U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Discussions and Recommendations from the Workshop on the Impacts of Volcanic Ash on Airport Facilities, Seattle, Washington, April 26-28, 1993

by

Thomas J. Casadevall

Open-File Report 93-518

1993

DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
DALLAS L. PECK, Director

For additional information write to
Chief, Volcanic Ash and Aviation Safety Project
U.S. Geological Survey
Box 25046, MS 903
Denver Federal Center
Denver, CO 80225

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

CONTENTS

Volcanic Ash and Airports

INTRODUCTION

Volcanic ash consists of finely fragmented particles of rock, minerals, and aerosol droplets generally less than 2 millimeters in diameter (less than 0.063 mm diameter for fine ash) produced by explosive volcanic eruptions. Volcanic ash injected into the atmosphere to altitudes exceeding 30 km (100,000 ft) may impact areas for hundreds to thousands of kilometers downwind from the volcano. Ash particle size of fallout generally decreases with distance from the source volcano. Physical properties of volcanic ash which make it especially harmful to aviation operations include its small grain size, hardness and abrasive nature, ability to hold an electrostatic charge, and ability to adsorb water and droplets of corrosive acid aerosol. Because of these properties, ash presents a number of unique problems when efforts are made to remove ash during the cleaning process.

Drifting ash can contaminate large volumes of airspace and threaten the safety of aircraft in-flight. Eventually ash will settle to the ground. Ashfall on aerodrome facilities will affect airport runways, taxiways and aprons, buildings, ground services, electrical utilities and communications facilities as well as airplanes parked on the ground. Returning these facilities and airplanes to normal service following an ashfall requires the removal and disposal of ash and the cleaning of surfaces, facilities, and airplanes.

Many airports have detailed plans for removal of snow, but few have any plans for dealing with volcanic ashfall. The majority of efforts to clean up ash at airports have been carried out on an ad-hoc basis relying heavily on local ingenuity and resources to achieve cleanup. While volcanic ashfall may be considered a rare event, the growing number of experiences with the problem requires that the aviation community be better prepared to deal with issues of ashfall at airports.

To document experiences in this area and to facilitate the exchange of information about this problem the Workshop *Impacts of Volcanic Ash on Airport Facilities* was convened at Seattle, Washington from April 26-28, 1993. The Workshop was coordinated with the Embry-Riddle Aeronautical University Emergency Services Seminar and hosted by the Port of Seattle. Fifty-three people participated in the Workshop (Appendix 1). The goal of the Workshop was to enhance aviation safety through exchange of information about proper removal and containment of volcanic ash at airport facilities. The Workshop included technical presentations covering experiences with cleanup of volcanic ash at airport facilities, followed by discussions in working groups which addressed four topics:

Surfaces
Electronics and communications systems
Emergency services
Airplanes and support vehicles.

This report summarizes the technical presentations and the recommendations for operating and cleanup procedures brought forth by the working groups. To make Workshop results available quickly, discussions and recommendations are summarized as a U. S. Geological Survey Open-File Report. Copies of this report can be obtained by writing: Chief, Volcanic Hazards and Aviation Safety Project, U.S. Geological Survey, Box 25046, MS 903, Denver Federal Center, Denver CO, 80225. The report may be purchased by contacting the Books and Open-File Reports Section, U. S. Geological Survey, Box 25425, Denver Federal Center, Denver, CO, 80225.

The United States Geological Survey (USGS) is the principal U. S. Government agency concerned with the impact of volcanic activity on life and property (Wright and Pierson, 1991). Many of the techniques and solutions which here focus on airport facilities apply equally well to other municipal and public services involving electrical and communications facilities, transportation activities (highways, railroads), as well as activities pertinent to the general public welfare, domestically and internationally. For an overview of volcanic hazards, the reader is encouraged to consult Volcanic Hazards: a sourcebook (Blong, 1984). A comprehensive review of volcanic ash is Volcanic Ash (Heiken and Wohletz, 1985).

EFFECTS ON AIRPORTS

Over the past 50 years, about 20 eruptions from volcanoes in 7 countries have produced ashfall which interrupted airport operations and caused approximately 40 airports to close temporarily for periods of hours to weeks (Table 1). The majority of these eruptions have been since 1980. The first documented closure of an airfield owing to volcanic activity was in 1924 when the Kilauea Military airfield in Hawaii was closed by fallout of large ejected blocks from the May 24 eruption of Kilauea Volcano (Blong, 1984). The first eruption that damaged modern aircraft and airport facilities was the March 22, 1944 eruption of Vesuvius volcano near Naples, Italy. Coarse ash from that eruption damaged 88 B-25 Mitchell Bombers (Lloyd, 1990). About 20 aircraft were returned to operation within a month of the eruption (New York Times, April 25, 1944, p.4). In addition to the United States and Italy, other countries which have had experiences with volcanic ashfall and airport facilities include the Philippines, Japan, Indonesia, and Argentina (figure 1).

UNITED STATES

In the United States, three recent eruptions have had a broad impact on aviation operations, especially on airports. The 1980 eruptions of Mount St. Helens disrupted air traffic and caused closing of airports in the Pacific Northwest. In Alaska, the 1989-1990 eruptions of Redoubt Volcano and the 1953 and 1992 eruptions of Spurr Volcano affected aviation operations in the State, especially in the Anchorage area.

Anchorage is a major hub for north Pacific air traffic and is home to three major airports: Anchorage International Airport (AIA), Elmendorf Air Force Base, and Merrill Field. These three airports were affected by ashfall from eruptions of Spurr Volcano in 1953 and 1992, from Mt. Augustine in 1976 and 1984, and from Redoubt Volcano in 1989-1990. The July 9, 1953 eruption of Spurr deposited from 3 to 6 mm (1/8 to 1/4 in) of ash at Anchorage and closed Anchorage Airport, Merrill Field, and Elmendorf for several days (Juhle and Coulter, 1955; Wilcox, 1959). The 1989-1990 eruptions of Redoubt produced light ashfall in Anchorage on December 15 and 16, 1989 and on February 28, 1990; ash fell over an area just south of Anchorage on February 21, 1990. Kenai airport, located on the Kenai Peninsula, 80 km east of Redoubt, was closed for several days by ash fall from the Redoubt eruption of January 8, 1990. The loss of revenue from curtailed operations at Anchorage International Airport following the Redoubt eruption was estimated at $2.6 million (K. Burdette, AIA, written commun., 1990).

Anchorage, Alaska and the 1992 eruption of Spurr Volcano

Spurr Volcano, located 125 km west of Anchorage, erupted on June 27, August 18, and September 17, 1992 (AVO, 1993). The August 18 eruption deposited approximately 1/16" to 1/4" of ash in the Anchorage area and closed the three Anchorage airports for several days. The cost of cleanup efforts at Anchorage International Airport was approximately $250,000. (L. Michou, AIA, written commun., 1993); cleanup costs at Elmendorf were approximately $350,000 (USAF, 1992); and at Merrill Field were $53,000 (Stewart, 1993).

The first indication of the August 18 Spurr eruption was a pilot report received at 15:48 Alaska Standard Time (AST) stating that there was an ash-producing eruption at the volcano. The main stage of the eruption began at 16:42. The ash column from the eruption climbed to 14 km altitude and the cloud began to drift towards Anchorage. At 16:45, the Alaska Volcano Observatory notified Anchorage International Airport and Elmendorf Air Force Base of the eruption. Merrill Field, managed by the Municipality of Anchorage was notified by AVO through the State Department of Emergency Services. While small in volume, the eruption was large in impact as it effectively closed down the three Anchorage airports. The following section includes information about the effects of the August 18 eruption on the three Anchorage airports and how cleanup was carried out. These reports are transcribed here.

Summarized from presentations by Larry Michou (AIA) and from the Anchorage International Airport Action report by Wayne Gibson (AIA)

Due to ash fall, Anchorage International closed at 8:18 p.m. (AST) (20:18) on August 18. Crews on duty at the time of ash fall were instructed to discontinue use of all equipment. As much equipment as possible was moved indoors. Crews attempted to cover all intake stacks on heavy equipment but were called inside for lack of personal protective gear. All computer stations, printers and modems were covered to prevent damage by ash. Phone calls were made to oncoming crews advising them to remain at their residence until such time as work could begin removing ash. At approximately 8:30 p.m. (20:30) Mount Spurr stopped erupting.

By 10:40 p.m. (22:40), ash fall in the Anchorage area ceased. Field Maintenance crews were briefed on initial removal techniques that were to be attempted. The overall objective was to return the airport to operational status as soon as possible.

At mid-night a meeting of airport personnel was called to coordinate resources and get a long range plan into effect. At the meeting was Airport Safety Chief, Building Maintenance Specialist, Building Maintenance Foreman, Leasing Officer, Chief of Field Maintenance, and Manager of Operations. The Manager of Operations declared the airport to be in a state of emergency and instructed all sections to schedule work details and assignments accordingly.

An action plan was developed. Building Maintenance declared air ducts for the air conditioning system and the roofs of the terminals to be their first points of interest. A "top down" approach is needed. Field Maintenance identified runway 6R/24L and taxiways Kilo, Golf, Charlie and Juliet to be their top priority. Airport Safety assigned two 6,000 gallon water tankers with operators to Field Maintenance.

At approximately 1:00 a.m. (01:00) August 19th, a meeting was held to brief airport tenants on the action plan. The overall objective of returning the airport to operational status was discussed. Air carriers with passenger loading bridges were requested to use their trucks to clean tops of the bridges. They were also asked to move all aircraft and equipment away from the terminal building to allow the removal of ash from the terminal roof so that cleanup in the gates could begin. The air carriers complied with our requests and offered to help in any way possible.

Several fire plugs around the terminals were opened for filling tankers and in some locations inch and a half fire hoses were used to clean under passenger loading bridges and from the face of the terminal buildings. The air carriers offered to assist in any way to speed up the ash removal process. The Manager of Operations assured the carrier representatives that we would keep an open line of communication throughout the cleanup process. It was decided to communicate using the SITATEX communication system. A series of meetings were held throughout the day to brief airport tenants on developments as they occurred.

Ash depth was approximately 1/4 to 1/2 inch deep in undisturbed areas. It was quickly established that using water to dampen the taxiways ahead of the graders and brooms made a mud paste that clumped up and would not move far without becoming labor intensive. The decision was made to sweep dry ash and move as much as possible, then after the bulk of the dry ash was removed, flush the remaining ash with water. Experimenting with different removal methods, we found two ways by which to move the ash effectively. One method was to move the ash dry. This created air quality problems and dropped ash back on top of the terminals, thereby creating HVAC problems for building maintenance. A second method found to be effective was to completely saturate the ash and attempt to float it with large quantities of water.

Field Maintenance laborers and Building Maintenance personnel began to move ash from around the domestic terminal roof and aircraft parking gates. Field Maintenance laborers, using one of the Airport Safety's tankers, washed ash from the face of the terminal and away from the gate areas so that it could be picked up by curb brooms. The average time that it took to fill a curb and gutter broom sweeping on the ramps was less than 5 minutes. The airport's 20 cubic yard snow haulers were brought to the aircraft parking ramps and placed in locations that allowed the curb and gutter brooms to dump into the trucks rather than spend 5 minutes sweeping and 20 minutes running to designated dump sites.

Field crews continued to remove ash from runway 6R and around the aircraft parking gates until about 4:00 a.m. (04:00) (on August 19) at which time the wind picked up from the southeast to about 10 to 15 knots. It was determined that blowing ash was re-covering the runway as fast as crews were removing it. Combined with the high wind as well as concern for safety of personnel and equipment, removal efforts were stopped until the wind calmed to a point where effective removal techniques could be applied. Equipment at that point was brought into the shop compound and flushed with water and a preventive maintenance program was activated. It was established by Equipment Maintenance that four hour increments would be the maximum time between air filter changes.

Building Maintenance personnel rigged a compressor with a hose on top of the building to start complete ash removal. The dust that was generated by this action caused immediate problems with the air intakes for the HVAC systems. Initially, areas in front of the air intake ducts has been cleaned so building crews could selectively run HVAC systems. To solve the problem additional filtering was added to combat ingestion problems. Ash from the roofs was hand swept into piles and placed in plastic trash bags and stacked in various locations on the roof for later disposal. Concerns were raised regarding the dead load dangers the ash represented for the roof structures. This was investigated by Building Maintenance personnel and it was determined not to be a problem.

Custodial crews began sweeping and flushing sidewalks leading to the entry doors into the passenger terminals. This greatly reduced the amount of ash that would have been tracked inside the buildings. Care had to be exercised in washing ash into drain systems as they tended to plug quickly with the heavy ash.

Operations and Field Maintenance personnel obtained a 2 inch hose to wash the upper level of the parking garage. Ash was washed to the curbs and into piles for later collection. Curb and gutter brooms that the airport used for street cleaning could not be taken to the top level of the garage because of height restrictions. Subsequently, most of the ash was removed by field laborers shoveling ash into pickup trucks and transporting it to a stockpile behind the Field Maintenance Compound. The remaining residue on top of the garage was hosed into the drainage system which caused clogging in the sump at the bottom of the parking garage. Cleaning the sump was in itself labor intensive as it had to be done by hand with a five gallon bucket. Small sweepers were located and tried on the top of the garage. This proved to be ineffective and there use was abandoned.

At approximately 8:00 a.m. (08:00) (on August 19) the wind calmed enough to allow Field Maintenance to resume ash removal from the aircraft operational surfaces. Runway 6R/24L and Kilo Taxiway were the first areas to receive concentrated efforts. Several removal techniques were reassessed in the daylight to see which methods proved most effective. What we found confirmed that there were two ways to handle the ash. You either had to move it completely dry or completely saturated with water. Moving the ash dry with the airfield brooms put large concentrations of dusk back into the air which drifted back over areas that were cleaned previously and had a tendency to plug the air ducts around the terminals. This method was later abandoned.

No accurate estimate can be made as to how much water was used to flush asphalt and terminal surfaces. The airport used all of Airport Safety's tankers (6000 gal. each) and their fire trucks (1500 to 3000 gal. each). By late morning, water pressure at the airport began to drop below levels considered to needed for fire protection. It was later determined that water pressure drops were caused by high residual and commercial uses in the city to clean driveways, roofs and sidewalks. Alternate methods for refilling tankers were needed. The problem was solved by drafting water out of Meadow Lake on the south side of the airfield and from Lake Hood.

Airfield crews used snow removal techniques in the operation of ash removal. Three graders and runway brooms would sweep water saturated ash as far as it could be swept then bermed ash was loaded into trucks and hauled to a dump site on the airport. Water trucks flushed the areas that the graders and runway brooms covered. Runway 6R/24L was re-swept and flushed with water more than six times before it was considered safe for use by aircraft. Approximately two hours before 6R/24L was reopened (runway 6R/24L was reopened at 4:00 p.m. (16:00), 20 hours after closure of the airport) air carrier representatives were given the opportunity to visually inspect the runway and access routes on the taxiways and decide whether they could operate their aircraft safely. Given that the airfield crews work together year round and are familiar with communication routines greatly enhanced the speed and continuity with which crews were able to respond.

An established preventive maintenance program assured that all equipment continued to operate without failure throughout the entire event. The Alaska Volcano Observatory sent, via fax, information about Mt. Spurr to Airport Safety that kept the airport updated on the size and location of the ash cloud and on the current level of concern for another eruption event. The use of the SITATEX communications system kept the air carriers up to date as areas were closed, reopened and the next work section was defined.

Water trucks, fire trucks, and mobile sweepers from other maintenance stations and from private contractors worked around the clock until all areas were considered usable for aircraft. The general aviation community on the airport were given access to a mobile wash down station that did a roving patrol throughout the small plane parking lots for one entire weekend. The tank truck supplied water for those private aircraft owners on the airport who wished to wash the ash from aircraft skins and control surfaces. The roving tank truck started the operation with only one wash-down hose. It became apparent very quickly that our wash schedule for each lot was in serious jeopardy. The wash truck was modified to a three hose setup which made the operation much faster. Some plane owners grew tired of waiting for the truck to get to their lot and towed aircraft to other lots. Overall this probably helped to speed up the final results but slowed down the scheduling and a couple of times tempers flared. A semi-permanent station was established outside the Field Maintenance Warm Storage and remained in service until the final cleanup was completed.

All of the ash residue that we accumulated throughout the cleanup had to be dealt with as final cleanup came to a close. We collected all the ash that had been swept, loaded, hauled or put into plastic trash bags, and took it to one central point behind the Field Maintenance facility. Various airport tenants and local citizens started to complain vigorously that all the ash being blown about by the winds in the area was coming from our pile. We attempted to keep it wet but as soon as the sun would come out the surface layer would dry and we were faced with the same problem again. One of the local sand and gravel outlets wanted to try utilizing the ash for a commercial enterprise with the stipulation that we haul it to their location, which we elected not to do. There were work requests made prior to the eruption of Mt. Spurr from the Federal Aviation Administration to fill some low-lying areas on localized fields and to remove material from dirt mounds in the area. This worked as a benefit to both the airport and the Federal Aviation Administration, we had plenty of fill material (ash) to fill in the holes and the mounded material was used to cover the ash and seal it so that it would not blow into the air and add to air quality problems.

