limited, Report AECL-7901 (1982).

4. Province of Ontario, Vital Statistics. Published annually by the Office of the Registrar General, Toronto (1944...1983).

5. International Classification of Diseases (9th revision), World Health Organization, Geneva (1977).

6. J.C. Bailar III, and F. Ederer, "Significance factors for the ratio of a Poisson variable to its expectation". Biometrics 20, 639-644 (1964).

7. J. Muller, W.C. Wheeler, J.F. Gentleman, G. Suranyi and R. Kusiak, "Study of mortality of Ontario miners". In: Occupational radiation safety in mining. H. Stocker (ed.), Canadian Nuclear Association, Toronto (1985).

8. R.C. Nair, J.D. Abbatt, G.R. Howe, H.B. Newcombe and S.E. Frost, "Mortality experience among workers in the uranium industry". In: Occupational radiation safety in mining. H. Stocker (ed.), Canadian Nuclear Association, Toronto (1985).

9. M.R. Alderson, R.J. Bayliss, C.A. Clarke and A.G. Whitefield, "Death certification". Brit. Med. J. 287, 444-445 (1983).

10. C. Percy, E. Stanek III and L. Gloeckler, "Accuracy of cancer death certificates and its effect on cancer mortality statistics". Am. J. Public Health 71, 242-250 (1981).

11. D.K. Myers and M.M. Werner, "The Atomic Energy of Canada Limited (AECL) Employee Health Study: Follow-up of long-term Chalk River employees". In: Epidemiological studies of some populations exposed to ionizing radiation, J.L. Weeks (ed.). Atomic Energy of Canada Limited, Report AECL-8360 (1985).

12. R.R. Monson, "Observations on the healthy worker effect". J. Occupational Med. 28, 425-433 (1986).

13. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). "Sources and effects of ionizing radiation". United Nations, New York, 1977.

14. National Academy of Sciences, Committee on the Biological Effects of Ionizing Radiation (BEIR), The Effects on Populations of Exposure to Low Levels of Ionizing Radiation. National Academy Press, Washington, D.C., 1980.

15. H. Kato and W.J. Schull, "Studies of the mortality of A-bomb survivors 7. Mortality, 1950-1978: Part 1. Cancer mortality". Radiat. Res. 90, 395-432 (1982).

16. E.S. Gilbert and S. Marks, "An updated analysis of mortality of workers in a nuclear facility". Radiat. Res. 83, 740-741 (1980).

17. V. Beral, H. Inskip, P. Fraser, M. Booth, D. Coleman and G. Rose, "Mortality of employees of the United Kingdom Atomic Energy Authority, 1946-1979". B. Med. J. 291, 440-447 (1985).

18. S.C. Darby, R. Doll and M. Pike, "Mortality of employees of the United Kingdom Atomic Energy Authority, 1946-79". B. Med. J. 191, 672 (1985).

19. P.G. Smith and A.J. Douglas, "Mortality of workers at the Sellafield plant of British Nuclear Fuels". B. Med. J. 293, 845-854 (1986).

20. S. Raman, C.S. Dulberg and R.A. Spasoff, "Mortality study of Canadian military personnel exposed to radiation: Atomic test blasts and Chalk River nuclear reactor clean-ups, 1950's". Department of Epidemiology and Community Medicine, Faculty of Health Sciences, University of Ottawa, Ottawa, August 1984.

21. M.E. Smith and P. Lalonde, "Mortality follow-up of Canadian servicemen involved in decontamination duties at Chalk River and observation of nuclear bomb tests". Unpublished report prepared by Statistics Canada, Ottawa for the Department of National Defence, Ottawa, June 1985.

22. G. Cowper and J.R. Johnson, "Radiation exposure records in AECL". Appendix G; Atomic Energy of Canada Limited, Report AECL-6813 (1981).

23. C.D. Robinette, S. Jahlon and T.L. Preston, "Mortality of nuclear weapons test participants". Report DOE/EV/01577, Medical follow-up Agency, National Research Council, Washington, D.C., May 1985.

24. Annual Safety Report, Atomic Energy of Canada Limited, Scientific Document Distribution Office, Atomic Energy of Canada Limited Research Company, Chalk River, Ontario K0J 1J0.

25. ICRP Publication 26. Recommendations of the International Commission on Radiological Protection, Annals of the ICRP, Vol. 1, No. 3 (1977). See also Statement from 1978 Stockholm Meeting of the ICRP (Annals of the ICRP, Vol. 2, No. 1, 1978) which clarified certain potential ambiguities in ICRP 26 by noting that, "These risk factors are intended to be realistic estimates of the effects of irradiation at low annual dose equivalents".

ISSN 0067 - 0367

To identify individual documents in the series we have assigned an AECL- number to each.

Please refer to the AECL- number when requesting additional copies of this document

from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
K0J 1J0

Price: A

ISSN 0067 - 0367

Pour identifier les rapports individuels faisant partie de cette série nous avons assigné un numéro AECL- à chacun.

Veuillez faire mention du numéro AECL- si vous demandez d'autres exemplaires de ce rapport

au

Service de Distribution des Documents Officiels
L'Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
K0J 1J0

Prix: A

313-86