CHAPTER 8

Evaluation of Physical Health Effects Due to Volcanic Hazards: Human Studies

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Introduction

This chapter focuses on the physical health effects of exposures to ash from Mount St. Helens, and chapter 9 focuses on the mental health effects.

Major Questions and Issues

The major questions and issues relating to the physical health effects of the eruptions of Mount St. Helens that were most appropriate to answer by means of human studies were as follows:

- What are the acute and chronic effect of exposure to volcanic ash on the eyes? Are these effects (if any) reversible or irreversible?
- Is there a subset of the population which is at particular risk for acute and/or chronic effects of the volcanic ash on the eyes? Are contact lens wearers or individuals with dry eyes (sicca syndrome) at increased risk?
- What are the acute and chronic effects of exposure to volcanic ash on the upper and lower respiratory tracts? Does the ash affect the airways and/or lung parenchyma? Are these effects (if any) reversible or irreversible?
- Is there a subset of the population which is at increased risk for the development of pulmonary-related problems? Are persons with chronic obstructive pulmonary disease (COPD) at increased risk? Are the elderly, especially those with heart and/or lung disease, at increased risk? Are asthmatics or persons with nonspecific bronchial hyperreactivity at increased risk? Are smokers at increased risk?
- Is lung growth and development in children likely to be affected?
- Does acute and/or chronic exposure to inhaled volcanic ash affect the reactivity of the airways?
- Does long-term exposure to inhaled volcanic ash cause chronic bronchitis?
- Does long-term exposure to inhaled volcanic ash cause silicosis or other fibrotic lung disease?

What Has Been Done

Some of these questions have been answered satisfactorily, others will be answered shortly when all the data from the ongoing studies are available, and a few of the questions will remain unanswered. Table 1 shows a list of the human studies that have been carried out and gives a brief description of their goals, study populations, and findings. As pointed out in chapter 4, the only real advantage that human studies have over animal studies is that the results are likely to be relevant to humans. Although this is a very important advantage, it must be weighed against the sizable disadvantage of drawing conclusions from observational studies. Specifically, 1) the generalizability of results obtained from observational studies may be limited because of the way in which the subjects were selected, the characteristics of the study population, or the inability to obtain an acceptable rate of participation; 2) they tend to be very costly; 3) they almost always take a long time; and 4) they are very difficult to control.

Because of the logistical and funding difficulties associated with carrying out a well-designed epidemiologic study, the amount of epidemiologic information available from human studies about the effect of the volcanic ash from Mount St. Helens on the respiratory system is somewhat limited. Nevertheless, the most important questions have been answered and from the available information it is possible to draw conclusions, which are probably valid, about the risks for the respiratory system of short- and long-term exposure to low concentrations of inhaled volcanic ash. Only limited information is available[1,2] about the effects of short- and long-term exposure to high levels of inhaled ash. However, since most exposures following a volcanic eruption, at least after the first few days, tend to be low-level exposures and since high-level exposures typically only occur among fatalities who are missed by the evacuation efforts, this piece of missing information is probably relatively unimportant.

Studies of Acute Effects on Ash-related Morbidity

Effects on the Eyes—Two approaches to evaluating the effects of volcanic ash on the eyes were carried out by Fraunfelder and coworkers.[3] The first of these was a survey of ophthalmologists in the ashfall area of four northwestern states in the US, asking for information about the types and frequency of adverse ocular effects attributed to volcanic ash. The second was a comparison of ocular findings between a group of loggers exposed to high concentrations of volcanic ash and a control group of loggers in an ash-free environment.

The ophthalmologists reported seeing 1,523 patients with complaints or findings which were considered to be related to the volcanic ash. In the opinion of the ophthalmologists, the majority of the ocular problems were anxiety reactions or foreign body sensation. Approximately half of the patients had developed an irritative conjunctivitis, presumably due to exposure to volcanic ash, but fewer than 20 per cent experienced conjunctival or corneal foreign bodies which required removal. In none of the patients seen was there a major secondary infection in the eyes or significant decrease in vision. Of importance was their observation that contact lens wearers (especially wearers of hard lenses) and patients with unusually dry eyes (sicca syndrome) had experienced the most problems. The volcanic ash had acted as an abrasive material and scratched hard contact lenses. Although these observations and conclusions fit our *a priori* armchair theorizing about the possible effects of ash on the eyes (chapter 4), the precise extent of the problem is hard to estimate from this study because of the poor rate of response from the opthalmologists surveyed.

The study of the loggers involved a complete external

NOTE: Author affiliations and addresses are listed on p vi.

TABLE 1—Human Studies to Evaluate Physical Health Effects of Volcanic Ash from Mount St. Helens

Author, Source	Population Studied	Methods	Findings
Fraunfelder, *et al.*[1]	1523 patients with eye complaints seen by ophthalmologists	Questionnaire to 425 ophthalmologists in ashfall areas	Acute irritative conjunctivitis in 50%; no chronic effects
	24 loggers exposed to ash 27 loggers not exposed to ash	External eye exam, bimicroscopy with eversion of lids; scrapings from conjunctiva	Ocular hyperemia, mucous secretion in eyes; no chronic effects
Johnson, *et al.*[6]	120 fourth and fifth graders in Missoula, Montana	Pulmonary function tests (FVC, FEV_1, FEF_{25-75}%), 6 times during 1979/80 school year and 4 days after May 18, 1980 eruption	Small decrease in FVC and FEV_1 in boys; small increase in FVC and FEV_1 in girls
Buist, *et al.*[7]	101 children 8–13 years, at 2-week summer camp in ashfall area	Pulmonary function tests (FVC, FEV_1, moment analysis) within-day and between-day effect measured. Personal breathing-zone exposures to dust measured.	No strong evidence of either a within-day or a between-day effect on lung function even in children with pre-existing lung disease or respiratory symptoms
Bernstein, *et al.*[8] Merchant, *et al.*[10]	471 loggers working in ashfall areas, 226 loggers in ash-free areas	Respiratory symptom questionnaire and pulmonary function teste (FVC, FEV_1) in June 1980. Shift changes in lung function in 39 loggers with highest ash exposure and 25 loggers in ash-free area.	Cough, phlegm, chest tightness, wheeze, stuffy nose, headaches, eye irritation in exposed loggers. No difference in baseline lung function between exposed and control groups. No difference in shift (AM to PM) changes in lung function between exposed and control groups
Olenchock, *et al.*[13]	471 loggers working in ashfall areas, 226 loggers in ash-free areas	Humoral immune factors IgE, IgA, IgM, C_3, C_4, ANA	C_3 and C_4 significantly lower in June 1980 and July 1981 in the exposed loggers than in non-exposed group

