MEDICAL ASPECTS OF VOLCANIC DISASTER : AN OUTLINE OF HAZARDS AND EMERGENCY RESPONSE MEASURES

Peter J. Baxter,* Robert S. Bernstein, Henry Falk, Jean French and Roy Ing

Chronic Diseases Division
Center for Environmental Health
Centers for Disease Control
U.S. Department of Health and Human Services
Atlanta, GA 30333, U.S.A.

The health and safety hazards posed by volcanic eruptions are outlined with special reference to experience gained from the eruptions of Mount St. Helens in 1980. The ability of Volcanologists to predict the timing and the impact on local communities of an impending eruption are limited, some recent devastating eruptions having occured without apparent warning. With the expansion of world populations into hazardous volcanic areas there is a growing need to develop appropriate emergency response measures. This paper describes the main preventive public and occupational health measures that are now a necessary part in dealing with volcanic emergencies.

Key Words: Volcanoes, eruptions, health effects, emergency response preventive medicine.

INTRODUCTION

Massive, dramatic volcanic events such as the eruption of Mount St. Helens on 18th May 1980, are uncommon, but they inevitably reawaken world interest in all aspects of volcanism. The violence of major eruptions makes the health and safety of nearby populations the first concern. In the last 500 years, at least 200,00 people are estimated to have died in volcanic eruptions worldwide (Williams and

MeBirney, 1979), but this figure is not large when compared with the number of deaths caused by other natural disasters such as earthquakes and floods. However, the expansion of growing world populations into volcanic regions, the Cascade Range with Mount St. Helens in the U.S. Pacific Northwest being but one example, will inevitably lead to increasing risks to human life from volcanism. To assist in the development of appropriate emergency response measures in at-risk areas we have briefly summarized in the paper the medical aspects of volcanic disasters, with special reference to the experience gained from the Mount St. Helens eruptions in 1980 (Baxter *et al.*, 1981; Centers for Disease Control, 1980). The geology and geologic hazards of Mount St. Helens have been summarized in USGS Professional Paper 1250 (Lipman and Mullineaux, 1981).

CLASSIFICATION OF VOLCANOES

When appraising volcanic hazards in a particular area, one must first classify the types of eruptions to be expected. In describing their potential for damage. Thorarinsson (1979) has divided eruptions into three types: effusive, with lava flows predominating; explosive, with little or no lava but a large volume of tephra (any solid fragments from a volcanic vent, including ash); and mixed, with certain features of both these types. A least three or four lava eruptions and 10 to 15 explosive eruptions occur in the world every year (Decker and Decker, 1981; Williams and McBirney, 1979). How a particular volcano may erupt can, with some success, be surmised from its past behevior, if known, and from the location of a volcano may erupt can, with some success, be surmised from its past behavior if known, and from the location of a volcano in relation to the boundaries in the earth's crust, where tectonic plate margins bear against one another. About 400 of the 500 known active volcanoes in the world lie where the plates are undergoing compression (subduction sones) (Simkin *et al.,* 1981); they form Island arcs and high mountain terrain (e.g. the so-called 'Ring of Fire' around the Pacific Ocean, which includes the Cascade Range) and tend to be explosive. In contrast, where the plates are separating, or side-slipping, the faults are known as rift or strike-slip, respectively, and volcanoes tend to be effusive; most are submarine, though rift volcanoes are to be found in Iceland, for example (Bullard, 1976).

The type of eruption is determined, among other things, by the silica content of the magma, or liquid rock, which is erupted. In effusive eruptions the silica content of the magma may be about 50% and the rocks are known as basalt; in explosive volcanoes the silica content may be as high as 75%, and the rocks are known as rhyolite. In order of increasing silica content, volcanic rocks are known as basalt, andesite, dacite and rhyolite. The important health implication of these differences is that free crystalline silica, mainly as quartz may be present when the silica content exceeds 55%, and is found in appreciable quantity when the silica content exceeds 65% (Hyndman 1972). Long term heavy exposure to the ash of respirable size from such magma has the potential to cause a chronic lung disease called silicosis, a fibrotic or scarring reaction of the lung tissue to the presence of inhaled free silica.

Volcanologists also classify eruptions by the pattern of activity (McDonald, 1971; Francis, 1976). Hawaiian-type eruptions are effusive, and their ejecta are partly fluid when they land; ash is scarce, but gaseous emissions may endanger life. Strombolian activity involves basaltic or andestic magma of moderate fluidity and is more explosive than the Hawaian. More violent are Vulcanian eruptions, which produce large explosions that often hurl ejecta a kilometer or more from the crater, amid clouds of ash and gas; the ash may include fresh (juvenile) material and pulverized old rock. More dangerous still are three other type which can lead to widespread devastation: Peleean eruptions, which produce glowing avalanches *nueesk ardentes or radially directed flows of hot ashes and gas which can burn and asphyxiate people in their path); the Plinian (Krakatoan) an exceptionally powerful continuous gas-blast eruption which releases large volumes of ash from fresh magma; and the Phreatic, or steam-blast eruptions where water and magma or water and hot rock come into contact at depth. Ash can thus be produced from the explosion of old rock (lithic ash) or from the release of pressure on fresh magma (vitric ash), with its composition and physical properties varying between eruptions and even during one continuous eruption. In addition, the composition, grain size and depth of an ashfall will depend upon distance and direction from the volcano, the finer material usually being transported farther away by winds.

