

THE HEALTH HAZARDS OF VOLCANIC AND GEOTHERMAL GASES

a guide for the public





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A GUIDE FOR THE PUBLIC

This guide has been prepared by the International Volcanic Health Hazard Network (IVHHN) to explain the potential adverse health effects of volcanic and geothermal gas and aerosol emissions.

It provides general information on how to protect yourself and your family. The information is based on a range of evidence from academics and health and regulatory agencies. Contact your local public health or emergency management agency for information tailored to your location.

The information in this booklet was written by Bernadette Longo (University of Nevada, USA), Tamar Elias (U.S. Geological Survey) and Claire J. Horwell (Durham University, UK) and has been reviewed by an expert panel: Fatima Vivieros (University of the Azores, Portugal); Peter Baxter (University of Cambridge, UK); Yasuhiro Ishimine (Kagoshima University, Japan); Carol Stewart (Massey University, New Zealand); Evgenia Ilyinskaya (University of Leeds, UK); Þórólfur Guðnason (Directorate of Health, Iceland); and David Damby and colleagues (U.S. Geological Survey). Thanks to Pierre Yves Tournigand for illustrations.



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1. WHAT ARE VOLCANIC AND GEOTHERMAL GASES?

Some volcanic eruptions are explosive, energetically erupting a mixture of gases and different-sized rock fragments (including ash and pumice) which pose a variety of hazards. Less explosive volcanoes may quietly emit gases and lava flows. Volcanic gases can also be released between eruptions, or for months-to-years following the end of an eruption, though gas release will generally be lower in these situations. Volcanic emissions can result in air pollution that may be hazardous to people, animals, agriculture, and property.

Volcanoes and geothermal areas emit a variety of air pollutants including gases and fine particles. By far the most abundant volcanic gas is water vapor, which is harmless. However, significant amounts of carbon dioxide (CO₂), sulfur dioxide (SO₂), hydrogen sulfide (H₂S) and lesser amounts of hydrogen halides (hydrogen chloride [HCl] and hydrogen fluoride [HF]) and carbon monoxide (CO) can also be emitted from volcanoes. In geothermal areas, groundwater heated by near-surface magma can create long-lived hot springs and fumaroles, which release steam that may also contain volcanic gases, particularly CO₂ and H₂S. Metals like lead and mercury may also be present in volcanic and geothermal emissions.

Where molten lava flows into the ocean, it reacts vigorously with sea water to create large, acidic steam plumes containing HCl and HF gas





and volcanic glass particles. In some parts of the world (for example, Hawaii), these plumes are referred to as 'laze' (a combination of the words lava and haze).

Some volcanoes and geothermal areas emit radon, a radioactive gas produced by the decay of uranium from deep in the Earth. In volcanic areas, radon is emitted from the ground along with CO₂. Outdoors, radon and CO₂ are quickly diluted in the atmosphere and are of no further concern. However, in confined spaces such as buildings, radon and CO₂ can accumulate to harmful levels.

Volcanic gases are all colorless (invisible), but have different odors:

- ❖ SO₂ – struck match or fireworks
- ❖ H₂S – rotten egg smell
- ❖ HF and HCl – strong, irritating, pungent
- ❖ CO₂ and radon – odorless

2. WHAT IS VOLCANIC AEROSOL?

As SO₂ gas is released from a volcano, it reacts in the atmosphere to form tiny solid particles and liquid droplets suspended in the air, called sulfate aerosol. Volcanic sulfates are acidic and create a visible haze downwind of a degassing volcano. In the United States, this pollution is known as 'vog' (volcanic smog or fog). Areas far downwind (more than 100 kilometers or 60 miles) are mostly affected by the aerosols, however, areas closer to the eruptive vents can be exposed to both SO₂ gas and aerosol.