ocular examination in which bimicroscopy was carried out with eversion of both upper and lower lids. Photographs were taken of the superior and inferior bulbar and palpebral conjunctiva of both eyes. Scrapings were also taken of the inferior temporal conjunctiva. As illustrated in Figures 1 and 2, the loggers working in the high-ash environment had more ocular complaints, ocular irritation, and foreign body sensation than those working in the ash-free environment. Objectively, ocular irritation occurred with greater frequency among loggers working in the high-ash environment than among loggers doing the same work in the ash-free environment. Epiphora and eye lid problems were about equal in both groups. The loggers in the high-ash environment reported noting more mucous and crusting than usual in the morning following exposure, with the amount of mucous apparently varying with the amount of ash exposure. Ocular symptoms usually subsided within one to two days after leaving the ash environment. The bimicroscopic examination showed increased hyperemia and chemosis but no increase in follicles, papillae, or conjunctival cysts in the high-ash exposure group. There were no major differences between the groups on examination of the scrapings; the ash group had fewer neutrophils and lymphocytes and more macrophages on Papinicolaou stain, but there was no increase in keratinazation or phagocytosis of ash within epithelial cells in the ash group. It is important to note that none of the loggers in either group wore contact lenses (nor do loggers in general); therefore, the question of increased risks for contact lens wearers could not be evaluated in this exposure setting.

These studies confirmed the subjective experience of

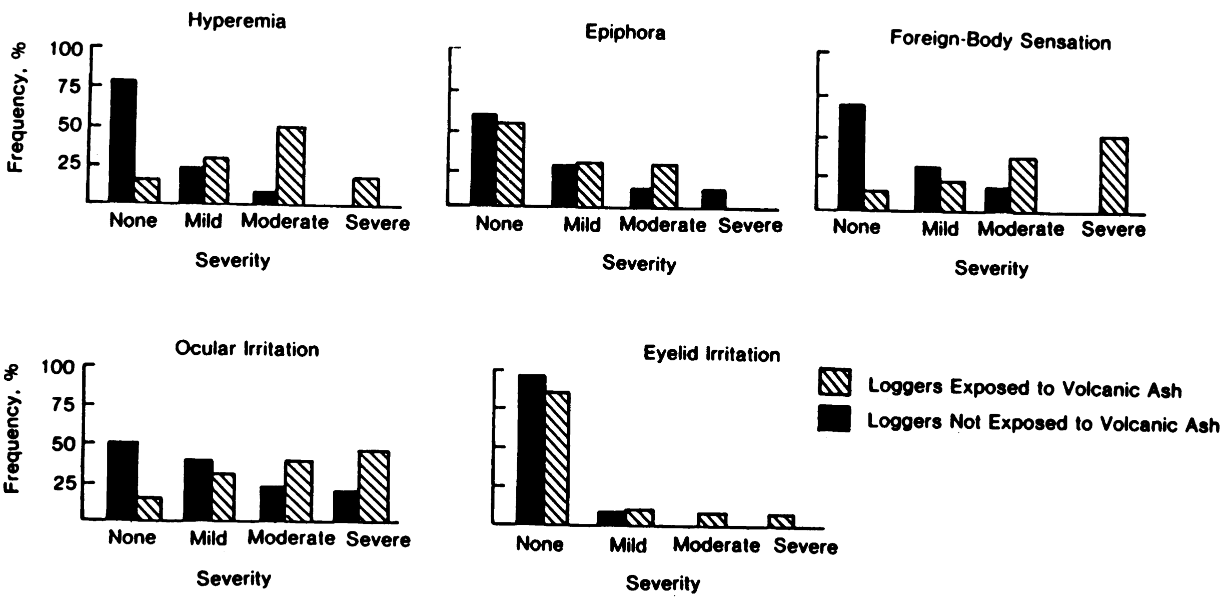

FIGURE 1—Frequency and severity of ocular problems in loggers exposed to high volcanic ash environment *v* loggers not-exposed to ash.
SOURCE: Fraunfelder, *et al*,[3] with permission of author and publisher.

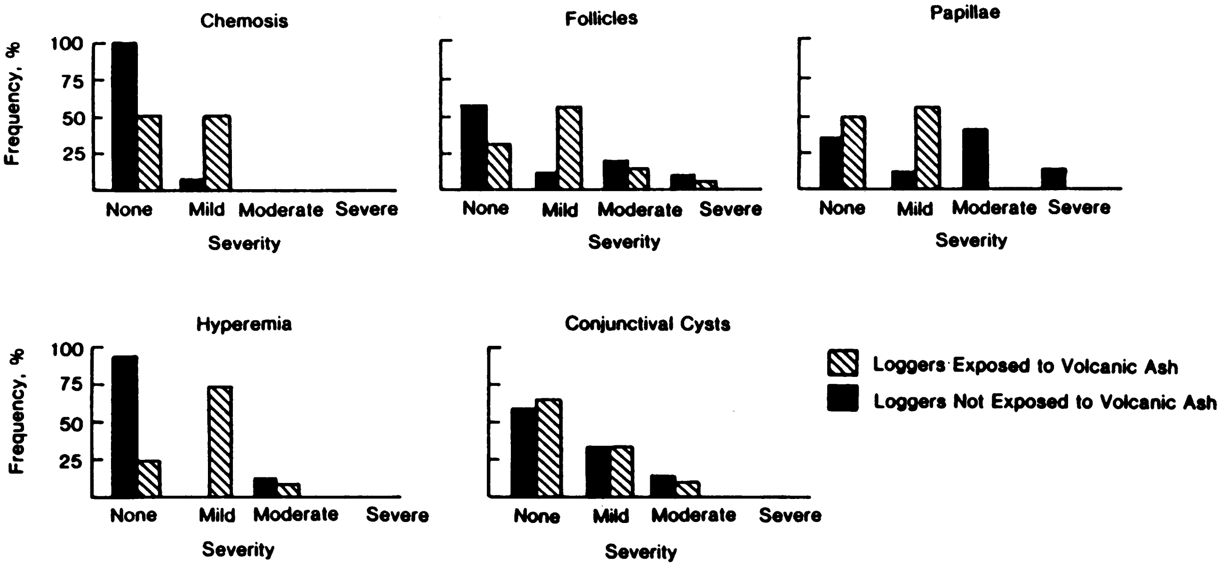

FIGURE 2—Frequency and severity of abnormal ocular bimicroscopy examination.
SOURCE: Fraunfelder, *et al*,[3] with permission of author and publisher.

most people who received any ash exposure, namely, that the ash is very irritating to mucous membranes but the effects of low to moderate exposures seem to resolve fairly rapidly. There was no evidence from this study that the ash was causing chronic inflammation and affecting overall ocular function. The practical lesson that was learned both from this study and from many personal anecdotes was that contact lens wearers may be at increased risk both because their lenses are likely to become scratched and because they are more likely to get ash lodged behind their lenses and sustain a corneal abrasion.

