Table of Contents

INTRODUCTION....1

MATERIALS AND METHODS....1

Surveillance Program Overview....1

Respiratory Disease Surveillance....4

RESULTS....5

Descriptive and Statified Analyses....5

Linear Regression Analysis....12

DISCUSSION....13

REFERENCES....17

FIGURES and TABLES....20

Figure I - Exposure Categories Tasks and Materials....20

Table I - Project Characteristics by Site....21

Table II - Definition of Respiratory Disease....22

Table III - Demographic Characteristics of Construction and Craft Workers....23

Table IV - Smoking Status of Construction and Craft Workers....24

Table V - Prevalence of Spirometric Abnormalities According to Smoking Status....24

Table VI - Prevalence of Abnormal Pulmonary Function by Trade and Site....25

Table VII - B-read Categories of CXR in Workers with Normal Spirometry....26

Table VIII - B-read Categories of CXR in Workers with Abnormal Spirometry....26

Table IX - PFT Categories of Workers with Normal Chest Radiographs....27

Table X - PFT Categories of Workers with Abnormal Chest Radiographs....27
Table XI - Prevalence of Lung Disease Diagnosis and Reported History by Pulmonary Function and Radiographic Categories....28
Table XII - Pulmonary Function Results by Duration of DOE Work....29
Table XIII - Pulmonary Function Results by Duration of Trade Years....29
Table XIV - Symptom Prevalence....30
Table XV - Prevalence of Pulmonary Function and Radiographic Categories by Years in Trade....31
Table XVI - Multipel Linear Regression Models....32
Table XVII - Linear Regression Versus Predictor Variables....32

INTRODUCTION

Since 1996, the Department of Energy (DOE) has been studying populations of construction workers from two nuclear weapons facilities, Hanford Nuclear Reservation in Richland, Washington and Oak Ridge National Laboratory in Oak Ridge, Tennessee. In 1997 the Savannah River Site in Aiken, South Carolina was added to the research. Since construction workers have potential exposure to a variety of respiratory hazards, the research has been aimed at medical surveillance for occupational lung disease in the exposed populations.

Previous work on a subset of these workers has been submitted for publication [Dement, et. al., 2002] and has shown a significant prevalence of pulmonary disease findings. Among the findings are a number of workers with abnormal pulmonary functions but normal chest radiographs. This report covers findings for lung disease on participants who have had examinations including chest radiographs and pulmonary function tests through May 2002. A focus of this effort is further examination of workers who have a normal chest radiograph but who have an abnormal pulmonary function test.

MATERIALS AND METHODS

Surveillance Program Overview

Two phases were designed and implemented for surveillance at the three project sites. The first phase, Phase 1, was a needs assessment that lasted approximately 12 months.

The purpose of the needs assessment was to determine whether workers had experienced exposures to hazards at levels that may place them at risk of occupational lung disease. Information was collected on site processes, work, and potential exposures to make this determination. After review of Phase I, a decision was made to authorize implementation of Phase 2 for all three project sites.

The second phase consisted of further development of surveillance instruments and protocols to assess the construction workers at each site. A detailed occupational history including type of work at each site, exposures to potentially toxic materials, work procedures and work in specified areas was performed. Additional medical history obtained information about prior diagnoses that are either related to work or work site as well as conditions that are possibly related to work site. These include questions about bronchitis, pneumonia, hay fever, chronic bronchitis, emphysema, asthma, and chest injuries. The occupational history is conducted either by telephone or in person by a trained interviewer using computer-driven screens to collect the data. During the occupational history, site maps and site-specific information are used to help with information recall.

The occupational interviews attempt to determine whether a worker has had exposure to hazardous substances that would warrant further medical screening for occupationally related disease. Part of the work history collected determines the trade of the worker and the types of toxic materials that the worker was exposed to during their work at the DOE sites. Duration of exposure is estimated from length of work at DOE sites or length of

work in their trade. There are detailed questions that ask about working around high hazard work tasks, high hazard materials and working in areas where there were known hazardous materials or exposure incidents. Workers are asked to qualitatively express their level of exposure to different hazardous materials using the following scale:

1- Rarely

2- Few times per month

3- Couple of times per week

4- Daily or most days per week

5- Constantly

Local clinical providers are contracted to perform the medical screening examinations and are required to adhere to a detailed protocol. The medical examination includes a detailed medical history including smoking, a limited physical examination and tests screening for occupational disease. A project nurse coordinator reviews each of the findings from the examinations and consults with the medical director as needed. The examining physician subsequently reports these results to the participant. A quality assurance program includes on-site visits, chart reviews, and periodic review of the data to determine and explain any irregularities. In addition, participating workers are asked to complete a questionnaire regarding the program quality and their level of satisfaction.

Table I shows that approximately 75,000 workers are potentially available for the screening program. Workers participate in the program voluntarily and may choose any

or all of the parts of the screening protocol. Due to the voluntary nature of participation, there is potential selection bias with regard to the screening program and tests that participants choose after acceptance into the program. This report includes data from 2888 workers who have completed both a chest radiograph and a pulmonary function test but focuses on those who have an abnormal pulmonary function test.

