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Respiratory Health Status of Gilsonite Workers

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Gilsonite, a solidified hydrocarbon used in the manufacture of automotive body seam sealers, is mined only in the Uinta Basin of Eastern Utah and Western Colorado. Health effects of gilsonite dust exposure have not previously been published and exposure to gilsonite dust is not regulated. To examine potential respiratory health effects associated with gilsonite dust exposures, this cross-sectional study surveyed the 100 current male employees who had been exposed to gilsonite dust at 3 existing gilsonite companies. Total dust exposures up to 28 times the nuisance dust standard were found, and 5 of 99 (5%) workers had chest radiographs consistent with pneumoconiosis of low profusion. Increased prevalences of cough and phlegm were found in workers with high-exposure jobs, but no evidence for dust-related pulmonary function impairment was noted. To prevent pulmonary health effects, we recommend reducing dust exposures for those workers in jobs currently characterized by relatively high dust exposures.

Key words: gilsonite dust, bronchitis, pneumoconiosis, occupational diseases

INTRODUCTION

Gilsonite is a solidified hydrocarbon, classed as one of the asphaltites, with commercial deposits located only in the Uinta Basin of Eastern Utah and Western Colorado [Thrush, 1968; Neel, 1980]. Veins of gilsonite are believed to have been formed when viscous crude oil from nearby oil shale deposits filled near-vertical fractures in the surrounding rock and then solidified [Neel, 1980; Jackson, 1981].

Gilsonite was discovered during the 1860s by settlers who first thought that the black substance was a variety of coal, but then found that it melted when heated. Samuel Gilson spent many years experimenting with the ore and by 1888, when he and a partner formed a company to market the tar-like varnish Gilson had developed, the ore had become known as gilsonite [Fene, 1928; Shushan, 1983]. Current markets include the use of gilsonite in the manufacture of automotive body seam sealers; as a principal ingredient in dark photogravure inks; as a component of oil-well drilling fluids and cements; as an additive in sand molds used by the foundry industry; and by the building board, explosive, and nuclear graphite industries [Neel, 1980; Jackson, 1981; Shushan, 1983].

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Veins of gilsonite vary in width from a few centimeters to 6 m and extend from surface outcroppings to depths of 600 m [Neel, 1980]. Mining starts near the top of a gilsonite vein, on both sides of vertically bored shafts. Air-powered hand-held chipping hammers are used to break the gilsonite as a miner works upward from the shaft at a 45° angle. The broken ore falls to the bottom of the slope where it is vacuumed into a pipe and pneumatically conveyed to the surface. At the processing plant, the ore is cleaned, classified into grades, and either bagged for shipment or transferred in bulk onto trucks [Jackson, 1981.]

The workforce consists of miners and miner's helpers who work underground with air-powered chipping hammers; hoistmen who work above ground, operating the "cages" that move men and equipment up and down the shaft; truckers who transport gilsonite from storage bins at the mine sites to the processing plant; processing plant workers who operate equipment including a dryer to remove moisture from the gilsonite, a vibrating screen to size the ore, a pulverizing machine, and bagging machines; and a maintenance crew who work in the shop and in the processing plant, but rarely in the mines [Jackson, 1981].

Heavy dust exposures arise during the mining and milling of this friable hydrocarbon. Health effects of gilsonite dust exposure have not previously been published and exposure to gilsonite dust is not regulated. Thus, an industry-wide cross-sectional study was conducted to examine potential respiratory health effects associated with gilsonite dust exposure.

METHODS

Participant Selection

This cross-sectional study surveyed the 101 current employees, 100 males and 1 female, who had been exposed to gilsonite dust at 3 of the 4 existing gilsonite companies. The smallest company, which employed only one full-time worker with more than 1 year of exposure, declined to participate in the study. In addition, the names of former workers who had been employed for a minimum of 5 years were provided by the companies, and these workers were invited by mail to participate in the study. Since many of these former employees were able to name other former employees who met the criteria for inclusion in the study but had not been listed by the companies, it became evident that the companies may not have been able to conduct a thorough record search. Of all identified former workers, approximately 50% (N=35) participated in the study, raising doubts as to whether those tested were representative of the entire former workforce. Thus, due to the probable incomplete record search and the low participation rate, data collected from former workers were analyzed separately. Data from the single female participant were excluded from the statistical analysis.

