

An Epidemiological Study of Salt Miners in Diesel and Nondiesel Mines

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A cross-sectional study of 5 NaCl mines and 259 miners addressed the following questions: 1) Is there an association of increased respiratory symptoms, radiographic findings, and reduced pulmonary function with exposure to nitrogen dioxide (NO₂) and/or respirable particulate (RP) among these miners? 2) Is there increased morbidity of these miners compared to other working populations? Personal samples of NO₂ and respirable particulate for jobs in each mine were used to estimate cumulative exposure. NO₂ is used as a surrogate measure of diesel exposure.

Cough was associated with age and smoking, dyspnea with age; neither symptom was associated with exposure (years worked, estimated cumulative NO₂ or RP exposure). Phlegm was associated with age, smoking, and exposure. Reduced pulmonary function (FVC, FEV₁, peak, flow, FEF₅₀, FEF₇₅) showed no association with exposure. There was one case of small rounded and one case of small irregular opacities; pneumoconiosis was not analyzed further.

Compared to underground coal miners, above ground coal miners, potash miners, and nonmining workers, the study population after adjustment for age and smoking generally showed no increased prevalence of cough, phlegm, dyspnea, or obstruction (FEV₁/FVC < 0.7). Obstruction in younger salt miners and phlegm in older salt miners was elevated compared to nonmining workers. Mean predicted pulmonary function was reduced 2-4% for FEV₁ and FVC, 7-13% for FEF₅₀, and 18-22% for FEF₇₅ below all comparison populations.

Key words: NaCl, NO₂, diesel, respiratory symptoms, spirometry, cross-sectional study

INTRODUCTION

The questions addressed in this report are the following: 1) Is there an association of respiratory symptoms, radiographic findings, and pulmonary function to NO₂

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and/or respirable particulate exposure (RP) and/or years worked underground? 2) Is there an increased prevalence of morbidity in the salt miner population compared to other populations? A third question of interest that cannot be answered directly is the hazard of diesel exhaust to respiratory health.

This population of salt miners is one of the mining groups included in the NIOSH/MSHA metal/nonmetal, diesel/silica study [Attfield, 1978; Sutton et al, 1978], with a shift study of changes in pulmonary function added to the study protocol [Gamble et al, 1978]. While extensive environmental sampling was performed [Gamble et al, 1978; Sutton et al, 1978], we were unable to measure exposure to diesel exhaust alone. Of the components of diesel exhaust we measured, NO₂ is probably the most hazardous as it relates to health effects. Blasting is also a source of this compound. Respirable particulate from diesel exhaust was mixed in variable quantities with NaCl. Thus, both NO₂ and RP are surrogate measures of diesel exposure reflecting actual diesel exposure to a variable and limited degree.

Sodium chloride is not considered hazardous to the respiratory system, as rabbits and rats exposed to airborne NaCl concentrations as high as 70 mg/m³ for up to 113 days show no apparent effects of exposure [Dautrebande et al, 1949].

Animal studies suggest no adverse health affect from chronic exposure to NO₂ levels as high as 5 ppm [Wagner et al, 1965; Freeman, et al, 1968; Azoulay et al, 1978]. Exposure of animals to high concentrations of NO₂ (45 ppm) over a short period may be more detrimental than lower concentrations (30 ppm) over a longer time, even though cumulative total exposure is similar [Campbell and Hall, 1976]. Low level exposure to NO₂ is of concern because of the emphysema-like changes seen in animals when chronically exposed to high levels of NO₂ [Freeman et al, 1972; Haydon et al, 1967].

There are few studies of human populations with chronic exposure to NO₂, and none where there is no exposure to other potential irritants [Shy et al, 1970a,b; Melia et al, 1977; Speizer et al, 1979]. The general interpretation is that NO₂ may decrease resistance to acute respiratory infections, increase lower respiratory tract symptoms (eg, cough, bronchitis), and reduce FEV₁ [Dawson and Schenker, 1979; Guidotti, 1978]. The threshold for acute changes in airway mechanics in healthy subjects is around 1.5 ppm [von Neiding et al, 1973; Hackney et al, 1978; Folinsbee et al, 1979].

While the knowledge of the hazard to health from diesel exhaust is of great interest, limited data are available. Morbidity studies of workers with exposure to diesel exhaust include diesel locomotive repairmen [Battigelli et al, 1964], iron miners [Jorgensen and Svensson, 1970; Pham et al, 1977], potash miners [Attfield et al, 1980], metal and nonmetal miners [Attfield, 1978], and coal miners [Reger et al, 1980]. NO₂ levels in the engine house did not exceed 1.8 ppm (median of <0.5 ppm) [Battigelli et al, 1964], were on the order of 0.5–1.5 ppm for the iron ore miners [Jorgensen and Svensson, 1970], ranged from 0.1 ppm to 3.3 ppm in the six potash mines [Attfield et al, 1980], and were all less than 1 ppm in the coal mines [Reger et al, 1980]. No effects on the respiratory system that could be clearly attributed to diesel exhaust were observed in these studies. Pham et al [1977] observed an effect on the respiratory system of both nitrous gases and dust (NO₂ levels were as high as about 3 ppm), but it is not clear that the effects could all be attributed to diesel exhaust. Thus the effects, if any, in human populations of chronic exposure to diesel exhaust and NO₂ need further documentation.

METHODS

This cross-sectional survey is part of the NIOSH/MSHA metal/nonmetal study of 20 mines and 5,000 miners, parts of which have been reported elsewhere [Attfield, 1978; Attfield et al, 1980; Sutton et al, 1978; Gamble et al, 1978]. The study population reported on here worked in five salt mines. Two had extensive diesel use, two had limited diesel use, and one used no diesels at all.

Measurements

The examination of each worker included a questionnaire, chest X-ray, and spirometry. The Medical Research Council respiratory symptom questionnaire containing smoking history was administered by trained interviewers. Complete work histories were obtained from each worker or from personnel records when available. Standard PA chest roentgenograms were read independently by three "B" readers using the ILO U/C 1971 classification. The median of the three readings was used for analysis. Flow volume curves from a minimum of five forced expirations were recorded on magnetic tape using an Ohio 800 rolling seal spirometer.* Maximum forced expiratory volume in one second (FEV₁), maximum forced vital capacity (FVC), and peak flow (PF) were used for analysis. A maximum envelope curve was used to obtain flows at 50 and 75% of expired FVC (FEF₅₀, FEF₇₅).

Respirable particulate and NO₂ samples were collected on a sample of workers [Gamble et al, 1978]. Respirable particulate was measured by drawing air at a flow rate of 1.7 liters per minute through a 10-mm nylon cyclone prior to collection of the respirable particulate on a pre-weighed filter. Personal exposures to NO₂ were measured with a passive sampler [Palmer, 1976]. Draeger indicator tubes were used to measure formaldehyde, sulfur dioxide, nitrogen dioxide, nitrogen oxides, and carbon monoxide.

