AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

O

APR 24 1951

Liu et al. 1

Poisson Regression Analysis of Mortality among Male Workers at a Thorium-
Processing Plant

Zhiyuan Liu¹, Tze-San Lee^{1,2} and Thomas J. Kotek¹

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Abbreviations: CI, confidence interval; SMR, standardized mortality ratio.

¹ Environmental Health Section, Biological and Medical Research Division,
Argonne National Laboratory, Argonne, IL.

² On sabbatical leave from Department of Mathematics, Western Illinois
University, Macomb, IL.

Reprint requests to Dr. Zhiyuan Liu, Environmental Health Section, Biological
and Medical Research Division, Argonne National Laboratory, Bldg. 202-A353, 9700
South Cass Avenue, Argonne, IL 60439.

This work was supported by the U.S. Department of Energy, Office of Health and
Environmental Research, under contract No. W-31-109-ENG-38, and in part by the
U.S. Nuclear Regulatory Commission under Interagency Agreement DOE 40-550-75.

We gratefully acknowledge numerous other staff members who have contributed to
the data base on which this work is based. We are greatly indebted to Drs. John
Rundo and Bruce A. Carnes for their helpful suggestions and comments.

ABSTRACT

Analyses of mortality among a cohort of 3119 male workers employed between 1915 and 1973 at a thorium-processing plant were updated to the end of 1982. Of the whole group, 761 men were deceased and 2161 men were still alive, while 197 men were lost to follow-up. A total of 250 deaths was added to the 511 deaths observed in the previous study. The standardized mortality ratio (SMR) for all causes of death was 1.12 with 95% confidence interval (CI) of 1.05-1.21. The SMRs were also significantly increased for all malignant neoplasms (SMR = 1.23, 95% CI = 1.04-1.43) and lung cancer (SMR = 1.36, 95% CI = 1.02-1.78). Poisson regression analysis was employed to evaluate the joint effects of job classification, duration of employment, time since first employment, age and year at first employment on mortality of all malignant neoplasms and lung cancer. A comparison of internal and external analyses with the Poisson regression model was also conducted and showed no obvious difference in fitting the data on lung cancer mortality of the thorium workers. The results of the multivariate analysis showed that there was no significant effect of all the study factors on mortality due to all malignant neoplasms and lung cancer. Therefore, further study is needed for the former thorium workers.

Keywords: cancer, occupational cohort; mortality; Poisson regression analysis; radiation; thorium

Poisson Regression Analysis of Mortality among Male Workers at a Thorium-Processing Plant

Studies on health effects and body radioactivity of former thorium workers have been reported since 1979 (1-8). Thorium ores and purified thorium materials contain thorium-232, thorium-228, and varying amounts of their radioactive daughter products. The radioactive properties and biological behavior of thorium and its daughter products in man have been reviewed by Rundo (9). A study of the mortality among male workers at the thorium-processing plant through 1975-1976 has been reported (2, 6). The present report is based on an analysis of the same cohort, extending the follow-up to the end of 1982. Poisson regression analysis was used to describe the joint effects of exposure factors on mortality of all malignant neoplasms and lung cancer.

MATERIALS AND METHODS

Study population

The study population, defined in detail in previous reports (2, 6), consisted of employees of a thorium-processing plant. The plant involved in the thorium extraction was founded in 1902 and closed in 1973. The company originally manufactured incandescent mantles which required thorium nitrate as one of the raw materials. Thorium nitrate was imported from Germany in a refined state. When World War I eliminated that source of supply, the company began its own processing of monazite sand to extract thorium. As the use of incandescent mantles declined with the widening use of electricity, the company developed refining processes for rare earth chemicals. During World War II, the company furnished thorium and rare earth products to the Manhattan Project, and for several years afterward it continued to supply them to the Government.

The total number of workers identified from the company records was 4582. The cohort defined for this study was limited to all male workers who worked in

1940 or later, including those hired earlier and still employed in 1940. The year 1940 was chosen because records of employees at the company prior to 1940 were incomplete. Workers with unknown social security number and year of birth, or unmatched social security number were excluded from the cohort. The present study was limited to analyses of 3119 male workers.

