VOLCANIC ASH EFFECTS

AND MITIGATION

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I. INTRODUCTION

The likelihood or magnitude of a volcanic eruption cannot be forecast with confidence. However, if an eruption of significant magnitude occurs, the volcanic ash cloud and fallout could be a hazard to a variety of military and civilian assets. Multiple eruptions – and, therefore, multiple volcanic ash falls – are possible and can be expected to continue over a period of months to years. Immediate and direct physiological hazards due to volcanic ash primarily exist only in close proximity to a volcano (i.e., a few tens of kilometers). However, volcanic ash effects on equipment and systems can be expected at ranges of up to hundreds of kilometers. Aircraft encounters with volcanic ash clouds have resulted in dangerous engine problems, and the Mount St. Helens ashfall seriously affected civil and military capabilities and equipment over a large area in the Northwest.

This document addresses techniques for mitigating the effects of volcanic ash on selected categories of critical equipment. It is based on information developed and experience gained in dealing with volcanic ash fallout produced from the eruption of Mount St. Helens in the State of Washington.

On May 18, 1980, Mount St. Helens erupted, covering 50% of Washington with approximately 1 km^3 of ash. Although 19 of the 39 counties in the state received some volcanic ash, five eastern counties were severely affected. Subsequent, less violent, eruptions deposited more ash in Washington and in the northern and western portions of Oregon.

Government agencies, hospitals, utilities, and private corporations within the affected areas were all forced to cope with ash deposits (ranging in depth from 1/8" to 3") in maintaining essential services and in carrying on normal activities. Their experiences provided much of the raw material for this report.

A review of the available literature – damage survey reports, newspaper and magazine articles, Federal and state agency advisories – formed the basic groundwork. In-depth interviews with equipment users, service companies, university researchers, utilities, and others affected by the ash elicited detailed information on ash-related damage and on methods of dealing with the ash. All of these methods would be useful in mitigating the likely effects of a volcanic eruption.

II. VOLCANIC ASH EFFECTS

Volcanic ash is abrasive, mildly corrosive, and conductive (especially when wet); 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 in the air for many minutes. Due to the combination of these qualities, volcanic ash is pervasive. It can penetrate all but the most tightly-sealed enclosures, and it can be very difficult to remove from electronic components.

The ash easily absorbs water and can weigh up to 1,400 kg/m^3; water-laden ash may collapse or damage flat roofs. Wet ash is very slippery and can cause traction problems. Dry ash, blown into the air, reduces visibility and piles up on roads and streets. Ash must be physically removed and controlled after removal to prevent re-entrainment.

Ash deposited on electronic components can cause arcing, short circuits, and intermittent failures due to its conductive nature. High-voltage circuits and components are especially vulnerable. Ash dampened by rain can cause arcing, flashovers, and pole fires on electrical distribution systems. Resulting outages may hamper mitigation efforts that require electrical power.

Moving parts are subject to abrasion damage from volcanic ash. The ash is attracted to – and entrained in – any exposed lubricant; thus, abrasion effects will continue even after the bulk of the ash has been removed. Bearings, brakes, and transmissions wear out very quickly. Computer disks, disk drives, and heads are very sensitive to abrasion and are easily damaged by ash. In addition, ash adhering to painted or polished surfaces will scratch and scour the surface unless it is removed carefully.

Filters on air handling and computer systems may become clogged with ash to the point that airflow is completely stopped, leading to equipment overheating. Clogged filters may collapse, severely contaminating the internal environment. Additional filtration can reduce ash penetration, but only at the cost of reduced airflow to critical equipment. Filtration systems that incorporate centrifugal separators can handle the ash much more easily.

Ash effects on equipment and systems may occur in various combinations and degrees of severity depending on the nature of the eruption, weather patterns, and other physical circumstances. In addition, damage from ash contamination is cumulative and will continue long after eruptions have ceased.

III. VOLCANIC ASH MITIGATION

Techniques for reducing the effects of volcanic ash can be grouped into three broad categories: (1) keeping the ash out; (2) controlling what gets in; and, (3) disposing of the ash. These categories are more illustrative than discrete, and some techniques will apply in all three cases. Mitigation actions will be required on a continuous basis as long as ash is present. Settled ash is easily re-entrained and a 2-mm layer can be as troublesome as a 50-mm layer.