Respiratory Disease Surveillance

Part of the medical examination includes a respiratory symptom questionnaire, a chest radiograph, and spirometry. The American Thoracic Society DLD-78 questionnaire was used and adapted to develop the respiratory history and symptom questionnaire [Ferris, 1978]. Workers were given the option to have a posterior-anterior (PA) chest radiograph interpreted by a local B-reader according to International Labour Office (ILO) Classification of Radiographs of Pneumoconiosis [ILO, 1980]. Any profusion score of 1/0 or greater was classified as a parenchymal abnormality. Pleural abnormalities were defined from any notation of a positive finding in section 3A-D of the NIOSH ILO coding form.

Workers were also given opportunities to have spirometry performed by local providers under the ATS standards [ATS, 1987]. Optimally, a minimum of three acceptable spirograms with forced expiratory volume in 1 second (FEV1) and forced vital capacity (FVC) variations less than 5% are desirable. No spirometry test was excluded for failing to meet these criteria. Standard prediction equations of Crapo, et al., were used to

determine worker variation from normal results of spirometric testing [Crapo 1981]. From these predicted values, 95% confidence intervals were calculated and used to categorize pulmonary dysfunction. For the purposes of these analyses the pulmonary function tests were classified as normal, obstructive, restrictive, or mixed according to the parameters listed in Table II.

All data collected by these programs have been entered into a Microsoft Access database [Microsoft]. Data queries were performed to extract demographic, work status, exposure history, and medical information. Data extracted by these queries were then exported to Microsoft Excel for statistical analysis. All analyses presented in this report were conducted using Microsoft Excel [Microsoft]. Both stratified and linear regression analyses were used to explore these data.

RESULTS

Descriptive and Stratified Analyses

Demographic data for the 2888 workers who completed both a chest radiograph and spirometric examinations are summarized in Table III. Mean ages for participants ranged from 53.3 at Savannah River to 60.9 at Hanford. The mean age for all sites was 58.0 with a standard deviation of 12.8. Males comprised 95.1% of the all participants but Savannah River had 10.5% female participants. Over 98% of the participants from Oak Ridge and Hanford were males. There was over 90% Caucasians at Oak Ridge and Hanford while 25.3% of the Savannah River participants were African-American. Other racial groups

represented less than 4% of the study population. The average length of time worked at DOE sites was 14.2 years for all participants. The mean total years in the trade were recorded for the Hanford and Savannah River sites and were 28.7 and 24.0 years respectively with a combined average of 26.3 years.

A cigarette smoking history was recorded for 97% of all participants and is summarized in Table IV. Over two-thirds of all the workers reported smoking at some time, but only 18.6% were current smokers. Only 32.8% of all participants reported never smoking. The mean pack-years for current smokers ranged from 26.4 to 33.5 with an overall mean of 30.0 pack years. Before quitting, former smokers smoked more on average than workers who continue to smoke (20.4 vs. 18.9 cigarettes per day, $p < .008$). The average length of time that former smokers quit smoking ranged from 16.4 years to 21.7 years with a mean of 19.3 years for all sites.

Smoking status is listed for workers with normal and abnormal spirometry in Table V. As expected, workers who never smoked had the highest prevalence of normal spirometry (66.3%) and current smokers had the lowest (46.5%). Current smokers had a 53.6% prevalence of abnormal spirometry while participants who never smoked had a 33.7% prevalence of abnormal spirometry.

Overall there were 1240 workers (42.9%) that had abnormal spirometric examinations with the highest prevalence found in the Oak Ridge site (52.9%). Savannah River and Hanford had prevalence rates just under 40%. The trades of these workers and the

prevalence of abnormal pulmonary function tests are summarized in Table VI. The Oak Ridge workers had a higher prevalence of abnormal pulmonary testing than workers from the other two sites in every trade with the exception of cement masons/finishers and ironworkers. The only trades with prevalence rates of less than 40% were boilermakers (31.1%), ironworkers (34.5%), and pipe fitters (38.5%). The highest prevalence of abnormal examinations was in welders (53.3%), millwrights (50.0%), and other trades (52.8%).

The chest radiograph results from workers with normal and abnormal spirometry are presented in Tables VII and VIII. Overall the prevalence of normal chest radiographs in workers with normal spirometry was 80.3% but when the spirometry was abnormal, the prevalence was 68.5%. The prevalence of positive findings for parenchymal disease was low in both normal and abnormal spirometry (1.9% and 2.6%). The prevalence of mixed parenchymal and pleural disease was higher in workers with abnormal spirometry (4.4%) when compared to workers with normal pulmonary tests (2.2%). The most striking feature of each of these tables is the high prevalence of pleural disease found in the Hanford participants. Workers from Hanford with normal spirometry had a 30.8% prevalence of pleural disease and workers with abnormal spirometry had a prevalence of 42.5%. Savannah River participants had the lowest prevalence of pleural disease with a rate of 5.2% in workers with normal spirometry and a rate of 12.8% in workers with abnormal spirometry. Parenchymal disease was most prevalent at Oak Ridge with rates of 3.8% and 3.3% for workers with normal and abnormal spirometry.

