CHAPTER 23

DIESEL EMISSIONS AND ASSOCIATED RESPIRATORY HEALTH EFFECTS IN MINING

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INTRODUCTION

The diesel engine is a power source that has several advantages over other sources. Its fuel economy has encouraged its development for use in automobiles. Its flexibility has led 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 inhaling diesel exhaust be assessed fully.

Diesel exhaust contains many chemicals potentially hazardous to health. The principal components having possible health effects are: nitrogen oxides (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, on which complex hydrocarbon compounds are adsorbed. The role of such particles in the development of nonneoplastic respiratory disease is not known, although it is believed that they have carcinogenic properties.

This latter aspect will not be considered in this chapter. The various studies that will be included commenced in 1976 and covered workers in metal, potash, salt, trona and coal mining [1–4]. The basic question explored was:

"Is exposure to diesel exhaust, by itself or in conjunction with dust exposure, associated with deleterious effects on respiratory morbidity?" This chapter reports on a composite of abbreviated results from the studies of the several groups of workers mentioned above.

METHODS

The mines at which examinations were performed were distributed as shown in Table I. Examination procedures utilized were relatively constant across the mines. Medical teams visited each mine, and every worker on duty was given a questionnaire on respiratory symptoms and smoking habits based on that of the Medical Research Council of Great Britain [5]. A detailed industrial history was also taken and simple spirometry performed. The latter consisted of a minimum of five blows on an Ohio 800 rolling sealed spirometer. Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1) and flowrates were determined from maximum envelope curves. Posterior-anterior and lateral radiographs were also taken.

Major symptoms of interest were cough, phlegm and dyspnea. Chronic cough was defined by a positive answer to: "Do you usually cough during the day (or at night) in the winter?" and "Do you usually cough like this on most days (or nights) for as much as three 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?" Radiological indices were based on the median of three readings undertaken using the 1971 ILO/UICC standard [6].

The detailed description of the dust-, vapor- and gas-measuring techniques was essentially that described by Sutton and colleagues [7]. Briefly, respirable dust samples for the metal and coal mines and total dust for the nonmetal mines were collected by personal gravimetric methods. X-ray diffraction analysis on the individual samples was undertaken to determine

Table I. Numbers of Mines and Miners Included in Study of Diesel Emissions by Material Mined

Material	No. of Mines	No. of Miners Examined
Metal	8	2,784
Potash	6	1,091
Salt	5	303
Trona	2	746
Coal	6	823

quartz percentages. Side-by-side total and respirable area samples were used to provide ratios with which the nonmetal total dust samples could be converted to respirable.

Personal samples of nitrogen dioxide were obtained using dosimeters. All personal samples were collected over the duration of a working shift. Aldehyde measurements by work area were collected by two methods: activated alumina and sodium bisulfite. Carbon monoxide and carbon dioxide were measured by work area.

A variety of exposure indices were used in the various studies, involving the use of years of work in diesel atmospheres; estimated cumulative exposures calculated by the sums of products of time spent in each job and concentration of dust and NO_2 for the job within a mine; matched control (nonexposed) subjects, and other measures such as horsepower per employee, fuel use per month per total ventilation, fuel use per month and number of diesel units.

RESULTS

Metal/Nonmetal Composite

Table II shows some indices of radiological abnormality often associated with industrial exposure. The prevalence rates were all low. Metal miners were found to have a marginally higher prevalence of small rounded opacities. This difference was significant when compared to potash workers, the only group having similar age and tenure structure. No consistent evidence of large opacities was noted.

Symptom prevalences by exposure group for smokers and nonsmokers are shown in Figure 1. Age and dust exposures were accounted for in the analysis. For smokers with aldehyde exposures, there was a tendency for men with

Table II. Metal/Nonmetal X-ray Results[a]

	Rounded Opacities 1/0+ (%)	Irregular Opacities 1/0+ (%)	Pleural Thickening (%)
Metal	1.1	0.6	2.2
Potash	0	0.2	1.2
Salt	1.4	0.7	1.4
Trona	0.3	0.3	0.3

[a]All prevalences based on medians of three readings.

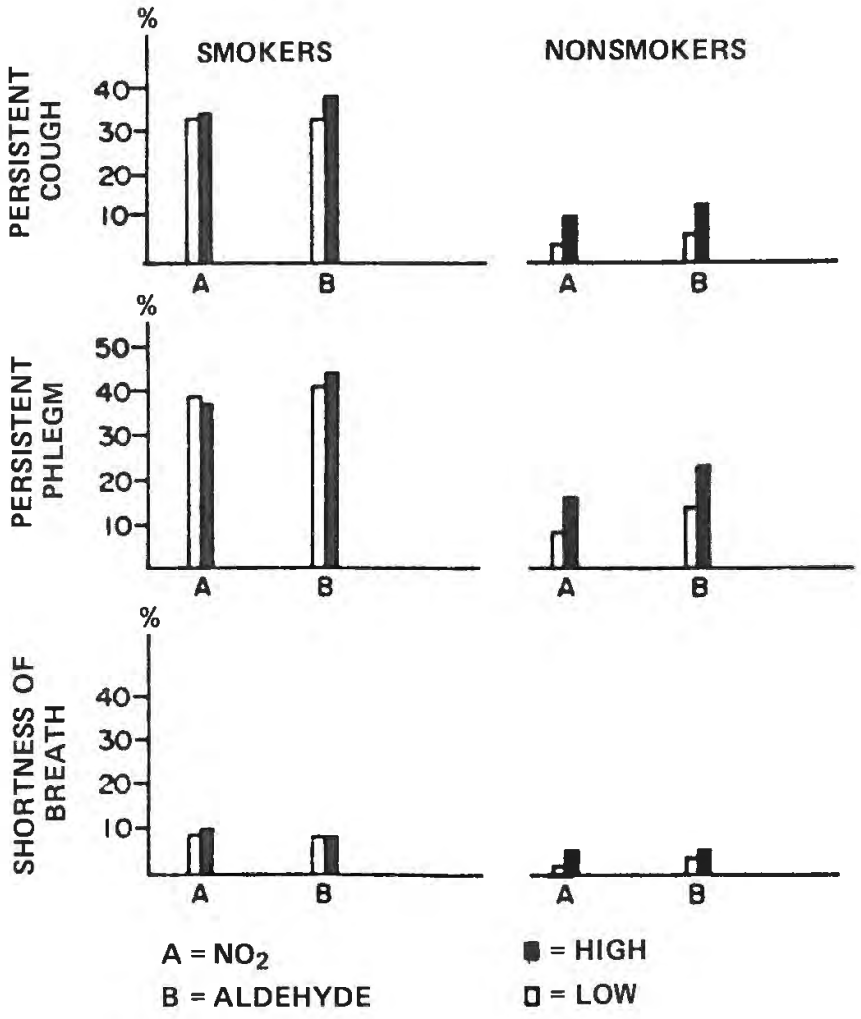


Figure 1. Effect of NO_2 and aldehyde exposures on symptoms.

higher exposure to report more symptoms. This effect was significant for persistent cough. Among nonsmokers, those with higher aldehyde and NO_2 exposures consistently reported more symptoms; these differences were not statistically significant.