The most effective technique for mitigating ash-related damage or upset to equipment is to avoid using it: shut down, close up, keep inside, or seal the area until the ash can be removed. This tactic is acceptable only for short periods of time because operations must be resumed at some point. In any case, disposal techniques will not eliminate all of the ash. A residue will remain on the ground and will be blown into the air by wind, passing vehicles, and aircraft takeoffs. Thus, an accelerated and intensive program of inspection, maintenance, cleaning, and monitoring will be necessary during and after the main part of ash deposition.

Cleaning the ambient air – and keeping it clean – is the key to reducing operation and maintenance problems. Blowing ash off a circuit board is useless if the ash is fine enough to remain suspended for several minutes. The difficulty of attempting to perform maintenance tasks in an already ash-contaminated atmosphere is obvious. "Clean room" procedures can be used to isolate an area and keep it free of ash, but only under ideal circumstances. Some equipment (aircraft engines, for example) may be too large for such treatment. Tents or tarps can be used to reduce gross contamination. However, fine particles can penetrate very small openings and seams; it is this property that makes fine particles more damaging to critical equipment than larger fractions.

Some mitigation procedures may cause additional problems or may be actually counterproductive depending on the circumstances. For example, adding filtration to a computer system will reduce the amount of ash contamination, but it will also decrease the airflow. The resulting rise in temperature may change the operating characteristics of sensitive components or even cause damage. Adding a larger fan would increase the airflow, but not all computers (especially smaller units) can be easily modified. Another example is the use of moisture to control ash. Wetting carpets will increase relative humidity and help to keep the ash down; however, wet (or even damp) volcanic ash is conductive.

No one technique will be absolutely effective; a combination of techniques will provide the best results. Constant monitoring and reassessment of ash effects and the mitigation process will be required to achieve the most effective balance between operational requirements and the desired level of damage limitation. The following sections summarize ash mitigation techniques.

A. Contamination/General

The following techniques provide general guidelines for removing or controlling ash in most buildings or work areas. They can be adapted to suit the circumstances.

Mitigation Techniques:

- Establish a written procedure; train personnel.
- Stockpile disposal containers, mops, brooms, shovels, pails, industrial vacuum cleaners, plastic bags, and sheets.
- Stock filters and filter materials.
- Remove ash from roofs and entryways prior to re-activating machinery.
- Keep roof drains, storm drains, gutters, etc. clear of ash clogging. It is best to sweep ash from roofs and not flush with water; roof drains clog very easily.
- Make a written record of all steps taken to secure the building, so these steps can be retraced for startup procedures, or if problems arise.
- Use a damp mop to clean hard floors.
- Use a water-type industrial vacuum cleaner, if possible, for cleaning rugs and cloth furniture.
- Use damp, disposable cloths to dust furniture, windowsills.

- Restrict building access to the most protected entrance. Admit only authorized personnel.
- Close and seal all unnecessary outside openings, including air intakes and vents. Shut down all unnecessary building operations and equipment.
- Establish decontamination rooms for personnel entering the building. Require personnel to brush down clothing and shoes prior to entering the building and to vacuum off clothing immediately upon entering the building, or to bring a change of clothing and shoes for use while in the building.
- If outside air intake is required, monitor air intake filters at regular intervals, and change as required. Remove ash from area of outside-air intakes.
- Maintain a relatively clean environment throughout the entire building. Damp-mop floors, wipe off machinery and furniture at least once a day.

B. Aircraft

The basic mitigation tactic is avoiding exposure to ash. The airports and airfields surveyed simply shut down for the duration of the ash problem or until the ash had been removed. Some aircraft at Fairchild AFB were evacuated, and the remainder were placed in hangers. Commercial airlines rerouted traffic away from ash-impacted airports.

Sealing aircraft seams, ports, vents, etc. with duct tape will keep out the bulk of the ash, especially if the aircraft is under some kind of cover. Maintaining positive pressure within aircraft components would help to keep the ash out, but it is very difficult, if not impossible, to pressurize an aircraft on the ground without severe damage to ground equipment.

<u>Mitigation Techniques:</u>

- Blow or vacuum ash off before washing (otherwise ash tends to flow into ports, vents, control surfaces).
- Flush or wash off residue. Do not dry scrub or broom.
- Wash down gear, underside, air-conditioning intakes, and engines.
- Check pH of aircraft/engine surfaces for acidity. Extra care is needed to prevent corrosion if ash is acidic.
- Neutralize sulfuric acid by adding petroleum-base solvent to wash water.

