Association Between ILO Abnormalities and Exposures Among Former Nuclear Weapons Workers

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Abstract

Nuclear weapons industry workers are recognized as being at risk for a variety of work-related respiratory exposures which may be associated with occupational lung disease. We reviewed CXRs of 757 former AEC nuclear weapons workers from the Iowa Army Ammunition Plant (IAAAP) in Burlington, IA screened for evidence of parenchymal and pleural abnormalities consistent with pneumoconiosis according to the 1992 International Labour Organization (ILO) Classification of Radiographs of Pneumoconioses. The screenings were part of the Department of Energy (DoE) Former Worker Program established in 1996 to identify hazardous exposures in atomic weapons production, and provide medical screenings to detect health effects from those exposures.

We found 60 former DoE workers (7.9%) with parenchymal abnormalities defined as ILO profusion score of 1/0 and greater. Of those, 42 (5.6%) had only parenchymal abnormalities and 18 (2.4%) had accompanying pleural abnormalities. In addition, 35 workers (4.6%) had isolated pleural abnormalities consistent with pneumoconiosis. A suggested dose-response trend was found between exposure to high explosives and parenchymal abnormalities, and exposure to asbestos and parenchymal/pleural and pleural abnormalities. The prevalence of parenchymal abnormalities was comparable or higher than rates in other DoE sites. These results confirm the need to screen former nuclear weapons workers for effects of airborne exposures in the manufacture of nuclear weapons.

Project Background

The University of Iowa College of Public Health Project started in 2001

Funded by DoE under Public Law 102-484 Section 3162 of the 1993 Defense Authorization Act

Goal: *Identifying, locating, and providing former IAAAP DoE workers employed in the manufacture of nuclear weapons with medical evaluation of long term health effects that might have resulted from employment*

Iowa Army Ammunition Plant (IAAAP)

Located in Middletown, IA (Des Moines County) ~ 70 miles south from Iowa City - over 19,000 acres of Government Owned Contractor Operated (GOCO) establishment with >1000 buildings, 142 miles of roads and 103 miles of railroad tracks

Built between 1941-1943 as conventional munitions (DoD) Loading, Assembly and Packing (LAP) facility. Atomic weapons assembled, disassembled and repaired between 1949 and mid-1975 on **Line 1** under Atomic Energy Commission (AEC, pre-DoE) contractual agreements with Silas-Mason Company

Production terminated/moved in 1975 to Pantex, Amarillo, TX

Nuclear Weapons Workers

Estimated up to 7,000 workers worked on or were exposed to Line 1 operations (a.k.a. Division B) between early 1949 and mid-1975

Substantial cross-over of workforce with adjacent conventional munitions manufacturing lines (95-100% of DoE workers worked on DoD lines too during their tenure at the plant)

Still in operation - current workforce approx. 600 employees

Primary exposures:

- *Ionizing radiation* — *High Explosives incl. Barium*
- *Beryllium* — *Isocyanates*
- *Asbestos* — *Epoxy adhesives*
- *Solvents* — *Curing agents*

Methods

Cohort selection was based on subcontractor employment records, plant radiation dosimetry records, union seniority records and employment validation by other former workers.

Participants were recruited by mail, telephone, press releases, town hall meetings and word of mouth.

All former workers participating in the screenings were offered CXR. Postero-Anterior (PA) films were reviewed by 3 experienced ILO readers blinded to radiologist's reports and each other's readings.

Average of 3 readings was used to reconcile inter-reader variability in ILO profusion scoring.

Parenchymal abnormalities were defined as average ILO profusion score $\geq$1/0. Pleural abnormalities were defined as those confirmed by at least 2 of 3 readers.

Beryllium, asbestos, high explosives and barium exposure categories for each worker were assigned based on job codes/job titles in subcontractor's and plant's employment records.

Highest exposure ever for each worker was used to estimate personal exposure

Job Exposure Matrix

The only available historical exposure data – limited beryllium surface wipe sample reports for 1970-1974 - served as indicators of the presence and relative levels of beryllium on surfaces in various locations within the plant - these could not be used to directly estimate workers' inhalational exposure to beryllium at the plant.

