Mortality among Female Workers at a Thorium-Processing Plant

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Running head: Mortality among former female thorium workers

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ABSTRACT

The mortality patterns among a cohort of 677 female workers at a thorium-processing plant are reported for the period from 1940 to 1982. Of the 677 women, 165 were reported dead; 459 were still alive; and 53 (7.8%) were lost to follow-up. The standardized mortality ratios from all causes (0.74), all cancers (0.53), and circulatory diseases (0.66) were significantly below those for the general U.S. population. In this cohort, 5 deaths due to lung cancer and 1 death from leukemia were observed, with 4.53 and 1.69 deaths expected, respectively. No deaths from cancer of the liver, pancreas, or bone were observed. Poisson regression analysis was used for an internal comparison within the cohort. The results of the Poisson regression analysis showed no significant effect on mortality rates of all causes and cancers from the study factors, including job classification, duration of employment, and time since first employment.

Key words: occupational cohort; mortality; Poisson regression; radiation; thorium; women

INTRODUCTION

Employment in a thorium-processing plant involves potential exposure to widely varying levels of thorium dust, thorium daughters and various chemicals involved in the production of compounds of thorium and of the rare earths. Inhaled thorium and thoron daughter-products can be considered as potential health hazards by analogy with known effects of radon daughters. Studies on mortality among male workers at the thorium-processing plant have been reported (Stehney et al. 1980; Polednak et al. 1983; Liu et al. 1991). In the latest analyses of the mortality among male workers, Liu et al. found excess death rates from all causes of deaths and all cancers when comparing with the general U.S. population. The mortality among female workers at the plant, however, has not been studied. The present study was conducted to describe the mortality experience of a cohort of female employees at the thorium-processing plant.

MATERIALS AND METHODS

Study Population

The study population consisted of 714 female workers employed during the years 1940 to 1973 at a thorium-processing plant in Illinois. The plant was built in 1902 and began manufacturing incandescent mantles for gas lamps with imported thorium and cerium nitrates. During World War I, the plant started its own chemical processing operation to extract thorium and rare earth chemicals from monazite ores. By 1952, the chemical business of the plant completely overshadowed the mantle production. For economic reasons, the plant was closed at the end of 1973. The female workers at the plant were indirectly exposed to the thorium productions.

Of the 714 women, 37 were excluded from the study group due to lack of social security number, hiring date and year of birth, or unmatched social security number. The present study was limited to analyses of 677 female workers. Table I shows the distribution by job group, year of first employment, and duration of employment. Among the women, 471 (69.6%) were employed in the production of mantles and 100 (14.8%) were chemists or laboratory technicians. The majority (68.4%) of the cohort were first employed between 1940 and 1949. The average length of employment was 19.7 months for the 608 women with known hiring and ending dates. There were 185 women employed by the plant for one month or less; 242 women for more than one month but less than one year; and 181 women for one year or more. The durations of employment of the remaining 69 women were unknown.

Vital Status

The vital status of the cohort was ascertained primarily through the Social Security Administration. Of the 677 women, 165 were reported dead; 459 were still employed elsewhere or were receiving payments or benefits; and 53 (7.8%) were lost to follow-up. All cohort members who were lost to follow-up were allowed to accumulate person-years in the study only until the date that their

status became unknown. The beginning and termination dates of the follow-up in this study were January 1, 1940 and December 31, 1982, respectively. Of the 165 deaths, 146 (88.5%) 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 (U.S. Public Health Service 1968).

Statistical Analysis

Person-years of follow-up were accumulated for each study subject beginning with either 1940 or the year of first employment and ending on the year of death, the date lost to follow-up, or the closing date of the study (1982). Expected numbers of deaths were estimated using a computer program which, since its original publication (Monson 1974), has been updated to version 88 (1988). The method of computation of expected numbers has been described in detail by Monson (1974). In the present study, U.S. death rates for white females were used as the reference group to calculate expected numbers of deaths. Racial information in the original records was unknown, but all the women known to be dead were white. Thus, use of U.S. death rates for white females appeared justified. 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 (1979).