In regard to lung function and NO_2 exposure (Figure 2), no consistent relationships could be discerned that supported the results on symptoms. For nonsmokers, the effect of exposure on lung function agrees with the findings on symptoms, but for smokers the effect is contradictory. The effect of aldehyde exposure, both in smokers and nonsmokers, is opposite to that implied by the symptoms results (Figure 3).

Carbon monoxide and carbon dioxide exposures were calculated as indices of diesel use rather than as measures of exposure per se. Their application to the symptom rates and lung function variables led to no significant findings.

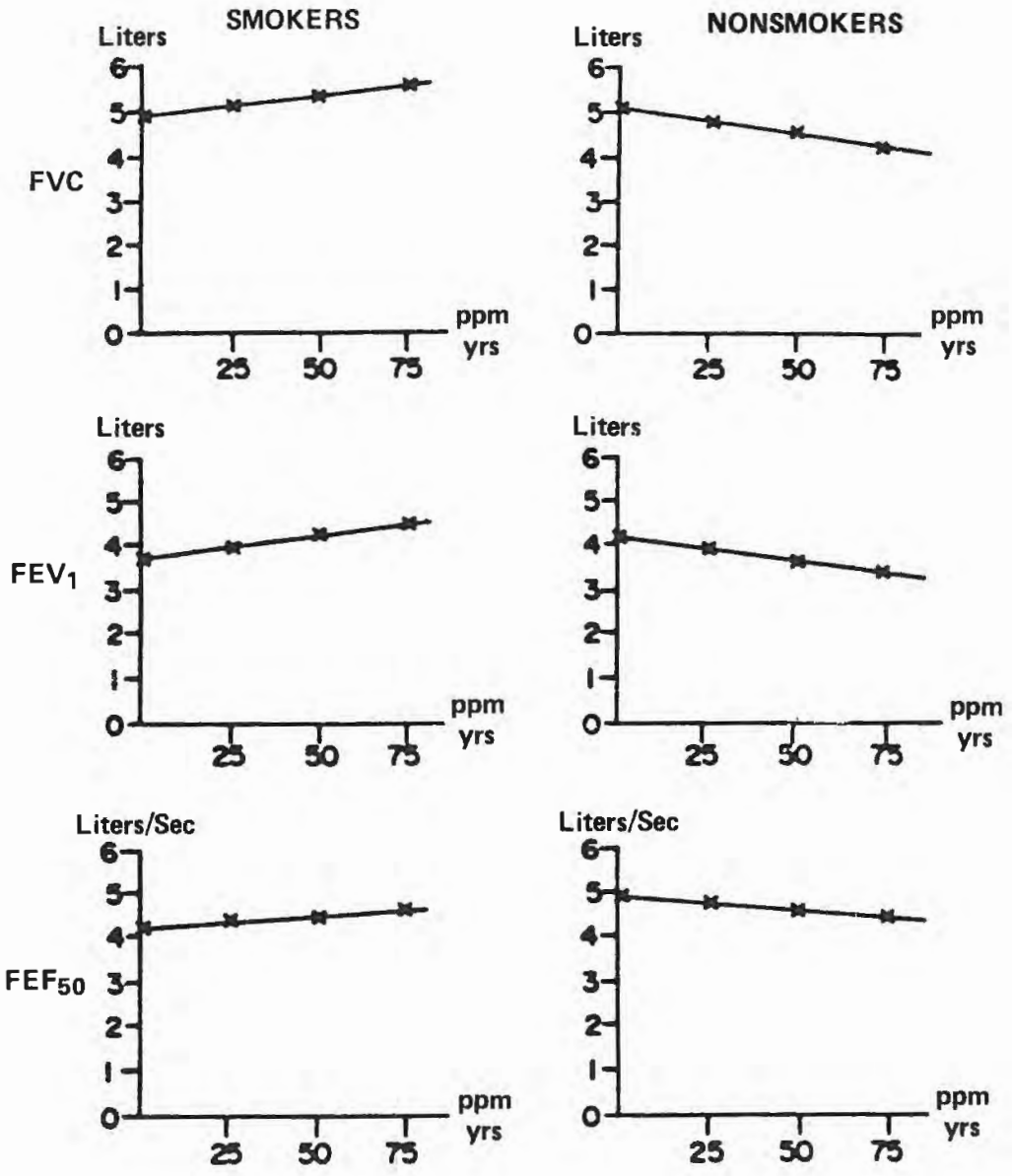


Figure 2. Effect of NO_2 exposure on lung function.

Years of work in diesel mines was used as an index of diesel exposure. This took no account of the environmental level of exposure. In the analysis of symptom prevalence, despite attempts to eliminate age effects by comparison of groups of like age, the groups of men exposed longer still tended to be slightly older on average. Thus, some confounding of age occurred with duration of exposure. The number of years of exposure was divided close to the median point (five years), and the prevalence of persistent cough, persistent phlegm and shortness of breath was examined for those with five or more years and those with less than five years of exposure. Allowances were made

