CHAPTER 3

Immediate Public Health Concerns and Actions in Volcanic Eruptions: Lessons from the Mount St. Helens Eruptions, May 18–October 18, 1980

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Introduction

Before the eruptions of Mount St.Helens in 1980, little information was available in the clinical and environmental science literature on the health effects of volcanic eruptions.[1,2] Some studies of volcanic hazards had been published in the literature of a variety of other disciplines (e.g., geology, sociology, psychology, and ecology)[3–6]; others were never published. Furthermore, despite the fact that Mount St. Helens was well known to earth scientists as the most active and dangerous volcano in the Cascade Range,[7] there had been no explosive volcanic eruptions in the United States since 1914 (Mount Lassen), none at Mount St. Helens for more than 125 years, and no historical record of any fatalities due to explosive eruptions in the sparsely populated volcanic regions of the west coast of the United States and Canada.[8]

Thus, when Crandell, *et al*, predicted in *Science* in 1975 that Mount St. Helens, last active for a 27-year period from 1831 to 1857, "will erupt again—perhaps within the next few decades,"[7] it was not too surprising that their report did not galvanize the local public health community.

After hazard prediction maps and disaster contingency recommendations were published in even more detail in a US Geological survey (USGS) Bulletin in 1978,[9] several local and state agencies did review and update their contingency plans for flood warning and evacuation, triage of mass casualties, and search and rescue operations. However, there was no apparent recognition of the desirability of coordinated predisaster consultation and planning for disaster response activities among government officials and technical experts in the psychosocial, geological, and biomedical sciences together with law enforcement officials and public health and safety officials.

As it turned out, the USGS volcanologists had been able to predict with considerable accuracy the types and geographic distribution of the principal safety hazards which ultimately resulted from the May 18 and subsequent eruptions of 1980. Unfortunately, they were unable to predict the precise times of onset or duration of any of the six major eruptions and they did not forecast the lateral direction and magnitude of the May 18 explosive blast and ashfall, or the earthquake and landslide which preceded it.[10]

As a result, the May 18, 1980 eruption of Mount St. Helens caught volcanologists, government officials, and others largely unprepared for the nature and magnitude of its impact. Similarly, government- and university-based scientists were unprepared for the unprecedented and rapidly perishable opportunity to address various research needs concerning the evaluation and control of adverse health effects of explosive volcanism.

In this chapter, we provide a chronology of events leading to the May 18 eruption and a description of the impact of the ashfall on local communities which led to state and federal requests for epidemiologic assistance from the Centers for Disease Control (CDC). Following that, we describe the formation and actions of a coordinated state and federal disaster response effort to develop accurate information about volcanic hazards and to recommend methods for prevention or control of adverse effects on safety and health. The purpose of this chapter is to provide a case study of the descriptive epidemiology of a major natural disaster. By studying the events preceding and resulting from the Mount St. Helens eruptions, high-risk communities in North America and elsewhere may be better able to address the issues concerning evaluation and control of adverse health effects of explosive volcanism and volcanic ash.

Chronology of Events and Response

Federal/State Responses

Premonitory activity began at Mount St. Helens on March 20, 1980, with an earthquake measured at 4.1 on the Richter scale. Earthquakes continued with increasing frequency until the first of a series of minor explosive eruptions occurred on March 27. Harmonic tremors, seismographic evidence of the movement of molten rock beneath the mountain, began to occur on April 3 a few days after it was noted that an area on the north side of the summit had begun to bulge ominously by as much as 1.5 m a day. By May 18, this deformation caused upward and outward displacement of up to 98 m per day and measured 1.6 by 1 km.

At 8:32 am on Sunday, May 18, a major earthquake, 5.0 on the Richter scale, caused the roof of the bulge to slide downhill, thereby permitting an estimated 50 billion liters of superheated water to expand into steam and escape in the form of an explosive blast directed toward the north. Fortuitously, hundreds of loggers who would have been authorized to be working within the area that was devasted were spared because the eruption occurred on a Sunday.[10]

Following the catacylsmic lateral blast of May 18, 1980, there were five additional major explosive eruptions (May 25, June 12, July 22, August 7, and October 16–18, 1980) and several non-explosive, "dome building" eruptions. Ashfalls of up to 70 mm or more in depth from four of the explosive eruptions were deposited by prevailing winds in sparsely populated areas to the north and east, while the ashfall of up to 10 mm from one blast and another of up to 5 mm were blown toward more populated centers to the west and southwest, respectively (Figure 1). The remaining 2.5 km of the volcano's cone provided an important "stack" effect in dissipating volcanic gases[11] (principally SO_2) which decreased gradually from the initial daily rates of more than 1,000 tons.[12,13] Within hours of the eruption, it was clear that mudflows were likely to cause flooding and blockage of waterborne transport downstream from the volcano.[10,14(12)]* In communities affected by heavy ashfalls, the mineral dust

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

*Parenthetic superscript numbers refer the reader to the numbered CDC reports within reference 14.