All of the above techniques require large amounts of time, manpower, and equipment. All have a significant effect on the level, scope, and time criteria of continued operations. These techniques were tried under conditions of greatly reduced operating levels; there is some question as to their effectiveness during normal (or near-normal) operations.

Operational Considerations:

- Sealing aircraft would take 4-5 hours; removing all seals and tape would take 1-2 hours. Very hard to seal up an aircraft completely; too many ports, vents, seams, joints.
- Sealing would increase alert reaction time by a factor of 3.
- Ash build-up in or around hatch seals could cause problems with pressurization after launch.
- Fuel tank vents must be open during loading, unloading, and transfer of fuel. If vents are plugged with ash, or if sealed and the seals are not removed, the tank could collapse. A 4-5 psi vacuum is sufficient to cause collapse.

C. Runways

If operations are not suspended, runways must be cleaned continually due to the fact that ash is easily re-entrained by wind, aircraft takeoff, and ground vehicle movement. There is some disagreement on the proper use of water in cleaning runways: some sources felt that water turns the ash to sludge (or causes it to harden); others found it impossible to control the ash without wetting it down first.

Basic Removal Technique:

- Wet ash down with water trucks
- Blade into windrows
- Pick up with belt loaders or front-end loaders
- Haul to dump areas
- Sweep and flush residue.

Supporting Technique:

- Sweep/vacuum ash first, then flush with water (best for ramps, etc.).
- Push ash to runway edge; plow under or cover with binder (Coherex or liquid lignin).
- Install sprinkler along edges of runway to control re-entrainment of ash from aircraft engine blast or wingtip vortices.
- Keep residue on taxiways and ramps wet.
- Sandbag around catchbasins; water level builds up and then runs over bags as ash precipitates. Catch basins remain clear, and ash can be vacuumed or loaded as above.
- Open graded ("popcorn" surface) runways are to some extent self-cleaning; engine blast on take-off will blow ash out of crevices.

Operational Considerations:

- Techniques require extensive mobilization of personnel and equipment on a continual basis.
- Extensive use of removal equipment would draw down POL supplies; equipment would also require increased maintenance due to ash damage.

D. Landing Aids and Air Traffic Control

Protection of landing aids and air traffic control systems will require periodic cleaning, maintenance, and monitoring. Also, turning off unnecessary equipment will reduce exposure. Exposed light and indicator systems, radar antennas, and any equipment that requires cooling air are especially vulnerable to ash contamination and damage. Interruption of commercial power supplies will require backup generators, which are vulnerable to ash damage.

Mitigation Techniques:

- Replace antennas which have Teflon insulators (ash hard to clean off and will cause shorting; ceramic insulators should be used).
- Seal relay boxes, remote indicator units, light systems to prevent ash entry.
- Increase cleaning and maintenance of systems that can't be sealed or that require cooling air.
- Vacuum out or blow out ash; clean relays, etc. with contact cleaner.
- Use high-pressure water wash on exposed antenna rotor bearings; re-lubricate.
- Cover exposed joints, seams, and bearings.
- Seal building, control access; vacuum shoes, clothes.
- Reduce operating levels: shut down unused equipment; reduce broadband displays to minimum; reduce cooling and power consumption.
- Change procedures: combine sectors for reduced coverage.
- Transfer responsibility to other control centers if "planned shutdown" required.
- Accelerate installation of solid state equipment - reduce power and cooling requirements.

E. Aviation Ground Support

The consensus at Fairchild AFB is that ground support equipment is the key to flight operations. If ground equipment is unserviceable due to ash, aircraft cannot be launched. Unfortunately, there are more problems than solutions in the ash contamination of ground equipment.

Gas turbines (for engine start and electrical power), air compressors, and air conditioners operate based on the ingestion of a large volume of air. This equipment has only coarse filtration – or none at all – and extra filtration cannot be added without affecting operation. Using air conditioners to pressurize aircraft compartments would only blow ash into the aircraft and ruin the air conditioners in the process.

Mitigation Techniques:

- Constant cleaning and maintenance.
- Don't wash equipment. Water turns ash to sludge and washes it into the equipment.
- Vacuum ash off equipment.
- Change oil and filters more often.
- Change design to include better filtration.