Thanks are due to the air carriers and their authorized representatives for listening to what the airport had to say and offering their assistance. This teamwork approach by the air carriers and the airport greatly increased access to resources. Direction, dedication, communication and cooperation by all parties to complete the amount of work it took to get the airport operational in such a short period of time, speaks highly of all parties involved. It was in the common interest of all concerned to get the airport operational as quickly as possible, and all parties cooperated toward that end.

From presentation by Robert Hartnett (Alaska Airlines), Effects of ashfall on Airline Operations:

As an airline operator, when there is an ashfall, it is important to contact media immediately to encourage people to stay at home; to reduce the number of passengers in gateway cities. During the August 1992 Spurr eruption, there were between 400-500 people on standby for 3 days. To handle these situations, it is important to have an active plan in place and a single point of communications. It is also important to know seating capacity, number of standby passengers, establish an order of passengers, and volume of cargo and mail. Stick with this plan until normal operations are resumed.

Elmendorf Air Force Base
From: Final After Actions Lessons Learned Report of Mount Spurr Volcano Eruption, December 22, 1992 (USAF, 1992)

The 3rd Wing Operations Center, Elmendorf AFB, received notification by phone from the Alaska Volcano Observatory at 16:45 (AST) on Tuesday, 18 August 1992, of a volcanic eruption of Mt. Spurr. Winds were blowing directly from Mt. Spurr toward Elmendorf AFB and ashfall was expected to cover the Anchorage area beginning within a two-hour period. Within two minutes the 3rd Wind Operations Center staff had contacted the Wing Commander, notified higher headquarters, and initiated a recall of the Wing Battle Staff and Survival Recovery Center personnel. Coordination with local civilian authorities was also accomplished. By 17:45, the command and control elements were aggressively following pre-established guidance to mitigate damage and protect personnel, equipment, and material. At 18:00, announcements were broadcast over both the base public address and base television cable override systems notifying personnel of the danger and providing instructions on protective measures. These messages were broadcast every fifteen minutes through the first hour of ashfall.

By 19:07, when ash began falling on Elmendorf AFB, 28 aircraft were evacuated to other bases, 70 aircraft were sheltered in hangars, and 6 large-frame aircraft parked on ramps were sealed for protection from the ash. Upon completion of these protective measures, all but essential personnel were released from duty with instructions to go home and stay inside until recalled by telephone or radio announcement.

Clean-up officially started shortly after ashfall ceased at 22:40 on Tuesday, 18 August 1992. Base residents were employed in clean-up on Wednesday, 19 August 1992, with extended duty hours. All assigned Elmendorf AFB personnel were employed for clean-up efforts 20-22 August 1992 with extended duty hours. Heavy equipment was used 24 hours per day under a systematic schedule of airfield during the day, then airfield and roads at night. This method worked well in an effort to limit the recurrence of airborne ash. Base clean-up details ended at 18:00 on Saturday, 22 August 1992.

Equipment ranged from push brooms and snow shovels for manual removal to heavy equipment such as runway brooms and sweepers and front-end loaders. Much equipment was supplied laterally through other organizations. On-hand masks and protective equipment were used to the maximum extent before local purchases were made. On hand stocks of clean-up equipment and personnel protective gear may need to be increased due to the lack of availability of these items in the local market when disaster strikes.

There were no significant casualties related to the natural disaster. Three people were treated for respiratory problems and released during the three-day period. Several individuals suffered blisters as a result of the manual ash removal detail.

Damage to facilities/estimate of property damage: HVAC systems were dirtied with the heavy ash deposits and required either intense cleaning or replacement. The HVAC system at the 3rd Medical Center sustained the most damage. Cleaning costs are estimated at $250,000.

Estimate of direct expenses incurred was approximately $350,000 (includes $250,000 for the 3rd Medical Center). This amount does not include man-hours, fuels, etc., expended for clean-up.

Merrill Field Airport *(extracted from Stewart, 1993)*

Merrill Field Assistant Manager related that Merrill Field had a problem with ash blowing from one leaseholder to the next leaseholder. The ash removal was treated like a snow removal operation by wetting down the ash and using a vacuum sweeper. By mid-morning on the 19th, the field became operational. The first day after the ashfall realized only 12 operations. By the 3rd and 4th day, there were between 40 and 50 operations. After that, operations progressed to approximately 3/4 of normal. Return to our prior operations level may take additional time. Runways, taxiways and most of the MOA owned aprons have been cleaned. Leaseholders are required to clean their own lots. Problems were experienced in picking up the ash and depositing it in a proper location. Merrill Field and Street Maintenance are utilizing Merrill Field property at 15th and Merrill Field Drive near Lake Otis. Public Works will cover the ash to keep it from blowing away.

Grant County Airport, Washington and the May 18, 1980 eruption of Mount St. Helens

The May 18, 1980 eruption of Mount St. Helens deposited ash over a wide region of the Pacific Northwest and closed airports at Spokane, Yakima, and Grant County, WA, Pullman, WA-Moscow, ID, and Missoula, MT for several days to 2 weeks (Schuster, 1981, 1983; Warrick and others, 1981). The May 25 and June 12, 1980 eruptions each deposited trace amounts of ash on the Portland metropolitan area and disrupted operations at Portland International Airport for several days (R. Bullock, Port of Portland, personal commun., 1993).

Summarized from presentation by David Bailey (Grant County)

The Grant County Airport, located in central Washington, is approximately 120 miles from Mount Saint Helens. The airport, formerly known as Larson Air Force Base, contains over 4,500 acres. The main runway is 13,500' x 300' and the cross-wind runway is 10,000' x 100'. The airport is extensively used as a research and development, heavy jet training facility by a number of air frame manufacturers and air carriers including the Boeing Company, Japan Airlines (JAL), McDonnell Douglas, McChord Air Force Base, Alaska Airlines, Big Bend Community College and a number of other foreign and domestic air carriers.

The amount of volcanic material that eventually was deposited from the May 18, 1980 eruption at the Grant County Airport ranged from 3-4 inches of fine powder ash. Since it was on a Sunday, aircraft were parked in hangers. Tail sections of 747's sticking out caused major cleanup problems and spring winds exacerbated problems. Four inches of ash did not cause any structural problems at the airport.

Initial cleanup proceeded by plowing with snowplows, but this did not work well and was like pushing talcum powder. If too much water was added to the ash, it behaved like soup. A moderate amount of water makes it like balls of clay, which can be pushed around.

The standard procedure which evolved was to spray the contaminated surface with water; windrow the ash with a grader; scoop up with front-end loader and loaded into dump trucks for hauling to disposal areas. Disposal of the ash was by spreading it out in the fields, where grass grew well and stabilized the ash. Fortunately a pavement contractor was available for this massive haulage job. While the pavement itself was clean, there were still big problems for areas adjacent to the runway where ash was continuously stirred up by wing-tip vortices. These adjacent areas were controlled by sprinkling the ash during the night.

After two weeks, it was determined that it was safe to operate at Grant County Airport on the main runway. Very little rain normally falls in the area at this time of year, but a late May rainfall helped stabilize the ash. JAL continued to train, but rotated training craft out every 30 days, rather than every 90 days. One of the big problems in the area was a shortage of filters and an adequate water supply. The airport was back in operation within thirty days.

PHILIPPINES

Ash from the June 15-16, 1991 eruptions of Pinatubo volcano closed civilian airports at Manila, Puerto Princesa, and Legaspi City and military air fields at Clark Air Base, Basa Air Base, Sangley Point Air Field, and Cubi Point Naval Air Station. In addition to effects on the airports, the drifting cloud of volcanic ash from the eruption was encountered by at least 16 jumbo-jetliners in the 24 hours after the eruption. The range of effects of this eruption on aviation operations is discussed in a paper by Casadevall and others (in press).

Cubi Point Naval Air Station and the June 12-16, 1991 eruption of Pinatubo

The principal damage to Clark, Cubi Point, and Basa was related to accumulation of from 15 to 20 cm (6 to 8 in) of coarse, sand-size ash on airport surfaces and buildings. Heavy rains associated with Typhoon Yunya also fell at the time of the eruption and saturated the ash significantly increasing the loading on roofs and other surfaces. As the ash dried it became indurated to the point where removal became very difficult and costly. In addition, a large number of airport buildings including hangars, warehouses, and operations facilities at Clark, Cubi Point, and Basa collapsed under the weight of the ash. Buildings which remained standing were usually those where ash had been removed as it fell.

A secondary effect of the ash was its corrosive nature. Corrosive gases such as SO_2 acidified the rainfall and caused corrosion of metal-roofed buildings, airport electrical systems, ground service equipment, and aircraft which were not properly cleaned immediately after the ashfall.

Advance warning of the eruption enabled U.S. Air Force officials at Clark to evacuate jet aircraft before the first explosive eruption on June 12. However, a squadron of eleven F-5 fighter jets of the Philippine Air Force at Basa Air Base were covered by ash from the June 15 eruption. At Cubi Point Naval Air Station, many aircraft had been evacuated in anticipation of Typhoon Yunya. However, several aircraft on the ground were covered by ash. The accumulation of water-saturated ash on the wings, horizontal stabilizers, and fuselages of these aircraft tilted them back on their tails and caused minor damage. The water-saturated ash weighed approximately 32 pounds per square foot (R. Rieger, USN, personal commun., 1991).

The greater thickness of ash (15 - 20 cm vs. 0.5 cm) which fell in the Olongapo-Subic Bay area required a considerably more intensive effort for ash removal from Cubi Point than at Manila International Airport. USN officials at Cubi took an aggressive, proactive approach to ash removal and utilized a contingent of 1800 personnel of a U.S. Navy Construction Battalion (Seabees) who were at Subic Bay in transit to the United States from Operation Desert Storm. In addition to the Seabee battalion there was a full complement of earth-moving equipment at Cubi, thanks again to Desert Storm.

Officials at Cubi successfully addressed many of the same problems with ash that faced base commanders at Clark and Basa. In the Cubi case, however, there was a readily available source of trained manpower and there was a highly motivated, aggressive effort to remove the ash. In the case of Clark, renegotiation of the base lease with the Philippine government was underway and there appeared to be little motivation to clear and re-establish use of the airfield. An added complication at Clark was the repeated ash fall from frequent secondary explosions during the rainy seasons in 1991 and 1992. Secondary explosions occurred when heavy rainfalls saturated the thick, still-hot accumulations of pyroclastic material on the slopes of the volcano deposited from the June 1991 eruptions. Secondary explosions in 1991 and 1992 occurred with no precursory seismic activity and produced ash clouds which often reached to 60,000 ft. Ash from the secondary explosions did not affect Cubi Point.

Summarized from presentation by Bruce Wood (USN) and Daniel Harrigan (USN)

Naval Air Station (NAS) Cubi Point is located on the south shore of Subic Bay 40 miles northwest of Manila and 19 miles south of Pinatubo. The air station was originally carved out of the jungle and mountainous terrain in the 1950's by Navy Seabee construction battalions and covered in excess of 20,000 acres. As the Navy's hub in the Western Pacific, the airfield operated around the clock in direct support of in-theater aviation units handling every aircraft in the Department of Defense inventory as well as 747's, DC-10's and DC-8's. The single runway (07-25/8000 ft x 200 ft) was flanked to the North by transient tactical aircraft parking adjacent to the aircraft carrier piers and to the south by hangars, terminals, rework facilities and aircraft ramps.

Three days before the eruption, the prediction by scientists was that the eruption would be 5-10 times larger than the 1980 eruption of Mount St. Helens. The plumes from June 12 eruptions drifted to the west and had little affect at Cubi NAS. The prediction of arrival of a typhoon motivated the base commander to evacuate people and aircraft in advance of the typhoon. About 1/4" of ash fell on Cubi from the June 12-14 activity, and with continuing ashfall on June 14, the airport was closed. Only a few aircraft were left on the ramp uncovered. The typhoon reversed wind directions about the time that the climactic eruption occurred and on June 15, 1991, "Black Saturday", darkness, lightning, and heavy ashfall with torrential rain came to Cubi. By Sunday morning there was 8-12" of ash, which together with torrential rains gave the new deposits the consistency and feel of wet concrete.

Following the end of ashfall, the focus of effort was to open the airfield for relief operations to bring in supplies and to ship people out.

The ash-covered pavement was very slippery for planes and cars, but there were few problems working around suspended ash. There were problems with repressurization of aircraft due to damage to seals. Crews undertook to clean roofs along with runway cleaning. There was a need to educate heavy equipment operators about protocol of working on an airport. During heavy rains, the water-saturated ash flowed everywhere; the berms were stabilized with sandbags. Planes were covered with tarps and plastic sheeting.

Roof collapse in the warehouse complex was common problem. These had corrugated metal roofs. However, few buildings along the flightline were lost since crews were cleaning immediately. New K-span buildings were put up to cover material salvaged from warehouses and equipment. These could be put up in a day and were easy to clean.

Many methods were used to accumulate the ash into piles where it could be picked up and put into dump trucks and hauled away. Brooms and shovels were used to sweep roofs and walkways. Bobcats (short wheelbase loaders) were invaluable in tight quarters and replaced many people with shovels. Sweeper trucks were used for final finishing. Fire vehicles and firemen moved a lot of ash with high-pressure hoses. Water was a problem and the base reservoir was quickly drawn down by the heavy load. In addition to the air station, virtually everyone else at the Subic Bay Naval Facility was using water for their cleanup. Eventually the air station got around this problem by pumping water for air field clean up directly from the bay. It was especially important to keep ramps wet to reduce suspended ash.

After experimentation with sweepers and washing, officials settled on a standard procedure where ash was first plowed into furrows using road graders. The accumulated ash was then loaded into dump trucks and dumped at the southwest edge of the runway in an area that had previously been designated for land-fill as part of a plan to expand the Cubi Point facility. The scraping-loading-dumping operation still left a residue of fine ash on the runway surface which was swept and washed onto grassy infield surfaces where it was sprayed with emulsified asphalt. After cleaning as much as possible in the infield, the ash was stabilized with an asphalt emulsion. The first flight, Cubi's own C-12 (BE-200 King Air), was launched off 3,500 feet of cleared runway just 5 days after "Black Saturday". Cubi Point NAS was back in partial operation by June 26, 1991. Ash removal activities continued through 1991.

Manila International Airport and the 1991 eruption of Pinatubo

At Manila's Ninoy Aquino International Airport (NAIA) and Sangley Point Air Field between 0.5 and 1 cm (1/4 to 1/2 in) of fine sand-size to powder-size ash from Pinatubo fell in a mostly dry condition on June 15-16, 1991. The Manila ashfall caused little direct damage, but did contaminate airport surfaces causing reduced visibility and affecting aircraft maneuvering, especially when ash was wet. Ash on runways was ingested into engines during taxiing, takeoffs and landings. Ash also contaminated landing gear assemblies and brakes and removal of ash from airport surfaces, hangars, and aircraft was a time-consuming process.

NAIA was closed twice in 1991 owing to ashfall from Pinatubo (E. Carrascoso, NAIA, verbal commun., 1991). The first closure began at 19:00 (local) on June 15 and remained in effect through 18:00 (local) on June 19. From June 19 through June 26, the airport was open for restricted operations which included towing of aircraft to and from the main runway to minimize resuspension of ash from partially cleared taxiways and aprons. Normal operations at NAIA resumed on July 4. A second ashfall occurred on July 17, 1991 and NAIA was closed from 17:00 on July 17 through 19:00 on July 18. On the morning of July 18, a 747 jetliner went about 10 m beyond the end of the runway, probably because of decreased friction because of mixed ash and water (R. Sternberg, Philippine Airlines, verbal commun., 1993). Normal operations at NAIA again resumed on July 19.

Eight jumbo-jet passenger airplanes were stranded on the ground at NAIA by the June 15-16 ashfall and could not depart until June 19. Aircraft on the ground were protected using plastic sheeting (Visqueen) and duct tape to cover windows and openings in the aircraft surfaces and engines. All incoming aircraft were diverted to Cebu, Bangkok or Hong Kong. Several aircraft received minor damage from the abrasion of windshields when window wipers were used to remove ash.

NAIA officials experimented with a variety of techniques to remove ash (E. Carrascoso, NAIA, verbal commun., 1991). The principal problem was that surface winds easily resuspended and redistributed ash thereby recontaminating previously cleaned surfaces. The first attempts on June 16 to remove the ash relied on a vacuum sweeper truck aided by towing coconut palm fronds behind service vehicles. However, this method did not remove all the ash. The airport authority next used pressurized water from its firetrucks. This method also met with only partial success since ash was resuspended by wind after it dried. The third method used manual sweeping to accumulate the ash into furrows and to collect the ash into sacks for removal. Approximately 30,000 sacks were filled. Later the filling of sacks was discontinued and the furrows of ash were stabilized by spraying them with emulsified asphalt known as SS-1 which acted as a binder on loose ash. SS-1 was sprayed on ash-covered areas adjacent to runways, taxiways, and aprons. Washing was the final step. In this regard, NAIA benefited from torrential rains during July and August. One concern which surfaced during the washing operation was that fire trucks often ran low on water, thereby threatening their capacity for any fire fighting needs. Fortunately, there were no fire emergencies during this period. Personal hygiene was a concern during the cleanup effort and personnel were encouraged to wear particle masks and to irrigate eyes with eyewash.

