CHAPTER 18

AN EPIDEMIOLOGICAL STUDY OF THE RESPIRATORY EFFECTS OF TRONA DUST

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INTRODUCTION

Trona ore (sodium sesquicarbonate, $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) is mined from rich underground deposits near Green River, Wyoming. The trona deposit is 10 feet thick and located 1500 feet below the surface. Four companies, employing approximately 4000 persons, mine about 8 million tons of ore each year from an estimated reserve of 50 billion tons. Trona ore is processed to soda ash (sodium carbonate) and is used in the manufacture of glass, paper, detergents, and in various chemical applications.

Trona dust is alkaline (pH 10.5), soluble and can be irritating to the skin, mucous membranes and respiratory airways. To determine whether occupational exposure to trona dust has an adverse effect on respiratory function and symptoms, an epidemiologic study was conducted with a company that

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employs 1300 persons and that has been in continuous operation since 1948. The study included a cross-sectional assessment of pulmonary function, a pre- and post-workshift evaluation, and a longitudinal five-year followup.

METHODS OF PROCEDURE

Study Population

A total of 230 individuals, or 18% of the total workforce, volunteered to participate in the respiratory study. The study population included (1) 125 workers who participated in a National Institute for Occupational Safety and Health (NIOSH) diesel study in 1976 (54% of our cohort and 60% of those still employed and previously studied by NIOSH); (2) 32 workers who had complaints of trona dermatitis and had seen a physician (14% of our cohort); and (3) 73 volunteers from dustier jobs (32% of our cohort). The study population included workers from all jobs, both underground and surface. Field stations were established at three sites consecutively, and workers were examined after each of the three shifts.

Each worker's interview was conducted by a trained interviewer and included a chronological occupational history enumerating all jobs, their duration and exposure details. A modified British Medical Research Council (BMRC) respiratory symptoms and smoking questionnaire was administered. The ex-smokers had not smoked for at least one year, and the nonsmokers had smoked less than one cigarette/day for one year.

Pulmonary Function Studies

Spirometry was performed using two rolling, dry-seal spirometers with a tape recording system to record each flow-volume curve. The spirometers were identical to those used by NIOSH in 1976. A flow-volume display was used to ensure proper test performance. A minimum of five acceptable tracings were obtained. The tests obtained included forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), FEV_1/FVC, peak flow, FEF_{50} and FEF_{75}. The best curve (largest sum of FEV_1 and FVC) was used for interpretation. The data tapes from 1976 and 1981 were treated the same.

A comparison group consisted of 125 men studied by Crapo et al. [1]. They were nonsmokers residing in the Salt Lake City area who were studied during 1979–1980. They had no cardiopulmonary symptoms, normal cardiopulmonary exams, normal chest radiographs and were not exposed to noxious dusts. Spirometry in the Crapo study was performed with a water-seal metal bell spirometer, and all displacement volumes were reported in liters BTPS.

The Crapo et al. [1] comparison values were used for FVC, FEV_1 and FEV_1/FVC ratio.

Exposure Determinations

Exposure determinations included total work-years, exposure categories (high, medium and low) and a cumulative trona dust exposure index. There were 56 job codes. Each worker was asked to code his job exposure on a scale of 1 to 4 (none, light, medium and heavy) to raw trona dust, sodium carbonate dust, sodium sesquicarbonate dust and sodium tripolyphosphate dust. A mean score was determined for all employees studied in that job category. The highest mean exposure was to raw trona dust in all job categories, and scores of 1–2.0 were assigned low, 2.1–3 medium, and 3.1–4 high. The categories were reviewed and approved by the company and union. The personal samples for total dust differed by a factor of four between high and medium and between medium and low. The personal samples for respirable dust differed by a factor of two between high and medium, but medium was only slightly higher than low. The cumulative trona dust exposure index was computed by multiplying the months at a certain job times high (3), medium (2) and low (1) and summed to develop a composite score.