Operational Considerations:

- Ash damage is cumulative, and equipment can withstand a certain level of contamination.
- A limited number of launch/recovery cycles could be carried out, but extended operations would become more difficult.
- Supply of oil, filters, spare parts may be limited.
- Problem of maintenance and repair in an ash-contaminated environment.

F. 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 ash. The simplest mitigation tactic is to cease operations.

Mitigation Techniques:

- High-voltage circuits may short out. Repair and clean.
- Wash antenna rotor bearings; re-lubricate; cover exposed bearings.
- Ash 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 ash into optical instrument mounts on aircraft (e.g. sextant). Ash 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 videotape from ash; ash will cause "drop-outs," scratches on tape.

G. Computer Systems

The most widely-advised tactic is to shut down all computer and electronic systems until the ash has been completely removed from the area and from the equipment. Computer heads and disks – and any high-voltage circuits – are especially vulnerable to ash upset and damage. Ash on digital circuits will not 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 ash. Ash that is acidic is conductive as well as corrosive. Continual cleaning and aggressive protection of computer systems should allow for continued operation in all but the heaviest ash fallout.

Mitigation Techniques:

- Clean and condition surrounding air to keep ash out of equipment.
- Cotton mat filters (used in clean rooms) were found to be best for filtering particles, but they reduce airflow. A solution is to use larger fans to maintain required airflow. Rack-mounted equipment can be modified to add a larger fan, but smaller instruments or components with a built-in fan would require a design change to increase fan capacity.
- Use fluted filters as a compromise; increases surface area, but reduces airflow by only about 20%.
- Humidifying ambient air (e.g., wetting carpets) will help to control ash re-entrainment.
- Ash 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 ash will stick. Relative humidity of 25-30% is best for compressed air.
- Cleaning with a pressurized mixture of water and detergent and using a hot-water rinse is quite effective; however, this process requires at least partial disassembly. Ash may have a high-static charge and be hard to dislodge; requires 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 for filtration, but do not operate (especially disk drives). Maintain room-within-a-room configuration, restrict access, re-circulate air, and accelerate cleaning of area.

H. Communications Systems

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

Mitigation Techniques:

- Teflon insulators on communications antennas were covered with ash and shorted out. Very difficult to clean as residue would adhere. Replacement with ceramic insulators required.
- Plastic switches and pushbuttons (especially those with self-cleaning contacts) abrade quickly. 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.

I. Electric Power

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

Mitigation Techniques (general):

- Compressed air to blow off insulators, bushings, and 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 incidence (less than 5%) of capacitative discharge when siliconed insulators were covered with ash.
- Washing and wiping may be necessary to remove residue.
- Knock or brush ash loose from substation equipment and structures.

- Blow off ash, then wash; ash 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% ash removed
  -40 km/hr 90% ash removed
  -55 km/hr only trace left
- Rubberized compound insulators burned and melted by flashover. Replace with ceramic insulators.

Mitigation Techniques (auxiliary generators):

- Stockpile filters.
- Add filters (30% 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 generators 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:

J. HVAC Systems

Air conditioning and air handling systems are subject to ash-related damage, and they can also transport ash to even more sensitive equipment. Many types of electronic, computer, and communications gear require cooling air and must be shut down in its absence. Mitigation tactics focus on stopping the ash before it enters the cooling air stream and then on protecting the air handling system itself.

Mitigation Techniques:

- Close external air intakes; use internal circulation only; this will create positive pressure inside building.
- Control access; seal doors.
- Establish decontamination rooms for entering personnel; provide vacuum cleaners, shoe covers, disposal caps.
- Stockpile cleaning supplies, duct tape, disposal containers.
- Use extra (and heavier) filters for external air intakes.

- Clean ash away from external intakes; restrict vehicle and foot traffic near intakes. Install intake hoods that extend farther above ground.
- Install pre-filters.
- Add sand filters to cooling towers.
- Cover cooling towers.
- Clean coils, radiators, etc. with compressed air and/or water. Add cooling coils to uninterruptable power supply to reduce temperature of incoming air by 10° (increases cooling capacity).
- Add back-flushed filters to cooler sumps.
- Install alarm circuit to warn of excessive pressure differential across filters; filters that get too clogged can break open.
- Change from open, drip-proof type motors to totally enclosed, fan-type motors. Reduce staff to minimum required.
- Close and seal unused rooms; turn off unused equipment.
- Shutdown air handling system to prevent damage to chillers, fans, pumps, etc.