JAPAN

In Japan, ash has caused relatively minor problems at only three airports during the past 20 years. These include Kagoshima International Airport, Miyake-jima airfield, and Kumamoto airport. Ten cm of ash fell at Miyake-jima airport in the Izu islands during the October 3, 1983 eruption of Miyake-jima volcano causing the airport to close for 4 days (Blong, 1984; McClelland and others, 1989). Volcanic ash from the June 3, 1991 eruption of Unzen volcano was detected at Kumamoto airport, approximately 80 km east of the volcano. One departing aircraft was damaged when it took-off into the ash cloud.

Kagoshima International Airport

Summarized from information provided by Kosuke Kamo (Kyoto University) and from presentation by Saburo Onodera (Japan Air Lines)

Kagoshima International Airport, 12 nautical miles (25 kilometers) north of Sakurajima volcano in Kyushu, Japan, is the third busiest airport in Japan with about 130 takeoffs and landings per day. Sakurajima is the most active volcano in Japan and erupts explosively more than one hundred times a year. For most of the year, upper level winds carry the ash away from the airport; however, ashfall at the airport occurs about 10 days/year. The main approach route for Kagoshima Airport reaches as close as 9 nautical miles east of the volcano and at the same altitude with the height of the crater.

Twelve aircraft damage cases have been reported during approach and departure just after an eruption of Sakurajima volcano. On the other hand, no incidents nor aircraft damage caused by deposited volcanic ash at the airport field have been reported at Kagoshima Airport. The light ashfall, usually observed with mild continuous eruptions in southerly wind conditions, has not caused any significant problems or damage to engines or fuselages.

Since 1971, there have been three ashfalls which were severe enough to disrupt or partially close down Kagoshima airport operations; on September 9, 1971, March 11, 1990 and June 6, 1992.

September 9, 1971: ash accumulated to a depth of 3 mm causing reduced visibility. Road sweepers were not effective in removing the ash. Water sprinkling by fire engines was effective, but time-consuming.

March 11, 1990: On the morning of March 11, 1990, about 2 mm of volcanic ash accumulated on runway, taxiway, ramp areas and airplanes. At first, the airport authority tried to suck up the volcanic ash on the ground using a regular vacuum cleaning car, but this method was not successful as most of the ash particles exhausted from the car and scattered again on the ground. Next, firetrucks were used to sprinkle water on the ground. This method proved to be effective.

Resuspension of ash was observed due to engine blast on takeoff and when outboard engines on 747 aircraft were used during taxiing.

June 6, 1992: Continuous light eruptions of Sakurajima produced very fine ashfall from 1200 to 1700, but caused no damage to aircraft. Volcanic ash was blown around and resuspended during taxiing and takeoffs. No special work was done to remove ash and airport continued to operate normally with suitable precautions taken primarily for reduced visibility. One aircraft, which took off after the ash fall ceased, had to stop overnight at Haneda for detailed inspection due to volcanic ash contamination; no damage was identified.

INDONESIA

Despite the large number of active volcanoes in the Indonesian archipelago, there have been relatively few reports of airport closures owing to ashfall. This partly reflects the fact that ash from explosive eruptions often drifts away from the island land masses out over the sea. The March 17, 1963 eruption of Agung volcano in Bali produced ash which drifted westward as far as Jakarta, temporarily closing the Surabaya airport in East Java (Jennings, 1969; Suryo, 1981).

Between April and September 1982, more than 20 eruptions of Galunggung volcano, West Java, produced large ash-rich eruption clouds. The majority of these clouds drifted south and southwest of the volcano over the Indian Ocean. Two of these clouds were encountered by jumbo-jets and resulted in loss of power while in-flight (Tootell, 1985). Several clouds from Galunggung eruptions drifted westward producing ashfall at Bandung, Indonesia's third largest city. Bandung airport was closed owing to reduced visibility associated with ashfall from eruptions between June 4-21 (De Neve, 1986), and on July 14, August 26, and September 2 (Katili and Sudradjat, 1984).

The October 24, 1991 eruption of Lokon volcano in North Sulawesi caused Medan airport to close for several days. While no ash was reported at Medan airport itself, airspace within the Medan air traffic region was heavily contaminated with ash.

ARGENTINA

Argentina has few active volcanoes, however, just west of its boarder with Chile there are a number of volcanoes which erupt frequently. With the dominant wind direction from the west to the east, the ash produced by eruptions in Chile is carried into Argentine airspace. Two of the largest eruptions of the century, at Quizapu volcano in 1932, and at Hudson volcano in 1991, and a smaller eruption of Lascar volcano in 1993, produced large ash falls which covered thousands of square kilometers of Argentine territory. The 1991 Hudson eruption and the 1993 Lascar eruption each contaminated enormous volumes of Argentine airspace and directly affected air traffic in Argentina as well as disrupting international flights to and from Buenos Aires.

In addition to the initial effects from the ash, strong westerly surface winds in the arid Patagonia region continued to resuspend ash from Hudson for months after the August 1991 eruption. On several occasions, the resuspended ash caused reduced visibility and cancellation of flights to Comodoro Rivadavia, Puerto Deseado, Puerto Julian, and Mar del Plata. Mount Pleasant airfield in the Falkland Islands, more than 1,300 km from Hudson, also received light ashfall after the August 1991 eruption.

The eruption of Lascar volcano, Chile on April 18-21, 1993, produced ash clouds that drifted eastward over Argentina, Paraguay, Uruguay, and Brazil. Airports at Salta, Jujuy, and Cordoba, Argentina, and at Asuncion, Paraguay received ashfall from the eruption and flights to these airports were temporarily suspended (F. Pequeño, Argentine Meteorological Agency, verbal commun., 1993).

EFFECTS ON FACILITIES AND AIRPLANES

Winter Operations Plans as a Model for Coping with Volcanic Ashfall

Summarized from presentation by Terry Spurgeon (Transport Canada)

Because of the unusual nature of a volcanic ashfall, Airport Emergency and Disaster Plans for airports in high risk areas should include a detailed Volcanic Ashfall Operations Plan that addresses the unusual conditions posed by this hazard. There are numerous similarities between snow removal and deicing operations, and volcanic ash removal requirements to make

Winter Operations Plans an excellent model for preparing plans to cope with a volcanic ashfall on an airport. While some of the actual operational techniques for ice and snow removal may not be applicable, the approach used to prepare the Winter Operations Plan will permit the airport operator to consider available options, assess equipment needs, establish priorities, and more importantly to address the new challenges posed by volcanic ash.

Volcanic ash may fall on an airport during any season and weather condition, presenting a host of new problems and considerations that are best addressed before the fact. Airlines have successfully operated during eruptions by avoiding airborne ash and using specific ground operating procedures. Winter operations experience worldwide has shown that preplanning involving discussion and commitment from all affected parties, will result in success in coping with what is essentially an emergency situation. Similarly, preparing a Volcanic Ashfall Operations Plan will allow the airport to continue functioning in a safe and effective manner.

Volcanic Ash Effects on Airport Operating and Support Systems
Summarized from presentation by John Labadie (Jaycor) (Also see Appendix 3)

Whereas much as been reported about the effects of volcanic ash on aircraft in flight, relatively little research has been conducted regarding ash effects on operating and support systems necessary to the effective functioning of an airport. Volcanic ash is abrasive, mildly corrosive, and conductive (especially when wet); and it may also carry a high static charge for up to two days after being ejected from a volcano. The ash is easily entrained in the air by wind or vehicle movement and may remain suspended for many minutes. Owing to these qualities, contamination by volcanic ash is pervasive. It can penetrate all but the most tightly sealed enclosures, and can be very difficult to remove from electronic components where it can cause arcing, short circuits, and intermittent failures. Ash dampened by rain can cause arcing and flashover on electrical distribution systems and the resulting outages may hamper mitigation efforts that require electrical power. Ash is attracted to--and entrained in--any exposed lubricant. Thus, any moving or rotating parts are subject to abrasion damage from ash, even long after the bulk of the ash is removed. Heating, ventilating, and air conditioning (HVAC) systems can be severely affected by ash, and can serve as an entry point for ash into airport building, control centers, and maintenance areas.

Emergency Procedures for Protecting Airplanes from Ashfall at Boeing Facilities
Summarized from presentation by Jo McNutt (Boeing Co.) (Also see Appendix 4)

A light dusting of volcanic ash occurred throughout the Puget Sound area after the May 1980 eruptions of Mount St. Helens. Three major Boeing flight lines used primarily for manufacturing airplanes in the area, at Everett's Paine Field, Renton's Municipal Airport, and Seattle's Boeing Field, were affected by this ash dusting. During this time, all aircraft were protected either by putting them into buildings or by covering the aircraft that were parked outside. As a precaution during future eruptive activity, a detailed protection and cleanup plan was developed by Boeing to protect aircraft from volcanic ash fallout. Personnel, plans, and equipment are identified in the emergency plan, which includes assignment of people to cover and seal up aircraft. This includes one supervisor and up to 14 people for each aircraft, including one experienced flightline person. Each group works from a checklist and aircraft are prioritized. Checklists for the ash fallout emergency plan are in Appendix 4.

Weather Advisories to Aircraft and the Public
Summarized from presentations by Lee Kelley (NWS-Anchorage) and Ken Dean (Univ. Alaska)

The Alaska Region National Weather Service Forecast Office (NWS WSFO) provides warnings and forecasts of airborne volcanic ash to the aviation and public communities and advisory service to airport officials for wind speed and direction forecasts and other weather parameters for forecasting the movement of ash clouds to aid in the ash cleanup operations. Coordination efforts are required because of the number of participating agencies who request specific forecasts and warnings (Federal Aviation

Administration, Alaska Division of Emergency Services, and other State and Local governments), and agencies who provide specific information concerning volcanic eruptions such as: the U. S. Geological Survey, the Alaska Tsunami Warning Center, and the University of Alaska.

Following the eruptions of Redoubt Volcano in 1989-1990, the National Weather Service Regional Headquarters in Alaska, acquired state of the art, remote sensing equipment, to improve the forecast and warning capabilities in Alaska. Specific techniques for the remote sensing of volcanic ash debris include: multispectral analysis of advanced very high resolution radiometer (AVHRR) data (subtraction and division of channels 4 and 5) and techniques for the confirmation and collection of volcanic eruption data using a 5.4 cm C-Band radar, and the use of wind profiler data to verify the initial ash plume trajectory. In addition, a comprehensive effort has been undertaken to develop techniques for the assimilation of remote sensing data into the forecast and coordinator efforts of the WSFO in Anchorage.

Forecasts and warnings covering volcanic ash debris issued by the WSFO in Anchorage include: SIGMETS (significant meteorological statements) which are available to all aircraft, Terminal Forecasts, Area Forecasts, Airmets (meteorological statements primarily for light aircraft), Non-precipitation warnings (ash fall information), Flash Flood warnings, Special weather statements, and graphical volcanic ash trajectory forecasts.

WORKING GROUP DISCUSSIONS

This workshop focused on what happens when volcanic ash falls at an airport. Unfortunately, during the past decade, this problem (Table) has become more frequent and had more severe consequences on aviation operations. While not every airport in the world is going to be subject to volcanic ashfall, a large number of airport facilities worldwide already have been affected.

In this workshop working groups addressed four key topics related to airport operations and recovery following volcanic ashfall. These were: airport surfaces, electronics and communication systems, emergency services, and airplanes and support vehicles on the ground. Appendix 2 contains the outlines prepared by each working group.

One consensus recommendation was that key points of the Workshop discussions should be documented. To this end, we recorded the summary presentations of the four working groups. These discussions were transcribed and are presented with minor editorial changes.

SURFACES

(Transcribed from presentation by Bruce Wood, (USN) with additional comments from participants)

Plan and organization: In our opinion the most important thing initially is your *plan and organization*, what we in the military call the Chain of Command. Something that can be done after the fact, but I think ideally each of us who might have to deal with this situation would like to have a plan in place and have drilled it several times, to see how people are going to interact. At Cubi NAS, we did not have a specific plan for volcanic ash. However, we did have an Emergency Operations Plan in place. For a military operation this is easy to do, but in a civilian or corporate environment it may be more difficult to achieve. Much of what I'll say here applies to the military situation.

An important element in a response is having a *centralized control center* close to your center of operations. This is a central place where everybody knows where the plans are coordinated and where the communications center is located so you can report back and ask questions. We had a crisis control center at Cubi NAS that had about 15 telephones and radio communications of every sort. In my case, we also had a mobile command center in a delivery van that had radios and other kinds of mobile equipment with its own generator and air conditioning that could serve as an alternate control tower for air traffic, and as an alternate crisis control center for everything from police to managing road graders. A lot of the things we built today rely upon stable power, air-conditioning. If you have a large scale disaster, some of the stuff that you count on daily is not available to you and its very fragile. You need to have something that's tough and rough and can deal with the elements.

Education about volcanic ash: You do yourself a lot of favors if you prepare your personnel for ashfall. If you think that you might have to deal with volcanic ash, knowing the principle properties of the ash, its physical structure and its potential health affects, before hand stops some misconceptions of how dangerous ash may be. I think that for most of us having this experience, during the first two or three days there was a great amount of trepidation about the health effects of the ash. We found that it was possible to work and live in an ash-contaminated environment. But I recommend that a Public Affairs program beforehand will help to minimize some of the fear that comes with the unknown. This could take the form of short information messages on radio and television, or as pamphlets or posters that would be in plain, non-technical language. Almost all of the Pinatubo eruptions were preceded by warnings that the volcano might erupt. This afforded time where the Public Affairs people could start putting information out.

Personnel, logistics, and sanitation: Logistics are a problem for your workers. Getting them home, getting them back, getting them fed, getting them sleep, getting them taken care of. You cannot necessarily count upon your dedicated workers to devote all their time and attention to your problem, because they have problems of their own. They've got dogs, cats, kids, cars, and roofs, and freezers that are melting, so your problem dimensions change a lot based upon how big are their personal problems. If you know the winds are blowing in your direction, I think the public affairs people will naturally recommend people prepare and that they buy bottled water, canned food goods, batteries, candles and so forth. If the people are self sufficient for say a week or so, that reduces your problem to some extent.

Sanitation, both personal hygiene as well as health, was a very big problem for us in a tropical setting like Cubi. Infections from abrasions were a problem. Ash gets into your shoes, your gloves, around your neck and causes abrasions which soon lead to skin rashes and other health problems. Fortunately, we had very little downtime due to personal injury or sickness.

Prioritize: Prioritize which areas to clean first. What's most important to you? Maybe it's a helicopter landing pad or maybe it's your primary runway. Maybe it's only enough runway to operate a particular kind of airplane. Maybe you don't have to worry about 747's initially. You need to start, not everywhere at the same time, but start cleanup at your high priority sites.

At Cubi, we started before the event was over and I think we probably wasted some time and effort. We probably learned something about what was going to work and what did not. But we did this while the ash was still falling. When it looked as though it was maybe going to stop, we hurried out with fire trucks and sweepers and tried to deal with the problem before the event was over. We didn't know when it was going to be over until it was over and even then you could not be sure. While it's raining death and destruction, you might as well go and work on your plan.

We decided "OK, we are going to clear the runway first." I think that the worst case scenario is the bone dry environment. The wind problem caused ash to drift around. This required cleaning up areas time and time again because the wind migration was very difficult. Trying to scoop up sandy ash is harder when it's dry than when it's wet. Some people would argue, because it lighter maybe it's easier to handle. In some ways wetting it down and keeping it wet certainly reduced the problem of reintroduction into the atmosphere and in some cases you can handle it better.

If the ash is dry, mechanically sweeping it into windrows and then wetting it and scooping it up is probably an option. Lets assume you have an accumulation of more than a quarter inch and you do have to remove it. We all felt that going down the center line of the runway and sweeping or pushing to the side utilizing the crown of the runway and the slope of the runway was certainly the best solution. It stops you from pushing material uphill. We recommend to wet the ash if it isn't already wet, road grade it into berms and then use scoops or front end loaders to pick it up. After scrapping and removal of the bulk of the ash, use high pressure water to hydroblast your surfaces to get them as clean as you can.

Disposal of ash: It has been said repeatedly at this meeting that it is certainly cost effective if you can figure out ahead of time where would you put the ash removed from your surfaces and buildings. We had approximately fifty-seven thousand truck loads of ash and you have to put it somewhere. If you only have to move it once, that certainly reduces your problem. Having a pre-approved dump site where you know you'll avoid environmental problems and drainage problems are all part of your response plan. At Cubi, we had already identified an area where we were trying to fill-in in order to expand the facility. This was an area on the southwest edge of the airfield. It was natural that we use this area for disposal of the ash.

Cover the ash to prevent it from being blown around back onto your facility. Based on our experience, we highly recommend using emulsions to stabilize your berms if you don't have time to sweep or scoop them up. The grass and non-weight-bearing surfaces use these emulsions to put a little frosting on your ash accumulations so it does not blow around. At Cubi, the ash naturally reseeded itself just due to the magic of biology in the tropics. Or you could plant seed and the ash will grow things quite handily.