Cumulative exposure to NO₂ and to respirable particulate were estimated by multiplying the average exposure in each job times the time spent in that job (months) and adding the products:

$$\begin{array}{l} \text{last job} \\ \Sigma \\ \text{first job} \end{array} \quad (\text{mg/m}^3 \times \text{months}) = \text{mg/m}^3 \text{ months for RP (abbreviated RP):}$$

$$\begin{array}{l} \text{last job} \\ \Sigma \\ \text{first job} \end{array} \quad (\text{ppm} \times \text{months}) = \text{ppm months for NO}_2 \text{ (abbreviated NO}_2\text{)}$$

(see Appendix Table VIII)

Average exposure for each individual was estimated by dividing estimated cumulative exposure by the number of months worked, and abbreviated RP for mean respirable particulate exposure, and $\overline{\text{NO}}_2$ for mean NO₂ exposure. Average NO₂ exposure for each job was estimated from NIOSH personal samples obtained at the time of the acute study and from a MSHA survey completed within a few months of the medical survey [Sutton et al, 1978]. Only the NIOSH values were used for respirable particulate as MSHA had sampled for total dust. The average concentration

*Mention of brand names does not constitute endorsement by the USPHS.

of NO₂ and respirable particulate of all jobs within each particular mine was assigned to those job categories not sampled during either the NIOSH or MSHA studies. For the most part these comprise job categories that no longer exist.

Statistical Considerations

For analysis of symptom prevalence, control for potentially confounding variables was accomplished by stratification into two age groups (<40, ≥40) and three smoking categories (nonsmoker, ex-smoker, smoker). For dose-response relations, exposure was classified into two duration-of-work categories, and into high, medium, and low RP and NO₂ exposure categories. Analysis was done by stratification using these categories (see Appendix Table IX for details). A linear logistic model was also used to analyze the association of symptoms and exposure after controlling for potential confounders. Age, RP, NO₂, and years worked were analyzed as continuous variables in the logistic model, but the categories were used for presentation of results. The conclusions from the logistics analysis and from analysis by stratification were similar, although only the former results are presented. The significance of the independent variables (age, height, smoking, mine, exposure) on pulmonary function were assessed by multiple regression. In our discussion of these relationships we will first discuss these potentially confounding independent variables that may also be related to exposure, followed by the analysis of the association of exposure with the dependent variables (symptoms and pulmonary function).

For external comparisons, the study population was compared after direct adjustment for age and smoking to several mining and nonmining populations (see Appendix Table XI for characteristics of these populations). Persons in each population were grouped into similar age and smoking categories. Symptom rates in each age and smoking category of the study population were multiplied by the combined number in that category from all populations to get observed numbers for each category in the study population. This observed number of salt miners with the symptom is based on the age and smoking characteristics of the total population, and can therefore be compared to the expected number of persons with the symptom derived from each comparison population. For pulmonary function results, predictive equations taking into account the effects of age and height were calculated for each smoking category in the comparison populations. The observed values in the salt population were then compared to the "predicted" values of the comparison populations.

Characteristics of Salt Population

The population from the five salt mines comprised 10 white females, 14 male Spanish-Americans, 14 male blacks, six males of other races, and 259 white males. The analysis of chronic effects was done only on the 259 white males. Flow rates were not available from Mines B and C. The proportion who had worked in other dusty occupations was less than 10% in both the salt and comparison populations.

The distribution of smoking categories was fairly typical of working populations. Slightly more than half (58%) were smokers with approximately equal numbers of ex-smokers (23%) and nonsmokers (19%). Ex-smokers were on average almost 10 years older than both nonsmokers and smokers. Ex-smokers and smokers had smoked about the same number of cigarettes per day and had the same number of pack years.

Mean exposure to NO_2 and respirable particulate ($\overline{\text{NO}_2}$ and $\overline{\text{RP}}$) was about the same in the three smoking categories. Ex-smokers, however, had worked 3.4 times longer than nonsmokers and 1.6 times longer than smokers. Thus the cumulative exposure of ex-smokers was greater than both smokers and nonsmokers (Appendix Table IX).

Exposure was quite variable from mine to mine (Appendix Table X). Mine D had the highest cumulative NO_2 , RP, and $\overline{\text{NO}_2}$. Mine E had 1.8 to 4 times the $\overline{\text{NO}_2}$ average of the three smallest mines, but only about one-third the score of Mine D. Most of this difference in NO_2 was probably due to diesels. Mean respirable particulate ($\overline{\text{RP}}$) averages among the five mines were similar. Mine E had the lowest average number of years worked (7), while Mine C and D (lowest and highest NO_2 , respectively) had the same average number of years worked (13 years). A higher proportion of workers in Mines D and E reported working in a foundry (6% versus 0%) and with asbestos (7% versus 0%) than in the other three mines. Two miners (9%) from Mine B had worked in a quarry.

To document the degree of fluctuation of gas concentrations in the mines, indicator tube samples were taken during the work shift at different locations within each mine. All samples collected for SO_2 and formaldehyde were below the limit of detection (1 ppm and 0.5 ppm, respectively) and so were not analyzed further. Results of samples taken for NO_2 , nitrogen oxides (NO_x), and CO are presented by mine in Figures 1–3. Within each mine, concentrations of all three gases fell within a relatively narrow range suggesting that exposure levels for these gases were more or less constant throughout the work shift. The lower variability of NO_2 concentrations compared to NO_x levels is not surprising. Since most NO_2 results from the oxidation of NO (initially formed in diesel engines), concentrations of this compound would tend to be buffered against sharp increases. NO_x levels, however, are a combination of both NO and NO_2 and are therefore more likely to rise sharply with increases in diesel traffic.

Cumulative NO_2 and RP exposure scores were highly correlated ($r = 0.86$), with the majority of workers having a low NO_2 and low RP score. A smaller number of workers had a high NO_2 and high RP score. A few miners had a moderately high RP score and low NO_2 score. Age and cumulative exposure were also correlated ($r = 0.62$ for age and RP exposure; $r = 0.55$ for age and NO_2 exposure; $r = 0.74$ for age and years worked).

Characteristics of Comparison Population

Four working populations were used for comparison purposes (see Appendix Table XI for details). The coal miner populations were examined as part of the second round of the National Study of Coalworkers' Pneumoconiosis, and were divided into white males working only underground and only aboveground. The potash mines were part of the MSHA/NIOSH epidemiologic-industrial hygiene study of metal and nonmetal underground miners [Attfield, 1978; Sutton et al, 1978]. White male miners from six potash mines were used for comparison. All of the potash mines used diesel engines [Attfield et al, 1980]. The nonmining comparison population was part of the NIOSH blue collar control study and included male and female workers from such industries as electronics, synthetic textiles, bakeries, and bottling plants [Martin Petersen, personal communication]. It is hereafter referred to as the blue collar comparison population.