Exposure data

Information on working conditions and exposure to radioactivity at the thorium-processing plant was provided by the report of an industrial hygiene survey made in 1952 (10). However, no individual dose of exposure to thorium is available for the study population. Job classification and duration of employment were used in the present analyses to provide information relevant to thorium exposure. The daily estimated exposures of 84 male employees in 1952 to thorium and thoron by job classifications were calculated from data of Klevin and Fresco (10) by Stehney et al. (2). The job classifications were divided into three groups. The first group (22 workers), including laborers and operators in the thorium extraction process, had the highest exposure to thorium (mean airborne alpha-particle activity concentration of 426 disintegrations per minute per cubic meter; α dpm/m³). The second group (34 workers) included other laborers, foremen, maintenance and repair men, and superintendents. The range of mean thorium exposure in this group was 56-120 α dpm/m³. The third group (28 workers), who had the lowest thorium exposure (6-29 α dpm/m³), included personnel in receiving, shipping, the control laboratory, offices, and others.

Vital status

The beginning and termination dates of the follow-up were January 1, 1940 and December 31, 1982, respectively. Vital status of the cohort was ascertained primarily through the Social Security Administration and supplemented by use of company records, postal questionnaires, driver's license bureaus, and contacts with former co-workers. Of the 3119 men, 761 were reported dead; 2161 were still employed or receiving payments and benefits; and 197 (6.3 percent) were lost to

follow-up. The percentage traced was much improved as compared with the previous report (6). A total of 250 deaths was added to the 511 deaths observed in the last study. All cohort members who were of unknown vital status were allowed to accumulate person-years in the study only until the date that they became unknown. Of the 761 deaths, 718 (94 percent) death certificates were obtained. Causes of death, as reported on death certificates, were coded by nosologists at the National Center for Health Statistics according to the International Classification of Diseases, Adapted for Use in the United States, Eighth Revision (11).

Statistical analysis

Person-years of follow-up were accumulated for each study subject beginning with either the year of first employment or 1940, and ending on the year of death, the date lost to follow-up, or the closing date of the study (1982). The expected number of deaths was estimated by using a computer program which, since its original publication (12), has been updated to version 88 (1988). The method of computation of expected number has been described in detail by Monson (12). In the present report, U.S. death rates for white males were used as the reference group in calculating the expected number of deaths, because racial information was unknown in the original records and there were only 6 (0.8 percent) blacks among all deaths. The standardized mortality ratio (SMR) was obtained by dividing the observed number by the expected number of deaths for each cause category. The confidence interval (CI) of the SMR was computed by using the method of Rothman and Boice (13).

Poisson regression analysis (14,15) was employed to describe the joint effects of exposure factors on mortality of all malignant neoplasms and lung cancer. This multivariate analysis can take into account all study factors simultaneously and control time-related confounders. Incorporation of external standard rates into the model leads to a regression analysis of the SMR that can help to identify situations where there is a serious problem of

"noncomparability" (16). Two types of Poisson regression models were used in the present paper. The first one is a model of an internal comparison of Poisson regression analysis, where the model equation is in the form of "Log(observed deaths) = Log(person-years) + study factors + stratification factors". The second one is a model of an external comparison of Poisson regression analysis, where the model equation is in the form of "Log(observed deaths) = Log(expected deaths) + study factors". The difference in the two models is that the first can take a direct comparison of different exposure groups without reference to the standard population. The details about the use of Poisson regression analysis have been described by Breslow and Day (14).

In the present study, Poisson regression models were fitted by using the Generalized Linear Interactive Modelling (GLIM) package (17). In the context of maximum likelihood estimation, the overall discordance between the predictions of a model and the observed data can be measured by "deviance", which is twice the difference between the log-likelihood of the present model and a completely saturated model. The deviance is distributed asymptotically as chi-square with degrees of freedom equal to the number of cells with nonzero person-years of observation minus the number of independent parameters in the model. When the value of the deviance exceeds its degrees of freedom by an amount significantly greater than expected under chi-square sampling, we conclude that the fit is inadequate.