Equipment: If you have an organization and a plan in place and the event has happened, you need to look immediately at the following questions. What is your short term equipment availability? What pieces of equipment and manpower can you initially lay your hands on? Some of these things are what we call "blinding flash of the obvious"; it is something that is a normal progression of how you would handle things. Initially you are not going to have a huge number of pieces of equipment and personnel to deal with. But almost certainly you will have something available to get started such as road graders, sweepers, vacuums, high pressure hoses, fire hoses. Obviously you are going to have to bring a lot more equipment and manpower and hopefully that would have been part of your plan. If you get six inches of ash and if you need equipment where would you go? Would you have some tentacles out there to equipment companies, or to the county, or to the National Guard, or someone who you would have interrelated with to say if this happens: "Can I count on you for help?"

There is no standard scenario here, just be prepared. For example, if you are going to have anticipated electrical problems, portable generators are very important for some of your key communications operations areas. Some number of standard road graders, front-end loaders, highway scrapers will certainly be valuable. At Cubi, we utilized about 15 of these monster highway scrapers to scrape up all of our berms. Dump trucks, bobcats, sweepers, fire trucks, lots of fire hose and high-pressure pumps, sprinkler systems were used to keep our infield and berm areas wet down. On days when it did not rain, we set up sprinklers and periodically keep the ash wet, mainly because blowing ash reduces visibility.

Based upon the extent of your problem, having mobile service to your equipment is important. We had teams that worked on our equipment 24 hours a day to change oil filters and fuel them rather than have them come back in from the field. Having mobile medical facilities available, as well as mobile water and food and portable latrine facilities for dealing with the sanitation problem were all important. If you loose electricity, you are not going to have water because all of our water supplies are pumped into reservoirs and pressure systems and when you run out of electricity, soon you run out of water. You could put a portable generator into a temporary emergency circuit board and get some pumps and other essential equipment to run.

In addition to the heavy mechanical gear, other equipment is very helpful to handle the ash. These include shovels, brooms, and biodegradable plastic bags to put ash in. With the heavy rainfalls in the Philippines, sand bags proved to be very valuable to control drainage and storm runoff.

Recommendations: Have somebody on your staff who is very familiar with your facility and who knows where drain lines and drainage patterns, power centrals and utilities, etc. are located and who knows the location of all the aircraft on your airfield.

Make an ash reaction plan part of an established emergency plan. This document is not going to be a stand alone and ought to be in the big folder that goes along with fire, crash, wind storm, earthquake. At Cubi, we did not have a plan for ashfall, but we had a basic disaster plan. I think people can probably learn from some of our experiences and play some "what if" drills.

It was recommended that airport operations be involved in a regional disaster drills that a lot of counties and municipalities and cities go through. Make sure that your airport operations people are part of these drills because in certain scenarios having your airfield as a top priority helps get the rest of the region back on its feet. To get the airport open so people like the National Guard and medical people can fly in is very important. To do this you have to have to get your airport open. Its valuable to have the chain of command acknowledge that initially all the equipment manpower go to the airports and then spread out from there.

If you are going to use water power to clean surfaces and buildings, as we all thought was necessary, sometimes nonpotable water, seawater may be available, but you will need adequate hydrant pressure, without compromising firefighting needs.

Political issues: A lot of us felt that it's fairly difficult to convince your boss or your governor, or your mayor, that ashfall could happen to you. However, I think you need to lay out your options and evaluate the cost of inaction and look at the number of opportunities you have to screw up your airport. The point here is that an ash accumulation on your airport can happen probably as easily as an earthquake that causes significant damage. Once again, based upon how big your problem is, someone hopefully at the very top has to be willing to cut though some red tape and not deal with some of the problems in an ordinary day in and day out manner.

Documentation: It is important to document what you did, how you did it, and to have somebody identified to keep track of what you spent. It's easy to lose grip of how you did it and where you did it and to reconstruct what happened. Documentation is not only for historical purposes, but when explaining to your boss about why you did certain things, it is very easy to forget the scenario of what made you make that decision.

Research needs: It is important for us to leave here with a set of recommendations that identifies areas where additional research and applied testing will help solve some of these problems. We can talk about this till we're blue in the face, but there is always work that has to be done to advance the state-of-the-art of what we are doing here. We found that the existing runway sweepers, vacuum systems are very ineffective. They don't work for these levels of contamination. They just move the stuff around, but they don't clean it up. Maybe we could entice somebody to engineer an effective industrial strength vacuum system that would work. Is there a cost effective way you can suck ash up, inject water with the ash and move it like they do in mining operations or certain construction operations?

Are there sensors which could be imbedded along the edges of your road or runway that shows you where these are so you can detect them without having to probe around and unnecessarily dig up things?

There is a fairly limited number of emulsion products currently available. However, if we got into the network of the farming or construction people, maybe we can come up with a cost effective, environmentally safe, and rapidly available product to put on ash in order to stabilize it.

We need to investigate the engineering and physical properties of the ash. Is it effective for landfill? How steep can you stack ash without it becoming unstable? We need a lot more information on the affects of ash on the braking action of airplanes and ground vehicles to answer the question: does ash reduce the friction properties of your runway? We think we know that ash decreases the friction and braking effectiveness, but is this really significant when you just have a small accumulation? To help us decide, well when it gets to 3/16 inch thickness that means that your breaking is going to be reduced by 50 percent and then you have to clean it up. But if it's only 1/32 of an inch maybe you don't have to worry about it. There are many unknowns. One of the papers to have been presented here was from the FAA which was proposing to carry out friction tests. We think this is certainly valuable work and hope that these tests are completed and the data made available.

Is there some way for the volcanologists and weather people to give an idea of how much ash we might expect. We need to try to predict ashfall, just like we do now for snow fall and we need to have more effort put into detecting and tracking the ash cloud.

Finally, let me say that I think there is a tendency to squint your eyes, cross your fingers and say I hope this never happens to me. Of course, we all feel that way but I think it is important to be aware of the possibility of this type of problem and its potential consequences. This meeting is an important step in making people aware of the problem and what can be done to solve it when it happens to you.

ELECTRONICS AND COMMUNICATIONS SYSTEMS

Transcribed from presentation by Ethan Powell (Allied-Signal)

The abrasive nature of ash presents a tremendous threat to any electronics, communications and electrical power facilities and operations. We focused on the ground power situation and decided that there was not time for addressing these systems aboard an airplane, although some of the same concerns and recommendations do apply to airplanes. Anomalous ground operations includes a number of items such as aircraft and computers, electrical shortages, transformers, and the power distribution grid. We want to prevent anomalous operation and to determine the anomalous operation that we are going to have to prepare for. John Labadie's reports (Labadie, 1983a, b) greatly facilitated discussions in the area of electronic communications and electric power. Summaries of these findings are presented in Appendix 3.

Jurisdictional responsibility: Before getting into technical questions, we feel it is important to be aware of potential problems that might crop-up because of jurisdictional responsibility. At an airport, several agencies have authority and responsibilities which during a crisis may overlap and even be somewhat in conflict. People regard the FAA, individual airlines, and the Port Authority and recognize that they typically they don't all talk with one voice. What sort of liaison can be set up to allow these agencies to work and pull together in the best possible way?

A related factor is the dispersion of services. For example, you have landing aids handled by one agency whereas each airline has its own computers and manages its own support and maintenance services. We need to be aware of the fact that we have this distribution of services and we have to come up with a contingency plan that helps these diverse groups to pull together.

Airport security: Most of us move around an airport with an electronically-activated badge that lets us into one place or another. These systems are either electrically or electromagnetically based. If ash is falling and there is a disruption of power, it is a sure bet that a lot of those locks that operate on electronics and electromagnetics may not work; they may fail.

Staff and equipment needs: One thing we have to plan for is to have the proper mitigation equipment available and at hand when we need it. We are talking about vacuum cleaners, air compressor systems, brushes, wipers, cleaning compounds with electronic filters, good air-handling filters, and different types of filters. These need to be available. We also need to have maintenance capability. There are a couple of concepts that we discussed. One is the clean room capability that we have in most of our businesses. We have a room within a room and perhaps we need to have the facility to be able to implement such capabilities on short notice. It may mean putting up a screen in an area where your important equipment is inside of a room. It also may mean having control of the traffic in and out of those critical areas so there is less tracking in of ash and dirt.

Supplemental air-conditioning, extra auxiliary generators, and battery power communications all have to be considered, because if the electric power goes down, the communications will go down. As a number of the speakers at this meeting said: If we have a need, everyone else has a need, they are doing this emergency too. So we need to know the type of personnel we need. We need to have trained personnel that are willing to address the unusual nature of the volcanic ash problem. We need to have those personnel that can deal with electronic communications and electronic power repair.

Recommendations:

1) Shut down all nonessential equipment. If you don't need it, turn it off. Experience shows that much electrical equipment will attract fine dust

particles. This is especially true of volcanic ash which is often electrostatically charged.

2) Cover up equipment. As we heard repeatedly, ash settles on to equipment. Much damage can be prevented simply by covering up equipment so that ash won't settle onto surfaces and enter inlet systems. Covering will eliminate a large majority of your problems.

3) Pre-planning as you have heard over and over is VITAL. We need to identify and prioritize equipment and resource needs before the emergency manifests. What do we need first? We have to identify and plan our mitigation strategy. This means prioritizing mitigation and cleanup strategies.

4) Evaluate specific mitigation techniques. The technique that we would use to clean the surface of a tarp is obviously not the same technique as we might need to clean a transmitter. Techniques we might use to maintain and keep a computer on line are probably the same or similar to those we would use to keep a VHF receiver operating. So we need to plan those specific techniques and to realize that a combination of these techniques may work.

5) Evaluate past experiences. Be open to new strategies, inputs, recommendations, and build a library of information and documentation through meetings like this one. Hopefully this will trigger ongoing dialogue of the most effective ways to address ash contamination as regards electronic communication and electrical power.

EMERGENCY SERVICES

Transcribed from presentations by Bill Wilkinson (Port of Seattle) and Terry Spurgeon (Transport Canada)

Plan and Prioritize: Plan ahead and practice plans. Table top exercises, and actual drills are essential for efficient emergency response. In many respects those areas that have to deal with snow at airports should be better prepared for volcanic ashfall than airports which don't deal with snow removal. They will have some equipment, techniques, and procedures already practiced and on hand. Setting priorities is essential for efficient use of staff and equipment. This could be a problem because different people are going to want different things. One group will want the terminal building open right away, another group wants the runway open right away. If you are cleaning the roof of a terminal building off, it's probably a good idea to take the top-down approach. Start at the high roofs and move the ash off. But it's not going to be a great idea to move the ash off the roof onto the apron that somebody has just cleaned. You need to set priorities.

They will be complacent sometimes, particularly elected officials who don't want to admit that this is going to happen and who don't want to set aside funds for preparation. Funds have to be allocated up front so you have on hand the right equipment when you need it. Inventory your needs and equipment to know what you need beforehand. This makes it easier to lay out contracts and to know if your going to be able to have the equipment and supplies available in the area when its needed.

If you have a written preparedness plan or an emergency disaster plan on the airport that has a component that deals with volcanic ashfall, you still have to deal with the concept of the wider community. Airports are surrounded by metropolitan areas. You're going to have to integrate with other agencies in the area for coordinated activity and response, and indeed the airport may turn out not to be the highest priority in some cases. Be involved in regional planning and coordination with other agencies who may be competing for limited resources. Get yourself into the pecking order, hopefully, towards the top. Assess the risk for your area in terms of what your particular operation is, whether it is an airport or other type of facility. Evaluate how essential that particular facility is for the operation of the region.

Methods: Volcanic ash does not equal snow. You will need special techniques to handle and remove it. The comment made to wait until it stops falling was a good comment. However, if it looks like you may be able to handle it, for example if ash is falling wet and chunky, large granular size, you might be able to start training your crews in removal and getting some practice as to the nature of the problems involved with handling ash.

Move ash once. You don't want to dump ash and then find that it blocks airplanes or other activities. Identify your dump site in your response plan. Be sensitive that these areas don't have adverse ecological impacts. It is also important that the areas be where you can cover them so the ash won't be resuspended in the air when it dries out. You need to identify where you are going to put the ash to minimize the handling and to get rid of it once and for all.

Lots of water equals control of ash. However, great care is needed to make sure we have the proper mix of water to ash. We don't want to make a slurry of it and then find you can't then scoop it up with a loader or scrap it with a broom or blade. Let your people know that ash, especially wet ash, is heavy. People can injure themselves if they try to pickup 500 lbs of ash in one garbage can.

Plans needs to be flexible. The methods of removal appear to be a problem for everybody. We've seen that a lot of people have experimented. It's taken them several hours to arrival at the right way of handling and everybody has come back to the water situation. Each ashfall is different.

Shut the airport off and close it up. This is very difficult to do for airports. We have people coming and going all the time. An airport is by its very nature designed for ease of access, ease of egress. Therefore, there are lots of doors, cubbyholes, openings, space for baggage, people, and vehicles. With a high density population, the heating ventilation/air conditioning systems (HVAC) are designed to handle lots of air and exchange the air several times in the building in the course of an hour. When you shut that equipment down you have people stranded. Since your airport is not a hotel, shutting it down and sealing it up becomes problematic.

Survey your building structures. At most airports we have acres of flat roofs. Survey your roofs so that when you have an ashfall and it gets wet, you will know just how much that roof can take. In many cases, that will determine your priorities with respect to removal. What you'll tackle first and how long you can let a particular area go before you have to assign manpower and other assets to clean up. If you get a heavy ashfall and you can't get it cleaned out at one time then you may have to evacuate your terminals that have weakened load capacities.

Staff and equipment: We would like to have special equipment on hand or be on the market off the shelf, but the closest thing we get are snow blast blowers and other kinds of snow-related equipment which may or may not be the equipment of choice with respect to moving ash. Specialty equipment operators: In airports particularly we have an extensive drivers training program, as required by Federal regulation. You can't let just anybody on the airfield to drive this equipment. Training for staff is important and it hooks back into occupations safety and health. Remember the people with push brooms standing on the wings of DC-10's and 747s without a buddy system. Falling off the wing of airplanes or the roofs of buildings will cause injury.

You are going to have a problem if you start having people get sick or injured. Have a program where they can get rotated, get their masks changed, rest for awhile, have a cup of coffee, get a sandwich, and send them back out. This keeps them on the job and effective.

Getting staff simply to respond, getting back to the transportation implications, in the larger community, you may not be able to get enough people to work initially to do the job. There is the potential for some problems related to medical needs and crash-fire rescue, in the sense that if your using your crash-fire rescue people as part of your clean up, we must not lose sight of that fact that they have another job that may be the most important job of all in the end, once airplanes are back moving.

Be prepared to take care of all the extra people who will be involved in cleanup. Once you've got people to work for awhile, it may be that you are not moving them back and forth. You've got to house and feed them. Streets may be closed, roads are slippery and in the larger community it is a problem just transporting the staff to work. Once you have them there you may have them for awhile. You certainly may need them for a long time as well.

The previous speakers have touched on equipment needed for ash removal. We would like to stress that from the perspective of emergency services, auxiliary power generators will probably be in great demand. These have a variety of advantages, especially inside terminal facilities. At most airports there will be large wheel-mounted generators which are used on the field for lights and heavy equipment. However, there will probably not be sufficient numbers of such large, wheeled generators to go around, so smaller generators, 1.5KW would be handy to have like in your auto shop or power generation situation where you can recharge batteries or work pumps. Those are reasonably low cost.

Proper funding: When you start buying heavy equipment and training people, it requires funding on a continuing basis. Experience indicates that the best approach here would be to start small but keep the funding coming continuously. Don't try to make a big splash requiring lots of money at one time since you won't be able to spend it all fast enough and also, they'll take it away and you won't have it next year. So keep it coming in low and slow.

Storage space: Personal storage space and personal safety health equipment are tied together. If you have all this equipment on hand, you have to store it someplace, hopefully in an area where you can secure the storage. Account for it, maintain it, and inventory it regularly. You will need staff, people and places and things to do this.

Documentation: We need an information clearing house to deal with the information that has been discussed during this Workshop. From all the areas that have experience with the heavy equipment, the procedures that have been used, the innovations, we need some coordinated way to ensure that this is documented. On the subject of documentation, people have discussed professional and unprofessional papers. I see a distinction there because the professional people in academia have one process and it's entirely different and it may not always be as fast as people who may be writing what we would term unprofessional papers. When we go back, if we've been involved in this process, and we know something about it, at our own special level or where ever it is at home that we are all obliged to prepare material, write articles, do documentation, and try to get the word around to other people. There is too much valuable information here that needs to be gotten out.

AIRPLANES AND SUPPORT VEHICLES ON THE GROUND

Transcribed from presentation by Greg Lawson (Boeing Co.) (See Appendix 4)

Many of the points discussed in this working group have already been covered in the earlier summaries. As we've heard repeatedly, *Plan Ahead.* Principle problems that concern airplanes on the ground and ground support equipment relate to damage to moving parts. To minimize this damage on the wings, wrap them to seal all the openings. We suggest moving airplanes inside a hangar and stabilizing the aircraft for protection. Check manufacturers' recommendations, for example, check the maintenance manuals for your airplanes.