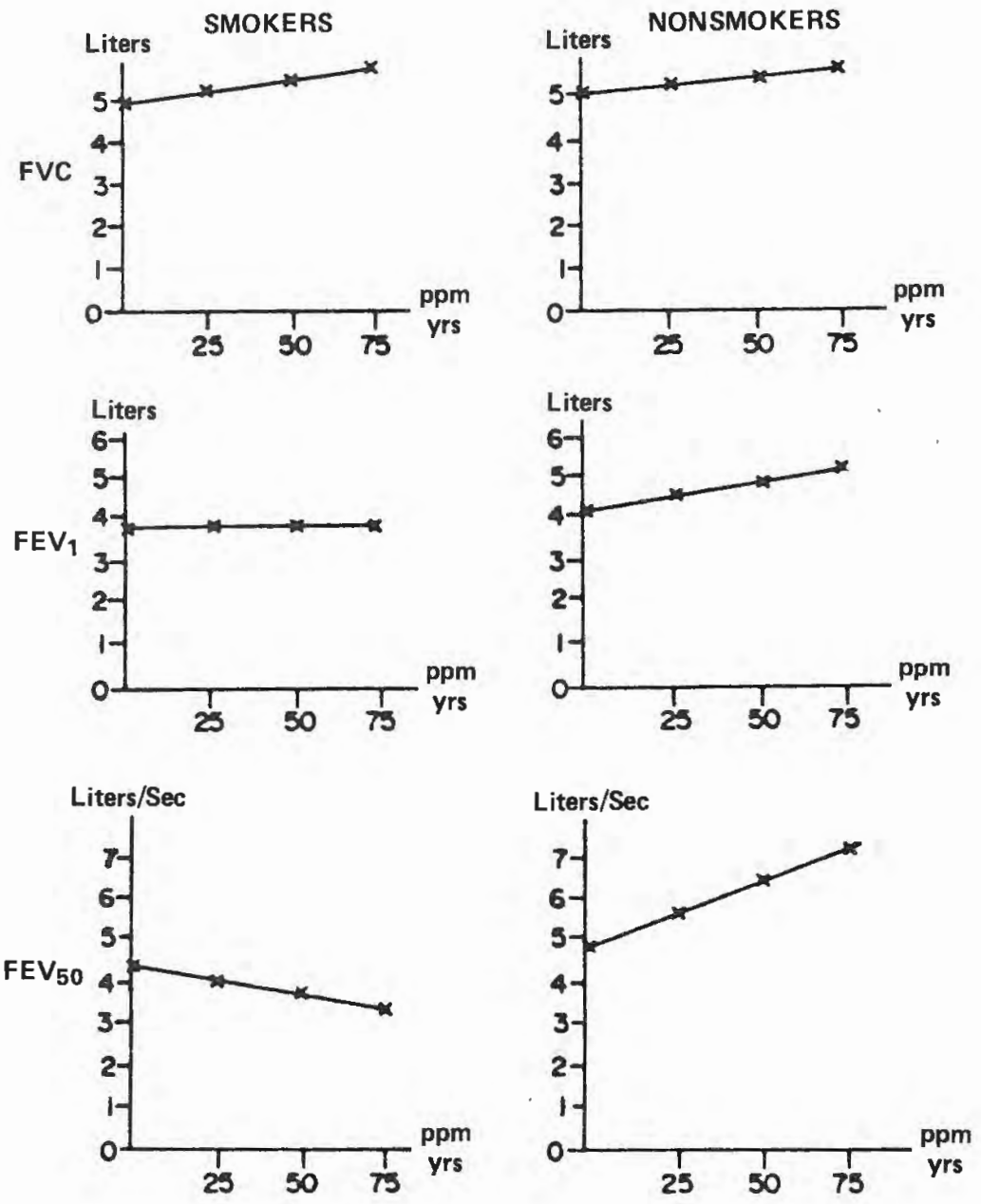


Figure 3. Effect of aldehyde exposure on lung function.

for dust, quartz exposure and age in the analysis, and results are shown separately for smokers and nonsmokers (Figure 4). Men with the greater years of exposure had more symptoms in five of the six groups, but in no case was there a statistical significance.

Lung function was also analyzed by including years of exposure in the model; age, height, smoking status and amount, region and mine effects were

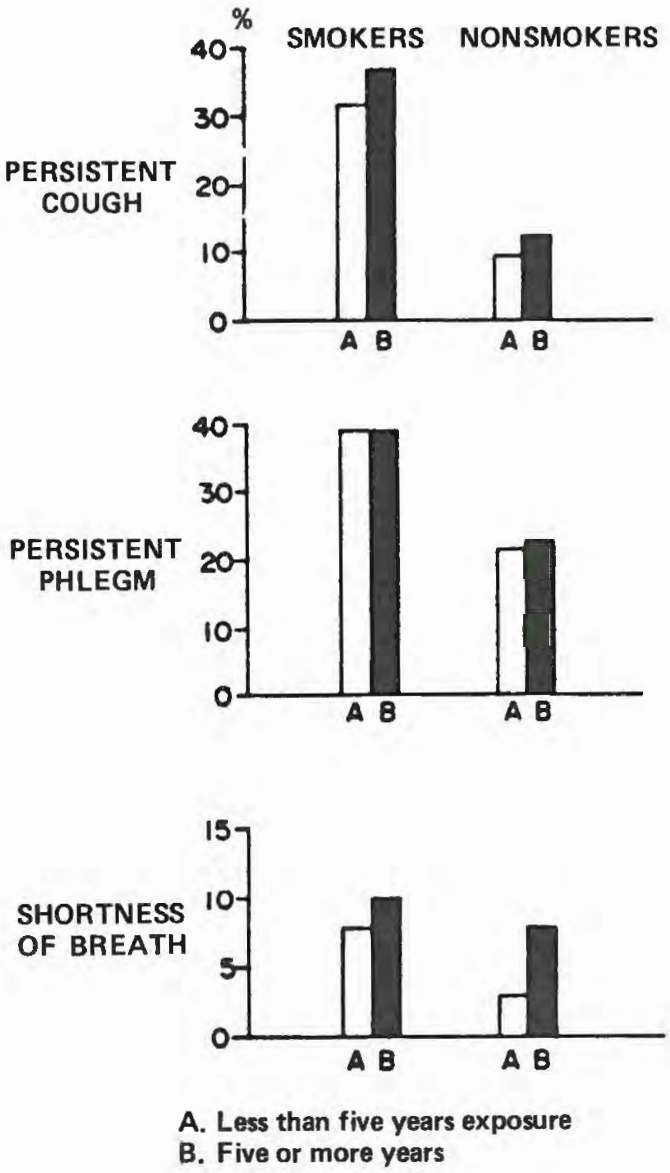


Figure 4. Prevalence of symptoms according to years of exposure to diesels.

also considered. The predicted lung function values for given years of exposure (Figure 5) present a picture contradicting that implied by study of the symptoms. In every group, the predicted lung function level increased with years of exposure.

The overall picture presented by the composite metal/nonmetal analysis is one of conflicting results. In some cases, there is a suggestion of deleterious effects from diesel exposure; in other cases, the opposite appears true. Generally, however, there appears to be no effect at all.

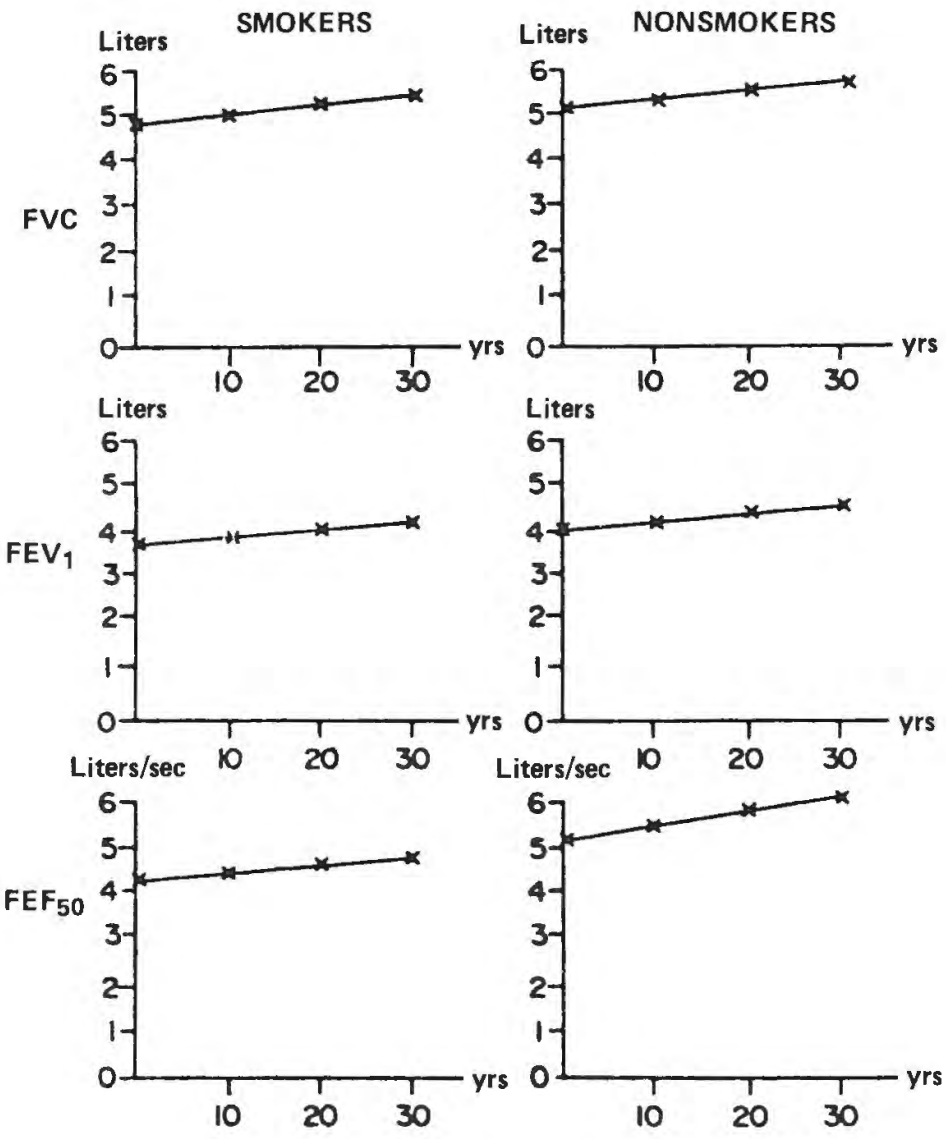


Figure 5. Effect of years exposure on lung function.