Five study factors were selected for Poisson regression analyses, which were job classification (3 levels, as described above), duration of employment (3 levels: ≤ 1 , 2-12, and ≥ 13 months), year of first employment (2 levels: 1915-54 and 1955-73), time since first employment (3 levels: < 15 , 15-29, and ≥ 30 years), and age at first employment (3 levels: < 20 , 20-29, and ≥ 30 years old). The 162 ($3 \times 3 \times 2 \times 3 \times 3$) possible cells of this five dimensional array were classified with 133 cells having nonzero person-years. This was set up for the external analysis by using the Poisson regression model. Because the sample size of this study is

not very large, only three of these five factors, including job classification (redefined for 2 levels), duration of employment and time since first employment, were used for the internal comparison of Poisson regression analysis. The two stratification factors used in the internal analysis were age divided in 4 intervals of 10 years and calendar period at follow-up also in 4 intervals. Of 286 possible cells, 186 cells with nonzero person-years were used for the internal analysis of lung cancer. The expected deaths and person-years in each cell were calculated with Monson's program (12).

RESULTS

Numbers of deaths observed and expected and SMRs, by cause of death, are shown in table 1. The overall SMR was 1.12, which was statistically significant with 95 percent confidence interval of 1.05-1.21. The overall SMR (1.12) is greater than that (1.05) in the earlier report, which was not significant (95% CI = 0.96-1.15). The SMRs of all malignant neoplasms (1.23, 95% CI = 1.04-1.43) and lung cancer (1.36, 95% CI = 1.02-1.78) were similar to those in the earlier report, and significant in this study due to the extension of follow-up. For several other cancer sites, SMRs were greater than 1.00, but none was statistically significant. The external causes, mainly due to motor vehicle accidents, still showed a significantly increased SMR (SMR = 1.37, 95% CI = 1.13-1.65). The SMR for diseases of the circulatory system, 0.96 (95% CI = 0.86-1.07), is different from the one in the earlier report which, at 0.82 (95% CI = 0.71-0.94), was significantly less than 1.00.

Table 2 shows variations of the SMRs for all malignant neoplasms and lung cancer according to five study factors. Because 120 workers were of unknown status for job classification or duration of employment, only 2999 of 3119 men were used for this type of analysis and subsequent Poisson regression analysis. No conspicuous variations of the SMRs for all malignant neoplasms and lung cancer were observed among the workers with different jobs. The SMRs for all malignant

neoplasms and lung cancer were significantly elevated in the group of the shortest duration of employment (≤ 1 month). In the group of the longest duration of employment (≥ 13 months), the SMR for all malignant neoplasms was also significantly elevated. The results of the "time since first employment" factor showed a similar trend for the "duration of employment" factor. For the workers, whose age at first employment were 30 or older, the SMRs for all malignant neoplasms and lung cancer were both significantly increased.

Table 3 presents the deviances of main-effects Poisson regression models and the changes of the deviances due to reduction of each of the study factors from the main-effects models and addition of interaction terms. External standard rates were incorporated in the Poisson regression analysis. The results of goodness-of-fit statistics (deviance) of main-effects models for all malignant neoplasms and lung cancer suggest that the assumption of Poisson models is valid. The changes of the deviances for each of the five factors showed that no one had a significant effect on rates of all malignant neoplasms and lung cancer. Since the tests for all two-factor interactions (some of them are not shown in table 3) were not significant, the simple multiplicative models may provide a reasonable description of the data.

The regression coefficients and associated relative risks of Poisson regression models for all malignant neoplasms and lung cancer are presented in table 4. The relative risks in table 4 are exponentiated regression coefficients. The reference group for the analysis is the group of workers who worked for 1 month or less, who were first employed at age 19 or younger and before 1955, whose job classification was the third group as described before, and for whom years since first employment were less than 15. All relative risks for all malignant neoplasms and lung cancer were not statistically significant. No dose-response relationships of cancer risk with duration of employment and time since first employment were observed from the results of the Poisson regression analysis.

Table 5 presents a comparison of external and internal analyses of Poisson regression models fitted to data on lung cancer according to three study factors and two stratification factors (age and year at follow-up). The estimated coefficients for the variable "duration of employment" were more similar than those for the variables "job classification" and "time since first employment". Nevertheless, there existed no obvious difference between the relative risks estimated from the internal and external analyses. The results indicate that age at follow-up is more important than year at follow-up in fitting the model of the internal analysis in the present study.