In terms of protecting airplanes on the ground, we suggest following the procedures outlined by the various manufacturers. Appendix 4 contains the procedures followed by Boeing Co. to protect aircraft on the ground during an ashfall. Much of this material is simply common-sense and it a matter of coordinating personnel and equipment to be in the right place at the right time.

We recognized that there is little equipment that is specifically designed to remove ash from an airplane. There needs to be effort of research to design some equipment to handle ash. Equipment, supplies, to obtain spare parts, protective equipment, and to clean up equipment in such a catastrophe, some of those things can become short of supply. So you have to stock pile ahead of time. Think ahead about where are you going to get supplies and equipment on short notice.

Initially you need to keep tabs on where this cloud is and when it's going to hit, to keep updated and adjust your plan as necessary. In implementing the plan, hopefully you already have such an emergency response plan for volcanic ash conditions.

Have on hand the equipment you'll need and planned for right down to the tape and plastic to cover your airplanes, as well as personnel you may need. If you recall personnel, you have to have food and supplies for workers.

Prioritize your storage location. If you are going to be pulling equipment and getting it out from the field and storing it somewhere, you want to be sure that the equipment you are going to need is not all packed into the back. Last in first out. Also position the equipment in advance where it's going to be needed. Because you don't want to be dragging it across the field that is full of ash if you can help it. So think ahead on that. Contact your contract personnel and supplier so you'll have that lined up.

Brief personnel, designate where everyone is going to work, cover equipment and protect it. Anything that is not in use, you can protect completely. Gather spare equipment and replacement stock.

General maintenance on equipment to be used: There is definitely going to be increased maintenance frequencies when your operating in an environment as dusty as ash can be and as harmful as it can be. Service and replenish, water, oil and filters. There will be a need to replace your oil and filters more often.

Minimize equipment use and movements that create ash hazards or blow ash around. Keep unused equipment sealed or wrapped or have maintenance done when ashfall threat is mitigated. Monitor your equipment, monitor serviceability, monitor damage, and repair as needed. Be alert to innovative ideas for preventive maintenance and equipment rotation.

Following the ashfall, clean top to bottom. Check equipment status, evaluate damage, locate equipment to be used. Coordinate equipment support and use with general airport management. This gets back to the issue of communication and coordination. Hopefully your plan will encompass the chain of command and that will coordinate the airplanes. Typically it will be the carriers that will be concerned about their airplanes, so there will have to be some sort of communications to discuss there. It's a good idea to encourage people to be creative because conditions can vary greatly in a volcanic ash situation. What works in one catastrophe may not work so well in another.

SUMMARY

During the workshop, a number of themes emerged which have a direct practical bearing on the issue of volcanic ash and airport operations. These are summarized below.

1. have a plan and make-sure the plan is practiced and staff is trained
2. water-water-water; any system that can provide water, especially under pressure, is valuable
3. move ash only once (plan ahead!); ash is not snow, it won't melt and disappear!
4. from trucks to brooms, have the right equipment on hand
5. get airplanes away from the airfield <u>before</u> ash starts to fall
6. do not start cleanup until ashfall is over (except when threatened by overloading of roofs)
7. in conditions of light ashfall, aircraft are not too badly affected: they can land and take off, but should exercise proper care and procedures such as tow-in/tow-out from ramp area
8. ash can be slippery when wet; aircraft and ground vehicles should watch out!
9. protect people working on roofs, on aircraft wings, and during poor visibility!
10. be innovative with your solutions!

Manufacturers' Procedures for Ash Cleanup

Each of the major airframe and engine manufacturers has developed operational and maintenance related procedures for dealing with volcanic ash. These may be found in the appropriate Flight Crew Operating Manuals (FCOM) and Aircraft Maintenance Manuals (AMM). Interested parties are urged to consult the appropriate manuals for their respective operational needs. A number of manufacturers' suggested procedures are derived from the Aerospace Industries Association Volcanic Ash Committee (PC334-1).

An additional facet of this problem is planning for volcanic ashfall at manufacturing facilities. For example, following the May 18, 1980 eruption of Mount St. Helens, concerns about potential ashfall at the three major Boeing Co. flight lines in the Seattle area at Everett, Renton, and Boeing Field, resulted in development of plans to protect these flight lines in the event of future eruptions. As a result of these experiences, Boeing Co. now has in effect plans for protecting aircraft and production facilities in the event of future ashfall (Appendix 4). These procedures include plans to cover all openings in aircraft which might be parked outside of hangars, and organizational plans for removing ash from runway surfaces and buildings.

ACKNOWLEDGMENTS

Thanks to the 53 participants of the workshop. I would also like to acknowledge the interest and support of Bill Minter of Embry-Riddle Aeronautical University, Florida and Bill Wilkinson, Port of Seattle, Emergency Services Coordinator for SeaTac Airport. Early planning included discussions and consultations with Captain Ed Miller (Air Line Pilots Association) and Captain Ernie Campbell and Thomas Murray (Boeing Company). I would like to thank all speakers and those who contributed to working group discussions. These working group members include the following:

1. Surfaces (Bruce Wood, Dan Harrigan, Grant Heiken, Richard O'Lone, Reuben Sternberg, Ed Miller, David Bailey, Dwayne Lung, Ron Doyle)
2. Electrical Systems (Thomas Murray, John Labadie, Ethan Powell, Jim Riehle)
3. Buildings and emergency services (Bill Wilkinson, Terry Spurgeon, Dale Eubanks, Dave Smith, Eric Schell, Jim Ellis, Jim Riehle, Willie Scott)
4. Aircraft (Jim Wood, Greg Lawson, Jo McNutt, Wes Dawson, Ed Miller, John Rankin, Saburo Onodera, Pat McGraw, Paul Smith).

Finally, I would like to acknowledge the efforts of Grant Heiken (LANL) who recorded notes for many of the technical presentations, and Ray Wilcox (USGS) who reviewed an early version of this report. Marsha Simpkins (USGS) skillfully transcribed the audio tape recordings from the summary session and prepared the final camera-ready copy of this report.

REFERENCES CITED

Anchorage International Airport, 1993, Mt. Spurr eruption, August 18, 1992: State of Alaska DOT and PF International Airport System, (unpublished memorandum, February 19, 1993), 21 p.

Alaska Volcano Observatory (AVO), 1993, Mt. Spurr's 1992 eruptions: Eos, Transactions of the American Geophysical Union, v. 74, p. 217, 221-222.

Blong, R. J., 1984, Volcanic Hazards: Academic Press, Sydney, Australia, 424 p.

Brantley, S. R. (ed.), 1990, The eruption of Redoubt volcano, Alaska December 14, 1989 - August 31, 1990: U. S. Geological Survey Circular 1061, 33 p.

Casadevall, T. J., 1992, Volcanic Hazards and Aviation Safety, *Federal Aviation Administration Aviation Safety Journal*, v. 2, no. 3, p. 9-17.

Casadevall, T. J., in press, The 1989-1990 Eruption of Redoubt Volcano, Alaska: Impacts on Aircraft Operations: Journal of Volcanology and Geothermal Research.

Casadevall, T. J., Matson, M., and Riehle, J., 1982, Volcanic hazards and aviation safety: minimizing the threat through improved communications [abs.]: Eos, Transactions, American Geophysical Union, v. 73, no. 43 (Supplement), p. 68.

Casadevall, T. J., De los Reyes, P., and Schneider, D. J., in press, The 1991 Pinatubo eruptions and their impacts on aircraft operations, *in* Punongbayan, R. and Newhall, C. G., eds., The 1991 Eruption of Pinatubo Volcano, Philippines, U.S. Geological Survey Professional Paper.

De Neve, G. A., 1986, Effects in the Atmosphere of the Galunggung eruption, *in* Letusan Galunggung 1982-1983: Volcanological Survey of Indonesia, Bandung, p. 367-372.

Federal Emergency Management Agency, 1984, The Mitigation of ashfall damage to public facilities: Lessons learned from the 1980 eruption of Mount St. Helens, Washington: FEMA Region X, 70 p.

Gibson, N. W., 1993, Anchorage International Airport Action Report: Mount Spurr Eruption, August 18, 1992: unpublished report, 5 p.

Guest, J., Murray, J., Kilburn, C., and Lopes, R., 1980, Eruptions of Mount Etna during 1979: Earthquake Information Bulletin, v. 12, no. 4, p. 154-160.

Jennings, P., 1969, Disruptions of the environmental balance: the eruptions of Mt. Agung and Mt. Kelut, Indonesia: University of Hawaii, thesis for Master of Arts in Geography, 159 p.

Juhle, W. and Coulter, H., 1955, The Mt. Spurr eruption, July 9, 1953: Eos, Transactions of the American Geophysical Union, v. 36, p. 199-202.

Heiken, G., and Wohletz, K., 1985, Volcanic Ash: Univ. California Press, Berkeley, CA, 246 p.

Katili, J. A., and Sudradjat, A., 1984, Galunggung: the 1982-1983 eruption: Volcanological Survey of Indonesia, Bandung, 102 p.

Kienle, J., and Swanson, S. E., 1985, Volcanic hazards from future eruptions of Augustine volcano, Alaska: UAG R-275, University of Alaska, Fairbanks, AK, 122 p.

Labadie, John, 1983a, Teal Granite Final Report: Mitigation of Volcanic Dust Effects: prepared for US Air Force Office of Scientific Research Defense Advanced Research Projects Agency; IRT Corp., 29 p.

_____, 1983b, Teal Granite: Mitigation of Volcanic Dust Effects from Long Valley Eruptions: prepared for US Air Force Office of Scientific Research Defense Advanced Research Projects Agency; IRT Corp., 29 p.

Lloyd, A. T., 1990, Vulcan's Blast: Boeing Airliner, Seattle, WA, p. 15-21.

McClelland, L., Simpkin, T., Summers, M., Nielsen, E., and Stein, T.C., 1989, Globval Volcanism 1975-1985: Prentice Hall, Englewood Cliffs, NJ, and American Geophysical Union, Washington, DC, 657 p.

Schuster, R. L, 1981, Effects of the eruptions on civil works and operations in the Pacific Northwest, *in* Lipman, P. W., and Mullineaux, D. R., eds., The 1980 eruptions of Mount St. Helens: U. S. Geological Survey Professional Paper 1250, p. 701-718.

Schuster, R. L., 1983, Engineering aspects of the 1980 Mount St. Helens Eruptions: Bulletin of the Association of Engineering Geologists, v. 20, p. 125-143.

Stewart, R. B., 1993, Lessons learned from the August 18, 1992 Mt. Spurr Eruption: Municipality of Anchorage Post-ashfall critique report: Office of Emergency Management, Anchorage, AK, (unpublished report, March 12, 1993), 27p.

Suryo, I., 1981, Report on the volcanic activity in Indonesia during the period 1961-1963: Bulletin of the Volcanological Survey of Indonesia, no. 104, 116 p.

Taylor, G. A., 1958, The 1951 eruption of Mount Lamington, Papua: Bureau of Mineral Resources, Bulletin 38, 117 p.

Tootell, Betty, 1985, All 4 engines have failed; the true and triumphant story of flight BA 009 and the Jakarta incident: Hutchinson Group Ltd., Auckland, 178 p.

U.S. Air Force, 1992, Final After Actions Lessons Learned Report of Mt. Spurr Volcano Eruption, 18 August 1992: Elmendorf AFB, AK, (unpublished report, December 22, 1992), 36 p.

Warrick, R. A., Anderson, J., Downing, T., Lyons, J., Ressler, J., Warrick, M., and Warrick, T., 1981, Four communities under ash after Mount St. Helens: Program on Technology, Environment and Man, Monograph 34, Institute of Behavioral Science, Univ. Colorado, 143 p.

Wilcox, R. E., 1959, Some effects of recent volcanic ash falls with special reference to Alaska: U.S. Geological Survey Bulletin, 1028-N, p. 409-476.

Wright, T. L., and Pierson, T.C., 1992, Living with volcanoes, The U.S. Geological Survey's Volcano Hazards Program: U.S. Geological Survey Circular 1073, 57 p.

Appendix 1: Workshop Participants

David Bailey
Executive Manager
Grant County Airport
7810 Andrews St NE
Moses Lake WA 98837
Phone: (509) 762-5364
FAX: (509) 762-2713

Robert Beal
Atmospheric Environment Service
700-1200 West 73rd Avenue
Vancouver B. C. V6P 6H9
CANADA
Phone: 604-664-9121
FAX: 604-664-9195

Don Burbank
United Airlines
SEA-TAC International Airport
Seattle WA 98158

Robert Bullock
Port of Portland
7000 NE Airport Way 6th FL
Portland Or 97218
Phone: (503) 335-1135
FAX: (503) 335-1124

Dr. Thomas J. Casadevall
U.S. Geological Survey
Box 25046, MS 903
Denver Federal Center
Denver CO 80225
Phone: (303) 236-1080
FAX: (303) 236-1414

Captain Ernest E. Campbell
Boeing Commercial Airplane Group
PO Box 3707, M/S 2T-61
Seattle WA 98124-2207
Phone: (206) 544-5203
FAX: (206) 237-0352

Wes Dawson
Central Air Safety Committee
ALPA
9723 Cherry Street
Edmonds WA 98020

Ron Doyle
Transport Canada
Aviation Weather Services
Place de Ville
Ottawa Ontario K1A 0N8
CANADA
Phone: (613) 991-9929
FAX: (613) 998-7416

Kenneson G. Dean
Geophysical Institute
University of Alaska-Fairbanks
Fairbanks AK 88665-0800
Phone: (907) 474-4764
FAX: (907) 474-7290

Dr. Rand Decker
Department of Civil Engineering
University of Utah
3220 Merrill Building
Salt Lake City UT 84112
Phone: (801) 581-3403
FAX: (801) 585-5477

Dr. James S. Ellis
Livermore National Laboratory
Regional Atmospheric Science Division
P.O. Box 808 (L-262)
Livermore CA 94550
Phone: (510) 422-1808
FAX: (510) 422-4527

William D. Fishel
Superintendent of Operations
Ontario International Airport
Ontario CA 91761
Phone: (917) 988-2811

Dr. William R. Hackett
EG&G Idaho Inc.
P.O. Box 1625 Geosciences MS 2107
Idaho Falls ID 83415-2107
Phone: (208) 526-6963
FAX: (208) 526-0875

Robert F. Hamley
Center Weather Service Unit
FAA ARTC
3101 Auburn Way South
Auburn WA 98002
Phone: (206) 931-5401
Fax: (206) 931-5208

Commander Daniel Harrigan, USN
Willow Grove NAS
VR-52
NAS Willow Grove PA 19090
Phone: (215) 443-6564
FAX: (215) 443-6591

Dr. Grant Heiken
ESS-1, Geology/Geochemistry
M/S D-462
Los Alamos Scientific Laboratory
Los Alamos, NM 87545
Phone: (505) 667-8477
FAX: (505) 667-3494

Dr. James R. Hill
U.S. Department of Energy
EH 332
Washington DC 20585
Phone: (301) 903-4508
FAX: (301) 903-3888

Lt. Commander James O. Jaczinski
Commandant (G-KSE-1)
United States Coast Guard
2100 2nd Street SW
Washington DC 20593
Phone: (202) 267-2972

Captain Hsio Run Jung
China Airlines
#131, SEC. 3
Nanking East Road
Taipei Taiwan
REPUBLIC OF CHINA
Phone: 886-2-5146863
FAX: 886-2-5146985

Lee Kelley
U.S. National Weather Service
Alaska Region
222 West 7th Ave., #23
Anchorage, AK 99513-7575
Phone: (907) 271-5098
FAX: (907) 271-3711

Dr. John R. Labadie
Vice President-JAYCOR
1212 NE 62 St.
Seattle WA 98115
Phone: (206) 526-5125
FAX: (206) 526-5531

Greg Lawson
Propulsion Engineer
Boeing Customer Service
P.O. Box 3707 M S 2H-81
Seattle WA 98124
Phone: (206) 544-9773
FAX: (206) 544-9696

Michael A. Lenick
ATC Procedures Specialist
Federal Aviation Administration
800 Independence Avenue SW
Washington DC 20591
Phone: (202) 267-9332
FAX: (202) 267-5120

Dwayne Lung
Transport Canada
Vancouver International Airport
318-4160 Cowley Crescent
Richmond BC V7B 1B8
CANADA
Phone: (604) 666-5836
FAX: (604) 666-9507

Barry D. Mawson
Manager, Flight Operations Safety
AIRBC
4740 Agar Drive
Richmond BC V7B 1A6
CANADA

Patricia McGraw
Safety Rep, NATCA
Attn: Will Faville
4444 N Capital Suite 845
Washington DC 20001
Phone: (202) 347-4572
FAX: (202) 393-6591

Jo McNutt
Emergency Preparedness
The Boeing Company
M/S 3U-80
PO Box 3707
Seattle WA 98124
Phone: (206) 657-9685

Lawrence W. Michou
Project Manager
Anchorage International Airport
PO Box 290649
Anchorage AK 99519-0649
Phone: (907) 266-2403
FAX: (907) 243-0663

Captain Edward K. Miller
Air Line Pilots Association (ALPA)
Aviation Weather Committee
535 Herndon Parkway
Herndon VA 22070
Phone: (703) 689-4388
FAX: (703) 689-4370