The underground coal miners were lighter smokers (ie, mean cigarettes/day and mean pack years were less) than all the other populations. Although we have attempted to adjust for smoking by comparing the same smoking category, ie, non-smokers with smokers, etc., the adjustment is not perfect because some symptoms were related to the amount smoked. Among the study population, for example, there was a relation between amount smoked and the symptoms of cough and phlegm:

Cigarettes/Day	% Cough	% Phlegm	% Dyspnea
< 10	11	20	4
10-29	24	26	10
≥ 30	36	38	7

The effect of the differences in amounts of cigarettes smoked would be to increase the prevalence of smoking-related symptoms in the aboveground coal, potash, salt, and blue collar populations relative to underground coal.

RESULTS

Internal Comparisons

Symptoms. The overall prevalence of cough was 24%. There was a statistically significant increase of cough with increasing age and smoking. The other variables, ie, mine, cumulative exposure, and years worked were not significant, whether analyzed separately or together. The high and medium RP exposure groups had a slightly higher-than-expected prevalence of cough, but the differences were not significant. Mine A was not used in the logistic analysis of exposure effects because the prevalence of cough was zero in that mine (Table I).

In summary, there was a statistically significant association of cough with age and smoking. There was no detectable statistical association with any of the exposure variables.

The overall prevalence of phlegm was 28%. The prevalence of phlegm increased with increasing age and smoking, and was significantly associated with each mine. The association with exposure (RP, NO₂, and years worked) was significant when each variable was the only exposure variable in the logistic model, but was not dose-related for RP as the highest observed/expected ratio was in the medium exposure categories (Table II).

In summary, there was a statistically significant association of phlegm with age, smoking, and exposure (years worked, cumulative RP and NO₂ exposure).

The overall prevalence of dyspnea was 7%. The prevalence of dyspnea increased significantly with increasing age. There was no statistical difference in prevalence by smoking category, although smokers had the highest observed/expected ratio. The prevalence of dyspnea did not increase with increasing tenure or particulate exposure. Although RP showed no significant association with dyspnea when it was the only response variable in the logistic model, it was significant when NO₂ and RP, and NO₂, RP, and years worked were included in the model. There was no dose-response relationship, however. (This is probably among the 5% that occurred by chance!) (Table III).

In summary, there was an association of ≥ Grade 2 shortness of breath with age, but no association with smoking, mine, and exposure (years worked, cumulative RP and NO₂ exposure).

TABLE I. Prevalence of Cough* by Age, Smoking, and Exposure in White Male Salt Miners

	n	Prevalence (%)		Ratio O/E	Comment
		Observed	Expected		
Total	259	24.3			
Age†					p < 0.01
< 40	136	19.1	24.8	0.77	Expected values
≥ 40	123	30.1	23.8	1.26	adjusted for smoking
Smoking status†					p < 0.01
Nonsmoker	50	10.0	23.4	0.43	Expected values
Ex-smoker	59	16.9	27.1	0.62	adjusted for age
Smoker	150	32.0	23.5	1.36	
Mine					NS
A	17	0	20.9	0	Expected values
B	22	22.7	24.2	0.94	adjusted for age
C	27	18.5	23.8	0.78	and smoking.
D	108	29.6	26.2	1.13	
E	85	24.7	22.8	1.08	
Cumulative RP exposure					Expected values
low (<47)	135	20.7	23.5	0.88	adjusted for age,
medium (47-75)	29	27.5	25.3	1.09	smoking, & mine.
high (>75)	78	34.6	30.7	1.13	Mine A not included in analysis.
Cumulative NO ₂ exposure					NS
low (<48)	115	21.7	23.2	0.94	Expected values
medium (48-100)	38	26.3	25.3	1.04	adjusted for age,
high (>100)	89	31.5	30	1.05	smoking, & mine.
Years worked underground					Mine A not included in analysis.
< 10	145	22.8	23.5	0.97	NS
≥ 10	97	30.9	29.8	1.04	Expected values adjusted for age, smoking, & mine.

Conclusions: Age and smoking are the only statistically significant variables associated with increased cough.

*Cough = answering yes to the question: "Do you usually cough on most days for as much as three months each year?"

†p < 0.05.

NS, p > 0.05.

The relationship of respiratory symptoms and reduced pulmonary function is presented in Appendix Table XII. In general, those with symptoms have a reduced FEV₁ and FVC compared to those without the symptom, although those with no phlegm have reduced pulmonary function compared to those with phlegm for less than three months of the year. The pattern for FEF₅₀ is not consistent and shows no trend of reduced function with increased severity of symptoms.

TABLE II. Prevalence of Phlegm* by Age, Smoking, and Exposure in White Male Salt Miners

	n	Prevalence (%)		Ratio O/E	Comment
		Observed	Expected		
Total	259	28.2			
Age					p < 0.01
< 40	136	21.3	28.2	0.76	Expected values
≥ 40	123	35.8	28.1	1.27	adjusted for smoking
Smoking status					p < 0.05
Nonsmokers	50	16.0	26.8	0.60	Expected values adjusted by age
Ex-smoker	59	25.4	32.4	0.78	
Smokers	150	33.3	27.0	1.23	
Mine					NS (p < 1)
A	17	0	24.0	0	Expected values
B	22	13.6	27.3	0.50	adjusted for age
C	27	14.8	27.8	0.53	and smoking.
D	108	37.0	30.9	1.20	
E	85	30.6	26.0	1.18	
Cumulative RP exposure					p < 0.05
low	135	20.7	26.2	0.79	Expected values
medium	29	41.4	29.2	1.42	adjusted for age,
high	78	42.3	37.4	1.13	smoking, & mine.
					Mine A not included in analysis.
Cumulative NO ₂ exposure					p < 0.01
low	115	19.1	24.8	0.77	Expected values
medium	38	31.6	29.2	1.08	adjusted for age,
high	89	43.8	37.5	1.17	smoking, & mine.
					Mine A not included in analysis.
Years worked underground					p < 0.05
< 10	145	25.5	26.4	0.97	Expected values
≥ 10	97	37.1	35.8	1.04	adjusted for age & mine. Mine A not included in analysis.

Conclusions: Phlegm significantly associated with age, smoking, and exposure (RP, NO₂, years worked).
 *Phlegm = Answering yes to the question: "Do you usually bring up phlegm for as much as three months each year?"

Pulmonary Function

Table IV summarizes the result of a multiple regression model of pulmonary function with the predictor variables age, height, smoking status, mine and exposure (years worked, cumulative respirable particulate, and NO₂ exposure). Age and height were significant (p < 0.05) for all pulmonary function parameters. Smoking was significant for all but FVC. Mine was a significant predictor for FEV₁, FVC, and peak flow; mines D and E had the lowest pulmonary function. There was no significant association of any of the exposure variables with any of the pulmonary function parameters.