DISCUSSION

The present report extends the follow-up of workers employed in the thorium-processing plant (2, 6), from 1975 or 1976 to December 31, 1982. A new search of the Social Security Administration records resulted in a small change in the sample size of the cohort, and intensified follow-up efforts improved the subjects' vital status ascertainment. The number of deaths identified increased from 511 to 761. Both a traditional SMR analysis and a new method of multivariate analysis (Poisson regression analysis) were employed in the present study.

SMR analysis has long been employed as a principal method of cohort studies (18,19). An advantage of the SMR analysis is that it can provide a mortality picture of the age- and time-specific observation period for any particular subgroup and may help to identify particular causes of death for further detailed analysis. However, the SMR analysis has also been recognized as having a serious problem of "noncomparability" between a study population and a reference population (20-23). The result of the SMR analysis should be interpreted with caution. However, in recent years, statistical methods of an internal comparison within a cohort and multivariate analysis have been developed for the cohort analysis (14).

In the present study, Poisson regression analysis incorporating external standard rates was principally used to describe the joint effects of the study factors on the mortality of all malignant neoplasms and lung cancer. An internal analysis of Poisson regression model was also used in order to compare the results of estimations with the external analysis. The estimated regression coefficients of the internal and external analysis in table 5 show some disagreement for the same study variables. This disagreement may be because: 1), the general U.S. male mortality rates may not apply to the study cohort; 2), residual confounding of age and calendar year may exist in the estimation of the internal analysis. Nevertheless, the relative risks calculated from the coefficients (table 5) indicate that there exists no obvious difference between the internal and external analyses. This suggests that the internal and external analyses of the Poisson regression model provide similar estimations of relative risks for the data on all malignant neoplasms and lung cancer of former thorium workers.

A number of studies on health effects in populations occupationally exposed to radiation have been published (24-27). Beral et al. (28) reviewed eight cohort studies which included the experience of 120,000 workers in the nuclear industry. They concluded that no major health hazard associated with working in the nuclear industry could be identified. In the entire workforce, overall mortality rates were below their respective national rates. Beral et al. noted that this was consistent with the relatively high social classes of the employees and the initial selection of healthy persons into the workforce.

In the present study, an increased overall mortality was observed, and no significant healthy worker effect was found. The SMRs for all causes among thorium workers were 1.05 (95% CI = 0.96-1.15) in the earlier report and 1.12 (95% CI = 1.05-1.21) in the present data. Although much of the excess mortality could be attributable to non-occupational motor vehicle accidents (SMR = 2.00, 95% CI = 1.50-2.60), SMRs were also significantly increased for all malignant

neoplasms (SMR = 1.23, 95% CI = 1.04-1.43) and lung cancer (SMR = 1.36, 95% CI = 1.02-1.78), and were increased, although not significant, for most other cancers and respiratory diseases. A mortality study among a cohort of World War II nuclear industry workers at Oak Ridge also showed significantly increased SMRs for all causes (1.11), lung cancer (1.27) and respiratory diseases (1.25) (26). In the study at the Hanford site, however, Gilbert et al (24,29) did not find the same result. In the latest study at Hanford (24), it was concluded that Hanford workers continued to exhibit a strong healthy worker effect with death rates substantially below those of the general U.S. population. However, other investigators have reported an increased risk of cancers for Hanford workers (25, 30-33). By combining data collected at a U.S. commercial nuclear power plant with records from NRC, Goldsmith et al. (34) found no evidence of excess mortality among the plant employees.

In the present study, the excess mortality for all cancers was statistically significant, and almost significant in the earlier study (SMR = 1.21, 95% CI = 0.99-1.48). The SMR for cancer of the pancreas was elevated, but not significantly (SMR = 1.47, 95% CI = 0.70-2.71). A total of 6 deaths from leukemia was observed, with 5.41 expected. The SMRs for cancers of the stomach, rectum, lung, bone, prostate, lymphosarcoma, and Hodgkin's disease were all greater than one, but none of them was statistically significant. The results of Poisson regression analysis showed that there was no significant effect of all five study factors on the mortality of all malignant neoplasms. No trend of dose-response relationships of cancer risk with duration of employment and time since first employment was observed (table 4). By combining mortality data on workers at the Hanford Site, Oak Ridge National Laboratory, and Rocky Flats Nuclear Weapons Plant, Gilbert et al. (35) found no evidence of a correlation between radiation exposure and mortality from all cancers or from leukemia. Of 11 other specific types of cancers analyzed, they found that multiple myeloma was the only cancer found to exhibit a statistically significant correlation with radiation exposure.