Area and personal dust samples were collected for total and respirable dust and presented as 8-hour time-weighted averages (TWA). The percentage respirable free silica also was determined. Ammonia, nitrogen dioxide, trace metals, asbestos, formaldehyde and polynuclear aromatics were also sampled. The polynuclear aromatics were analyzed by high-pressure liquid chromatography for fluoranthene, pyrene, benzo(a)pyrene, chrysene and benzo(a)anthracene.

Statistical Analysis

Analysis of variance was used to test the effect of smoking, work-years, work sites and cumulative dust index on pulmonary function. The paired t test was used for the comparison of pre- and post-shift pulmonary function tests and for the longitudinal study of pulmonary function (1981 versus 1976). Pearson's correlation procedure was used to test for associations between pulmonary function measurement, smoking and work-years.

Regression analysis was used to estimate the linear regression equations and to test the linearity of the slope of the regression equations for pulmonary function measurement in relation to smoking, work-years and age. Multivariate regression analysis was used to determine whether FEV_1 was affected by several risk variables, including age, work-years, years smoked and pack-years.

RESULTS

Study Subjects

There were 142 underground miners and 88 surface workers. The mean age of the entire group was 37.6 (±11.9) years and the mean length of employment was 10.0 (±8.2) years. There were no differences in age between surface and underground workers, but the nonsmokers were significantly younger (33.3 years) than smokers (37.3 years) and ex-smokers (40.8 years). Surface workers had a significantly greater length of employment (11.0±9.4 years) than underground miners (9.3±7.2 years).

Respiratory Function and Examination Results

The mean percentage of predicted pulmonary function values for the whole group, underground and surface, and smoking categories are listed in Table I. There were no significant differences between underground and surface mean values, although surface values were lower for FVC, FEV_1 and FEV_1/FVC ratio. Also, there were no significant differences among smoking groups for FVC, FEV_1 or FEV_1/FVC ratio, although the values for smokers were lower.

Table II illustrates that there were no differences in mean percentage of predicted FVC, FEV_1 or FEV_1/FVC ratio by the high, medium or low exposure categories. However, workers in the low category were significantly older (low 42 years, medium 37.5 years, high 33.5 years, $p = 0.0002$) and had a significantly greater duration of exposure (low 13.9 work-years, medium 9.6 work-years, high 6.8 work-years, $p < 0.01$). Furthermore, there were no differences within smoking categories or by underground or surface for the high, medium or low categories.

The percentage of predicted FVC, FEV_1 and FEV_1/FVC were evaluated by work-years (3, 3–6, >6–9, >9–12, >12) by underground, surface and

Table I. Mean Percentage Predicted Pulmonary Function Results for All Workers by Worksites and Smoking Categories

Category	N	FVC	FEV_1	FEV_1/FVC
All	230	104.2	95.9	92.1
Underground	142	105.0	97.0	92.5
Surface	88	102.8	93.9	91.6
Smokers	98	103.6	94.1	90.0
Ex-smokers	77	103.5	95.4	92.3
Nonsmokers	54	105.9	99.3	94.0

Table II. Mean Percentage Predicted Pulmonary Function Results by Exposure Category

Exposure	N	FVC	FEV_1	FEV_1/FVC
High	66	105.4	98.5	93.6
Medium	102	105.1	96.1	91.5
Low	62	101.1	92.3	91.5

various smoking categories (Table III). There was a significant association between the percentage of predicted FEV_1 and work-years, but this was not significant for the cumulative trona dust exposure index. There were no significant trends for either work-years or the cumulative trona dust exposure index when evaluated by underground or surface jobs or by smoking category.