Potash Subgroup

Table III presents information on production methods and diesel usage at the potash mines where examinations were performed. 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, also had 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.

The great difference in pattern of diesel usage at Mines C and E suggests

Table III. 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[a]	CON	CON	CM[b]	CM	CON
Date of Diesel Introduction	1964	1952	1950	1964	1966	1964
Total Number of Diesel-Powered Units	7	55	57	35	14	20
Number of Ramcars	0	6[c]	10	0	0	0
Number of Diesel-Powered Units with Horsepower Greater than 50	0	13	26	8	1	6
Gallons of Diesel Fuel Consumed per Month (approximately)	400	1,800	7,100	400	300	1,000

[a]CON = conventional = cutting, blasting, removal. CM = continuous miners.
[b]Mine D had one conventional production area and one using a heliminer; the rest were using continuous miners.
[c]Not all in use at once.

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 is direct, simple and free of the problems inherent in estimating exposures retroactively from environmental data collected over a short period of time.

This direct comparison of mine populations was the first analysis undertaken to explore the effect of diesel exposure on lung function and respiratory symptoms. 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, Starmer and Koch [8]. For a dichotomous response, this reduces to the logistic model of Cox [9]. Again, age, smoking habits and mine effects were included in the models as appropriate. To represent diagrammatically any associations between health indices and mine effects, the following procedure has been utilized. 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 to 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.

Figures 6 and 7 show these mine residuals for FEV_1 and FVC, respectively. 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

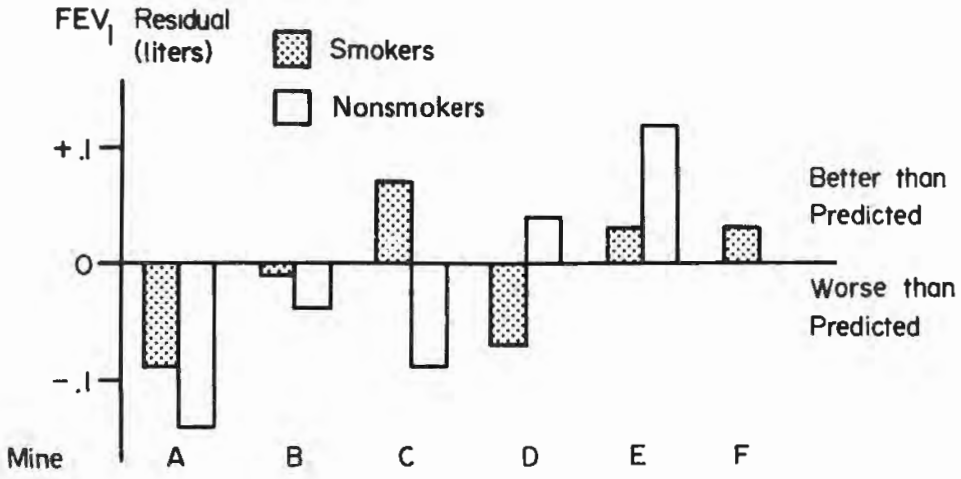


Figure 6. FEV_1 residuals by mine.

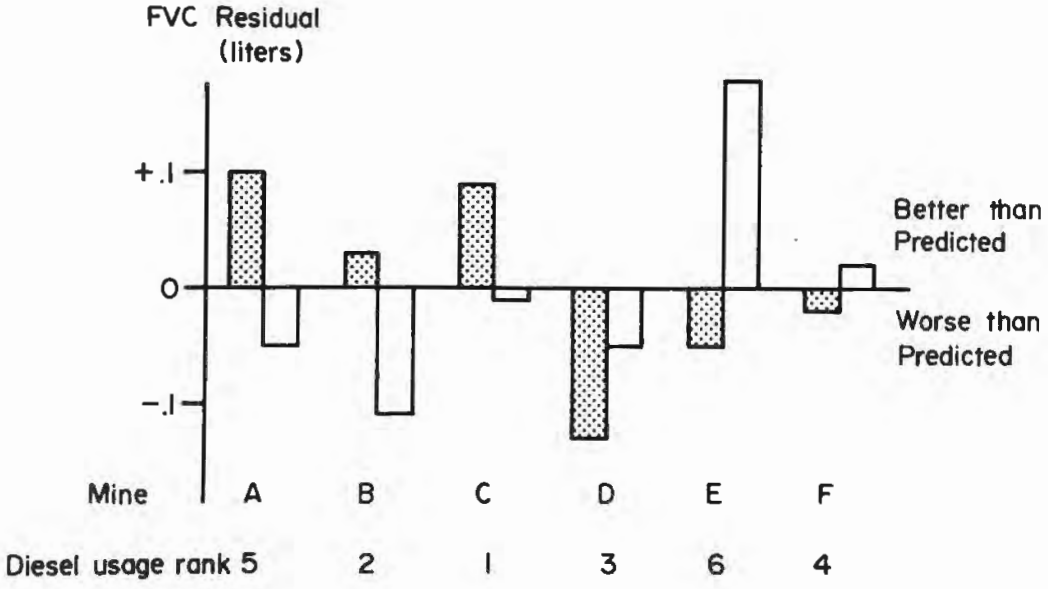


Figure 7. FVC residuals by mine.

no consistent deficit in both smoking groups (despite the fact that the nonsmokers in this mine had FEV_1 values consistently lower than expected and 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 IV, 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.

As it would be expected that FEV_1, rather than FVC, would vary in response to NO_2 and other diesel-related contaminants, FVC mean values may be of secondary importance. However, they do serve to indicate whether there may have been differences between mines arising from technician and other related factors. The data 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 Figures 8–10 for smokers and nonsmokers and concern persistent cough, persistent phlegm and shortness of breath.