In the earlier evaluation of this cohort, an excess of lung cancer was observed, although it was not statistically significant (SMR = 1.44, 95% CI = 0.98-2.02). In the present data the SMR for lung cancer was 1.36 (95% CI = 1.02-1.78). However, the results of Poisson regression analysis did not show any significant effect of all five study factors on the mortality due to lung cancer. The relative risk of lung cancer was 1.30 among the workers whose job classification was laborer or operator. The workers with longer duration of employment (≥ 13 months) were shown to have a low risk of lung cancer. Internally adjusted analysis showed the same result.

Diseases of the respiratory system are of interest because of inhalation exposure at the thorium-processing plant (4). There was increased, but not statistically significant SMR from respiratory diseases in the present study. Even though the observed and expected deaths from emphysema were 13 and 7.91, respectively, there is no strong evidence for increased deaths from respiratory diseases associated with employment in this thorium-processing plant. The observed number of deaths from diseases of the respiratory system is too small to be studied by Poisson regression analysis.

In summary, this study is a second follow-up of mortality among male workers at a thorium-processing plant. The SMR analyses showed significantly increased mortality ratios for all causes (SMR = 1.12, 95% CI = 1.05-1.21), all malignant neoplasms (SMR = 1.23, 95% CI = 1.04-1.43), lung cancer (SMR = 1.36, 95% CI = 1.02-1.78), and external causes (SMR = 1.37, 95% CI = 1.13-1.65). On the other hand, Poisson regression analysis showed no significant effect on mortality of all malignant neoplasms and lung cancer from all study factors, including job classification, duration of employment and time since first employment. Therefore, a further follow-up study is needed for the former thorium workers.

REFERENCES

1. Rundo J, Polednak AP, Brues AM, et al. A study of radioactivity and health status of former thorium workers: preliminary report. *Environ Res* 1979;18:94-100.
2. Stehney AF, Polednak AP, Rundo J, et al. Health status and body radioactivity of former thorium workers. Interim Report, NUREG/CR-1420, ANL-80-37, 1980.
3. Rundo J, Brewster DR, Essling MA, et al. Radioactivity in former workers at a thorium refinery. In: *Actinides in Man and Animals*, Proc. Snowbird Actinide Workshop, 15-17 October 1979, Wrenn ME (ed.), R.D. Press, Salt Lake City, UT, 1981:261-8.
4. Mausner LF. Inhalation exposures at thorium refinery. *Health Phys* 1982; 42:231-6.
5. Conibear SA. Long term health effects of thorium compounds on exposed workers: the complete blood count. *Health Phys* 1983;44(Suppl. 1):231-7.
6. Polednak AP, Stehney AF, Lucas HF. Mortality among male workers at a thorium-processing plant. *Health Phys* 1983;44(suppl. 1):239-51.
7. Serio CS, Henning CB, Toohey RE, et al. Measurement of lymphoblastogenic activity from thorium workers. *Int J Radiat Biol* 1983;44:251-6.
8. Rundo J, Toohey RE. Long-term retention of thorium in lung: report of a case (abstract). *Health Phys* 1986;50(Suppl. 1):24.
9. Rundo J. The radioactive properties and biological behavior of ^{224}Ra (ThX) and its daughters. *Health Phys* 1978;35:13-20.
10. Klevin PB, Fresco J. Lindsay chemical company industrial hygiene survey, I. Occupational exposure to thorium dust and thoron. U.S. Atomic Energy Commission, New York Operation Office, Health and Safety Division (Jan. 21, 1953), unpublished.
11. U.S. Public Health Service. International classification of diseases Adapted for use in the United States. U.S. Public Health Service Publication 1693, 8th Rev. Washington, D.C.: U.S. Government Printing Office, 1968.

