Mortality of Older Construction and Craft Workers Employed at Department of Energy (DOE) Nuclear Sites

John M. Dement, PhD, CIH,[1*] Knut Ringen, Dr. PH, MHA, MPH,[2] Laura S. Welch, MD,[3] Eula Bingham, PhD,[4] and Patricia Quinn, BA[3]

Background *The U.S. Department of Energy (DOE) established medical screening programs at the Hanford Nuclear Reservation, Oak Ridge Reservation, the Savannah River Site, and the Amchitka site starting in 1996. Workers participating in these programs have been followed to determine their vital status and mortality experience through December 31, 2004.*

Methods *A cohort of 8,976 former construction workers from Hanford, Savannah River, Oak Ridge, and Amchitka was followed using the National Death Index through December 31, 2004, to ascertain vital status and causes of death. Cause-specific standardized mortality ratios (SMRs) were calculated based on US death rates.*

Results *Six hundred and seventy-four deaths occurred in this cohort and overall mortality was slightly less than expected (SMR = 0.93, 95% CI = 0.86–1.01), indicating a "healthy worker effect." However, significantly excess mortality was observed for all cancers (SMR = 1.28, 95% CI = 1.13–1.45), lung cancer (SMR = 1.54, 95% CI = 1.24–1.87), mesothelioma (SMR = 5.93, 95% CI = 2.56–11.68), and asbestosis (SMR = 33.89, 95% CI = 18.03–57.95). Non-Hodgkin's lymphoma was in excess at Oak Ridge and multiple myeloma was in excess at Hanford. Chronic obstructive pulmonary disease (COPD) was significantly elevated among workers at the Savannah River Site (SMR = 1.92, 95% CI = 1.02–3.29).*

Conclusions *DOE construction workers at these four sites were found to have significantly excess risk for combined cancer sites included in the Department of Labor' Energy Employees Occupational Illness Compensation Program (EEOCIPA). Asbestos-related cancers were significantly elevated.* Am. J. Ind. Med. 52:671–682, 2009.

KEY WORDS: DOE; Amchitka; Hanford; Oak Ridge; Savannah River; construction; trades; mortality; cancer; surveillance

[1]Division of Occupational and Environmental Medicine, Duke University Medical Center, Durham, North Carolina
[2]Stoneturn Consultants, Seattle, Washington
[3]The Center for Construction Research and Training (CPWR), Silver Spring, Maryland
[4]Department of Environmental Health, University of Cincinnati Medical Center, Cincinnati, Ohio
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*Correspondence to: John M. Dement, Division of Occupational and Environmental Medicine, Department of Community and Family Medicine, Duke University Medical Center, 2200 West Main Street, Suite 400, Durham, NC 27710. E-mail: john.dement@duke.edu

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BACKGROUND

In 1993, Congress added Section 3162 to the Defense Authorization Act, calling for the Department of Energy (DOE) to determine whether workers within the nuclear weapons facilities were at significant risk for work-related illnesses and if so, to provide them with medical surveillance. In 1996 and 1997, DOE established surveillance programs for construction workers at the Hanford Nuclear Reservation in Richland, Washington, the Oak Ridge Reservation in Oak Ridge, Tennessee, the Savannah River Site (SRS) in Aiken, South Carolina, and the Amchitka site in Alaska. Surveillance programs for multiple sites have been consolidated to form the Building Trades National Medical Screening Program. These construction worker programs are conducted by a consortium from the CPWR: The Center for Construction Research and Training (CPWR; formerly The Center to Protect Workers' Rights); the University of Cincinnati; Duke University; and Zenith Administrators. We have previously reported on the prevalence of respiratory diseases, hearing loss, and beryllium sensitivity among workers at these sites [Dement et al., 2003a, 2005; Welch et al., 2004].

Construction trade workers employed at nuclear weapons facilities have potential exposures to a number of hazards, including known carcinogenic agents, during facility construction, maintenance, and renovation. In addition to external and internal radiation exposures, construction and trade workers are exposed to asbestos, silica, solvents, metals, and welding/cutting gases and fumes while conducting work tasks or while in the vicinity of other crafts. While several studies have investigated mortality risks among DOE production workers, little data exist concerning mortality among construction and trade workers. This study investigated mortality among construction and trade workers who participated in the screening programs at Hanford, Oak Ridge, Savannah River, and Amchitka through 2004.

MATERIALS AND METHODS

Cohort Definition

Participation in the medical screening programs is voluntary and without cost to workers. Details concerning worker outreach and enrollment have been previously published [Dement et al., 2003a, 2005; Welch et al., 2004]. Workers potentially eligible for participation are identified through multiple sources including union rosters, contractor records where available, media advertisement, and presentations at worker meetings. The Building Trades National Medical Screening Program operates a web site (http://www.btmed.org) to provide workers with information about the program, instructions for participation, and health information. Ten staffed outreach offices are located in regions with covered DOE sites.

