STATEMENT OF
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Mr. Chairman and Members of the Subcommittee, thank you for this opportunity to discuss the natural hazard threat that volcanoes pose to aviation, the U.S. Geological Survey role in volcano research, monitoring, and eruption warnings, and our national strategy for a proactive, fully-integrated volcano hazard mitigation effort.

Overview of Volcanic Hazards Program

For more than 125 years, USGS has provided the Department of the Interior, the Nation, and the world with relevant science to guide policy and safeguard society. This legacy of scientific excellence is reinforced by the authority afforded USGS under the Disaster Relief Act (P.L. 93-288, popularly known as the Stafford Act) as the lead Federal agency with responsibility to provide notification for earthquakes, volcanic eruptions, and landslides, to enhance public safety, and to reduce losses through effective forecasts and warnings based on the best possible scientific information.

The United States is home to 169 volcanoes considered to be active, more than any other country in the world. The USGS has recently completed a systematic assessment of the relative societal threat posed by each of the Nation's 169 geologically active volcanoes. For each volcano, the study determined a level of societal threat based on an evaluation of the hazards that could be anticipated and the societal exposure to those hazards. This study, **An Assessment of Volcanic Threat and Monitoring Capabilities in the United States: Framework for a National Volcano Early Warning System (NVEWS)**, the recommendations of which are discussed later in my testimony, is being used to guide long-term improvements to the national volcano-monitoring infrastructure operated by USGS and its partners. The USGS and its Federal, State, and university partners operate five volcano observatories to monitor eruptive activity and unrest at 50 volcanoes in the Cascade Range, Hawaii, Alaska, California, and Yellowstone National Park. Currently, three U.S. volcanoes are erupting (Mount St. Helens in Washington, Kilauea in Hawaii, and Augustine in Alaska), and two are being closely watched closely for unrest or renewed eruptive activity, Mauna Loa in Hawaii and Anatahan in the Northern Mariana Islands.

The threats that volcanoes pose to populations on the ground are generally understood in the United States. Most people are aware of the hazards that erupting volcanoes create, such as lava flows, hot, gaseous flows of volcanic blocks and ash, and mudflows. The potential harm of these phenomena, in terms of loss of life and societal and economic disruption, are very serious considerations for communities near *or* downwind and downstream of many of the Nation's volcanoes. For example, lava flows from Mauna Loa Volcano, which has been exhibiting signs of increased unrest for two years and may be advancing toward eruption, can reach the highly developed Kona Coast of Hawaii in as little as two hours. Within the Cascade Range, 13 volcanoes pose significant threats to people and infrastructure on the ground. At Mount Shasta in California, searing avalanches of volcanic rock and gas could reach more than 6,000 people in the vicinity of the town of Weed and Mount Shasta City in less than 10 minutes. Large mudflows formed by melting of thick ice and snow on Mount Rainier, Mount Baker, or Glacier Peak in Washington could race down populated valleys at speeds of up to sixty miles per hour, devastating communities lying in the path of the potentially deadly mudflows.

With appropriate monitoring, impending volcanic eruptions can be forecast and warnings issued before the hazardous events occur. This capability was demonstrated in advance of the June 1991 eruption of Mount Pinatubo, Philippines – the largest volcanic eruption of the 20th century to affect a heavily populated area. Because the eruption was forecast by scientists from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) and USGS, civil and military leaders were able to order massive evacuations and take measures to protect property before the eruption. The USGS and PHIVOLCS estimate that their eruption forecasts saved at least 5000 and as many as 20,000 lives. At least $200 million to $275 million in losses of military aircraft and equipment were averted by having those assets flown to safe areas or covered in advance of the eruption. A more recent example of this successful forecasting ability was demonstrated at Augustine Volcano near Alaska's most populated area, the Cook Inlet. Utilizing monitoring networks already in place, the Alaska Volcano Observatory detected the onset of unrest and raised the alert level on November 29, 2005, and began monitoring the unrest closely to determine if activity was likely to escalate, plateau, or die down. Unrest continued to escalate, and the USGS issued an information bulletin on January 10, 2006, that indicated a heightened possibility of an explosive eruption within the "next few weeks or months." The following day, an eruption at Augustine Volcano was underway. Timely forecasts and warnings such as these examples depend on telemetered, real-time data from adequate arrays of different types of monitoring instruments located on and near volcanoes and on remotely sensed data transmitted by other agencies (e.g. GOES satellite data from National Oceanic and Atmospheric Administration (NOAA)).