TABLE III. Prevalence of Shortness of Breath* by Age, Smoking, and Exposure in White Male Salt Miners

	n	Prevalence (%)		Ratio O/E	Comment
		Observed	Expected		
Total	259	7.3			
Age					p < 0.05
< 40	136	3.7	7.4	0.50	Expected values
> 40	123	11.4	7.3	1.56	adjusted for
					smoking
Smoking status					NS
Nonsmoker	50	6.0	6.9	0.87	Expected values
					adjusted for age
Ex-smoker	59	6.8	9.1	0.75	
Smoker	150	8.0	6.8	1.18	
Mine					NS
A	17	5.9	6.1	0.97	Expected values
B	22	0	6.7	0	adjusted for age
C	27	0	7.4	0	and smoking.
D	108	8.3	8.5	0.98	
E	85	10.6	6.3	1.68	
Cumulative RP exposure					NS
low (<47)	120	7.5	7.1	1.06	Expected values
medium (47-75)	24	8.3	9.5	0.87	adjusted for age,
high (>75)	66	12.1	12.3	0.98	smoking, & mine.
					Mines B & C not
					included in
					analysis.
Cumulative NO ₂ exposure					NS
low (<48)	92	6.5	7.6	0.86	Expected values
medium (48-100)	32	12.5	8.1	1.54	adjusted for age,
high (>100)	86	10.5	11.0	0.95	smoking, & mine.
					Mines B & C not
					included in
					analysis.
Years worked underground					NS
< 10	132	7.6	7.1	1.07	Expected value
≥ 10	78	11.5	12.4	0.93	adjusted for age,
					smoking, & mine.
					Mines B & C not
					included in
					analysis.

*Shortness of breath = Answering yes to the question: "Do you get short of breath walking with other people of your own age on level ground?"

Conclusions: Age is the only statistically significant variable associated with dyspnea.

TABLE IV. Summary of Multiple Regression Model for Lung Function and Selected Least Squares Means (With SE)

	259	259	259	210	210	210	210
	FEV ₁	FVC	Peak flow	FEV ₅₀	FEV ₇₅	FEF ₇₅	FEF ₇₅
Age (β_1)	-36 (4)***	-33 (5)***	-36 (12)**	-32 (11)**	-31 (4)***	-31 (4)***	-31 (4)***
Height (inches) (β_2)	88 (4)***	99 (16)***	235 (44)***	117 (39)**	63 (16)***	63 (16)***	63 (16)***
Smoking status		NS	*	*	**	**	**
nonsmokers	3.99 (0.08)	5.04 (0.10)	9.66 (0.26)	4.62 (0.22)	1.56 (0.09)	1.56 (0.09)	1.56 (0.09)
ex-smokers	3.92 (0.08)	4.98 (0.09)	9.26 (0.24)	4.31 (0.21)	1.47 (0.09)	1.47 (0.09)	1.47 (0.09)
smokers	3.73 (0.06)	4.98 (0.06)	8.99 (0.17)	3.89 (0.15)	1.25 (0.06)	1.25 (0.06)	1.25 (0.06)
Mine		*	**	NS	NS	NS	NS
A	4.04 (0.14)	5.19 (0.16)	9.92 (0.38)	4.57 (0.33)	1.58 (0.14)	1.58 (0.14)	1.58 (0.14)
B	4.06 (0.13)	5.24 (0.15)	—	—	—	—	—
C	3.87 (0.11)	4.91 (0.13)	—	—	—	—	—
D	3.78 (0.06)	4.90 (0.07)	8.57 (0.17)	4.13 (0.14)	1.35 (0.06)	1.35 (0.06)	1.35 (0.06)
E	3.65 (0.07)	4.77 (0.07)	9.41 (0.18)	4.12 (0.16)	1.34 (0.07)	1.34 (0.07)	1.34 (0.07)
Years worked (β_5)	-6 (7)+	8 (8)+	3 (20)+	-28 (18)+	-4 (7)+	-4 (7)+	-4 (7)+
RP (β_6)	0 (1)+	0 (1)+	-5 (3)+	1 (3)+	-1 (1)+	-1 (1)+	-1 (1)+
NO ₂ (β_7)	0 (0)+	0 (0)+	1 (1)+	0 (1)+	0 (0)+	0 (0)+	0 (0)+

Lung Function = $\alpha + \beta_1$ (age) + β_2 (height) + β_3 (smoking status) + β_4 (mine) + β_5 (years worked) + β_6 (cumulative dust) + β_7 (cumulative NO₂)

*p < 0.05.
**p < 0.005.

***p < 0.0005.
NS or + = p > 0.05.

SE in parentheses; β coefficients are in ml (FEV: FVC) or ml/sec (flows). Values by smoking category and mine are at least squares means.

External Comparisons

Symptoms. Tables V and VI summarize the age and smoking adjusted rates of cough, phlegm, dyspnea, and obstructive airflow of the salt and comparison populations.

There was no apparent difference among salt, blue collar, potash, and above-ground coal populations in the prevalence of cough. These populations had a significantly lower prevalence of cough than did the underground coal miners in the older age group and overall. There was no apparent difference among any of the populations in those less than 40 years of age (Table V).

The prevalence of phlegm among the salt population was not noticeably different than in the blue collar, potash, and aboveground coal populations, but was reduced in both age groups compared to underground coal miners. The blue collar workers reported less phlegm than all the other populations, and the reduced prevalence was significant overall and in the ≥ 40 year age group (Table V).

The prevalence of shortness of breath was significantly higher among underground coal miners in both age categories when compared to all other populations. The prevalence among aboveground coal miners was elevated in the older age group (and overall) compared to potash, blue collar, and salt, but was less than underground coal miners. There were no apparent differences in prevalence of dyspnea among salt, potash, and blue collar populations (Table VI).

The prevalence of air flow obstruction ($FEV_1/FVC < 0.70$) in the younger age group of salt miners was higher than the prevalence in all the comparison populations, but the difference was significant only when compared to blue collar workers. The rates were very similar in the older age category (Table VI).

In summary, there were no consistent differences in age and smoking adjusted symptom prevalence among the salt, potash, blue collar, and aboveground coal populations. The underground coal population consistently had an elevated symptom prevalence.

Pulmonary Function

After adjustment for age, height, and smoking, the salt miners' lung function was lower than all other comparison groups (except for FVC compared to blue collar workers). FEV_1 and FVC were 2–5% less than the comparison populations. Peak flow was reduced 2–10%, FEF_{50} was reduced 7–13%, and FEF_{75} was reduced 17–22% (Table VII). The reduced pulmonary function of the study population was fairly evenly distributed among the smoking categories. Mine E consistently had the lowest percent predicted pulmonary function and Mines A and B the highest. Mines C and D tended to be intermediate (Appendix Table XIII).

Differences of mean pulmonary function between groups could be the result of exposure, differences in region, temperature, time of year, technicians, equipment, and/or other unknown or unmeasured biases. The latter biases are more likely to occur when the comparison groups were done in different studies by different researchers, and is probably of little consequence here, as the same equipment and research personnel were used for all populations. To minimize the problems of measurement differences and differences due to factors unrelated to exposure, we have compared intercept-free estimates of pulmonary function. These include: 1) comparison of pulmonary function age coefficients, and 2) association of predicted pulmonary function and exposure.

