MORTALITY AMONG WORKERS AT THE SAVANNAH RIVER NUCLEAR FUELS PRODUCTION FACILITY

Donna L. Cragle and Janice P. Watkins, Center for Epidemiologic Research;
Kathryn Robertson-DeMers, Bechtel Hanford, Inc.
Donna Cragle, Oak Ridge Associated Universities, P.O. Box 117, Oak Ridge, TN 37831-0117

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INTRODUCTION

Since 1952 the Savannah River Site (SRS), located in Aiken, South Carolina, has operated as a Department of Energy (DOE) production facility for nuclear fuels and other materials. A previous study[1] through 1980 of 9,860 white males employed at least 90 consecutive days at the SRS between 1952 and 1974 found an increased number of leukemia deaths among hourly employees compared to expected numbers from the U.S. white males (13 observed versus 7.95 expected). The current investigation of the same cohort included six additional years of follow-up and radiation dosimetry data for 99% of the cohort.

METHODS

Vital status was ascertained through 1986 using a combination of sources including the Social Security Administration, Pension Benefits Incorporated, and the National Death Index. Death certificates were coded to the eighth revision of the International Classification of Diseases, Adapted for Use in the United States.

Radiation monitoring files provided by the plant included yearly and accumulated shallow dose equivalent, deep dose equivalent, tritium-effective dose equivalent, and neutron dose equivalent. Of the 9,860 cohort members, 9,757 had external radiation doses available from 1943 to 1986. External doses obtained at other DOE facilities were included in calculating the annual dose estimates.

Standardized Mortality Ratios (SMRs) were stratified by paycode as a surrogate for socioeconomic status. Person-years were calculated from the hire date plus 90 days. Dose response analysis consisted of both trend tests and Poisson regression using time-dependent cumulative external dose stratified into nine groups with mSv ranges as follows: 0, >0 -, 5 -, 10 -, 20-, ..., 160 -, 320 or greater. The person-years weighted mean dose in each cell was used in analysis, which approximated modeling dose as continuous. Poisson trend tests[2] stratified by age, calendar period, and paycode for 14 selected cancer causes of death used radiation doses lagged ten years (two years for leukemia) to screen for possible dose-response relationships. Dose-response analysis for leukemia excluded chronic lymphocytic leukemia (CCL) and included two cases where leukemia was the non-underlying cause of death. Poisson regression modeling based on maximum likelihood methods produced parameter estimates based on an excess relative risk (ERR) model in which relative risk has the form $1 + \beta x$, with β the change in ERR per Sv. The regression used an internal comparison group of unexposed workers at the reference level of all possible confounders included, which were calendar period (before 1970, 1970-79, 1980-86), paycode (hourly, salaried), and age (natural log of age/52.5). Confidence intervals were likelihood based.

RESULTS

We obtained and coded death certificates for 1,686 (97.9 %) of the 1,722 deaths ascertained (17.5 % of the cohort) with 376 occurring among the 2,561 salaried workers (14.7 %) and 1,346 occurring among the 7,299 non-salaried workers (18.4 %). Table 1 shows that few SMRs are greater than one and at the five-percent significance level none were significantly elevated. There were significant deficits in several categories, including: all causes, all cancers, cancer of the digestive organs and peritoneum (salaried only), lung cancer (salaried only), brain cancer (hourly only), all diseases of the circulatory system, arteriosclerotic heart disease, all respiratory diseases, all diseases of the digestive system, and all external causes of death (salaried only). Both salaried and non-salaried groups exhibited a slight, but not statistically significant, increase in deaths attributable to leukemia.

Total population dose with no lag was 399 Sv with the mean, median, and maximum final cumulative doses 40.5, 7.4, and 475.6 mSv, respectively. The skewed distribution is due to many doses being zero. For a two-year lag the mean and median drop to 40 and 7.2, and for a ten-year lag they drop to 35.8 and 6.1.

Table 2 presents trend test statistics for selected cancers, and observed and expected deaths by external dose group. Only leukemia results indicate a trend of rising mortality with increasing radiation dose. This trend is significant for the ten-year lag and the two-year lag with nonunderlying causes of death included; one occurred in the 0-5 mSv category and the other in the 80-160 mSv category.

The parameter estimate for increased risk per Sievert for leukemia mortality was 13.61 [90% confidence interval (0.61,50.62)]. The likelihood ratio test statistic, which is the differences in the deviance of the models with and without dose, was 3.64 and may be compared for statistical significance to a chi-square distribution with one degree of freedom whose 90th percentile is 2.71 and 95th percentile is 3.84.