A survey of surface contamination at this facility in 2007 revealed only two beryllium samples out of one hundred collected throughout the facility which exceeded the DoE surface contamination housekeeping level of 3 µg/100 cm^2 and both of these were from surfaces in the area in which millwrights used belt sanders to occasionally resurface alloy tools. (Sanderson et al., JOEH 5(7) p.475, 2008)

Interviews of former DoD and DoE workers - production, trade and health and safety – were used to assess areas, activities and eras for risk of beryllium, asbestos, and high explosives/barium exposure.

Job codes, job titles, and work tasks were reviewed by industrial hygienists and a group of former workers to develop a qualitative exposure matrix (JEM) for beryllium, asbestos, high explosives and barium. The estimates for each job code/category were based on task frequency and proximity to potential sources of airborne exposures and reflected the group's consensus.

Exposure Categories/Jobs

Exposure	Beryllium	Asbestos	High Explosives/Barium
Category 0 No exposure, same as background:	Administrative, Security, Storage, Medical, Power Plant, Firing Site, Auto/Equipment Mechanics, Cafeteria, Carpenter, Custodian	Not assigned	Administrative, Security, Medical, Power Plant, Cafeteria, Carpenter, Custodian, Auto/Equipment Mechanics
Category 1 Rare/low indirect or bystander	Production and Explosive Operator, Scientist, Engineer, Pipefitter, Plumber, Electrician, Laundry,	Administrative, Security, Storage, Medical, Laundry, Custodian, Electrician, Firing site, Production and Explosive Operator, Millwright, Tool and Die, Machinist,	Production (assembly), Laundry, Millwright, Tool and Die, Machinist, Inspector, Storage
Category 2 Occasional, direct or indirect	Millwright, Tool and Die, Machinist,	Power Plant, Auto/Equipment Mechanics	Pipefitter, Plumber, Process Engineer, Firing Site
Category 3 Frequent, direct	Not assigned	Pipefitter, plumber, carpenter,	Production (fabrication) and Explosive Operator Melt, Scientist,

Results

Table 1.Characteristics of screened workforce and unadjusted analysis of predictors of ILO abnormalities

Parameter	Total screened N=704 n, (%)	Parenchymal (Y) n, (%)	Parenchymal (N) n , (%)	p-value
Gender				
Male	563 (80.0)	**34 (6.0)**	529 (94.0)	1.0[a]
Female	141 (20.0)	8 (5.7)	133 (94.3)	
Race				
White	674 (95.7)	**41 (6.1)**	633 (93.9)	1.0[a]
Other	30 (4.3)	1 (3.3)	29 (96.7)	
Age				
$\leq$ 59	117 (16.6)	2 (1.7)	115 (98.3)	*0.0003*[b]
60-69	217 (30.8)	8 (3.7)	209 (96.3)	
70-79	260 (37.0)	19 (7.3)	241 (92.7)	
80-89	103 (14.6)	12 (11.7)	91 (88.3)	
$\geq$ 90	7 (1.0)	**1 (12.5)**	6 (87.5)	
Smoking				
Ever-smoker	481 (68.3)	**31 (6.4)**	450 (93.6)	0.61[a]
Never smoker	221 (31.4)	11 (5.0)	210 (95.0)	
Missing	2 (0.3)	-	2 (100.0)	
First date of hire				
1/1/1947-12/31/1950	82 (11.6)	**12 (14.6)**	78 (85.4)	*0.0002*[b]
1/1/1951-12/31/1953	179 (25.4)	11 (6.1)	179 (93.9)	
1/1/1954-12/31/1964	133 (19.0)	11 (8.3)	129 (91.7)	
1/1/1965-6/30/1975	300 (42.6)	7 (2.3)	302 (97.7)	
Missing	10 (1.4)	1 (10.0)	9 (90.0)	
Beryllium exposure				
Cat 0	343 (48.7)	18 (5,3)	342 (94.7)	0.68[b]
Cat 1	301 (42.7)	**21 (7.0)**	297 (93.0)	
Cat 2	47 (6.7)	2 (4.3)	46 (95.7)	
Cat 3	-	-	-	
Missing	13 (1.9)	1 (7.7)	12 (92.3)	
High explosives exposure				
Cat 0	240 (34.1)	13 (5.4)	240 (94.6)	0.18[b]
Cat 1	144 (20.5)	5 (3.5)	147 (96.5)	
Cat 2	51 (7.2)	3 (5.9)	50 (94.1)	
Cat 3	256 (36.4)	**20 (7.8)**	248 (92.2)	
Missing	13 (1.8)	1 (7.7)	12 (92.3)	
Barium exposure				
Cat 0	240 (34.1)	13 (5.4)	240 (94.6)	0.18[b]
Cat 1	144 (20.5)	5 (3.5)	147 (96.5)	
Cat 2	51 (7.2)	3 (5.9)	50 (94.1)	
Cat 3	256 (36.4)	**20 (7.8)**	248 (92.2)	
Missing	13 (1.8)	1 (7.7)	12 (92.3)	