An internally adjusted method of Poisson regression analysis (Breslow and Day, 1987) was employed to describe the joint effects of exposure factors on mortality of all causes and cancers. This multivariate analysis can take into account all study factors simultaneously and control time-related confounders. The Poisson regression model of the internal analysis is in the form of "log(observed deaths) = log(person-years) + study factors". Three study factors were selected for the Poisson regression analysis, which were job classification

(2 levels: 1, workers in the production of mantles, and 2, all others), duration of employment (3 levels: ≤1, 2-12, and ≥13 months), and time since first employment (3 levels: <20, 20-29, and ≥30 years). Age and year at follow-up were adjusted in the internal analysis, where age was divided into 4 intervals (<45, 45-54, 55-64, and ≥65 years old) and year in 3 intervals (1940-54, 1955-69, and 1970-82). The 216 (2*3*3*4*3) possible cells of this five dimensional array were classified, with 123 cells having nonzero person-years. In the present study, Poisson regression models were fitted by using the Generalized Linear Interactive Modelling (GLIM) package (Baker and Nelder, 1985). The goodness of fit of the model was evaluated by the log likelihood ratio statistic (deviance).

RESULTS

Numbers of observed and expected deaths and SMRs for the total cohort are shown in Table II. For the 19 women who died but for whom a death certificate could not be obtained, deaths were counted only under mortality for all causes. Thus, cause-specific SMRs in Table II were slightly understated and should probably be multiplied by a factor of 165/146, or 1.13. The overall SMR for the total cohort was 0.74, which was statistically significant with 95% CI of 0.63-0.86. The SMRs for all cancers and circulatory diseases were also significantly below 1.00. There were slight, but not significant, excesses of observed over expected deaths from lung cancer and digestive diseases. It should be noted that observed numbers of deaths from some causes were too small for a meaningful analysis.

Table III shows observed and expected deaths and SMRs among the cohort of 677 female thorium workers according to the year of first employment. Two groups of workers, first employed in 1922-1944 and 1945-1973, were selected. The SMRs for all causes, all cancers, and circulatory diseases were significantly less than 1.00 in the earlier (1922-1944) employment group. In the later employment group, only the SMR for all cancers was significantly below 1.00. There was an excess, but not a significant one, of deaths from lung cancer in the earlier employment group.

Table IV presents observed and expected deaths and SMRs according to the job group. The SMRs for all causes and circulatory diseases were similar in the two groups. The SMRs for all cancers in both groups were significantly less than 1.00. The expected number of deaths among 100 chemists and laboratory technicians was also computed. In this group, 5 deaths from all causes were observed, with 16.31 deaths expected, and no cancer death was observed, with 3.97 cancer deaths expected.

Table V presents observed deaths and SMRs among the 608 women according to

the duration of employment. Because of unknown duration of employment, 69 women were excluded from the analysis. In the first two groups (≤1 month and 2-12 months), the SMRs from all causes were similar and significantly less than 1.00. In the third group (≥13 months), the SMR from all causes was 0.97. The SMRs from all cancers and circulatory diseases showed the same trend among those from all causes in the three groups. However, there was no strong evidence for any kind of dose-response relationship between the duration of employment and the mortality ratios.

Table VI presents observed deaths and SMRs among the 608 women according to time since first employment. Among the 608 women, 383 (63%) women lived for 30 years or longer since first employment at the thorium-processing plant. The SMRs for all causes, cancers, and circulatory diseases were all significantly less than 1.00 and showed a strong heathy worker effect.

Table VII presents the results of Poisson regression analyses, adjusting for age and year at follow-up. The relative risks in Table VII are exponentiated regression coefficients. The reference group for the analysis is the group of workers who worked for one month or less, whose job classification was the second group (other than the workers employed in the production of mantles), and for whom time since first employment was less than 15 years. The tests of deviance for each of the three study factors showed that none had a significant effect on mortality rates of all causes and cancers. All relative risks for all causes and cancers in Table VII are greater than 1.00, but none are statistically significant. A trend of dose-response relationships of cancer risk with duration of employment and time since first employment was observed, but was also not significant.