Volcanic Threats to Aviation Safety

Less well known by the public is the threat posed to aviation by erupting volcanoes. Volcanic eruptions pose a serious threat to aviation, but one that can be mitigated through the combined efforts of earth and atmospheric scientists, the aviation industry, and air-traffic control centers. Volcanoes threaten aviation safety when magma erupts explosively to form clouds of small jagged pieces of rocks, minerals, and volcanic glass the size of sand and silt that rises miles above the earth’s surface and is spread by winds aloft over long distances across flight paths of jet aircraft. Unlike the soft fluffy material created by burning wood, leaves, or paper, “volcanic ash” particles are angular, abrasive fragments having the hardness of a pocket-knife blade. Upon impact with an aircraft traveling several miles per minute, ash particles abrade the windscreen, fuselage, and fan blades in the turbine engines. In addition to the problem of abrasion, the melting temperature of the glassy rock material that comprises ash is lower than the operating temperatures of jet engines. Consequently, ingested ash particles can melt in hot sections of aircraft engines and then fuse onto critical components in cooler parts of the engine. An aircraft encounter with ash can result in loss of visibility, and failure of critical navigational and flight systems, and can immediately and severely degrade engine performance, resulting in engine flame out and total loss of thrust power.

The volcanic-ash hazard to aviation extends the volcanic threat far beyond the local area or region where a volcano is located. For example, the 1992 eruption of Mount Spurr in Alaska produced an ash cloud that was tracked on satellite images for three days and more than 3000 miles downwind of the volcano over Canada and the Great Lakes region.

Many major air routes traverse the world's most volcanically active regions, and numerous instances of aircraft flying into volcanic ash clouds have demonstrated the life-threatening and costly damages that can be sustained. From 1973 through 2003, 105 encounters of aircraft with airborne volcanic ash have been documented. This is a minimum number of encounters because incidents have not been consistently reported.

The potential for a disastrous outcome of an ash/aircraft encounter has been illustrated by three dramatic encounters. The first occurred in 1982 when a Boeing 747 – at night over water with 240 passengers – flew into an ash cloud about 100 miles downwind from Galunggung volcano in Indonesia. The aircraft lost power in all 4 engines and descended 25,000 ft from an altitude of 37,000 ft above sea level. After 16 minutes of powerless descent, the crew was able to restart three engines and make a safe landing in Jakarta. A few weeks later, a second Boeing 747 with 230 passengers encountered an ash cloud from another eruption of the same volcano. The aircraft lost power to 3 engines and descended nearly 8000 ft before restarting one engine and making a nighttime emergency landing on two engines. In both cases, the aircraft suffered extensive damage. Fortunately, a greater human tragedy was averted.

A third incident occurred in 1989 and was related to an eruptive event at Redoubt Volcano in Alaska. A Boeing 747 with 231 passengers onboard was nearing Anchorage International Airport and flew into what appeared to be a thin layer of weather clouds. It was actually an ash cloud erupted by Redoubt Volcano, approximately 150 miles distant. The aircraft lost power from all four engines and descended for four minutes over mountainous terrain. With only one to two minutes remaining before impact, the engines were restarted and the aircraft safely landed in Anchorage. Damage was estimated at more than $80 million (in 1989 dollars).

