Ann. occup. Hyg., Vol. 26, Nos. 1-4, pp. 817-831, 1982.
Printed in Great Britain.
Inhaled Particles V

0003-4878/82/010817-15$03.00/0
Pergamon Press Ltd.

EXPOSURE TO DIESEL FUMES AND DUST AT SIX POTASH MINES

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Abstract—Workers at six potash mines located close to each other in New Mexico were visited by medical and industrial hygiene teams in 1976. Demographic, anthropometric and spirometric information was collected, and data on chest symptoms, work and smoking history were elicited. Posterior-anterior and lateral chest radiographs were taken. About the same time a thorough assessment of the environment was made at each mine. The data were examined for possible relationships between health indices, dust exposure and measures reflecting exposure to diesel exhaust. No obvious links incriminating either dust or the diesel exhaust could be ascertained, though symptom prevalences were elevated compared with a non-dust exposed group.

INTRODUCTION

THE DIESEL engine is an economical and flexible power source that has several advantages over other power sources. Its fuel economy has encouraged its development for use in automobiles. Its flexibility has lead to its use in underground mining where, its proponents argue, it is more efficient and safer than conventional machines powered by electricity. The potential increase in exposure to diesel exhaust in the general urban population and, perhaps more importantly, in industrial workers already exposed to hazardous substances makes it imperative that the health effects of inhalation of diesel exhaust be assessed fully.

Diesel exhausts contain many chemicals potentially hazardous to health. The principal components having possible health effects are: oxides of nitrogen (NO_x), sulfur oxides (SO_x), carbon monoxide, and organics such as aldehydes, hydrocarbons and particulate matter. Of these, nitrogen oxides, sulfur oxides and the aldehydes are all toxic to man and can cause both acute and chronic respiratory changes. The particulate matter in diesel exhaust consists mainly of carbon upon which complex hydrocarbon compounds have been adsorbed. The role of such particles in the development of non-neoplastic respiratory disease is not known, though it is believed that these particles have carcinogenic properties. This latter aspect will not be discussed further.

The substance loosely named 'potash' is mined in the United States principally in two adjacent counties in southern New Mexico. Mining started in 1931 and further mines were opened until, at maximum, nine mines were operating. By 1976, when this study was commenced, seven mines were in operation, six of which were visited by the survey teams. The mineral mined at five of the mines was sylvite (KCl); at the sixth both langbeinite ($K_2SO_4 \cdot 2MgSO_4$) and sylvite were mined. At all mines the ore was contaminated with various proportions of halite (NaCl). The ore was won universally by room and pillar mining, either by under-cutting and blasting or by continuous miners. While most of the machines used were electrically powered, every mine employed some diesel powered equipment. The date of introduction and usage of diesels varied widely from mine to mine.

Little published information exists concerning the health effects of inhaling potash dust. At extremely high exposures (up to 2000 mg m^{-3} for a continuous miner operator), WILLIAMS (1974) has shown that inhalation of the dust sometimes led to nasal septum perforation. However, at lower levels, potash dust is considered benign and, in the United States, is subject to a 12 mg m^{-3} total dust compliance level. The mortality study of WAXWEILER *et al.* (1973) failed to demonstrate any respiratory hazards associated with length of exposure underground in eight potash mines.

In consequence of this apparent non-toxicity of potash dust, and because of the wide range of diesel use at the mines, it was felt that the New Mexico potash miners formed an excellent group for study of exposure to diesel exhaust. Accordingly, in 1976, six of the seven mines were visited by medical and environmental teams. The results of their endeavours are reported here.

METHODS

The six mines were visited by the medical team in the period between February 1976 and April 1976. Each participant was administered a questionnaire on respiratory symptoms, work history and smoking habits. The format and text of the questions on symptoms was almost identical to that of the British Medical Research Council (MRC) questionnaire on respiratory symptoms (MRC, 1960). Analysis was concentrated on three respiratory symptoms. Chronic cough was defined by a positive answer to: 'Do you usually cough during the day (or at night) in the winter?' plus 'Do you usually cough like this on most days (or nights) for as much as 3 months of the year?' Chronic phlegm production was defined similarly, while shortness of breath was indicated by a positive answer to: 'Do you get short of breath walking with people of your own age on level ground?' The industrial history and questions on smoking habits followed a format rather different from that of the MRC questionnaire.

Each participant also received a posterior–anterior and lateral chest radiograph. The former films were read according to the 1971 ILO/UICC standards (ILO, 1972) independently by three experienced readers. For analysis, medians of the three readings of small rounded opacities profusion, small irregular opacities profusion, large opacities and pleural changes were employed.

Simple spirometry was performed by each subject. A minimum of five blows were undertaken on Ohio 800 rolling seal spirometer. Maximum values of FVC and FEV_1 were taken.

