A Prospective Study of Lung Function Among Boilermaker Construction Workers Exposed to Combustion Particulates

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Background *Given the evidence of both acute cross-shift and short-term decrements in lung function in boilermaker construction workers following occupational exposure to combustion particulates, we sought to determine whether exposure is associated with an annual loss in lung function.*

Methods *As part of an ongoing investigation, we conducted a 2-year longitudinal study of lung function among 118 boilermakers. Exposure was assessed with a work history questionnaire. Spirometry measurements were performed annually.*

Results *We found an association between annual FEV_1 and hours worked at a gas-fired plant during the previous year, $\beta = -9.8$ mls/100 hours worked (95% CI: $-16.0, -3.5$) after adjustment for age, baseline FEV_1 and cigarette smoking status. The adjusted association between FEV_1 and "ever" worked at a gas-fired plant was -99.7 mls (95%CI: $-154.8, -44.5$). There was also evidence of a negative association between FEV_1 and "ever" worked and hours worked at oil and coal-fired plants.*

Conclusions *These data suggest an association between annual lung function loss and working at gas, coal and oil-fired plants. Further follow-up of this cohort of boilermakers is in progress.* Am. J. Ind. Med. 39:454–462, 2001. *© 2001 Wiley-Liss, Inc.*

KEY WORDS: boilermakers; lung function; combustion particulates; welding; occupational health; respiratory diseases; natural gas

INTRODUCTION

Fossil fuels (i.e., oil, coal and natural gas) comprise the major source of energy for the production of electric power. The combustion of fossil fuels results in the production and release of particulate matter, referred to as fly ash, to the environment through stack emissions [Henry and Knapp, 1980; Kimble et al., 1982; Fisher et al., 1983]. In addition to the environmental release of particulates, a considerable quantity of ash is deposited on the walls and bottom of the boiler and is referred to as bottom ash. Workers are exposed to these fossil fuel ash particulates when large amounts of airborne dusts are generated during equipment maintenance, cleaning and repair [Williams, 1952; Sjoberg, 1955]. One trade with extensive exposure to boiler fossil fuel ash is boilermaker construction work; work which includes constructing, repairing and maintaining industrial boilers, vessels and tanks.

Despite the large numbers of workers with potential exposure to fossil fuel ash, there are few studies of the effects of occupational exposure to fossil fuel ash on the

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respiratory tract. Early studies reported clinical symptoms and signs, such as upper respiratory tract irritation, a cough with dyspnea, and rhonchi on physical examination resulting from occupational exposure to fuel oil ash [Williams, 1952; Sjoberg, 1955]. This suggests that fuel oil ash is a respiratory irritant capable of inducing respiratory symptoms, including those suggestive of asthma. However, these early studies had limited measures of exposure and effect and the exposures were generally extremely high compared to occupational exposure today. More recently, a study of 17 men cleaning bottom ash from an oil-fired boiler found marked reductions in lung function (FEV_1) [Lees, 1980]. In another study of respiratory symptoms, Levy et al. [1984] investigated a large outbreak of ‘‘boilermakers’ bronchitis,’’ described as asthmatic bronchitis, after 100 boilermakers worked on the oil-to-coal conversion of a utility company power plant. Recent studies on acute (i.e., across a work shift) and short-term (over several weeks) changes in FEV_1 demonstrated decrements in lung function among workers who overhauled an oil-fired boiler [Hauser et al., 1995, 1996]. Given the evidence of both across-shift and short-term decrements in lung function among boilermakers with occupational exposure to combustion particulates, we sought to examine chronic effects by studying exposure and annual lung function decline over a 2-year period.

Boilermaker construction workers are exposed to combustion particles from multiple sources since they work at a variety of plants that burn different fuels. They build, maintain and repair boilers and related structures at power plants burning oil, coal and/or natural gas. At these fossil fuel burning plants, they are exposed to the combustion particles when working inside the boiler. Outside the boiler, they are exposed to particles generated through work on ancillary structures such as the air-heater and condenser [Hauser et al, 1995, 1996; Woodin et al., 1999]. When repairing and maintaining fossil fuel combustion boilers they are exposed to metals such as vanadium, nickel, iron, zinc, chromium and arsenic [Woodin et al., 1998].