A decade of these harrowing events prompted action by airlines, dispatchers, air-traffic control, aviation meteorologists, and volcanologists. It had become clear to all that damaging, even life-threatening, aircraft encounters with volcanic ash are not flukes but rather a persistent hazard that requires a coordinated, multi-pronged, operational response for the purpose of ash avoidance. Responding to this newly recognized hazard, the International Civil Aviation Organization (ICAO) – with strong participation from USGS scientists –established procedures on a global scale for the rapid dissemination of information related to ash-producing eruptions and the movement of ash clouds to the aviation sector. One of these procedures is the use of a color-coded alert system for volcanic ash warnings to the air carrier industry. This alert system, originally developed in 1990 by USGS scientists at the Alaska Volcano Observatory (AVO), is now recommended for worldwide use by ICAO.

Areas Targeted for Increased Monitoring

As the USGS has increasingly recognized that volcano monitoring is needed to protect against aviation hazards as well as the more well-known ground hazards, we have adjusted our monitoring program accordingly. For example, although the ground population is sparse in the volcanically active Aleutian Islands of Alaska, the risk to aviation is high. More than 200 flights carry roughly 25,000 people over Northern Pacific air routes on a daily basis. Since 1996, with funding support from FAA, AVO has undertaken to expand its monitoring beyond the few volcanoes that threaten communities around Cook Inlet in the south central portion of the state. Over the past decade, AVO has systematically expanded its seismic monitoring into the Aleutian chain, from 4 instrumented volcanoes in 1996 to 28 at the end of this past summer's field work. This increase in real-time monitoring capability is an amazing accomplishment of both planning and execution on the part of AVO, a partnership between USGS, the University of Alaska Fairbanks, and the State of Alaska.

AVO also developed a capability for frequent, systematic satellite monitoring of active volcanoes throughout the North Pacific, to recognize pre-eruptive thermal signals at volcanoes and to detect eruptive plumes. This pioneering effort at regional satellite monitoring complements traditional seismic monitoring and serves as a model to other volcano observatories worldwide. AVO is also contributing to National Weather Service (NWS) efforts to develop the Volcanic Ash Collaboration Tool, a system that uses networked workstations for real-time collaboration among agencies by providing common views of data sources and the ability to rapidly delineate and discuss areas of ash hazard.

Another area where USGS recently began volcano monitoring due to volcanic hazards to aviation is the Commonwealth of the Northern Mariana Islands. Like the Aleutians, ground population is sparse on most of these islands, but the aviation risk is significant, including the threat to stealth B-2's and other military aircraft housed at Andersen Air Force Base on Guam. The initial eruption in May 2003 of Anatahan – a long dormant volcano with no real-time ground-based monitoring in place – was a surprise. Since then, USGS has installed a rudimentary seismic system with real-time data transmission and is working closely with local emergency management officials, the U.S. Air Force, NOAA, and FAA to provide eruption notifications.

The activity at Anatahan has demanded sustained vigilance. In 2005, the volcano erupted to over 40,000 feet numerous times and expelled several million cubic yards of ash during a nearly continuous eruptive episode that lasted eight months. After the largest ash eruption, USGS provided forecasts of ash deposition on Saipan to the local government there. USGS also supports AFWA's mission of providing volcanic-ash advisories and situational awareness to DOD aviation. For example, USGS volcanologists furnished short-term forecasts of potential ash-plume heights to AFWA for use in planning and completing a critical training exercise in the Marianas region by the USS Nimitz Carrier Strike Group.

Interagency and International Coordination

Ash avoidance is not a simple matter – it requires the coordinated efforts of volcanologists, meteorologists, air-traffic control centers, dispatchers, and pilots. It involves elements of: ground-based volcano monitoring, satellite-based detection of ash clouds, modeling cloud movements in the atmosphere, and specific communication protocols among the diverse parties responding to the hazard.

In the United States, the USGS, NOAA, Federal Aviation Administration (FAA), and Air Force Weather Agency (AFWA) at Offutt Air Force Base in Nebraska collaborate according to International Civil Aviation Organization (ICAO) guidelines, sharing data and refining communication protocols so that necessary information reaches commercial and military pilots, dispatchers, and air-traffic controllers quickly. The USGS has responsibility for providing notifications of significant pre-eruption volcanic activity, volcanic eruptions, and volcanic ash in the atmosphere. The USGS capability to provide such notifications is based on data and observations collected from monitoring networks operated by the five U.S. volcano observatories supported by the USGS Volcano Hazards Program.