HEALTH HAZARDS

The principal health hazards are summarized in Fig. 1. For descriptive purposes, it is useful to distinguish between hazards near volcanoues and those at a distance, perhaps as far as hundreds of kilometers away, and which are mainly due to tephra fallout, though in practice the two groups will overlap (for further details see United Nations, 1977). Explosive eruptions are the most likely to be hazardous and so this paper concentrates mainly on these.

Pyroclastic flows

Hot avalanches, nuees ardentes, directed blasts, pyroclastic or base surges, and ignimbrites are related phenomena from a health standpoint. They are characteristically associated with the viscous magmas of subduction zone volcanoes and are extremely hot mixtures of gas, ash, pumice and dense rocks which can travel at high speeds and for considerable distances. The momentum of the hurricane winds laden with particles can cause a devastating blast, as shown by the wide area where trees were destroyed around Mount St. Helens after the 18th May 1980, eruption; deaths occurred as far as 27 km away from the crater (Baxter *et al.,* 1981; : *Eisele* et al., 1981). Death may therefore be caused by the effects of blast, intense heat (exposure to hundreds of degrees centigrade for 1 – 2 mins), and asphyxiation from air densely laden with ash particles (Taylor, 1958; Eisele *et al.,* 1981). Toxic gases are not likely to be important. Autopsies of 23 bodies recovered after the Mount St. Helen's lateral blast showed that asphyxiation was the underlying cause of 18 deaths (Eisele *et al.,* 1981). Perhaps if adequate shelter and clothing had been available along with canister-type full face masks* more persons at the periphery of the cloud would have survived. However, the presence or absence or survivors correlated with the distance from the volcano, thus confirming the longstanding advice of volcanologists that the best expedient is to keep well away from dangerous areas around active volcanoes.

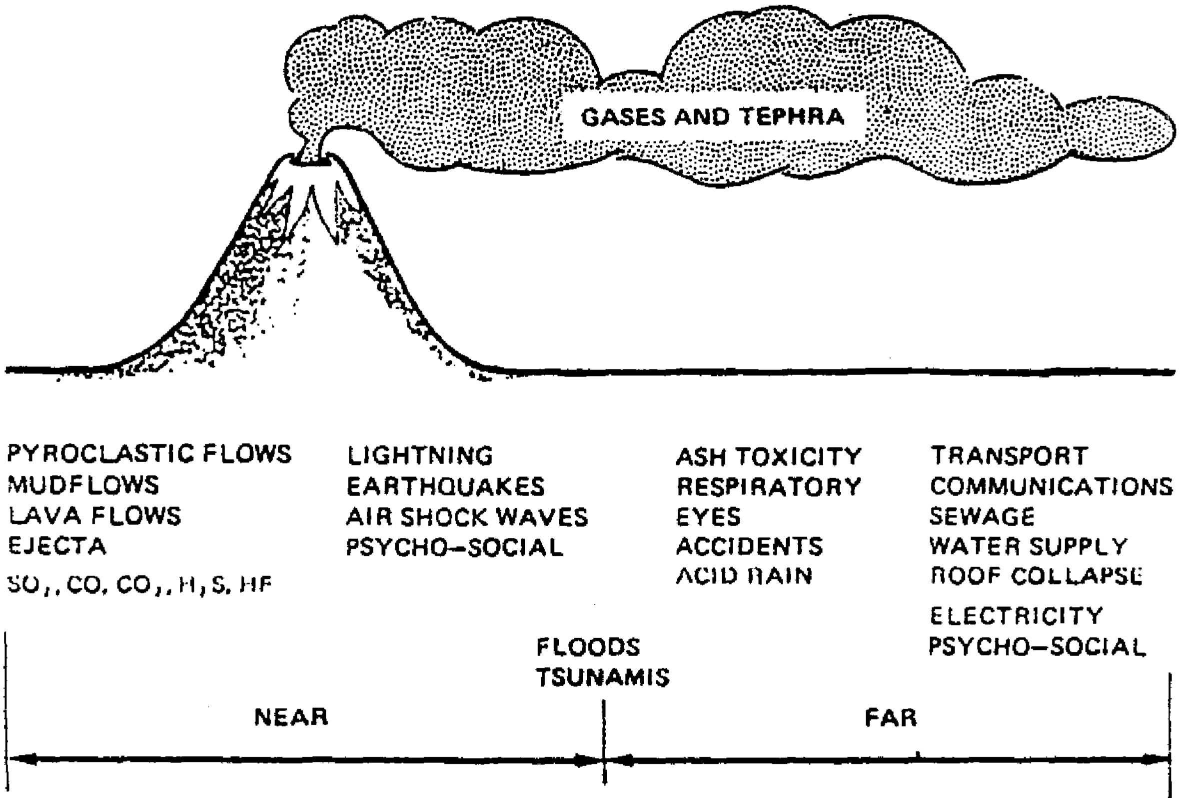

Fig. 1. Principle health and safety hazards of volcanic eruptions.