In addition to working on fossil fuel fired boilers, boilermakers also maintain and repair boilers at trash incinerators that burn trash and at paper mills that burn tree bark and sap for disposal. Repair and maintenance of trash incinerators results in exposure to metals such as lead and cadmium. The exposures in the paper mills are generally to organic combustion products. Furthermore, boilermakers may work at nuclear power plants and other industries in which boilers, vessels or tanks require maintenance and repair. Particulate exposure in nuclear power plants is generally minimal, and serves as a reference site for comparison. During their work, they routinely perform welding, cutting/burning and grinding. These tasks generate dusts of variable composition and size, as well as fumes and gases.

It is apparent that boilermaker construction workers' exposure is heterogeneous. As part of an ongoing investigation, we conducted a prospective longitudinal study of lung function among boilermaker construction workers exposed to combustion particulates from multiple sources.

METHODS

Cohort Description

Between December 1997 and March 1998, a cohort of 118 boilermaker construction workers from Local 29 of the International Brotherhood of Boilermakers, Iron Shipbuilders, Blacksmiths, Forgers and Helpers was assembled with the help of the union staff. The invitation to participate in the study was extended (by telephone) to a subset of the active union members by the union staff. Although exact numbers are unavailable, the union reported that they initially contacted approximately 145 union members (35% of the local's total membership). Of these, 123 agreed to participate. Two of these individuals were excluded because chronic disease prohibited participation in testing and three individuals later decided not to participate prior to signing the consent form. Reasons given for not participating included not wanting to perform the required tests. Therefore, 118 individuals comprised the inception cohort (81% participation rate).

The study was explained to each of the subjects and all their questions were answered prior to signing the consent form approved by the Harvard School of Public Health Institutional Review Board. Upon signing the consent form, each subject participated in baseline spirometry tests and completed a modified American Thoracic Society Questionnaire [Ferris, 1978]. At the yearly follow-up (Year 1 and Year 2) each subject completed spirometry and a detailed work history questionnaire described below.

Exposure Measurement

The boilermakers' trade is such that throughout the course of a typical year they will work on numerous boilers at multiple plants burning a variety of fuels. This is not unique to boilermakers in New England; it is typical for them throughout the country. The characterization of exposure is logistically difficult in the boilermaker trade because of this diversity of sites. The plants are often located far apart and require separate approval and arrangements for study access. Throughout the manuscript the term ‘‘plant’’ is used to refer to fossil fuel combustion plants (natural gas, oil, and coal), trash incinerators, paper mills or nuclear power plants. The term ‘‘fuel’’ is used to refer to the type of fuel predominately burned at the plant. Fuels include oil, coal, natural gas, trash, tree bark/sap (black liquor), and nuclear. There is a direct association between plant type and fuel burned. Therefore, a worker working at a coal plant is exposed to coal ash while working on the boiler, and a worker at a paper-mill is exposed to tree bark/sap ash. To examine whether work at fossil fuel combustion power plants, trash incinerators, paper mills, or nuclear power plants is associated with an annual decline in lung function we collected data on the number of hours worked at each type of plant.

Detailed work history information was collected using a self-administered questionnaire. The questionnaire was completed 6 months after entrance into the study, at the 1-year follow-up and again at the 2-year follow-up. To assist the workers in recalling their yearly work history, the union provided printed records that contained information about the dates worked, the number of hours worked, and at which plant an individual worked during the previous year. The self-administered questionnaire included questions on the number of hours the boilermakers performed specific tasks, i.e., welding, cutting or grinding at each plant; and whether they wore a respirator, the type of respirator worn and the percentage of time they wore the respirator while welding, cutting or grinding. The investigators reviewed each questionnaire immediately after the worker completed it, and clarified any inconsistencies and solicited any missing information.

Although the questionnaire collects information on duration of exposure it does not directly collect information on intensity of exposure. Our earlier studies however showed clear differences in exposure intensity based on work location within a plant. For instance, work within the firebox was associated with higher particulate exposure than work performed outside the firebox. Therefore, in future analyses information on work location can be used to quantify exposure intensity.

We also collected information on work performed by boilermakers at sites outside their primary trade where they may have been exposed to dusts and fumes. These sites included locations where they welded (e.g., railroad cars) or were exposed to wood dust (e.g., carpentry) and are referred to as ‘‘non-boilermaker sites.’’ Given the limited number of workers who reported to have worked at specific sites within the ‘‘non-boilermaker site’’ category, we were unable to perform separate analyses for the components of that category.

Spirometry

Most of the spirometry testing was performed in the boilermakers union hall (Quincy, MA) or at an apprentice training site (Portland, ME). The yearly tests were performed between December and March to control for possible seasonal variation in lung function that may result from seasonal allergies. To accommodate workers living a distance from these sites or who were working a schedule that did not permit them to attend testing sessions on Saturdays, we also conducted testing at one work site in Year 2.