The screening programs use a two-step design with the initial step consisting of an intake questionnaire followed by a detailed work history interview. The intake questionnaire captures basic demographic information as well as DOE sites and trades. The detailed work history provides information concerning: (1) performing or working near high-hazard work tasks, such as sand blasting or asbestos insulation application or removal, (2) working with or around high-hazard materials such as asbestos, silica, or beryllium, and (3) working in buildings or areas associated with potential exposures to hazardous materials or where known exposure incidents or emergencies occurred. The medical screening examinations are performed under contract with local clinical providers who meet certain credentialing requirements and are required to adhere to a detailed protocol. All data from the intake, work history, medical history, physical examination, and medical examination are entered into a quality-controlled database for purposes of reporting and statistical analyses.

The current mortality cohort was defined to be former building trades workers from Hanford, Savannah River, Oak Ridge, and Amchitka who participated in an intake interview starting in 1998 and provided demographic information (Name, SSN, and Date of Birth) sufficient for follow-up through the National Death Index (NDI). At the time of NDI submission, the NDI included deaths through calendar year 2004; therefore, the cohort was restricted to 8,976 workers interviewed through December 31, 2004. In order to be included in the mortality analysis, workers were not required to have participated in the medical examination component of the program. This criterion was used in order to minimize potential selection bias due to current disease status and medical program participation. Of the 8,976 cohort members, 7,359 (82%) completed a medical screening examination.

Ascertainment of Vital Status and Causes of Death

The entire cohort was followed to identify deaths and causes of deaths through December 31, 2004, using the NDI Plus system [Bilgrad, 1995], maintained by the National Center for Health Statistics (NCHS). The NDI provided information on the dates of death for cohort members as well as underlying and contributing causes of death, coded according to the revision of the International Classification of Disease (ICD) in effect at the time of death (ninth revision for deaths that occurred before 1999, tenth revision for deaths that occurred since 1999). Record linkage with the NDI was accomplished using probabilistic scores assigned by the NDI and recommended cut-off scores by class for records without a perfect match [Horm, 1996]. The NDI has been shown to provide virtually complete ascertainment of deaths among men and among employed women [Stampfer et al., 1984; Boyle and Decouflė, 1990]; therefore, we assumed that workers not identified, as deceased by the NDI, were still alive as of December 31, 2004.

Data Analyses

Data analyses followed traditional epidemiologic methods for occupational cohort studies [Breslow and Day, 1987; Checkoway et al., 1989a,b,c]. Construction workers from all DOE sites were pooled for overall analyses. Analyses included descriptive analyses of the cohort, and calculation of standardized mortality ratios (SMRs).

The Life Table Analysis System (LTAS.Net Version 2.0.8) developed by the National Institute for Occupational Safety and Health (NIOSH) [Steenland et al., 1990; NIOSH, 2008] was utilized to compute cause-specific SMRs, comparing the mortality experience of the cohort to that of the U.S. national population, adjusting for age, race, sex, and calendar year. These death rates covered the tenth revision of the ICD codes, with deaths grouped into 119 categories for analyses [Robinson et al., 2006]. The cohort was restricted to workers with information on the date that they completed the informed consent for program participation. The informed consent date was selected as the starting point for person-years calculation for each cohort member. Person-years were accumulated until death or the study cut-off date of December 31, 2004. The LTAS program stratified person-years at risk for each worker by race, sex, 5-year age groups, and 5-year calendar time periods. SMRs were calculated as the ratio of observed to expected deaths with 95% confidence intervals for SMRs computed assuming that the observed number of deaths in the cohort is a Poisson random variable. The Byar approximation was used when the number of cases was six or more, and the exact Poisson confidence interval was calculated when the number of cases was fewer than five [Rothman and Boice, 1979; NIOSH, 2008]. In addition to overall results for the combined cohort, we investigated mortality for selected causes by DOE site, trade, year of first DOE work, and age at first DOE work.

The DOE medical surveillance programs collected sex on all individuals who completed the interview and race only on those who participated in the medical examinations. Since our cohort included all workers contacted, information on sex and race was missing for a small proportion of cohort members. The vast majority of DOE construction workers were males; therefore, workers with missing sex data were assumed male for all analyses. A review of the first names of workers with missing sex verified that little error was introduced by this assumption. For workers missing race data, we performed preliminary SMR analyses, first assuming those missing race were White, followed by repeating the SMR analyses assuming those missing race were non-White. These range finding analyses produced comparable results; therefore, missing race was assumed White for all subsequent analyses. This assumption introduced negligible error in that only approximately 11% of workers with known race were non-White.

This project was reviewed and approved by the Institutional Review Boards serving each DOE site.