The spirometric studies are summarized for the three sites in Tables IX for participants with normal chest radiographs and in Table X for participants with abnormal chest radiographs. Workers with normal chest radiographs had a 60.9% prevalence of normal spirometry but workers with abnormal chest radiographs had a 45.5% prevalence of normal radiographs. Hanford participants had the highest prevalence of normal spirometry in workers with both normal and abnormal chest radiographs (66.0% and 52.6%). The restrictive pattern was the most common type of spirometric abnormality seen in both workers with normal and abnormal chest radiographs with prevalence rates of 19.2% and 24.6% respectively. The obstructive pattern was the next most common type of abnormality seen in workers with normal chest radiographs, with a prevalence of 11.6%. In participants with abnormal chest radiographs, the mixed pattern was slightly more prevalent (15.1%) than the obstructive pattern (14.8%). Hanford workers had the highest prevalence of obstructive abnormalities in both categories of normal radiography (18.5%) and abnormal radiography (17.5%). Oak Ridge workers had the highest prevalence of restrictive abnormalities in workers with normal chest radiographs (32.2%) and Savannah River workers had the highest prevalence of restrictive abnormalities in workers with abnormal chest radiographs (39.5%).

Selected medical history from the workers regarding bronchitis, emphysema, pneumonia, asthma, and chronic bronchitis are summarized in Table XI. These findings show that participants with abnormal spirometry had a higher prevalence of the pulmonary diseases mentioned than did workers with normal spirometry. Workers who had abnormal chest radiographs and normal spirometry had less prevalence of pulmonary disease history and

diagnosis than workers who had normal chest radiographs but abnormal spirometry. In every category, the highest prevalence of pulmonary disease was in the subset of workers with abnormal chest radiographs and abnormal spirometry. When a history of chronic bronchitis is considered, participants with abnormal spirometry had about twice the prevalence of disease (14.6% in those with normal chest radiographs and 19.0% with abnormal chest radiographs) as those with normal spirometry (5.8% with normal chest radiographs and 8.3% with abnormal chest radiograph). The prevalence rates of asthma history and diagnosis were also about twice higher between these two groups. When comparing emphysema history and diagnosis, the prevalence rates for workers with abnormal spirometry are over 7 times those as compared to workers with normal spirometry. Workers with abnormal spirometry and abnormal chest radiographs reported a history of emphysema 14 times more frequently (17.2%) than workers with both normal studies (1.2%).

Table XII presents pulmonary function results stratified by years of DOE site work. Workers that have worked at DOE sites 15-19 years had the highest prevalence of normal spirometry (61.2%) and workers that had 20 or more years of DOE site work had the lowest prevalence of normal spirometry (54.6%). The prevalence rates of restrictive disease increased over DOE work years from 17.9% in workers with less than 5 years of DOE experience to 22.7% in workers with more than 20 years of DOE experience. The prevalence rates of obstruction ranged from 9.4% to 14.4%. The prevalence rates of mixed pulmonary disease ranged from 8.6% to 11.4%. The highest prevalence of obstructive and mixed pulmonary disease was seen in workers with less than 5 years of

DOE experience. Overall, the prevalence rates for all abnormalities of spirometry ranged from 38.8% to 45.4% with no trend if DOE work years are considered. Workers with the most DOE work experience did represent the group with the highest prevalence of any spirometric abnormality.

Spirometric results are stratified by the number of years in any trade in Table XIII. These results represent only workers from Savannah River and Hanford, as the trade year data for Oak Ridge participants was unavailable. Abnormal spirometric abnormalities were more prevalent after 30 years of trade experience, with prevalence rates of any abnormality ranging from 29.1% in the least experienced workers to 48.7% in the most experienced. Workers with less than 5 years of trade experience had the highest prevalence of obstructive disease (20.0%). Prevalence rates for restrictive spirometric patterns ranged from 5.5% in workers with less than 5 years of experience to 22.2% with workers with greater than 44 years of trade experience. The second and third highest prevalence rates of restrictive disease were observed in the 15-19 year and 10-14 year categories respectively. Prevalence rates of mixed spirometric results ranged from 3.6% in workers with the least experience to 18.1% in workers with 10-14 years of trade experience. Trade experience was unknown in 6 of the 2159 participants from Savannah River and Hanford.

The prevalence rates of pulmonary symptoms cross-tabulated with spirometric and radiographic categories are presented in Table XIV. The definitions of symptoms with sample questions from the survey are given under Table XIV. Prevalence of cough

ranged from 20.8% in workers with both normal spirometry and radiographs to 39.2% in workers with both abnormal studies. Dyspnea 1 was present in 40.8% of workers with normal studies and was 76.4% in workers whose spirometry and chest radiographs were both abnormal. Symptom prevalence rates for phlegm ranged from 21.2% to 43.8% while prevalence rates for dyspnea 2 ranged from 23.4% to 56.9%. For each symptom, the lowest prevalence rates were observed in workers with both normal studies, followed by workers with normal spirometry and abnormal radiography. After that the next highest prevalence rates were seen in workers with abnormal spirometry and normal radiography. As expected workers with both abnormal spirometry and abnormal chest radiography had the highest rates of symptom prevalence.

Table XV presents a cross-tabulation of spirometric and radiographic results stratified by years of trade experience. Normal chest radiography and normal spirometry prevalence rates were highest (67.3%) in workers with < 5 years of trade experience while workers with greater than 44 years of trade experience had the lowest prevalence (16.7%) of both normal studies. After 30 years of trade experience the prevalence rates of both normal studies drop below 50%. In the category of both abnormal spirometry and radiography, there is a fairly consistent increase in prevalence rates as work experience increases (3.6% to 27.3%). A similar increase in prevalence rates is seen in the category of normal spirometry and abnormal radiography with a range of 3.6% to 30.3%. Prevalence rates for workers in the category of abnormal spirometry and normal radiography range from 19.8% to 31.0% with no pattern of change as work experience increases. Workers with less than 5 years of experience had a 25.5% prevalence of having normal chest

radiography and abnormal spirometry. The prevalence of combined abnormal spirometry and abnormal chest radiographs increased rapidly with duration of trade work. In general, the increasing prevalence of abnormal chest radiographs correlated well with duration of years in trade.