In cooperation with the Union, we attempted to schedule spirometry tests after the worker had had several days off work. As this was not always possible, we collected information on the number of days since they last worked. Testing was generally performed between 9:00 A.M. and 2:00 P.M.; the time was recorded on the spirometry data sheet. To minimize technical variation, the same nurses and technicians used the same equipment and techniques each year.

Spirometry was performed with a portable 8-L water-filled spirometer (Survey spirometer; Warren E. Collins Inc., Braintree, MA) with an Eagle II microprocessor attachment. Tests were performed with the subject seated and wearing noseclips. Each subject performed a minimum of three acceptable forced vital capacity (FVC) maneuvers, and up to a maximum of seven maneuvers to obtain at least three acceptable curves [Ferris, 1978]. A result was considered reproducible when the maximum forced expiratory volume in one second (FEV_1) from the two best maneuvers were within 5% or 100 mL of each other, whichever was larger.

Analysis

Linear regression was used to examine the associations between FEV_1 and exposure, adjusting for potential confounders. A generalized equations (GEE) approach was used to account for the correlation between repeated measures of FEV_1 for each person [Liang and Zeger, 1986]. Using Proc Genmod (SAS 6.12), the maximum lung function at each survey was examined in relation to hours worked during the previous year in each specific type of plant [SAS, 1999]. By including hours worked at different types of plants in the same model, we controlled for confounding of one type of fuel by another. Exposure was also measured by classifying the number of hours the worker performed each of three specific operations; welding, cutting or grinding. Hours spent performing specific operations were determined for each specific type of plant. The regression models also included current cigarette smoking status and age.

Because change in lung function was of interest, FEV_1 at entry into the study was also included as a predictor of subsequent lung function [Vollmer, 1988]. This allowed for adjustment for unmeasured exposures prior to the start of the study period. To examine the implications of adjusting for initial values on the measures of association, regression coefficients were compared between exposure-response models with and without baseline FEV_1 included. In order to account for the more short-term effects of exposure, the number of days since most recent exposure was also examined as a predictor. Finally, for use of respirators among the workers, we also included the percentage of time that a respirator was worn while performing specific tasks (welding, grinding or cutting) in specific types of plants.

RESULTS

Cohort Demographics

Of the 118 boilermakers in the study population, 79 had complete data consisting of baseline, Year 1, and Year 2 spirometry. Ninety-eight boilermakers completed Year 1 spirometry (FY1), and 94 completed Year 2 spirometry (FY2) (Table I); four were missing baseline spirometry. The reasons cited for missing spirometry and work history included: illness, working out of state, family matters preventing participation, and scheduling difficulties. Note that in Table I, there were 18 non-participants in Year 1 follow-up and 17 non-participants in Year 2 follow-up. Only nine boilermakers participated in the baseline tests.

During the 2-year follow-up, there was minimal withdrawal of workers from the cohort. During FY1, one boilermaker moved out of state and one withdrew making the eligible cohort 116 (98% remained in the study). During FY2, four boilermakers left the trade because of economic reasons (i.e., lack of work), one moved out of state, and two passed away (hunting accident and cardiovascular disease) making the eligible cohort 109 (92% remain in the study).

The study population was slightly older than typical working cohorts. The mean age of the cohort was 42.6 years and 25 boilermakers (21%) were over 50 years old. When the cohort was assembled an attempt was made to enrich the cohort by over-recruiting apprentices. However, the hiring of apprentices by the union was limited at this time due to the economic climate surrounding the deregulation of the electric industry. There were 14 apprentices (individuals with less than 5 years experience) in the cohort. All boilermakers were male and 97% were Caucasian. Thirty-one percent were current smokers and 32% were never smokers. Six boilermakers had a physician diagnosis of asthma and 18 reported on the modified ATS questionnaire to have symptoms of chronic bronchitis (Table II). The average baseline FEV_1 was only 90% of predicted based on predicted values derived from Hankinson et al. [1999]. The mean baseline FVC was 94%. When stratified by follow-up status, the mean baseline FEV_1 was lower for those lost to follow-up than for those who were tested in Year 1 or 2, 86.4 and 91.2%, respectively.