The amount of sulfate aerosol in the air can be measured using pollution monitors that measure very small particles such as $PM_{2.5}$ or PM_{10} (particulate matter with diameters less than 2.5 or 10 micrometers). For comparison, a human hair is roughly 30 times wider than $PM_{2.5}$. These small particles can be inhaled deep into the lungs. Other sources of $PM_{2.5}$ include vehicle exhaust and wildfire smoke. Volcanic ash particles tend to be larger, with only some ash particles in the $PM_{2.5}$ or PM_{10} category.

3. WHAT IS ACID RAIN?

In areas where a plume of volcanic gases and aerosols is present, there is likely to be acid rain, which is rain that is acidified by SO_2 and other acid gases. In areas near a vent, the rain could have acidity like a freshly squeezed lemon (pH of 2). Acid rain can irritate the skin and eyes and cause a stinging sensation. It can also damage plants and accelerate the rusting of metal surfaces on buildings, vehicles, farm equipment and utilities infrastructure. Acid rain can also impact surface water quality and may kill fish in open air ponds.




4. TRANSPORT AND SETTLING OF VOLCANIC POLLUTION

During eruptions, plumes of volcanic emissions can travel for hundreds to thousands of kilometers (miles) downwind, creating air pollution locally and in distant locations. In any location, gas and aerosol concentrations on a given day are mostly due to the amount released by the volcano, the distance from the source vents, and the wind direction and speed.

In both volcanic and geothermal areas, gases can be released directly from the ground, over a wide area. Some gases, such as CO_2 , H_2S , and radon, are denser than air and can pond in windless, confined or low-lying areas creating a severe hazard (for example, basements, excavation holes, lava or snow tubes and caves, or poorly-ventilated buildings). Workers, children low to the ground, and people using hot springs are particularly vulnerable. Very rarely, volcanic crater lakes have overturned, releasing a large amount of dense CO_2 that can flow downslope, displacing the air and suffocating people and animals in its path.





HF and HCl gases are quickly diluted in the air, dissolve readily in water, and may affect water supplies close to the eruption. If ash is also being erupted, then fluoride and other contaminants can stick to the ash particle surfaces and travel much further downwind.



5. WHAT ARE THE HEALTH EFFECTS OF VOLCANIC GASES AND AEROSOLS?

People are exposed to volcanic gases and aerosols by breathing or through contact with the skin and eyes. Adverse health effects range from mild to serious with occasional lethal exposures. The health effects depend on the type and concentration of gas in the air, the length of time of exposure, and a person's sensitivity. Our nose and breathing passage can filter, dissolve, and/or neutralize some gases and aerosols, reducing the amount that reaches the lungs. However, sulfur gases, HF, HCl, and volcanic aerosols are acidic and can irritate the moist surfaces in our breathing passage and lungs. CO₂ and H₂S can cause asphyxiation.

People should be aware of potential health effects when visiting a volcanic or geothermal environment. In some areas, travelling alone is not advised in case immediate assistance is needed. If someone in your group becomes ill or collapses, you should all immediately leave the area. Move the affected person into fresh air and contact emergency rescue services, if needed.

Temporary volcanic air pollution health effects

Physical symptom	SO ₂	H ₂ S	CO ₂	HF/HCl	PM*
Irritation of the nose, throat, eyes, or skin	x	x	x	x	x
Cough and/or phlegm	x	x	x	x	x
Chest/lung tightness or irritation	x	x	x	x	x
Shortness of breath	x	x	x	x	x
Headache	x	x	x	x	x
Aggravation of asthma (wheezing)	x	x		x	x
Fatigue and/or dizziness	x	x	x		
Rapid breathing			x		
Nausea	x	x	x		
Cardiovascular effects (at high concentrations)	x			x	x

*PM - particulate matter includes volcanic sulfate aerosols.
Evidence of some effects is derived primarily from urban pollution studies.