Captain Horacio Domingo Mino
Argentina Air Force
Aeropuerto Comodoro Rivadavis
Region Aerea Sur
Chubut CP 9000
ARGENTINA
Phone: 54-1-967-33355
FAX: 54-1-967-34008

William Minter
Assistant Director
Embry-Riddle Aeronautical University
Center for Professional Programs
600 S. Clyde Morris Boulevard
Daytona Beach FL 32114
Phone: (904) 226-6186
FAX: (904) 226-6220

Tom Morrow
Office of Airport Safety & Standards
AAS-200
Federal Aviation Administration
800 Independence Ave SW
Washington DC 20591

Dr. Mark T. Murphy
Pacific Northwest Lab
P.O. Box 999
Richland WA 99336
Phone: 509-376-8337

Thomas M. Murray
Product Safety Engineer
Boeing Commercial Airplane Group
PO Box 3707, MS 69-33
Seattle WA 98124-2207
Phone: (206) 965-9615
FAX: (206) 965-9949

Richard O'Lone
40 Sunrise Ave
Mill Valley CA 94941
Phone: (415) 383-9230
FAX: (415) 383-1523

Saburo Onodera
Meteorology Section, Flight OPS Dept
JAL Operation Center Bldg
1-1 Hanedakuko 2 Chome
Ota-Ku Tokyo 144
JAPAN
Phone: 81-3-3747-3357
FAX: 81-3-3747-4619

Captain Fernando Francisco Pequeno
Meteorologist Pronosticador
Fuerza Aerea Argentina
Servicio Meteorologico Nacional
25 De Mayo 658
Buenos Aires CP 1002
ARGENTINA
Phone: 51-1-311-1906
FAX: 54-1-311-3968

Ethan Powell
Allied Signal Aerospace Company
Bendix/King Air Transport Avionics Div.
300 - 120th Ave. N.E.
Bldg. 2 Suite 200
Bellevue WA 98005
Phone: (206) 454-4941
FAX: (206) 454-1780

Captain John A. Rankin
British Airways
P.O. Box 10
Heathrow Airport (London)
Hounslow ENGLAND TW6 2JA
UNITED KINGDOM
Phone: 81-562-5616
FAX: 81-562-5639

Ron Rice
Systems Engineer
SEA-ME Alaska Airlines
PO Box 68900
Seattle WA 98168
Phone: (206) 431-7187
FAX: (206) 433-3311

Dr. James R. Riehle
U.S. Geological Survey
905 National Center
12201 Sunrise Valley Drive
Reston VA 22092
Phone: (703) 648-6709
FAX: (703) 648-6717

Captain Eric Schell, USAF
Air Force Flight Standards Agency
Randolph Instrument Flight Center
431 'I' Street E, Suite 2
Randolph AFB TX 78150-4334
Phone: (210) 652-3077

Dr. William E. Scott
Cascades Volcano Observatory
U.S. Geological Survey
5400 MacArthur Boulevard
Vancouver WA 98661
Phone: (206) 696-7909
FAX: (206) 696-7866

Captain Dave Smith
Central Air Safety Committee
Air Line Pilots' Association
21606 NE 73rd Place
Redmond WA 98503-7753
Phone: (206) 868-5727
FAX: (206) 868-4727

Paul H. Smith
Manager, Air Traffic Services
NBAA
1200 18th Street NW Suite 200
Washington DC 20036
Phone: (202) 787-9000
FAX: (202) 331-8364

Captain Terry Spurgeon
Regional Coordinator
Transport Canada - Aviation Group
Emerg Prep/Contingency Ops
620-800 Burrard Street
Vancouver BC V6Z 2J8
CANADA
Phone: (604) 666-5489
FAX: (604) 666-1175

Captain Reuben Sternberg
Director, Safety
Philippine Airlines
Pal Gate 2 Andrews Avenue
Pasay City Metro Manila
PHILIPPINES
Phone: 63-2-833-6433
FAX: 63-2-831-1810

Captain Jim H.H. Sung
China Airlines
#131, Sec. 3
Nanking East Road
Taipei Taiwan
REPUBLIC OF CHINA
Phone: 886-2-5146863
FAX: 886-2-5146985

Dr. Ann Tallman
Westinghouse Hanford Company
PO BOX 1970 H5-60
Richland WA 99352
Phone: 509-376-0986
FAX: 509-376-7382

Captain Tim Timmins
Air Carrier Inspector
Transport Canada AARXB
200 Kent Street
Ottawa Ontario K1A 0N8
CANADA

William P. Wilkinson
Senior Airport Supervisor
Sea-Tac International Airport
PO Box 68727
Seattle WA 98168-0727
Phone: (206) 433-5284
FAX: (206) 439-7710

Captain Bruce V. Wood, USN
Aviation Safety Programs (034)
Naval Post Graduate School
Monterey CA 93943
Phone: (408) 656-2581
FAX: (408) 656-3262

James Wood
Technical Services
Product Support Department L33 (76-40)
Douglas Aircraft Company
3855 Lakewood Blvd.
Long Beach CA 90846
Phone: (310) 593-2780
FAX: (310) 593-7710

Appendix 2: WORKING GROUP OUTLINE SUMMARIES

Working Group 1: SURFACES

1. Planning and Organization
   -Identify Chain of command
   -Establish a control and communications center
   -Publication with basic physical properties of ash
   -Occupational and health hazards of the ash
   -Short term equipment available
   -Manpower available
   -Prioritize areas to clean
   -Long-term equipment and manpower
   -Define the problem—depth, extent, winds, goals
   -Logistics-feeding, transportation

2. Clear runway first; tow aircraft to/from terminal
   Dusting (<1/4 inch):
   -Mechanically sweep while dry.
   Accumulation (>1/4 inch)
   -Start on runway centerline
   -Wet the ash and road-grade into berms
   -High-pressure water to clean surfaces
   -Worst case-dry ash; wet the ash for control, grade into windrows; load up and remove.
   -Use emulsions to stabilize berms and infields

3. Move ash only once
   -Identify final dump site
   -Document the volume, use it as a future aggregates resource
   -Approved dump site
   -Cap it with emulsion or soil; seed it
   -Observe local rules for dumping ash

4. Equipment
   -Graders
   -Front end loaders
   -Dump trucks
   -Scrapers
   -Bobcats
   -Water trucks
   -Fire hoses and high-pressure pumps
   -Emulsion sprayers
   -Mobile communications equipment
   -Mobile service and fuel, mobile medical, mobile food and water, mobile sanitary.
   -Gloves, masks, goggles, fuel and air filters for vehicles, shovels, brooms, and biodegradable bags.

5. Recommendations
    - -Know your facility
        - -Slope of runway
        - -Drainage patterns
        - -Buried utilities
    - -Plan; Table-top drills; replan
    - -Strong chain of command
    - -Robust communication capability
    - -Identify water sources; volume and quality
    - -Include airport operations in regional disaster drills.
    - -Make ash reaction plan part of *established* emergency response plan
    - -Be willing to cut red tape and do the right thing
    - -Document the cleanup; designate person responsible for documentation and photographs.

6. Research Needs
    - -Effective vacuum sweeper
    - -Slurry procedure
    - -Emulsion products
    - -Engineering and physical properties of ash--results in summary form.
    - -Friction testing of ash on runway
    - -Improve short-term weather and eruption cloud movement observation and prediction
    - -Predictive models of ash fallout
    - -Temporary conveyor belt operation like those used in mines

Working Group 2: ELECTRONICS AND COMMUNICATIONS SYSTEMS
refer to Appendix 3

1. Principal Problems
   - -Contamination of components (ash is corrosive, abrasive, conductive)
   - -Abrasion damage to rotating/moving parts (Disks, Heads, Switches)
   - -Anomalous operation of equipment
     - Hard disk crashes
     - Shutdown
     - Power Surges and Transients
   - -Jurisdictional responsibilities for mitigation, cleanup
     - Port Authority
     - FAA
     - Airlines
     - Service Companies
   - -Disposition of computer, communications, navigational aids over wide area.
   - -Damage to and malfunction of security systems card readers and keypads

2. Equipment
   - -Vacuum cleaners
   - -Compressed air system
   - -Brushes, wipes, etc.
   - -Cleaning compounds
   - -Plastic wrap/bags, tape, etc.
   - -Extra/different filter materials
   - -Auxiliary generators
   - -Battery-powered communications equipment
   - -Maintenance capability
     - -clean room capability (installed or expedient)
     - -supplemental air conditioning

3. Personnel
   - -Extra personnel for general clean-up and mitigation
   - -Electronics technicians for equipment cleaning/repair
   - -Additional trained personnel for cleaning of electrical substations, transformers, etc.

4. Recommendations
   - -General principle: non-essential equipment/systems should be shut down and covered/bagged with plastic.
   - -Pre-planning is vital
   - -Identify resource needs
   - -Prioritize equipment/system needs (see general principle)
   - -Pre-position spare parts, and mitigation supplies
   - -Identify and plan for best combination of mitigation techniques (depending on your facilities resources, circumstances

Working Group 3: EMERGENCY SERVICES

1. Principal Problems
   - -Complacency
   - -Short Dollars
   - -Correct Equipment
   - -Training Staff
   - -Disposal of Ash
   - -Methodology of removal
   - -Care of Passengers
   - -Care of Staff
   - -Setting Priorities

2. Staff and Equipment
   - -Specialty Removal Equipment
   - -Specialty Equipment Operators
   - -Proper Funding
   - -Simple-hand Operated Equipment: shovels, brooms, bags, masks
   - -Personal Safety/Health Equipment
   - -Storage Space
   - -Various Supplies and Filters, Goggles
   - -Auxiliary Electrical Power

3. Summary
   - -Ash does not equal Snow
   - -Lots of Water - Control
   - -Ash is Heavy, Move Ash Once
   - -The Threat is Real, Plan Ahead and Practice
   - -Inventory Your Needs - Equipment and Personnel
   - -Assess the Risk for Your Area
   - -Be Flexible in Approach
   - -Shut it Off and Close it Up
   - -Survey Building Structures

4. Recommendations
   - -Coordinating Agency for Area/Activity Wide Response
   - -Competent Funding through Federal and State Departments of Transportation
   - -Written Ash Plan for each Airport
   - -Do Local Risk Evaluation - Situation
   - -Clearing House for Equipment Innovations Procedures
   - -Systematic Records on maintenance of equipment and airplanes
   - -Backup Emergency Power
   - -Threat Assessment
   - -Communications
   - -Current Technical Information
   - -Staff Response to Job(s)
   - -Multiple Demand on Medical and Crash-Fire Vehicles
   - -Power Reliability

Working Group 4: AIRPLANES AND GROUND SUPPORT EQUIPMENT
(Refer to Appendix 4: Emergency Operations and Volcanic Ash by Jo McNutt, Boeing Co.)

1. Summary
   - -Plan ahead
   - -Communicate
   - -Operate equipment to minimize damage
   - -Service and maintenance more frequently
   - -Protect personnel and equipment
   - -Clean, Clean, Clean

2. Problems
   - -Damage to moving parts
   - -Equipment failure
   - -Safety hazards
   - -Equipment not designed to remove ash (Snow plow vs. ash plow)
   - -Equipment supplies: obtaining spare parts, protective and clean up equipment

3. Recommendations

Impending Ash Fall

- -Communications regarding Ash Fall (Early Alert, Avoidance, On-going Updates)
- -Ash precautions - where to start
- -Equipment inventory - gather data
  - what's working
  - what's to be covered
  - what equipment needed - water, oil, filters, tape, plastic
- -Move aircraft out of threat area, if possible
- -Hanger aircraft remaining in threat area, if possible.
- -Personnel
  - -Automatic recall of workers
  - -Food and supplies for workers
  - -Equipment Storage: prioritize location: last in -- first out
  - -Contact contract personnel and suppliers lists and leased equipment
  - -Brief personnel and designated work groups
- -Locate water source for refills
- -Equipment
  - -Inventory protective equipment
  - -Prepare packets of tape and plastic wrap
- -Maintenance
  - -Wrap, cover and seal all openings on aircraft that remain in threat area
  - -Stabilize aircraft (i.e., use tail stands, ballast or ties)
  - -Check manufacturers recommendations
  - -Cover equipment/Protection anything not in use
  - -Gather spare equipment and replacement stock
  - -General maintenance on equipment to be used
  - -Service and replenish: water, oil, filters, etc.
  - -Check of equipment (does stored equipment work?)

During Ash Fall

-Perform Impending Ash Fall consideration if not done previously
-Protect personnel (breathing masks, safety equipment, goggles
-Mitigate safety hazards
-Minimize equipment use, if you have to use it - protect it as you can (change oil, filters, service)
-Planning and preparation for follow-on operations
-Position equipment for safe and convenient use
-Minimize aircraft use
-Special safety criteria must be considered during ash fall. (wet ash is heavy and slippery)
-Monitor equipment - revise maintenance schedules
-Monitor serviceability of emergency equipment (generators, too)
-Monitor damage - repair or seal areas, as needed
-Consider innovative ideas for preventative maintenance
-Consider equipment rotation
-Monitor level of ash fall on aircraft (clean, if appropriate)
-Keep aircraft free of excessive ash accumulation
-Monitor damage. Repair or seal, as necessary
-Do not fly aircraft when ash is falling

Following Ash Fall

-Clean from top to bottom (roof to ground)
-Check equipment status
-Evaluate damage
-Locate equipment to be used - prioritize ground support equipment
-Coordinate equipment support with General Airport Management
-Ongoing condition checks on equipment
-Revise maintenance schedules
-Review inventory - what's working
-Minimize equipment use
-Follow manufacturers recommendation
-Personnel safety considerations must be emphasized
-Equipment location - coordinate use with other airport operations
-Improvise equipment, as needed
    -plywood shovel or fort lift and panty hose for filtration
-Minimize movement that create ash hazards or blow ash around
-Safety considerations such as slippery, wet ash, must be emphasized.
-Move electric/electronic equipment away from heavy ash fall areas, if possible
-Keep unused equipment sealed or wrapped or have maintenance done when ash fall threat ends.
-Follow recommended manufacturers instructions
-Increase maintenance inspections for continued operations
-Minimize blowing or disturbing ash around aircraft

Appendix 3: ELECTRONIC SYSTEMS

From reports by John Labadie, Jaycor (1983a, b)

Computer Services

The most widely advised tactic was to shutdown all computer and electronic systems until the dust had been completely removed from the area and from the equipment. Computer heads and disks - any high-voltage circuits - are especially vulnerable to dust upset and damage. Continual cleaning and aggressive protection of computer systems should allow continued operation in all but the heaviest dust fallout.

Mitigation: Best tactic for dust mitigation is prevention. Clean and condition surrounding air to keep dust out of equipment. Cotton mat filters (used in clean rooms) were found to be best for filtering particles, but they reduce the air flow. A solution is to use larger fans to maintain required air flow. Rack-mounted equipment can be modified to add a larger fan; smaller instruments or components with a built-in fan would require design change to increase fan capacity. Use fluted filters as a compromise; increases surface area but reduced air flow by only about 20 percent.

Digital integrated circuits can very 5-10 percent in performance (depending on type of circuit) and still be acceptable. It is difficult to generalize about other equipment (e.g. high-voltage power supplies).

Humidifying ambient air (e.g. wet down carpets) will help to control dust entrainment.

Dust on equipment can be blown out with compressed air. If the air is too dry, static discharge could damage sensitive components (e.g. MOS integrated circuits). If the air is too damp, the dust will stick. Relative humidity of 25-30 percent is best for compressed air.

Cleaning with a pressurized water-detergent mix and a hot water rinse is quite effective. However, this process required at least partial disassembly.

Dust on digital circuits won't cause much of a problem because of the low voltages involved. High voltage or high-impedance circuits are very vulnerable to leakage caused by semi-conductive dust. Dust that is acidic is conductive as well as corrosive.

Dust should be blown or brushed away from power supplies and CRTs (especially high-voltage leads, capacitors).

Dust may have high static charge and be hard to dislodge; required brushing to dislodge.

Accelerate filter change; use pre-filters.

Change to absolute filters; will keep out particles down to 1 micron.

Keep computer power on to operate filtration, but don't run (especially disk drives).

Maintain "room-within-a-room" configuration; restrict access; re-circulate air; accelerate cleaning of area.

Communications Systems

Except for short circuits by conductive dust and abrasion of moving parts, few serious radio problems were reported.

Mitigation: Teflon insulators on communications antennas were covered with dust and shorted out. Very difficult to clean as residue would adhere. Replacement with ceramic insulators required.

Plastic switches and push buttons (especially those with self-cleaning contacts) abrade quickly; may be necessary to replace.

Seal up repeater stations and other installations; shut air intakes; internal air circulation and leakage should be sufficient for cooling.

Blow out or vacuum out radio equipment; brush off.

Seal equipment that is not already watertight. Smaller units have low-power consumption and do not generate much heat.

Magnetic particles that stick to relay cores should be blown off.

Keep moisture out of equipment.

Clean equipment daily; increase use of filter paper.

Clean out microwave dishes, feed horns, wave guides. Install covers; plastic tarp will do in an emergency.

These techniques are based primarily upon commercially available communications equipment and reflect civilian operating circumstances. Some military equipment may differ in configuration, power requirements, operating parameters.