TABLE I. Number of Boilermakers Participating in Baseline Testing (Baseline), Year 1 Spirometry (FY1) and Year 2 Spirometry (FY2)

	Baseline spirometry	FY1 spirometry	FY2 spirometry
Participants	114 (97%)	98 (83%)	94 (80%)
Non-participants	4 (3%)	18 (15%)	17 (14%)
Withdrew from Study	0 (0%)	2 (2%)	7 (6%)
Number remaining in study cohort	118	116	109

TABLE II. Demographics and Lung Function for the Cohort of Boilermaker Construction Workers

	Mean (SD)	Range[a]	% Predicted
Age (years)	42.6 (8.8)	20.5–56.5	
FEV_1 (ml)			
Baseline[b]	3700 (760)	1290–5700	90.4 (15.9)
Follow-up year 1[b]	3728 (703)	1440–5590	91.0 (14.1)
Follow-up year 2[b]	3597 (700)	1060–5520	89.2 (14.3)
FVC (ml)			
Baseline[b]	4854 (860)	3020–6890	93.9 (12.5)
Follow-up Year 1[b]	4892 (812)	3400–6920	94.0 (12.0)
Follow-up Year 2[b]	4732 (861)	2940–6840	94.7 (12.1)
Smoking status (Number, %)			
Non-smokers	38 (32.2%)		
Ex-smokers	43 (36.4%)		
Current smokers	37 (31.4%)		

[a]Minimum and maximum value.
[b]Baseline: n = 114; Follow-up Year 1: n = 98; Follow-up Year 2: n = 94.

Type of Plant

The primary exposure variable was the number of hours worked at each specific type of plant (oil, coal, natural gas, paper-mill, trash incinerator, or nuclear). We also collected information on the number of hours worked at other non-boilermaker sites (i.e., non-boilermaker work). The numbers and percentages of workers that ever worked at each specific type of plant are presented in Table III. The data show that for each type of plant, there were many boilermakers who did not work at that type of plant during the follow-up interval. These individuals were therefore unexposed during the follow-up interval. In analyses of the effects of each specific type of plant, the unexposed workers served as an internal reference group. In Table III, the mean number of hours worked, categorized by plant type is based only on those workers who ever worked at that type of plant during the follow-up interval. The most common type of plant in which the boilermakers worked was fueled with oil. A total of 82% of the workers in the first year and 74% in FY2 spent some time working in an oil-fired plant. Overall, the number of hours worked was substantially higher in FY2 for all types of plants, with the exception of trash incinerators.

The number of boilermakers working at different types of plants during the annual follow-up interval was similar in years 1 and 2. During each year, only a small percentage worked at a single type of plant, 7% in Year 1 and 14% in

TABLE III. Distribution of the Number of Hours Worked at Each Specific Type of Plant for Boilermakers That Worked at Least 1 Hour at the Specific Type of Plant During the Follow-Up Interval (Data are Presented for Follow-up Years 1 and 2 Separately)

	Year 1[a]		Year 2[a]	
Plant type	Number (%) boilermakers that ever worked at specific type of plant	Hours worked[b] Mean (SD) Median [Min.–Max.]	Number (%) boilermakers that ever worked at specific type of plant	Hours worked[b] Mean (SD) Median [Min.–Max.]
Gas-fired	30 (31)	202 (220) 110 [14–740]	52 (55)	518 (536) 290 [12–2800]
Oil-fired	80 (82)	159 (144) 104 [8–600]	70 (74)	322 (314) 224 [12–1660)
Coal-fired	65 (66)	176 (181) 80 [10–782]	60 (64)	297 (215) 242 [53–1090]
Trash incinerator	28 (29)	95 (145) 44 [7–712]	35 (37)	130 (344) 38 [12–2000]
Paper-mill	61 (62)	136 (168) 80 [10–1118]	21 (22)	388 (307) 285 [36–1110]
Nuclear power	55 (56)	541 (375) 500 [8–1600]	17 (18)	651 (544) 600 [8–1650]
Non-boilermaker work	73 (74)	576 (642) 327 [7–3400]	32 (34)	743 (707) 535 [4–2200]

[a]Follow-up Year 1: 98 boilermakers participated; Follow-up Year 2: 94 boilermakers participated.
[b]Calculated using data from those who ever worked at the specific type of plant

Year 2. Most worked in many different types of plants. Approximately 70% of boilermakers worked at three or more types of plants. The Spearman correlations between the number of hours worked at different types of plants were weak (−0.2 to 0.30), suggesting minimal confounding of one specific type of exposure by another.