Table IV. Lung Function, Symptoms and Related Data by Mine

	Mine					
	A	B	C	D	E	F
Nonsmokers						
FEV_1, liters	3.5	4.0	4.0	4.2	4.0	4.1
FVC, liters	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, liters	3.5	3.7	3.7	4.0	3.6	3.6
FVC, liters	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

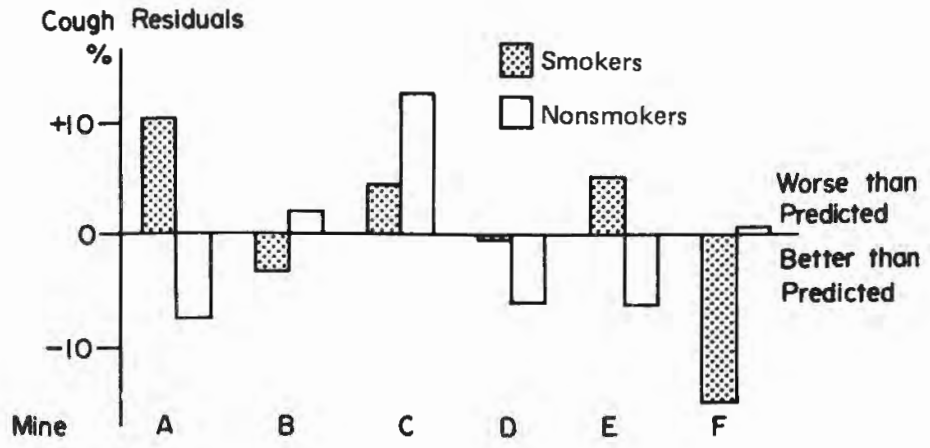


Figure 8. Persistent cough residuals by mine.

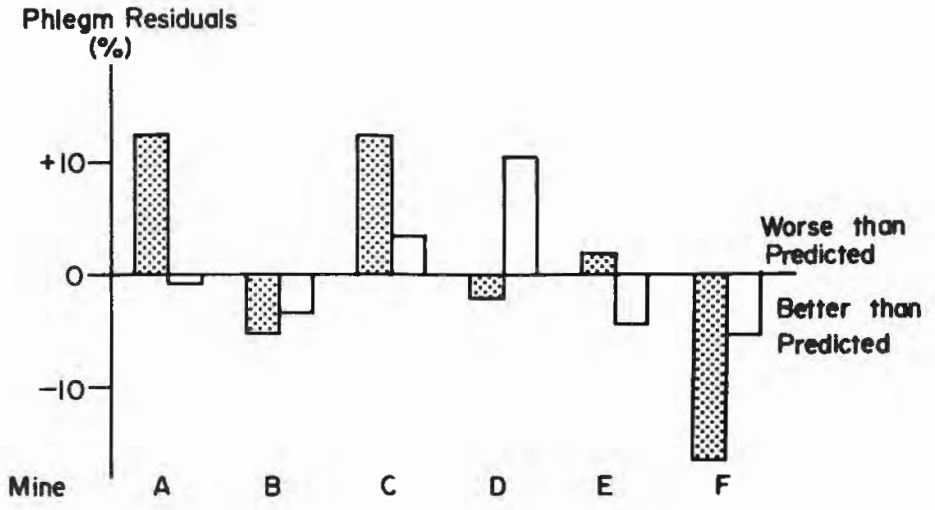


Figure 9. Persistent phlegm residuals by mine.

They were derived by subtracting from observed prevalence for each mine the expected prevalence determined on the basis of age (and pack-years for smokers) using the logistic model. No consistent trends are revealed. 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 nonsmokers. Despite appearances, no statistically significant differences between the mines could be detected for lung function in either smokers or nonsmokers.

Although there were valid a priori reasons for investigating differences

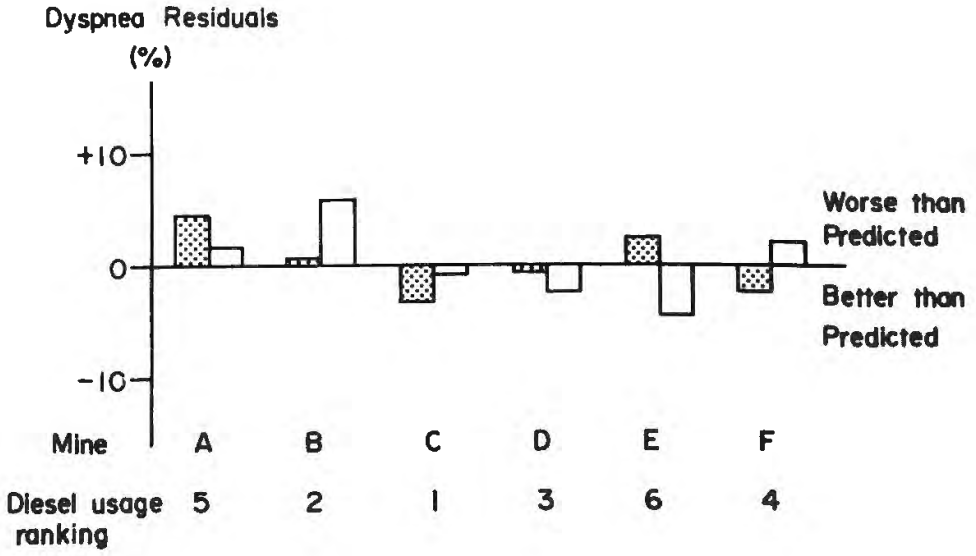


Figure 10. Dyspnea residuals by mine.

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, neither 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. Accordingly, a different approach was attempted to take these factors into account.

For this analysis, lung function residuals were obtained by fitting a linear model that included age, height, mine effects (pack-years) and cumulative dust exposure. The resulting mean residuals are shown in Figures 11 and 12 grouped by exposure to NO_2. No obvious trend could be discerned, neither was there any consistency between the patterns for smokers and nonsmokers. The regressions with the additional term for cumulative exposure to NO_2 confirmed visual impressions. The results for symptoms are shown in Figures 13–15. As can be seen, no clear trend emerged. Agreement between the residuals for smokers and nonsmokers was poor.

Trona Subgroup

About 680 white male trona workers were studied overall. Table V shows statistics on age and exposure. Although some workers had remained at work in the mines for many years, the predominant duration of exposure was low.

To explore the possible effect of NO_2 on lung function, the data were

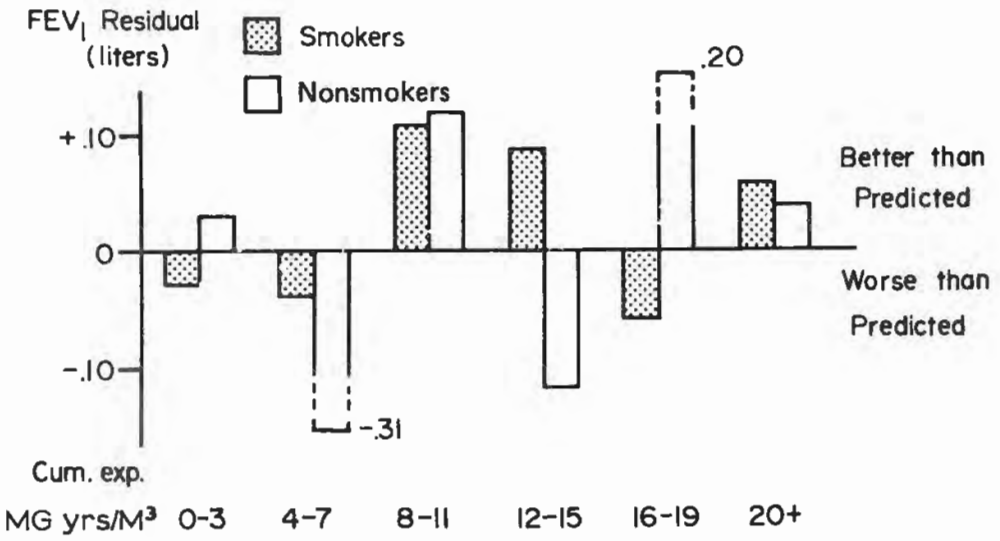


Figure 11. FEV_1 residuals by NO_2 cumulative exposure group.