Detailed description of the dust, vapour and gas measuring techniques is given by Sutton and colleagues (SUTTON *et al.*, 1979). Briefly, personal total dust samples were collected by gravimetric methods. Total and respirable area gravimetric samples were also collected. All samples were analysed by X-ray diffraction for free silica. Full shift exposures to NO_2 were obtained by use of personal passive dosimeters employing a gel-coated grid which was examined with a spectrophotometer. Aldehyde area samples were collected at five mines by bubbler method and at the other mine by an activated alumina method. In addition to these data, measurements of general air quality, fibre concentration, diesel soot, hydrocarbons, settled dust, temperature and humidity were made, but sulphur dioxide determinations were not made.

For purposes of general validation and for information, recourse was made to federal data on compliance, but these data were not used in estimating exposures.

Cumulative exposures were calculated by the sums of products of time spent in each job in years and concentration of total dust and NO_2 for the job within the appropriate mine. Further details of the exposure calculations, the estimation procedures used and the problems inherent in their estimation are given in Appendix A.

RESULTS

Table 1 presents information on production methods and diesel usage at the six mines. Most of the production was achieved by conventional means using electrical equipment. At only one mine were continuous miners used exclusively (Mine E). Diesel usage was principally confined to use of service vehicles except at two mines. At one of these (C) diesel shuttle cars were employed extensively, while at Mine B they were used to a limited extent. In addition to being the heaviest user of diesels, Mine C had employed them the longest. In contrast, Mine E, which had few diesels and none of any size, had also employed them the fewest years. Thus Mines C and E could be taken to represent, within this study, limits encompassing the range of exposure to diesels.* The data on diesel fuel usage support this statement.

Table 2 summarizes the information collected during the industrial hygiene surveys. The gaseous contaminants could have arisen from diesel usage or as by-products of shotfiring. However, they support, in general, the data of Table 1. This is especially true for Mines C and E which have the highest and lowest concentrations of NO_2 respectively.

TABLE 1. PRODUCTION METHODS AND DIESEL USAGE

	Mine Code					
	A	B	C	D	E	F
Date of start	1964	1952	1940	1964	1934	1964
Predominant mining method	CON	CON	CON	CM†	CM	CON
Date of diesel introduction	1964	1952	1950	1964	1966	1964
Total no. of diesel powered units	7	55	57	35	14	20
No. of ramcars	0	6‡	10	0	0	0
No. of diesel powered units with horsepower > 50	0	13	26	8	1	6
Gallons of disel fuel consumed per month (approx.)	400	1800	7100	400	300	1000

* CON = Conventional = cutting, blasting, removal; CM = continuous miners.

† Mine D had one conventional production area and one using a heliminer, the rest using continuous miners.

‡ Not all used at once.

* We use the shortened forms 'diesels' and 'exposure to diesels' and other such phrases to avoid the repeated and tiresome use of the more appropriate longer forms.

Table 2. Environmental data*

	Mine					
	A	B	C	D	E	F
No. of samples†	26	32	28	26	34	25
Total dust concentration‡ mg m^{-3}	9	23	23	11	18	19
NO_2 Concentration (ppm)‡	0.7	0.7	3.3	0.5	0.1	0.3
Total dust/Respirable dust ratio§	3	7	3	2	11	5
Aldehydes§ (ppm)	0.7	4.0	3.2	0.8	0.7	0.1¶
Carbon monoxide‖ (ppm)	5	7	9	7	5	5

* To avoid problems with weighting, these data apply only to production jobs and areas. Concentrations for other activities were proportionately lower.
† Applies to total dust and NO_2 only.
‡ Personal samples.
§ Area samples.
‖ General air quality.
¶ Activated alumina method used here.

The large difference in pattern of diesel usage at Mines C and E suggests that, other things being equal, comparison of health indices between these two mines would be a reasonable and valid method by which to explore the diesel effect on health. Such an approach would be direct, simple and free of the problems inherent in estimating exposures retroactively from environmental data collected over a short period of time.

Before this course is pursued, however, some background information on the miners at these operations is presented (Table 3). The total number of people studied was 1091 spread fairly evenly over the six mines. Of those that participated (and these participation rates are rather less than desirable) most were white males. The analysis was confined to white male smokers and non-smokers and the remainder of the Table deals only with these people. About 32% of the miners had worked in another dusty industry (principally coal mining), although this part of their total dust exposure accounted for only 11% of their total time worked in dusty jobs. The mean years worked in potash mines was 12.4, indicating a fairly settled workforce. Furthermore, these people had experienced an average of 10.1 yr exposed to diesel exhaust in these mines. Lastly, the pattern of mine average NO_2 exposures echoed that previously noted concerning the difference between Mines C and E.

In the following analyses, the exposure variables of prime interest are those associated with use of diesels. Exposure to potash *per se* has been considered of subsidiary importance, firstly, because there was no convincing pre-existing knowledge incriminating potash dust as harmful and, secondly, because exposure to diesels rather than potash is more universal and thus a greater potential hazard.