Tasks

Welding. The number of boilermakers who had welded at different types of plants at FY1 ranged from 17 (17%) at trash incinerators to 66 (67%) at oil-fired plants. Among those who performed at least 1 hour of welding, the mean (SD) number of hours welded at the different type of plants ranged from 42 (89) hours at trash incinerators to 92 (121) hours at nuclear power plants. In FY2, the number of workers welding was similar to FY1, but the number of hours welding increased. The correlation between the number of hours welded and the hours worked at different types of plants was weak (−0.06 to 0.24).

Grinding. The number of boilermakers who had performed grinding in FY1 ranged from 17 at trash incinerators to 57 at oil-fired plants. Among those who performed at least 1 hour of grinding, the mean (SD) number of hours of grinding ranged from 17 (22) at trash incinerators to 60 (100) at nuclear power plants. This was similar to FY2. The correlation between the number of hours grinding and the hours worked at the different type of plants was moderately weak (−0.01 to 0.38). The highest correlation was between hours worked at an oil-fired plant and hours grinding.

Cutting/burning. The number of boilermakers who performed cutting/burning in FY1 ranged from 8 at trash incinerators to 57 at oil-fired plants. Among those who performed at least one-hour of cutting/burning, the mean (SD) number of hours ranged from 11 (10) at trash incinerators to 45 (52) at gas-fired plants. In FY2, the mean hours of cutting/burning was larger. The correlation between the number of hours and the hours worked at different types of plants was moderate (−0.12 to 0.40). The highest correlation was between hours worked at an oil-fired plant and hours cutting/burning.

Pulmonary Function

Prior to modeling the relationship between the number of hours worked at a specific type of plant and FEV_1, the relationship between known predictors of FEV_1 were explored. *A priori*, age, cigarette smoking history, and baseline FEV_1 were examined as predictors of subsequent FEV_1 level. Other covariates of interest were number of years worked as a boilermaker and the number of days between the last day worked and the follow-up spirometry test. As expected, age (−38.0 ml FEV_1/year of age; 95% CI [−51.0, −25.0]) and FEV_1 baseline (0.92 ml FEV_1/ml baseline FEV_1; 95% CI [0.87, 0.98]) were statistically significant predictors of FEV_1 at follow-up. Being a current cigarette smoker reduced annual FEV_1 by 54 mls (95% CI [−383, 274]). The number of years worked as a boilermaker was also a significant predictor of annual FEV_1 (−33.5 mls/years worked as a boilermaker; 95% CI [−45.9, −21.1]). However, the number of days between the last day of work and the spirometry test was not a significant predictor of FEV_1 (−0.2 ml/day; 95% CI [−0.6, 0.16]), and suggested that FEV_1 was lower, the longer the time since last exposure.

Exposure-Response Models

In linear regression models, the relationships between total hours worked at specific types of plants during the follow-up interval were examined in relation to FEV_1. Total hours worked (the sum of hours worked in oil-fired plants, gas-fired plants, coal-fired plants, nuclear power plants, paper-mills, and trash incinerators) was not a significant predictor of annual FEV_1 (−2.1 ml/100 hours worked, 95% CI [−8.0, 3.9]), although the negative coefficient suggested that increased number of hours was associated with a reduced FEV_1. After adjusting for age, cigarette smoking status and FEV_1 baseline, the coefficient for total hours worked was reduced to −0.4; 95% CI [−5.6, 4.8].

We conducted separate analyses in which we regressed FEV_1 at each survey on hours worked in the previous year at a single plant type, ignoring other covariates (Model 1,Table IV). These models suggested that gas hours was a significant predictor of FEV_1 (−11.0 mls/100 hours; 95% CI [−18.0, −4.0]). Moreover, gas hours worked remained a significant predictor of FEV_1 after adjusting for age, baseline FEV_1 and cigarette smoking status (−9.8 mls/100 hours; 95% CI [−16.0, −3.5]) (Model 2, Table IV).

The impact of adjusting for baseline FEV_1 was examined by refitting Model 2 without the baseline term included. The exposure-response parameter for hours worked

TABLE IV. Regression Coefficients (95% Confidence Intervals) Based on GEE Models With FEV_1 Regressed on Hours Worked at Plants Burning Specific Types of Fuel*