Survey Procedure

Testing was conducted at the worksites during May 1985 in a trailer equipped with spirometers and an X-ray machine. After receiving an explanation of the study and consenting to participate, each volunteer was administered a standardized questionnaire [Medical Research Council, 1960], had standing height measured, performed spirometry using standardized techniques [Gardner, 1979], and received a posteroanterior chest radiograph using the technique specified for pneumoconiosis [Anon, 1978].

A modified version of the Medical Research Council (MRC) questionnaire on respiratory symptoms, supplemented with questions concerning smoking habits, demographic information, and occupational history, was administered by trained interviewers. For the purposes of this analysis, "cough" was defined as a cough on most days for as much as 3 months each year. "Phlegm" was defined as the production of phlegm on most days for as much as 3 months each year [Medical Research Council, 1960].

Spirometry was performed using a dry rolling-seal spirometer (Model 840, Ohio Medical Products) interfaced to an oscilloscope and an analog tape recorder (Model 3964, Hewlett Packard). At least five maximal expiratory maneuvers were recorded for each person. All values were corrected to BTPS (body temperature, pressure, saturated with water vapor). The largest forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), and peak flow (PF) were selected for analysis regardless of the curves on which they occurred. Expiratory flow rates at 50% and 75% of expired FVC ($FEF_{50\%}$ and $FEF_{75\%}$) were obtained from the curve with the greatest sum of FVC and FEV_1. The spirometer and methods met the quality-control recommendations of the American Thoracic Society (ATS), with the exception that excessive variability was defined as a 10% or greater difference in the two largest FEV_1 or FVC values, instead of the 5% recommended by ATS [Gardner, 1979].

Each chest radiograph was read independently by three certified pneumoconiosis ("B") readers who, without knowledge of subjects' ages, occupations, or smoking histories, classified the films according to the 1980 ILO International Classification of Radiographs of the Pneumoconioses [International Labour Office, 1980]. The median profusion of the three readings was used in the analysis. A chest radiograph was defined as positive for pneumoconiosis if at least two of the three "B" readers categorized small opacity profusion as 1/0 or greater.

Industrial Hygiene Monitoring

Personal breathing zone and area samples were collected to assess the airborne concentrations of respirable dust, total dust, and respirable crystalline silica [Kullman et al, 1986]. Respirable dust was collected using portable pumps, calibrated to 1.7 L/min, with 10 mm cyclone preselectors. Total dust was collected on 37 mm filter cassettes at 2.0 L/min. Samples were collected for a minimum of six hours and were reported as time weighted averages. Respirable and total dust samples were analyzed gravimetrically and the alpha-quartz content of the respirable samples was measured using X-ray diffraction [NIOSH, 1984].

Statistical Methods

Separate analyses were conducted to examine the respiratory effects of current exposures and long-term exposures to gilsonite dust. To examine respiratory effects of current exposures, all employees were divided into low- and high-exposure groups based on the exposure level of their current job. To examine respiratory effects of long-term exposures, those workers who had been employed for at least 75% of their gilsonite work history in either high-exposure jobs or low-exposure jobs were classified as high-exposed or low-exposed, respectively, and stratified into two tenure groups: less than 10 years and 10 years or greater. To reduce the possibility of misclassification, 20 employees who did not meet these criteria were excluded from this phase of the analysis since their work history could not be used to place them clearly in either category.

Both internal and external comparisons were conducted in the examination of respiratory effects of current and long-term gilsonite dust exposure. Internal analyses involved the comparison of gilsonite workers in high-exposure groups with those in low-exposure groups. External analyses compared the gilsonite workers to blue-collar workers who had minimal, if any, occupational exposures to known lung irritants and who had been surveyed using identical methods [Petersen and Castellan, 1984; Petersen and Hankinson, 1985].