DISCUSSION

SMR analysis has long been employed as a principal method of cohort studies (Park et al. 1991; Saracci and Johnson 1987). 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, it has also been recognized that the SMR analysis may have a serious problem of "noncomparability" between a study population and a reference population (McMichael et al. 1974; Wen et al. 1983; Monson 1986; Carpenter 1987). The result of the SMR analysis should be interpreted with caution. However, in recent years, statistical methods for an internal comparison within a cohort and multivariate analysis have been developed for the cohort analysis (Breslow and Day, 1987). Both SMR and Poisson regression analyses were used in the present study.

Analyses of the cohort showed little evidence of adverse health effects. The SMRs from all causes (0.74), all cancers (0.53), and circulatory diseases (0.66) were significantly below those for the general U.S. female population. These low SMRs probably resulted from factors related to the healthy worker effect, and were generally consistent with results reported in other studies of workers who have been exposed occupationally to low levels of external radiation (Beral et al. 1985, 1987; Gilbert et al. 1989a, 1989b; Wilkinson et al. 1987; Goldsmith et al. 1989). The multivariate Poisson regression analysis in the present study found no significant effect of all study factors on mortality rates of all causes and cancers.

Nevertheless, the results of this study on female workers are different from those on male thorium workers at the same plant (Liu et al. 1991). The analyses of male workers showed significantly elevated SMRs for all causes (1.12) and all cancers (1.23). In the present study, a strong healthy worker effect was

observed among female workers. Gilbert et al. (1989a) observed similar results for female workers at the Hanford site, and so did Smith and Douglas (1986) at the Sellafield plant of British Nuclear Fuels. The contrasting results between male and female workers at the thorium-processing plant might be due to potentially greater thorium exposure of male workers than of female workers. Most of the male workers (78.1%) were employed as laborers and operators in the thorium extraction process, which has been known to result in high exposure to thorium (Stehney et al. 1980). The majority of the females (69.6%) were, however, involved in the production of incandescent gas mantles. The exposure to thorium involved in mantle production is unknown, but was probably small (Evans and Goodman 1940).

In the cohort of the present study, no deaths from cancer of the liver, pancreas, or bone were observed. For all cancers, only lung cancer showed a slightly increased SMR, but this was not significant. The average duration of employment for the 5 women who died of lung cancer was five months. None of these women was employed for more than one year. There was no suggestion of a relationship between duration of employment and lung cancer. Stebbings et al. (1984) conducted a mortality analysis among a cohort of female radium dial workers employed before 1930. They concluded that liver, pancreatic, cervical, and uterine cancers were clearly unrelated to radium exposure; lung cancer required further investigation.

In summary, this study was conducted to describe the mortality experience of a cohort of 677 female employees at a thorium-processing plant. The female workers exhibited a strong healthy worker effect, having death rates substantially below those of the general U.S. population. An internal comparison by using Poisson regression analysis found no significant effect on mortality rates of all causes and cancers from all study factors, including job classification, duration of employment, and time since first employment.

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TABLE I. Distribution of 677 Female Thorium Workers by Job Group, Duration of Employment, and Year of First Employment

	Job group				
	Mantle	Technical	Office	Other	Total
Year of first employment					
1922-39	31	2	1	0	34
1940-49	419	20	6	18	463
1950-59	21	42	19	11	93
1960-73	0	36	48	3	87
Months of employment					
≤1	158	15	5	7	185
2-12	171	43	22	6	242
≥13	101	36	43	1	181
unknown	41	6	4	18	69
Total	471	100	74	32	677

TABLE II. Observed and Expected Deaths and Standardized Mortality Ratios among 677 Female Thorium Workers, 1940-1982