Variable	Model 1[a]: single fuel models	Model 2[a]: adjusted single fuel models	Model 3[a]: adjusted multiple fuel model	Model 4[b]: adjusted ever worked on specific fuel models
Gas-fired plant work hrs	−11.0 (−18.0, −4.0)	−9.8 (−16.0, −3.5)	−6.9 (−13.8, 0.1)	−99.7 (−154.8, −44.5)
Oil-fired plant work hrs	−13.6 (−25.5, −1.7)	−12.1 (−24.7, 0.6)	−8.2 (−20.8, 4.5)	−77.6 (−151.1, −4.1)
Coal-fired plant work hrs	−13.6 (−33.3, 6.2)	−11.9 (−30.4, 6.7)	−7.6 (−22.4, 7.2)	−73.4 (−128.8, −18.0)
Trash incinerator work hrs	1.4 (−6.4, 9.3)	3.5 (−5.3, 12.2)	3.3 (−7.8, 14.5)	−29.5 (−97.5, 38.6)
Paper-mill work hours	7.6 (−14.7, 29.9)	15.6 (−14.5, 45.7)	14.4 (−16.0, 44.9)	74.4 (9.1, 139.7)
Nuclear power work hrs	5.1 (−8.8, 18.9)	2.5 (−6.2, 11.2)	0.8 (−8.6, 10.3)	28.9 (−37.7, 95.4)
“Non-boilermaker” work hrs	6.1 (0.3, 11.9)	6.5 (1.7, 11.2)	4.4 (−0.8, 9.6)	76.4 (17.7, 135.0)

*Model 1, crude analysis: FEV_1 regressed on hours worked at a single fuel type in previous year (each model has only one fuel type; no covariates); Model 2, adjusted analysis: FEV_1 regressed on hours worked at a single fuel type in previous year with covariates for age, baseline FEV_1, and cigarette smoking status (each model has only one fuel type); Model 3, adjusted analysis: FEV_1 regressed on all six specific fuel hours plus non-boilermaker hours simultaneously (includes covariates for age, baseline FEV_1, and cigarette smoking status); Model 4, FEV_1 regressed on ever worked at a specific fuel type (yes/no), adjusting for age, baseline FEV_1 and cigarette smoking status (each model has only one fuel type).

[a]Coefficients are mls/100 hours worked.

[b]Coefficient is mls/ever worked at specific fuel type.

in gas-fueled power plants changed from −9.8 mls/100; 95% CI [−16.0, −3.5] hours worked in the model adjusting for baseline, to −8.1 mls/100; 95% CI [−14.8, −1.4] hours worked in the model without adjustment. Although baseline was a significant predictor of subsequent FEV_1, there was evidence that it was acting as a confounder.

Hours worked at oil-fired and coal-fired plants were negatively associated with annual FEV_1 (−13.6 mls/100 hours; 95% CI [−25.5, −1.7] and −13.6 mls/100 hours; 95% CI [−33.3, 6.2], respectively). After adjusting for age, baseline FEV_1 and cigarette smoking history, hours worked at oil and coal-fired boilers remained negatively associated with annual FEV_1, however the association decreased in magnitude and the significance level decreased (Model 2, Table IV). Hours worked at trash incinerators, paper-mills, or nuclear power plants were positively associated with annual FEV_1, however, none of the associations were significant.

When hours worked at each specific plant were simultaneously placed in the same model (Model 3, Table IV), the coefficient for the relationship between gas hours worked and yearly FEV_1 decreased in magnitude and the significance level decreased, (−6.9; 95%CI: [−13.8, 0.1]). This suggested some confounding by other fuels. In this multiple plant model, the relationship between the hours worked at oil and coal-fired plants and yearly FEV_1 remained negative, but non-significant.

Using ever worked at the specific plant as the exposure metric, ever worked gas, oil and coal during the yearly interval (yes/no) were statistically significant predictors of yearly FEV_1 [(−99.7 mls/ever worked gas; 95%CI:[−154.8, −44.5]), (−77.6 mls/ever worked oil; 95%CI:[−151.1, −4.1]) and (−73.4 mls/ever worked coal, 95%CI;[−128.8, −18.0], respectively], (Model 4, Table IV).

The relationship between yearly FEV_1 and ever working non-boilermaker hours was statistically significant (76.4 mls/ever worked; 95%CI: 17.7, 135.0) and in the positive direction, suggesting that working on non-boilermaker jobs increased FEV_1. Boilermakers that worked non-boilermaker jobs generally did so to increase their work hours to account for the lack of work that year on boiler jobs. Therefore, boilermakers that worked non-boilermaker work hours generally had fewer hours working at fossil fuel-fired plants. The correlation coefficients between non-boilermaker work hours and specific plant hours were negative but weak (−0.18 to −0.01). Surprisingly, the relationship between yearly FEV_1 and ever working at a paper-mill was positive and statistically significant (74.4 mls/ever worked; 95%CI: [9.1, 139.7]).