The first analysis undertaken to explore the effect of diesel exposure on lung function and respiratory symptoms was that of direct comparison of mine populations. In this, models including appropriate confounding variables and a set of factors representing mine effects were fitted to various respiratory health indices. Possible potash exposure effects were ignored in this first analysis. For lung function (FVC and FEV_1), the model was a simple linear fit of age and height (and pack years for smokers) plus individual coefficients for each mine. The analysis of symptoms was undertaken using the categorical model analysis approach of Grizzle *et al.* (1969). For a

TABLE 3. DETAILS ON POTASH WORKERS

	Mine A	B	C	D	E	F	All mines*
Participation (%)	89	72	95	69	70	78	79
(%) white males	87	83	79	79	84	74	80
No. (white male s+ns)	56	103	122	121	121	107	630
Mean age (yr)	43	40	39	31	43	42	39
Mean height (cm)	175	174	176	175	176	176	175
Non-smokers (%)	21	26	29	26	31	33	28
Mean pack years†	29	26	29	19	32	29	27
(%) with other dusty exposure	57	44	20	21	33	34	32
(%) of time spent in other dusty jobs	20	19	7	9	10	10	11
Length of work in potash mines (yr)	14	13	11	5	17	15	12
Length of exposure to diesels	14	13	10	5	8	14	10
Cumulative potash dust exposure mg yr m^{-3}	116	154	99	36	169	146	119
Cumulative NO_2 exposure (ppm yr)	12	11	28	3	1	10	11

* All averages for 'all mines' group were weighted by number of miners except for the participation mean which is a direct average of the six values.

† Packs of 20 cigarettes smoked per day × years of smoking.

dichotomous response this reduces to the logistic model (COX, 1970). Again, age, smoking habits and mine effects were included in the models as appropriate. In order to represent diagrammatically any associations between health indices and mine effects as an aid to understanding, the following procedure has been followed. Using similar models to those described above, but omitting terms representing mine effects, predicted values were obtained for each person. These were aggregated by mine and compared to the corresponding figure for observed responses. The resulting differences, termed 'mine residuals', indicate how much better or worse a mine's population was compared with values predicted on the basis of age and the other confounding variables. These residuals were thus obtained from predicted values derived internally and not from external 'normal' populations. A brief discussion of the models is given in Appendix B.

Figures 1(a) and (b) show these mine residuals for FEV_1 and FVC respectively. The results for smokers and non-smokers are shown side-by-side for direct comparison. For FEV_1, the mean residuals for both smoking groups were in the expected direction for Mine E (which had the lowest diesel usage and least NO_2 levels). However, the values for Mine C, which had the greatest use of diesels, showed no consistent deficit in both smoking groups (despite the fact that the non-smokers in this mine had FEV_1 values consistently lower than expected, the smokers had the greatest positive mean residual over all the mines). In addition, Mine A, which was unremarkable for its use of diesels, showed the worst set of FEV_1 residuals. Reference to Table 4, which shows the observed values and related information, indicates that the pattern of potash dust exposures does not appear to explain the observed variations between mines.

The set of mean values for FVC are shown in Fig. 1(b). As it would be expected that FEV_1 rather than FVC would vary in response to NO_2 and other diesel related

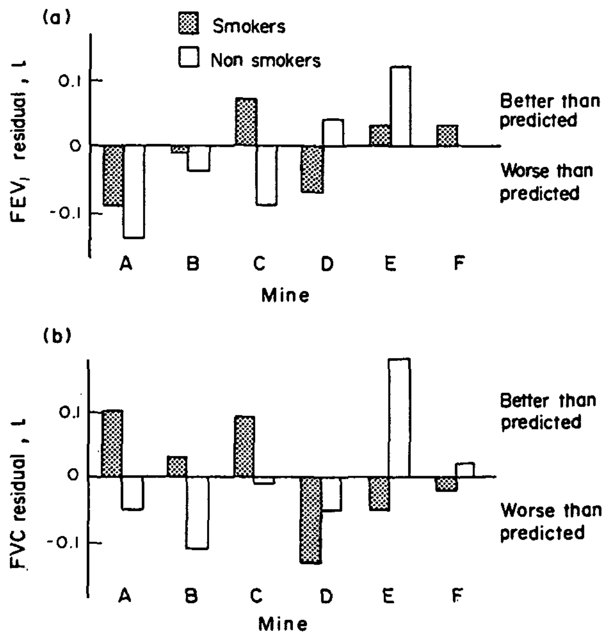

FIG. 1. Residuals by mine: (a) FEV_1, (b) FVC.

TABLE 4. LUNG FUNCTION, SYMPTOMS AND RELATED DATA BY MINE

	Mine A	Mine B	Mine C	Mine D	Mine E	Mine F
Non-smokers						
FEV_1 (l.)	3.5	4.0	4.0	4.2	4.0	4.1
FVC (l.)	4.7	5.0	5.2	5.1	5.1	5.2
Cough (%)	8	15	23	3	8	11
Phlegm (%)	25	19	23	28	19	14
Dyspnea (%)	8	11	3	0	3	6
Age (yr)	49	41	36	33	44	37
Height (cm)	174	177	176	175	175	177
Pack years	0	0	0	0	0	0
Potash Exp. (mg yr m^{-3})	18	14	10	6	17	13
n	12	27	35	32	37	35
Smokers						
FEV_1 (l.)	3.5	3.7	3.7	4.0	3.6	3.6
FVC (l.)	4.0	4.9	5.0	5.1	4.8	4.8
Cough (%)	48	33	43	34	44	22
Phlegm (%)	52	33	52	31	43	24
Dyspnea (%)	16	12	8	9	14	10
Age (yr)	42	40	40	31	42	44
Height (cm)	176	173	176	175	176	175
Pack years	29	26	29	19	32	29
Potash Exp. (mg yr m^{-3})	13	12	11	5	18	16
n	44	76	87	89	84	72

contaminants, these values are of secondary importance. However, they do serve to indicate whether there may have been differences between mines arising from technician and other related factors. Figures 1(a) and (b) do not indicate clearly that this was the case.