DISCUSSION

Studies of two other cohorts of workers in the radiation industry have found increases in the rate of leukemia when compared to standard national populations but did not identify a significant dose-response relationship between leukemia and dose.[3,9] Other studies[5,7,8,12] found no increase in leukemia deaths but did identify a significant dose-response when controlling for age, calendar period and the exclusion of chronic lymphocytic leukemia. However, recent analyses of the Hanford population[6] do not indicate increased risks.

Table 3 presents characteristics reported in recently published studies of populations occupationally exposed to ionizing. Generally, the five studies[5,7,8,12] (including the present study) that show positive dose-response relationships for leukemia are those that have the highest average cumulative dose per radiation worker. There does not appear to be a similar relationship between positive risk estimates for cancer and average cumulative dose. Comparison of ERR estimates for these populations show the estimate for SRS (13.61 per Sv) is commensurate with the estimates derived for the Atomic Energy of Canada[12] (19.0 per Sv) and Sellafield[9](13.92 per Sv) populations. The SRS estimate is much higher than those for the International Combined population[10] (2.18 per Sv) and the A-bomb survivors[12] (3.67 per Sv). Highest estimates are based on the fewest number of deaths while lowest estimates are based on the most deaths. Confidence intervals for all estimates overlap. Since leukemia is a relatively rare disease, there will be few deaths in small population studies, leading to uncertainty in the risk estimates.

Modeling of prostate cancers was not attempted because the dose distribution among the individuals who died with prostate cancer or who were known to have prostate cancer but actually died of another cause, revealed that 19 of the 22 individuals had a total cumulative dose of less than 20 mSv. With additional years of follow-up, examination of the prostate cancers with respect to radiation exposure, particularly tritium, should be undertaken, particularly in light of findings in Atomic Weapons Establishment[9] workers and the potential for exposure to tritium at the Savannah River Site.

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TABLE 1. SMRS FOR SALARIED AND HOURLY WORKERS

CAUSE OF DEATH	Salaried (N=2,561) OBS	SMR	95% CI	Hourly (N=7,299) OBS	SMR	95% CI
All causes (001-998)	376	0.60	(0.54,0.67)	1,346	0.85	(0.80,0.90)
All cancers (140-209)	102	0.71	(0.58,0.87)	311	0.86	(0.76,0.96)
Cancer of buccal cavity and pharynx (140-149)	3	0.69	(0.14,2.01)	11	0.97	(0.48,1.74)
Cancer of digestive organs, peritoneum (150-159)	22	0.62	(0.39,0.94)	72	0.82	(0.64,1.04)
Cancer of stomach (151)	3	0.54	(0.11,1.58)	11	0.82	(0.41,1.46)
Cancer of large intestine (153)	9	0.74	(0.34,1.40)	27	0.90	(0.60,1.32)
Cancer of rectum (154)	1	0.30	(0.00,1.65)	5	0.61	(0.20,1.43)
Cancer of pancreas (157)	5	0.68	(0.22,1.59)	19	1.04	(0.62,1.62)
Cancer of respiratory system (160-163)	32	0.59	(0.40,0.83)	144	1.03	(0.87,1.22)
Cancer of lung (162)	31	0.60	(0.41,0.85)	144	1.08	(0.91,1.28)
Cancer of skin (172-173)	4	1.26	(0.34,3.24)	8	0.90	(0.39,1.77)
Cancer of prostate (185)	9	1.27	(0.58,2.41)	9	0.64	(0.29,1.21)
Cancer of bladder (188)	4	1.24	(0.33,3.18)	6	0.85	(0.31,1.85)
Cancer of brain and other CNS (191-192)	6	1.22	(0.45,2.66)	5	0.36	(0.12,0.84)
Leukemia and aleukemia (204-207)	6	1.10	(0.40,2.40)	19	1.34	(0.80,2.09)
Other lymphatic tissue (202, 203, 208)	6	1.34	(0.49,2.93)	12	1.05	(0.54,1.84)
All lymphopoietic cancer (200-209)	14	0.98	(0.54,1.64)	34	0.90	(0.62,1.25)
Benign neoplasms (210-239)	1	0.54	(0.01,3.01)	6	1.22	(0.45,2.66)
All diseases of circulatory system (390-458)	180	0.62	(0.53,0.72)	627	0.89	(0.82,0.97)
All respiratory diseases (460-519)	15	0.42	(0.23,0.69)	45	0.55	(0.40,0.74)
All diseases of digestive system (520-577)	13	0.40	(0.21,0.69)	50	0.57	(0.42,0.75)
Cirrhosis of liver (571)	7	0.35	(0.14,0.73)	34	0.60	(0.42,0.84)
All external causes of death (800-998)	32	0.45	(0.30,0.63)	197	0.90	(0.78,1.04)