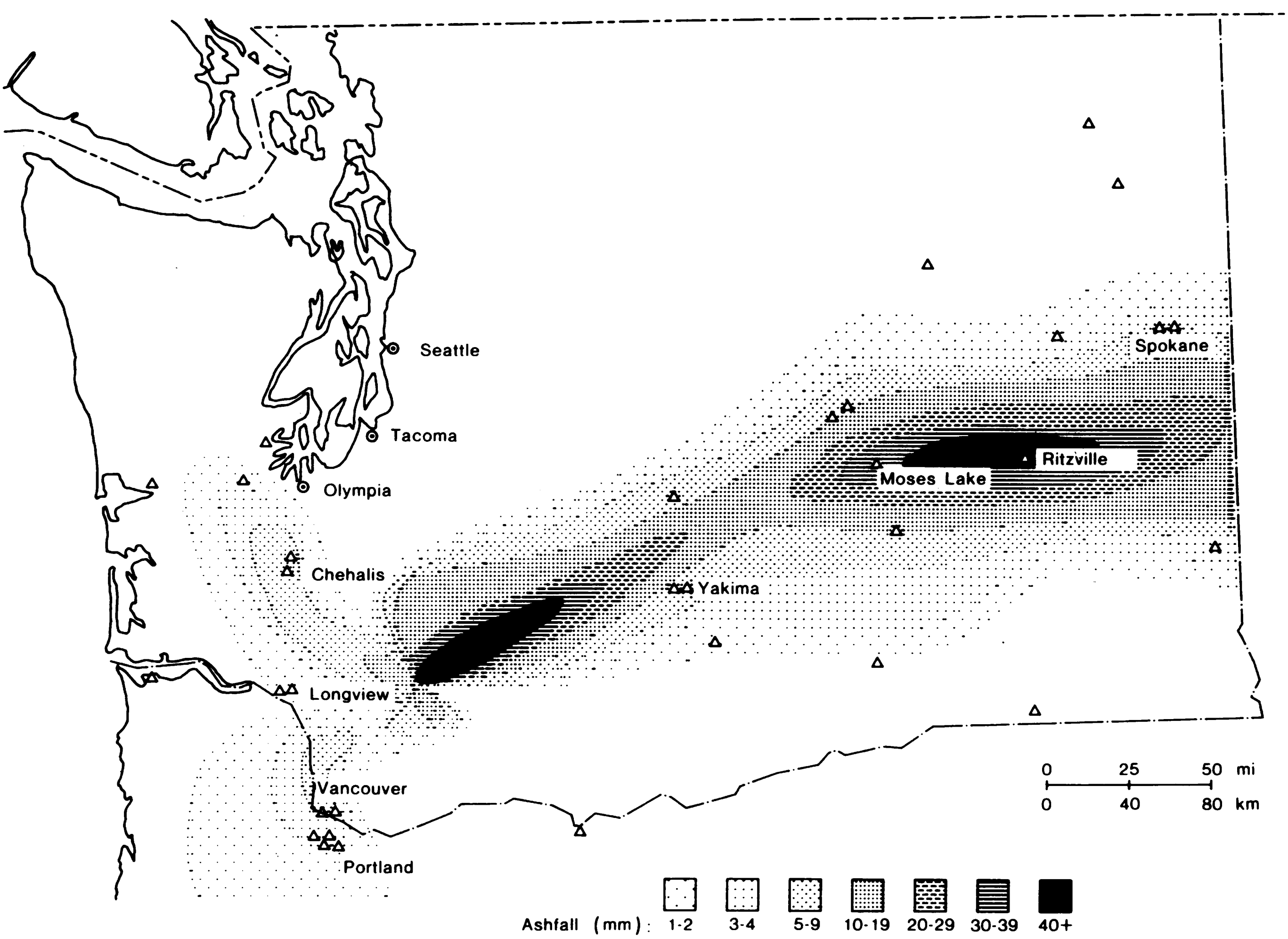

FIGURE 1—Ashfalls after first three major eruptions of Mount St. Helens and locations of Washington and Oregon hospitals under Centers for Disease Control surveillance. Ashfall paths: May 18, 1980, northeasterly affecting Yakima, Ritzville, and Spokane, Washington; May 25, northwesterly affecting Chehalis and Centralia, Washington; June 12, southwesterly affecting Vancouver, Washington and Portland, Oregon.

SOURCE: US Geological Survey professional paper #1250. Reprinted with permission from the *Journal of the American Medical Association*.[26]

was inadvertently washed into water treatment plants where it occasionally overburdened filters and damaged machinery.[14(4,5,9,10,12)]

As one would expect, there were widespread and significantly adverse socioeconomic effects due to the mudflows and resultant flooding in local communities.[15–21] However, the question most often posed to physicians and public health officials was, "Is the volcanic ash harmful to health?"[22,23]

On May 19, 1980, State Health Department officials in Idaho telephoned the Center for Environmental Health (CEH) at CDC requesting information on the health effects of volcanic ash because of widespread public concern over the recent ashfalls. As a result, on May 20, 1980, environmental health scientists from CEH and the National Institute for Occupational Safety and Health (NIOSH), CDC, met with officials from the Federal Emergency Management Agency (FEMA), Environmental Protection Agency (EPA), USGS, United States Forest Service (USFS), National Oceanographic and Atmospheric Administration (NOAA), and the National Weather Service, as well as other concerned federal agencies, to assess the apparent disaster in the northwest. It was subsequently learned that from May 18 through May 21 the 24-hour average concentrations of total suspended particulates (TSP), monitored by EPA's roof-top air monitoring stations in Yakima and Spokane, Washington, and Coeur d'Alene, Idaho, persistently exceeded the "warning levels" (625 $\mu g/m^3$) of EPA's National Ambient Air Quality (NAAQ) Standards for TSP derived from fossil fuel pollutants (see Table 1).[14(3,4,9),24,25]

On May 21, 1980, at the request of the State of Washington, the President declared the State a disaster area. The State Health Officer had already requested epidemiologic assistance from CEH and NIOSH, CDC. As a result, between May 21 and September 13, 1980, more than 30 CDC professionals—including medical epidemiologists, industrial hygienists, engineers, statisticians, nurses, technicans, and interviewers—conducted field studies and provided technical consultation to state and federal agencies in Washington and Oregon, while others were engaged in laboratory studies and support activities at CDC facilites.[26–30]

Community Response to Public Health Concerns

In Yakima, a town of more than 50,000 residents in an irrigated desert valley approximately 135 km northeast of Mount St. Helens, 24-hour average concentrations of TSP during the week after the May 18 eruption persistently

TABLE 1—Results of Environmental Protection Agency (EPA) Air Monitoring for Total Suspended Particulates (TSP) Before and After the May 18 Eruption, 24-Hour Average Concentrations (ug/m³), Yakima, Washington, 1980*

Before May 18	On May 18	May 19–May 25	On May 26	May 27–June 11
≤50	33,400	5,800–13,000	250	50–250

*In the early morning of May 26, a prolonged and heavy rainfall occurred in the town of Yakima. Ashfalls from the major eruptions of May 25 and June 13, 1980, were deposited to the west and southwest of Mount St. Helens, respectively (i.e., in the opposite direction from Yakima).[14] (3, 4, 9) The EPA Action Levels for 24-hour average concentrations of TSP, derived from the combustion of fossil fuel pollutants, are: Alert, 375 ug/m³; Warning, 625 ug/m³; Emergency, 875 ug/m³; and Significant Harm, 1000 ug/m³.[25]

exceeded the EPA "significant harm" (1000 μg/m³) NAAQ Standards designed for monitoring and control of fossil fuel air pollution (see Table 1). The air quality problem was exacerbated by continual resuspension of sedimented volcanic ash by wind or by automobile traffic.

Yakima residents and public health officials were caught unprepared for the eruption, the ashfall, and the total darkness which engulfed the town by late morning. They were alarmed by the irritant effects of the ash on the eyes and respiratory tract and worried about the possible adverse effects on water quality, agricultural products, farm animals, and machines.[10,16,17] Furthermore, the ash, which smelled of sulfur, severely limited visibility and led to motor vehicle accidents.[14(5,14)]

Every able-bodied person was mobilized to clean up the ash, using wetting methods to reduce the resuspension of dusts and improvising makeshift masks of every sort—including wet or dry cloths, surgical masks, disposable industrial masks, and elaborate filtered- and supplied-air respirators—to reduce the concentration of inhaled particles.[10]

Throughout the week from May 18–26, volcanic ash fell in Washington and Idaho on a total area containing more than a million people, many of whom sought advice from physicians and public health officials. The most commonly expressed concerns were about the short- and long-term hazards of inhalation of ash, ingestion of ash-contaminated food and water, and appropriate and effective methods of protection.

A team of CDC, state, and university-based environmental health scientists visited Yakima on May 25–26, guided to the town by local officials through a blinding dust storm. Discussions with emergency room physicians and preliminary reviews of hospital records confirmed news reports and passive surveillance data concerning apparent increases in respiratory morbidity. These findings suggested the need for detailed epidemiologic surveillance and epidemic field investigations (as outlined in Table 2).[31] On May 26, a steady rainfall in the Yakima area brought relief by purging the air of ash and aiding cleanup operations; however, concerns about the effects of volcanic ash on public health remained. Accordingly, refinement of the epidemiologic surveillance system and organization of more detailed studies were rapidly accomplished as described below.