Linear Regression Analysis

Linear regression models were used to explore pulmonary function parameters (FEV1 and FVC) as a function of trade years of work and pack-years of smoking history. A change in FEV1 and FVC was calculated as the deviation from the standardized prediction. These two variables were regressed against the number of cigarette pack years and the number of trade years for every worker at Savannah River and Hanford. Multiple regression model equations are listed in table XVI. As shown in Table XVII, an excess of 7.5 ml per year loss in FEV1 was observed when the change in FEV1 was regressed against the number of pack years. The excess loss per year was 5.7 ml when the change in FEV1 was regressed against the number of trade years. The excess loss of FVC per year was 4.8 ml and 8.1 ml for pack years and trade years respectively. The same regression model was for % Predicted FVC and % Predicted FEV1 as the outcome. All regression statistics were statistically significant at the .0001 level and both the change in pulmonary function and % Predicted gave comparable results.

DISCUSSION

Department of Energy workers at Oak Ridge, Savannah River, and Hanford performed a variety of new construction, renovation, and maintenance tasks that resulted in potential exposures to a variety of pulmonary toxicants including silica, welding fumes and asbestos. Accurate exposure monitoring was not in place during the period of their work exposure. In this setting, questionnaires regarding work history and exposure history are the means used to assess workers for exposure frequency and duration. Trained interviewers conducted detailed interviews with the maps, photos, and other site-specific materials to improve worker recall. The data collected from these interviews determined the need for medical screening and selection of appropriate tests to assess potential occupational respiratory disease. The data are limited by the ability of each individual to recall work history and exposure information despite the use of tools such as maps, photos and other site-specific material.

In this population of 2888 exposed workers, more than 50% reported constant exposure to asbestos and more than 40% reported constant exposure to silica as shown in Figure 1. More than three quarters of this population reported exposures to silica, welding fumes and asbestos on a weekly basis. With a lack of exposure monitoring, the best exposure surrogate available is either by years of DOE work or years of trade work.

The data analyzed in this report are from workers from Hanford, Savannah River, and Oak Ridge sites who have had both chest radiographs and spirometric testing. Overall

42.9% of the workers had abnormal pulmonary function demonstrated through spirometry and 25.8% had abnormal chest radiographs. Some workers who had a prior diagnosis of lung disease were not re-examined, therefore true prevalence of pulmonary disease may be underestimated. Self-selection into the program may bias the data but this effect cannot be directly evaluated. Although inconclusive, there is no evidence found to support any adverse effect from self-selection.

The effect of smoking as a confounder cannot be ignored when considering pulmonary disease data. Over two-thirds of the population examined had smoked cigarettes at some point in their lifetime. Smoking prevalence of construction workers in other studies range from 39% to 53.5% [Rothenbacher 1996; Rothenbacher 1998; Millar 1989]. The process required to enter the medical screening aspect of the program may select subjects with respiratory histories that may over represent smokers in this subset.

Workers from the Oak Ridge site had the highest prevalence (52.9%) of spirometric abnormalities but without a similarly high prevalence of smoking when compared to the other two sites. The high prevalence of radiographic abnormalities seen in the Hanford workers is attributed to the high prevalence of pleural abnormalities. Although different B-readers were used for interpretation of radiographs at each site, quality assurance in this program has indicated that variability in prevalence of the radiographic abnormalities observed cannot be explained by practitioner differences alone. Overall, the prevalence of symptoms and positive respiratory histories were significantly higher in workers who had abnormal tests but more so in those that had abnormal spirometric tests.

Without exposure monitoring, the best surrogate of exposure for these workers is duration of work. The duration of years in a given trade is better than the years of work at the DOE site since most construction workers rarely stay at a single site for their entire career. Our data suggest a strong correlation between duration of work and abnormal spirometric and radiographic findings.

Studies on the effect of age on pulmonary function demonstrate a normal decline in pulmonary function starting after the age of 35 in nonsmokers [American Thoracic Society 1995]. Normal pulmonary function deteriorates at about 30 ml per year in FVC and FEV1 [Musk 1977]. Pulmonary function prediction equations control for age, race, sex, and body size and allow interpretation of changes in spirometric testing to be attributed to other factors. The linear regression analyses show statistical significance for the effects of smoking and duration of trade work on changes in pulmonary function as presented in the results. An excess loss of 7.5 ml per year in FEV1 (in addition to the 30 ml per year expected) is consistent with Cowie's study on silica-exposed gold miners who demonstrated an average annual loss of 37 ml for FEV1 [Cowie 1998]. Though not performed, an interesting analysis would be on workers who never smoked and considering work duration as an explanatory variable for change in pulmonary function.