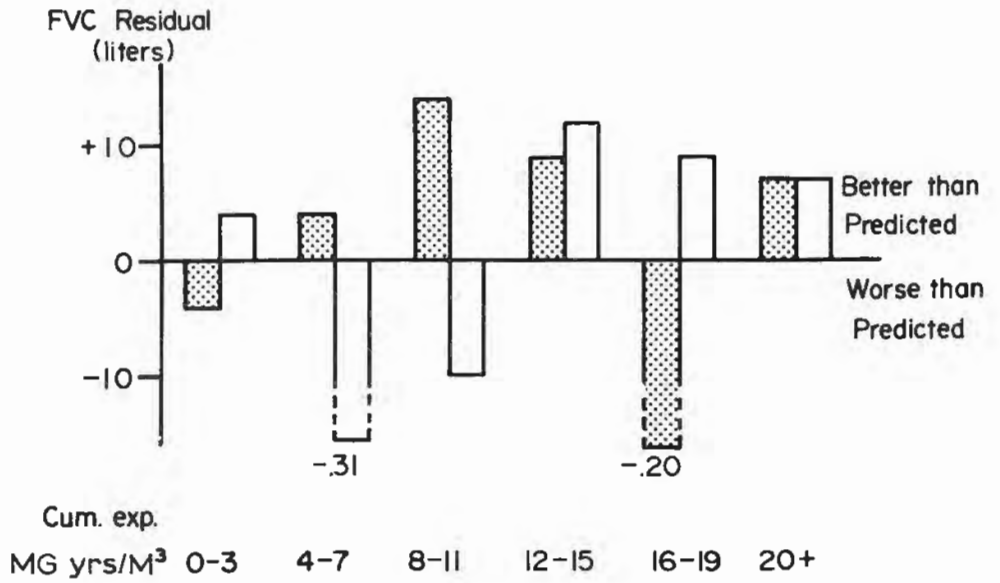


Figure 12. FVC residuals by NO_2 cumulative exposure group.

analyzed separately by age group, first overall and again with the omission of those with other dust exposure (359 workers). To do this, linear least squares models were fitted to FVC, FEV_1 and flow at 50% of FVC (FEF_{50}). In the older group, both with and without those with other exposure, lung function decline with age was unusually and significantly great in all smoking groups (0.05 or worse, liter/yr for smokers). Despite this, no clear deleterious relationship between lung function and either dust or NO_2 exposure could be detected.

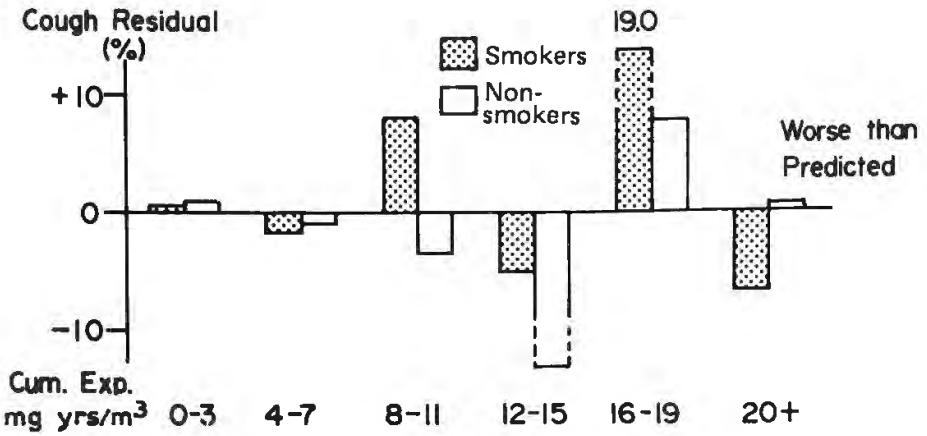


Figure 13. Persistent cough residuals by NO_2 cumulative exposure group.

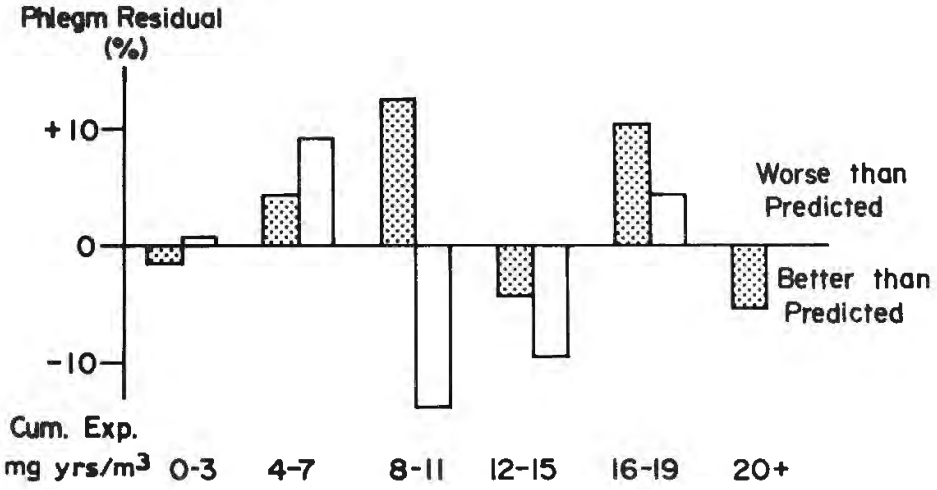


Figure 14. Persistent phlegm residuals by NO_2 cumulative exposure group.