These techniques are based on the operation of many different types of equipment and a variety of operating configurations, modes and circumstances. Also, these tactics may be used in various combinations and phased-response methods. Techniques appropriate for one type of system and operating conditions may not be useful for other systems.

K. Cars and Trucks

The most damaging and most extensive effects of volcanic ash may occur in cars, trucks, and buses. Urge people to keep their vehicles off the streets until the ash has been removed. Vehicles that must be used (police, fire, removal, etc.) will experience greater or lesser engine, transmission, or other damage depending on the level and quality of maintenance applied.

Vehicles designed for a dusty environment (e.g., construction, farming) will have fewer problems. Filters on these vehicles, often incorporating a centrifugal precipitator, are designed to handle dust. Generally speaking, ash particles will remain suspended in the 20-micron oil layer that forms on moving parts within an engine. As the ash contamination increases to about 5 % by weight, oil sludge will form. This will change the lubricating properties of the oil and could lead to engine damage.

<u>Mitigation Techniques:</u>

- Increase maintenance, oil change, etc.; interval will depend on degree of exposure (see maintenance instructions below).
- Extend air intakes (use dryer vent hose) farther above ground.
- Seal air filter with spot welds and/or silicon sealer; add air hose to external, truck-type filter; seal all connections.
- Purge-lube all joints, bearings, etc.

- Use pre-filters: polyester batting, oil-soaked foam rubber, rubberized foam slip-on filters (like a shower cap; cheap and disposable).
- Seal crankcase; use positive seals on dipstick. Gasoline engines are less susceptible to oil contamination due to positive pressure of PCV system. Diesels may be more vulnerable to ash: no PCV; supercharged; crankcase and transmission vents open.
- Wash vehicle and engine to remove ash.
- Install fuel filters – 70 gallons of gas means 70 gallons of contaminated air as tank empties. Maintain positive pressure in cab/interior by keeping heater on. Do not lead engine air intake hose into car interior; an engine will draw in up to 200ft of air per minute at freeway speeds.

1. Preventative Maintenance Under Volcanic Ash Conditions

   Every 1½ to 3 hours of exposure:

   Blow out dry-type air filter elements, air compressors, breathers, valve cover to air breather filter, valve cover breather, hydraulic oil reservoirs, power steering breather, radiators, transmission coolers, electrical plug-in connectors, ignition switches, toggle switches, starters, alternators, distributors (inside and out), spark plug wires, engine compartments.

   Inspect all inner and outer visible wheel seals. Blow out inside of cabs; inspect exhaust discoloration for loading up of engine caused by restriction in the intake system.

   Remove oil bath type air breathers, clean out residue, flush breather in solvents, air dry, re-install, and test-operate.

2. Maintenance Of Vehicles After Exposure To Ash

   - Wash with high-pressure water system. Steam clean completely. Remove all lubricants from engines, transmission, auxiliary transmission, transfer cases, torque converters, differentials. Take samples of the above, send to laboratory for analysis. Clean all units, replace filters as required. If noise is audible, the above should be removed and inspected for wear, seal leakage, bearing and gear wear; reconditioned, refilled with proper lubricants, tested, and inspected for sound and leaks again.

   - Inspect air compressor breathers. Change oil; inspect for seal leakage and wear. Inspect air conditioner units, cab pressurize units. Change breather and foam filters, blow out automatic transmission coolers and inspect for leaks.

- Inspect front and rear wheel bearings, seals, drums, and brake linings. Adjust brakes as required.

- Inspect drive line "U" joints; clean or replace as required and lubricate.

- Inspect radiators and cooler systems for leaks and proper ventilation. Flush out and replace fluids; change water filters where applicable in the cooling system.

- Inspect windshields, door glasses, and rear cab glass for wear from sanding action; replace as required.

- Inspect paint finish and repaint where required.

L. Railroads

Diesel-electric locomotives are very well designed and filtered. They do, however, draw in large volumes of air and generate strong vacuum pressure in the intake systems. Clogged filters were sucked into the engine itself in one case. Otherwise, problems were few and mostly annoying rather than serious.