Selected causes of death	Observed deaths	Expected deaths	SMR[a]	95% CI[b]
All causes (000-999)	165	224.21	0.74	0.63-0.86
All infective and parasitic (000-139)	2	2.90	0.69	0.08-2.49
All malignant neoplasms (140-209)	26	48.89	0.53	0.35-0.78
Digestive organs, peritoneum (150-159)	3	14.15	0.21	0.04-0.62
Liver (155-156)	0	1.46		
Pancreas (157)	0	2.31		
Respiratory system (160-163)	5	4.71	1.05	0.34-2.46
Lung (162)	5	4.53	1.10	0.36-2.58
Bone (170)	0	0.21		
Breast (174)	5	10.04	0.50	0.16-1.16
Uterus (180-182)	3	4.53	0.66	0.13-1.94
Genital organs (180-184)	6	8.01	0.75	0.27-1.63
Leukemia, aleukemia (204-207)	1	1.69	0.59	0.01-3.29
Diseases of blood and blood-forming organs (280-289)	0	0.81		
Circulatory diseases (390-458)	82	123.89	0.66	0.53-0.82
Respiratory diseases (460-519)	7	10.36	0.68	0.27-1.39
Digestive diseases (520-577)	9	8.59	1.05	0.48-1.99
External causes (800-998)	8	9.47	0.84	0.36-1.66
Unknown cause	19			
Total person-years of follow-up		21,468		
Average age at entry		31.83		
Average year at entry		1947.8		

[a] Standardized mortality ratio (ratio of observed to expected deaths)

[b] 95% confidence interval of the SMRs

TABLE III. Observed and Expected Deaths and Standardized Mortality Ratios among 677 Female Thorium Workers according to the Year of First Employment, 1940-1982

Selected causes of deaths	1922-1944 (N=362) Observed deaths	Expected deaths	SMR[a]	95% CI[b]	1945-1973 (N=315) Observed deaths	Expected deaths	SMR	95% CI
All causes	107	152.99	0.70	0.57-0.85	58	71.22	0.81	0.62-1.05
All malignant neoplasms	21	32.45	0.65	0.40-0.99	5	16.44	0.30	0.10-0.71
Digestive organs	3	9.61	0.31	0.06-0.91	0	4.54		
Lung	4	2.89	1.39	0.37-3.55	1	1.64	0.61	0.01-3.39
Breast	5	6.55	0.76	0.25-1.78	0	3.49		
Uterus	1	3.08	0.32	0.00-1.80	2	1.45	1.38	0.16-4.99
Genital organs	4	5.37	0.74	0.20-1.91	2	2.63	0.76	0.09-2.74
Circulatory diseases	53	85.71	0.62	0.46-0.81	29	38.18	0.76	0.51-1.09
Respiratory diseases	4	7.11	0.56	0.15-1.44	3	3.26	0.92	0.19-2.69
Digestive diseases	4	5.77	0.69	0.19.1.77	5	2.82	1.77	0.57-4.14
External causes	3	6.00	0.50	0.10-1.46	5	3.48	1.44	0.46-3.36
Unknown cause	13				14			

[a] Standardized mortality ratio (ratio of observed to expected deaths)

[b] 95% confidence interval of the SMRs

TABLE IV. Observed and Expected Deaths and Standardized Mortality Ratios among 677 Female Thorium Workers according to the Job Group, 1940-1982

Selected causes of deaths	Mantle[a] (N=471) Observed deaths	Expected deaths	SMR[c]	95% CI[d]	Others[b] (N=206) Observed deaths	Expected deaths	SMR	95% CI
All causes	141	192.24	0.73	0.62-0.87	24	31.97	0.75	0.48-1.12
All malignant neoplasms	24	40.80	0.59	0.38-0.88	2	8.09	0.25	0.03-0.89
Digestive organs	3	12.11	0.25	0.05-0.72	0	2.04		
Lung	4	3.62	1.10	0.30-2.83	1	0.90	1.11	0.01-6.17
Breast	5	8.22	0.61	0.20-1.42	0	1.81		
Uterus	3	3.84	0.78	0.16-2.28	0	0.69		
Genital organs	6	6.71	0.89	0.33-1.95	0	1.30		
Circulatory diseases	70	108.05	0.65	0.51-0.82	12	15.84	0.76	0.39-1.32
Respiratory diseases	4	8.88	0.45	0.12-1.15	3	1.48	2.03	0.41-5.92
Digestive diseases	8	7.22	1.11	0.48-2.18	1	1.37	0.73	0.01-4.05
External causes	5	7.58	0.66	0.21-1.54	3	1.90	1.58	0.32-4.62
Unknown cause	18				1			