Figure 1 illustrates the regression equations and plot of the percentage of predicted FEV_1 versus age by smoking category. The regressions for the slopes for smokers and ex-smokers were significant compared to the non-smoking comparison population. Figure 2 illustrates the regression equations and plot of the percentage of predicted FEV_1 and work-years by smoking category; the decline for ex-smokers was also significant. All three groups lost FEV_1 in relation to increasing work-years after correcting for age and height. The declines were also calculated for the actual FEV_1 and were similar to the percentage predicted, and the same statistical significances were found. The correlation coefficients for FEV_1 and work-years were −0.16 for smokers ($p = 0.059$), −0.27 for ex-smokers ($p < 0.05$) and −0.04 for nonsmokers (NS). There was a significant correlation between the decline in percentage predicted FEV_1 and the measured respirable dust for the 13 nonsmokers who had personal samplers. A multiple regression of FEV_1

Table III. Mean Percentage Predicted Pulmonary Function Results by Work-Years

Work-Years	N	FEV	FEV_1
Total	230	104.2	95.6
<3	33	104.4	97.5
3–6	46	105.5	99.1
>6–9	72	102.8	85.4
>9–12	25	109.3	100.9
>12	54	101.9	90.3
p-value[a]		NS	<0.025

[a]Regression analysis.

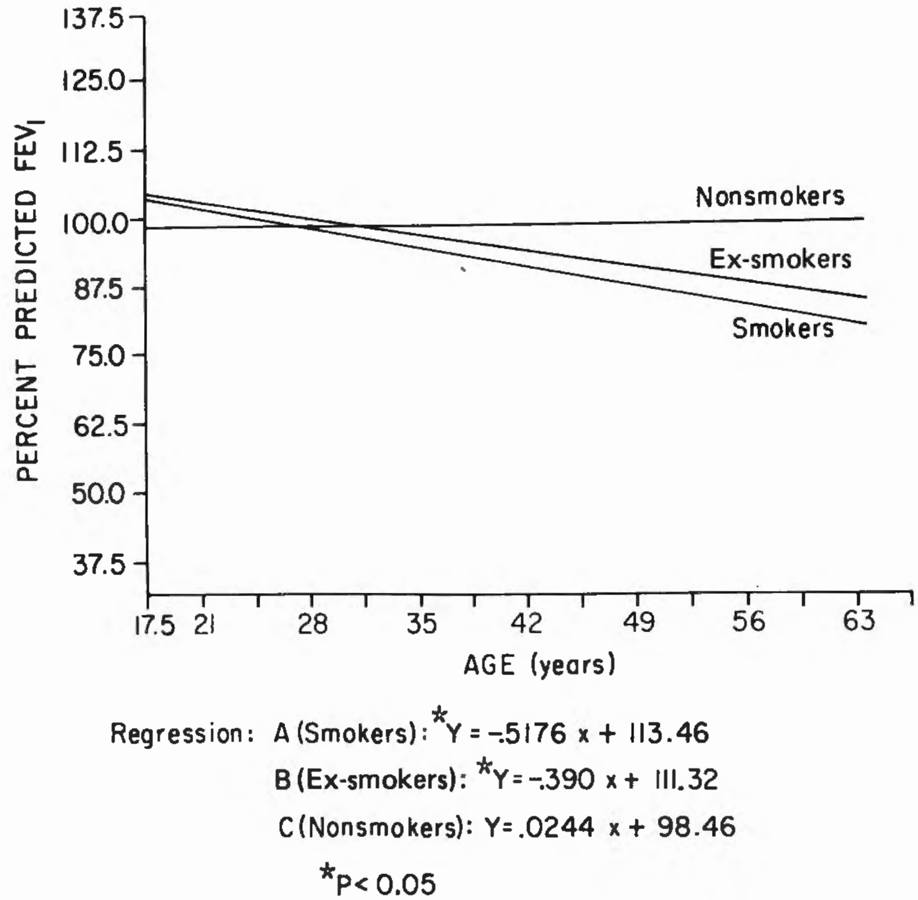

Figure 1. Decline in percentage predicted FEV_1 by age and smoking category.

against three independent variables found age ($p < 0.01$) and pack-years ($p < 0.01$) significant, but work-years not significant.