Mud flows and floods

Mud flows, or lahars, are also deadly volcanic phenomena and are responsible for much of the destruction caused by volcanic eruptions. Water (from rain, crater lakes; or melted snow) from such eruptive activity as steam blasts, pyroclastic flow, or lava can mix with old or new volcanic debris to form mud flows. Mud flows have the consistency of wet concrete, and because of their large volume and the effect of gravity they can travel many kilometers along valley floors causing destruction and flooding of rivers and reservoirs. The best means of protections is for people to evacuate or stay away from low-lying areas at risk; the Japanese use systems of diversion dams and giant sereenlike barriers to divert or temporarily control mud flows. Roads and bridges are readily destroyed so that ground transport may be impossible. Because the average speed of the two large mud flows from Mount St. Helens on 18th May was about 20 miles/hr, rescuers had adequate time to warn or evacuate families living at a distance in the path of destruction. Mud flows and water run off from erupting volcanoes can also be very hot and cause fatal burns.

Floods, in addition to causing death by drowning and widespread devastation, can destroy intakes for water supplies and outlets for sewage along river beds. Furthermore, animal carcasses and the ponds and lakes of still water formed after the destruction of natural river courses can cause outbreaks of infectious disease. The still water becomes heavily laden with putrefying organic material and bacteria, and can serve as a breeding place for disease vectors, e.g. mosquitoes. In streams and rivers draining from destroyed areas, indicators of organic contamination (e.g. increased turbidity, elevated bacterial counts and elevated concentrations of phenols) may be found.

Lava flows

Although they can be immensely destructive, lava flows generally pose little risk to life because they travel so slowly that people can walk away from them. There are exceptions: In 1977 a lava lake on the Nyiragongo Volcano, Zaire, drained after a fissure eruption, and 300 people died in the very fluid lava flows which ensued (Tazieff, 1976).

Ejecta

Eruptions may sometimes become unexpectedly violent and cause death, e.g. nine tourists were struck by rocks exploded from Mount Etna in 1979 (Guest *et al.*, 1980). During explosive eruptions, dense rock fragments can be thrown far from the volcano. When Mount St. Helens erupted on 22nd July 1980, rocks up to 1 in, in diameter were blown by the wind as far as 19 km away and reached an estimated terminal velocity of 50–60 km/hr (C.G. Newhall, personal communication); theoretically, much larger fragments could be hurled up to 6 km away. Local fires can also be started by hot ejecta.

Gases

The main volcanic gases are H_2O, CO_2, SO_2 and HC1, and minor ones are HF, CO and H_2S (the asphyxiants are CO_2, CO and H_2S, and the lung irritants are SO_2, HC1 and HF). In general, gases do not pose a serious hazard, but some exceptional situations have shown that gases warrant close study. In 1979, during an eruption of Dieng Volcano, Java, 149 people were killed by CO_2 and H_2S (Scientitie Event Alert Network Bulletin, 1979). In Iceland, animals have suffocated from the pooling of CO_2 in low lying regions, and the Eldfell eruption in 1973 resulted in one death from this cause in the town of Vestmannaeyjar (Thorarinsson, 1979). One death due to volcanic H_2S has been reported from Japan (Kawari. Inoue and Ishida, 1978); in Iceland. H_2S reportedly has killed birds and caused temporary blindness in sheep (Thorarinsson, 1979). HC1 and HF are both irritant gases and corrosive acids when dissolved in water, especially the latter. SO_2 is the gas next to H_2O most copiously emitted from volcanoes, and is thus likely to affect surrounding communities. A remarkable eruption occurred from the Laki fissure in Iceland in 1783; in addition to a record size lava flow, huge emissions of gases occurred over a 7-month period that resulted in fogs of mainly SO_2 and particulates throughout much of Europe that summer. Creighton (1965) quotes Holm, 'Vom Erdbrande Auf Island im Jahre 1783,' Kopenhagen, 1784, on the acute health effects of this eruption in Icelanders:

> 'Since the outbreak began, the atmosphere of the whole country has been full of vapour, smoke and dust, so much so that the sun looked brownish red, and the fishermen could not find the banks . . . . Old people, especially those with weak chests, suffered much from the smell of sulphur and the volcanic vapours, being affected with dyspnoea. Various persons in good health fell ill, and more would have suffered had not the air been cooled and refreshed from time to tome by rains.'
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> pp. 57 and 60

In Nicaragua, several thousand people live in an area bathed every 25 years by a plume of H_2O, SO_2 and lesser amounts of other gases from the Masaya Volcano, Nicaragua, a unique low-lying volcano that degasses in cyelical periods which last for 5–10 years, causing considerable damage to vegetation, structures and machinery for many kilometers downwind. In addition, rain that is made acid (pH 2–3) by falling through the plume may cause skin and eye irritation (Williams *et al.,* 1980; Stoiber *et al.,* 1981a). Human exposure to toxic gases from both rift and subduction zone volcanoes must therefore be considered an occupational hazard to volcanologists and a potential threat to nearby communities. Though the height of some volcanic peaks results in the dilution of gases before they reach ground level, some volcanoes, e.g. Mount Shasta, North California, could erupt from low vents in their flanks or as Masaya, Nicaragua, be lower in elevation than the surrounding ridges. Mercury vapour may also be a problem and requires further study (Baxter et al. 1982; Johannsson et al., 1981).

Lightning

Lighting is frequently discharged from ash clouds in the vicinity of a volcano and, in the event of massive eruptions like that of Mount St. Helens on 18th May 1980, may accompany the cloud for many kolometers downwind. The lightning may cause fires and damage to electricity supplies or property, and death from electrocution.