Strength of this study is in the large population of construction workers who have had spirometric tests, chest radiography, and detailed medical history focusing on pulmonary disease. While medical tests are intuitively objective, there may be variability between

B-readers and technicians performance of spirometric tests. Weaknesses of this study are the ability of workers to recall site-specific work history and the lack of accurate personal or environmental monitoring of hazardous materials. Further studies with accurate exposure monitoring need to be performed on DOE construction workers to determine worker susceptibility to occupational respiratory disease despite the fact that conditions have changed due to federal regulatory control of hazardous exposures [OSH Act 1970].

These construction workers have been exposed to a combination of hazardous substances, some of which are known carcinogens. The radiographic abnormalities described here are consistent with occupational exposures to asbestos and silica. These workers should have continued medical surveillance screening for signs and symptoms of respiratory disease especially considering the latency associated with mesothelioma related to asbestos exposure [Bianchi 2001]. Construction workers, especially plumbers, carpenters, electricians and insulators, have been demonstrated to be at increased risk for developing occupationally related mesothelioma [McDonald 2001]. In addition, silica was classified by IARC as a group I human carcinogen in 1997 due to excess mortality from lung cancer [Steenlan 2001, Neuberger 1990]. Measures for prevention of respiratory disease should be aimed at education of workers regarding occupational respiratory hazards and smoking cessation.

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FIGURE I

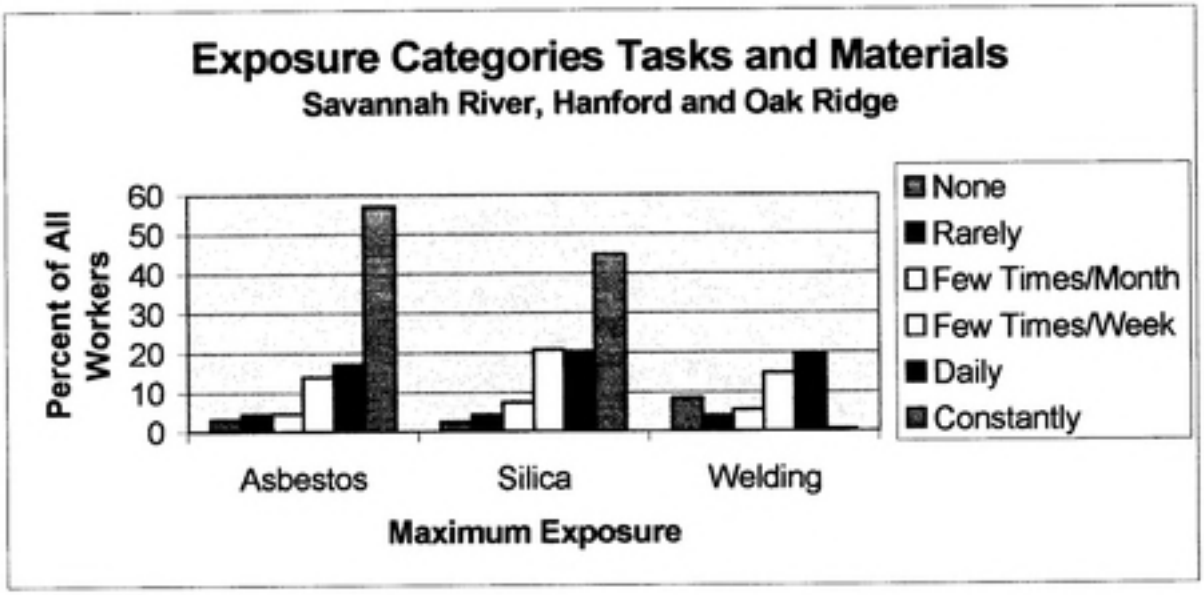

Exposure Categories Tasks and Materials
Savannah River, Hanford and Oak Ridge
Percent of All Workers
60
50
40
30
20
10
0
None
Rarely
Few Times/Month
Few Times/Week
Daily
Constantly
Asbestos
Silica
Welding
Maximum Exposure

TABLE I

Project Characteristics by Site

Parameter	Hanford	Savannah River	Oak Ridge
Date site opened	1943	1949	1943
Number of construction and trade workers potentially available for screening	30,000	37,000	8,000

TABLE II

Definition of Respiratory Disease [1]	
Respiratory Classification	**Spirometric Parameters**
Normal	FVC ≥ 95% CI for Predicted Value FEV1/FVC ≥ 95% CI for Predicted Value
Obstructive Disease	FVC ≥ 95% CI for Predicted Value FEV1/FVC < 95% CI for Predicted Value
Restrictive Disease	FVC < 95% CI for Predicted Value FEV1/FVC ≥ 95% CI for Predicted Value
Mixed Obstructive/Restrictive Disease	FVC < 95% CI for Predicted Value FEV1/FVC < 95% CI for Predicted Value