A total of 104 workers had their pulmonary function tested before and after their workshifts. Table IV illustrates that the FEV_1 declined for all workers, was significant for surface workers and nonsmokers, and approached significance for those in the high exposure category. The percentage of predicted FEV_1 showed a significant fall for all workers ($p = 0.035$).

The 125 workers tested in 1981 had been tested in 1976. The mean values for the percentage of predicted FVC and FEV_1 actually were greater in 1981 (5.2% for FVC and 1.8% for FEV_1). Of these workers, 87% had worked underground. There were 43 workers in the longitudinal study who also participated in the shift study. Only 1 of the 43 workers had a 1% decline in the percentage of predicted FEV_1 in both the longitudinal and shift studies. The correlation coefficient between the shift study and the longitudinal study was 0.1533, with the $r^2 = 0.0235$. Table V lists the annual changes in FEV_1 determined from the cross-sectional study for age and work-years,

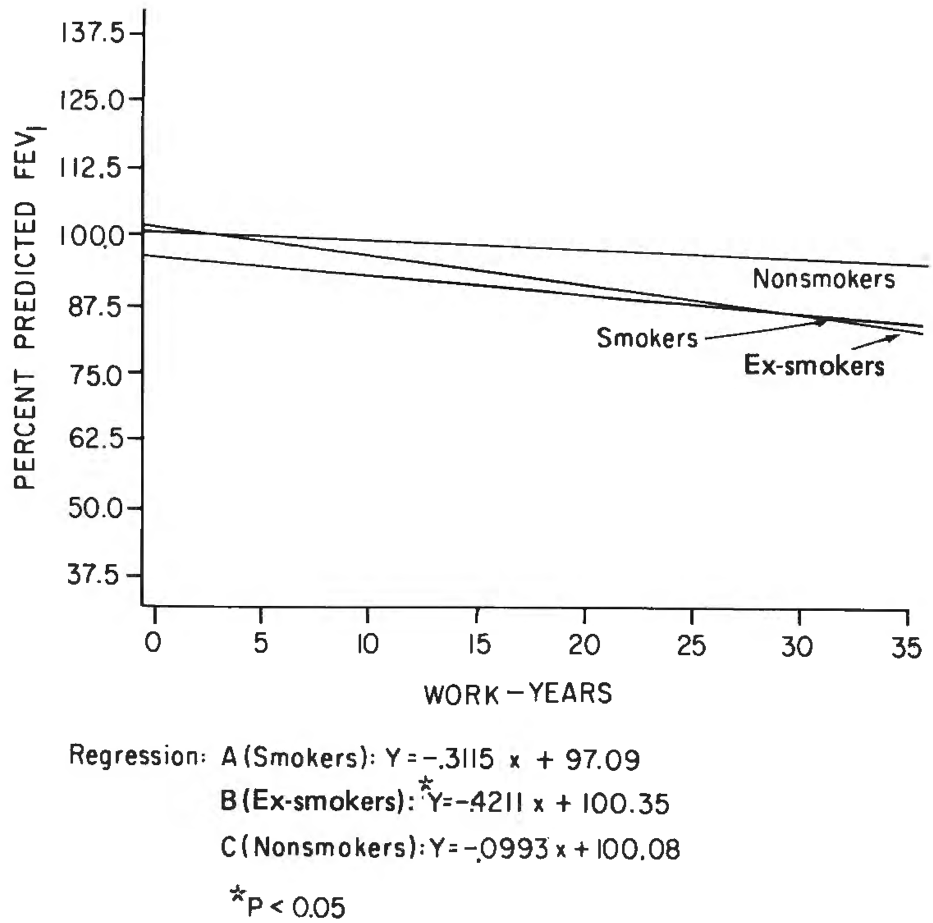

Figure 2. Decline in percentage predicted FEV_1 by work-years and smoking category.