Radar and Optical Systems

Most radar equipment in the heaviest ashfall areas was shut down for the duration. Thus, few problems were recorded aside from cleanup and control of residual dust. The simplest mitigation tactic is to cease operations.

Mitigation: High-voltage circuits may short out. Repair and clean.

Wash antenna rotor bearings; re-lubricate; cover exposed bearings.

Dust on optical components should be blown off or washed away with copious amounts of water. Do not wipe, brush, or rub as this will abrade the optics.

Take care not to wash dust into optical instrument mounts on aircraft (e.g. sextant). Dust will seize up mounts, hinges, etc.

Turn off non-essential radar equipment to reduce cooling load, power requirements.

Reduce operating performance requirements.

Transfer radar coverage to other facilities; combine sectors.

Remove and replace camera bearings, clean gear drives.

Protect video-tape from dust; dust will cause "drop-outs," scratches on tape.

Electric Power

Electric power - supplied from commercial sources or by standby generators - is essential to almost every activity. Dust fallout can render electrical distribution systems somewhat unreliable due to grounding and flashover caused by wet, conductive dust. Transmission systems are less vulnerable to ash contamination because of the higher voltages and different insulator configurations involved. Generally speaking, a heavy accumulation of dust is required to produce significant problems with outages. Outages that do occur may require the use of standby generators that are quite vulnerable to dust damage.

Mitigation: Compressed air to blow off insulators, bushings, circuit breakers.

High pressure water wash (60-150 psi); higher pressure (2000 psi) uses less water but takes longer. Lines and substations must be de-energized prior to washing. Wet down ground in substation prior to cleaning lines.

Coat insulators with silicon grease; however, this requires hand application and hand cleaning. Grease tends to harden over time; coated insulators are expensive to clean and maintain. Some incident (less than 5 percent) of capacitative discharge when silicone insulators were covered with dust.

Washing and wiping may be necessary to remove residue.

Knock or brush dust loose from substation equipment and structures.

Blow off dust, then wash; dust that has been wetted and then dried is more difficult to remove.

Install water tank and pump on helicopter. Can clean more structures more quickly. Not necessary to de-energize lines.

Self-cleaning by wind and rain:

-25 km/hr	5 percent dust removed
-40 km/hr	90 percent dust removed
-55 km/hr	only trace left

Rubberize compound insulators burned and melted by flashover should be replaced with ceramic insulators.

Mitigation (Auxiliary generators):

Stockpile filters.

Add filters (30 percent efficient) to generators; change often.

Install hoses on air intakes; raise opening farther above ground.
Clean radiators with compressed air.
Install alarm circuit to warn of excessive pressure differential across filters.
Seal outside air intakes when not in use.
Keep generator in manual start mode and rely on uninterruptable power supply for as long as possible during power outages; this will protect generators with little or no filtration.
Gas turbines should be flushed inside and out with water and heavy-duty detergent. water-bath filters should be flushed periodically.

Install three-stage filter system for gas turbines:
inertial separator
pre-filter
high-efficiency filter; removes 95 percent of particles to 2 microns.
automatic blow-back to clean filter at 6-9 inches pressure differential.

Install protection circuits for filter system in gas turbines:
alarm at 6 inches vacuum pressure
turbine trip-out at 9 inches vacuum pressure
filters will collapse at 12 inches vacuum pressure

EMERGENCY OPERATIONS AND VOLCANIC ASH
April 26, 1993

PART I
VOLCANIC ASH CLEANUP

Cleanup:

- o Roads
- o Walkways
- o Parking lots
- o Roofs
- o Electrical Substations
- o Vaults

General Supervisor Plant Maintenance Responsible

Equipment List:

- o Road Graders
- o Street Sweepers
- o Front End Loader
- o Backhoe
- o Hi Ranger
- o JLG Lift
- o Marathon Generators
- o Vac - All Vacuum/Sweeper Truck
- o Mini Bulldozer
- o Forklifts with snow blades
- o Hand Tools-Shovels, Brooms, Squeegees

Maintain automotive equipment. Monitor filters/oil/lube changes.

On Call Support:

- o Maintain supplier lists.
- o Maintain Purchase Order numbers.

Cleanup Methods:

- o Roofs:
  - Start near air handling units
  - Use vacuum equipment (if available)
  - Use brooms & squeegees & shovels
- o Walkways:
  - Use brooms & shovels & squeegees
  - Damper ash with water to improve handling
- o Streets, Parking Lots:
  - Use snow blades
  - Load into containers with front end loaders, backhoes or shovels
- o Substations:
  - Use qualified electrical personnel
  - Turn power off

Disposal:

- o Designate site storage areas
- o Level off storage sites
- o Keep material wet
- o Spray with an emulsifier agent
- o Transport to a designated land fill

EMERGENCY OPERATIONS AND VOLCANIC ASH
April 26, 1993

PART II
PROTECTION OF BOEING 747 & 767 AIRPLANES

Impending Ash Fallout or Active Fallout Threat

Flightline Duty Supervisor:

- o Establish control center and staging area.
- o Assign one Flightline supervisor to patrol flightline to assist unfamiliar supervisors and crews with locations, instructions, interpretation, etc.
- o Assign people to call in additional employees and supervisors as required.
- o Contact Flightline general supervisors for assistance.

Establish crews and prioritize assignments:

- o 1 supervisor and 12 people per aircraft.
- o 1 supervisor and 8 people to APU protection.
- o 1 supervisor and 8 people to materiel dispensing.
- o 1 supervisor and 4 people to galley vent protection.
- o 1 supervisor and 8 people to windshield protection.

- o Build additional crews as people arrive.

- o Continue to build crews until each aircraft has 1 supervisor and 14 people.

- o Maintain status of all field airplanes and issue instructions as required.

- o Ensure Hi Rangers and manlifts are operated by qualified personnel.

- o Distribute existing Flightline personnel with inexperienced personnel.

- o Move ground support equipment into buildings (oil service carts, EPR test benches, water service and test carts, hydraulic service carts)

- o Identify and maintain sufficient fire-resistant plastic and tape to adequately protect all aircraft.

- o Accomplish protection within a 2 hour period, if possible.

- o Contact food service company to provide food and beverage for emergency personnel, if necessary.

- o Maintain packets of data and instructions in the general supervisor's office.

FIELD POSITION AND A/P PRIORITY CHECKSHEET

ATTACHMENT B

FIELD POS.	AIRPLANE PRIORITY	ENGINE #1	ENGINE #2	ENGINE #3	ENGINE #4	ADP OUTLETS	AC INLETS	PITOT PROBES	STATIC PORTS	GALLEY VENT	APU INLET	APU EXHAUST	APU GEN. VENT	TEMP PROBES	WINDSHIELD		DATE ____ REMARKS

ASSIGNMENT SHEET - MATERIAL DISPENSING

ASH FALLOUT EMERGENCY PLAN

ASSIGNMENT SHEET

MATERIEL DISPENSING: SHIFT ________ SUPERVISOR ____________

CREW A ____________ CREW B ____________

AIRPLANE	FIELD POS.	STATUS

AIRPLANE	FIELD POS.	STATUS

CREW C ____________ CREW D ____________

AIRPLANE	FIELD POS.	STATUS

AIRPLANE	FIELD POS.	STATUS

- SPECIFIC INSTRUCTIONS -

1. Assign two (2) people to a company vehicle to deliver material to each aircraft.
2. Ensure company vehicle driver is a licensed driver.
3. Instruct drivers to obey speed limits and driving lanes.
4. Priority is as listed by crew.
5. Deliver tooling covers, if available, as directed by Field Operations Duty Supervisor.
6. If tooling covers are not available, deliver plastic and tape as follows:
   a. Two (2) rolls plastic, four (4) rolls green tape by each engine.
   b. Two (2) rolls plastic and four (4) rolls green tape underneath 48-Section.
   c. Four (4) rolls plastic and eight (8) rolls green tape underneath nose of the aircraft.
   d. Fire resistant plastic and tape will be available in Paint Hangar Crib, 45.01 Bldg., Door E3, east side of the building.
7. Report to Field Operations Duty Supervisor as each aircraft is complete.

ASSIGNMENT SHEET - ENGINES/AC INLET/PITOT STATIC PORTS

ASH FALLOUT EMERGENCY PLAN

ASSIGNMENT SHEET

AIRCRAFT __________ CREW ______ POS. ________ SHIFT ____ SUPERVISOR ______________

	STATUS				
	INLET	EXHAUST	EPR PROBE	STRUT ACCESS	ADP OUTLET
ENGINE NO. 1 ______________ ______________					
ENGINE NO. 2 ______________ ______________					
ENGINE NO. 3 ______________ ______________					
ENGINE NO. 4 ______________ ______________					

A C INLET ______________ ______________ ☐

PITOT STATIC PORTS ______________ ______________ ☐

- SPECIFIC INSTRUCTIONS -

1. Install tooling covers if available; if not, cover openings with plastic and tape in place.
2. If engines are cowled, close all cowling.
3. If engines are not cowled, close whatever is installed and cover uncowled portions of the engine with fire resistant plastic and tape in place.
4. Position 2 10 ft. stand by each engine.
5. Position 1 15 ft. stand by each set of Pitot Probes.
6. Report status to Field Operations Supervisor and receive next assignment.

ASSIGNMENT SHEET - APU PROTECTION

ASH FALLOUT EMERGENCY PLAN

ASSIGNMENT SHEET

APU PROTECTION: SHIFT________ SUPERVISOR____________

CREW A ____________________ CREW B ____________________

AIRPLANE	FIELD	POS.	STATUS

AIRPLANE	FIELD	POS.	STATUS

CREW C ____________________ CREW D ____________________

AIRPLANE	FIELD	POS.	STATUS

AIRPLANE	FIELD	POS.	STATUS

1. Utilize four (4) lift stands to perform this operations.
2. Assign two (2) people to each lift stand.
3. Ensure personnel are wearing safety harness.
4. Install tooling covers if available; if not, cover openings with fire resistant plastic and tape in place.
5. Cover APU exhaust, inlet and generator vent.
6. Priority is as listed by crew.
7. Report to Field Operations Duty Supervisor as each aircraft is completed.

ASSIGNMENT SHEET - WINDSHIELD AND TEMPERATURE PROBE PROTECTION

ASH FALLOUT EMERGENCY PLAN

ASSIGNMENT SHEET

WINDHSIELD AND TEMPERATURE PROBE PROTECTION: SHIFT____ SUPERVISOR______________

CREW A ______________________ CREW B ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

AIRPLANE	FIELD POS.	STATUS	AIRPLANE	FIELD POS.	STATUS

1. Utilize 2 B6 stands for this phase of the operation.
2. Assign four (4) people per B6 stand.
3. Ensure personnel are wearing safety harness.
4. Install tooling covers if available. If not, cover windshield and temperature probes with fire resistant plastic and tape in place.
5. Priority is as listed for each crew.
6. Report to Field Operations Duty Supervisor as each aircraft is completed.

ASSIGNMENT SHEET - GALLEY VENT PROTECTION

ASH FALLOUT EMERGENCY PLAN

ASSIGNMENT SHEET

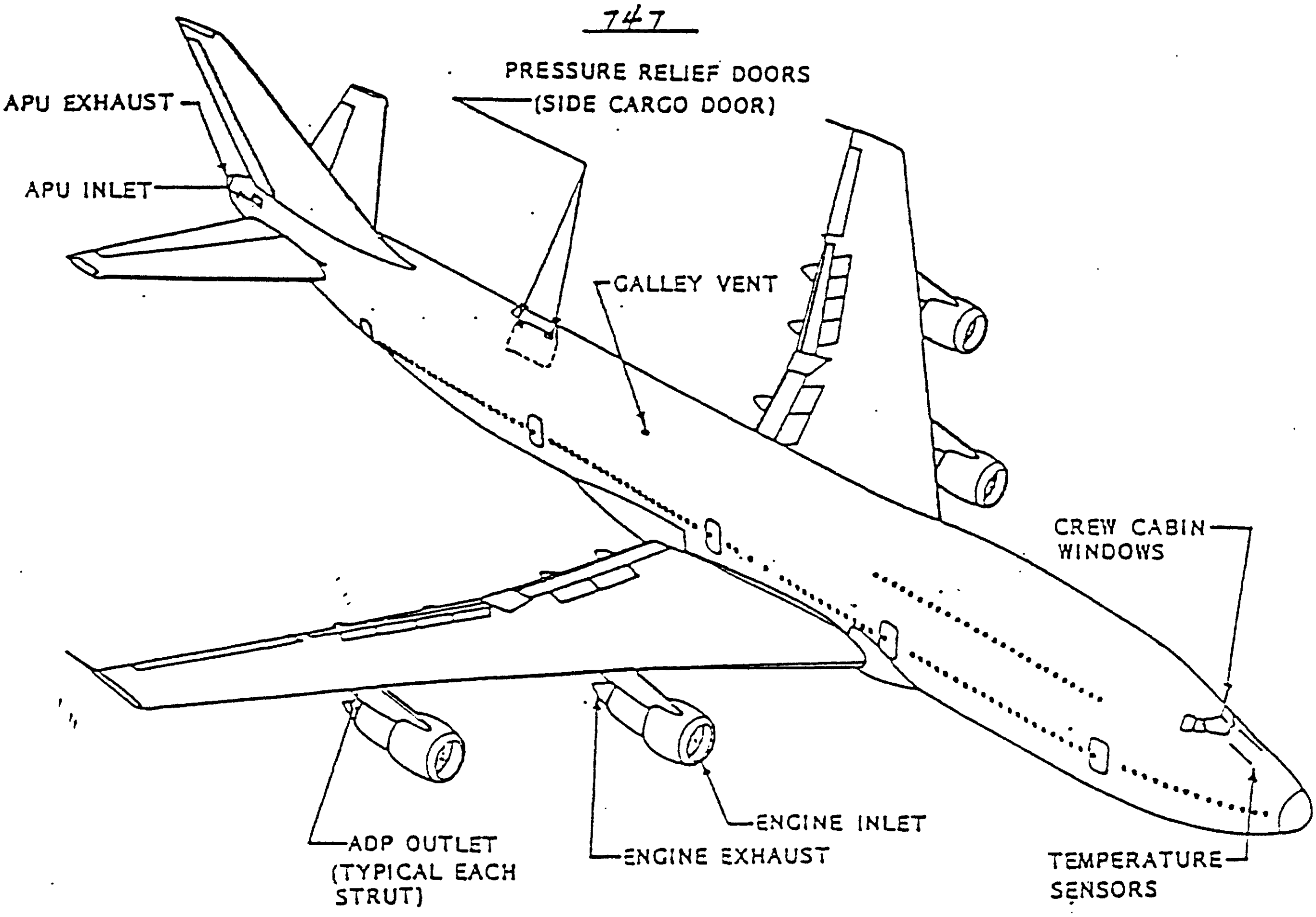
GALLEY VENT PROTECTION: SHIFT ______ SUPERVISOR ______________

CREW A ______________ CREW B ______________

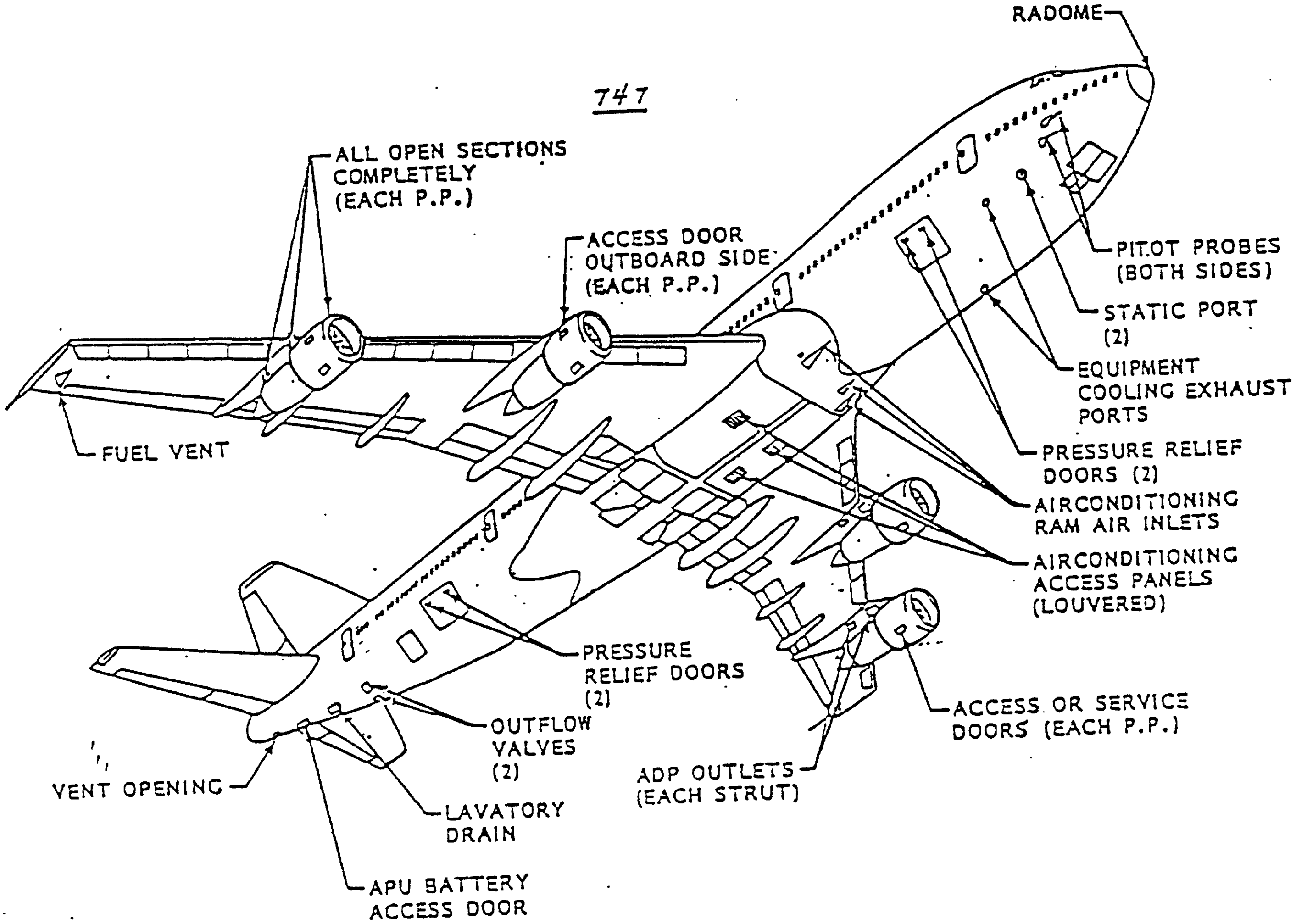
AIRPLANE	FIELD POS.	STATUS	AIRPLANE	FIELD POS.	STATUS

1. Utilize Hi-Rangers for this phase of the operation.
2. Assign two (2) people per Hi-Ranger.
3. Ensure personnel are wearing safety harness.
4. Install tooling covers if applicalbe; if not, cover openings fire resistant plastic and tape in place.
5. Priority is as listed for each crew.
6. Report to Field Operations Duty Supervisor as each aircraft is completed.