RESULTS

The cohort included 8,976 workers (30,707 person-years of observation) and 674 observed deaths (Table I). The race distribution was 86.68% White and 94.63% male. The mean age at start of cohort follow-up was 58.2 years (std. dev. = 13.0) and ranged from 53.6 to 60.9 years by DOE site (Table II). The mean duration of working at a DOE site ranged from 1.3 years at Amchitka to 14.1 years at Oak Ridge. The distribution of cohort members and observed deaths by site is summarized in Table II. Savannah River workers comprised 32.3% of the cohort followed by Hanford, Oak Ridge, and Amchitka.

A wide distribution of construction trades was represented in this cohort; however, only electricians, and pipe trades/boilermakers had 100 or more observed deaths through 2004. Overall, mortality for all trades combined was slightly less than expected (SMR = 0.93, 95% CI = 0.86–1.01), demonstrating a ‘‘health worker effect’’ typically observed in occupational mortality studies. A similar pattern of overall mortality was observed for most trades (Table III), although the number of deaths for some trades was small. Significant excess mortality was observed for asbestos workers/insulators (SMR = 1.93, 95% CI = 1.15–3.05) and teamsters (SMR = 1.60, 95% CI = 1.13–2.19) and a significant overall mortality deficit was observed for machinists/millwrights (SMR = 0.64, 95% CI = 0.40–0.96).

Mortality patterns by year of cohort entry (Table IV) were similar to those observed for the entire cohort. Table V

TABLE I. DOE Construction Worker Mortality Analyses Cohort Members by Gender and Race

Gender	Race	Number of workers	%
Female	Non-White	164	1.8
Female	White	318	3.5
Female	All	482	5.4
Male	Non-White	942	10.5
Male	White	7,552	84.1
Male	All	8,494	94.6
All	Non-White	1,106	12.3
All	White	7,870	87.7
All	All	8,976	

TABLE II. DOE Mortality Cohort: Cohort Members and Deaths by DOE Site

Site	Number of workers	Deaths	Mean age at cohort entry (std. dev.)	Mean years at DOE site (std. dev.)
Amchitka	1,334	71	60.2 (11.7)	1.3 (2.5)
Hanford	2,779	266	60.2 (13.1)	10.7 (9.9)
Oak Ridge	1,957[a]	192	60.9 (13.2)	14.1 (11.5)
Savannah River	2,906	145	53.6 (12.1)	10.6 (8.2)
All sites combined	8,976	674	58.2 (13.0)	10.1 (9.9)

[a]Oak Ridge included multiple production sites (K-25, Y-12, X-10). The cohort includes 96 workers employed only at K-25, 147 workers only employed at Y-12, and 31 workers only employed at X-10. The majority of workers (N = 1,683) were employed in multiple Oak Ridge sites.

shows mortality patterns by age at cohort entry. While our cohort consisted of former DOE workers, the age distribution shows that approximately 56% were less than 60 years old upon cohort entry. Mortality patterns by age at cohort entry were similar to those observed for the entire cohort.

Mortality by major LTAS disease category is presented in Table VI. Overall, mortality was slightly less than expected (SMR = 0.93, 95% CI = 0.86–1.01), demonstrating a ''health worker effect'' typically observed in occupational mortality studies. The reduced mortality among this cohort was largely accounted for by reductions in risks for heart diseases (SMR = 0.75, 95% CI = 0.64–0.87) and other diseases of the circulatory system (SMR = 0.80, 95% CI = 0.59–1.05). While overall mortality was less than expected, excess mortality was observed for all cancers (SMR = 1.28, 95% CI = 1.13–1.45).

Detailed results by cancer site are presented in Table VII. Among the total cohort, significantly elevated risks were observed for malignant neoplasms of the trachea, bronchus, and lung (SMR = 1.54, 95% CI = 1.24–1.87) and mesothelioma (SMR = 5.93, 95% CI = 2.56–11.68). For cancer sites with five or more observed deaths, non-statistically significant elevations in risks were observed for esophagus, stomach, intestine, biliary/liver/gall bladder, kidney, bladder, brain and central nervous system, non-Hodgkin's lymphoma, multiple myeloma, and other/unspecified sites.

We investigated mortality patterns by date of first DOE work and age at first DOE work for causes seen in excess for the whole cohort (Tables VIII and IX). Mortality patterns for all causes, all cancers, and lung cancer were very similar by year of first DOE work and age at first DOE work. Elevated risk for mesothelioma and asbestosis was confined to workers

TABLE III. DOE Construction Worker Mortality Analyses: Cohort Members and Overall Mortality by Usual DOE Site Trade

	Vital status				
Trade group	Number of workers	Deaths	All causes SMR	Lower 95% CI	Upper 95% CI
Administrative/technical	291	9	0.60	0.27	1.13
Asbestos worker/insulator	221	18	1.93	1.15	3.06
Carpenter	664	58	0.86	0.65	1.11
Cement mason/brick mason/plasterer	100	11	1.37	0.68	2.45
Drilling and mining workers	72	6	1.12	0.41	2.44
Electrician	1,557	102	0.86	0.70	1.04
Ironworkers	469	33	0.89	0.61	1.25
Laborers	1,202	81	0.96	0.76	1.19
Machinists/millwrights	323	23	0.64	0.40	0.96
Operating engineers	557	38	0.85	0.60	1.16
Painters	252	14	0.90	0.49	1.51
Pipe trades/boilermakers	1,810	152	0.94	0.80	1.10
Security/services	242	2	0.24	0.03	0.86
Sheet metal workers	339	31	1.13	0.77	1.61
Teamster	334	38	1.60	1.13	2.19
Other crafts and trades	85	11	1.46	0.73	2.62
Other and unknown	458	47	0.92	0.68	1.22
All trades combined	8,976	674	0.93	0.86	1.01