To adjust for potential confounding by task, we added variables for welding hours at a gas-fired plant, grinding hours at a gas-fired plant, and cutting hours at a gas fired plant to Model 2 (i.e., yearly FEV_1 regressed on gas hours, age, baseline FEV_1, and cigarette smoking). After adjusting for task, the relationship between gas hours and yearly FEV_1 remained significant (−11.5 mls/100 hours worked a gas-fired plant; 95% CI [−19.2, −3.8]). In addition, welding hours, cutting hours, and grinding hours at a gas fired plant were not significant predictors of yearly FEV_1. When we added the welding, cutting, and grinding hours at the specific type of plant, respectively, to the models for oil-fired and coal-fired work hours (Model 2), the relationship between yearly FEV_1 and the hours worked was reduced in strength and became non-significant.

TABLE V. Percentage of Time Worker Reported Wearing a Respirator While Welding, Cutting/Burning or Grinding

	Percentage of time wearing a respirator at work[a]	
	Year 1	Year 2
Gas	38.4	31.8
Oil	48.7	63.7
Coal	59.0	66.9
Trash	53.0	67.5
Papermill	47.7	37.1
Nuclear	16.0	48.0
Non-boilermaker work	28.3	24.8

[a]Includes dust mask, quarter face, half face, and full face respirator.

Table V shows that the percentage of time boilermakers wore respirators varied between fuels and between follow-up years. The variability is partially a result of the fact that different workers are represented in the different years. However, in general, respirators were worn more often at oil, coal and trash fired plants than at gas or nuclear plants. The percentage of time a respirator was worn at trash incinerators and paper-mills over time varied. In follow-up Year 1, the percentage of time a respirator was worn at paper-mills was relatively high (47.7%), whereas in Year 2 it was lower (37.1%). The opposite pattern was seen at trash incinerators; 53.0% in Year 1 and 67.5% in Year 2. When the percentage of time the worker wore a respirator at a gas plant was added to Model 4 it was statistically significantly associated with an increase in yearly FEV_1 (16.7 mls/10% increment in respirator use; 95% Cl [5.7,27.7]). Ever-working on a gas-fired plant remained a statistically significant predictor of yearly FEV_1 when percentage of time wearing a respirator was included in Model 4.

DISCUSSION

Boilermaker construction workers work at a variety of plants that burn multiple fuels. This heterogeneity makes it a difficult trade to study. Therefore, to study the long-term health effects of work on the boilermakers one must design a study to explore, simultaneously, the risks associated with multiple exposures from multiple sources. To accomplish this, we designed a longitudinal study in which the number of hours worked per year at each type of plant (i.e., oil-fired power plant, coal-fired power plant, natural gas-fired power plant, trash incinerator, paper-mill and nuclear power plant) was used as the exposure metric. Based on the work history diaries, the study participants worked at well over 100 individual plants in over 20 states; it was impossible to perform workplace sampling at even a small fraction of the plants. This is typical for this trade.

The study cohort did not include a ''comparison'' group of non-exposed workers from another trade because in a given year of follow-up many boilermakers are not exposed to each of the multiple sources of particulate exposure and therefore served as an internal comparison group. For instance, at FY1 only 30 (31%) boilermakers reported working at least 1 hour at a gas-fired plant (Table III). Therefore, in year one, 68 (69%) of the boilermakers did not work at a gas-fired plant and served as the comparison subjects for the 30 boilermakers who worked a median of 110 hours on a gas-fired boiler. Among the 30 boilermakers working at a gas-fired plant there was a wide range of exposure; the number of hours worked on the gas-fired boiler ranged from 14 to 740 hours. Table III shows that for FY1 and FY2, there was a comparison group of at least 18 non-exposed boilermakers for each fuel type (ranges from 77 to 18 non-exposed boilermakers). Using boilermakers who did not work at a specific type of plant as comparison subjects for those who did work at that plant type improves the power of the study and, more importantly, minimizes bias that may occur from using another trade for comparison.