TABLE V. Comparative Rates of Cough and Phlegm Among Salt Workers Compared to Blue Collar, Potash, and Coal Workers (Directly adjusted for age and smoking)

	Age groups		TOTAL % (95% CI)
	<40 % (95% CI)	≥40 % (95% CI)	
Cough			
salt	18.1 (12-26)	29.3 (21-38)	23.3 (18-28)
blue collar	15.2 (12-18)	18.6 (15-24)	16.8 (14-20)
potash	20.6 (17-25)	29.7 (26-35)	24.8 (22-28)
aboveground coal	16.1 (11-23)	35.4 (29-40)	25.0 (21-29)
underground coal	18.2 (17-19)	*44.9 (44-46)	*30.6 (30-32)
Phlegm			
salt	20.5 (14-29)	35.5 (27-45)	27.5 (22-34)
blue collar	16.3 (13-20)	*18.6 (15-24)	*17.3 (14-20)
potash	25.4 (20-29)	34.4 (29-38)	29.6 (26-34)
aboveground coal	18.6 (13-26)	40.7 (35-47)	28.9 (25-33)
underground coal	*32.7 (32-34)	*50.1 (49-51)	*40.8 (40-42)

*95% Confidence intervals (CI) do not overlap.

SUMMARY

Cough: Underground coal significantly higher prevalence in ≥40 year group and overall. No apparent difference between study and other comparison populations.

Phlegm: Underground coal significantly higher prevalence in both age groups. Salt population prevalence significantly greater than blue collar population in older group and overall.

TABLE VI. Comparative Rates of Dyspnea and Airflow Obstruction Among Salt Workers Compared to Blue Collar, Potash, and Coal Workers (Directly adjusted for age and smoking)

	Age groups		Total % (95% CI)
	<40 % (95% CI)	≥40 % (95% CI)	
Grade ≥2 shortness of breath			
salt	3.8 (2-9)	11.2 (6-18)	7.2 (4-11)
blue collar	4.8 (3-7)	10.7 (8-15)	7.5 (5-10)
potash	5.4 (3-7)	11.9 (9-15)	8.4 (6-10)
aboveground coal	1.9 (0-6)	*28.0 (23-34)	*14.0 (11-17)
underground coal	*9.8 (9-11)	*40.5 (40-42)	*24.1 (23-25)
Airflow obstruction (FEV₁/FVC < 0.70)			
salt	12.2 (7-19)	32.5 (25-42)	21.9 (17-27)
blue collar	*4.0 (3-6)	30.4 (25-36)	16.6 (14-20)
potash	9.2 (6-12)	32.7 (29-37)	20.4 (17-24)
aboveground coal	8.5 (5-14)	31.1 (25-36)	19.3 (16-23)
underground coal	10.7 (10-12)	37.2 (36-38)	23.3 (22-24)

*95% Confidence intervals (CI) do not overlap.

SUMMARY

Dyspnea: Aboveground coal significantly higher in older age category and overall.

Underground coal significantly higher in all age categories. No apparent differences between study, blue collar, and potash populations.

Obstructive Airflow: No apparent difference between study population and comparison populations, except prevalence of airflow obstruction in blue collar workers in younger age group is reduced compared to salt miners.

TABLE VII. Mean Percent Predicted Pulmonary Function of Salt Miners Compared to Coal, Potash, and Blue Collar Workers (Adjusted for age, height, and smoking)

	% Predicted pulmonary function compared to:			
	Underground coal	Aboveground coal	Potash	Blue collar
	% (SE)	% (SE)	% (SE)	% (SE)
FEV ₁	96.4 (0.9)	95.0 (0.9)	97.1 (0.9)	98.0 (1.0)
FVC	95.0 (0.8)	95.3 (0.8)	97.1 (0.8)	98.3 (0.8)
Peak flow	98.4 (1.2)	93.2 (1.1)	90.4 (1.1)	94.3 (1.1)
FEF ₅₀	89.7 (2.1)	86.9 (2.0)	88.9 (2.1)	92.8 (2.3)
FEF ₇₅	77.6 (2.3)	78.3 (2.3)	83.1 (2.4)	82.0 (2.5)

All significantly less than 100 ($p < 0.05$) except FVC compared to blue collar workers.

When comparing the age coefficients of the study and comparison populations, the salt workers had no reductions that were significantly greater than the comparison populations. Salt workers generally had the smallest reductions for flows and intermediate reductions for FEV₁ and FVC. (See Appendix Table XIV for the detailed comparisons.)

To relate percent predicted lung function to exposure, the following regression equation was used:

$$\text{Predicted pulmonary function} = \alpha + \beta_1 (\text{mine}) + \beta_2 (\text{years worked}) + \beta_3 (\text{RP}) + \beta_4 (\text{NO}_2).$$

The models for predicted flow rates (FEF₅₀, FEF₇₅) were not significant, and so the predictor variables could not be assessed. For FEV₁ and FVC, mine was significant ($p \leq 0.005$) for all comparison populations. There were no statistically significant associations with any exposure variable.

In summary, mean predicted pulmonary function of the salt workers was reduced compared to all comparison populations, although the reductions were not large. Age coefficients from pulmonary function regressions equations were not higher than those of the comparison populations, and there was no association of predicted pulmonary function and exposure.

DISCUSSION

The internal and external comparisons of symptom prevalence are generally consistent. Cough and dyspnea were not related to exposure and prevalence was not elevated. The prevalence of phlegm was elevated (compared to blue collar workers only), and was related to exposure.

The agreement of internal and external comparisons in the analysis of pulmonary function is more difficult to interpret. Pulmonary function within the study population showed no association with exposure, and the age coefficients derived from regression equations were not consistently different from those of the comparison populations. Mean predicted pulmonary function of salt workers, however, was reduced although the average values were greater than 90% for FEV₁ and FVC.

Problems that make the assessment of risk difficult include: relatively rough estimates of exposure, imperfect measure of effect, undocumented role of selection, high correlation of age and estimated exposure, and lack of contemporary regional comparison groups.

To calculate exposure in this study we assumed that past exposures were the same as current exposures. Diesels were first introduced into the mines in the following years: Mine A = 1963-1967; Mine B = 1963 (one unit); Mine C = no diesels; Mine D = 1956; Mine E = 1957. Although some miners worked in the mines when there were no diesels, the number of years diesels were in the mines exceeded the mean years worked by 1, 3, 8, and 13 years in Mines A, B, D, and E, respectively. Arguments could be made to support the notion of either higher or lower levels of both respirable particulate and NO₂ in the past. However, in lieu of acceptable data to verify past environmental exposures, we believe that the approach used here (with its limitations) is still a useful and appropriate tool in estimating exposure.