Table IV. Mean FEV_1 Pre- and Post-Shift by Worksites, Smoking and Exposure Categories

	N	Pre	Post	Pre/Post Difference	p Value[a]
All Workers	104	4.12	4.07	0.05	NS
Underground	61	4.12	4.11	0.01	NS
Surface	43	4.11	4.03	0.08	0.005
Smokers	55	4.08	4.06	0.02	NS
Ex-smokers	28	4.05	4.02	0.03	NS
Nonsmokers	21	4.30	4.21	0.09	0.025
Low	5	3.62	3.59	0.03	NS
Medium	43	4.10	4.07	0.03	NS
High	56	4.17	4.13	0.04	0.065

[a]Paired *t* test.

Table V. Annual Change in FEV_1 (liters) by Age, Work-Years, and the Longitudinal Study

	Age (n = 230)	Work-Years (n = 230)	Longitudinal Study (n = 125)
Smokers	−0.048	−0.038	−0.017
Ex-smokers	−0.031	−0.041	+0.016
Nonsmokers	−0.042	−0.059	+0.014

and the longitudinal study by smoking habit. The cross-sectional study predicted a decline in FEV_1, whereas those who participated in the followup actually had a mean increase if they were non- or ex-smokers.

Respiratory Symptoms

Of the study population, 23% complained of the presence of cough and phlegm for three months' duration. A total of 33% of the smokers and 21% of the nonsmokers had chronic cough and phlegm; 33% complained of dyspnea when hurrying on level ground or walking up a slight hill. Respiratory symptoms did not increase with the cumulative trona dust exposure index, and there were no differences between surface or underground workers. Only ex-smokers had significantly reduced FEV_1 or FEV_1/FVC associated with chronic cough or chronic phlegm.

Nasal drainage reflecting upper airway irritation was common (48%), and two-thirds of these had their nasal drainage for at least three months. Of the workers, 25% showed signs of mucous membrane inflammation that was equally divided between conjunctivitis and pharyngeal inflammation. Eye and nose irritation were reported by over half of the workers, and a significant dose-response was noted (Table VI).

Table VI. Special Symptoms on Eye, Nose and Throat by Exposure Category

	Total		Exposure Category			
	N	%	Low	Medium	High	p-Value
Eye Irritation	128	55.7	15	56	57	<0.001
Nasal Irritation	133	57.8	19	55	59	<0.001
Sore Throat	41	17.8	3	21	17	<0.01

Industrial Hygiene

The total and respirable dust sampling is summarized in Table VII. The mean values for total dust were two to three times the recommended threshold limit value (TLV) of 10 mg/m^3, with ranges up to 98 mg/m^3; however, the mean values for respirable dust were half the recommended TLV of 5 mg/m^3, with levels ranging up to 11 mg/m^3. The underground respirable dust levels were significantly higher than surface (2.16 mg/m^3 versus 0.83 mg/m^3, $p < 0.01$). The respirable free silica was below the limit of detection (0.03 mg) in all samples.

The concentration for NO_2 had a low mean value of 0.14 ppm for 45 samples. A total of 30 samples were obtained for fibers to evaluate using phase contrast microscopy; all samples were below the limit of detection of 0.03 fibers per field. Levels for polynuclear aromatics were in the nanogram (background) range. Only seven samples for ammonia were obtained with a mean of 71 ppm (range 15 to 203 ppm), with the higher sample values taken proximate to blasting operations.

DISCUSSION

An epidemiological survey of trona miners and millers found relatively normal ventilatory function in a young and volunteer population. The population surveyed was rather small (230 of 1300 active employees, 18%) and not randomly selected, but included workers from all the various job

Table VII. Total and Respirable Dust from Personal and Area Sampling (8-hour TWA)

	Total Dust (mg/m^3)		Respirable Dust (mg/m^3)	
	N	$\bar{x}$	N	$\bar{x}$
Area Samples				
All	27	18.13	17	2.65
Surface	11	15.49	9	2.13
Underground	16	19.94	8	3.24
Range	(0.73 – 64.03)		(0.1 – 6.7)	
Personal Samples				
All	20	27.83	52	1.65
Surface	17	27.15	20	0.83[a]
Underground	3	31.70	32	2.16[a]
Range	(0.59 – 98.80)		(0.10 – 11.0)	

[a]Significant ($p < 0.01$).

categories, including the dustier jobs and workers with both short and long durations of employment. The study population was also an active working group and, thus, may have been a "survivor" population. However, the objectives of the study were to perform a five-year followup study and a shift study of both surface and underground workers.