TABLE IV. DOE Mortality Cohort: Vital Status and Overall Mortality by Year of Cohort Entry

	Vital status				
Year of cohort entry	Number of workers	Deaths	All causes SMR	Lower 95% CI	Upper 95% CI
1998	767	118	0.80	0.66	0.96
1999	1,429	139	0.82	0.69	0.97
2000	1,575	173	1.14	0.98	1.33
2001	1,714	110	0.85	0.70	1.03
2002	1,547	86	1.10	0.88	1.36
2003	1,323	44	1.05	0.76	1.41
2004	621	4	0.65	0.18	1.66
All years combined	8,976	674	0.93	0.86	1.01

first employed prior to 1980. Interpretation of risks for mesothelioma and asbestosis after 1980 is hampered by the small number of deaths among workers first employed in 1980 or latter (N = 137).

SMR results for selected causes by DOE site are presented in Table X. All cancers and lung cancers were elevated across all sites with the highest SMRs observed at Savannah River. The eight observed mesothelioma deaths occurred among Hanford (SMR = 11.08, 95% CI = 4.07–24.11) and Oak Ridge (SMR = 5.18, 95% CI = 0.63–18.70) workers. Mortality patterns for lymphatic and hematopoietic cancers varied by site with a significant excess of non-Hodgkin's lymphoma observed at Oak Ridge (SMR = 2.78, 95% CI = 1.02–6.04) and a significant excess of multiple myeloma at Hanford (SMR = 3.20, 95% CI = 1.04–7.47). Highly elevated asbestosis risks were observed for all sites except Amchitka. Chronic obstructive pulmonary disease (COPD) was significantly elevated among SRS workers (SMR = 1.92, 95% CI = 1.02–3.29).

The NIOSH LTAS results for all cancers combined closely matches the list of cancers identified for compensation by the Energy Employees Occupational Illness Compensation Program (EEOICPA) [DHHS, 2002]. The EEOICPA compensable cancer sites include bone, renal, leukemia (other than chronic lymphocytic leukemia (CLL)), multiple myeloma, lymphomas (other than Hodgkin's disease), thyroid, male or female breast, esophagus, stomach, pharynx, small intestine, pancreas, bile ducts, gall bladder, salivary gland, urinary bladder, brain, colon, ovary, and liver (except if cirrhosis or hepatitis B is indicated). The NIOSH LTAS program does include CLL, which is not included in the list of radiation cancers; however, we observed only five leukemia deaths in our cohort. Significant excess mortality was thus observed for cancer sites included in the EEOICPA compensation program (SMR = 1.28, 95% CI = 1.13–1.45) as well as excesses by site (Table X).

The large number of trades included in our analyses and the resulting small number of deaths for any particular trade precludes detailed trade-specific analyses. Only two trades had more than 100 deaths (electricians and pipe trade/boilermakers). Patterns of mortality for all cancers, lung cancer, and mesothelioma among these two trades were consistent with patterns observed for the overall cohort. Statistically significant excess mortality for asbestosis was observed for electricians (six cases, SMR = 89.2, 95% CI = 32.75–194.23) and pipe trade/boilermakers (three cases, SMR = 34.3, 95% CI = 7.06–100.11). The number of deaths due to lymphatic and hematopoietic cancers among these two trades was too few for meaningful analyses.

TABLE V. DOE Mortality Cohort: Vital Status and Overall Mortality by Age at Cohort Entry

	Vital status				
Age at cohort entry	Number of workers	Deaths	All causes SMR	Lower 95% CI	Upper 95% CI
<40	573	3	0.70	0.14	2.05
40–49	1,977	26	0.88	0.57	1.28
50–59	2,479	76	0.98	0.77	1.22
60–69	1,935	152	1.03	0.87	1.21
70+	2,012	417	0.90	0.82	0.99
All ages combined	8,976	674	0.93	0.86	1.01

TABLE VI. DOE Construction Worker SMR Analysis—All Sites Combined NIOSH LTAS Results by Major Cause—December 31, 2004