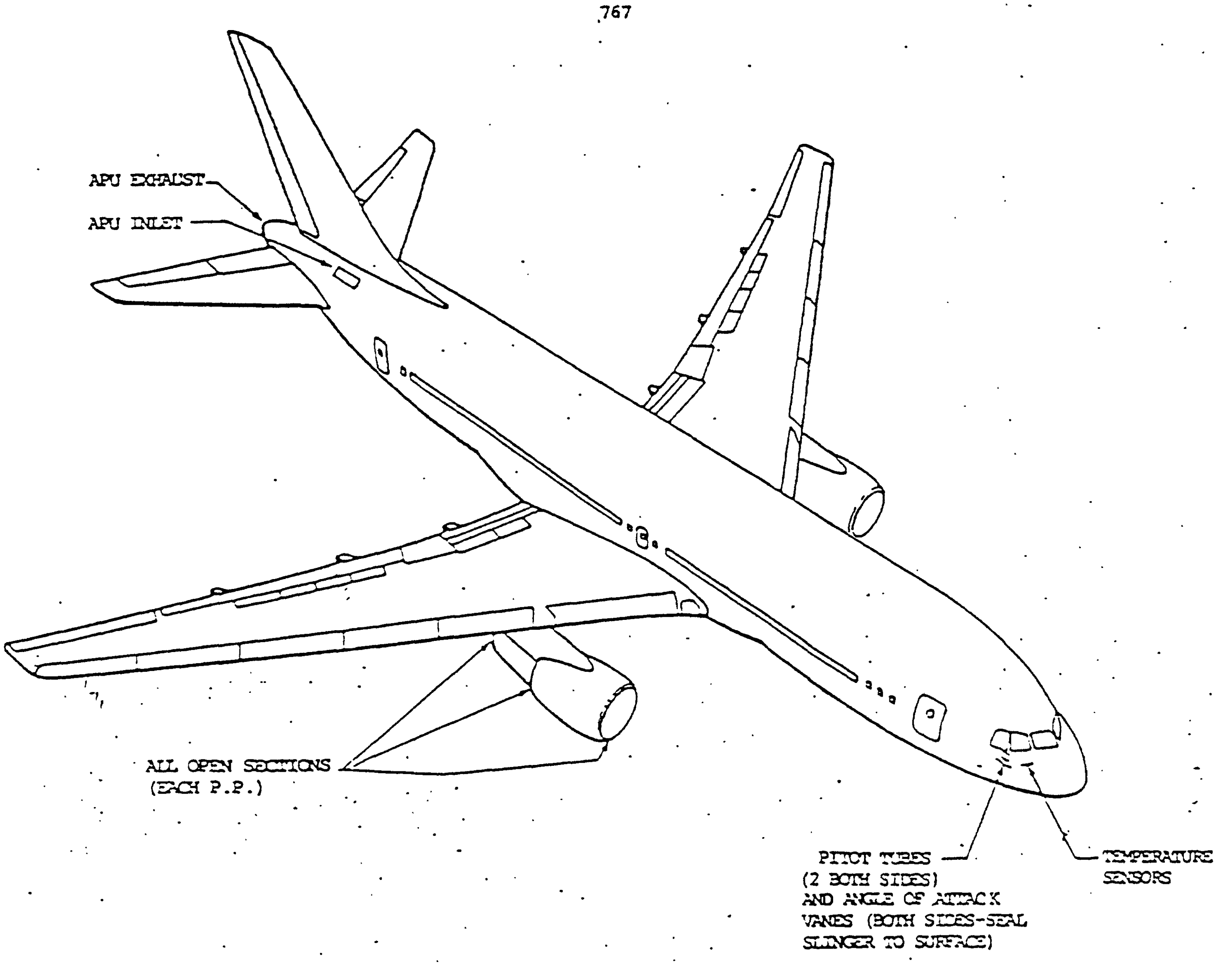
A/P OPENINGS - TOPSIDE (747)



A/P OPENINGS - UNDERSIDE (747)



A/P OPENINGS - TOPSIDE (767)



A/P OPENINGS - UNDERSIDE (767)

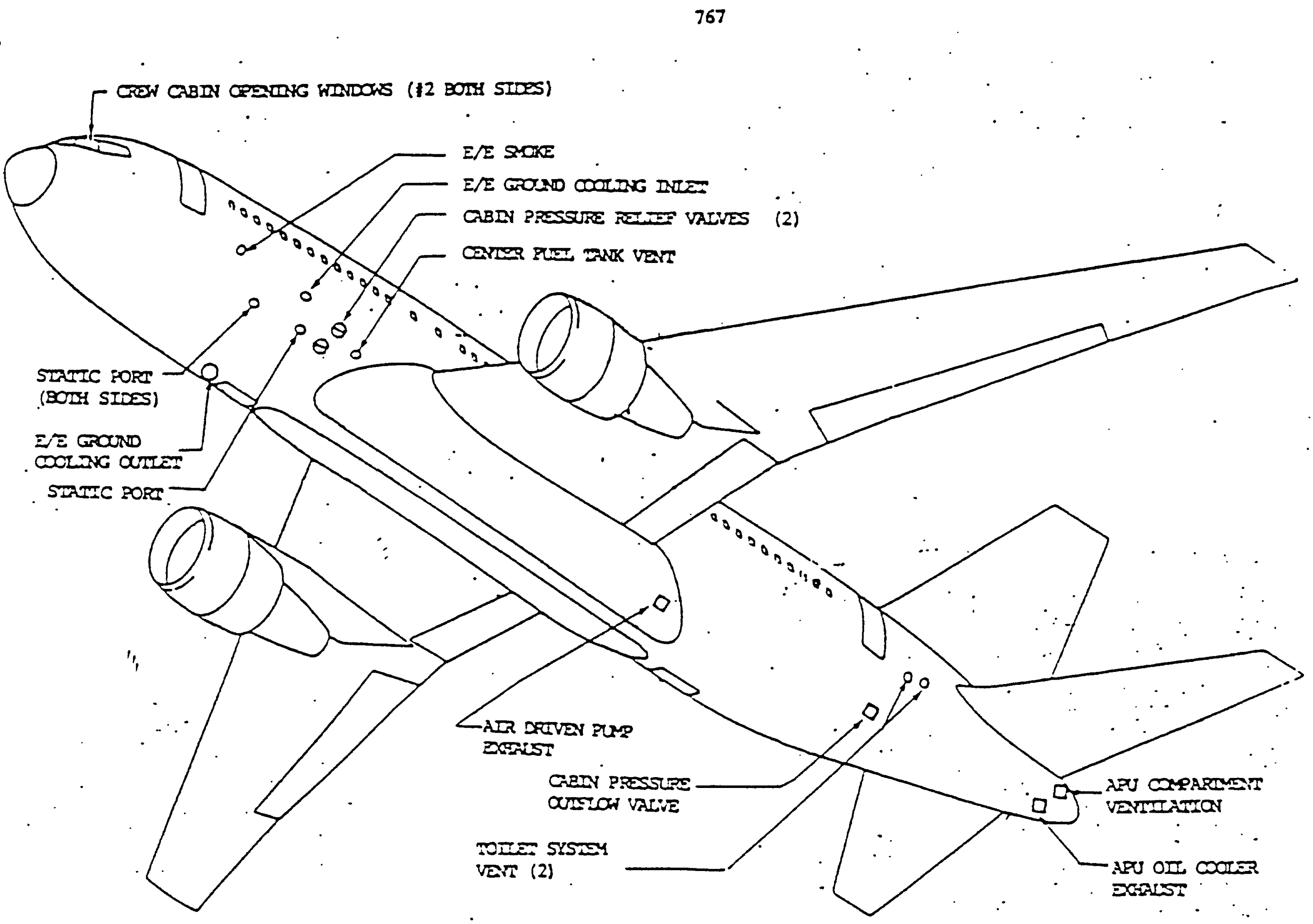


Table 1. Airports affected by volcanic ash

Date	City/Airport	Volcano	Ash Depth	Days closed	Comment	Reference
1924, 24 May	Kilauea	Kilauea	large blocks	?		Blong, 1984
1944, 22 March	Naples	Vesuvius	?	?	88 planes damaged	Lloyd, 1990; NY Times, April 25, 1944
1951, 21 January	Port Moresby	Lamington	?	?		Taylor, 1958
1953, 9 July	Anchorage	Spurr	3-6 mm	4-7		Juhle and Coulter, 1955; Wilcox, 1959
1963, 17 March	Surabaya	Agung	<10 mm	1		Jennings, 1969; Suryo, 1981
1971, 9 September	Kagoshima	Sakurajima	3 mm	<1		K. Kamo, written commun., 1993
1976, 23-25 January	Anchorage	Augustine	trace	no closure; some cancellations		Kienle and Swanson, 1985
1979, 3 August	Catania	Etna	trace	1-?		Guest and others, 1980
1980, 18 May	Spokane Yakima Pullman Grant County, Missoula, MT	Mount St. Helens	0.5-1 cm 0.5-1 cm 1 cm 7-9 cm 1-2 cm	3 days 7 days 7 days 15 days several days		Schuster, 1981,83 Warrick and others, 1981
1980, 25 May	Portland area	Mount St. Helens	trace (<0.1 cm)	no closure; some cancellations		Schuster, 1983
1980, 12 June	Portland area	Mount St. Helens	2 - 3 mm	several days;	some carriers continued to operate	Schuster, 1983
1982	Bandung	Galunggung	various	various including June 4-21	closure due primarily to reduced visibility	De Neve, 1986
1983, 3 October	Miyake-jima	Miyake-jima	10 cm	4 days		Blong, 1984
1984	Anchorage	Augustine	trace	no closure; some cancellations		Kienle and Swanson, 1985
1989, 15 December and 1990, February 21 & 28	Anchorage	Redoubt	trace	no closure; many cancellations (see text)	ash in airspace, and several encounters	Casadevall, 1993

Date	City/Airport	Volcano	Ash Depth	Days closed	Comment	Reference
1990, 8 January	Kenai, Alaska	Redoubt	approx. 5 mm	several days		Casadevall, 1993
1990, 11 March	Kagoshima	Sakurajima	2 mm	<1		K. Kamo, written commun., 1993
1991, 16 April	Colima, Mexico	Colima	<5 mm	several days		Bull. Global. Vol. Net. (1991, v. 16, n. 4, p.7)
1991, 15 June	Manila Sangley Point Cubi Point Clark Basa Legaspi Pt. Princessa	Pinatubo	0.5-1 cm " 15-20 cm " " trace trace	various (see text)		Casadevall and others, in press
1991, August-December	Argentina: Comod. Riv. Pto. Deseado and Stanley, Falkland Isl.	Hudson	original thicknesses were variable	see text	resuspended ash - major problem	T. Manzanares, written commun., 1991
1991, 24 October	Medan	Lokon	no ashfall	several days	ash in airspace	L. Pardyanto, written. comm., 1991
1992, 6 June	Kagoshima	Sakurajima	trace (<1 mm)	1		K. Kamo, written commun., 1993
1992, 18 August	Anchorage	Spurr	<5 mm	3		AVO, 1993
1993, 18-21 April	Argentina: Salta, Jujuy, Cordoba	Lascar	various	various	ashfall reported at Asuncion	F. Pequeno, verbal commun., 1993
1993, 7 June	Pasto, Colombia	Galeras	trace	< 1 day	NOTAM issued @ 12:15pm	Bull. Global Vol. Net. (v. 18, no. 5, p.3).

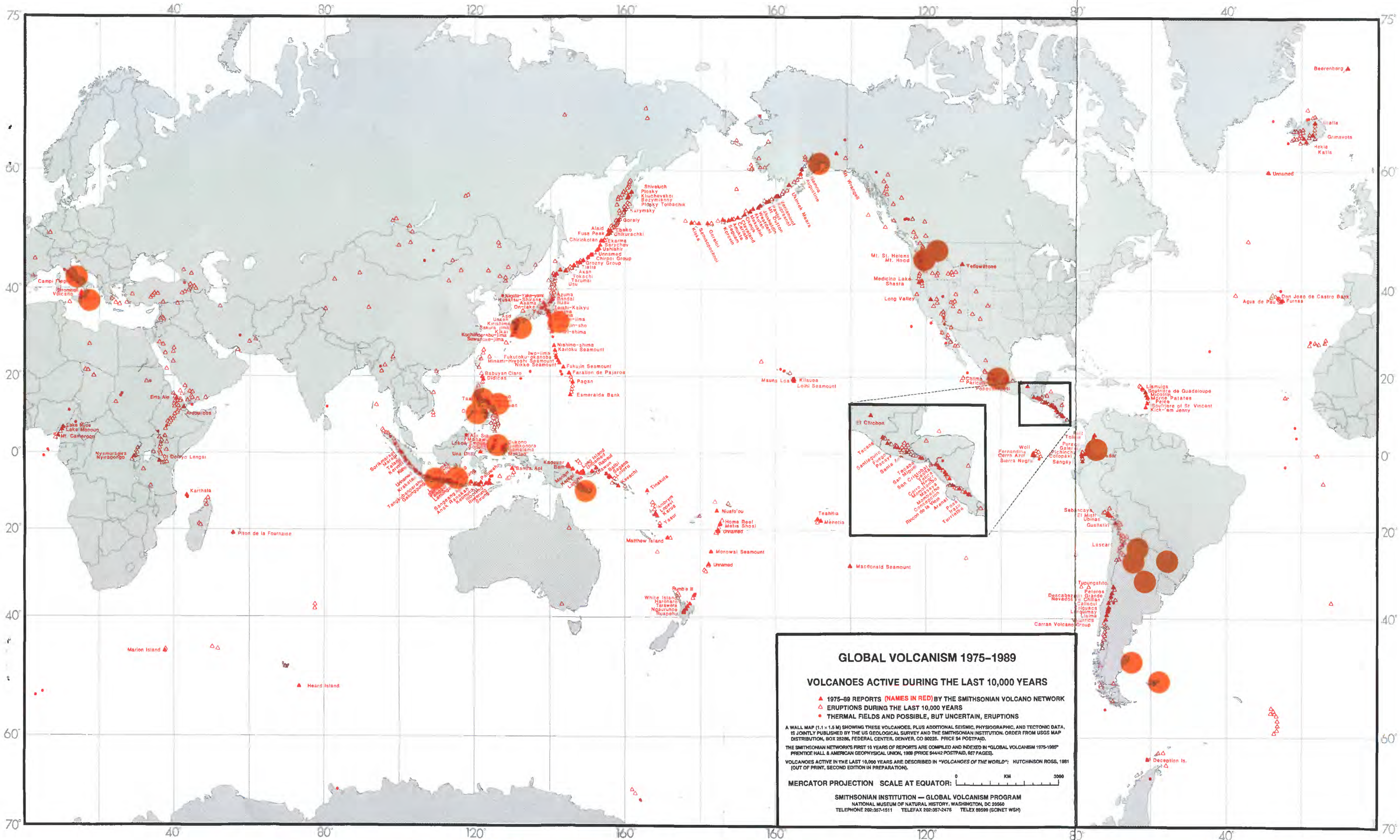


Figure 1. Map showing locations (●) of airports affected by volcanic ash between 1944 and 1993; see Table 1 for details. Modified from McClelland and others (1989).