12. Monson RR. Analysis of relative survival and proportional mortality. Comput Biomed Res 1974;7:325-32.
13. Rothman KJ, Boice JD Jr. Epidemiological analysis with a programmable calculator (NIH Publication 79-1649), Washington DC, US Government Printing Office, 1979.
14. Breslow NE, Day NE. Statistical methods in cancer research II: design and analysis of cohort studies. IARC Scientific Publication No. 82, International Agency for Research on Cancer, Lyon, 1987.
15. Frome EL. The analysis of rates using Poisson regression models. Biometrics 1983;39:665-74.
16. Breslow N. Statistical Issues in the analysis of data from occupational cohort studies. Recent Results in Cancer Research 1990;120:78-93.
17. Baker RJ, Nelder JA. The generalised linear interactive modelling system: release 3.77. The Numerical Algorithms Group, Oxford, 1985.
18. Park RM, Maizlish NA, Punnett L, et al. A comparison of PMRs and SMRs as estimators of occupational mortality. Epidemiology 1991;2:49-59.
19. Saracci R, Johnson E. A note on the treatment of time in published cancer epidemiology studies. J Chronic Dis 1987;40(suppl. 2):77s-78s.
20. McMichael AJ, Spirtas R, Kupper LL. An epidemiologic study of mortality within a cohort of rubber workers, 1964-72. J Occup Med 1974;16:458-64.
21. Wen CP, Tsai SP, Gibson RL. Anatomy of the healthy worker effect: a critical review. J Occup Med 1983;25:283-9.
22. Monson RR. Observation on the healthy worker effect. J Occup Med 1986;28:425-33.
23. Carpenter LM. Some observations on the healthy worker effect. Editorial. Br J Ind Med 1987;44:289-91.
24. Gilbert ES, Petersen GR, Buchanan JA. Mortality of workers at the Hanford site: 1945-1981. Health Phys 1989;56:11-25.
25. Kneale GW, Mancuso TF, Steward AM. Identification of occupational mortality risk for Hanford workers. Br J Ind Med 1984;41:6-8.
26. Frome EL, Cragle DL, McLain RW. Poisson regression analysis of the

- mortality among a cohort of World War II nuclear industry workers. *Radiat Res* 1990;123:138-52.
27. Beral V, Inskip H, Fraser P, et al. Mortality of employees of the United Kingdom Atomic Energy Authority, 1946-1979. *Br Med J* 1985;291:440-7.
  28. Beral V, Fraser P, Booth M, et al. Epidemiological studies of workers in the nuclear industry. In: *Radiation and Health* (Jones RR and Southwood R eds.), John Wiley & Sons Ltd. New York, pp.97-106, 1987.
  29. Gilbert ES, Marks S. An analysis of the mortality of workers in a nuclear facility. *Radiat Res* 1979;79:122-48.
  30. Mancuso TF, Stewart AM, Kneale GW. Hanford I: radiation exposures of Hanford workers, dying from cancer and other causes. *Health Phys* 1977;33:369-84.
  31. Kneale GW, Mancuso TF, Stewart AM. Hanford radiation study III: a cohort study of the cancer risks from radiation to workers at Hanford (1944-77 deaths) by the method of regression models in life-tables. *Br J Ind Med* 1981;38:156-166.
  32. Kneale GW, Mancuso TF, Stewart AM. Job related mortality risks of Hanford workers and their relation to cancer effects of measured doses of external radiation. *Br J Ind Med* 1984;41:9-14.
  33. Stewart AM, Kneale GW. Mortality of Hanford workers. *Health Phys* 1990; 57:839-41.
  34. Goldsmith R, Boice JD Jr, Hrubec Z, et al. Mortality and career radiation doses for workers at a commercial nuclear power plant: feasibility study. *Health Phys* 1989;56:139-50.
  35. Gilbert ES, Fry SA, Wiggs LD, et al. Analysis of combined mortality data on workers at the Hanford Site, Oak Ridge National Laboratory, and Rocky Flats Nuclear Weapons Plant. *Radiat Res* 1989;120:19-35.