Table 2.Unadjusted analysis of asbestos exposure as a predictor of ILO abnormalities

Exposure	Parenchymal (Y/N)[1] N=704 n, (%)	ParPleural (Y/N)[2] N=680 n,(%)	Pleural (Y/N)[3] N=697 n, (%)	p-value[1]	p-value[2]	p-value[3]
Asbestos						
Cat 0	-	-	-			
Cat 1	37 (5.8) / 561 (94.2)	14 (2.4) / 561 (97.6)	27 (4.6) / 561 (95.4)	0.29[b]	0.23[b]	0.08[b]
Cat 2	**3 (7.3) / 35 (92.7)**	1 (2.8) / 35 (97.2)	2 (5.4) / 35 (94.6)			
Cat 3	1 (1.6) / 54 (98.4)	**3 (5.6) / 54 (94.4)**	**6 (10.0) / 54 (90.0)**			
Missing	1 (7.7) / 12 (92.3)	0 (0.0) / 12 (100.0)	0(0.0) / 12 (100.0)			

[a] Fisher's exact test; [b] Cochran-Armitage chi-square Test

Table 3. Analysis of exposure predictors of ILO parenchymal abnormalities adjusted for age, sex, race, and smoking

Exposure	OR (95% CI)	p-value
Beryllium exposure		
Cat 0	1.0	0.38
Cat 1	**1.37 (0.71-2.64)**	
Cat 2	0.54 (0.12-2.45)	
High explosives exposure		
Cat 0	1.0	0.38
Cat 1	0.66 (0.23-1.90)	
Cat 2	0.92 (0.25-3.42)	
Cat 3	**1.49 (0.72-3.04)**	
Barium exposure		
Cat 0	1.0	0.38
Cat 1	0.66 (0.23-1.90)	
Cat 2	0.92 (0.29-3.98)	
Cat 3	**1.49 (0.72-3.09)**	
Asbestos exposure (Parenchymal)		
Cat 0	-	0.25
Cat 1	**1.0**	
Cat 2	0.97 (0.28-3.38)	
Cat 3	0.18 (0.02-1.36)	
Asbestos exposure (Parenchymal and Pleural)		
Cat 0	-	0.76
Cat 1	1.0	
Cat 2	0.92 (0.12-7.26)	
Cat 3	**1.63 (0.44-6.09)**	
Asbestos exposure (Pleural)		
Cat 0	-	0.62
Cat 1	1.0	
Cat 2	0.93 (0.21-4.12)	
Cat 3	**1.59 (0.61-4.16)**	

Results

Table 4.Analysis of the first hire date as a predictor of ILO abnormalities adjusted for sex, race, and smoking history