Cause of death by LTAS Major Group	Observed	Expected	SMR	Lower 95% CI	Upper 95% CI
All causes	674	722.51	0.93	0.86	1.01
Tuberculosis and HIV	2	3.07	0.65	0.08	2.35
All malignant neoplasms	248	193.68	1.28*	1.13	1.45
Benign and unspecified nature neoplasms	1	2.51	0.40	0.01	2.22
Diseases of blood and blood-forming organs	3	3.71	0.81	0.17	2.36
Diabetes mellitus	13	21.20	0.61	0.33	1.05
Mental and psych. disorders	9	10.98	0.82	0.37	1.56
Nervous system disorders	18	23.87	0.75	0.45	1.19
Heart diseases	167	222.33	0.75*	0.64	0.87
Other diseases of circulatory system	51	64.08	0.80	0.59	1.05
Diseases of respiratory system	88	75.17	1.17	0.94	1.44
Diseases of digestive system	22	24.97	0.88	0.55	1.33
Diseases of skin and subcutaneous tissues	0	0.82	0.00	0.00	4.52
Diseases of musculoskeletal and connective tissues	2	2.32	0.86	0.10	3.11
Diseases of genito-urinary system	7	15.85	0.44*	0.18	0.91
Symptoms and ill-defined conditions	5	6.19	0.81	0.26	1.89
Transportation injuries	11	7.82	1.41	0.70	2.52
Falls	2	4.60	0.44	0.05	1.57
Other injury	5	9.26	0.54	0.18	1.26
Violence	8	9.45	0.85	0.37	1.67
Other and unspecified causes	12	20.63	0.58	0.30	1.02

*$P < 0.05$.

DISCUSSION AND CONCLUSIONS

The current cohort included workers from four geographically diverse sites and a wide spectrum of construction trades. Many of our cohort members were employed by subcontractors and not by the site operations contractors. While the overall cohort is of reasonable size, the duration of follow-up is short, resulting the few deaths for many disease categories and reduced statistical power to detect excess risks. The small number of deaths at each site precludes detailed trade-specific analyses.

Our cohort included workers who completed an intake questionnaire that provided sufficient information for follow-up through the NDI. We chose to include workers completing the intake questionnaire rather than just those completing a medical examination in an effort to minimize potential selection bias based on health status. Nonetheless, the potential for self-selection still exists. However, our observed mortality patterns by age at cohort entry and year of cohort entry are reasonably uniform across age and year categories and the patterns are consistent with those generally observed for other worker cohorts, providing some assurance that self-selection by health status did not significantly impact results and interpretations.

The overall mortality experience of this cohort is similar to that observed for other construction and trade cohorts. In addition to their work at DOE sites, many of our cohort members did construction-related work at sites other than DOE; therefore, attribution of excess mortality to DOE work alone is not possible. The excess risk for mesothelioma, lung cancer, and asbestosis reflects significant past exposure to asbestos. Significant excess risk was observed for cancer sites included in the current Department of Labor compensation program for DOE workers. The data for lymphatic and hematopoietic cancer risks are difficult to interpret due to the small numbers of observed cases; however, a significant excess of non-Hodgkin's lymphoma was observed at Oak Ridge and a significant excess of multiple myeloma was observed at Hanford. Excess risk for non-Hodgkin's lymphoma and multiple myeloma have not typically been observed for construction workers; however, these excess have been observed in studies of other DOE site workers [Gilbert et al., 1993; Wing et al., 2000].

Cigarette smoking information was available for 6,993 (77.9%) of the workers in this cohort. At the time of their interviews, 21.4% were current smokers, 45.3% past smokers, and 33.2% reported to have never smoked. The prevalence of current smokers in our DOE worker cohort is considerably less than reported by Lee et al. [2007] among most construction-related trades during 1987–2004 and lower than all U.S. males during 1987–2004 (26.1%). In a study examining the potential for tobacco and alcohol to

TABLE VII. DOE Construction Worker SMR Analysis—All Sites Combined NIOSH LTAS Results for Malignant Neoplasms—December 31, 2004