Questionnaire responses were compared by means of chi-square tests of independence or the Poisson test, as appropriate, to the prevalences expected if the gilsonite workers had experienced the same respiratory symptom prevalences as the blue-collar workers; expected prevalences were calculated using linear logistic prediction equations [Petersen and Castellan, 1984]. Logistic regression was also used to control for the potential confounding effects of age and smoking status in the internal analyses between low- and high-exposure groups.

Percent predicted pulmonary function values were calculated using blue-collar predictive equations [Petersen and Hankinson, 1985]. For internal analyses, analysis of covariance (ANCOVA) was used to determine if age-, height-, and smoking-adjusted mean pulmonary function values were significantly different between low- and high-exposure groups.

Tests of hypotheses were carried out with a level of significance of 0.05. When multiple pairwise procedures were used, the significance level for each individual test was reduced to 0.01 to maintain an overall significance level approximating 0.05.

RESULTS

Industrial Hygiene Samples

Personal breathing zone concentrations of respirable and total dust are presented by job title in Table I. Miners and miner's helpers were the only workers with mean concentrations above the nuisance particulate Threshold Limit Exposure Value (TLV) for respirable dust (5 mg/m^3) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH, 1984). Mean dust concentrations exceeding the

TABLE I. Total Dust and Respirable Dust Exposures (mg/m^3) for Current Gilsonite Workers by Job Title

	Total dust		Respirable dust	
	Geometric mean	No. of samples	Geometric mean	No. of samples
Miner and miner's helper	136.9 (2.2)[a]	6	6.0 (4.1)	8
Hoist operator	0.6	1	0.6	1
Trucker	13.3 (2.2)	3	1.0 (4.1)	3
Processing plant workers				
Bagging operator	7.9 (2.7)	6	0.5 (1.5)	5
Pulverizing operator	77.1 (1.7)	2	0.8 (4.3)	2
Maintenance	2.5	1	0.9	1

[a]Numbers in parentheses indicate geometric standard deviation.

nuisance particulate limit for total dust (10 mg/m^3) were found in three job categories: truckers, pulverizing operators, and miners.

For the analysis, miners and miner's helpers were classified as being in the high-exposed group, whereas all other workers were in the low-exposed group, since these two job titles had a mean respirable dust concentration at least six times greater than that of any other job title, and a mean total dust concentration at least ten times greater than that of any other job title with the exception of pulverizer operator. However, the pulverizing operators were only intermittently exposed to these levels since the pulverizers are not in operation continuously and workers alternate between pulverizing and sacking operations.

Of the respirable dust samples, 90% (18/20) had non-detectable crystalline silica concentrations; the 2 measurable samples, both collected from miners, had crystalline silica concentrations of 0.11 mg/m^3 and 0.44 mg/m^3, both exceeding the TLV for quartz-containing dust and the NIOSH recommended exposure limit of 0.05 mg/m^3 for respirable alpha-quartz. Crystalline silica was detected in only 1 of 7 bulk samples collected from various gilsonite veins, at a concentration of approximately 4% by weight.

Demographic Variables

The study population consisted of 100 white male employees. Demographic characteristics are presented by smoking status for currently high-exposed versus currently low-exposed workers (Table II).

Symptom and Pulmonary Function Analyses

After adjustment for age and smoking status, current employment in jobs with high exposure to gilsonite dust did not significantly increase the odds of cough (1.66) or phlegm (2.05), relative to low-exposure jobs; the corresponding approximate 95% confidence intervals for the odds ratios for cough and phlegm are (0.49, 5.70) and (0.61, 6.96), respectively. Analysis of covariance tests of the height-, age-, and smoking-adjusted mean values of pulmonary function (Table III) indicated no significant differences between low- and high-exposure categories.