TABLE 2—Outline for Epidemic Field Investigations of Suspected Outbreaks

1.	Confirm Epidemic Occurrence and/or Distribution Cases • Review medical records and available epidemiologic surveillance data • Discuss with federal and state or local public health investigators
2.	Verify Diagnoses of Index Cases • Examine patients and medical and laboratory reports, if possible • Discuss diagnostic criteria with reporting health professionals
3.	Develop Standardized Case Definition(s) • Define criteria for definite, probable, and suspect cases • Include clinical, laboratory, and epidemiologic criteria • Characterize potential etiologic exposures by quantitative measures
4.	Seek and Investigate Additional Cases (Numerator Data) • Ask index cases about other affected individuals • Establish a "hotline" telephone number, using public media • Review records of hospitals and physicians in expanding circle • Conduct surveys of affected communities or workplaces
5.	Develop a Rough Case Count and Line-Listing of Descriptive Data
6.	Orient the Descriptive Data on Cases by Person, Place, and Time • Prepare an epidemic curve and other graphic representations of data
7.	Determine Who is at Risk of Becoming Affected (Denominator Data)
8.	Develop an Etiologic Hypothesis and Appropriate Statistical Methods for Testing its Validity • Consider opportunities for prevention and/or control • Explain source and mode of transmission of putative agent(s)
9.	Analyze Descriptive Data: Compare the Hypothesis with Established Facts • Identify possible host-related and environmental risk factors • Identify possible sources, reservoirs, vectors, and agents
10.	Implement Interim Control Measures and Refine Epidemiologic Surveillance
11.	Analyze Surveillance Data and Conduct Additional Studies as Necessary • Refine case definition(s) and case-finding procedures • Determine the need for case-control or longitudinal studies • Identify a suitable reference or comparison population
12.	Prepare and Disseminate Timely Reports of Findings and Recommendations
13.	Evaluate the Effectiveness of Control and/or Prevention Measures
14.	Develop and Implement Refined Control and/or Prevention Measures

State/Federal Disaster Response

It was immediately apparent after the May 18, 1980 eruption that a coordinated effort among many different agencies was necessary in order to protect the public's health and safety.[32–38] State public health officials were presented with important problems of identifying, evaluating, and controlling a unique new set of acute health and safety hazards. Simultaneously, there was the opportunity to carry out applied and basic science research to identify and control the potential adverse chronic health effects associated with the eruption. Furthermore, it was likely that the explosive activity would continue intermittently, perhaps for years,[7–9] and valid and reliable data were needed to provide timely advice to clinicians and the public on the nature and prevention of hazardous exposures. In view of the limitations on human and technical resources available at the local and state

TABLE 3—Concerns and Actions of Public Health Agencies Following the May 18, 1980 Eruption of Mount St. Helens

State Health Departments' Concerns About Needed Actions	Federal and State Public Health Agencies' Coordinated Responses to These Concerns
1. Assessment of potential health impact and recommendations about prevention and control.	Rapid establishment of community-based active surveillance system for cause-specific increases in emergency room visits and hospital admissions.
	Epidemic field investigations of suspected eruption-related outbreaks.
	Assessment of factors associated with death or survival with and without injuries for persons within 40 km of Mount St. Helens' crater, May 18, 1980.
	Initiation of cross-sectional, case-control, and longitudinal studies of adverse respiratory effects among high-risk (hypersusceptible or heavily exposed) groups.
	Laboratory studies of the toxicity of volcanic ash by *in vitro* and *in vivo* methods.
2. Restricted areas—designation and enforcement near Mount St. Helens, for the general public and for logging operations.	Continuous reassessment of restricted area boundaries, nature of restrictions, and risk factors for adverse effects.
3. Public warning system—premonitory events, eruptions, or adverse secondary events such as floods, mudflows, or ashfalls requiring evacuation or other priimary preventive measures.	Review of literature concerning volcanic hazards effects on public health and safety.
	Dissemination of accurate public health information, including investigation and control of rumors, in coordination with officials from local, state, and federal agencies, and private institutions.
4. Air monitoring—nature and concentration of respirable and/or total suspended particulates in ashfall areas, determination of sampling methods and locations, and interpretation of data.	Systematic collection and analysis of sedimented and airborne volcanic ash and estimation of human exposures in environmental and occupational settings.
5. Protection of drinking water systems located downstream from sewage treatment plants operating in a bypass mode due to ash sediment.	Systematic collection and analysis of waterborne concentrations of ash leachates and evaluation of the chemical and biological quality of drinking water supplies.

levels, requests for federal epidemiological assistance were met with appropriate responses (Table 3).

The US Public Health Services is one of the leading Federal agencies to respond to emergency preventive health needs resulting from natural and man-made disasters. In this capacity, CDC provides epidemiological and technical health-related assistance to other federal agencies and to state health departments upon request. By providing assistance of this type, the CDC works to meet the goals of the Surgeon General for promoting health and preventing disease.[39]

Hospital-Based Surveillance Network

The main hospitals in affected areas of eastern, central, and western Washington State were coordinated in a systematic assessment of emergency room (ER) visits and hospital admissions for respiratory and other health and safety problems. This was done initially by active telephone surveillance of daily totals for selected cause-specific ER visits and admissions. Later, hospitals permitted CDC and state health department professionals to have access to hospital records for epidemic field investigations and detailed reviews of those patients attending the surveillance hospitals after April 1, 1980 (to provide some baseline, pre-eruption data on ER visits and admissions).[14,26]

As an example, a list of diagnostic labels and the number of patient visits to one of the ash-affected ERs is shown in Table 4. These surveillance data were the first to indicate potential eruption-related problems requiring epidemic field investigations by a team of state and federal public health professionals. Since these are numerator data and the numbers are generally small, it is important not to overinterpret any apparent increases or decreases in specific diagnostic categories (e.g., visits for ear problems and foreign bodies in the eyes) without first confirming the surveillance findings in other communities with comparable exposures or carrying

TABLE 4—Reasons for Emergency Room Visits in Moses Lake, Washington, by Week, May 4–31, 1980

Reason for Visit	5/4–10	5/11–17	5/18–24	5/25–31	% Change
Accidents/injuries, total	61	63	43	45	−29
Motor vehicle accidents	2	4	11	5	+117
Falls	1	3	6	3	+125
Other injuries	58	56	26	37	−45
Respiratory, total	8	9	27	21	+182
URI	1	1	6	9	+650
Pneumonia/influenza	0	1	1	1	+100
Asthma	2	1	8	5	+333
Bronchitis	2	2	3	4	+75
COPD/emphysema	2	2	3	2	+25
Other pulmonary	1	2	6	0	+71
Ear (otitis)	1	0	6	1	+600
Eye (foreign bodies)	9	8	9	6	−12
Psychiatric	3	1	3	0	−25
All others	125	140	212	152	+39
Overall Total	207	221	300	225	+23

*Per Cent increase or decrease in ER visits for May 18–31, 1980, compared with visits for May 4–17, 1980. The first volcanic eruption with ashfall in Moses Lake (30- to 70-mm depth) occurred on May 18, 1980.[14(5)]

out more detailed field studies. In Table 2, we have provided an outline of the procedures to be followed in such epidemic field investigations; these procedures are described in more detail elsewhere.[31,40]

The surveillance network proved valuable in several ways. It made possible the confirmation of physicians' impressions that there was no convincing evidence of excessive ash-related *mortality* in affected communities due to cardiopulmonary problems, traffic accidents, flooding, or other causes. However, transient increases in *morbidity* due to motor vehicle accidents and falls were seen in some communities affected by heavy ashfalls.

Undue anxiety did not appear to occur in excess nor did severe eye injuries, although ashfall-related visits for mild anxiety and eye injuries did occur.[14,41] The ability to detect subtle mental health effects was limited because data on such effects were collected in hospital ERs and not in community mental health facilities or by private mental health practitioners. Chapter 9 presents the results of a detailed community-based study of mental health effects.

No increases in communicable diseases were detectable, although delayed effects of the eruptions on the local ecology were subsequently associated with an outbreak of giardiasis.[42] It is not clear whether this represented a true outbreak or a pseudoepidemic due to the increased intensity and quality of surveillance activities.