[1] For These Analyses

TABLE III

Demographic Characteristics of Construction and Craft Workers [1]				
Parameter	**Hanford**	**Savannah River**	**Oak Ridge[2]**	**All Sites**
Workers Completing Exam				
Number with PFT & B-reads	1067	1092	729	2888
Age				
Mean (SD)	60.9 (12.4)	53.3 (11.9)	60.7 (12.7)	58.0 (12.8)
Sex				
Male (%)	1055 (98.9%)	977 (89.5%)	715 (98.1%)	2747 (95.1%)
Female (%)	12 (1.1%)	115 (10.5%)	14 (1.9%)	141 (4.9%)
Race				
Caucasian (%)	965 (90.4%)	783 (71.7%)	684 (93.8%)	2432 (84.2%)
African-American (%)	33 (3.1%)	276 (25.3%)	32 (4.4%)	341 (11.8%)
Hispanic (%)	27 (2.5%)	5 (0.5%)	1 (0.1%)	33 (1.1%)
Asian/Hispanic (%)	3 (0.3%)	1 (0.1%)	0	4 (.1%)
Alaskan/Indian (%)	13 (1.2%)	6 (0.5%)	5 (0.7%)	24 (0.8%)
Other and Unknown (%)	26 (2.4%)	21 (1.9%)	7 (1.0%)	54 (1.9%)
Years at DOE Site				
Mean (SD)	13.5 (10.0)	13.2 (8.3)	16.8 (11.5)	14.2 (10.0)
Years in Trade				
Mean (SD)	28.7 (12.3)	24.0 (11.3)	-------	26.3 (12.1)

[1] Workers with both PFT and B-read studies

[2] Total trade years not available for workers at Oak Ridge

TABLE IV

Smoking Status of Construction and Craft Workers [1]				
Parameter	**Hanford**	**Savannah River**	**Oak Ridge**	**All Sites**
Number of Workers	1067	1092	729	2888
Smoking Status				
Never (%)	325 (30.5%)	407 (37.3%)	215 (29.5%)	947 (32.8%)
Former (%)	545 (51.1%)	445 (40.8%)	329 (45.0%)	1319 (45.7%)
Current (%)	173 (16.2%)	210 (19.2%)	153 (21.0%)	536 (18.6%)
Smoking Unknown (%)	24 (2.2%)	30 (2.7%)	32 (4.4%)	86 (3.0%)
Pack-years				
Current, Mean (SD)	33.5 (23.6)	26.4 (23.5)	31.2 (21.9)	30.0 (23.2)
Former, Mean (SD)	29.9 (24.9)	21.5 (24.1)	17.8 (22.2)	23.8 (23.4)
Cigarettes per day				
Current, Mean (SD)	19.6 (9.6)	19.1 (10.7)	18.5 (10.1)	18.9 (10.1)
Former, Mean (SD)	21.5 (11.2)	22.3 (13.4)	16.5 (13.0)	20.4 (12.7)
Former Smokers, Years Quit Mean (SD)	20.1 (13.7)	16.4 (12.2)	21.7 (14.3)	19.3 (13.6)

[1] Smoking status unavailable for 86 workers

TABLE V

Prevalence of Spirometric Abnormalities According to Smoking Status			
	Never Smoked	**Ever Smoked**	**Current Smokers**
Normal PFT	628 (66.3%)	972 (52.4%)	249 (46.5%)
Abnormal PFT	319 (33.7%)	883 (47.6%)	287 (53.6%)

TABLE VI

Prevalence of Abnormal Pulmonary Function By Trade and Site [1]				
	Hanford	**Savannah River**	**Oak Ridge**	**All Sites**
Asbestos	4 (36.4%)	13 (25.0%)	5 (50.0%)	22 (42.3%)
Boilermaker	13 (37.1%)	6 (39.2%)	4 (40.0%)	23 (31.1%)
Carpenter	39 (48.1%)	39 (45.9%)	40 (49.4%)	118 (47.8%)
Cement Masons/Finishers	7 (58.3%)	5 (41.7%)	2 (20.0%)	14 (48.3%)
Electricians	54 (37.5%)	97 (42.4%)	78 (47.0%)	229 (42.5%)
Insulators	4 (44.4%)	6 (35.3%)	3 (75.0%)	13 (43.3%)
Ironworkers	26 (59.0%)	16 (18.0%)	19 (43.2%)	61 (34.5%)
Laborers	56 (42.1%)	67 (36.6%)	82 (62.6%)	205 (45.9%)
Machinists	3 (50.0%)	3 (33.3%)	3 (60.0%)	9 (45.0%)
Millwrights	21 (47.7%)	13 (52.0%)	7 (53.8%)	41 (50.0%)
Operating Engineers	30 (40.0%)	19 (29.6%)	19 (63.3%)	68 (42.8%)
Painters	16 (47.1%)	15 (34.1%)	15 (71.4%)	46 (46.5%)
Pipe fitters	82 (34.7%)	92 (40.9%)	33 (42.9%)	207 (38.5%)
Plumbers/Steam Fitters	30 (39.0%)	3 (42.9%)	8 (50.0%)	42 (42.0%)
Sheet metal Workers	19 (43.2%)	18 (38.3%)	28 (54.9%)	65 (45.8%)
Teamsters/Truck Drivers	17 (48.6%)	16 (43.2%)	17 (63.0%)	50 (43.9%)
Welders	0 (0.0%)	2 (25.0%)	6 (75.0%)	8 (53.3%)
Others	0 (0.0%)	3 (33.3%)	16 (59.3%)	19 (52.8%)
All Trades	421 (39.5%)	433 (39.7%)	386 (52.9%)	1240 (42.9%)

[1] Workers with both PFT and B-read studies

TABLE VII

	B-read Categories of CXR in Workers with Normal Spirometry			
	Hanford	**Savannah River**	**Oak Ridge**	**All Sites**
Negative	417 (64.6%)	616 (93.5%)	290 (84.5%)	1323 (80.3%)
Positive Parenchymal Only	12 (1.9%)	6 (0.9%)	13 (3.8%)	31 (1.9%)
Positive Pleural Only	199 (30.8%)	34 (5.2%)	25 (7.3%)	258 (15.7%)
Both Positive	18 (2.8%)	3 (0.5%)	15 (4.4%)	36 (2.2%)
Total	646	659	343	1648