Effects on the Respiratory Tract—The lungs have a remarkable ability to cleanse themselves of inhaled particulates. As pointed out in chapters 3 and 4, size is the major determinant of where a particle will land in the respiratory tract. With nose breathing, the majority of particles >10 μm in diameter will be trapped in the nose; 10 μm is therefore usually considered to be the cutoff for the aerodynamic diameter of respirable-sized particles. Of course, if the nose is bypassed and an individual breathes through the mouth, either because of nasal obstruction or because of an increased workload (as would occur with heavy work or exercise), particles >10 μm in diameter will penetrate into the lower respiratory tract. In general, however, penetration to the respiratory bronchioles and alveolar spaces is limited to particles ≤10 μm aerodynamic diameter.

Inhaled particulates are generally tolerated very well and an individual is not aware of their deposition and subsequent clearance up the muco-ciliary escalator.[4] However, some individuals do not have this tolerance; 10–15 per cent of the population have airways which are hyperreactive or "twitchy" and which respond to inhaled particulates or a variety of other stimuli with bronchoconstriction or narrowing of the airways.[5] Persons with clinical asthma fall in this end of the spectrum of airway reactivity. This is the segment of the population which would be most likely to be at increased risk of airway narrowing up to and including a full-blown asthmatic attack when exposed to a very dusty environment. Children might be expected to be at greater risk than adults for bronchoconstriction or airway narrowing, first because their airways are much smaller than adult airways (this is particularly true in children under age two) and because the prevalence of airway hyperreactivity is higher during childhood than it is in adult life.[5]

TABLE 2—Comparison of Children's Average Adjusted Pulmonary Function Tests before and after Exposure to Mount St. Helens Volcanic Ash*

Pulmonary Function	Sex	5 Tests† Average	Following Ash
FVC	Male	2473	2458 (.099)
	Female	2197	2218 (.051)
FEV_1	Male	2036	2011 (.095)
	Female	1872	1892 (.185)
FEF_{25-75}	Male	2199	2135 (.065)
	Female	2252	2262 (.818)

*Numbers represent averages (in milliliters) of all individuals adjusted for test room temperature, individual differences, and height. Numbers in parentheses represent covariance analysis probability levels.
†The 5 tests conducted on low TSP days prior to the volcanic eruption.
SOURCE: Johnson, *et al*,[6] with permission of author and publisher.

Two groups of investigators have addressed the question of the acute effects of the volcanic ash from Mount St. Helens on lung function in children,[6,7] and one group on the effects in adults.[8–10] Johnson and coworkers[6] were fortunate in having a cohort of 120 children in the 4th and 5th grades in Missoula, Montana who had had their pulmonary function tested on six occasions during the 1979–80 school year. The major eruption of Mount St. Helens resulted in very high total suspended particulate (TSP) levels in the Missoula area over a period of four days (peak day = 11,054 μg/m³ 24-hour average). When the children returned to school on May 23rd, their pulmonary function was measured for a 7th time. From experience during the 1978–79 school year, the investigators anticipated that the height-adjusted pulmonary function tests would improve a few per cent in May compared with the previous winter months. After the ashfall, both the forced vital capacity (FVC) and the 1-sec forced expiratory volume (FEV_1) improved slightly (5 per cent or less) in the girls but both the FVC and the FEV_1 decreased slightly (3 per cent or

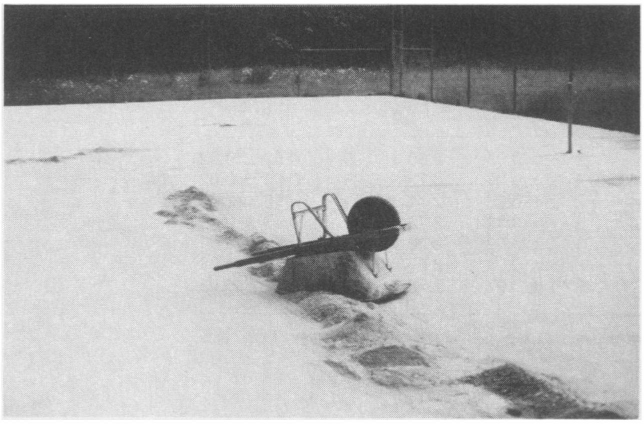

FIGURE 3—Thick carpet of volcanic ash in tennis court of children's summer camp. (*Photo from: Neil Buist*)

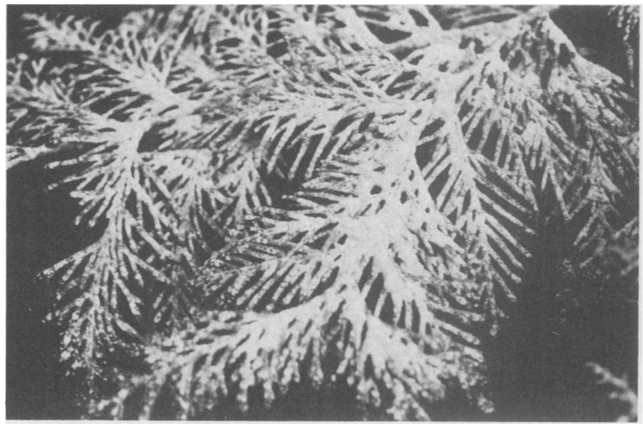

FIGURE 4—Volcanic ash sticking tenaciously to the foliage of evergreens. (*Photo from: Neil Buist*)

less) in the boys (Table 2). For the boys, these differences were all significant at the 0.10 level, although none were significant at the 0.05 level. In comparison, both girls and boys showed reductions in FVC and FEV_1 on a day of high urban fossil fuel air pollution with TSP levels of 440 $\mu g/m^3$. These reductions were all less than 2 per cent, and, for the boys, were not significant for FVC.