TABLE 1. Observed and expected deaths and standardized mortality ratios among 3119 male thorium workers, 1940-1982

Selected causes of death	Observed deaths	Expected deaths	SMR*	95% CI†
All causes (000-999)	761	677.22	1.12	1.05-1.21
All malignant neoplasms (140-209)	158	128.72	1.23	1.04-1.43
Buccal cavity, pharynx	4	4.07	0.98	0.26-2.52
Digestive organs, peritoneum (150-159)	42	36.79	1.14	0.82-1.54
Stomach (151)	10	7.48	1.34	0.64-2.46
Large intestine (153)	11	11.66	0.94	0.47-1.69
Rectum (154)	7	4.10	1.71	0.68-3.51
Pancreas (157)	10	6.79	1.47	0.70-2.71
Respiratory system (160-163)	56	41.26	1.36	1.03-1.76
Lung (162)	53	38.95	1.36	1.02-1.78
Bone (170)	2	0.71	2.83	0.32-10.21
Prostate (185)	11	8.94	1.23	0.61-2.20
Brain, C.N.S. (191-192)	3	4.03	0.75	0.15-2.18
Lymphosarcoma, reticulosarcoma (200)	3	2.62	1.14	0.23-3.34
Hodgkin's disease (201)	3	1.83	1.64	0.33-4.79
Leukemia, aleukemia (204-207)	6	5.41	1.11	0.40-2.41
Diseases of blood and blood-forming organs (280-289)	0	1.74		
Circulatory diseases (390-458)	325	339.47	0.96	0.86-1.07
Respiratory diseases (460-519)	45	37.71	1.19	0.87-1.60
Pneumonia (480-486)	16	14.85	1.08	0.62-1.75
Emphysema (492)	13	7.91	1.64	0.87-2.81
Asthma (493)	1	1.45	0.69	0.01-3.83
Digestive diseases (520-577)	33	32.36	1.02	0.70-1.43
Genitourinary diseases (580-629)	10	11.34	0.88	0.42-1.62
External causes (800-998)	111	81.02	1.37	1.13-1.65
All accidents (800-949)	89	56.02	1.59	1.28-1.96
Motor vehicle accidents (810-827)	55	27.56	2.00	1.50-2.60
Suicide (950-959)	13	17.53	0.74	0.39-1.27
Unknown cause	43			
Total person-years of follow-up		71,982		
Average age at entry		29.73		
Average year at entry		1956.2		

* Standardized mortality ratio (ratio of observed to expected deaths).

† 95% confidence interval of the SMR's.

TABLE 2. Standardized mortality ratios for all malignant neoplasms and lung cancer among male thorium workers according to selected study factors

Study factors	All cancers		Lung cancer	
	Deaths	SMR (95% CI)*	Deaths	SMR (95% CI)*
Job classification†				
Group 1	113	1.23(1.01-1.47)	39	1.38(0.98-1.89)
Group 2	19	1.44(0.86-2.24)	6	1.37(0.50-2.99)
Group 3	21	1.28(0.79-1.96)	5	1.12(0.36-2.62)
Duration of employment				
≤1 month	55	1.38(1.04-1.80)	22	1.80(1.13-2.73)
2-12 months	44	0.99(0.72-1.33)	15	1.10(0.62-1.81)
≥13 months	54	1.44(1.08-1.88)	13	1.16(0.62-1.99)
Year at first employment				
1915-54	115	1.27(1.05-1.53)	33	1.24(0.85-1.74)
1955-73	38	1.21(0.85-1.65)	17	1.65(0.96-2.64)
Time since first employment				
<15 years	57	1.40(1.06-1.82)	17	1.73(1.01-2.77)
15-29 years	67	1.21(0.94-1.54)	21	1.17(0.73-1.80)
≥30 years	29	1.12(0.75-1.61)	12	1.29(0.67-2.25)
Age at first employment				
<20	7	0.85(0.34-1.75)	3	1.16(0.23-3.39)
20-29	25	0.97(0.63-1.43)	7	0.81(0.33-1.67)
≥30	121	1.38(1.15-1.65)	40	1.55(1.11-2.11)
All cohort	153	1.26(1.07-1.47)	40	1.35(1.00-1.78)

* SMR = Standardized mortality ratio (ratio of observed to expected deaths);
CI = confidence interval of the SMR's.

† 1. Group 1 includes laborers and operators in the thorium extraction process;
2. Group 2 includes other laborers, foremen, maintenance and repair men, and superintendents;
3. Group 3 includes personnel of receiving, shipping, control laboratory, office, and others.