Cause of death by LTAS cancer site	Observed	Expected	SMR	Lower 95% CI	Upper 95% CI
MN of buccal and pharynx	4	3.19	1.25	0.34	3.21
MN of lip	0	0.04	0.00	0.00	102.75
MN of tongue	2	0.73	2.74	0.33	9.91
MN of other buccal	0	0.78	0.00	0.00	4.74
MN of pharynx	2	1.65	1.21	0.15	4.38
MN of digestive and peritoneum	51	47.07	1.08	0.81	1.42
MN of esophagus	8	6.31	1.27	0.55	2.50
MN of stomach	7	4.62	1.52	0.61	3.12
MN of intestine	19	16.24	1.17	0.70	1.83
MN of rectum	2	3.22	0.62	0.08	2.24
MN of biliary, liver, gall bladder	8	6.26	1.28	0.55	2.52
MN of pancreas	7	9.85	0.71	0.29	1.46
MN of peritoneum, other and unspecified sites	0	0.57	0.00	0.00	6.49
MN of respiratory	100	65.49	1.53*	1.24	1.86
MN larynx	2	1.97	1.02	0.12	3.67
MN of trachea, bronchus, lung	97	63.19	1.54*	1.24	1.87
MN of pleura	0	0.04	0.00	0.00	84.33
MN of other respiratory	1	0.29	3.42	0.09	19.06
MN of breast (major)	1	0.81	1.23	0.03	6.88
MN of breast	1	0.81	1.23	0.03	6.88
MN of female genital organs	0	0.30	0.00	0.00	12.18
MN of male genital organs	16	20.96	0.76	0.44	1.24
MN of prostate	16	20.87	0.77	0.44	1.24
MN of testis	0	0.09	0.00	0.00	42.75
MN of urinary	17	11.07	1.54	0.89	2.46
MN of kidney	9	5.06	1.78	0.81	3.38
MN of bladder and other urinary site	8	6.02	1.33	0.57	2.62
MN of other and unspecified sites	34	25.06	1.36	0.94	1.90
MN of bone	1	0.29	3.51	0.09	19.53
MN of melanoma	1	2.94	0.34	0.01	1.90
MN of other skin	1	1.10	0.91	0.02	5.06
MN of mesothelioma	8	1.35	5.93*	2.56	11.68
MN of connective tissue	2	0.97	2.07	0.25	7.47
MN of brain and other nervous system	5	4.02	1.24	0.40	2.90
MN of eye	1	0.08	13.05	0.33	72.72
MN of thyroid	0	0.37	0.00	0.00	9.84
MN of other and unspecified sites	15	13.95	1.08	0.60	1.77
MN of lymphatic and hematopoietic	25	19.73	1.27	0.82	1.87
Hodgkin's disease	2	0.35	5.70	0.69	20.59
Non-Hodgkin's lymphoma	11	8.03	1.37	0.68	2.45
Multiple myeloma	7	3.80	1.84	0.74	3.80
Leukemia	5	7.55	0.66	0.22	1.55

*$P < 0.05$.

confound the relationship between laryngeal cancer and metal working fluids, Kriebel et al. [2004] concluded that, for large studies, systematic or chance differences in smoking and drinking habits among the exposure groups are unlikely to cause more than a 17% change in the relative risk. Given the magnitude of the lung cancer risk observed in this cohort (SMR = 1.54) and the relatively low prevalence of current smokers reported during medical examinations, cigarette smoking alone is not a likely explanation for the excess risk of lung cancer. The large excess observed for mesothelioma and asbestosis support an asbestos etiology, at least in part, for excess lung cancer risk among these DOE workers.

TABLE VIII. DOE Mortality Cohort: Mortality by Year of First DOE Site Work

Year of first DOE work	All causes SMR (95% CI)	All cancers SMR (95% CI)	Lung cancer SMR (95% CI)	Mesothelioma SMR (95% CI)	Asbestosis SMR (95% CI)
Before 1960	0.90 (0.81 – 1.01)	1.10 (0.89 – 1.35)	1.46 (1.04 – 1.99)	10.57 (4.25 – 21.77)	39.48 (18.05 – 74.95)
1970 – 1979	0.97 (0.84 – 1.10)	1.36 (1.10 – 1.67)	1.19 (0.78 – 1.72)	2.29 (0.06 – 12.76)	40.77 (11.11 – 104.39)
1980+	0.95 (0.80 – 1.12)	1.54 (1.18 – 1.97)	2.30 (1.55 – 3.28)	No cases	No cases
Overall	0.93 (0.86 – 1.01)	1.28 (1.13 – 1.45)	1.54 (1.24 – 1.87)	5.93 (2.56 – 11.68)	33.89 (18.03 – 57.95)

Furthermore, among 6,904 cohort members with chest X-ray interpretations by ILO criteria, 327 (4.7%) had parenchymal changes with a profusion score of 1/0 or greater and 1,208 (17.5%) had pleural changes, both supporting significant asbestos exposure among these workers.

Our study cohort included 106 workers with a medical history of lung cancer at the time of their examination and 39 of these died during the follow-up period. Twenty-four of the 39 deaths listed lung caner as the underlying cause of death and three listed mesothelioma. Among cohort members, 783 reported a medical history of asbestosis or were found to have an ILO profusion score of 1/0 or greater for small opacities on chest X-ray. One hundred and eight of these workers died during the follow-up period with 8 deaths being attributed to asbestosis, 3 due to mesothelioma, 21 due to lung cancer, and 7 due to COPD. Lung nodules or masses were detected in 248 workers by chest X-ray and 41 of these died during follow-up, with 6 deaths being due to lung cancer and 1 due to asbestosis.