Parameter	OR (95% CI)	p-value
First date of hire and parenchymal abnormalities		
1/1/1947-12/31/1950	1.0	0.0009
1/1/1951-12/31/1953	0.39 (0.16-0.91)	
1/1/1954-12/31/1964	0.53 (0.22-1.29)	
1/1/1965-6/30/1975	0.14 (0.05-0.40)	
First date of hire and parenchymal + pleural abnormalities		
1/1/1947-12/31/1950	1.0	0.1234
1/1/1951-12/31/1953	3.75 (0.47-30.16)	
1/1/1954-12/31/1964	2.30 (0.25-20.94)	
1/1/1965-6/30/1975	0.96 (0.11-8.68)	
First date of hire and pleural abnormalities		
1/1/1947-12/31/1950	1.0	0.0727
1/1/1951-12/31/1953	0.57 (0.22-1.49)	
1/1/1954-12/31/1964	0.50 (0.18-1.44)	
1/1/1965-6/30/1975	0.27(0.10-0.72)	

Table 5. Agreement between ILO readers n=757

Agreement Parameter/Reader	Reader 1 vs. 2	Reader 1 vs. 3	Reader 2 vs. 3
Profusion Score *Unweighted Kappa Statistic* *Weighted Kappa Statistic (FC)*	**0.31;** 95% CI 0.24-0.37 **0.68;** 95% CI 0.57-0.78	**0.36;** 95% CI 0.30-0.42 **0.72;** 95% CI 0.64-0.80	**0.52;** 95% CI 0.45-0.59 **0.70;** 95% CI 0.59-0.81
Parenchymal Abnormalities (Y/N) *Unweighted Kappa Statistic*	**0.57;** 95% CI 0.47-0.67	**0.67;** 95% CI 0.59-0.76	**0.56;** 95% CI 0.46-0.66
Pleural Abnormalities (Y/N) *Unweighted Kappa Statistic*	**0.61;** 95% CI 0.50-0.72	**0.53;** 95% CI 0.41-0.64	**0.56;** 95% CI 0.43-0.69

Summary of Findings/Conclusions

The 5.6% prevalence rate of parenchymal abnormalities in this study is higher than the 2.2% rate found in current and former construction and craft workers from three nuclear weapons sites (Dement et al., 2003 AJIM, 43:559-573) but comparable to a 5.4% rate found in former production workers from Savannah River Site (Makie et al., 2005, 48:365-372)

The 2.4% prevalence rate of parenchymal/pleural and the 4.6% prevalence rate of pleural abnormalities found in this study are lower than rates reported from other nuclear weapons sites: 3.2% and 19.9% respectively in current and former construction and craft workers from three nuclear weapons sites (Dement et al., 2003 AJIM, 43:559-573) and 3.7% and 11.3% in former production workers from Savannah River Site (Makie et al., 2005, 48:365-372) .

None of the modeled exposures were statistically significantly associated with the increase in risk of parenchymal abnormalities and age was a strong confounder in all the models ($p<0.001$)

A suggested dose-response trend was found between exposure to high explosives/barium and the risk of parenchymal abnormalities. A suggested dose-response trend was also found between exposure to asbestos and the risk of parenchymal/pleural abnormalities and pleural abnormalities alone.

The first hire date on-site was associated with the decrease in risk of parenchymal abnormalities and pleural abnormalities ($p=0.0009$ and $p=0.0727$ respectively) with those first hired during the Vietnam War era (1965 to mid-1975) having a statistically significant lower risk of both types of abnormalities as compared to those hired in the first years (1947-1950) of nuclear weapons operations on site (OR=0.14 95% CI 0.05-0.40 and OR= 0.27 95% CI 0.10-0.72 respectively).

This study used multiple ILO readers protocol but found a substantial inter-reader agreement with regards to both profusion score and pleural abnormalities.

The results of this study confirm the need to screen former nuclear weapons workers for pulmonary health effects of airborne exposures in the manufacture of nuclear weapons

Further epidemiological studies are needed to investigate the suggested increased risk of parenchymal abnormalities in those exposed directly to high explosives and barium.