Earthquakes, shock waves and Tsunamis

Minor earthquake are frequent concomitants of eruptions, but destructive earthquakes are less common. Air shock waves from explosive eruptions have broken windows as far as 18 km away. Tsunamis are giant sea waves produced by a submarine earthquake or volcanic eruption; those from volcanoes are rare, the most famous being caused by Krakatoa in 1883 (Walker, 1974).

Ash toxicity

When freshly fallen ash is mixed with distilled water, numerous soluble materials are removed (Taylor and Stoiber, 1973). These leachable constituents are scavenged by the ash from the volcanic plume and reflect the type and quantity of the erupted gases (Rose, 1977); they will dissolve in surface waters (and possibly alter their pH) or be washed off by rain in a few weeks. Geologists gain an understanding of the eruption type from these leachates (Stoiber *et al.,* 1980, 1981 b). Tephra from Icelandic eruptions are historically noted for their high fluoride content. Eruptions of Hekla in 1947 and 1970 have been studied for the effects of fluoride; in both eruptions, levels of fluoride as high as 9 ppm were found in surface waters soon after major ashfalls (Oskarsson, 1980). Consumption of water with a fluoride concentration of 2 - 10 ppm would not be expected to cause ill health if the contamination lasted only a few days, though it would be prudent for susceptible people, mainly those with chronic sickness, to use uncontaminated water. Acute exposure to higher concentrations can cause gastrointestinal illness. Consumption of water containing geater than 1 ppm flouride over long periods could lead to dental mottling in children and, at higher concentrations, osteofluorisis (Royal College of Physicians, 1976). No cases of human fluoride intoxications have been reported in recent Icelandic eruptions (G. Georgsson, personal communication), but in the 1970 eruption of Hekla thousands of grazing sheep and some horses died from fluride poisoning. A tephra layer of about 1 mm thick or even less was sufficient to cause the deaths of animals the fluoride content of the ash being high as 2.000 ppm in places Thorarinsson and Sigvaldason 1972). In theory, other adsorbed elements, e.g. heavy metals, might also be present in hazardous amounts the suface of the tephra, but to the authors' knowlendge there is no evidence in the scientific literature that this has occurred. Nevertheless, for the protection of human and animal health in future eruptions, detailed leachate studies should be made toexclude this possibility. The biological availability of elements including components not readily leached in water, especially to foraging animal, can also be determined in animal-feeding studies; such studies after the Mount St. Helens eruption on 18th May 1980, confirmed that the ash did not contain toxic levels of fluoride (Taves, 1980).

Asha-related respiratory and eye problems

Ash particles less than 10 micrometers in size are respirable and are commonly produced in explosive eruptions. Effusive or mixed eruptions usually release smaller quantities of ash of larger grain size. and this would be expected to cause fewer, if any, respiratory problems The 1902 erupton of Sante Maria volcano in Guatemala has been found to have released 2.15 x 10^{10} g of 2 mm size ash of dacitic composition, of this 2 x 10^{14} g is estimated to be 2 um in diameter (S. Williams and R. Stoibef, unpublished data). The potential for acute adverse respiratory effects newly erupted ash of respirable size would depend upon its chemical and physical properties, the level of exposure , and the susceptibility of exposed people. Possible manifestations in populations subjected to eruptions of respirable ash include the precipitation, or worsening, of asthmatic conditions as an acute response to heavy exposure (Leus *et al.,* 1981). With repeated heavy exposure, increased secretion of mucus in airways which might contribute to the development of chronic bronchitis; and, if the ash contained free silica. a fibrotic reaction of the lung tissue (silicosis), as mentioned above. Few studies on the health effects of volcanic ash have been undertaken to evaluate these hazards, primarily because many eruptions which could have provided such information have occurred in remote areas or in developing countries where the health infrastructure does not readily permit the collection of morbidity and mortality. The 1980, Mount St. Helens eruptions therefore provided special opportunities for study. Over 90% of the ash particles were respirable, and increases in the number of emergency room visits due to respiratory illnesses, mostly asthma, occurred in hospitals in areas of heaviest ashfall (Baxter *et al.,* 1981). In one survey, about one-third of the residents with chronic lung problems reported a worsening of their condition (Baxter *et al.,* in preparation). Asthma sufferers of all ages were the most susceptible to the high airborne levels of suspended particulates after each ashfall. However, there were no increased mortality rates due to respiratory illnesses when mortality data by country were reviewed, even though the depth fine ash exceeded 50 mm in some areas (Centers for Disease Control, unpublished observations).

The fibrogenic (silicotic) potential of the ash would be expected to be closely related to its crystalline free silica content, though other components, including silicates (e.g. feldspar), could be important (Sherwin *et al.,* 1979). The proportion of free silica in the respirable portion of Mount St. Helen's ash lay in the range 3–7% by weight as part quartz and part crystobalite; studies of experimental animals and *in-vitro* laboratory tests have also shown that the ash has moderate fibrogenic potential (Green *et al.,* 1981). Thus certain outdoor occupational groups, e.g. loggers, might be at increased risk of contracting pneumoconiosis if repeated heavy exposures were to occur over many years (Bernstein *et al.,* in press). Mount St. Helen's ash had a dacitic composition, whereas ash from rhyolite magma might have a free silica content of ground 15%, about the maximum concentration anticipated in volcanic eruptions- and would, therefore, be expected to be more hazardous.

Ash particles can affect the eyes by causing irritation, injury from foreign bodies and conjunctivitis, as experienced in, some areas after Mount St. Helen's eruptions (Fraunfelder *et al.,in press); these problems were* also documented after the 1977 eruption of Mount Usu in Japan (Saito *et al.,* 1978).