[a] Employed in the production of mantles

[b] Included technical, office and other personnel

[c] Standardized mortality ratio (ratio of observed to expected deaths)

[d] 95% confidence interval of the SMRs

TABLE V. Observed Deaths and Standardized Mortality Ratios among 608 Female Thorium Workers according to the Duration of Employment, 1940-1982

Selected causes of deaths	≤1 month (N=185)		2-12 months (N=242)		≥13 months (N=181)	
	Observed deaths	SMR[a]	Observed deaths	SMR	Observed deaths	SMR
All causes	52	0.60**	55	0.69**	39	0.97
All malignant neoplasms	7	0.42*	9	0.53	8	0.74
Digestive organs	1	0.19	2	0.40	0	(2.77)[b]
Lung	0	(1.38)	5	3.20	0	(1.14)
Breast	2	0.62	0	(3.48)	3	1.26
Uterus	1	0.65	1	0.64	0	(1.01)
Genital organs	2	0.75	1	0.36	2	1.09
Circulatory diseases	29	0.57*	26	0.59*	19	0.99
Respiratory diseases	1	0.25	5	1.35	1	0.56
Digestive diseases	4	1.33	4	1.32	0	(1.81)
External causes	1	0.32	1	0.30	2	0.95
Unknown cause	4		7		6	

* $p<0.05$; ** $p<0.01$

[a] Standardized mortality ratio (ratio of observed to expected deaths)

[b] Where the observed number of deaths is zero, the expected number is given in parentheses instead of the SMR.

TABLE VI. Observed Deaths and Standardized Mortality Ratios among 608 Female Thorium Workers according to the Time since First Employment, 1940-1982

Selected causes of deaths	<15 years (N=608)		15-29 years (N=563)		≥30 years (N=383)	
	Observed deaths	SMR[a]	Observed deaths	SMR	Observed deaths	SMR
All causes	22	0.53**	66	0.73*	58	0.78
All malignant neoplasms	6	0.57	9	0.48*	9	0.59
Digestive organs	1	0.33	0	(5.63)[b]	2	0.47
Lung	0	(0.51)	3	2.01	2	0.96
Breast	1	0.45	2	0.51	2	0.69
Uterus	2	1.27	0	(1.72)	0	(0.83)
Genital organs	4	1.71	0	(3.08)	1	0.54
Circulatory diseases	7	0.39*	42	0.81	25	0.57**
Respiratory diseases	1	0.70	4	1.03	2	0.47
Digestive diseases	2	0.98	4	1.22	2	0.79
External causes	1	0.35	3	0.80	0	(2.06)
Unknown cause	1		1		15	

* $p<0.05$; ** $p<0.01$

[a] Standardized mortality ratio (ratio of observed to expected deaths)

[b] Where the observed number of deaths is zero, the expected number is given in parentheses instead of the SMR.

TABLE VII. Regression coefficients and associated relative risks for Poisson regression models fitted to data on former female thorium workers

Factors	All causes		All cancers	
	Coefficient ± S.E.	Relative risk*	Coefficient ± S.E.	Relative risk*
Job classification†				
Group 2	---	1.00	---	1.00
Group 1	0.340±0.312	1.40	0.392±0.815	1.48
Duration of employment				
≤1 month	---	1.00	---	1.00
2-12 months	0.041±0.194	1.04	0.183±0.505	1.20
≥13 months	0.273±0.221	1.31	0.599±0.533	1.82
Time since first employment				
<15 years	---	1.00	---	1.00
15-29 years	0.527±0.419	1.69	0.780±1.086	2.18
≥30 years	0.499±0.486	1.65	1.466±1.359	4.33
Deviance (d.f.)	107.4 (112)		49.85 (112)	

* 1. Adjusted for age (<45, 45-54, 55-64, and ≥65) and year (1940-54, 1955-69, and 1970-82) at follow-up.

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

† 1. Group 1 includes the workers employed in the production of mantles;

2. Group 2 includes all other workers.