USGS volcano monitoring activities do not stand alone. For both aviation and ground hazards, no single geophysical monitoring technique or system can confidently provide timely alerts of eruptions; neither seismic networks, GPS arrays, nor remote sensing techniques on their own are adequate for reliable forecasting or alerting purposes. Recognizing this, we have developed very close working relationships with groups that track ash clouds using civilian meteorological satellites, in particular the AFWA and NOAA's Volcanic Ash Advisory Centers (VAACs) located in Washington D.C. and Anchorage. During precursory unrest and eruptive episodes, we share observational data and maintain frequent telephone contact to ensure consistent interpretations of volcanic activity and potential hazards. No one organization has a monopoly on critical monitoring information. Effective communication among the various groups is crucial to successful mitigation of the hazard.

In addition to USGS monitoring efforts, we also are working to improve the communication procedures that are critical for eruption and ash-cloud information to reach the cockpit. In call-down lists at U.S. volcano observatories, FAA, VAACs, and aviation weather offices of the National Weather Service (NWS) are among the first agencies to be notified. Since the mid-

1990's, USGS scientists have worked with Russian scientists to disseminate information about eruptions from the Kamchatka Peninsula that could affect U.S. controlled airspace. Recently, USGS scientists played a key role in the establishment of the first-ever monitoring and reporting group for the Kurile Island chain of volcanoes. The USGS has organized the formulation of inter-agency operating plans for dealing with ash episodes in the North Pacific and Marianas regions. These plans provide operational guidance by documenting the required procedures of the government agencies responsible for ensuring safety of flight operations. The USGS is working with FAA, NOAA, and AFWA to complete a national operational plan for volcanic ash hazards to aviation.

Another important role for USGS is hazard education - building awareness among volcanologists, meteorologists, pilots, dispatchers, and air-traffic controllers of the nature of the hazard and how to respond to it. The USGS has assisted in the development of training videos for pilots and air-traffic controllers, provided technical briefings for airlines and industry groups, organized technical symposia, and published articles in aviation journals.

Research Priorities

Research is also a critical component of mitigation. To improve our forecasting abilities, we need to gain a much better fundamental understanding of eruption processes. Research and experience in the 25 years since the 1980 eruption of Mount St. Helens has brought volcanology to a point where, with adequate monitoring systems in place, the timing of volcanic eruptions can be forecast with some confidence hours to days in advance. The next major scientific goal for volcanology is to accurately forecast the size and duration of eruptions, which bears directly on hazards issues confronted by enroute aircraft and people on the ground. For instance, being able to forecast that an eruption will be small and unlikely to erupt ash to altitudes above 15,000 feet versus one that sends ash to 50,000 feet will have major impact on response by the aviation community. Another aspect is the ability to identify when an eruption is over, not just temporarily paused. This is quite a complex problem. Such information is valuable to airports, for example, because it tells them when they can start cleaning up from ashfall and hasten the return to normal operation.

Air routes over active volcanic regions will continue to be heavily used, and volcanic ash will persist as a serious aviation hazard. Much has been done to mitigate the volcanic threat to aviation. More volcanoes are being monitored now than 10 years ago, and eruption reporting targeted to the aviation sector is in place. Satellite detection of ash clouds and forecast models of ash-cloud dispersion have greatly improved. As a result of increased awareness and improved information in support of ash avoidance, no multiple-engine airplane failures have occurred since 1991. Despite these successes, much work remains. Many hazardous U.S. volcanoes are not monitored at a level that provides for adequate tracking of volcanic unrest that precedes eruption. It is still possible for there to be significant periods of time when ash clouds drift undetected in or near air-traffic routes, as was the case with the surprise eruption in 2003 of Anatahan volcano in the Mariana Islands. Hours elapsed from the eruption's onset to the issuance of the first warning to aviation of ash in the atmosphere.