The mines themselves reflect a difference in exposure. If exposure is having an effect on respiratory health, we would expect these differences to be reflected in differences in the prevalence of symptoms and reduced pulmonary function in the mines with higher exposure. Although there was a significant difference in pulmonary function from mine to mine, the differences showed little association with exposure. Mine D, for example, had by far the highest NO₂ exposures, yet adjusted pulmonary function values were higher than in Mine E which had about one-sixth the NO₂ exposure and 28% of the average NO₂ exposure. Mine C had the lowest exposure of all mines, but pulmonary function was intermediate. Thus, although there was a significant mine effect on pulmonary function, it did not appear to be related to exposure as we measured it. There was no statistically significant mine effect on respiratory symptoms, although the observed/expected ratios were highest for Mines D and E for cough and phlegm. The lack of a significant association of reduced pulmonary function with exposure (NO₂, RP, tenure) and a mine effect that is not dose-related is not consistent with the notion that the reductions in predicted pulmonary function are a result of exposure. The difficulties of the external comparisons are exemplified by the higher prevalence of symptoms in the underground coal workers. Thus the small but statistically significant reduction (2-5%) in predicted FEV₁ and FVC cannot clearly be attributed to work exposure.

Workers with symptoms and reduced pulmonary function leaving the salt mines in a greater proportion than nonsymptomatic workers could also explain the lack of a dose-response relation. We do not know the extent or effect of selection in this study.

Confounding is a problem that also makes it difficult to conclusively answer the question of the relationship of adverse health effects with exposure. For example, there was a high correlation of age and exposure; ie, there were few old workers with low exposure and fewer young workers with high exposures. Thus in the internal comparisons it is difficult to accurately estimate the separate effects of age and exposure on cough and phlegm because of their high correlation and association of age with both symptom and exposure.

While age and exposure are somewhat confounded in the internal comparisons of cough and phlegm, age is controlled for in the external comparisons. The logistic analysis showed an association of exposure with phlegm, but not cough. Both conclu-

sions are supported by the external comparisons. The internal and external comparisons are consistent in showing no association of dyspnea and exposure.

Predicted pulmonary function of salt miners was, however, reduced when compared with coal, potash, and blue collar workers. Age and height adjustments were made by regression, and smoking adjustments by comparing the appropriate smoking categories of salt workers with the same category in the control population. While these are among the more important of the known variables that must be adjusted for in the estimation of a dose-response relationship, they are not the only ones. Other factors can also affect changes in lung function that could result in differences in predicted lung function; eg, measurement differences between studies, different regions of the country, different ethnic background, etc. An approach to try to avoid these potential biases is to compare age-related changes in lung function, rather than comparing the actual magnitude of the lung function. The conceptual and practical importance of comparing age-related intercept-free changes in lung function rather than mean lung function is exemplified in the differences observed in a prospective study of lung function in London working men [Fletcher and Peto, 1977]:

	Mean FEV ₁ /h ³ (cl/m ³)	Intercept-free FEV ₁ slope ± SE (mL/yr)
Lifetime nonsmokers with mild obstruction	44	-37 ± 8
Heavy smokers with mild obstruction	43	-80 ± 6

There was no difference in mean height standardized FEV₁, but the reduction of FEV₁ per year in heavy smokers was twice that of nonsmokers.

Unfortunately, none of the analytical tools can control for the effects of selection, so we can only speculate as to what effect it would have on the results. Short of examining workers who left the industry and following all workers prospectively, we cannot conclusively answer the question relating to effects of exposure.

The estimates of cumulative exposure and chronic effects in cross-sectional studies are somewhat crude. The reasons for an absence of a dose-response relation may therefore include: Exposure is not hazardous; exposure is hazardous but our estimates are too imprecise to detect an association; our estimates of exposure and effect are valid but selection is such that no association with exposure exists.

In the absence of a contemporary control group and past exposure measurements, we have attempted to answer the question of exposure effects by also comparing both mean predicted pulmonary function and age coefficients of the salt worker with several comparison populations. Neither of these comparisons rely on exposure estimates per se. The mean predicted comparison is more likely to suffer from measurement differences than is the comparison of age coefficients. The results of these two methods are not in agreement.

Years worked is also an exposure variable. While precise in terms of time, it makes no distinction between high and low exposure jobs. The problem here is not one of misclassification as in cumulative exposure estimates, but of dilution. Sensitivity is lost because an exposure group classified by tenure is a mixture of workers with high and low exposure to diesel exhaust.

Potential respiratory irritants from diesel exhaust include aldehydes, SO₂, nitrogen oxides, and particulate. Formaldehyde was the only aldehyde sampled for, and it was nondetectable using indicator tubes. Acrolein is both more irritating and more toxic than formaldehyde; it may cause lacrimation and eye, nose, and throat irritation. It is possible that aldehydes could have had an effect on respiratory health, but since the highest levels were only at the eye irritant stage, they are considered to have no chronic or permanent effect on symptoms and pulmonary function. Diesel exhaust exposure at levels resulting in eye irritation appears to produce no acute reductions in pulmonary function [Battigelli, 1965; Gamble et al, 1981].

We reached the same conclusion for SO₂; ie, that SO₂ was not adversely affecting the respiratory system of the salt miners. The reasons for this conclusion include: low exposure concentrations (nondetectable by detector tubes); the protective detoxification ability of the body, and the lack of any experimental evidence of SO₂ toxicity after long term low exposures [NAS, 1978].

Diesel exhaust particulate in part meets the definition of carbon black in that it is more than 85% elemental carbon in the form of near spherical particles formed by the partial combustion of hydrocarbons [Frey and Corn, 1976; Vuk et al, 1976]. Not all diesel particles are colloidal, as the size can range from a single 100 Å particle to an agglomerate 30 μm in diameter [Vuk et al, 1976]. The characteristics of the particulate will vary depending on the sampling protocol, as Schreck et al, [1978] found a lower percentage of elemental carbon, but all particles and agglomerates were submicron in size. Diesel particulate and carbon black particles are nearly all respirable [Stewart et al, 1975], and both are also alike in that they contain polycyclic aromatic hydrocarbons (PAHs) [Schreck et al, 1978; Kotin et al, 1955; Lyons and Johnston, 1957].

NIOSH recommends that occupational exposure to carbon black be controlled so that exposure to carbon black be no greater than 3.5 mg/m³, or exposure to PAHs be no greater than 0.1 mg/m³, measured as the cyclohexane-extractable fraction over a 10-hour work shift in a 40-hour work week. The basis for the 3.5 mg/m³ limit was to prevent primarily pneumoconiosis and pulmonary fibrosis. The TWA limit of 0.1 mg/m³ PAHs is recommended to protect against the risk of cancer [NIOSH, 1978].

The highest average exposure to respirable particulate in this study was 1.4 mg/m³. Since a portion of the collected particulate was NaCl, respirable particulate exposure of salt miners appears well below the recommended standard for carbon black. This study cannot address the question of the carcinogenicity risk from the PAHs on the particulate.

Nitrogen oxides (NO_x) are formed wherever there is combustion or high temperature (and so are found in engine exhaust, cigarette smoke, fires) and is a common air pollutant. The acute effects of exposure to high concentrations of NO₂ are well known [Guidotti, 1978].