Specific information

SO₂ The sensitivity of individuals varies, however, people with asthma are particularly sensitive to SO₂, and exposure may worsen their symptoms. Asthmatics should follow their Asthma Action Plan, if they have one, and carry relief medication with them in volcanic areas. The general population should avoid exposure to SO₂ above recommended air quality levels (which are country specific). Exposure to high concentrations (more than around 40 parts per million or ppm) can cause nausea, vomiting, stomach pain and damage to the airways and lungs. At very high concentrations (more than 100 ppm), SO₂ can cause rapid unconsciousness, pulmonary edema and death. Exposure to a combination of SO₂ and respirable particles may increase negative health effects. The long-term health effects of persistent exposure to low concentrations of volcanic SO₂ are still being evaluated.



H₂S Exposure to high concentrations (more than 100 ppm) of H₂S, or long periods spent at low concentrations, can cause a person's sense of smell to become fatigued. So, the ability to smell H₂S as a warning sign can be misleading, since sometimes the 'rotten egg' aroma can't be detected. Repeated exposures can result in health effects at concentrations that were previously tolerated without ill effect. The U.S. Occupational Safety and Health Administration (OSHA) sets a maximum exposure limit of 20 ppm for workers but notes that as little as 2-5 ppm may cause irritation of the eyes, headache, nausea, or breathing problems in some asthmatics. As concentrations increase, symptoms may include fatigue, loss of appetite, dizziness, or respiratory tract irritation. Very high exposures (more than 500 ppm) can cause rapid unconsciousness or death within minutes.

CO₂ While CO₂ is present in our atmosphere at around 400 ppm (0.04%), exposure to 50,000 ppm (5%) can cause labored breathing, headaches, sweating, and increased heart rate. As concentrations increase, dizziness, muscular weakness, mental confusion, drowsiness, ringing in ears, and vomiting can occur. At very high concentrations (more than 100,000 ppm; 10%), CO₂ can cause rapid unconsciousness, asphyxiation and death.

HCl and **HF** Both of these gases are usually minor components of a volcanic plume, but can cause acute irritation of the skin, eyes, nose, throat, and lungs. Special caution should be taken if you are close to an area where lava is entering the ocean (Section 1). Very high concentrations of HCl (50-100 ppm) can cause swelling of the breathing passage and pulmonary edema (a build-up of fluid and swelling in the lungs) that can lead to death. HF concentrations greater than 50 ppm are dangerous even for brief exposures.

Sulfate aerosol In urban populations, studies have shown that both short and long-term exposure to $PM_{2.5}$ or PM_{10} may cause respiratory and cardiovascular disease, and premature death. It is not yet known if the health effects of exposure to sulfate aerosols are the same as urban PM exposures.

Radon Short-term exposure to radon gas is symptomless. Long-term exposure to elevated radon concentrations (for example, indoor exposures) is a cause of lung cancer.

The above effects of gases at different airborne concentrations are from the U.S. Agency for Toxic Substances and Disease Registry (ATSDR). Also see www.ivhhn.org/information/information-different-volcanic-gases.



Sensitive groups

People vary in their susceptibility to air pollution, and some groups may be more likely to experience ill effects. Sensitive groups include:

- ❖ People with asthma, lung or heart problems
- ❖ Older adults
- ❖ Infants and children
- ❖ Pregnant women



Exposure to volcanic and geothermal gases may worsen symptoms for people who have pre-existing health conditions. Older adults may also be sensitive to effects because of declining lung and heart health. Children are more sensitive than adults because they breathe faster, are more active, and have larger lungs in proportion to their body size than adults. Their noses are less efficient at filtering gases and particles and they frequently mouth breathe, bypassing the filtering effect of the nose. Sensitive groups should be especially cautious and follow recommended actions in volcanic settings (see next section).