Mean residuals for respiratory symptoms were examined in a similar manner. These are shown by mine in Figs. 2(a), (b) and (c) for smokers and non-smokers, and concern persistent cough, persistent phlegm and shortness of breath. They were derived by subtracting from the observed prevalence for each mine the expected prevalence determined on the basis of age (and pack years for smokers) using the logistic model.

Figures 2(a), (b) and (c) do not reveal any consistent trends. Mine C shows an excess of cough and phlegm as might be predicted from its use of diesels, but shortness of breath showed a slight deficit. Mine E, which might have been expected to have had a lower prevalence than predicted, revealed this only for cough and phlegm among non-smokers.

The statistical significance of the mine effects for both symptoms and lung function was assessed by adding coefficients representing the mine factors to the models

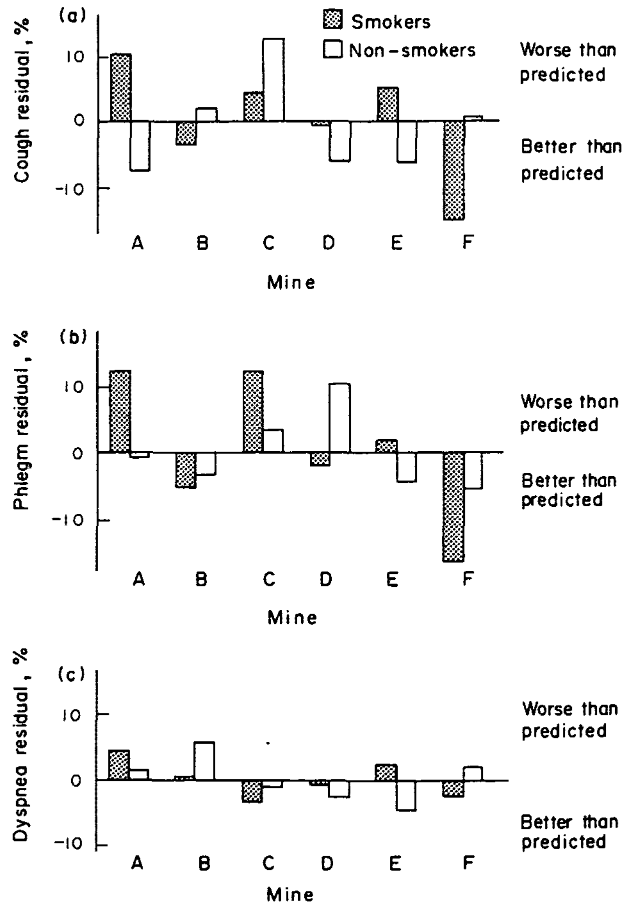

FIG. 2. Residuals by mine: (a) persistent cough, (b) persistent phlegm, (c) dyspnea.

described above (see Appendix B for more detail). Despite appearances, no statistically significant differences between the mines could be detected for lung function in either smokers or non-smokers. The mine coefficients for symptoms again followed the differences seen in the residuals. This time the differences for cough and for phlegm in smokers showed statistically significant deviations ($P < 0.05$, $P < 0.01$ respectively), but this was not so for the remainder.

Although there were good *a priori* reasons for investigating differences between mines—principally a clear-cut difference between two particular mines and a fairly stable mining population, the defects of this type of approach are obvious. The method did not take into account important factors such as duration of work or work in other potash mines, nor did it allow for mine effects unrelated to exposure. Clearly the best analytical method for this type of study would rely on accurate and comprehensive quantitative measures of exposure. Such an approach is attempted later but, since it was felt that the exposures used there were sufficiently prone to error and uncertainty, a simpler analysis will be described beforehand. This more rudimentary approach used length of exposures in years as an indirect measure of exposure.

The methods of analysis used in this analysis were similar to those used earlier. Usual least squares models were used for FEV_1 and FVC, and logistic curves employed for symptom analysis. The models all included terms for age, mine factors and length of exposure to potash dust. Pack years was added for the smoking group analysis while height was included for investigation of lung function. The length of diesel exposure variable showed a statistically significant increase in both FEV_1 and FVC with increasing years of exposure ($P < 0.05$ in both cases). Among non-smokers a similar trend was seen, but the coefficients did not attain significance at the 5% level. FEV_1 showed a significant drop with increasing years of exposure to potash dust ($P < 0.05$) among smokers, but this was not true for FVC or for non-smokers. In the case of the diesel exposure variable, the coefficients for FEV_1 and FVC were almost identical. Thus it might be concluded that these findings were not indicative of decreasing obstruction with length of exposure, but rather indicate some other real or artefactual mechanism at work.