TABLE VIII

	B-read Categories of CXR in Workers with Abnormal Spirometry			
	Hanford	**Savannah River**	**Oak Ridge**	**All Sites**
Negative	215 (51.1%)	347 (80.7%)	288 (74.0%)	850 (68.5%)
Positive Parenchymal Only	8 (1.9%)	11 (2.6%)	13 (3.3%)	32 (2.6%)
Positive Pleural Only	179 (42.5%)	55 (12.8%)	70 (18.0%)	304 (24.5%)
Both Positive	19 (4.5%)	17 (4.0%)	18 (4.6%)	54 (4.4%)
Total	421	430	389	1240

TABLE IX

	PFT Categories of Workers with Normal Chest Radiographs			
	Hanford	**Savannah River**	**Oak Ridge**	**All Sites**
Normal	417 (66.0%)	616 (64.0%)	290 (50.2%)	1323 (60.9%)
Restrictive	44 (7.0%)	187 (19.4%)	186 (32.2%)	417 (19.2%)
Obstructive	117 (18.5%)	94 (9.8%)	41 (7.1%)	252 (11.6%)
Mixed	54 (8.5%)	66 (6.9%)	61 (10.6%)	181 (8.3%)
	632	963	578	2173

TABLE X

	PFT Categories of Workers with Abnormal Chest Radiographs			
	Hanford	**Savannah River**	**Oak Ridge**	**All Sites**
Normal	229 (52.6%)	43 (33.3%)	53 (35.1%)	325 (45.5%)
Restrictive	71 (16.3%)	51 (39.5%)	54 (35.8%)	176 (24.6%)
Obstructive	76 (17.5%)	11 (8.5%)	19 (12.6%)	106 (14.8%)
Mixed	59 (13.6%)	24 (18.6%)	25 (16.6%)	108 (15.1%)
	435	129	151	715

TABLE XI

Prevalence of Lung Disease Diagnosis and Reported History by Pulmonary Function and Radiographic Categories

Positive History	Normal Spirometry		Abnormal Spirometry	
	Normal CXR	Abnormal CXR	Normal CXR	Abnormal CXR
Bronchitis history	266 (20.1%)	76 (23.4%)	234 (27.6%)	137 (35.1%)
Bronchitis diagnosis	217 (16.4%)	65 (20.0%)	198 (23.3%)	111 (28.5%)
Pneumonia history	305 (23.1%)	104 (32.0%)	282 (33.2%)	156 (40.0%)
Pneumonia diagnosis	271 (20.5%)	96 (29.5%)	258 (30.4%)	135 (34.6%)
Chronic bronchitis history	93 (7.0%)	28 (8.6%)	124 (14.6%)	74 (19.0%)
Chronic bronchitis diagnosis	77 (5.8%)	27 (8.3%)	105 (12.4%)	64 (16.4%)
Emphysema history	16 (1.2%)	7 (2.2%)	111 (13.1%)	67 (17.2%)
Emphysema diagnosis	13 (1.0%)	7 (2.2%)	94 (11.1%)	61 (15.6%)
Asthma history	91 (6.9%)	28 (8.6%)	130 (15.3%)	61 (15.6%)
Asthma diagnosis	70 (5.3%)	16 (4.9%)	108 (12.7%)	53 (13.6%)

TABLE XII

Pulmonary Function Results by Duration of DOE Work					
Years of DOE Site Work	**Normal PFT**	**Obstruction**	**Restriction**	**Mixed**	**All Abnormal PFT**
<5	261 (56.3%)	67 (14.4%)	83 (17.9%)	53 (11.4%)	203 (43.7%)
5-9	355 (56.2%)	87 (13.8%)	120 (19.0%)	70 (11.1%)	277 (43.8%)
10-14	327 (59.0%)	56 (10.1%)	118 (21.3%)	53 (9.6%)	227 (41.0%)
15-19	255 (61.2%)	39 (9.4%)	87 (20.9%)	36 (8.6%)	162 (38.8%)
≥ 20	442 (54.6%)	107 (13.2%)	184 (22.7%)	77 (9.5%)	368 (45.4%)
Unknown	8	2	1	0	3
Totals	1648	358	593	289	1240

TABLE XIII

Pulmonary Function Results by Duration of Trade Years [1]					
Years in Trade	**Normal PFT**	**Obstruction**	**Restriction**	**Mixed**	**All Abnormal PFT**
<5	39 (70.9%)	11 (20.0%)	3 (5.5%)	2 (3.6%)	16 (29.1%)
5-9	77 (59.7%)	21 (16.3%)	21 (16.3%)	10 (7.8%)	52 (40.3%)
10-14	117 (63.2%)	18 (9.7%)	35 (18.9%)	15 (18.1%)	68 (36.8%)
15-19	166 (63.6%)	25 (9.6%)	50 (19.2%)	20 (7.7%)	95 (36.4%)
20-24	240 (68.0%)	42 (11.9%)	46 (13.0%)	25 (7.1%)	113 (32.0%)
25-29	202 (65.4%)	43 (13.9%)	43 (13.9%)	21 (6.8%)	107 (34.6%)
30-34	153 (53.7%)	51 (17.9%)	50 (17.5%)	31 (10.9%)	132 (46.3%)
35-39	127 (52.7%)	46 (19.1%)	39 (16.2%)	29 (12.0%)	114 (47.3%)
40-44	99 (55.9%)	19 (10.7%)	31 (17.5%)	28 (15.8%)	78 (44.1%)
≥ 45	81 (51.3%)	21 (13.3%)	35 (22.2%)	21 (13.3%)	77 (48.7%)
Unknown	4	1		1	2
Totals	1305	298	353	203	854