It is tempting to conclude from these findings that very high TSP levels four days after an ashfall had less of an affect on pulmonary function than did three days of high urban air pollution. Such a conclusion may not be valid, however, because most children took precautions to minimize ash exposure by remaining indoors or by wearing a mask for limited outdoor activity when the ash was falling. On the days of high urban air pollution, on the other hand, there were no restrictions placed on outdoor activity. If there is, in fact, a spectrum of responsiveness to inhaled volcanic ash, as there is to other inhaled particulates, one would expect that the majority of the children probably showed no effect and that it was only the children with increased airway reactivity who showed a response either to the volcanic ash or to the air pollution. Although the investigators used each child as his or her own control in this longitudinal study, they did not characterize the nonspecific airway reactivity of each child as a risk factor for adverse reactions to inhaled particles. Thus, it is uncertain whether greater individual susceptibility based on airway hyperreactivity could explain the likelihood or intensity of reactions among children in this study.

Buist and coworkers[7] studied 101 children aged 8–13 who were attending two-week summer camps in the area where about 1-2 cm of ash had fallen after the June 12, 1980 eruption of Mount St. Helens (Figures 3 and 4). In addition to the ash on the ground, there was a considerable amount of ash in the trees and bushes that surrounded the camp which became resuspended as a result of wind and human activity. Pulmonary function tests were performed on the children when they arrived in camp and twice (early morning and late afternoon) every second or third day during the two weeks of camp. A within-day effect was measured by the ratio of the late afternoon to early morning measurement of FVC and FEV_1; a between-day effect was measured by the change in the late afternoon measurements over the two weeks of camp (Table 3 and Figure 5). They also specifically looked at the within-day and between-day response in a group of children who had frequent and/or exercise-induced wheezing, doctor-diagnosed asthma, chronic cough and/or phlegm, or a history of childhood chest infections before age 3; they considered this group as a "susceptible" subgroup who might be expected to show an exaggerated response to dust/ash. Total and respirable dust levels were measured using personal sampling pumps carried in backpacks because the pumps were too heavy and awkward for small children to wear on their belts.[11] From these, a time-weighted average concentration of total and respirable inhaled dust was estimated. Nighttime dust levels were measured by samplers in the dormitories. Daytime breathing-zone TSP levels averaged 1,240 $\mu g/m^3$ for one camp and 1,460 $\mu g/m^3$ for the other camp. Nighttime TSP levels were at or below the limit of detection (10 $\mu g/m^3$). For comparison, the EPA NAAQ "alert" and "warning" action levels for 24-hour average (rooftop) concentrations of airborne TSPs are 375 $\mu g/m^3$ and 625 $\mu g/m^3$, respectively. The average respirable dust levels during the day were 179 $\mu g/m^3$ for one session and 163 $\mu g/m^3$ for the second session. Nighttime respirable dust levels were close to zero.

The investigators found no strong evidence of a within-day or overall change in lung function in the group as a whole or in the "susceptible" individuals. These results are reassuring because the levels of dust/ash, although not nearly as high as the levels experienced during an ashfall, were quite typical of the levels that are likely to be encountered in a minimally impacted ashfall area until the ash is washed away, blown away, or incorporated into the topsoil.

The largest scale study that has addressed the question of the acute effect of volcanic ash from Mount St. Helens on the respiratory tract is the study carried out by the National Institute for Occupational Safety and Health (NIOSH).[8–10] The study originated as a request for a NIOSH Health Hazard Evaluation from the International Woodworkers of America and the Weyerhaeuser Company because of their concern that loggers working in the ashfall areas around Mount St. Helens might be at risk. The design of the study and a description of its short-term findings are summarized here (see chapter 3 for full presentation) in order to introduce the long-term follow-up results described below.

Loggers were recruited for the study by a random, but nonsystematic, selection of crews and individuals from four ash-exposed logging camps in Washington State (Figure 6) and two unexposed camps (control group) in southern Oregon. Loggers with a wide range of job-related ash exposures were included in the study although work crews of the most

TABLE 3—PM Measurements for FEV_1, FVC and $\alpha_1(\infty)$

	Session 1			Session 2		
	FEV_1	FVC	$\alpha_1(\infty)$	FEV_1	FVC	$\alpha_1(\infty)$
Baseline	1.93 ± 0.05*	2.22 ± 0.07	0.59 ± 0.03	2.48 ± 0.08	2.80 ± 0.09	0.52 ± 0.02
Test Day 1	1.87 ± 0.05	2.15 ± 0.07	0.60 ± 0.04	2.43 ± 0.07	2.73 ± 0.09	0.50 ± 0.02
Test Day 2	1.85 ± 0.06	2.14 ± 0.07	0.62 ± 0.04	2.42 ± 0.08	2.71 ± 0.09	0.52 ± 0.02
Test Day 3	1.84 ± 0.06	2.15 + 0.07	0.58 ± 0.04	2.41 ± 0.08	2.72 ± 0.09	0.53 ± 0.03
Test Day 4	1.83 ± 0.05	2.13 + 0.07	0.60 ± 0.05	2.47 ± 0.08	2.76 ± 0.09	0.53 ± 0.03
Test Day 5				2.46 ± 0.08	2.57 ± 0.09	0.50 ± 0.02
Test Day 6				2.44 ± 0.07	2.73 ± 0.09	0.53 ± 0.03

Definition of abbreviations: FVC = forced vital capacity; FEV_1 = forced expiratory volume in one second; $\alpha_1(\infty)$ = mean transit time of the untruncated spirogram.

*Results are mean values ± SEM.

SOURCE: Buist, *et al.*[7]

heavily ash-exposed jobs (cutting, rigging, yarding—Figures 7 and 8) were purposely overrepresented in the study groups. Initial testing was done in June 1980 and consisted of pulmonary function tests (flow-volume curves) for measurement of FVC, FEV_1, FEV_1/FVC, and flows at 5 per cent intervals of FVC; standard antero-posterior 14" × 17" chest roentgenograms; venous blood for measurement of immunoglobulins and complement factors C_3 and C_4; a standardized respiratory symptom questionnaire; and air-sampling using personal (breathing-zone) samplers to measure respirable and total dust exposures (Figure 9). In addition, both in June and in September 1980, a study was carried out to obtain information about shift-related changes (AM to PM) in lung function among cutters many of whose within-shift exposures to respirable and total dust/ash were measured by personal samplers.