No trend of symptoms with increasing years of exposure was ascertained. This impression was confirmed by the formal tests of significance. In addition, the patterns of residuals for smokers and non-smokers were dissimilar.

Lastly, we turn to the analysis involving cumulative exposures. To obtain residuals for lung function, the linear model involving age, height, mine effects (pack years) and cumulative dust exposure was fitted to FEV_1 and FVC. The resulting mean residuals are shown in Figs. 3(a) and (b) grouped by exposure to NO_2. No obvious trend can be discerned, nor is there any consistency between the patterns for smokers and non-smokers. The regressions with the additional term for cumulative exposure to NO_2 confirmed the visual impressions. The observed values of lung function and related information are given in Table 5. The results for symptoms are shown in Figs. 4(a),(b) and (c).* As for most of the earlier findings, no clear trend emerges. Agreement between the residuals for smokers and non-smokers is poor.

The results up to now have dealt only with the symptomatology and spirometric

* The logistic model to shortness of breath could not be fitted because of the few positive responders.

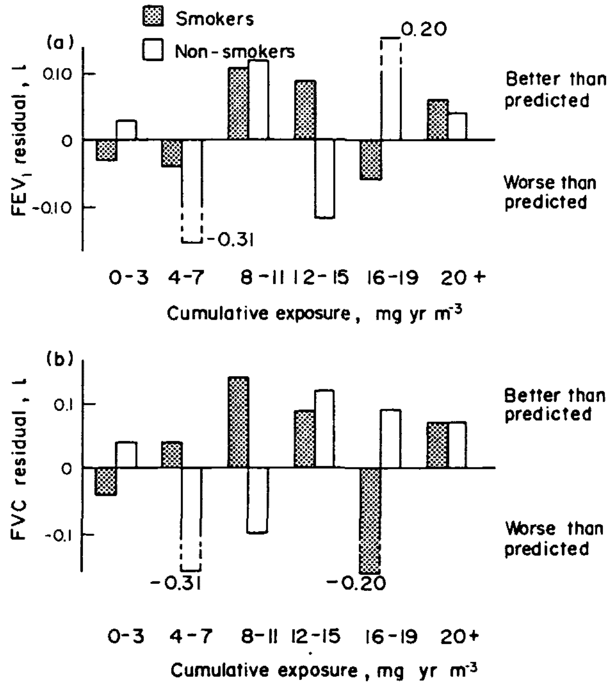

FIG. 3. Residuals by NO_2 cumulative exposure group: (a) FEV_1, (b) FVC.

information. Two other features of the medical information need to be described. Firstly, those concerning the radiographic data; they indicated that signs of all abnormalities commonly associated with occupation were few. Of the 52 with either small rounded or small irregular opacities or pleural thickening among the complete set of 1091 miners, 31 or 60% had worked previously in coal mines, or more rarely with asbestos or in other dusty work (compared to about 30% in the study group). No large opacities were seen and the degree of abnormality was generally low. Miners in two of the mines (E and F) were given a quick nasal examination. Four cases of perforated nasal septa were found.

DISCUSSION

In a study in which the findings were predominately negative it is natural to try to assess why this was so. Apart from there being no true effects of potash and diesel exhaust, negative findings could have resulted because of poor data, particularly in exposure estimates, from low statistical power, and because of selection effects.

Any weakness in the data probably exists in the estimates of exposure, since conventional and standardized practices were used in the collection of the medical data. To estimate degree of exposure, three sets of measures were used. Problems were apparent in each of them. The mine effects could have been confounded with factors not associated with exposure. Length of exposure ignored intensity of exposure, and the cumulative exposures were dependent on data collected over a short interval and