Transient increases in ER visits for acute effects on the respiratory tract (primarily asthma and acute bronchitis) were consistently observed following ashfalls. These increases were significantly increased in affected communities of all sizes, not only in the smaller communities where doctors' offices were temporarily closed; ERs were the predominant resources for provision of medical services (Figures 2 and 3).[14,23,26]

The apparent absence of any excess of respiratory mortality due to the five-day period of extremely high levels of TSP may have been due to several factors: 1) the precautions taken by susceptible members of the community as a result of advisories from physicians and the Washington Lung Association to avoid exposure to the ash; 2) the relatively less severe adverse effects which may be experienced from exposure to high levels of TSP alone versus the combined effects of exposure to TSP, complex organic chemicals, and metal fumes in fossil fuel emissions; and 3) the limited sensitivity to detect such an excess by hospital-based surveillance data alone.[43–50]

Of course, a surveillance system is never completely accurate. There were several limitations to the surveillance system established in the week following the May 18, 1980 eruption of Mount St. Helens. For example, no pre-eruption plan had been prepared for standardizing data collection, for defining ash-related adverse respiratory effects,[51] or for routine recording of such information as occupation, smoking, and intensity, frequency, and duration of exposure to ash. In an ongoing surveillance system, it may be possible to make refinements which will provide more information about specific health and safety problems in relation to well characterized exposures to volcanic hazards.

However, it is the distribution and trends in reporting of diseases or injuries that, upon routine analysis of surveillance data, are most important.[35,52] Even if the surveillance system captures only a small proportion of the incident cases, as long as the system and the population at risk do not change substantially, it should provide reliable data about trends in the incidence of specific safety and health problems.

Public health officials can monitor these trends to determine the need for epidemic field investigations and more detailed epidemiologic studies to evaluate the effectiveness of various control measures. In the wake of the eruptions of Mount St. Helens, several types of epidemiologic studies were carried out to develop accurate information about risk factors for adverse effects on safety and health in volcanic eruptions. These are described below.

Assessment of Death or Survival Factors

Relatively low mortality—35 known deaths, and 23 missing persons presumed dead—has been associated to date with the initial and five subsequent explosive eruptions. Investigators from CDC reviewed the autopsy findings, investigated the circumstances surrounding the deaths, and interviewed 100 survivors to determine factors related to death or survival. Results are summarized in Table 5.**

All known deaths were directly attributable to the blast, pyroclastic flow, mudflows, and ashfall of the May 18 eruption. All but two of the 58 dead and missing had been in

**Previously unpublished data were provided in a personal communication from Drs. R. Ing., G. Rogers, J. Horan, and H. Falk, CDC, Atlanta, GA.

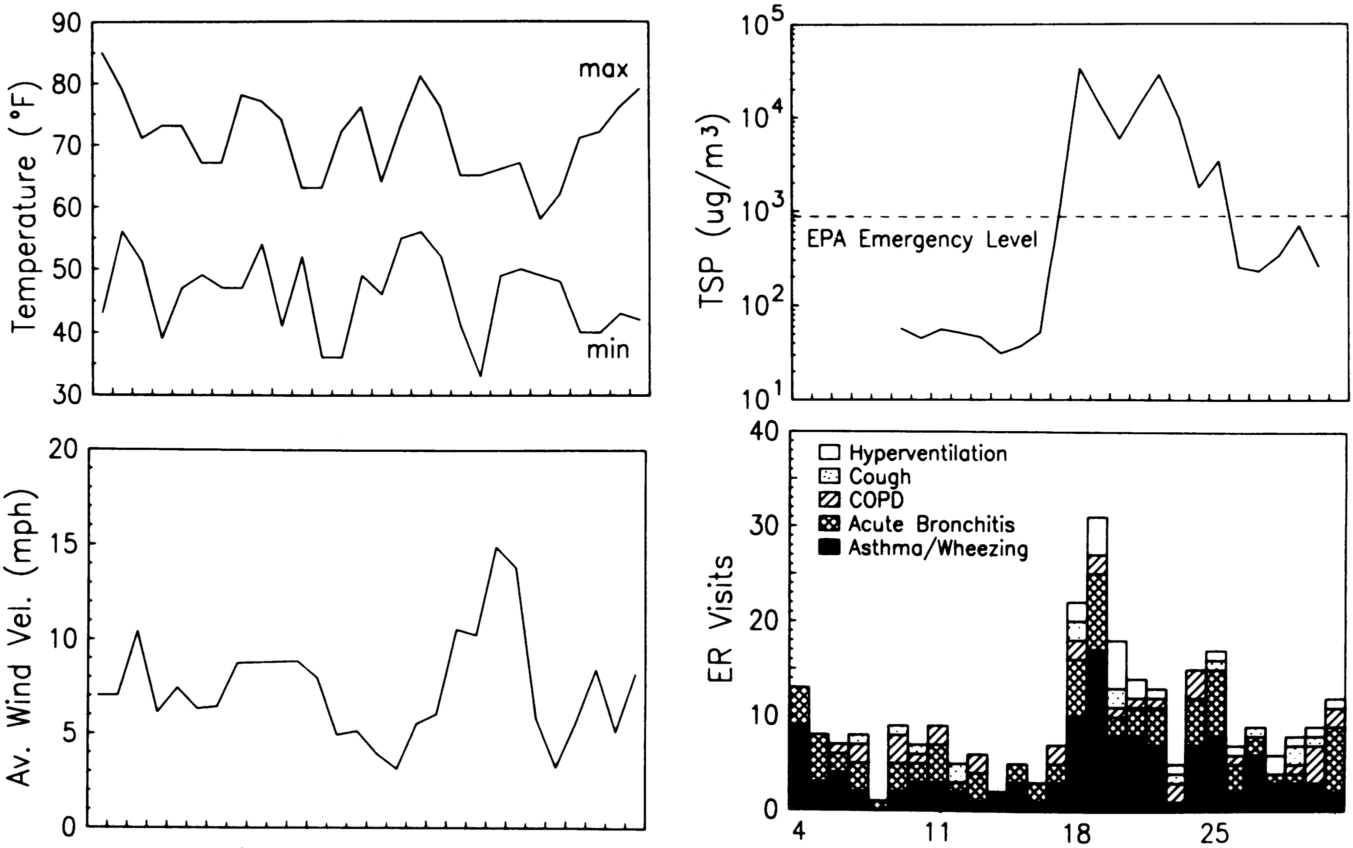

FIGURE 2—Daily temperatures (maximum and minimum), average wind velocities, 24-hour average concentrations of total suspended particulates (TSP) ($\mu g/m^3$), and number of emergency room visits due to asthma and bronchitis at the two major hospitals in Yakima, May 4 to June 2, 1980. The Environmental Protection Agency's Emergency Action Level for potential health problems due to increased air pollution (derived from the combustion of *fossil fuels*) is a 24-hour mean concentration of 875 $\mu g/m^3$ of TSP.
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the areas of blast, mudflow, tree blowdown, and tree damage which occurred within a wedge-shaped sector extending 10–19 km from the crater in a northerly direction (Figure 4 and Table 5).

Only 17 known survivors had been within the damaged areas, and all of them had been at the edge of the blowdown area or even farther away from the crater in the area of damaged timber. Thus, in the 19 × 40 km wedge-shaped area of blast, mudflows, and tree blowdown and damage, the overall mortality rate was 48/65 or about 74 per cent (approximate 95 per cent confidence limits = 62 per cent to 83 per cent). Twelve (71 per cent) of the survivors in the damaged areas suffered from serious injuries—six with second degree burns, and six with adverse respiratory effects due to ash inhalation.