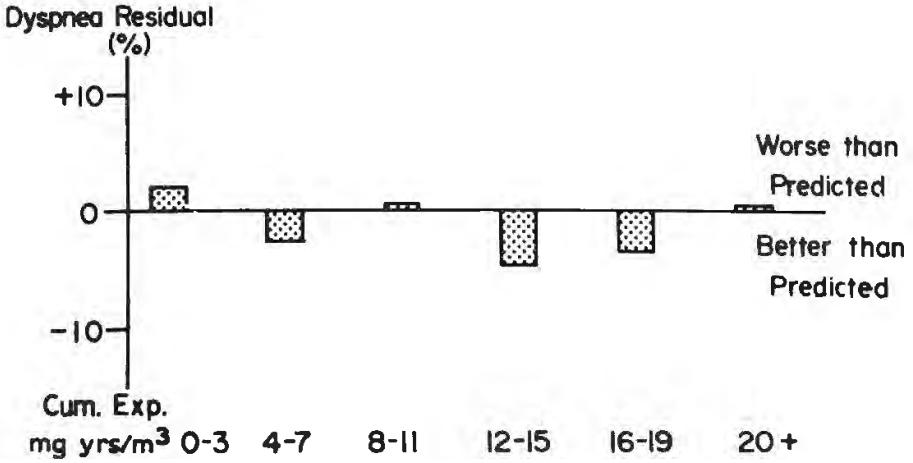
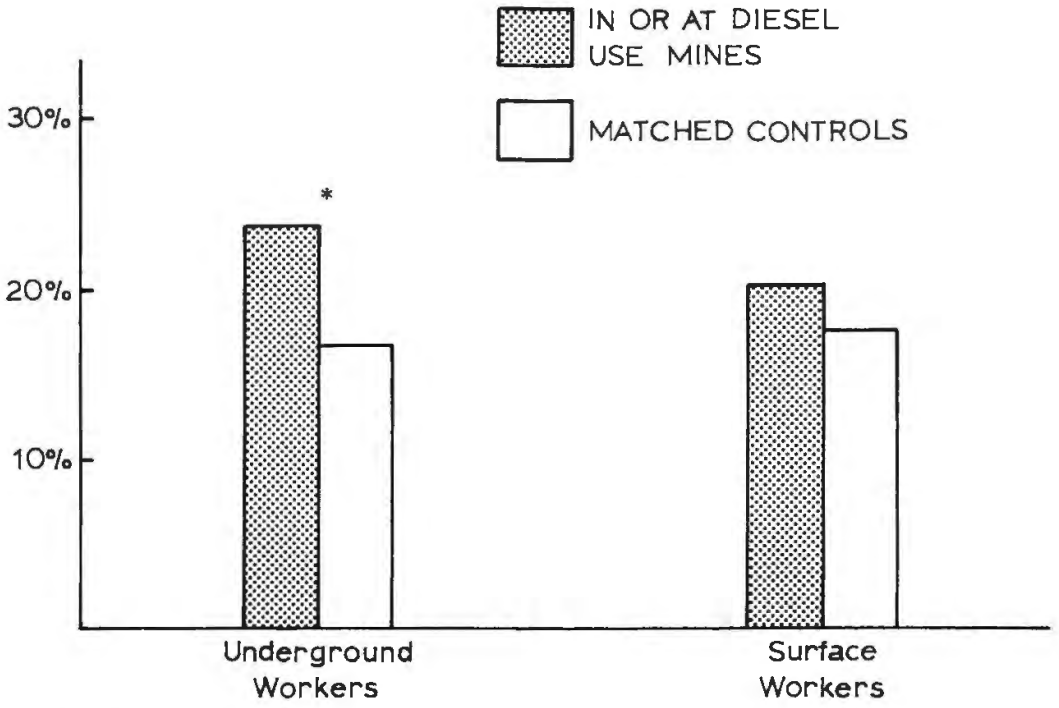


Figure 15. Dyspnea residuals by NO_2 cumulative exposure group.

Table V. Age and Exposure Statistics of Trona Mine Workers

	Age < 25	(SD)	Age ≥ 25	(SD)
Age, yr	22	(2)	38	(12)
Dust Exposure, yr	2	(1)	5	(16)
Dust Exposure, mg-yr/m^3	24	(23)	74	(104)
Diesel Exposure, yr	2	(1)	3	(2)
NO_2 Exposure, ppm-yr	0.2	(0.1)	0.4	(0.4)
Other Dust Exposure,[a] yr	1	(3)	6	(8)

[a]Principally in coal mining.



*Significantly different, $p < 0.05$.

Figure 16. Prevalence (%) of persistent cough.

Coal Subgroup

Analysis was performed of pulmonary indices from 823 white male coal miners who worked with diesels, and comparisons were made to a like number of nondiesel-exposed controls. Both groups (exposed and controls) were dichotomized, depending on whether they worked underground or on the surface. The basic analysis showed that underground miners in diesel use mines had more symptoms of cough and phlegm and generally lower pulmonary function performance than matched controls. However, similar trends

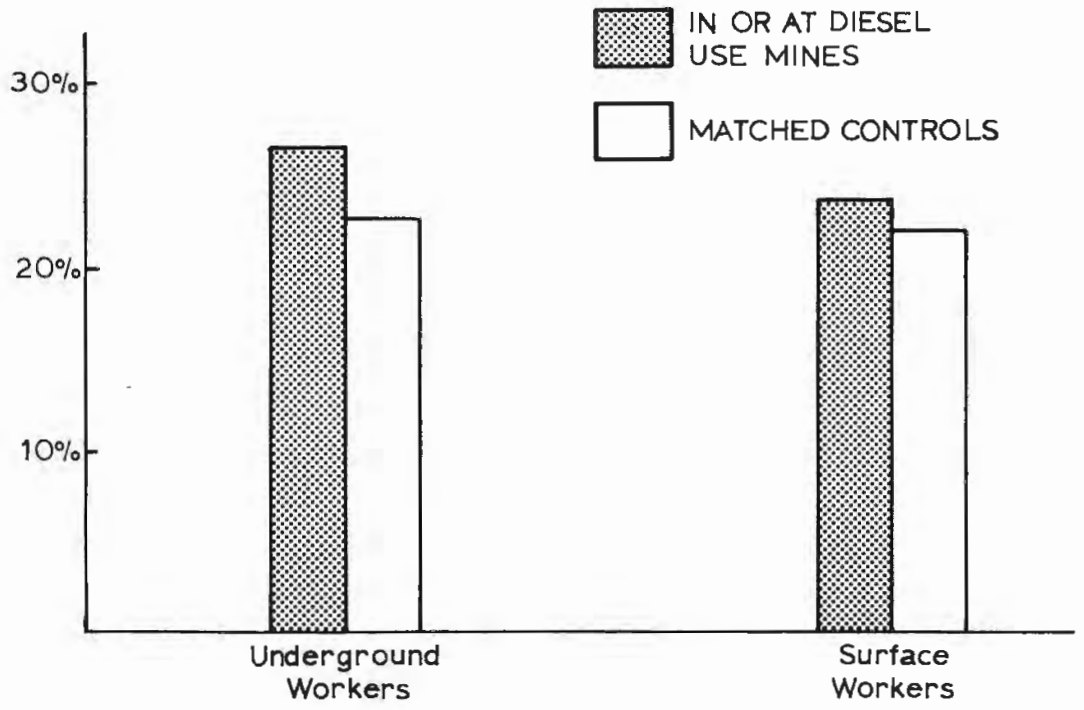


Figure 17. Prevalence (%) of persistent phlegm production.