Accidents

Even light ashfalls if accompanied by rain, can lead to slippery roads and traffic accidents. During cleanup operations, people have been injured by falling off the roofs of their homes.

Tansport and communications

Damage to transport and telephone networks from lava or mud flows and from associated flooding in the vicinity of volcanoes is a fairly obvious sequela of the more destructive eruptions. In addition, tephra fallout from plinian eruption maybe voluminous enough to cause impenetrable darkness for up to several days after a massive eruption, and the clogging of engine air filters and abrasive damage to machinery pose strong hindrances to traffic. On 18th May, in Yakima-the first major city in the path of the plume, situated 140 km from Mount St. Helens–daylight was obscured for about 8 hours until the ash settled; the final compacted depth of ash was 1 cm. One can easily imagine the problems which would be caused by an ashfall 0,3 m (*ca:* 1 ft) deep at this distance, an event which has occurred in Mount St. Helen's past activity.

Theoretically, local radio and television communications can be hampered by static electrictiy in ash clouds. Electronic equipment and telephone exchanges can be damaged by ash; air-filter systems in at-risk areas need to be modified to prevent such damage. As happened after the massive of Mount St. Helens local telephone system can become overloaded with callers and should not be relied upon for emergency communications. Electricty blackouts (see below) are also a possibility, but modern telephone excanges can use batteries and generators to continue independent operation.

Sewage disposal and water supplies

Sewage teatment plants are easily put out of action by heavy ashfalls, because filter beds become overhelmed, and abrasive ash several damages machinery. Under these cirumstances, the diversion of raw sewage (with or without chlorination) into surface waters, where it could potentially cause infectious disease, may be inevitable. Water supplies might also be threatened by the occlusion of surface water intakes by ash, the heavy of water in communities during ash clean up operations, and the stopping of water pumps due to power failures.

Roof collapse

Very heavy ashfalls could build up on roofs; the weight of the ash especially if wetted by rain, can impose intolerable strains on structures, with the risk of catastrophic collapse. Large flat-roofed buildings (e.g. bowling alleys, gymnasiums) may be designated as evacuation centers, but such structures are often built to minimum building code requirements, expecialy in areas where roofs do not require strenghtening to cope with heavy snowfalls. The regular removal of accumulated ash from a roof during a very heavy ashfall would be made difficult by poor visibility and the irritative effects of the ash on the eyes and the respiratory system: old or infirm persons would be unable to undertake this task. Rates of accumulation could be high (0.5 – 5.0 ton/m2 over an 8 – 24 hr period are not unusual (S. Williams and R. Stoiber, unpublished observations). Bonis and Salazar (1973) have emphasized the problems of roof collapse in Guatemalan houses during the 1971 and 1973 eruptions of Fuego Volcano, Guatemala.

Electricity

Ash moistened with rain may cause shorting of exposed electrical insulators, particularly the horizontal type that permits ash to accumulate along the insulator's length. Maintenance teams would need to remove the ash from the insulators ro restore power but would be hindered in a heavy ashall if transport were curtailed. The implications of prolonged electrical failures on public utilities, hospitals and homes must therefore be considered.

Psychological factors

Cultural factors will determine the ability of communities to cope with the tresses of living on or near active volcanoes and in areas subject to ashfalls and floods. In modern technological societies such as the U.S. these tresses may be substantial. To the authors' knowledge, no scientific studies of the mental health impact of volcanic disasters have been published. The distinction between the acute psychological effects of major eruption and the continuing threat of renewed volcanic activity may not be possible in such studies. In areas which have received heavy ashfall or which are threatened by future eruptions, temporary disturbance of local industries such as tourism or manufacturing might result in unemployment with attendant psychological sequelae; and prolonged periods of evacuation can lead to severe disruption of communities and their means of subsistence.

EMERGENCY MEDICAL RESPONSE MEASURES

In the United the U.S. Geological Survey publishes hazard evaluations of volcanoes in the Cascade Range (e.g. Miller, 1980) and organizes workshops to inform local emergency officials. Undoubtedly, as many as possible of the world's volcanoes in populated areas should be closely studied though, for economic reasons, relatively few of them are likely to be regularly monitored for renewed activity. In some instances warning that a volcano has reawakened has been recognized from premonitory events, e.g. earthquakes or minor eruptive activity, but in many other cases (e.g. Mount Lamington in New Gunea and Arenal in Costa Rica) either no events occurred or they went unrecognized. If a major eruption is anticipated, a key problem is who should be evacuated and when, as volcanologists cannot accurately predict the size and timing of a pending eruption.