[1] Savannah River and Hanford only

TABLE XIV

Symptom Prevalence				
Symptom	**Normal PFT**		**Abnormal PFT**	
	Normal CXR	**Abnormal CXR**	**Normal CXR**	**Abnormal CXR**
Cough	275 (20.8%)	81 (24.9%)	282 (33.2%)	153 (39.2%)
Phlegm	280 (21.2%)	85 (26.2%)	293 (34.5%)	171 (43.8%)
Dyspnea 1	540 (40.8%)	170 (52.3%)	532 (62.6%)	298 (76.4%)
Dyspnea 2	309 (23.4%)	106 (32.6%)	410 (48.2%)	222 (56.9%)

Definitions:

Cough - "Yes" to "Do you usually have a cough?" and "Yes" to "Do you usually cough like this on most days for 3 consecutive months or more during the year?"

Phlegm- "Yes" to "Do you usually bring up phlegm from your chest?" and "Yes" to "Do you bring up phlegm like this on most days for 3 consecutive months or more during the year?"

Dyspnea Grade 1 - "Yes" to "Are you troubled by shortness of breath when hurrying on the level or walking up a slight hill?"

Dyspnea Grade 2+ - "Yes" to "Do you have to walk slower than people of your age because of breathlessness?" or questions showing a more severe dyspnea.

TABLE XV

Prevalence of Pulmonary Function and Radiographic Categories By Years in Trade				
Years in Trade	**Normal Spirometry**		**Abnormal Spirometry**	
	Normal CXR	**Abnormal CXR**	**Normal CXR**	**Abnormal CXR**
<5	37 (67.3%)	2 (3.6%)	14 (25.5%)	2 (3.6%)
5-9	70 (54.3%)	7 (5.4%)	40 (31.0%)	12 (9.3%)
10-14	110 (59.5%)	7 (3.8%)	53 (28.6%)	15 (8.1%)
15-19	154 (58.8%)	13 (5.0%)	76 (29.0%)	19 (7.3%)
20-24	214 (60.6%)	26 (7.4%)	80 (22.7%)	33 (9.3%)
25-29	166 (53.7%)	36 (11.7%)	74 (23.9%)	33 (10.7%)
30-34	107(37.5%)	46 (16.1%)	82 (28.8%)	50 (17.5%)
35-39	74 (30.7%)	53 (22.0%)	65 (27.0%)	49 (20.3%)
40-44	63 (35.6%)	36 (20.3%)	35 (19.8%)	43 (24.3%)
≥ 45	11 (16.7%)	20 (30.3%)	17 (25.8%)	18 (27.3%)

[1] Savannah River and Hanford only

Table XVI

Multiple Linear Regression Models	
Predictor Variable	**Model**
Change in FEV1	$\Delta FEV1 = \beta_o + \beta_1(\text{Trade Years}) + \beta_2(\text{Pack Years}) + \text{residual}$
Change in FVC	$\Delta FVC = \beta_o + \beta_1(\text{Trade Years}) + \beta_2(\text{Pack Years}) + \text{residual}$
%Pred FEV1	$\%\text{Pred FEV1} = \beta_o + \beta_1(\text{Trade Years}) + \beta_2(\text{Pack Years}) + \text{residual}$
%Pred FVC	$\%\text{Pred FVC} = \beta_o + \beta_1(\text{Trade Years}) + \beta_2(\text{Pack Years}) + \text{residual}$

Where β_o = Intercept; β_1 = slope of Trade Years simple linear regression; β_2 = slope of Pack Years simple linear regression; residual = correction for error

Table XVII

Linear Regression Versus Predictor Variables[1]					
Variable	**Degrees of Freedom**	**Parameter Estimate**	**Standard Error**	**t value**	**Pr >|t|**
Change in FEV1					
Intercept	1	-0.31158	0.03967	-7.85	< .0001
Pack Years	1	-0.00748	0.00070378	-10.63	< .0001
Trade Years	1	-0.00570	0.00138	-4.13	< .0001
Change in FVC					
Intercept	1	-0.28249	0.04575	-6.17	< .0001
Pack Years	1	-0.00482	0.00081164	-5.93	< .0001
Trade Years	1	-0.00811	0.00159	-5.10	< .0001
%Pred FEV1					
Intercept	1	91.81930	1.11277	82.51	< .0001
Pack Years	1	-0.21643	0.01974	-10.96	< .0001
Trade Years	1	-0.18664	0.03867	-4.83	< .0001
%Pred FVC					
Intercept	1	93.78288	0.99787	93.98	< .0001
Pack Years	1	-0.10856	0.01770	-6.13	< .0001
Trade Years	1	-0.10854	0.03468	-5.21	< .0001

[1] Savannah River and Hanford only