The airborne concentrations of respirable dust (geometric mean) in June for those in the Washington logging areas with the most ash were 900 and 280 μg/m³ for the cutting and rigging crews, respectively. In September 1980, the levels were 270 and 320 μg/m³, respectively. Assuming 6 per cent crystalline free silica in the respirable dust, persistent exposure at airborne concentrations greater than or equal to 833 μg/m³ would exceed the NIOSH recommended exposure limit (REL) for free silica of 50 μg/m³ for a 10-hour day or a 40-hour week.[12] Actual exposures were probably modified by the use of appropriate work practices and respiratory protection throughout the summer and fall of 1980. By occupational standards for exposure to crystalline free silica, these exposure levels are fairly low and one would have to consider the risk of silicosis due to the volcanic ash to be minimal. In

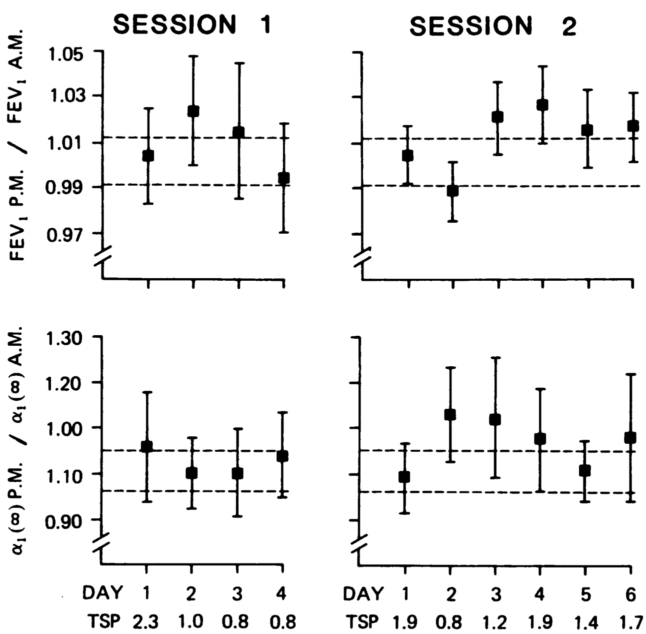

FIGURE 5—Daily 95% confidence intervals for PM/AM ratios of FEV_1 and mean transit time of the truncated spirogram, $\alpha_1(\infty)$, in 1980 based on the same children tested each day. Dashed lines indicate the corresponding 95% confidence intervals for a group of 53 children attending an ash-free camp in 1981. Total suspended particulate levels (mg/m³) are indicated for each observational day. **SOURCE:** Buist, *et al*,[7] with permission of author and publisher.

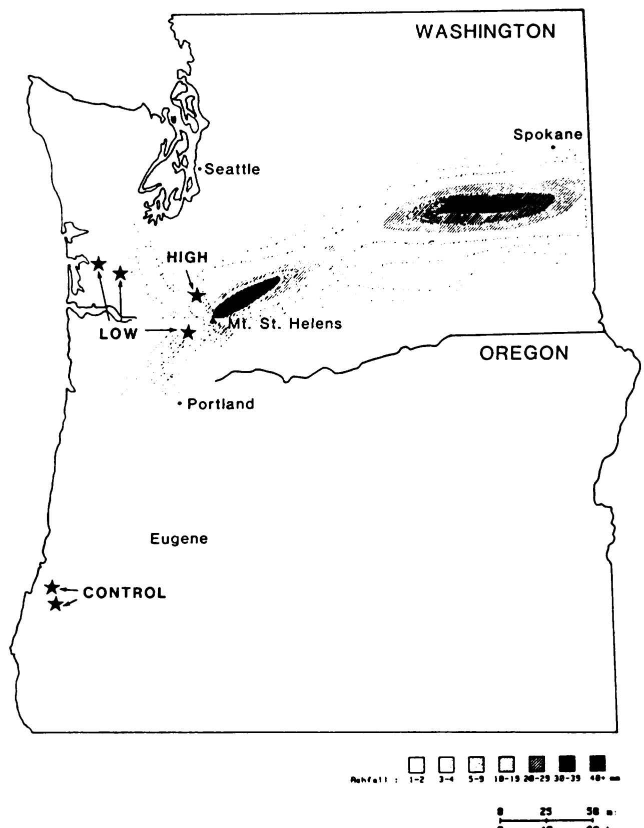

FIGURE 6—Map showing exposed/unexposed logging camp locations. **SOURCE:** Buist,et al.,[14] with permission of author and publisher.

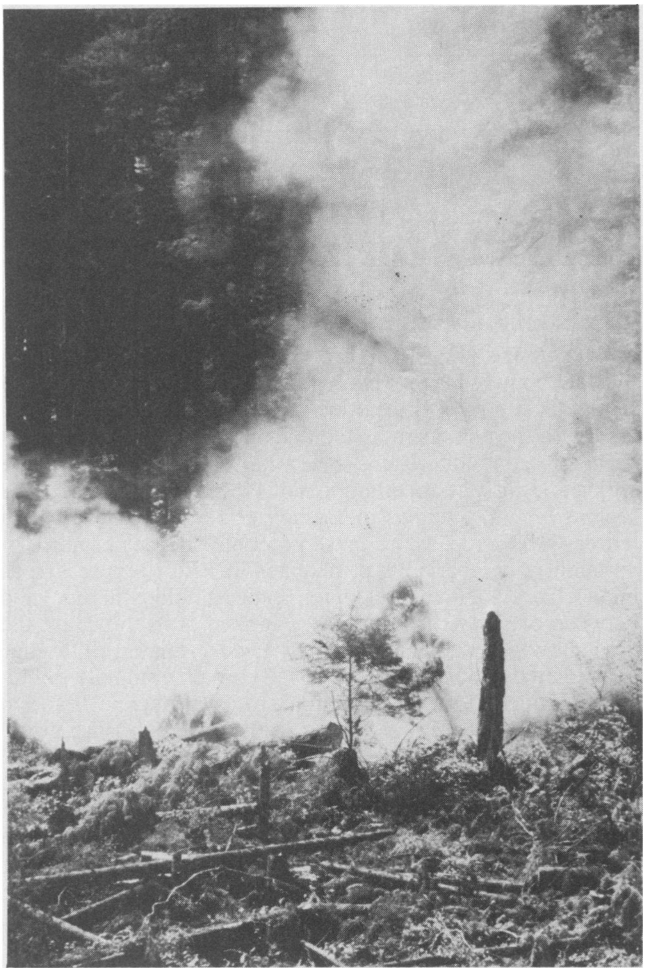

FIGURE 7—Ash cloud after a Douglas fir had been cut.

terms of any adverse effects, it therefore seems more appropriate to view the ash as a potential airways irritant.