Surface workers had slightly lower values for FVC, FEV_1 and FEV_1/FVC than underground miners. The occupational histories of the 21 surface workers with the lowest percentage of predicted FEV_1 were reviewed; only 5 had previously worked underground and may possibly have moved to less dusty surface jobs. Thus, the lower pulmonary function values for surface workers probably reflect their greater duration of employment, rather than migration of affected workers from underground to surface.

Significant declines were noted in FEV_1 for those with a history of smoking related to age and for ex-smokers with increasing work-years compared to the nonsmoking comparison population after standardizing for height and age. An accelerated decline of FEV_1 among susceptible cigarette smokers has been described [2]. There was only limited evidence of an adverse effect on FEV_1 from trona dust exposure, e.g., the significant decline in FEV_1 with work-years for ex-smokers. Furthermore, a multiple regression of FEV_1 against three independent variables found age and pack-years significant but work-years not significant. The nonsmokers showed no effect with FEV_1 and age or work-years, but had a significant association between FEV_1 and respirable dust. Thus, nonsmokers may not be totally immune from the irritant properties of trona dust on airway function.

A significant shift effect was shown by a fall in the percentage of predicted FEV_1 during a working shift. This was significant among surface rather than underground workers, among nonsmokers rather than smokers and ex-smokers, and approached significance among those in the high exposure category. Thus, trona dust, especially in the processing stages of crushing, roasting, calcining and filtering, may have an acute effect on the lung, regardless of smoking. A history of smoking may obscure or desensitize the lung to an acute effect, although Ames et al. [3] noted a shift effect among smokers in a study of underground miners exposed to diesel exhaust.

No chronic loss of pulmonary function was noted among workers participating in the five-year longitudinal followup. The reasons for an improvement in the tests on the longitudinal study could be related to: improvement in dust controls with reduced dust levels (particularly in the mining jobs); more aggressive pulmonary function technicians on the second survey; movement of workers in dusty jobs to less dusty jobs over the five years as their seniority increased; a significant decrease in cigarette smoking; loss of those with bronchial hyperirritability; or lung growth, as many of the miners were still young [4]. Also, only 60% of those originally studied and still employed participated in the followup study. Not only did the shift study not predict those who might have been losing FEV_1 at an accelerated pace over the previous five years, there was no correlation between acute effects that could be detected by the shift study and the longitudinal five-year followup.

There was a poor correlation between pulmonary function values and indices of dust exposure, probably because workers in the low category were older and had more work years of exposure. There was a significant difference among exposure categories for total dust. The exposure categories differed with respect to eye and upper airway symptoms and approached significance in the shift study. A cumulative trona dust exposure index was less predictive than work-years of exposure.

Respiratory symptoms such as cough and phlegm for three months were low (23%), but the study group was a young, working population. Fletcher et al. [2] found percentage rates in London Transport Workshops that were similar: percentage with chronic mucous hypersecretion age 30–39 (n = 76 men), 24%; age 40–49 (n = 112 men), 28%; and age 50–59 (n = 195 men), 43%. We previously reported [5] higher percentage rates for chronic bronchitis among 242 older Utah underground coal miners (smokers 57% and nonsmokers 50%). Cough and phlegm are increased in smokers, those in lower socioeconomic classes, urban residents exposed to particulate air pollution, and in certain dusty industries (industrial bronchitis), especially mining, textile plants with exposure to raw cotton dust, and so forth. The effect of smoking is usually to increase the percentage rate (e.g., from 10% in nonsmoking steelworkers to 20% among smoking steelworkers, standardizing for age), although some occupational dust exposures in older study populations may obscure this effect [6].