TABLE II. Demographic Characteristics of White Male Gilsonite Workers by Smoking Status and Current Exposure Status*†

	Smokers		Ex-smokers		Non-smokers	
	current exposure		current exposure		current exposure	
	High (N=21)	Low (N=20)	High (N=9)	Low (N=15)	High (N=9)	Low (N=26)
Age (y)	35.5 (2.2)[a]	43.6 (3.3)[a]	36.6 (3.0)[a]	51.7 (3.2)[a]	37.3 (3.8)	37.8 (2.4)
Height (cm)	175.7 (2.0)	175.0 (1.3)	172.6 (2.2)	173.6 (1.4)	174.3 (3.0)	175.8 (1.2)
Weight (kg)	82.1 (3.7)	80.1 (2.7)	80.1 (3.4)[a]	95.6 (4.8)[a]	84.8 (5.6)	89.3 (3.1)
Education (y)	10.8 (0.3)	9.9 (0.4)	9.8 (1.2)	11.1 (0.6)	11.9 (0.1)[a]	12.7 (0.4)[a]
Pack years	21.8 (4.2)[a]	35.6 (5.2)[a]	8.6 (4.8)	16.9 (3.9)		
Gilsonite exposure (y)	9.2 (1.6)[a]	15.7 (2.6)[a]	12.1 (2.9)	22.5 (3.7)	13.9 (3.1)	10.6 (1.9)

*Current miners and miner's helpers were classified as having high exposure; other workers were classified as having low exposure.

†Numbers in parentheses indicate standard error.

[a]Significant at $p < 0.05$ for comparisons within smoking categories.

TABLE III. Height-, Age-, and Smoking-Adjusted Mean Values of Pulmonary Function for Gilsonite Workers Classified by Current Exposure Status*

	FVC (L)	FEV_1 (L)	FEV_1/ FVC (%)	PF (L/s)	$FEF_{50\%}$ (L/s)	$FEF_{75\%}$ (L/s)
High exposure	4.79 (0.11)	3.79 (0.09)	79.2 (1.2)	9.37 (0.25)	4.31 (0.22)	1.66 (0.10)
Low exposure	4.79 (0.09)	3.85 (0.07)	80.1 (0.1)	9.68 (0.20)	4.46 (0.18)	1.68 (0.08)

*Numbers in parentheses indicate standard error.

TABLE IV. Observed and Expected Prevalences of Respiratory Symptoms by Current Gilsonite Exposure Status*

	Smoker	Ex-smoker	Non-smoker	Overall observed	Overall expected	O/E
High exposure						
Cough	43.0% (9/21)	11.1% (1/9)	0% (0/9)	10	5.23	1.9[a]
Phlegm	38.0% (8/21)	33.3% (3/9)	0% (0/9)	11	5.53	2.0[a]
Low exposure						
Cough	25.0% (5/20)	13.3% (2/15)	0% (0/26)	7	7.25	1.0
Phlegm	15.0% (3/20)	26.7% (4/15)	0% (0/26)	7	8.75	0.8

*Smoking- and age-adjusted expected prevalences derived from Petersen and Castellan [1984].
[a]Significant at $p < 0.05$ using chi-square test.

TABLE V. Percent Predicted Pulmonary Function Values of Gilsonite Workers by Smoking Status and Current Exposure Status*

	Smokers current exposure		Ex-smokers current exposure		Non-smokers current exposure	
	High (N=21)	Low (N=20)	High (N=9)	Low (N=15)	High (N=9)	Low (N=26)
FVC	99	96	97	95	105	102
FEV_1	99	100	98	102	102	103
FEV_1/FVC	100	104	105	106	98	99
PF	97	104	105	100	100	101
$FEF_{50\%}$	90	98	100	91	86	90
$FEF_{75\%}$	101[a]	134[a]	103	128	92	98

*Predicted pulmonary function values derived from Petersen and Hankinson [1985].
[a]Significant at $p < 0.05$ for comparisons within smoking categories.

In the external comparisons, the age- and smoking-specific prevalences of cough and phlegm were significantly greater than expected for the workers currently employed in high-exposure jobs but not for those in low-exposure jobs; no symptoms were reported by nonsmokers in either exposure category (Table IV). Mean percent of predicted pulmonary function values were normal within each smoking and exposure category, and there was only one statistically significant difference in comparisons between exposure categories: among current smokers, workers in the high-exposure group had significantly lower mean percent of predicted $FEF_{75\%}$ than those in the low-exposure group (Table V). In addition, mean percent of predicted pulmonary function values were not significantly different in comparisons between gilsonite workers with and without symptoms of either cough or phlegm.