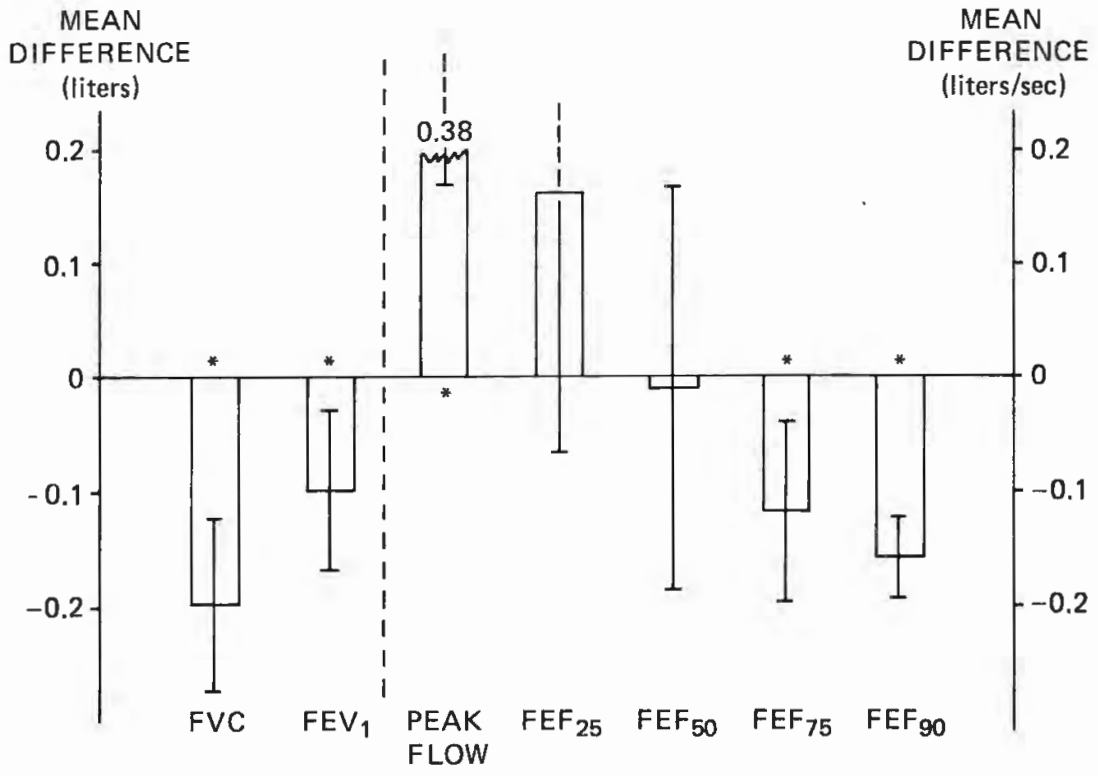
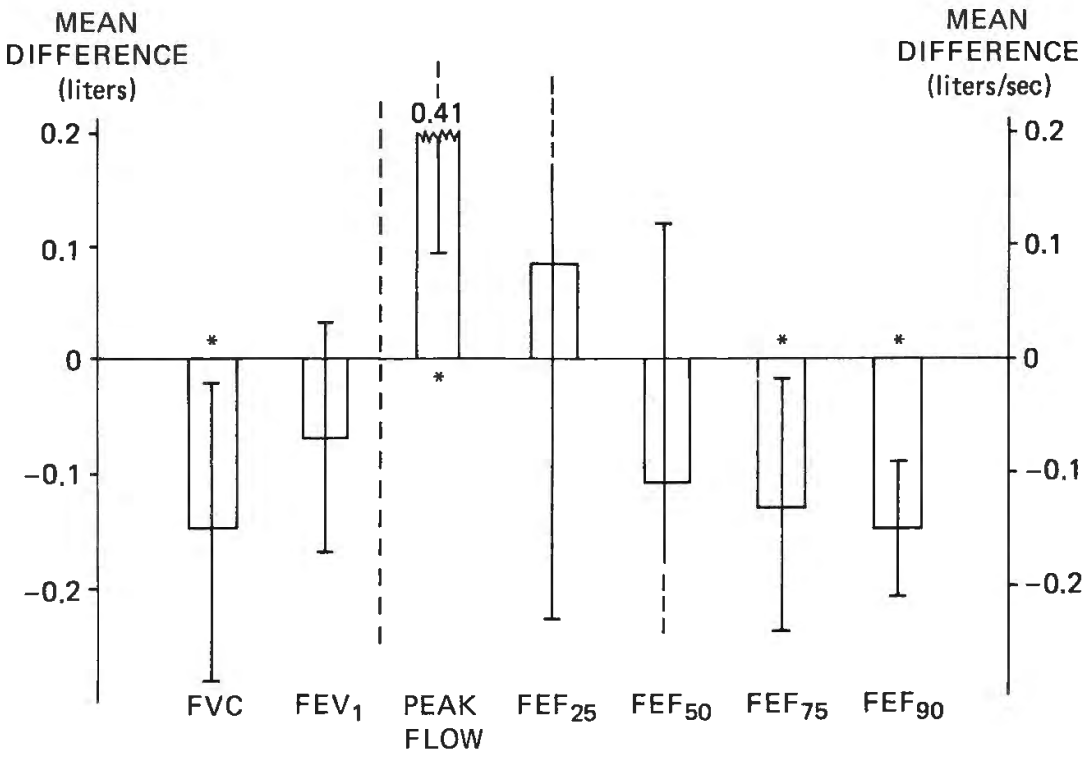


Figure 18. Mean differences in pulmonary function for underground miners (workers in diesel use mines minus matched controls).



*Significantly different from zero ($p < 0.05$).

Figure 19. Mean difference in pulmonary function for surface miners (workers at diesel use mines minus matched controls).

were noted for surface workers at diesel use mines compared to their matched controls. These data are shown in Figures 16–19. A pattern somewhat consistent with small airways disease is shown, but factors other than diesel exposure may be responsible. The exposure time to diesel emissions for this subgroup of miners is relatively short, and measured concentrations of gases, vapors and dusts were exceedingly low.

DISCUSSION

On the basis of the data presented in this chapter, no consistent effects due to diesel emissions are evident. Most results are either mixed or negative. For example, for the metal/nonmetal composite, there was an increased prevalence of cough associated with exposure to aldehydes, but the trend was not confirmed by lung function data. There were no effects in relation to exposure to NO_2. Age-adjusted symptom prevalence did rise with increased years of exposure, but lung function performance also increased.

Various qualitative indicators of diesel use failed to show any consistent trends with symptoms and lung function. For the potash group, no obvious links incriminating diesel exhaust could be ascertained. However, symptom prevalences were somewhat elevated compared to a nondust-exposed group. For the trona subgroup, no clear, deleterious relationship between lung function and duration of exposure or nitrogen dioxide could be detected. For the coal workers, all health indicators for matched surface workers were directionally the same as for the matched underground workers. If the assumption of no difference in exposure levels for matched surface workers holds true, then the phenomena observed for the underground workers rules out a clear-cut effect due to diesel emissions.

Although the data to date do not show any consistent effects due to diesel emissions, several limitations in the data need to be highlighted. All results reported here are from cross-sectional morbidity studies and, therefore, are subject to the so-called "healthy worker effect." Local controls were often not available. In all of the studies there were variable selection factors involving differing levels of participation. The bias that might be introduced by this selection is unknown. For most of the work there were exceedingly low levels of exposure, some of short duration. Hence, there may be insufficient sensitivity to detect changes at such low levels of exposure, or insufficient time may have elapsed to detect true adverse health effects. For the most part, a serious limitation in these data involves the availability of comprehensive past exposure data. While beyond the scope of this work, it must be mentioned that none of these studies was designed to address the cancer-causing potential of diesel exhaust emissions.

Further work is continuing on several fronts in an attempt to overcome some of these limitations. A five-year followup of the health status of the coal miners exposed to diesel emissions and their matched controls is underway. This includes followup medical examinations, industrial hygiene surveys and followup on those individuals who have left the industry during the intersurvey period. Mortality and case control studies are being pursued amongst subgroups of railroad employees exposed to diesels and metal miners so exposed. Further work is continuing relating to carefully controlled animal exposure studies pertaining to coal dust and diesel exhaust. These results will be available in the near future.

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