At the warning,. health workers must be involved in planning. Two types of medical functions can be distinguished. First, the undertaking of traditional emergency tasks (evacuation, treatment etc.) as in other natural disasters (e.g. floods), and second, a coordinating intelligence activity requiring more specialized expertise. The first function can readily be performed by local emergency services and, since general guidance can be obtained from disaster manuals or other sources, this aspect will not be described further. Should a major eruption occur, workers involved in the intelligence function need to be physically present at a center co-ordinating the overall emergency response among the different agencies so that information on health matters can be rapidly obtained and from where authoritative statements can be disseminated to the public. A model center was established for the Mount St. Helens eruptions in 1980 by the Federal Emergency Management Agency whose bulletins on Mount St. Helens (1980) should be consulted by anybody involved in future volcanic disasters. The kinds of activities the medical group will perform are described in Table 1,

Emergency ash analysis

Analysis of ash should be undertaken on bulk samples and also on the respirable portion (below 10 um in diameter), preferably collected by personal or static monitoring devices. Bulk specimens

Table 1. Outline scheme of medical measures requiring co-ordination in an eruption

Emergency ash analysis
Collection
Acute Toxicity (pH, F, ect).
Particle size
Free silica, fibers, radioactivity.
Emergency air monitoring
Particulates
Gases – aerosols
SO_2,HCL, HF, CO, CO_2, H_2S
Emergency medical mensures
Casualties (injuries, deaths)
Hospital surveillance
Occupational protection
Masks
Water and food supplies
Sewage disposal
Evacuation

can be collected for analysis from any clean horizontal surface, e.g. benches and patios. Bulk specimens must be free from contamination by road dust, earth, or other materials. Ash should be collected as soon as possible after it has fallen to prevent its becoming contaminated or rained upon, but this may not be possible if rain accompanies an ash cloud. If an ashfall can be anticipated, a clean plastic sheet can be laid on a horizontal surface (e.g. a hospital roof), and the ash then can be easily collected and transfered into containers for shipment to the laboratory. These collections should be repeated to check for changes in the nature and quantity leachates as the eruption continues. Collections downwind at different distances from the vent may also emphasize differences in chemical character of the leachates. Leachate studies, ineluding pH measurements, should be conducted as soon as possible to determine the levels of leachable toxic substances, expecially fluoride, This is the most important testing to be performed concerning acute toxicity to humans (via dringking supplies from surface waters) and foraging animals. The particle-size distribution, as determined by fractionation techniques, would indicate to what degree the ash is respirable. As well as the usual mineralogical analyses (Fruchter *et al.,* 1980). careful X-ray examination for the presence of free silica (quartz, cristobalite and tridymite) should be performed. The presense of plagioclase feldspar may interfere with these estimations, and the appropriate methodologies have been described (Green *et al.,* 1981). Fibrous minerals should be excluded by seanning electron microscopy; large numbers of asbestiform fibers might pose a lung cancer hazard as can the gas radon. Radon is realeased during eruptions, and its radioactive daughters act like particulates in being able to adhere to falling ash and to lodge in the respiratory tract No hazardens levels of radioactivity were found in Mount St. Helen's ash (Soldat *et al.,* 1981).

The health status of domestic animals living outdors in the ash should be monitored, as the bilogical availability of toxic substances may not be apparent in leachate studies. Illnesses arising in animals, including respiratory problems, which are not a result of starvation should be alerting to a potential human hazard from the ash.

Emergency air monitoring

In the U.S. and other industrialized countries, air monitoring sations are located in many cities for monitoring total suspended particulates and SO_2 (Holland *et al.,* 1979). However, these stations monitor air pollution from fossil fuel combustion in cities and are not readily adaptable for use in evaluating the health impact from volcanic eruptions, their main drawback being that they may not be located where needed, particularly for gas measurement at ground level. Acceptable limits for community exporsure to SO_2 are shown in Table 2 (World Health Organization, 1979); no limits are established for community exposures to the other gases shown. The evacuation of the elderly, chronic sick, or patients with pre-existing respiratory disease may be necessary should these levels be regularly excceded. Residents in the vicinity of the plume from the Masaya Volcano are, at the time of this writing, being exposed to air concentrations of SO_2 as great as 1 ppm Stoiber *et al.,* 1981a), levels at which the evacuation of entire communities should be considered.

Table 2. Permissible exposure limits (NIOSH recommendations) for occupational exposure to principal volcanic gases, and WHO-recommended mean SO_2 limits for community exposure (work shift average is a time-weighted average over a work shift of up to 10 hr/day, 40 hr/week), in parts per million (ppm)

	Occupational (ppm)		Community (ppm)	
	Work sift Average	Celling	24-hr	Annual
Irrtants				
SO_2	0.5	–	0.05	0.02
HC1	–	5	—	—
HF	3	6	—	—
Asphyxiants				
CO	35	200	—	—
CO_2	10,000	30,000	—	—
H_2S	–	10	—	—

Measurements of occupational exposures to particulates are important for workers such as cleanup crews, rescue workers, police, etc. who have to work outdoors in the ash. The National Institute for Occupational Safety and Health's criterion for maximum occupational exposure to free silica is 50 g of respirable free silica/m^3 of air for up to a 10-hr workday and a 40-hr week over a lifetime (Mackison *et al.,* 1981). This level was regularly exceeded in outdoors workers in some areas immediately after the Mount St. Helens eruption on 18th May 1980, and respiratory protection was recommended. Geologists and others working in or near craters or fumaroles should ensure that their exposure to ash and the gases shown in Table 2 are all within safe limits or that the appropriate respiratory protection is used; CO, CO_2, and H_2S can pass through the canister-type masks usually worn by these scientists. *CO and H2*S are particularly dangerous, the latter—at high concentrations—leading to very rapid unconciousness. Geologists and rescue workers need to be aware that at altitudes over about 2,400 m (8000 ft), the cold and the reduced barometric pressures may accentuate health problems with gases in addition to the better known risks of altitude sickness (Heath and Reid, 1981).