Results of the analyses conducted to examine the respiratory effects of long-term exposures to gilsonite dust were consistent with those analyzed by current exposure status. Questionnaire results indicated significantly increased prevalences of cough and phlegm with increased dust exposure. Adjusted for age and smoking, the relative odds of phlegm (9.68), but not cough (4.39), were significantly associated with long-term high-exposure to gilsonite dust. Results of the external analysis revealed that the age- and smoking-specific prevalences of cough and phlegm were significantly greater than expected for workers who had worked at least 75% of their time in high-exposure jobs, but not for those who had spent at least 75% of their gilsonite work history in low-exposure jobs. No significant reductions in pulmonary function were found in either the internal or external comparisons.

Radiographic Findings

Of the 100 films of current gilsonite workers, one was considered unreadable. None of the other radiographs had large opacities, but five (5%) had a median reading of ⩾ 1/0 profusion of small opacities. Characteristics for these workers, presented in Table VI, indicate that 4 of the 5 had at least 10 years of employment in jobs with high exposure to gilsonite dust and no substantial prior exposure to other respiratory hazards; however, 3 of these 4 had substantial smoking histories. The remaining case had only 2 years of high exposure to gilsonite dust but had previously worked 8 years with a cutting torch in a salvage operation.

DISCUSSION

Results from this cross-sectional study indicate that gilsonite dust is a respiratory irritant that produces symptoms of cough and phlegm in workers with high exposures. Long-term employment in the high-exposure jobs of miner or miner's helper was associated with a significantly increased risk of phlegm, relative to working in low-exposure jobs. Workers currently employed in high-exposure jobs had an increased, though not statistically significant, risk of cough or phlegm. In comparison with a non-exposed blue-collar population, prevalences of cough and phlegm for gilsonite workers with high-exposure jobs were twice as high as those expected ($p < 0.05$), but prevalences for workers with low-exposure jobs were not significantly different from the blue-collar population.

TABLE VI. Predicted Lung Function* and Related Data Among Gilsonite Workers With Small Rounded or Small Irregular Opacities† of ⩾1/0 Profusion by Median Reading

				Gilsonite exposure		% Predicted		
	Profusion (median reading)	Age (y)	Pack years	High exposure (y)	Low exposure (y)	FEV_1	FVC	FEV_1/FVC
Rounded								
1	1/1	63	37.0	19	10	86	73	113
Irregular								
2	1/1	64	46.0	11	19	106	109	99
3	1/0	51	0.0	21	6	114	104	105
4	1/0	55	26.6	16	10	101	84	120
5[a]	1/0	30	0.4	2	2	87	86	104

*Predicted pulmonary function values derived from Petersen and Hankinson [1985].
†Readers were unanimous in classifying the shape of the small opacities.
[a]Substantial prior exposure to other occupational respiratory hazards.

Since the blue-collar comparison group had a substantially lower number of pack years than the gilsonite workers, a question may be raised as to whether this increased prevalence in symptoms of cough and phlegm is actually associated with gilsonite exposure or merely reflects the effects of tobacco smoking. The prediction equations included age, but not pack years, as an independent variable within each smoking status category, and may not have adequately adjusted for pack year usage. However, differences in the number of pack years does not appear to be the explanation for the increased prevalence of symptoms, since internal comparisons showed the workers with high gilsonite exposures to have significantly fewer pack years than the workers with low exposures and yet, in comparisons with the blue-collar workers, it was the high-exposure and not the low-exposure group which had significantly higher prevalence of cough and phlegm.

Many studies support the finding that workers exposed to long-term inhalation of dust have an increased prevalence of cough and phlegm. For instance, in coal miners, a definite relationship has been demonstrated between the level of dust exposure and chronic bronchitis, defined either as persistent phlegm production regardless of complaints of coughing, or as moderate phlegm production coupled with persistent coughing [Kibelstis et al, 1973]. It is therefore not surprising to find an increased prevalence of cough and phlegm among gilsonite workers in the high-exposure jobs, since their average respirable dust exposure was 6.0 mg/m^3, exceeding the respirable nuisance dust standard of 5 mg/m^3, and their average total dust exposure was 136.9 mg/m^3, 13 times the nuisance dust standard.