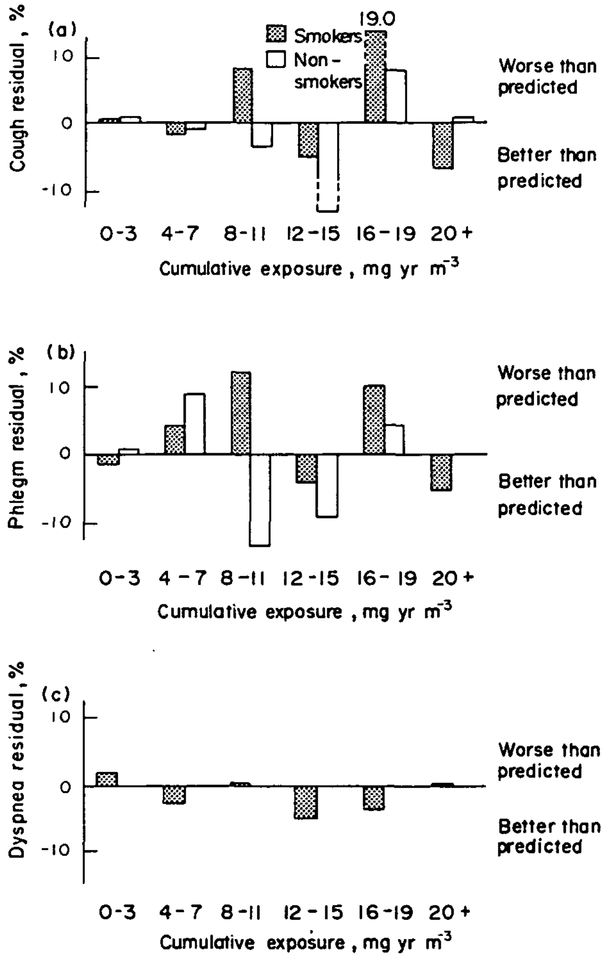

FIG. 4. Residuals by NO_2 cumulative exposure group: (a) persistent cough, (b) persistent phlegm, (c) dyspnea.

suffered from missing information. Despite these problems, it would be wrong to leave the impression that the measures were so weak as to be ineffectual. The mine analysis was based on a substantial difference in mines, established through observation of a number of indices reflecting diesel usage. In addition, mining methods, diesel usage and conditions at those mines had been fairly stable over the years. The cumulative exposures were based on samples collected during typical production, and the mine ranking based on this data agreed well with other indicators of diesel use. Furthermore, the average period of exposure was relatively long (10 yr) and one mine had fairly heavy NO_2 levels (3.3 ppm) indicating that exposures were not minimal.

The statistical power has been explored for the relationship between NO_2 exposure and FEV_1. Calculations based on the existing data with a significance level of 5% indicate that, if a true regression of about 0.01 l. reduction in FEV_1 for every ppm/yr of exposure existed amongst smokers, the number of observations and the spread of the

TABLE 5. LUNG FUNCTION, SYMPTOMS AND RELATED DATA BY NO_2 CUMULATIVE EXPOSURE GROUPS

	Exposure group ppm yr^{-1}					
	0–3	4–7	8–11	12–15	16–19	20+
Non-smokers						
FEV_1 (l.)	4.3	3.7	4.0	3.7	3.9	3.7
FVC (l.)	5.3	4.8	4.9	5.0	4.9	4.9
Cough (%)	7	14	9	0	27	23
Phlegm (%)	19	33	0	13	27	26
Dyspnea (%)	1	10	9	25	9	3
Age (yr)	33	40	39	45	50	50
Height (cm)	176	176	175	176	175	176
Pack years	0	0	0	0	0	0
Potash Exp. (mg yr m^{-3})	9	10	12	16	19	22
n	96	21	11	8	11	31
Smokers						
FEV_1 (l.)	3.9	3.7	3.8	3.5	3.3	3.3
FVC (l.)	5.0	5.1	5.1	4.8	4.5	4.7
Cough (%)	36	33	42	30	57	37
Phlegm (%)	33	42	50	35	52	46
Dyspnea (%)	13	9	12	7	9	10
Age (yr)	34	38	41	46	47	50
Height (cm)	175	176	177	176	174	176
Pack years	23	21	26	33	35	41
Potash Exp. (mg yr m^{-3})	9	10	14	17	20	21
n	223	69	26	43	23	68

data would be sufficient to detect it with a 95% probability. Such a decline would correspond to about a 0.5 l. drop over a lifetime exposed to 1 ppm of NO_2. A decline of close to half of that would be detectable with a probability of 50%.

Like many other cross-sectional epidemiological studies, this investigation suffers from problems induced by sampling and selection. These problems, associated with the decision of a miner to participate with and selection into and out of the industry and into and out of jobs within the industry, are usually intractable and serve to distort the findings. In this study, the problem of participation was particularly acute, but there are arguments both in favour and against the view that selection was a source of bias in this study.

An additional reason why dose–response relationships can go undetected is that the general level of disease was so severe that relationships were obscured. The levels of symptom prevalence shown on Tables 4 and 5 certainly indicate higher than normal prevalences and support this contention. To explore this further, the data were compared to predicted values obtained from a non-dust-exposed 'blue-collar' group of white males.* The observed potash workers' prevalences and their corresponding predicted values are shown in Table 6.

* The data for this group were collected using the same methodology as for the potash workers. At the time of the survey the participants were working in a non-dusty job, and to be included in this analysis had to have had experienced less than 5 yr in total work in dusty jobs.

TABLE 6. SYMPTOM LEVELS AND LUNG FUNCTION OF POTASH WORKERS COMPARED WITH PREDICTED VALUES OBTAINED FROM NORMAL 'BLUE-COLLAR' WORKERS

	Variable	Observed	Predicted
Non-smokers	Cough (%)	12	6
	Phlegm (%)	21	8
	Dyspnea (%)	4	1
	FEV_1 (l.)	4.02	3.98
	FVC (l.)	5.10	4.88
Smokers	Cough (%)	37	20
	Phlegm (%)	38	23
	Dyspnea (%)	11	9
	FEV_1 (l.)	3.70	3.69
	FVC (l.)	4.93	4.80

The predicted values were obtained using the logistic model based on age (and pack years). In every case the observed values are greater than predicted. A similar analysis, this time using usual regression methods, was undertaken on FEV_1 and FVC and the results are also shown in the Table. This time the observed and predicted FEV_1 values agreed almost exactly, while the observed FVC means were rather higher than predicted. Thus, the overall impression from these data indicates that the high symptom levels may have caused difficulty in the detection of dose–response relationships, but this does not seem to have been the case for lung function.