6. PROTECTING YOURSELF FROM VOLCANIC AND GEOTHERMAL EMISSIONS

Be prepared

- ✦ Understand the hazard:
 - ✦ Get familiar with any websites that monitor the air quality (e.g., SO₂, PM) and weather forecasts for the area. Changes of wind patterns could carry emissions into your area.
 - ✦ Stay informed about the volcanic conditions in your area and be aware of the concentrations of volcanic gases and aerosols. Eruptions and gas emissions may change suddenly, so stay alert.
 - ✦ Each volcanic setting is different and the specific gas hazards will vary.
- ✦ Follow general disaster preparedness guidelines:
 - ✦ Stay informed about civil and health protection information specific to your location.
 - ✦ Keep an emergency supply kit in your home (food, water, essential medicine etc.) should you need to leave the area or shelter in place.
 - ✦ Have an evacuation plan, pack all essential items, and be prepared to rapidly evacuate your family and pets.
 - ✦ Make a family plan on how to communicate with, and account for, each family member.
 - ✦ Keep medications handy. If you have asthma or other lung or heart conditions, keep your relief medication available and use as prescribed. If you don't have medications, but feel you might need them, call your doctor.




Protect yourself

- ✦ Take care of yourself:
 - ✦ Do not smoke and avoid secondhand smoke.
 - ✦ Stay hydrated. Drink plenty of liquids to help loosen congestion. Warm or hot liquids may help some people.
 - ✦ Manage congestion or irritation. Over-the-counter nasal sprays or eye drops can help reduce symptoms for some people.
 - ✦ People with a pre-existing health condition should carefully monitor their health and contact their doctor as necessary.
 - ✦ If you are experiencing chest pain, dizziness and weakness, breathing difficulties, or other unusual symptoms you should contact a medical professional.
- ✦ Reduce your exposure:
 - ✦ In an active volcanic or geothermal environment, move upwind and away from the smell of the gases, if you find yourself in uncomfortable concentrations.
 - ✦ Limit strenuous activities during poor air quality. Outdoor work, exercise and exertion increase your chances of being affected by the gases and aerosols. Try to breathe through the nose and reduce mouth breathing while outdoors.

- ❖ Stay indoors when there is poor outdoor air quality. Close all doors and windows, and seal up large gaps to the outdoors (for example, using tape or plastic sheeting). Be aware of becoming overheated as a result of sealing your house. Even if your house is not well-sealed, it may still offer some protection. If available, consider visiting indoor areas that are better-sealed and/or have air conditioning (for example, commercial buildings or businesses).
- ❖ Try to eliminate sources of indoor pollutants (for example, smoking, candles/incense, un-vented cooking and heating stoves, or other appliances which produce smoke or carbon monoxide).
- ❖ Reduce indoor pollution with an air cleaner. If possible, close doors and windows and use an air cleaner to help reduce the levels of gases and aerosols that have entered. To reduce particles, you need a particle filter ('HEPA' filter) and, to reduce SO₂, you need an acid gas filter for the air cleaner. Air conditioners (outside vent closed and set to recirculate) and dehumidifiers can also help to improve indoor air quality.



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- ❖ Refresh the air in your home or building after pollution levels drop by opening doors and windows.
 - ❖ Leave the area if appropriate. If indoor areas have poor air quality, consider temporarily relocating to a less impacted area.
 - ❖ Restrict volcanic emissions from entering your vehicle. Temporarily close your windows and vents and turn your fan and air conditioner off when driving in heavily-affected areas. Be aware of becoming overheated as a result of sealing your vehicle.
 - ❖ Facemasks designed to filter particles are not effective for gases but are helpful for aerosols and ash. See www.ivhhn.org/ash-protection for more detail. There are commercial masks specific for filtering gases, but these are not recommended for the general public. This is because safe use of gas masks requires correct mask and/or filter cartridge selection, fit testing, and training on correct use, maintenance and storage.
 - ❖ Monitor children for changes in their health. Adults should ensure that children's exposure is reduced by limiting exertion, staying indoors or leaving the area.
 - ❖ If a home or building is in a geothermal area, then good ventilation is important to reduce potential indoor concentrations of radon and CO₂. In areas with radon, testing for indoor concentrations may be advised.