The design of this study allowed us to explore multiple exposures simultaneously and provided preliminary data on working at specific types of plants and the risk of an accelerated decline in yearly lung function. An association was found between FEV_1 and both ever-working at a gas fired boiler and hours worked at gas fired plant during the follow-up interval. The crude association between yearly FEV_1 and hours worked at a gas-fired boiler was -11.0 mls/100 hours worked, and -9.8 mls/100 hours worked after adjustment for age, baseline FEV_1 and cigarette smoking status. The median number of hours worked during the 2-year study was 110 hours during FY1 and 290 hours during FY2. The range of hours worked was wide, varying from not working at a gas-fired plant during the interval to working over 2,000 hours at a gas-fired boiler. Therefore, the negative association between yearly FEV_1 and hours worked at a gas-fired boiler may indicate more than a 200-mL decrease in FEV_1 in a worker working over 2,000 hours at a gas-fired boiler. The association between yearly FEV_1 and working on a gas-fired plant was extremely robust. The association was unchanged after controlling for: (1) confounders (age, baseline FEV_1 and cigarette smoking status; (2) work hours at other types of plants; and (3) the use of respirator.

In the northeastern United States there has been tremendous growth in the construction of gas-fired power plants for both economic and environmental reasons. Therefore, the number of gas fired plants constructed in the coming years will increase further. This is reflected in Table III in which 31% boilemakers worked at least 1 hour of a gas-fired power plant in the first year of the study and 55% worked at least 1 hour in the second year. This was a doubling during the 2 years of follow-up.

During the review of the work histories, workers reported that they were generally most concerned about health risks associated with their work at coal-fired power plants. They described coal-fired power plants as the dustiest plants. They reported that they were therefore more likely to wear a respirator at a coal plant because of the visible dust in the air. This is supported by the data in Table V where the percentage of time a respirator was worn at work was highest in the coal plants in Year 1 (59.0%) and the second highest in Year 2 (66.9%) (second only to trash incinerators). The use of a respirator at gas-fired plants was fairly low (38.4% in Year 1 interval and 31.8% in Year 2 interval).

When the percentage of time a respirator was worn was included in the model regressing yearly FEV_1 on ever working at a gas fired plant during the yearly interval (i.e., Model 4 in Table IV), the association remained statistically significant. Furthermore, the association between the percentage of time a worker wore the respirator and yearly FEV_1 was statistically significant and positive (16.7 mls/each 10% increment in respirator use). This suggests that respirator use while working on gas-fired plants will protect the workers health.

There were negative associations found between yearly FEV_1 and hours worked at an oil and coal-fired plant and ''ever'' working at an oil or coal-fired plant during the year follow-up interval. Earlier studies have shown both an acute (i.e., across shift) as well as a short-term (i.e., over 4 weeks) decrement in lung function among boilermaker construction workers working on an oil-fired boiler [Hauser et al. 1995, 1996]. The present study extends these findings to long-term changes (i.e., over 2 years) in workers engaged in the same type of work. Together, these studies provide support for a consistent association between exposure to fuel-oil combustion particulates and adverse effects on lung function. The finding of an association between yearly FEV_1 and ever working at an oil or coal-fired power plant is suggestive and warrants follow-up.

In a recent cross-sectional study by Hessel et al. [Hessel et al., 1998] on 102 actively employed boilermakers with 20 or more years of union membership, they reported that boilermakers had more symptoms than telephone workers (comparison subjects), but lung function did not differ. They found that exposure (as a boilermaker) to fumes in the gas and oil industry were significantly associated with usual cough, wheeze in the absence of a cold, chest tightness, attacks of wheeze, and pneumonia. The cross-sectional design, and therefore healthy worker effect bias, may partially account for the lack of an association between being a boilermaker and lung function decrements.

In this cohort, the mean percent predicted FEV_1 was low (between 89 and 91% predicted). This is surprising considering the fact that the mean in occupational cohorts is usually close to or larger than 100% because of the healthy worker hire and survivor effect. The low percentage predicted may indicate a chronic effect of boilermaker construction work on FEV_1. The equations of Hankinson et al. [1999] are based on a general population sample from the National Health and Nutrition Examination Survey (NHANES III). The reference values from Hankinson are similar or slightly higher than those from Crapo et al. [1981], Knudson et al. [1983] and Glindmeyer et al. [1995].

The results of this two-year longitudinal study suggest that working at gas, oil and coal-fired plants is associated with an annual loss in FEV_1. However, these results must be replicated and confirmed upon further follow-up of this cohort as well as other cohorts of boilermaker construction workers. It is hoped that this report will serve to increase interest and research on workers exposure during the construction of gas-fired plants, as well as research on workers exposure at other plants, especially coal, but also oil. Future research directions include exploring whether host characteristics such as airway responsiveness, assessed by methacholine challenge tests, increase the workers susceptibility to yearly loss in FEV_1.

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