In June 1980, acute respiratory symptoms, eye irritation, and headache were significantly higher among exposed cutters than among the non-exposed. By September 1980, there was no significant difference except for a persistent excess of eye irritation and headache among exposed cutters. There were no significant differences in the occurrence of acute (shift-related) or short-term (June vs September) changes in lung function between exposed and non-exposed camps as a whole, although those loggers working closest to the mountain did show a significant decline in both FEV_1 and FVC from June to September. There were no correlations of lung function changes over 8-hour shifts with respirable dust concentrations in either June or September. There was also no evidence of exacerbations of pre-existing chronic respiratory disease among those who were seen in June and September.[8]

FIGURE 8—A logging road just above 19-mile camp in the blow-down zone of Mount St. Helens. Thick layer of ash covers everything. Tree stumps and snags are a result of the May 18, 1980 blast.

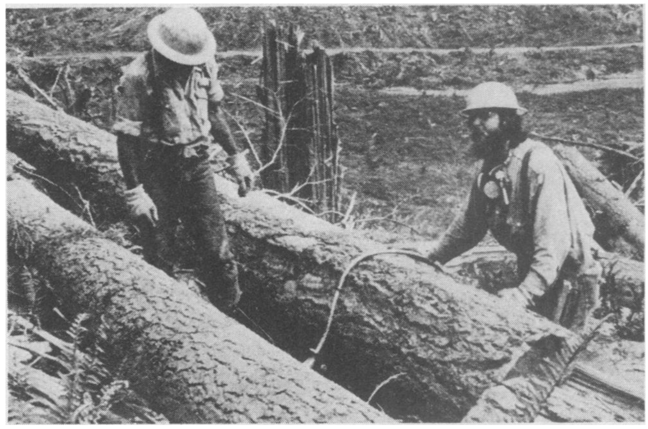

FIGURE 9—Two cutters "bucking" a tree into lengths for transportation. Cutter on the right is wearing a personal air sampler (intake pinned to his collar) to measure ambient levels of total and respirable particulates.

Analysis of complement factors C_3 and C_4 and immunoglobulins in the loggers by Olenchock and coworkers[13] revealed that C_3 and C_4 levels were significantly lower both in June 1980, and in July 1981, in exposed loggers when compared to the control group (Tables 4 and 5). There were no differences between groups either in June 1980, or in 1981 for immunoglobulin or antinuclear antibody levels. The exposed loggers did show a marked decrease in serum IgG in 1981, following a year of exposure to the volcanic ash. This was not seen in the control group. There was also a significant mean increase in IgA in the exposed group in 1980, not seen in the control group. These observations are hard to interpret. The authors speculate cautiously that the ash that was inhaled and swallowed may have preferentially stimulated the mucosal and secretory (IgA) immune system, thereby raising the IgA levels. They suggest that the reduced IgG levels may have resulted from selective adsorption of IgG by volcanic ash or as a result of interference by the volcanic ash with the antigen-processing and presenting functions of the alveolar macrophage. Whatever the explanation, these observations are interesting and merit further investigation. Since blood was not obtained in the follow-up study (in order to minimize invasive procedures), we unfortunately do not have any information about the more long-term effects of volcanic ash exposure on immunoglobulins.

The logger study has been continued as a cohort study by investigators at the Oregon Health Sciences University with the continuing technical support of NIOSH and funding through the Centers for Disease Control (CDC).[14] This study is described below in more detail.

TABLE 4—Serum C3 Levels in Matched Populations of Loggers from 1980 and 1981

Group	1980 (mg/dl)[a]	1981 (mg/dl)[a]	Significance
Exposed (N = 400)	89.5 ± 0.7	92.2 ± 0.9	$p < 0.01$
Reference (N = 185)	99.1 ± 1.5	106.9 ± 1.3	$p < 0.005$
Significance	$p < 0.005$	$p < 0.005$	

[a]Mean ± SE.
SOURCE: Olenchock, *et al*,[13] with permission of author and publisher.

TABLE 5—Serum C4 Levels in Matched Populations of Loggers from 1980 and 1981

Group	1980 (mg/dl)[a]	1981 (mg/dl)[a]	Significance[b]
Exposed (N = 400)	24.0 ± 0.4	23.8 ± 0.4	NS
Reference (N = 185)	26.5 ± 0.5	26.0 ± 0.6	NS
Significance[b]	$p < 0.005$	$p < 0.005$	

[a]Mean ± SE.
[b]NS = not significant.
SOURCE: Olenchock, *et al*,[13] with permission of author and publisher.

Studies of Long-term or Chronic Effects

Long-term studies are logistically difficult and inherently expensive because they entail the maintenance of a cohort over an extended period of time. The logger study, described above, was chosen as the most cost-effective group to follow because reliable data had been obtained soon after the eruption and soon after the workers had started working regularly in the ash, and because limited resources made it highly desirable to study a group with a reasonably high ash exposure. If no effect was seen in this group, it seemed reasonable to conclude that it would be even more difficult to find an effect in groups of individuals with lower exposures. It was thought that the study probably would be able to answer the question of the effect of acute or long-term ash exposure on individuals with pre-existing lung disease because there would be such individuals (e.g., cigarette smokers with chronic bronchitis) included in the study. However, it was soon realized that this study of loggers engaged in physically demanding work would not be able to answer the question of the effect of ash exposure (either acute or long-term) on the elderly or chronically ill who might have a number of coexisting health problems.

Both the exposed group and the control group were followed with annual testing from 1980 through 1984. To minimize the contribution of seasonal effects to the variability of lung function measurements, each year's testing was carried out between June and September. The five-year study included four or five measurements of pulmonary function and respiratory symptom questionnaires for 73 per cent of the loggers. Blood was drawn in 1980 and 1981 and chest roentgenograms were obtained in 1980 and 1984. Data are presented here in preliminary and summary form.