Radiographic evidence of pneumoconiosis was found in 5% (5/99) of the gilsonite workers, which compares to a 0.2% (3/1422) overall prevalence found among currently employed blue-collar workers with minimal history of occupational exposure to respiratory hazards [Castellan et al, 1985]. When limited to white males at least 40 years of age, an 8.3% (4/48) prevalence of pneumoconiosis for the gilsonite workers compares to a 0% (0/164) prevalence found among the blue-collar population ($p < 0.05$) (unpublished data, RM Castellan). The one positive radiograph among gilsonite workers less than 40 years of age may have reflected his previous occupational exposure as an oxyacetylene cutter.

In addition to prior occupational exposures, concurrent silica exposure and smoking may also be contributing to the radiographic evidence of pneumoconiosis. Excluding the worker with prior oxyacetylene torch exposures, each of the remaining 4 workers with radiographs which were positive for pneumoconiosis had been employed for more than 10 years in the high gilsonite exposure jobs of miners or miner's helpers, and 25% (2/8) of the respirable dust samples collected from miners had crystalline silica concentrations exceeding the TLV for quartz-containing dust. However, three of the four also had substantial smoking histories. Since long-term cigarette smoking has been associated with the occurrence of small, irregular opacities of mild profusion on chest radiographs [Weiss, 1984], the irregular opacities on two of the positive radiographs may be evidence of cigarette exposure.

Thus, in the absence of histologic material, doubts may be raised about whether the positive radiographs reflect gilsonite dust deposition, particularly since no categories of pneumoconiosis higher than 1/1 were observed. Although one must be cautious in interpreting results from the former workers since they are probably not representative of the entire former workforce, 5 of the 34 examined former workers had radiographs which were positive for pneumoconiosis. All 5 workers had been employed for more than 18 years in the gilsonite industry, had no prior exposure to other respiratory hazards, and only 2 had substantial smoking histories. Similar to the findings for current workers, 4 of these 5 positive chest radiographs had irregular opacities with no profusion greater than category 1/2.

Although increased prevalences of cough and phlegm were found, no evidence for dust-related pulmonary function impairment was noted among workers reporting either of these symptoms. This is consistent with findings among coal miners that indicate that dust-induced simple bronchitis is associated with little impairment of pulmonary function [Hankinson et al, 1977]. Although this was essentially an industry-wide study, slight pulmonary function effects associated with dust-induced bronchitis probably could not have been detected given the small number of current workers employed in the gilsonite industry.

On the other hand, the absence of pulmonary function impairment may be due to self-selection, which can potentially bias all cross-sectional designs. Workers most susceptible to the irritating effects of gilsonite dust may have left the industry, leaving a selected population with a decreased susceptibility to airways disease. Such a selection process could lead to an underestimate of the respiratory effects of gilsonite dust.

Mindful of these caveats, we can conclude the following from this cross-sectional survey. First, gilsonite dust is a respiratory irritant, and exposure to high concentrations of gilsonite dust is associated with increased prevalence of bronchitis symptoms; however, this association may be partly explained by smoking habits. Second, the inhalation of gilsonite dust is not associated with pulmonary impairment. And, finally, gilsonite dust deposition in the lungs may be associated with the development of pneumoconiosis.

Although worker exposure to gilsonite dust is currently not regulated by the federal Mine Safety and Health Administration, in order to prevent pulmonary health effects, we recommend reducing dust exposures for those workers in jobs currently characterized by relatively high gilsonite dust exposures. A more definitive understanding of the respiratory health effects of gilsonite dust exposure may be obtained by serial questionnaires, spirometry, and chest radiographs among all individuals with occupational exposure to gilsonite dust. Such a prospective surveillance program would eliminate selection bias and provide data on the changes in respiratory symptoms, pulmonary function, and chest radiographs over time.

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