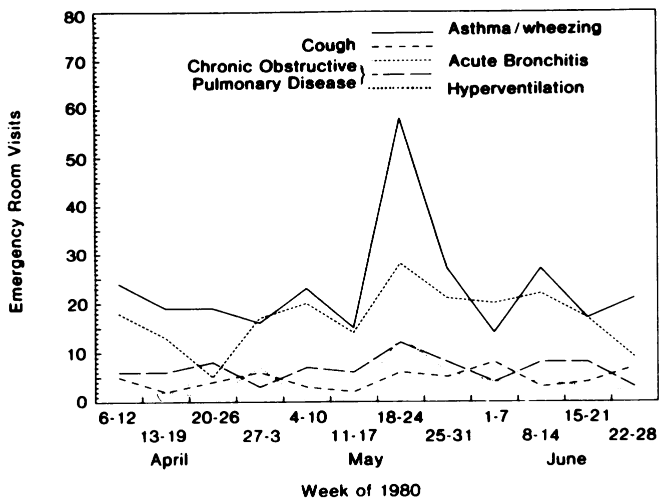
Despite the establishment of "red" (no public access) and "blue" (daylight entry with special permit) danger zones on the basis of the best available information prior to the May 18 eruption, all of the victims were recovered from outside (or were authorized to be within) the danger zones (Figure 4).[14(10,19),53,54] Beyond the tree destruction zone to the north, two deaths had occurred due to ash inhalation, and 37 survivors were identified, giving an overall mortality rate of 2/37 or about 5.4 per cent (approximate 95 per cent confidence limits = 1.5 per cent to 18 per cent). All of these survivors—as well as 48 additional survivors located south of the volcano out of the path of the lateral blast, pyroclastic and mud flows, or heavy ashfalls—escaped without serious injury.

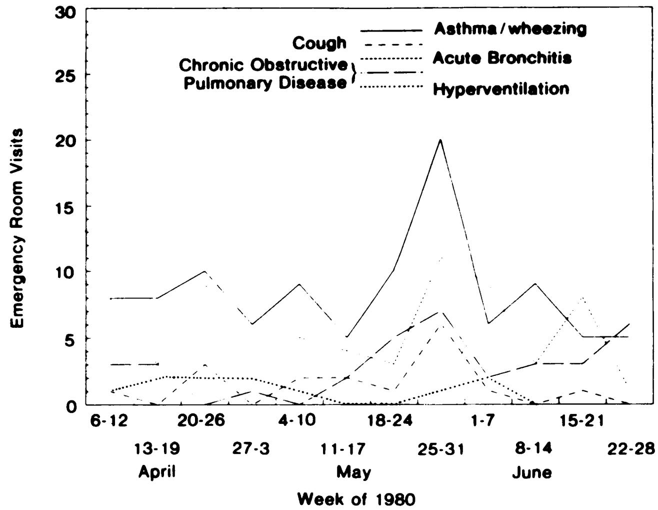
Among the 25 victims who were autopsied, suffocation by airway obstruction with ash was the cause of death in 17 and contributory in two others with thermal injuries (76 per cent); thermal injuries alone accounted for three deaths (12 per cent); and three victims (12 per cent) died of trauma, primarily head injuries.[53,54]

Although other interpretations are possible, the investigators reached the following conclusions:[14(11,19),53,54,55(3)†]

- Mortality and severe injuries were highest in the zones of greatest physical damage, including areas to which commercial and public access were permitted under specific circumstances.
- Within each damage zone, mortality and injuries were increased with increasing proximity to the mountain.
- Enclosed vehicles provided some degree of protection against exposures to the blast, heat, projectiles, and ash.
- Within comparable damage areas, survivors with least injuries appeared to be those who: were familiar with the area and had planned escape routes; were close to their vehicles and departed promptly; and/or improvised protective measures against burns and ash inhalation.
- Medical personnel caring for evacuees and survivors should be prepared to adequately treat infected burn wounds and respiratory tract injuries.

†Parenthetic superscript numbers refer the reader to the numbered CDC reports within reference 14, and FEMA reports within reference 55.





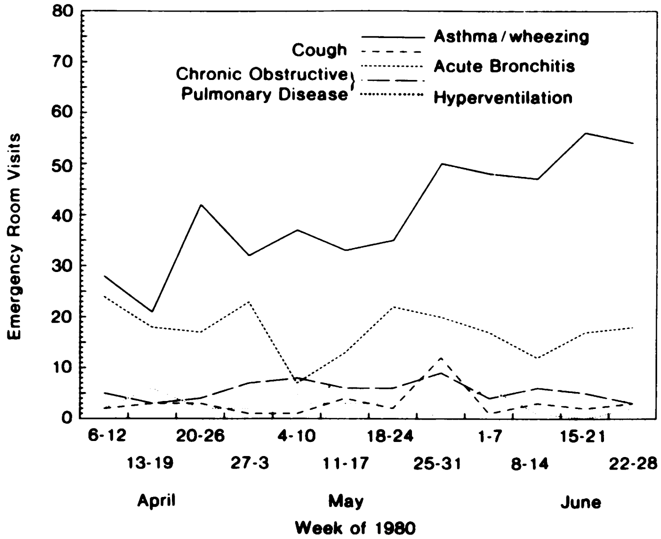


FIGURE 3—Weekly total numbers (April to June 1980) of main airways-related logbook diagnoses for emergency room visits at two hospitals in Yakima (May 18 eruption, 8-mm ashfall) (top left), two hospitals in Chehalis and Centralia (May 25 eruption, 8-mm ashfall) (top right), and three hospitals in Portland (May 25, trace of ash, and June 12, 3-mm ashfall) (bottom).

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TABLE 5—Deaths, Missing Persons, Survivors, and Mortality by Damage Zones, May 18, 1980, Eruption of Mount St. Helens

Damage Zones	Deaths	Missing (Presumed Dead)	Survivors	Total	% Mortality
Blast, Mudslides	1	10	2	13	85
Downed Timber	30	5	7	42	83
Damaged Timber	1	1	8	10	20
Intact Timber	2	0	35*	37*	5 (2+)
Unknown	1	7	—	8	—
Total	35	23	52*	110*	53 (37+)

*Excluding 48 survivors located on the south side of the mountain.
+In parentheses is the % mortality including in the denominator the 48 survivors on the south side of the mountain (no eruption-related deaths occurred south of the mountain).

Collection, Analysis of Volcanic Ash

While public safety officials were engaged in finding and recovering survivors and victims in the devastated "blowdown" area north of Mount St. Helens, environmental health scientists were investigating the nature and potential toxicity of the volcanic ash.[22,23] Flooding and other safety hazards of an eruption of Mount St. Helens had been anticipated and perceived in advance as real risks by local residents and health officials, but extensive ashfalls had not been widely anticipated or perceived as major risks.[15,18–20,56,57] As a result of pre-eruption planning and coordination between the National Weather Service and the state and local safety officials, residents of communities threatened by mudflows and flooding were evacuated within hours of the May 18 eruption.[57] However, the lack of anticipation of heavy ashfalls left safety and health officials with no pre-disaster plans for respiratory protection, hospital-based surveillance of cardiopulmonary problems, coping behavior by individuals with preexisting chronic respiratory diseases, or ash clean-up and disposal.[15,18,20]

Dry sedimented samples of the May 18 volcanic ashfalls were collected from Spokane and Yakima by state laboratory personnel and NIOSH industrial hygienists, taking care not to include soil or road dusts. Preliminary NIOSH analyses of four