7. OTHER EFFECTS OF VOLCANIC EMISSIONS

Contamination of water supplies

- ❖ **Acid rain:** Acid rain can dissolve harmful metals, such as lead, from metal roofs and plumbing systems, into catchment drinking water. If you have lead-bearing nails, flashing, paint or other materials, they should be removed from your roof catchment system. If possible, downspout pipes should be disconnected from tanks before acid rain or ashfall events and reconnected afterwards.
- ❖ **Human health impacts:** Gastrointestinal problems (nausea, vomiting, stomach pain and/or diarrhea) have been reported by people drinking water contaminated by volcanic emissions, likely due to dissolved metals. Volcanic emissions may also raise fluoride concentrations in roof-collected drinking water which, when consumed on a regular basis, may contribute to fluorosis. This condition can damage developing teeth and, potentially, the bones. In some situations where water is scarce, roof-collected water may still be the best source of domestic water.
- ❖ **Actions to minimize human health risks:** If your regular drinking water supply has been disrupted, then use water that is bottled, boiled, filtered, or chemically disinfected. Roof-collected drinking water should always be treated to reduce or eliminate microbes. In high-risk areas, if possible, drinking water should be tested by an accredited laboratory for chemical contaminants, including fluoride. This is particularly important for children under 8 years old. Let the tap run before using the water, because water standing in pipes for long periods (like overnight) can contain higher levels of dissolved metals.



Health of domestic animals, livestock and plants

- ❖ **Acidic emissions:** Acid gases, aerosols and acid rain can affect livestock, crops, flowers and foliage. Plants can show damage within a few hours of exposure although some plants are more susceptible than others. Open fields are most vulnerable but crops under cover can still be exposed to gases. Rinsing plants with fresh water, immediately upon exposure, can help minimize the chemical damage.
- ❖ **Animal health impacts:** Grazing animals may experience health effects from exposure to excess fluoride and sulfur through breathing or ingesting contaminated water and feed. Excess fluoride intake over time can result in dental or skeletal fluorosis. Short-term, very high fluoride intake can lead to acute fluoride poisoning, which can be lethal. Excessive sulfur intake from high concentrations in feed, water, or the environment can lead to neurological disorders, or mineral imbalances. Breathing SO₂ gas may also cause respiratory effects in animals.
- ❖ **Actions to minimize animal health risks:** To reduce exposure by ingestion, ensure a clean water and food supply. Farmers may want to protect exposed feed by covering it. Farmers and pet owners should monitor the health of their animals especially for eye, dental, gastrointestinal and/or breathing problems. Farmers and ranchers may want to consult a veterinarian about providing supplementary feed or minerals for livestock, or for other assistance, as necessary. If possible, consider moving animals to a non-affected area.

Damage to infrastructure

- ❖ Volcanic emissions and acid rain can quickly corrode metal, including farming, building and utilities infrastructure. In some cases, it may be possible to substitute more resistant materials.



8. SOURCES

Agency for Toxic Substances and Disease Registry (USA). Toxic substances web portal for **hydrogen sulfide** (CAS#:7783-060-4), **sulfur dioxide** (CAS#:7446-09-5), **hydrogen fluoride** (CAS#:7664-39-3) and **hydrogen chloride** (CAS#:7647-01-0), 2018.

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For further information, please visit:

Volcanic ash hazards and protection:

ivhhn.org/pamphlets;

volcanoes.usgs.gov/volcanic_ash

Volcanic gases:

ivhhn.org/information/information-different-volcanic-gases

Local volcano monitoring observatories:

wovo.org/observatories

Example of volcano-specific color-coded SO₂ levels and
recommended actions:

hiso2index.info/assets/FinalSO2Exposurelevels.pdf