A number of studies have examined mortality among construction workers as a group. Elevated proportional mortality ratios (PMRs) or proportional cancer mortality ratios (PCMRs) were reported for all cancers, [Dong et al., 1995; Sun et al., 1997], malignant neoplasms of the buccal cavity [Wang et al., 1999], pharynx [Wang et al., 1999], and lung [Wang et al., 1999; Dong et al., 1995; Sun et al., 1997]. Elevated PMRs have been reported for accidental deaths [Wang et al., 1999; Dong et al., 1995; Robinson et al., 1995; Sun, 1997]. Elevated SMRs have been reported for oral, pharyngeal, and gastrointestinal cancers [Thuret et al., 2007], and fatal accidents [Arndt et al., 2004]. A longitudinal study of a cohort of Swedish construction workers reported excess mortality from COPD among those with any exposure to inorganic dust, gases and irritants, and wood dust [Bergdahl et al., 2004], and an excess of myeloma among those exposed to diesel exhaust [Lee et al., 2003].

Studies of specific construction trades have reported elevated PMRs for a wide range of cancers (Table XI); most of these studies also found elevated rates for traumatic injuries, including transportation injuries and falls. Two studies reported elevated PMRs for conditions not likely to be occupational, including mental disorders, alcohol-related disease, digestive diseases, poisonings, and homicides [Robinson, 1995; Wang et al., 1999]. Many of these studies reported an excess of deaths from asbestosis or pneumoconiosis [Robinson et al., 1995, 1996, 1999; Stern and Haring-Sweeney, 1997; Wang et al., 1999; Stern et al., 2000]. A study of cancer incidence among carpenters in New Jersey [Dement et al., 2003b] observed significantly excess standardized incidence ratios (SIRs) for cancers of the digestive system and peritoneum, lung cancer, and cancers of pleura and other parts of the respiratory system. Testicular cancer also was in excess in analyses that lagged results by 15 years from initial union membership.

Workers in our cohort experienced occupational exposures usually associated with their construction craft or trade and many were involved in maintenance and renovation activities at DOE sites, potentially exposing these workers to occupational hazards specific to the nuclear sites under study. While a number of mortality studies have been conducted among workers at Hanford, Oak Ridge, and the SRS, relatively little has been published specifically addressing risks experienced by construction and craft workers, especially among craft and trade workers not employed by site operations contractors. Several analyses have stratified workers into salaried and non-salaried groups

TABLE IX. DOE Mortality Cohort: Mortality by Age at First DOE Site Work

Age at first DOE work	All causes SMR (95% CI)	All cancers SMR (95% CI)	Lung cancer SMR (95% CI)	Mesothelioma SMR (95% CI)	Asbestosis SMR (95% CI)
<30	0.91 (0.81 – 1.03)	1.19 (0.97 – 1.44)	1.57 (1.14 – 2.11)	6.59 (1.80 – 16.88)	53.35 (24.40 – 101.28)
30 – 39	0.95 (0.82 – 1.09)	1.30 (1.01 – 1.66)	1.39 (0.87 – 2.10)	9.21 (1.90 – 26.92)	10.29 (0.27 – 58.44)
40+	0.94 (0.82 – 1.08)	1.40 (1.11 – 1.73)	1.61 (1.09 – 2.28)	2.40 (0.06 – 13.37)	25.08 (5.17 – 73.30)
Overall	0.93 (0.86 – 1.01)	1.28 (1.13 – 1.45)	1.54 (1.24 – 1.87)	5.93 (2.56 – 11.68)	33.89 (18.03 – 57.95)

TABLE X. DOE Construction Worker SMR Analysis: NIOSH LTAS Results for Selected Causes by Site—December 31, 2004

Cause and DOE site	Observed	Expected	SMR	Lower 95% CI	Upper 95% CI
All cancers					
Amchitka	36	25.62	1.41	0.98	1.95
Hanford	94	80.06	1.17	0.95	1.44
Oak Ridge	62	50.81	1.22	0.94	1.56
Savannah River Site	56	37.19	1.51*	1.14	1.96
All sites combined	248	193.68	1.28*	1.13	1.45
MN of trachea, bronchus, and lung					
Amchitka	12	8.41	1.43	0.74	2.49
Hanford	32	25.52	1.25	0.86	1.77
Oak Ridge	25	16.81	1.49	0.96	2.20
Savannah River Site	28	12.45	2.25*	1.49	3.25
All sites combined	97	63.19	1.54*	1.24	1.87
Mesothelioma					
Amchitka	0	0.18	0.00	0.00	20.78
Hanford	6	0.54	11.08*	4.07	24.11
Oak Ridge	2	0.39	5.18	0.63	18.70
Savannah River Site	0	0.24	0.00	0.00	15.14
All sites combined	8	1.35	5.93*	2.56	11.68
Non-Hodgkin's lymphoma					
Amchitka	0	1.02	0.00	0.00	3.62
Hanford	4	3.36	1.19	0.32	3.05
Oak Ridge	6	2.16	2.78*	1.02	6.04
Savannah River Site	1	1.49	0.67	0.02	3.73
All sites combined	11	8.03	1.37	0.68	2.45
Multiple myeloma					
Amchitka	1	0.51	1.97	0.05	10.96
Hanford	5	1.56	3.20*	1.04	7.47
Oak Ridge	0	1.00	0.00	0.00	3.69
Savannah River Site	1	0.73	1.38	0.03	7.68
All sites combined	7	3.80	1.84	0.74	3.80
Asbestosis					
Amchitka	0	0.05	0.00	0.00	78.58
Hanford	5	0.17	29.82*	9.68	69.60
Oak Ridge	5	0.11	45.62*	14.81	106.46
Savannah River Site	3	0.06	50.47*	10.41	147.51
All cites combined	13	0.38	33.89*	18.03	57.95
Chronic obstructive pulmonary disease					
Amchitka	8	5.27	1.52	0.66	2.99
Hanford	16	18.42	0.87	0.50	1.41
Oak Ridge	12	11.53	1.04	0.54	1.82
Savannah River Site	13	6.76	1.92*	1.02	3.29
All sites combined	49	41.99	1.17	0.86	1.54