Industrial hygiene sampling suggested that some jobs at both surface and underground positions had high values for trona dust, although many of the particles were not respirable, as respirable dust samples were lower. There were seven samples for ammonia, with four elevated; ammonia is also a respiratory irritant and was found near the face following blasting. Free silica was below the limit of detection in all the respirable dust samples; pneumoconiosis has previously been reported to be less than 0.3% of 746 trona miners studied by NIOSH at two mines in 1976 [7].

Investigators in the Soviet Union have reported a clinical epidemiological study of port workers exposed to soda ash, which was followed by animal experimentation [8]. Dust levels over 300 mg/m^3 were reported in ship holds and freight cars. Shipping workers exhibited "soda ash burns" and a 1.5 times increase in the incidence of skin diseases and lost work days due to skin inflammation. Clinical exams of 145 workers revealed skin diseases (ulcers, erosion, eczema), as well as rhinitis, pharyngitis and conjunctivitis.

Hygienic measures were instituted, reducing dust levels ten-fold; the number of skin diseases was lowered three-fold and the diseases of the upper respiratory tract by 1.5 times. Soviet investigators [8] reported an irritant threshold (presumably irritation to the upper respiratory tract) of 40 mg/m^3 in 14 volunteers after a one-minute exposure.

In summary, we found that pulmonary function was within normal limits, but significant declines may be occurring with FEV_1 among those who have smoked related to age and possibly work-years. Nonsmokers and surface workers had a shift effect with a decline in FEV_1. This shift study did not predict those who might have been losing FEV_1 at an accelerated pace over the previous five years. Eye and upper respiratory tract irritation was common, but only 23% had chronic cough and phlegm. The study population was young, with a short duration of exposure, so further followup studies and continued dust control measures are recommended.

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DISCUSSION

Question: I think this is interesting, although obviously without an unexposed control group and without a random sample of the population, it's hard to know what to make of your pulmonary function findings. I had the opportunity to retrospectively look at two outbreaks of mucous membrane irritation in two different building settings in which we demonstrated that the symptoms were due to detergent dust exposure that resulted from a misapplication of carpet shampoo and, presumably, some of the dust was respirable. In reviewing the literature on detergent exposures, I could find very little, with the exception of two health hazard evaluations that NIOSH had done–one on soapmakers and one on detergent makers. In the soapmakers' HHE, there were pulmonary function abnormalities in young, nonsmoking women, even though they couldn't demonstrate pre- and post-shift changes. The investigators had no explanation for these abnormalities, and I think this is an area in which a lot of work needs to be done in a careful, systematic way.

Response: I might comment on the nonrandom sample of this study population. We had two goals. First, we tried to maximize the number of people who participated in this survey who had also participated in the previous NIOSH study in 1976. This gave us the same selection bias (if any) of the earlier NIOSH study that was geared toward underground workers rather than surface workers. Second, we wanted to try and have about half of our participants on the shift study from underground jobs and half from surface jobs, which we accomplished. The study is representative of conditions that actually are in the mine. We did notice, however, that of those workers employed five years earlier, many had moved to foreman and supervisory-type positions by the time of our study. There may have been a trend toward less dusty or less dust-exposed workers in our study. There is a report on soda ash exposure from the Soviet Union, which is the only one I've been able to find, that reports on a group of port workers who loaded and unloaded soda ash from a freight ship onto trains. Exposures there were much higher than in our study, and they had considerable problems with nasal irritation, trona dermatitis (actually skin sores as they described them), and a lot of absenteeism. They reduced their dust levels, and their health problems diminished significantly.

HEALTH ISSUES RELATED TO METAL AND NONMETALLIC MINING

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