Long-term studies of exposures to low concentration of NO₂ are largely limited to animal studies. The only difference between exposed and control rats exposed to 0.8 ppm NO₂ for a lifetime was tachypnea in the exposed animals; tachypnea and elevated lung weights occurred when exposure was 2 ppm [Freeman et al, 1966, 1968]. No difference in body weight, hematologic values, biochemical indices, morphology, or susceptibility to pulmonary inflammation was observed in several species exposed for 18 months to 5 ppm NO₂ [Wagner et al, 1965]. Resistance to

infection is a more sensitive indicator, however. Mice exposed to 0.5 ppm NO₂ over a three-month period had higher mortality and morbidity after challenge with *Klebsiella pneumoniae* bacteria [Ehrlich and Henry, 1968].

Campbell and Hall [1976] exposed hamsters and rats to a constant level of 30 ppm NO₂ for 4.8 days and another group to 25 ppm for 18 hours and 45 ppm for 6 hours for 4.8 days. The question of interest was the significance of variations in exposure. While the exposure time was short and concentrations high, exposure groups with a varied exposure to NO₂ experienced a higher mortality, and mortality occurred earlier. The conditions of exposure in the salt miner study were similar to the constant level exposure in that there was little variation in NO₂ levels over the shift. Time weighted average exposures of NO₂ in the mines were much lower as well.

There are no epidemiological or animal studies that clearly delineate a safe level for human exposure to NO₂, although adverse effects have been observed at concentrations below the current 5-ppm standard. Continuous exposure is more toxic than intermittent exposure, with the toxic hazard determined primarily by the peak concentration rather than the average. NIOSH [1976] recommends a ceiling value of 1 ppm NO₂ to prevent acute irritant effects in the lungs and to lessen the risk of developing chronic obstructive lung disease in workers exposed to NO₂.

Mean NO₂ exposure of salt miners in this study was 1.3 ppm, with a low of 0.17 ppm NO₂ in Mine C and a high of 2.5 ppm in Mine D. The highest individual job exposure was 4.3 ppm NO₂. Thus a large proportion of the workers were exposed to average concentrations greater than the 1 ppm ceiling standard recommended by NIOSH [1976]. Acute irritant effects (as measured by reductions in pulmonary function over the work shift) are associated with NO₂ exposure in this population [Gamble et al, 1978]. The reductions are not large at lower exposure levels and are therefore consistent with the proposed standard of 1 ppm.

SUMMARY

We attempted to answer two questions in a cross-sectional survey of 259 white male workers in five diesel and nondiesel salt mines:

1) Were respiratory symptoms, radiographic findings, and reduced pulmonary function associated with years worked underground, cumulative respirable particulate, and cumulative nitrogen dioxide exposure? Cough and phlegm were associated with age and smoking. Exposure variables were associated with phlegm but not cough. Shortness of breath was associated with age, but not with smoking or exposure. The prevalence of pneumoconiosis was too low to analyze for dose-response relations.

None of the exposure variables showed any significant association with reduced pulmonary function. Although none of the exposure variables were significant, the accuracy of the association is difficult to assess because of the unknown accuracy of the assessment of past exposure.

2) Was there an increased morbidity in the salt miner population compared to other working populations? The prevalence of cough, dyspnea, and obstruction were not elevated compared to coal workers, potash miners, and blue collar workers. Phlegm was elevated in older salt miners compared to blue collar workers. Mean lung function was lower than all comparison populations. Intercept-free, age-related

changes in pulmonary function were not associated with years worked, estimated cumulative respirable particulate, or estimated cumulative NO₂ exposure.

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APPENDIX TABLES

TABLE VIII. Example Calculation for Cumulative and Average Exposure

	1	2	3	1 × 2	1 × 3
	Time in job	Job RP exposure	Job NO ₂ exposure		
Laborer	4 mo	0.6 mg/m ³	0.8 ppm	2.4 mg/m ³ × mo	3.2 ppm × mo
Truck driver	12 mo	0.5 mg/m ³	1.3 ppm	6.0 mg/m ³ × mo	15.6 ppm × mo
Driller	16 mo	1.2 mg/m ³	1.1 ppm	19.2 mg/m ³ × mo	17.6 ppm × mo
Total	32 mo			27.6 mg/m ³ × mo	36.4 ppm × mo

Cumulative RP exposure, RP = 27.6 mg/m³ × months.

Average RP exposure, $\overline{RP} = (27.6 \text{ mg/m}^3 \times \text{mo}) \div 32 \text{ months} = 0.86 \text{ mg/m}^3$.

Cumulative NO₂ exposure, NO₂ = 36.4 ppm × months.

Average NO₂ exposure, $\overline{NO}_2 = (36.4 \text{ ppm} \times \text{months}) \div 32 \text{ months} = 1.14 \text{ ppm}$.

TABLE IX. Characteristics of White Male Salt Miner Population

	Nonsmokers		Ex-smokers		Smokers		Total	
n (%)	50	(19)	59	(23)	150	(58)	259	
Age (SD)	36.9	(14.2)	45.2	(13.2)	37.7	(11.8)	39.3	(13.0)
Years worked (SD)	9.7	(9.7)	14.8	(11.2)	9.3	(9.8)	10.6	(10.4)
Cumulative exposure (SD)								
respirable particulate (RP)	85	(108)	103	(115)	66	(91)	78	(101)
in mg × months/m ³								
NO ₂ (ppm months)	221		272		157		195	
Average exposure	0.59		0.56		0.57		0.57	
respirable particulate (\overline{RP})								
in mg/m ³								
\overline{NO}_2 (ppm)	1.26		1.40		1.32		1.33	
Cigarettes/day	—		26.0	(17.6)	24.8	(12.7)	—	
Pack years	—		24.6	(24.9)	26.9	(21.5)	—	
n								
Cumulative RP (mg × mo/m ³)								
low (<47)	18		28		93		149	
medium (47-75)	5		7		19		31	
high (>75)	17		24		38		79	
Cumulative NO ₂ (ppm × mos)								
low (<48)	27		21		79		127	
medium (48-100)	5		11		24		40	
high (>100)	18		27		47		92	
Years worked								
< 10	32		26		100		158	
≥ 10	18		33		50		101	

TABLE X. Exposure of White Male Salt Miners by Mine

	Mine									
	A		B		C		D		E	
n	17		22		27		108		85	
Cumulative exposure (SD)										
NO ₂ (ppm months)	53	(103)	71	(139)	31	(36)	387	(428)	63	(80)
RP (mg/m ³ months)	20	(27)	94	(107)	48	(65)	115	(122)	49	(66)
Mean exposure (SD)										
NO ₂ /months (ppm) = $\overline{NO_2}$	0.4	(0.3)	0.3	(0.5)	0.2	(0.1)	2.5	(1.3)	0.7	(0.4)
RP/months (mg/M ³) = \overline{RP}	0.2	(0.1)	0.7	(0.3)	0.3	(0.3)	0.7	(0.3)	0.5	(0.3)
Years worked	9	(11)	11	(11)	13	(11)	13	(12)	7	(6)