Results of the Volcanic Threat and Monitoring Capabilities Assessment

In order to better focus resources on improved monitoring of volcanoes that present the greatest threat, USGS recently published the results of the first overall evaluation of the Nation's volcano-monitoring needs based on a systematic assessment of the societal threats posed by all of the 169 geologically active U.S. volcanic centers. The publication is entitled **An Assessment of Volcanic Threat and Monitoring Capabilities in the United States: Framework for a National Volcano Early Warning System (NVEWS)**. The report scores various hazard and exposure factors for each volcano and identifies volcanoes where monitoring capabilities are inadequate – and in some cases nonexistent – for the threats posed. The results of the NVEWS assessment are being used to guide long-term improvements to the national volcano-monitoring infrastructure operated by USGS and affiliated partners.

Aviation hazards carried substantial weight in the NVEWS assessment. The USGS developed a methodology for assessing aviation threat on a regional and local basis at each volcano and determined that about half of US volcanoes represent a significant threat to aviation. Of this group, 19 volcanoes in Alaska and the Northern Mariana Islands that pose substantial threats to aviation have no real-time ground-based monitoring. These 19 volcanoes are identified as high-priority NVEWS targets where better monitoring is needed.

Surprise eruptions occur at volcanoes that lack real-time ground-based sensor networks. Depending on the remoteness of the volcano, even eruption reports may be delayed without proper monitoring. Recent experience shows that while eruptions can be confirmed in a matter of minutes at volcanoes with ground-based monitoring, it may require several hours for eruption confirmation at un-instrumented volcanoes by remote sensing or pilot reports. Because of the speed with which an aircraft can travel toward a potential volcanic-ash encounter (about 8 miles per minute), real-time 24/7 eruption reporting is necessary. Our goal is that an observatory shall notify the appropriate regional air traffic center of an ash-producing eruption within five minutes of the start of the event. This level of notification requires 24/7 operations at U.S. volcano observatories, adequate networks of seismic and other instruments and, in some cases, portable ground-based RADAR to detect ash clouds at night and in bad weather.

In the NVEWS assessment, other very-high-threat volcanoes, including nine in the Cascade Range in California, Washington, and Oregon and four in Alaska, were identified as having inadequate or antiquated networks and are considered under-monitored for the threats posed to both aviation and ground communities and infrastructure. Eruptions at Mount St. Helens, Kilauea, Augustine, and Anatahan and unrest at Mauna Loa in Hawaii and Spurr in Alaska also require a robust monitoring capability.

Conclusion

Volcanic ash will continue to be a dangerous and costly threat to aviation into the foreseeable future. The USGS will continue its efforts to enhance monitoring capabilities at those sites where the greatest risk exists.

Hazard mitigation for U.S. volcanoes requires:

- **Continued improvement of monitoring capabilities and instrumentation of U.S. volcanoes with high aviation risk.** Concerns should focus not only on reporting where and when an eruption has occurred and how high its plume went, but also with reliably diagnosing volcanic unrest and forecasting likely eruptive activity, including how long eruptive activity might continue and the potential for recurring explosive events.

- **Continued refinement of protocols for communicating eruption and ash hazard information to other agencies and clientele.** The aviation community must be familiar with and confident in monitoring and notification abilities through the use of conferences, publications, drills, and demonstrations.

- **Continued USGS leadership in building awareness of the ash hazard to aviation.** Without broad-based hazard awareness, the commitment to carry out a mitigation strategy is severely weakened. The USGS will continue to foster hazard education through a variety of venues and methods.

There are no remote volcanoes when we consider aviation hazards. Mitigating this risk requires efficient teamwork by multiple agencies. The USGS will continue to do its part by providing timely information based on reliable monitoring data. However, as the ability to prevent ash encounters improves to the point that fewer incidents occur, we must not mistakenly conclude that no threat exists. Rather, we must call for continued vigilance and support of proven, broad-based mitigation efforts.

Thank you, Mr. Chairman, for the opportunity to present this testimony.