From a statistical viewpoint, the investigation of health effects when two or more potential exposures are involved can involve problems of its own. In this study, the basic potential airborne contaminants were potash dust and NO_2. Exposure measures for these two entities involve a third—time. This can cause large correlations between derived exposures, and this correlation can lead to unexpected and unusual findings when the exposure variables are used simultaneously in model fitting. In the case of the length of exposure variables, the correlation between potash exposure and that for diesel exposure was 0.80 (this can also be inferred from the data on Table 3). This high correlation may have played a role in the models involving length of exposure. However, dropping the potash term from the model did not substantially change the findings. The situation was quite different for the cumulative exposures. Here the correlation between the potash and NO_2 exposures was 0.33 and it can be inferred that a value this low should not have given rise to any problems.

The results from this study confirm the mortality findings reported by WAXWEILER *et al.* (1973) for potash workers. In the report of their study of about 4000 potash miners undertaken at many of the same mines as studied here, they concluded that no excess mortality was attributable to the presence of diesel engines in the mines, but noted that there had probably been too little elapsed time at that stage to be certain. Their study did show a significant excess of deaths from lung diseases other than tuberculosis, malignant neoplasms, influenza and pneumonia, but they noted that five of the 11 observed deaths were attributed to silicosis, probably arising from previous work in siliceous mines which the five had experienced. When these five deaths are removed, the excess becomes virtually zero. ATTFIELD (1979) reported on diesel exhaust and silica effects on health in a large group of metal and non-metal miners, of which these potash miners formed a part. He found essentially the same picture as reported here. Among iron ore miners, JORGENSEN and SVENSSON (1970) found no obvious links between diesel exposure and indices of health in their study of 200 workers. In an analysis of coal miners exposed to diesel exhaust matched individually with control coal miners, REGER *et al.* (1982) found that underground diesel exposed workers had slightly lower lung function and a higher prevalence of cough and phlegm (though less shortness of breath) than the control underground workers. However, similar, though smaller, tendencies were also seen among surface workers. Reger and colleagues point out that exposure levels and duration were low and that further monitoring must be undertaken before confident conclusions can be drawn.

CONCLUSIONS

No trend could be established between measures of diesel use, NO_2 exposure, dust exposure and worsening of health. In addition, no obvious pattern emerged which could be interpreted as a worker selection effect but, nevertheless, selection out of the industry could have affected the detection of dose–response relationships. However, symptom prevalence were elevated compared with a non-dust exposed group of workers and this may have acted to obscure dose–response relationships. Sufficient uncertainties remain in the data to rule out an absolutely definitive statement on the effect of diesel exhaust exposure on health.

Acknowledgments—There have been too many workers from NIOSH and MSHA involved in the collection and processing of data to name; this study would never have resulted without their efforts, and we are grateful for them. Thanks are also due to the MSHA mine inspectors who have suffered from our repeated inquiries and to the people who have discussed and supplied comments on the analysis and manuscript. Last but not least, our appreciation goes to Mary, and in particular to Ann, who repeatedly retyped the manuscript with (relatively) good humour.

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APPENDIX A—DERIVATION OF CUMULATIVE EXPOSURES

Industrial histories

The histories noted company name, sometimes mine name, occupation and time in years for work in potash mines. The occupations were given codes corresponding to those used for the environmental data. Sometimes occupations of like nature were combined under one code. A job held for under 6 months was ignored. The lack of definitive mine name sometimes created problems. Two companies, those operating mines A and F, had also operated or did operate other mines in the area. There was thus the difficulty of correctly assigning the recorded time to the right mine in the absence of a specific name. The procedure followed is exemplified for Mine A. If the mine name was not mentioned and the job had been worked before A was in production, the time was assigned to the other mine operated by that company. If however, the time was recorded for the period in which Mine A was operating then it was assigned to that mine. This procedure should have led to the correct assignment in most cases. The same principal was followed for Mine F.

Environmental sampling

The environmental sampling concentrated almost exclusively on underground jobs. Even then, not all underground jobs were sampled. Neither were those for the one remaining active mine nor, of course, were those for mines no longer producing. For estimation of missing data, the information was averaged into four groups per mine: face and production, transportation, maintenance and miscellaneous. The same averaging was undertaken over all mines. Jobs in the mines studied with missing data were placed into one of the four groupings above and the appropriate concentrations assigned. Jobs in the non-visited mines were allocated concentrations by the same method but using the overall averages. Surface jobs were a problem as no concentrations had been obtained for them. Inquiries with inspectors and recourse to some compliance data gave no stronger indication than that NO_2 levels should be low for all surface workers and that only crusher and mill workers should be exposed to dust. Accordingly, all surface jobs were assigned zero as the level of NO_2 and all except the crusher and mill jobs were given zero for dust level; the latter occupations were assigned the overall mine average level. It is fair to say that this was pure guess work. As compensation it is worth noting that surface jobs formed a minor part of the industrial histories and few surface workers attended for interview in 1976.