Preliminary analysis of the longitudinal data suggests that loggers working in ashfall areas experienced a short-term, reversible decline in lung function consistent with an exposure-related effect of volcanic ash. The main outcome variable used was the FEV_1 which provides a measure of airflow obstruction. This transient decline was greatest in both magnitude and duration for those loggers working in the immediate vicinity of the Mount St. Helens blast zone (and thus experiencing the most intense and frequent chronic ash exposure). Figure 10 presents the longitudinal FEV_1 data, adjusted for both age and height, for those loggers tested at each visit. The 1983 data for the low-exposure group is based on only 65 subjects since two of the three low-exposure camps were not tested that year. All three groups, including the control loggers, had abnormally steep declines in FEV_1 from 1980 to 1981, followed by increases from 1981 to 1982 and from 1982 to 1983. After this point, the data again began to decline. While the overall pattern was very consistent with the hypothesis of a short-term, reversible ash effect, the fact that the control loggers evidenced the same trend indicates that at least part of the pattern was due to factors unassociated with the ash, such as technician variability, equipment variability, and differences in weather. For example, the late spring and early summer months of 1980 were very wet in the regions tested, whereas the same period in 1981 was much hotter and drier. Despite these potential sources of noise or variability, comparisons of changes in FEV_1 (expressed as ml/yr) from 1980 to any given year should still be valid between exposure groups. When looked at in this way, the data show a statistically significant, dose-related difference between the exposure groups in 1981 which gradually diminished through 1984. For example, rates of decline between 1980 and 1981 were −186 ml/yr in the high exposure group and −133 ml/yr in the control group, whereas by 1984 these rates of decline were −64 ml/yr and −46 ml/yr, respectively.

We found a similar pattern when we compared the prevalence of respiratory symptoms over time. As seen in Figures 11 and 12, reported prevalence rates of cough and/or phlegm and wheezing increased sharply through 1983 for the high-exposure loggers. The pattern was less clear for low-exposure loggers, although their rates do show a peak in 1982. By contrast, the reported prevalences among control loggers remained very stable over time. While these prevalence rates are subject to reporting bias, they have been shown over the years to be fairly robust measures of risk for pulmonary impairment and related mortality on a population basis.[16] The fact that they corroborate the findings from the spirometric data also support their validity.

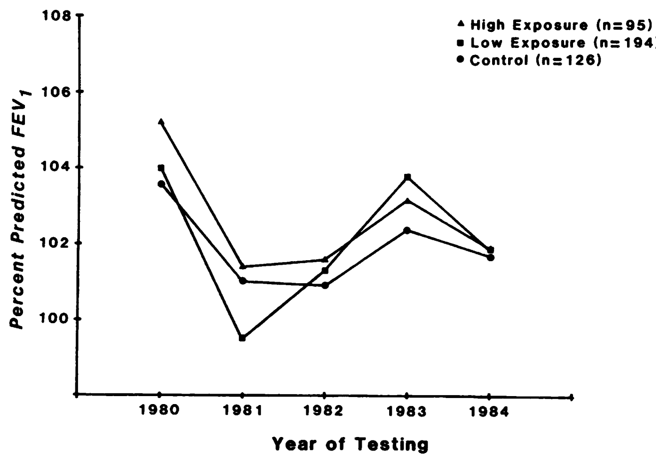

FIGURE 10—Per cent of predicted FEV_1 for loggers tested each year. The 1983 low exposure point is based on only 65 subjects since two of the exposed logging camps were not tested that year.
SOURCE: Prediction equations were derived from Knudson, *et al.*[15]

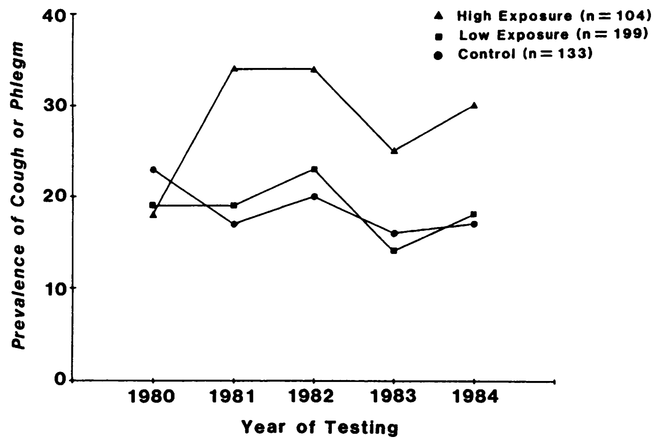

FIGURE 11—Reported prevalence of cough and/or phlegm for three months of the year for loggers tested each year. The 1983 low exposure point is based on only 66 subjects since two of the exposed logging camps were not tested that year.

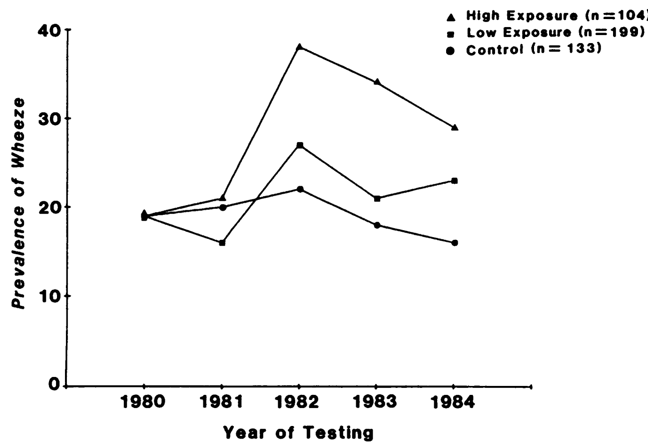

FIGURE 12—Reported prevalence of wheeze for loggers tested each year. The 1983 low exposure point is based on only 66 subjects since two of the exposed logging camps were not tested that year.

No chest X-ray changes that are likely to have been ash-related were observed over the four-year interval. This is not surprising since bronchitic changes are not usually detectable on chest roentgenograms and fibrotic changes (if they were going to occur) would probably take many more years of exposure to develop to a point at which they were detectable on a chest roentgenogram.

A more detailed analysis of this data set is presently underway. We do not, however, expect to alter our conclusion that chronic exposure to low airborne concentrations of volcanic ash may lead to reversible changes in pulmonary function and other respiratory complaints. Again, we would emphasize that since this study involved a working (and therefore largely healthy) population, it may not be valid to extend our findings to other groups, e.g., the elderly and chronically ill.