Emergency medical measures

Preplanning should include location and staffing of triage centers and referral hospitals for the injured if casualties are invisaged. Survivors with severe burns and inhalation injuries of the lungs must be anticipated. All survivors of a severe eruption who were close to the volcano should be examined and the clinical and exposure details recorded. The locations of the survivors and the dead at the time of the eruption, and the condition of nearby trees, equipment, cars, etc., should be noted for the purposes of studying factors relating to survival. An emergency field morgue will be necessary if there are many deaths, and autopsies should be performed whenever possible to establish the nature of injuries and cause of death. A hospital surveillance system in ashfall areas is an invaluable intelligence network for monitoring health problems, whether due to respiratory, infectious, accidental or other causes (Baxter *et al.,* 1981). Hospitals should be contacted for daily reports of the numbers of, and diagnoses for patients attending emergency rooms and being hospitalized. Any marked deviations in the daily numbers of cases compared with those in previous weeks and, if the figures are available, in the same period in the previous year, would be alerting to new hazards which might warrant investigation or special preventive measures.

Preventive advice and appropirate protective equipment (e.g. masks and goggles) should be given to emergency and cleanup workers who have to work outdoors and be heavily exposed to ash. Masks must be available for the general public. Low-cost, high-efficiency, disposable masks are now widely available in the U.S. and were distributed in ashfall areas in Washington after the 18th May eruption; in the future they should be distributed before an impending eruption. People should be advised to stay indoors during an ashfall or periods of heavy resuspension of ash and to wear masks if they must venture outside. Where possible, houses should be made weatherproof, though fine ash usually infiltrates inside, and outside-air intakes in homes and offices should be closed during ashfalls.

Water supplies should be monitored for turbidity, bacterial counts, toxic elements, and pH. Standard chlorination procedures will usually prevent bacterial contamination of drinking water. The quality of milk supplies from cattle that forage in the ash should also be checked. In addition, ash with a high fluoride content might contaminate growing vegetables. Special measures to protect the public health by preventing water shortages and the breakdown of sewage treatment plants may need to be instigated.

Other measures

In remote areas in developing countries, a major eruption may cause such great losses of crops and animals that the resulting famine may cause more deaths than the immediate effects of the eruption itself. Ensuring that adequate food supplies and medical aid reach such areas maybe the most important task that the relief teams can undertake. Inevitably, serious problems will arise if communities have to be abandoned because of the threat of continuing eruptions.

CONCLUSIONS

The main lesson for health workers from the Mount St.. Helens disaster is that a wide range of community and occupational health problems can arise from volcanic eruptions. It must also be remembered that the eruption of Mount St. Helens was important but not exceptional, other eruptions this century (e.g. Santa Maria, 1902) erupted 10–20 times greater volume of tephra in the same time period. Unfortunately, in developing countries where most of the dangerous eruptions are expected to occur, the appropriate emergency responses may be difficult to mount for financial and organizational reasons. In more affluent countries, numerous agencies become directly or indirectly involved with public health measures after an eruption, and thus it is essential that the medical aspects are incorporated into emergency planning from the beginning. Unlike other natural disasters, such as floods and hurricanes, tephra and gases may pose problems requiring special expertise in environmental medicine for their solution. In future major eruptions in populated areas, medical workers and disaster epidemiologists, undoubtedly will face a broad scope of problems.

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EMERGENCY COUNTERMEASURES AGAINST DISASTER IN JAPAN

NAOKAZU TAKEMOTO
Director

Disaster Prevention Policy Planning Division
Disaster Prevention Bureau, National Land Agency

(1) EMERGENCY COUNTERMEASURES AGAINST DISASTER

Upon the breaking out of a disaster, or when such is anticipated the national administrative organs, local governments, and public corporations will proceed to take various emergency countermeasures to prevent or control such a disaster.

Once a disaster occur, the municipality will at first establish a Municipal Headquaters for Disaster Countermeasures to executive emergency operations. If necessary, the prefectural goverenment would establish its Headquaters for Disaster Countermeasures.