Mitigation Techniques:

- Accelerate filter change.
- Wash locomotives inside and out.
- Seal cab and compartments with duct tape, etc.
- Pressurize compartments with compressed air line from engine.
- Accelerate cleaning, maintenance of signals, gears, etc.; wash with high-pressure water, re-lube.
- Wet ash can cause leakage/grounding in signal system:
  - increase line voltages
  - accelerate cleaning and maintenance
  - develop alternate signal procedure.
- Microwave coaxial cable is pressurized; will keep ash out.

M. Roads and Streets

Roads, streets, and drainage channels will require continual cleaning, as the ash is easily re-entrained. Disposal and control of the ash is just as much a problem as removal. Cleaning, disposal, and control of ash on roads require an extensive mobilization of personnel and equipment.

Basic Removal Method:

- Wet down with water truck (and keep wet).
- Blade into windrows with grader.
- Pick up with belt loader or front-end loader (load into trucks). Haul to dump site.
- Sweep up remainder.
- Flush residue to side/ditch/curb with water. Vacuum out catch basins.

Supporting Techniques:

- Build sandbag dams around catch basins; water will flow over dam, but ash will precipitate. Ash can then be scooped or vacuumed out.
- Spray emulsified asphalt over ash in dump area; forms covering layer. Blade ash off roads, parking lots, etc.; add gravel to keep ash down. Apply ash retardant. One example is Coherex (Golden Bear Division of Witco Chemical Corp.). Emulsion of petroleum resins. Diluted (1: 10) with water; .1 to .2 gal/yd depending on depth of ash. Particles turn into agglomerated mass; form neutral, non-toxic mat that adheres to asphalt and concrete.
- Apply lignin sulfate (pulp-mill liquor) as road surface binder. Dilute 50:50 with water; re-apply after rain. Works best for light coatings of ash.
- Use rock salt (calcium chloride, 32%) to stabilize ash. Salt draws moisture from air; associated ash absorbs moisture and becomes more stable. Salt also forms an ionic bond between volcanic ash and soil. Ash will stand up to bladeing.

IV. PLANNING FOR ASH MITIGATION

Techniques for reducing the effects of volcanic ash are basically "low tech" and depend more on procedural approaches than on technical fixes. Also, they are quite labor-intensive and resource-intensive. Normal stocks of daily-use items – such as filters, lubricants, spare parts, cleaning supplies, etc. – may be expended much faster than they can be replaced through the normal reordering process. Prior planning is necessary to reduce the severity of ash effects. Planning actions include:

- Conduct a vulnerability analysis of equipment and facilities to determine which would be most affected by ash, which are adequately protected, and which need long-term or expedient modification.
- Develop a priority list of facilities that must be kept in operation versus those that can be closed or shut down for the duration of the ash fall.
- Ensure hazard alerting and information channels are properly maintained with USGS, FEMA, weather bureau, local news media, and state and local governments.
- Establish plans and procedures for alerting and notification, reduced operations, accelerated maintenance, protection of critical facilities, and cleanup and disposal.

- Stockpile spare parts for critical equipment, filters, fuel, lubricants, and cleaning and disposal equipment.
- Plan for extended cleanup and maintenance activities including 24-hour operations, work force augmentation, and training of cleanup crews.
- Ensure that sufficient water and backup power is available to support cleanup operations should normal supply sources fail.

Additional planning considerations include the following:

- Vehicles, aviation ground support equipment, and related equipment not designed to operate in a normally dusty area are likely to experience damage if used in a volcanic ash environment. Construction equipment, truck transport, etc. should be operable provided careful maintenance practices are followed.

- Large areas of highway networks may be rapidly paralyzed by fallout, requiring extensive removal of volcanic ash and disabled vehicles and impacting normal supply channels for days. Communications and electric power networks are likely to remain operable, although propagation anomalies and local outages are to be expected. "Minimize" and energy conservation measures should be implemented to reduce the load on these systems.

- Special water and sewage measures may be required in heavy fallout areas.

- Personnel should be alerted to the possibility that variations in wind and weather conditions may result in volcanic ash cloud movement in unexpected directions. Multiple volcanic ash cloud exposures are to be expected over a period of months to years if eruptions begin; conditions may be dramatically different in each case.

Ash cleanup operations may have to continue for weeks or months if multiple eruptions occur. Effective mitigation of volcanic ash effects depends on prior planning and preparation, mobilization of resources, and persistence.