*$P < 0.05$.

and construction and craft workers, if included in the studies, are more likely to be included in the non-salaried group.

Cragle et al. [1998] reported elevated but non-statistically significant lung cancer and leukemia mortality among SRS non-salaried workers compared to US White men. Richardson et al. [2007] reported mortality among a cohort of 18,883 Savannah River workers hired between 1950 and 1986. Significant excess risk for leukemia and cancer of the pleura was observed among hourly paid men, and female workers had a significant excess risk for kidney cancer.

The Oak Ridge site is comprised of three facilities (X-10, Y-12, and K-25), each with different processes and

TABLE XI. Summary of Construction Worker Cancer Studies Showing Excess Risk by Cancer Site

Construction trade	Cancer site									
	Lung cancer	Melanoma	Bone cancer	Stomach cancer	Nasal cancer	Scrotal cancer	AML	Esophageal cancer	Laryngeal cancer	Mesothelioma or pleural cancer
Concrete masons	13	1	1	1,6					13	
Roofers	3			1				3	3	
Operating engineers	7		7							
Laborers	5			5						5
Electricians	4	4				1				4
Boilermakers							1			
Ironworkers	1,7									7
Carpenter	2,11		2							11
Plumber	13				1					13
Brick masons	9,12			9,12				9		
Sheet metal	13									7,10,13

(1) Robinson et al. [1995] (all), (2) Robinson et al. [1996] (carpenters), (3) Stern et al. [2000] (roofers), (4) Robinson et al. [1999] (electricians), (5) Stern et al. [1995] (laborers), (6) Stern et al. [2001] (masons), (7) Stern et al. [1997] (ironworkers), (8) Stern et al. [1997] (operating engineers), (9) Salg and Alterman [2005] (bricklayers and allied trades), (10) Michaels and Zoloth [1988] (sheet metal), (11) Dement et al. [2003] (carpenters), (12) Finkelstein and Verma [2005] (bricklayers and allied trades), and (13) Engholm and Englund [1995] (excess mortality or cancer incidence).

occupational risks. Frome et al. [1997] studied mortality patterns among workers employed at Oak Ridge between 1943 and 1985. Excess mortality was observed for lung cancer (SMR = 1.18) and non-malignant lung diseases (SMR = 1.12) for all Oak Ridge sites combined. Internal analyses found that non-salaried workers experienced higher lung cancer risk compared to salaried workers. Loomis and Wolf [1996] as well as Checkoway et al. [1988] also observed excess lung cancer risk among Y-12 workers. Richardson and Wing [1999] observed increased cancer mortality among Oak Ridge workers to be associated with low-level external exposures to ionizing radiation with potentially greater effects after age 45. An association between external radiation dose occurring at ages 35 years and older and lung cancer mortality was observed among Y-12 workers [Richardson and Wing, 2006].

A number of studies have examined mortality among production workers at Hanford and some of these analyses have included craft workers employed by the site operations contractors. Generally, operators and skill craft workers (e.g., millwrights, steamfitters) have been found to have higher cumulative external radiation doses compared to other Hanford workers [Gilbert and Marks, 1980]; however, mortality patterns among craft workers have not been separately reported. Multiple myeloma has been reported to be in excess among Hanford workers [Gilbert et al., 1993], a finding consistent with our study. In a case–control study in four DOE sites, Wing et al. [2000] observed an association between the risk of multiple myeloma and low-level whole body penetrating ionizing radiation dose at older ages. A specific association between cancer mortality and radiation doses accrued at older ages has been reported in studies of Hanford workers [Kneale et al., 1984; Kneale and Stewart, 1993], and this association appears particularly strong for lung cancer [Wing and Richardson, 2005].

Our study has several strengths including a reasonable cohort size and a diversity of trades and crafts not previously studied in detail in other epidemiologic studies of DOE workers. However, the follow-up period is short for many cohort members, resulting in only 674 total deaths, thus limiting our ability to address risks for several cancers previously observed in excess among DOE workers or associated with radiation exposures in other studies. Continued expansion of this cohort to include workers from other DOE sites now included in the Building Trades National Screening Program and follow-up of this cohort using the NDI is recommended.

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