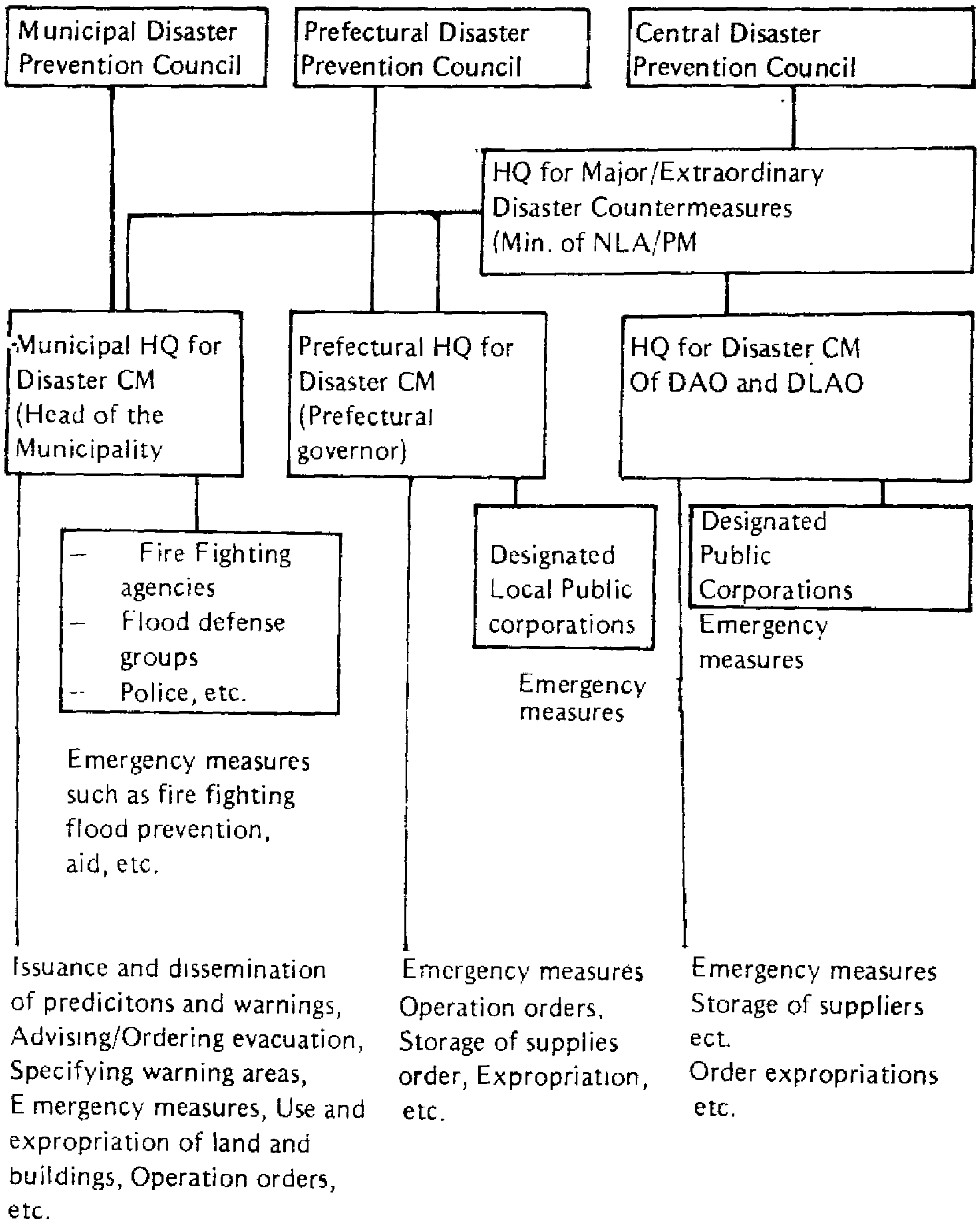
In the meantime, National Land Agency will make the assessment of its gravity, and if deemed necessary will call up the Meeting of Ministries and Agencies related to Disaster Countermeasures for exchanging pertinent information. Should the need be recognized, the national government would establish the Headquaters for Major/ Extraordinary Disaster Countermeasures, in accordance with the Disaster Countermesures Basic Act, and proceed to execute a comprehensive disaster emergency countermeasures.

In order to carry out such emergency countermeasures smoothly and promptly, the administrative organs on each level from the national, prefectural, to municipal have prepared Plans for Emergency Countermeasures in order to cope with disaster.

(2) COUNTERMEASURES IN IZU–OSHIMA IS. ERUPTION NOVEMBER 1986

Izu–ozhima Is. erupted from the crater at 17:25 November 15, 1986. Chasm eruption occured from the crater at 16:15 November

Main Emergency Measure to be Taken upon a Major Disaster



CM : Countermeasures
DAO : Designated Administrative Organs
DLAO : Designated Local Administrative Organs
PM : Prime Minister
NLA : National Land Agency

21, 1986. At 17:46 chasm eruption occured at outside of somma. Lava flew down to Motomachi town and volcanic smoke reached 10000 meters high. Earthquakes of intensity V occured twice. Eruption calmed down at November 23.

Izu–ozhima Municipal Headquarters for Disaster Prevention was established at 17:22. Ordering of evacuation was issued to Okada and other 4 districts residents at 17:57 by Mayor of Oshima town. At 20:23 ordering of evacuation to outside of Is. was issued to all residents of Izu–Oshima Is. .

Tokyo metropolitan government established Headquarters for Disaster Prevention at 19:00. The headquarters requested to sail vessels to Maritime Safety Agency, Maritime Self–Defence Force and Tokai Kisen Line. 23 patrol boats of M.S.A., 12 vessels of M.S.D.F. and 6 passenger ships of Tokai Kisen Line were departured toward Izu–Oshima Is. at 19:00. 13 vessels shuttled between Is. and mainland 17 times. 10476 persons except 314 persons belong to disaster countermeasures divisions boarded to Tokyo and Shizuoka pref.

National government established 1986 Izu Oshima Is. Eruption Disaster Headquarters for Disaster Prevention in National Land Agency at 23:45.

Tokyo Police Department established Headquarters for Disaster Prevention and mobilized 20000 officers. Maritime Self Defence Force mobilized 8300 officers, 30 vehicles, 230 airplanes and 60 patrol boats by the request of Tokyo Metropolitan government in 32 days from November 21 to December 22. Maritime Safety Agency mobilized 23 patrol boats from November 21. M.S.A. carried refuges and patients by vessels and helicopters. Helicopter carrier patrol boat permanently stationed in offshore of Is. after all residents came back to Is. Tokyo Fire Department mobilized 12084 fire fighters. They were involved evacuation activities and fire fightings. From 24 to 26 of November, lava cooling operation was taken.

Disaster Relief Act was issued to Oshima town and settlement of refuges places, supplement of foods and other materials were offered.