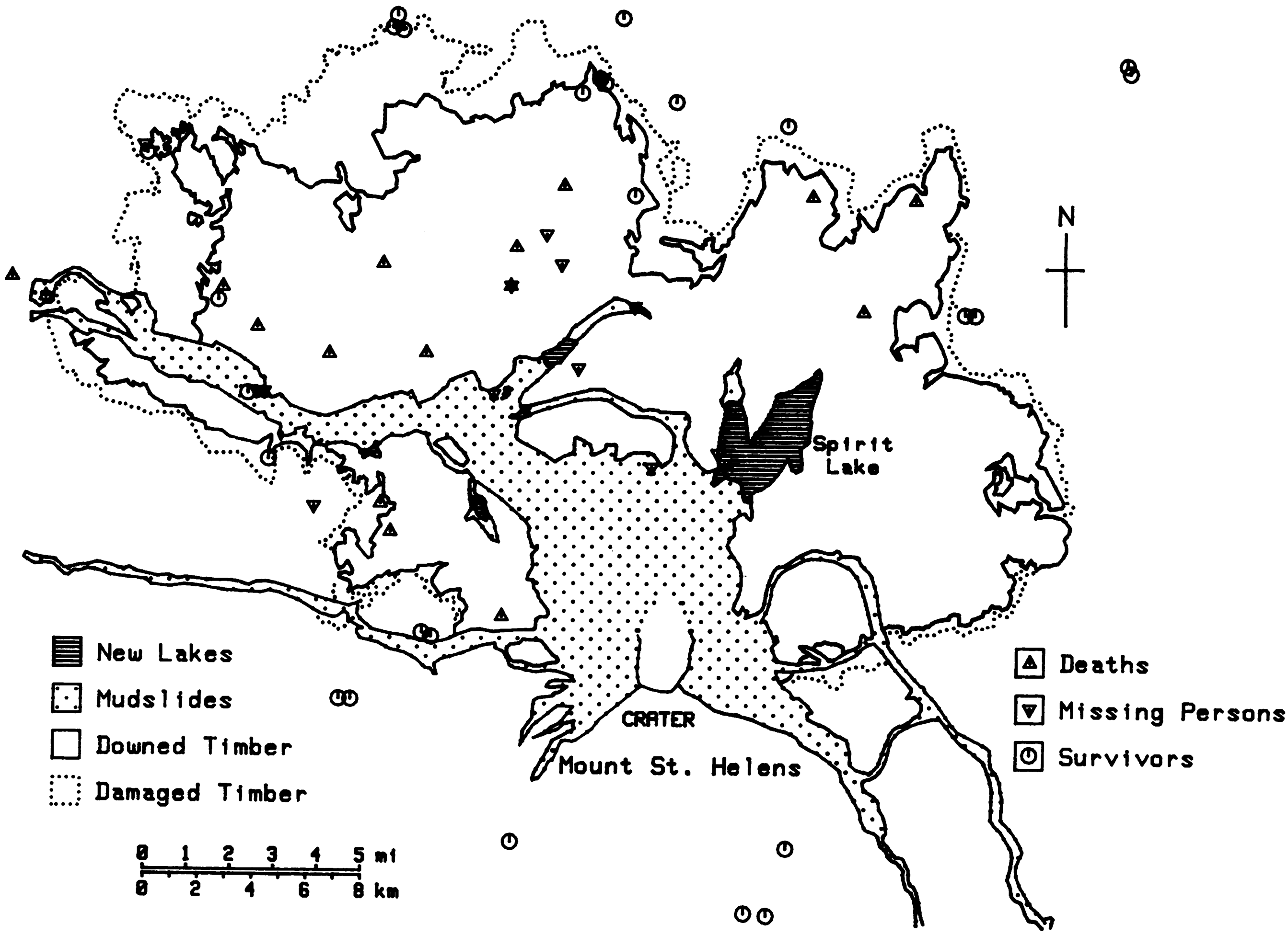

FIGURE 4—Locations of deaths, missing persons, and survivors following the May 18, 1980, eruption of Mount St. Helens.
SOURCE: Modified from the CDC—Mount St. Helens Volcano Health Reports[14(19)]

samples were reported on May 30 and June 3, 1980[14,55] as follows (chapters 5 and 6 present more detailed information):

- The majority of ash particles (> 90 per cent by count) were ≤ 10 μm in aerodynamic diameter, respirable in size, and belonged to the plagioclase (glass) mineral class of aluminum silicates and other oxides.[30]
- A small percentage of the respirable-size particles consisted of potentially hazardous polymorphs of free crystalline silica (about 4 per cent cristobalite and 3 per cent quartz by weight) which can cause pulmonary fibrosis (silicosis) if inhaled over prolonged periods of time at airborne concentrations greater than about 50 μg/m^3 (i.e., ambient concentrations of respirable size volcanic ash ≥ 700 μg/m^3, containing ≥ 7 per cent free silica).[27,30,58]
- No harmful amounts of respirable-size asbestiform fibers were detected and no excessive amounts of leachable toxic metals or acids (e.g., mercury, fluorides, and arsenic) were noted.[30]

Air Sampling

Between June 3 and 13, 1980, a team of four NIOSH industrial hygienists collected personal ("breathing-zone") and general area samples of airborne dusts in ash-affected communities of Washington, Idaho, and Oregon. Indoor samples were collected in homes, schools, and other public buildings. Outdoor samples were collected in a variety of occupational settings in which workers were likely to be exposed to resuspended volcanic ash (e.g., clean-up crews, forest and agricultural workers, and law enforcement personnel). Standard occupational air sampling methods were used to collect respirable-size (< 10 μm in diameter) dusts suspected of containing toxic and inert minerals.[14(4,12,16–18)]

Geometric mean concentrations of respirable mixed dusts ranged from 30 to 100 μg/m^3 for nonoccupational exposures, while most community occupational exposures ranged from 50 to 570 μg/m^3.[14(4,14,16–18),27] The results of NIOSH air sampling indicated that only the occupational exposures for certain categories of workers in heavy ashfall areas exceeded 800 μg/m^3 in a significant number of samples taken during dry weather. However, even these exposures were transient, and the per cent of volcanic ash in environmental dusts was likely to decrease with time if there were no further major ashfalls. Because of the potential for more intense, frequent, and prolonged exposures, workers involved in operations that created a visible dust cloud (e.g., certain job categories in logging and agriculture) were advised to wear goggles and NIOSH-recommended single-use or multiple-use high-efficiency face masks.[14,55]

For reasons discussed below, it was considered unlikely that the adult general population exposed to volcanic ash from the eruptions of Mount St. Helens would be at risk of developing pulmonary fibrosis or new onset of obstructive airways diseases.[14,27,58] However, it was considered possible that those with preexisting bronchial hyperreactivity or chronic lung disease might experience exacerbations of their problems. In addition, the risks for exposed children could not be predicted from available data, and avoidance of exposure was generally recommended.[14,55]

Toxicity Studies

Laboratory studies were initiated to determine the toxicity of the volcanic ash. Several different *in vitro* biologic tests indicated the ash to be mildly fibrogenic in a fashion which was dose-dependent[59] and proportional to the surface area or particle count in the test media.[30,60,61] The fibrogenic potential of volcanic ash was also observed *in vivo* in short-term animal experiments[30,62,63] and supported in the pulmonary histological findings of autopsy studies of two loggers who died in hospital following thermal injuries and heavy exposures to ash on May 18.[51,63,64]

Ash extracts were not mutagenic in two microbial assay systems and particulate ash had no effect on interferon production by monkey kidney cell monolayers or on the human complement system *in vitro*.[14(9),30] Marked inhibition of the antibacterial substance superoxide anion from ash-exposed and zymosan-stimulated alveolar macrophages suggested that volcanic ash may impair antibacterial lung defense mechanisms.[30,65]

The results of the above NIOSH toxicology studies and those of investigators in other laboratories are reviewed in more detail in chapter 6. In order of decreasing likelihood, the following adverse respiratory health effects were deemed biologically plausible if individuals received intense, frequent, or prolonged exposures:[14,27-30,32,33,51]

1. Acute irritation of the eyes, nasopharynx, and airways;
2. For individuals with preexisting or ash-induced bronchial hyperreactivity, more severe forms of respiratory distress and pulmonary impairment;
3. For individuals with preexisting chronic mucus hypersecretion or obstructive airways diseases, exacerbation and/or acceleration of these diseases and related impairment;
4. Potential for delayed-onset of ash-induced mucus hypersecretion or obstructive airways disease;
5. Potential for delayed-onset of ash-induced pulmonary fibrosis or "pneumo(vol)coniosis."