The changes we observed (a slight decrease in FEV_1 and an increase in respiratory symptoms) are consistent with the hypothesis that the ash acted as a nonspecific irritant on the airways, leading to an increase in the amount of mucous produced by the mucous glands, and perhaps to inflammation. We have no evidence that the exposures resulted in any fibrosis, although, as emphasized above, the process of fibrosis probably takes many years to become detectable by roentgenographic or pulmonary function studies.

What We Have Learned

The studies that have been carried out to try to answer the questions of the acute and chronic effects of exposure to volcanic ash have provided important new information which is mostly reassuring. It has been interesting to watch the answers from the animal studies and the human studies converge and provide more or less the same conclusions (see chapter 7). There are still some unanswered questions which are discussed below in the next section. However, from the available information, it is probably fair to conclude that at low to moderate concentrations, the ash appears to act as an irritant. In all likelihood, the exposures that are most commonly experienced after a volcanic eruption, similar to that of Mount St. Helens, are going to be too low to pose a serious threat for the development of silicosis or "pneumo(vol)coniosis" (the shortened form of the word "pneumonoultramicroscopicosilicovolcanoconiosis" coined by Francis Xavier in 1936). A more complete summary of what we have learned is as follows:

Acute Effects

On the Eye—

- Volcanic ash is irritating to the eyes and can cause transient hyperemia and conjunctivitis. These soon resolve when the individual is no longer exposed to the ash. Irrigation with water helps to mechanically remove the ash.
- Volcanic ash may be a particular problem in contact lens wearers; persons with hard lenses are more affected than those with soft lenses.

On the Upper and Lower Respiratory Tract—

- In extremely high concentrations (e.g., in the path of a pyroclastic flow or near the volcanic vent during an ashfall), volcanic ash may cause severe tracheal injury, pulmonary edema, and bronchial obstruction leading to death from acute pulmonary injury or from suffocation.[1,17]
- On the upper respiratory tract, volcanic ash causes nasopharyngeal irritation and nasal stuffiness.
- On the lower respiratory tract, volcanic ash probably acts as a nonspecific particulate irritant stimulating cough, phlegm production, and chest tightness.
- Volcanic ash has no measurable effect on lung function in children at relatively low levels of exposure for which data are available.

Long-Term or Chronic Effects

On the Eye—

- No chronic effects of volcanic ash on the eye have been documented.

On the Respiratory Tract—

- Irritation and inflammation of the upper and lower respiratory tracts continue while low-level chronic exposure continues or after intense short-term exposure.[8]
- With low-level exposures, there is a slight decrease in FEV_1, probably due to increased mucous production and possibly to inflammatory changes in the small and medium-sized airways.

Unanswered Questions

The studies described above that have involved groups exposed to varying levels of airborne resuspended volcanic ash have provided some reassuring answers to the fundamental questions about the potential risk attached to living and working in an ashfall area. The answers obtained so far are reassuring because they provide evidence that the effects of low-level exposures to ash on the eyes and on the respiratory tract are probably temporary and probably mostly inflammatory in nature. It must be stressed, however, that these conclusions are based on the subjective appreciation and reporting of respiratory symptoms and on pulmonary function tests. They are not based on structure-function correlation studies since tissue (except for eye scrapings) has only been available from a few hospitalized victims and autopsy studies, not from large numbers of survivors, or the subjects participating in these studies.[1,17] The conclusions may be biased because of errors in the reporting of respiratory symptoms and because the lung function tests used may not be sensitive enough to detect subtle and relatively minor changes in lung function. Also, it is conceivable that relatively modest exposures over a period of four years may have initiated a chronic process, such as interstitial fibrosis, which takes many years to develop and which is impossible to detect in the early stages. We consider that this possibility is extremely remote for the following reasons:

- An interstitial lung disease, such as silicosis, usually requires a consistent heavy exposure over two to three decades. There have been no exposures of this magnitude anywhere in the world as a result of volcanic eruptions, although "liparosis" (an occupational lung disease associated with exposure to volcanic pumice) may be an exception.[18]
- After four years of exposure, the changes in lung function are in the direction of a very mild *obstruction* to airflow, probably due to increased mucus or inflammation, and not restriction of the lung, due to fibrosis.

The question of whether there is a subset of the population which is at increased risk for the development of pulmonary-related problems when exposed for a short or long period to inhaled volcanic ash has not been answered. There are numerous case reports and epidemiologic surveys which suggest that persons with chronic obstructive pulmonary disease (COPD) and asthma are adversely affected,[19–22] presumably because they already have airflow obstruction and any further narrowing of their airways is likely to have an exaggerated effect.

The human studies have not been able to provide an answer to the question of whether acute and/or chronic exposure to inhaled volcanic ash affects the reactivity of the airways. This is a very important question because increased airway reactivity is associated with an increase in morbidity[5] and with an increased rate of decline of lung function[23–25] and may increase an individual's susceptibility to the development of COPD.[24,25] Unfortunately, at present, there is a real lack of good information about what factors turn on and turn off airway reactivity. Studies carried out on guinea pigs[26] and on rat tracheal tissue[27] have attempted to address the question of the effect of inhaled volcanic ash on airway reactivity and are discussed in chapter 7.

The question of whether long-term exposure to inhaled volcanic ash causes chronic bronchitis has not yet been answered satisfactorily because the follow-up time for the cohorts of loggers under study has been insufficient. If one can extrapolate from occupational studies, it is conceivable that volcanic ash, like other occupational dusts, can result in a chronic or "industrial" bronchitis.[28,29]

In view of the dearth of information currently available on the long-term health effects of exposure to volcanic ash, continued surveillance of population groups who live and work for many years in ashfall areas is recommended. Special attention should be paid to the identification of subgroups of these populations who are at increased risk by virtue of their age (the very young and elderly), their health status, or because their exposures are particularly high.

In summary, despite certain gaps in the knowledge that has been gained from the studies done in the aftermath of Mount St. Helens and following previous major volcanic eruptions, we can be confident that the health effects of both short- and long-term exposures to the relatively low levels of airborne volcanic ash that are typical following such a volcanic eruption are minor. These effects seem to relate more to the irritating effect of the ash on mucous membranes and airway epithelia than to the potential of the ash (due to its free crystalline silica content) to initiate a fibrotic response. Nevertheless, common sense dictates that exposures should be minimized whenever possible by use of appropriate preventive measures, such as wetting the sedimented ash before disturbing it, and using commercially available disposable paper masks meeting NIOSH code TC-23 for dusts for light exposures and industrial half- or full-faced "respirator" and goggles for more extensive and heavy exposure.

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