APPENDIX B—STATISTICAL METHODS

This Appendix gives a brief insight into the statistical methods used. It does not give details on all the models, but concentrates on demonstrating the methods used by illustration of certain examples.

Lung function

Usual least squares regression methods were used.

(a) Mine effect residuals and assessment of significance in smokers.

Residuals: $[FEV_{1(obs)} - FEV_{1(pred)}]$ averaged over each mine where $FEV_{1(pred)} = a_0 + a_1 \times \text{age} + a_2 \times \text{height} + a_3 \times (\text{pack years})$

Significance: model as above but including M in the predictor set where $M = M_A \times X_A + M_B \times X_B + M_C \times X_C + M_D \times X_D + M_E \times X_E$ where $X_A = 1$ if miner is from Mine A and 0 otherwise, and so on.

(b) Cumulative exposure residuals and assessment of significance in smokers.

Residuals: $[FEV_{1(obs)} \times FEV_{1(pred)}]$ averaged over pre-set intervals where $FEV_{1(pred)} = a_0 + a_1 \times \text{age} + a_2 \times \text{height} + a_3 \times (\text{pack years}) + M + a_4 \times (\text{potash exposure})$ where M is as defined above.

Significance: model as immediately above but with the addition of $a_5 \times (NO_2 \text{ exposure})$.

The coefficients for confounding variables in both smoking groups had magnitudes in the ranges commonly encountered in studies of this type and in most cases were statistically significant.

Symptoms

Symptom responses were recorded as 1 or 0 for positive and negative responses respectively. These were entered into a program which solved for the coefficients iteratively using the Newton–Raphson approach. Statistical significance was assessed either through the large sample variance, assuming Normality, or through transformation of the difference in log-likelihood to the χ^2 statistic.

(a) Mine effect residuals and assessment of significance in smokers.

Residuals: $[P_{(obs)} - P_{(pred)}]$ (P = proportion)

where $P_{(pred)} = \exp(y)/[1 + \exp(y)]$

and $y = a_0 + a_1 \times \text{age} + a_2 \times (\text{pack years})$

Significance: model as above but with the inclusion of M defined as above.

(b) Cumulative exposure residuals and assessment of significance in smokers.
Residuals: $[P_{(obs)} - P_{(pred)}]$
where $P_{(pred)} = \exp(y) / [1 + \exp(y)]$
and $y = a_0 + a_1 \times \text{age} + a_2 \times (\text{pack years}) + M + a_3 \times (\text{potash exposure})$
Significance: model as immediately above but with the addition of $a_4 \times (NO_2 \text{ exposure})$.

DISCUSSION

J. R. Johnston: In Table 2 you quote total dust concentrations (measured by personal samplers) ranging from 9 to 23 mg m^{-3}. Were these values obtained by full-shift or short-term sampling? The concentrations seem excessively high even when related to the compliance level of 12 mg m^{-3} that you quote.

Mr Attfield: All the figures relate to full-shift samples.

J. Willems: To what extent were the lung-function tests standardized, with respect to calibration and the time of day and time of year when they were performed, between the different mines?

Mr Attfield: Lung function tests in our Division of NIOSH are undertaken using standardized techniques. Before each working session the current temperature and pressure are entered to the system (whenever the temperature changes it is re-entered). The system is then calibrated to a 3 l. syringe and tested. Two trained technicians were employed at the Potash study; it is possible that there may have been some imbalance between their employment at the different mines. No time of year effect should be apparent since the mines were visited close together in time.

R. L. Kell: Were the diesel vehicles fitted with any means of reducing exhaust emissions?

Mr Attfield: I believe that they were originally fitted with water scrubbers which at some later date were changed to catalytic converters.

G. Major: If that really happened, it would have solved the carbon monoxide problem at the expense of re-introducing aldehydes. Water scrubbers could have reduced the aldehyde concentration but catalytic converters would be ineffective.

Mr Attfield: From talking to inspectors, I gather that conditions at the mines did alter in that way. We did carry out aldehyde measurements, but the technique was changed part-way through the study and we thought some bias had been introudced. I did not, therefore, quote the results in the paper.

D. K. Verma: In potash mines, a large fraction of the airborne dust is soluble material. Do you have any data on the free silica content of the insoluble portion of the respirable fraction?

Mr Attfield: The quartz content of the *whole* sample was found to be low (*ca.* 0.5%) by X-ray diffraction; no data from this study on the silica content of the insoluble fraction are available. However, since potash from the Carlsbad region contains between 1 and 3% insoluble material, it would seem that the percentage of quartz in that fraction could be substantial.