Epidemiologic Studies of High-risk Groups

Surveillance or "numerator" data alone could not be used to assess the adverse respiratory health impact of volcanic ash exposures on high-risk groups. For example, such data could not be used to evaluate the effectiveness of media directives advising patients with chronic respiratory disease to remain indoors or use respiratory protection. Additional information was obtained by cross-sectional, case-control, and longitudinal studies of high risk groups—those who were presumed to be hypersusceptible because of risk factors such as pre-existing chronic respiratory disease, or those who were heavily exposed to volcanic ash at work.

Hypersusceptible Individuals

To examine the possible etiologic relationships between ash exposure and acute onset or exacerbation or pre-existing respiratory problems, two studies were conducted—a case-control study, and an exposure-referent study.[24] For both studies, data on personal exposures were estimated from the EPA's rooftop monitoring of TSP levels because it was not possible to obtain or reliably estimate data on breathing-zone concentrations of respirable-size dust. In the study community which had received the heaviest ashfalls (Yakima), TSP levels varied as described in Table 1 and Figure 2. Over 90 per cent of the ash particles which sedimented to the ground in central and eastern Washington were < 10 μm in diameter and thus were within the respirable range. Presumably, the vast majority of excess TSP, collected by EPA monitoring devices at rooftop levels, consisted of this highly respirable volcanic ash.

For the case-control study, patients with symptomatic asthma and acute bronchitis were identified from surveillance hospitals located in the most heavily impacted communities and one control was selected for each patient: a person of the same age (adults ± 5 years, children ± 1 year), race, and sex who lived in the same neighborhood was selected in order to match for socioeconomic status and neighborhood levels of ashfall. Cases were selected from among those patients who attended the ER during the four weeks following the May 18 eruption.

In the exposure-referent study, lists of all patients known to have attended therapeutic classes for asthma and chronic bronchitis (prior to the eruptions of 1980) were obtained from the Washington Lung Association. The experiences of residents of the ash-exposed communities of Yakima and Ellensburg were compared with those of residents from a referent (unaffected) rural community, to determine the extent to which volcanic ash exacerbated chronic lung problems for patients who may not have been seen at the surveillance hospital ERs.

All participants were interviewed in their homes by interviewers trained in the use of the questionnaire and in the selection of matched controls. The questionnaire was based on the British Medical Research Council Respiratory Symptom Questionnaire[66] which was extended to include questions on:

- exposure to ash (time spent outdoors, involvement in house and community clean-up, wearing of masks, incidents when heavy exposure may have occurred);
- onset and duration of respiratory symptoms before and after the May 18 ashfall, including visits to medical facilities and use of medications; and
- housing information (location, number of rooms and occupants, use of storm windows and doors, and type of home heating, cooking, and ventilation).

The results of these studies supported the *a priori* hypothesis that pre-existing chronic respiratory diseases (primarily asthma and chronic bronchitis) are important risk factors[24,47] for adverse respiratory reactions[51] to levels of TSP (largely volcanic ash) exceeding EPA's Emergency (875 $\mu g/m^3$) and Significant Harm (1000 $\mu g/m^3$) NAAQ Standards (Figure 2). About one-third of the patients with chronic lung disease who were registered with the Lung Association stated that their respiratory problems had been worsened by volcanic ash exposure, and one-half of these patients were sufficiently affected so that they curtailed their usual activities for at least three months afterwards. It is likely that widespread adverse respiratory effects among people with chronic lung problems were averted to some extent because most of these people had followed the official advice, issued through the media, to stay indoors and wear respiratory protection when exposure to volcanic ash could not be avoided.[24]

It was not possible to use surveillance or case-control methods to evaluate the occurrence of new onset of asthmatic bronchitis in previously non-asthmatic individuals (which had been reported after the eruption of Soufriere volcano on St. Vincent[67]). Valid, reliable, objective data on the pre-eruption clinical status (e.g., the severity of any pre-existing asthma[47] or asymptomatic bronchial hyperreactivity[68,69]) and actual breathing-zone levels of respirable dust exposures were not available in either setting. Chapter 8 provides a review of several studies[70–72] which addressed this question with pulmonary function testing and environmental exposure measurements.

Loggers with Heavy/Prolonged Exposures

On June 4, 1980, the International Woodworkers of America (IWA) and the Weyerhaeuser Company (Weyco) made a joint request of NIOSH for a Health Hazard Evaluation of the potential health risks for loggers from intense, frequent, or prolonged occupational exposures to volcanic ash. Prior to this request, Weyco industrial hygienists had collected and analyzed sedimented bulk and airborne respirable dusts in six ash-affected logging areas in Washington.[73]

The Weyco industrial hygienists found that sedimented and resuspended dusts, including newly deposited volcanic ash, were highly respirable in size and contained 1 per cent to 5 per cent quartz and 1 per cent to 10 per cent cristobolite in the respirable fraction in logging areas affected by ashfalls. The results of air-sampling by Weyco were confirmed by NIOSH investigators: breathing-zone exposures for certain job categories of logging operations exceeded the 50 $\mu g/m^3$ NIOSH-recommended exposure limit for free silica in a substantial portion of samples. As a result of these findings, NIOSH conducted a cross-sectional study of the respiratory status of the Weyco/IWA loggers in Washington and a comparison group of non-exposed loggers in Oregon which provided baseline data for a longitudinal follow-up.[27–29] The results of the baseline and follow-up studies are described in detail in chapter 8.

Dissemination of Public Health Information

Immediately following the May 18 eruption, the news media, government authorities, and members of the public in areas affected by ashfalls sought information and advice about the health effects of volcanic ash from several different sources: local and state public health, environmental quality, and occupational health officials, as well as university-affiliated and private practice physicians. There was widespread confusion and disagreement about certain common questions that had to be answered rapidly with valid and consistent responses. The questions asked most often concerned the necessity to remain indoors, the advisability of limiting outdoor exercise and sporting events, the risk of exposure for individuals with pre-existing lung disease, the need for respirators outdoors, and the use of automobiles.

Providing answers to these questions was difficult because of the paucity of directly relevant literature.[1,2] This difficulty was compounded during the first days after the May 18 eruption by a lack of data regarding the concentrations of toxic substances in the ash, such as respirable-size crystalline free silica. Even weeks later, the wide variation in "silica" levels determined by different laboratory methods hampered efforts to formulate consistent advice to the public. Finally, the potential duration of ash exposure could not be predicted because no one could reliably predict how long the airborne concentration of respirable-size ash particles would remain elevated from a particular ashfall, or how long new ashfalls would continue to occur.

TABLE 6—Consensus Recommendations to the Public from the Oregon Public Health Committee on Volcanic Ash Fallout, Summer 1980

1.	When airborne volcanic dust levels are high, avoid activities which would lead to dust exposure. Examples include jogging, lawn mowing, and dry clean-up of fallen ash.
2.	Persons who must work in dusty situations should wear a mask, recommended by the National Institute for Occupational Safety and Health (coded by the designation, "TC-21-C"), for filtering out small ash particles. Goggles should be considered for eye protection as well.
3.	Remove fallen ash from your property by wetting it first to avoid raising unnecessary dust during clean-up.
4.	Take caution to avoid motor vehicle accidents and falls caused by slippery or dusty conditions from wet volcanic ash.
5.	If you have chronic lung or heart disease and experience an increase in symptoms, consult your physician.
6.	Don't drive unnecessarily when conditions are dusty.
7.	Avoid smoking. The hazards of smoking are far greater than any known to be caused by volcanic ash.