TABLE 2. TREND TEST STATISTICS FOR SPECIFIC TYPES OF CANCER

CAUSE OF DEATH	TT[2]	Observed and Expected[1] Deaths by Dose Category in mSv (obs/exp)								
		0	>0-5	5-	10-	20-	40-	80-	160-	≥320
Doses Lagged 10 Years										
Esophagus	0.92	3/2.06	2/1.18	0/0.43	0/0.32	0/0.30	0/0.28	0/0.29	0/0.13	0/0.01
Stomach	0.35	2/1.89	4/4.83	2/1.68	3/1.36	0/1.33	2/1.26	1/1.03	0/0.60	0/0.03
Colon	0.09	7/6.14	15/13.8	5/4.79	6/3.29	1/3.36	1/3.55	2/3.32	3/1.68	0/0.10
Rectum	0.60	3/1.26	1/1.89	0/0.61	0/0.54	2/0.52	0/0.57	0/0.50	0/0.10	0/0.01
Pancreas	0.16	5/4.98	7/8.87	5/2.42	3/2.03	0/2.20	1/1.96	3/1.66	1/0.84	0/0.04
Lung	1.28	31/29.6	62/63.4	30/23.7	19/16.2	15/16.1	9/17.03	19/15.5	5/8.07	0/0.44
Bone	0.26	1/1.39	1/1.53	2/0.54	0/0.34	0/0.26	1/0.32	0/0.34	0/0.24	0/0.03
Prostate	0.77	2/2.17	10/8.97	4/2.87	3/2.80	0/1.90	2/1.53	1/1.23	0/0.51	0/0.02
Bladder	0.00	2/2.22	5/4.56	1/1.73	0/1.23	2/0.75	1/0.73	1/0.53	0/0.22	0/0.03
Kidney	0.01	1/0.96	1/2.38	1/0.78	0/0.50	2/0.44	1/0.39	0/0.36	0/0.19	0/0.01
Non-Hodgkins lymphoma	0.38	4/2.30	2/3.84	1/1.29	0/0.88	1/0.87	2/0.77	0/0.67	1/0.36	0/0.02
Multiple myeloma	0.04	1/0.50	2/1.93	1/0.70	0/0.59	0/0.50	0/0.36	1/0.31	0/0.10	0/0.00
Doses Lagged 2 Years										
Leukemia excluding CLL	2.47	1/2.33	6/6.12	1/2.19	2/1.68	2/1.62	2/1.61	2/1.47	1/0.90	1/0.09
Leukemia excluding CCL, nonunderlying cause included	3.86	1/2.60	7/6.62	1/2.43	2/1.81	2/1.78	2/1.79	3/1.73	1/1.12	1/0.11

[1]Expected deaths calculated based on person-years distribution of age, calendar year, and paycode of entire cohort such that observed = expected.
[2]Trend test statistic calculated using average dose per cell, stratified by 15 age groups, 8 time periods, and 2 paycodes. Maybe compared to a Chi-square distribution with one degree of freedom (95^{th} percentile = 3.84; 90^{th} percentile = 2.71)

TABLE 3. CHARACTERISTICS OF RECENTLY PUBLISHED STUDIES OF OCCUPATIONALLY-EXPOSED POPULATIONS

	1	2	3	4	5	6	7	8	9	10
Number of study subjects	95,217	8,318	14,327	39,546	22,552	75,006	44,154	8,977	95,673	9,860
Population dose (Sv)	3,198	144	1,259	660	73	2,303	861	135	3,843	399
Leukemia Dose-response?	Yes	No	Yes	No	No	Yes	No	Yes	Yes	Yes
Mean dose (mSv) for all workers/ radiation workers only	33.6/ 71.9	17.3/ 23.2	87.9/ 124.0	16.7/ 34.4	3.3/ 7.8	30.7/ 56.5	19.5/ 23.3	15.0/ 52.1	40.2/ 45.4	40.5/ 46.2

[1] National Registry of Radiation workers (1992)
[2] Oak Ridge National Laboratory (1991)
[3] Sellafield (1994)
[4] U.K. Atomic Energy Authority (1993)
[5] Atomic Weapons Establishment (1988)
[6] U.K. Nuclear Industry (1994)
[7] Hanford (1993)
[8] Atomic Energy of Canada (1993)
[9] International Combined (1995)
[10] Current Study

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