TABLE XI. Characteristics of Comparison Populations for Salt Miner Study

		Potash	Aboveground coal	Underground coal	Blue collar
n		875	509	5722	843
Age	(SD)	41 (13)	44 (12)	39 (13)	38 (14)
Height	(SD)	176 (6)	175 (6)	174 (6)	173 (7)
Years worked	(SD)	16 (13)	18 (13)	15 (13)	12 (12)
(range)		(0-50)	(0-55)	(0-56)	(0-50)
Nonsmokers	n (%)	178 (20)	105 (22)	1112 (21)	207 (25)
Ex-smokers	n (%)	244 (28)	150 (32)	1234 (23)	194 (23)
mean pack years	(SD)	23 (20)	24 (19)	17 (18)	21 (23)
mean cigarettes/day	(SD)	25 (14)	23 (12)	19 (12)	23 (15)
Smokers	n (%)	451 (52)	214 (46)	3023 (56)	442 (52)
mean pack years	(SD)	28 (23)	27 (18)	17 (14)	23 (19)
mean cigarettes/day	(SD)	25 (12)	22 (9)	17 (8)	23 (11)
Mean current NO ₂ concentration (ppm)		0.90 ^a	NA	NA	NA
Mean current total dust (mg/m ³)		3.45 ^a	NA	NA	NA
Respirable dust		NA	1.44 ^b	1.36 ^b	NA

^aPersonal samples, from Attfield [1978] and Sutton et al [1978]. Total dust and NO₂ from the salt mines in this same study were 1.22 mg/m³ dust and 1.25 ppm NO₂.

^bCollected between the first and second rounds of the National Coalworkers' Study. The 25 coal mines were in both the first and second rounds of examinations of the coal study.

NA = not available.

TABLE XII. Residual Pulmonary Function* of Those With and Without Cough, Phlegm, and Shortness of Breath in White Male Salt Miners (Adjusted for age, height, and smoking)

	FVC ml(SD)	FEV ₁ ml(SD)	FEF ₅₀ ml/sec(SD)	n FEV ₁ &FVC	n FEF ₅₀
Cough					
none	43 (654)	45 (548)	-4 (1178)	156	128
first thing in morning and/or during day in winter	13 (565)	12 (481)	-51 (1044)	39	29
3 mo/yr	-113 (604)	-119 (597)	37 (1549)	63	63
Phlegm					
none	20 (648)	13 (561)	38 (1185)	160	126
first thing in morning and/or during day in winter	208 (464)	153 (472)	-229 (1107)	25	18
≥3 mo/yr	-116 (626)	-81 (554)	-10 (1437)	73	66
Shortness of breath					
none	12 (602)	34 (527)	78 (1227)	168	133
dyspnea when hurrying on level ground or walking up slight hill	40 (618)	-38 (529)	-182 (1284)	71	58
dyspnea when walking with other people own age on level ground	-217 (905)	-112 (818)	-2 (1404)	16	16
have to stop for breath when walking at own pace on level ground	-490 (745)	-392 (911)	52 (1812)	3	3

*Residual pulmonary function = predicted - actual, where predicted is the regression equation for appropriate smoking category with age and height as independent variables.

TABLE XIII. Mean Percent Predicted Lung Function by Mine

	A	B ^a	C ^a	D	E
	% (SE)	% (SE)	% (SE)	% (SE)	% (SE)
FEV ₁ —potash	105.1 (3.7)	103.8 (2.6)	97.8 (3.8)	97.6 (1.3)	92.9 (1.5)
FEV ₁ —blue collar	105.7 (3.8)	104.9 (2.6)	99.3 (4.1)	98.7 (1.4)	92.6 (1.5)
FVC—potash	103.8 (3.3)	105.1 (2.2)	99.5 (3.2)	96.5 (1.2)	93.8 (1.4)
FVC—blue collar	104.6 (3.3)	106.3 (2.2)	101.0 (3.1)	97.4 (1.2)	95.4 (1.5)
Peak flow—potash	100.7 (3.8)	—	—	85.9 (1.5)	94.0 (1.7)
Peak flow—blue collar	105.1 (4.1)	—	—	90.0 (1.5)	97.6 (1.7)
FEF ₅₀ —potash	97.7 (6.4)	—	—	89.4 (3.1)	86.6 (3.0)
FEF ₅₀ —blue collar	102.1 (7.0)	—	—	94.4 (3.5)	88.8 (3.2)
FEF ₇₅ —potash	101.4 (7.4)	—	—	83.4 (3.7)	78.9 (3.3)
FEF ₇₅ —blue collar	99.1 (8.4)	—	—	84.7 (4.0)	75.3 (3.1)

^aPeak flow, FEV₅₀, and FEF₇₅ were not obtained in Mines B and C.

TABLE XIV. Comparison of Age Coefficients of Salt Miners, Underground Coal Miners, Aboveground Coal Miners, and Potash Miners

	Salt	Underground coal	Aboveground coal	Potash	Blue collar
FEV ₁ (ml)					
nonsmokers	-30 (5)	-32 (1)	-31 (5)	-28 (3)	-30 (3)
ex-smokers	-35 (6)	-39 (1)	-43 (4)	-32 (3)	-36 (3)
smokers	-42 (4)	-43 (1)	-44 (4)	-40 (2)	-39 (2)
FVC (ml)					
nonsmokers	-29 (6)	-26 (2)	-23 (6)	-23 (3)	-24 (3)
ex-smokers	-27 (8)	-30 (2)	-36 (6)	-26 (4)	-25 (3)
smokers	-36 (4)	-33 (1)	-37 (4)	-31 (3)	-25 (2)
FEF ₅₀ (ml/sec)					
nonsmokers	-32 (13)	-47 (3)	-40 (11)	-36 (7)	-43 (6)
ex-smokers	-44 (16)	-62 (3)	-71 (10)	-44 (8)	-58 (8)
smokers	-48 (11)	-72 (2)*	-67 (8)	-63 (5)*	-71 (5)
FEF ₇₅ (ml/sec)					
nonsmokers	-37 (5)	-37 (2)	-35 (5)	-32 (4)	-38 (4)
ex-smokers	-25 (7)	-40 (1)*	-44 (4)*	-29 (3)	-40 (3)
smokers	-33 (5)	-44 (1)*	-39 (3)	-41 (2)	-50 (2)
Peak flow (ml/sec)					
nonsmokers	-59 (14)	-52 (4)	-23 (14)**	-32 (8)	-40 (9)
ex-smokers	-48 (21)	-64 (4)	-69 (15)	-64 (10)	-75 (10)
smokers	-54 (13)	-69 (3)	-61 (12)	-51 (7)	-56 (7)

PFT = $\alpha + \beta_1$ (age) + β_2 (height)

*Significantly higher than salt.

**Significantly lower than salt.