After the Presidential designation of the disaster area on May 21, 1980, FEMA established an interagency center for coordination of disaster response efforts, dissemination of scientific information, and control of rumors. The center was in Vancouver, Washington where the USGS volcano monitoring and state and local search and rescue operations were located. A NIOSH medical epidemiologist was assigned to work full time with USGS, USFS, and other federal, state, and local disaster response personnel at the FEMA coordinating center in Vancouver. Several other CDC professionals worked with state health department officials in Seattle, Washington and consulted with state officials in Portland, Oregon.

In Oregon, an ad hoc committee was eventually established to provide sound and consistent advice, in spite of early limitations on data concerning ash toxicity. This committee included representatives of state and local public health agencies, both private and university-based physicians, and concerned voluntary health organizations. The committee met to consider available data and to develop consensus recommendations for the public on health questions related to the ashfalls (which first affected the Portland area on June 13, 1980). These consensus recommendations, developed in cooperation with federal experts in the FEMA coordinating center, were then communicated to the media and the public (Table 6). This effort successfully reduced the earlier confusion that had resulted from separate, sometimes contradictory, recommendations issued by the various organizations with which committee members were affiliated.

By May 26, 1980, the FEMA Coordinator began publishing a series of Mount St. Helens Technical Information Network Bulletins.[54(1–33)] Field staff from CDC collaborated with FEMA on the health aspects of these bulletins and also published a series of CDC Mount St. Helens Volcano Health Reports, initiated on May 30, 1981 and distributed nationally to state and county health officials.[14(1–23)] These reports included technical advice on driving and vehicle maintenance

TABLE 7—Indices of Centers for Disease Control (CDC) Public Health Bulletins and Federal Emergency Management Agency (FEMA) Technical Bulletins: Information Resources on the Evaluation and Control of Volcanic Hazards

Subject Area	CDC Report Numbers*	FEMA Report Numbers*
Disaster planning	4, 12, 14, 23	4, 25, 28, 34
Deaths, injuries near eruption	10, 15, 16, 19, 23	32
Public health aspects of volcanic eruptions, ashfalls	1–23	1–4, 10, 12, 14, 18, 19, 20, 26, 32
Socioeconomic aspects of volcanic eruptions, ashfalls	4, 9–11, 13, 14, 16–18, 20, 23	2b, 5–7, 9, 11, 16, 17, 21–24, 29–31
Collection, analysis of ash	3, 7–9, 12, 13, 16, 23	1, 8, 13, 32, 34
Monitoring and controlling ash, gas exposure in air/water/food	3, 4, 9–12, 14, 15, 17, 18, 22, 23	15, 18, 19, 26, 27, 30, 32
Literature review	8, 10, 13, 18, 21	33

*Copies of CDC reports[14] may be available upon request to: Dr. Henry Falk, CDC/CEH/DEHHE, Atlanta, GA 30333, USA; request FEMA reports[55] from: Bill Brown, FEMA Region 10, Bothell, WA 98101, USA.

in heavy ashfall areas; descriptive and analytical data on the occurrence and distribution of morbidity and mortality due to volcanic hazards; results of bulk ash analyses, area air-sampling, and personal exposure monitoring; results of water and food quality testing; updated descriptions of current and potential volcanic hazards; and guidelines for further pre-disaster planning and post-disaster responses, including control of flooding and resuspended ash in affected areas (Table 7). These FEMA and CDC publications provided health professionals and the public with valid, reliable, and timely information about the nature and impact of volcanic hazards and appropriate control measures. Federal, state, and local safety and health officials reported that these publications and daily news briefings at the FEMA Coordinating Center were extremely helpful.[74,75]

Conclusions

Continuing volcanic activity at Mount St. Helens[76] and premonitory activity at other volcanoes in the northwestern United States[77] raise the remote, but serious, threat of further widespread environmental damage and the potential for widespread morbidity and mortality.[78] This chapter has outlined the range of public health concerns and the methods and actions involved in responding to the explosive eruptions of a volcano in a relatively isolated area of western North America.

In developing countries, the human and technical resources available for disaster response efforts are considerably more limited. However, in the West Indies, Indonesia, Japan, and certain other areas, the magnitude and frequency of hazards from volcanic eruptions may rival those associated with other natural disasters which are somewhat more predictable (e.g., severe weather) or less predictable (e.g., earthquakes).[34,79] Considering the expansion of world populations into potentially hazardous volcanic areas and current limitations in the reliability, precision, and availability of predictive monitoring technology, there is a growing need to develop appropriate pre-disaster planning and response measures. Resources for epidemiologic surveillance and epidemic field investigations of suspected outbreaks are needed following widespread environmental damage, mass evacuation, refugee resettlement, and disruption of routine public health services.[31–38]

It is hoped that the experiences following the eruptions of Mount St. Helens described here can serve as a case study in secondary preventive measures for use by populations which are more vulnerable and more often exposed to volcanic hazards.

Summary

A comprehensive epidemiological evaluation of mortality and short-term morbidity associated with explosive volcanic activity was carried out by the Centers for Disease Control in collaboration with affected state and local health departments, clinicians, and private institutions. Following the May 18, 1980 eruption of Mount St. Helens, a series of public health actions were rapidly instituted to develop accurate information about volcanic hazards and to recommend methods for prevention or control of adverse affects on safety and health. These *public health actions* included:

- establishing a system of active surveillance of cause-specific emergency room (ER) visits and hospital admissions in affected and unaffected communities for comparison;
- assessing the causes of death and factors associated with survival or death among persons located near the crater;
- analyzing the mineralogy and toxicology of sedimented ash and the airborne concentration of resuspended dusts;
- investigating reported excesses of ash-related adverse respiratory effects by epidemiological methods such as cross-sectional and case-control studies; and
- controlling rumors and disseminating accurate, timely information about volcanic hazards and recommended preventive or control measures by means of press briefings and health bulletins.

Surveillance and observational studies indicated that:

- excesses in morbidity were limited to transient increases in ER visits and hospital admissions for traumatic injuries and respiratory problems (but not for communicable disease or mental health problems) which were associated in time, place, and person with exposures to volcanic ash;

• excessive mortality due to suffocation (76 per cent), thermal injuries (12 per cent), or trauma (12 per cent) by ash and other volcanic hazards was directly proportional to the degree of environmental damage—that is, it was more pronounced among those persons (48/65, or about 74 per cent) who, at the time of the eruption, were residing, camping, or sightseeing (despite restrictions) or working (with permission) closer to the crater in areas affected by the explosive blast, pyroclastic and mud flows, and heavy ashfall; and

• *de novo* appearance of ash-related asthma was not observed, but transient excesses in adverse respiratory effects occurred in two high-risk groups—hypersusceptibles (with preexisting asthma or chronic bronchitis) and heavily exposed workers.

Laboratory and field studies indicated that:

• volcanic ash had mild to moderate fibrogenic potential, consisting of >90 per cent (by count) respirable size particles which contained 4–7 per cent (by weight) crystalline free silica (SiO_2);

• importantly, community exposures to resuspended ash ony transiently exceeded health limits normally applied to entire working lifetime exposures to free silica; and

• there were no excessive exposures to toxic metals, fibrous minerals, organic chemicals, radon, or toxic gases of volcanic origin in community water supplies or air.

Recommended preventive measures include: avoidance of areas of predicted hazards during premonitory and ongoing volcanic activity and use of respiratory protection and wetting methods to control unavoidable exposures to ash. In densely populated countries with relatively frequent explosive volcanic activity, resources for epidemiological surveillance and investigation are needed following widespread environmental damage, mass evacuation, refugee resettlement, and disruption of routine public health services.

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