TABLE 3. Deviances of Poisson regression models fitted to the data on all malignant neoplasms and lung cancer of former thorium workers*

Model	Degree of freedom	All cancers		Lung cancer	
		Deviance	p value	Deviance	p value
Main-effects model:					
JOB+DOE+YFE+TFE+AFE	123	79.48	>0.50	41.04	>0.50
Changes form the main-effects model:					
- JOB	2	0.19	>0.50	0.39	>0.50
- DOE	2	4.12	>0.10	2.92	>0.10
- YFE	1	0.60	>0.25	0.58	>0.25
- TFE	2	0.48	>0.50	1.02	>0.50
- AFE	2	3.18	>0.10	2.84	>0.10
+ JOB*DOE	4	0.47	>0.50	3.39	>0.25
+ JOB*TFE	4	6.69	>0.10	3.67	>0.25
+ DOE*TFE	4	1.07	>0.50	0.96	>0.50

* JOB: Job classification, 3 levels;
 DOE: Duration of employment, 3 levels;
 YFE: Year at first employment, 2 levels;
 TFE: Time since first employment, 3 levels;
 AFE: Age at first employment, 3 levels.

TABLE 4. Regression coefficients and associated relative risks for the Poisson regression models fitted to the data on all malignant neoplasms and lung cancer of former thorium workers

Study factors	All cancers		Lung cancer	
	Coefficient ± S.E.	Relative risk [*]	Coefficient ± S.E.	Relative risk [*]
Job classification [†]				
Group 3	---	1.00	---	1.00
Group 2	0.105 ±0.319	1.11	0.086±0.612	1.09
Group 1	-0.0054±0.245	0.99	0.259±0.491	1.30
Duration of employment				
≤1 month	---	1.00	---	1.00
2-12 months	-0.356 ±0.204	0.70	-0.513±0.338	0.60
≥13 months	-0.0029±0.196	1.00	-0.492±0.358	0.61
Year at first employment				
1915-54	---	1.00	---	1.00
1955-73	0.155 ±0.200	1.17	-0.260±0.341	0.77
Time since first employment				
<15 years	---	1.00	---	1.00
15-29 years	-0.124 ±0.185	0.88	-0.268±0.340	0.76
≥30 years	-0.126 ±0.256	0.88	0.050±0.462	1.05
Age at first employment				
<20	---	1.00	---	1.00
20-29	0.133 ±0.424	1.14	-0.251±0.691	0.78
≥30	0.469 ±0.369	1.60	0.444±0.637	1.56

* The reference group for the analysis is the group of workers who worked for ≤1 month, who were first employed at age <20 and before 1955, whose job classification was the third group, and for whom years since first employment were <15.

† 1. Group 1 includes laborers and operators in the thorium extraction process;
2. Group 2 includes other laborers, foremen, maintenance and repair men, and superintendents;
3. Group 3 includes personnel in receiving, shipping, control laboratory, offices, and others.

TABLE 5. Comparison of internal and external analyses of Poisson regression models fitted to data on lung cancer of former thorium workers

Factors	External analysis		Internal analysis	
	Coefficient ± S.E.	Relative risk ^a	Coefficient ± S.E.	Relative risk ^a
Job classification [†]				
Group 2+3	---	1.00	---	1.00
Group 1	0.118±0.351	1.13	0.038±0.357	1.04
Duration of employment				
≤1 month	---	1.00	---	1.00
2-12 months	-0.504±0.336	0.60	-0.453±0.337	0.64
≥13 months	-0.466±0.355	0.63	-0.348±0.358	0.71
Time since first employment				
<15 years	---	1.00	---	1.00
15-29 years	-0.421±0.329	0.66	-0.194±0.381	0.82
≥30 years	-0.392±0.387	0.68	-0.126±0.470	0.88
Age at follow-up				
<45			---	
45-54			3.046±0.767	
55-64			3.982±0.756	
≥65			4.185±0.784	
Year at follow-up				
1940-49			---	
1950-59			-0.078±0.838	
1960-69			0.188±0.795	
1970-82			0.504±0.793	
Deviance (d.f.)	4.45 (12)		116.27 (174)	

* The reference group for the analysis is the group of workers who worked for ≤1 month, whose job classification was the second or third group, and for whom years since first employment were <15 years.

- † 1. Group 1 includes laborers and operators in the thorium extraction process;
 2. Group 2 includes other laborers, foremen, maintenance and repair men, and superintendents;
 3. Group 3 includes personnel of receiving, shipping, control laboratory, office, and others.

**DATE
FILMED**

7/18/94

END