

MITIGATING VOLCANIC ASHFALL AT A HIGH-LEVEL WASTE TREATMENT FACILITY

Stephen McDuffie¹
Elaine Diaz²

¹ Seismic Engineer, U.S. Department of Energy, Richland, WA (stephen.mcduffie@rl.doe.gov)

² Mechanical Engineer, U.S. Department of Energy, Office of River Protection, Richland, WA

ABSTRACT

Since 2002, the U.S. Department of Energy has been constructing the Waste Treatment and Immobilization Plant (WTP) at the Hanford Site in Washington State. This facility will vitrify high-level liquid waste currently held in underground storage tanks. WTP safety systems must perform their functions under the effects of natural phenomena hazards (NPH), such as ashfall from Mt. St. Helens, the recently active volcano 200 km away. Volcanic ash poses two challenges for WTP. In addition to structural loads from ash deposits, the facility's air handling and other equipment must withstand the hazards posed by airborne particles.

WTP safety systems have a performance goal to fail with an annual frequency less than 10^{-4} . The initial design value for WTP called for ashfall structural loading of 61 kg/m^2 , and an airborne concentration of 220 mg/m^3 . The Hanford site ashfall hazard analysis was reviewed in 2010. A new analysis of the hazard completed in 2012 derived an ashfall structural load of approximately 112 kg/m^2 , with a mean annual frequency of exceedance of 10^{-4} , nearly twice the previous value. A new airborne concentration analysis calculated 1500 mg/m^3 during a 10^{-4} annual frequency ashfall event. Considering possible ash re-suspension during the ashfall event, the concentration could rise as high as 2600 mg/m^3 . In the current facility design, WTP processes require considerable clean air to drive tank mixing, and removing such a high concentration of ash from large volumes of air is challenging. Several options for resolving this technical challenge are discussed.

INTRODUCTION

The Hanford site in eastern Washington State, U.S.A., played a central role in the production of plutonium during World War II and the Cold War. Since 1989, the site's mission has been exclusively one of environmental remediation. The most hazardous legacy from over four decades of plutonium production is approximately 56 million gallons of high-level radioactive waste stored in 177 underground storage tanks on site. The U.S. Department of Energy's (DOE) Office of Environmental Management is responsible for remediating the Hanford site, and since 2002 DOE and contractor Bechtel National, Inc. (BNI) have been constructing the WTP to vitrify the high-level tank wastes for permanent geologic disposal.

DOE is a self-regulating agency, with external oversight of defense-related nuclear activities provided by another Federal agency, the Defense Nuclear Facilities Safety Board (DNFSB). DOE establishes its own nuclear safety requirements. A primary safety requirement applicable to WTP is DOE Order 420.1, *Facility Safety* (DOE, 2015). A requirement within Order 420.1 states, "Facilities must be designed, constructed, maintained, and operated to ensure that SSCs [systems, structures, and components] will be able to perform their intended safety functions effectively under the combined effect of NPH and normal loads." The Order references DOE Technical Standard 1020-2012, *Natural Phenomena Hazards Analysis*

and Design Criteria for DOE Facilities (DOE, 2012), as a requirement for natural hazard analysis and design.

DOE-STD-1020-2012, and its predecessors, establish the performance goals for safety systems, which vary depending on the inherent hazards posed by a facility. By the hazard classification scheme in effect when WTP design began, it fell into category 3 of 4, the second highest hazard. This equates with a performance goal that SSCs fail to perform their safety function with an annual frequency of exceedance (AFE) not greater than 10^{-4} . DOE-STD-1020-2012 introduced a new five-tier categorization scheme, but the 10^{-4} AFE performance goal for WTP remains unchanged.

VOLCANIC HAZARD

One of the natural hazards of concern at the Hanford site is volcanic ash, also known as tephra. Hanford lies approximately 200 km east of Mt. St. Helens, a stratovolcano in the Cascade mountain range. Mt. St. Helens is the most active volcano in the western U.S.A., famous for a catastrophic eruption in 1980. That eruption provided only a dusting of ash on the Hanford site (<1 cm), but Hanford lies in the prevailing downwind direction and is subject to ashfall from future eruptions that may occur. Since 1980 Mt. St. Helens has continued to have intermittent periods of activity, so it remains a threat during the estimated 40-year WTP operating life.

Volcanic ash is composed of very small, abrasive glass particles. It can negatively impact the WTP in three ways: excessive roof loading from thick accumulations; loss of site power due to ash-related arcing of electrical components; and failure of air-cooled mechanical equipment or equipment that provides compressed air for safety-related plant processes. The present WTP design relies on abundant compressed air to drive in-tank pulse-jet mixers, and high airborne ash concentration can clog filters and impair the ability to provide compressed air. A failure to maintain tank mixing can lead to hydrogen buildup in tanks and several accident scenarios. The ashfall hazard at Hanford was originally characterized by U.S. Geological Survey (USGS) volcanologists (Hoblitt et al., 1987, and Scott et al., 1995). They determined that an ashfall event with an AFE of 10^{-4} is approximately 10 cm.

ASHFALL DESIGN VALUES

The 10 cm ashfall estimate, and estimates for the other hazard categories, was subsequently incorporated into a site-wide volcanic ashfall design standard (Conrads, 1996). Converting the ash thickness to a structural load, Conrads (1996) estimated a 10^{-4} AFE ashfall event at Hanford to present a design structural load of 12.5 pounds per square foot. This figure was incorporated into the WTP design criteria. Order 420.1 requires a periodic review of NPH analyses for any changes to data, models, or analysis methods that might lead to a significant change in hazard. Since the Conrads (1996) analysis was over ten years old, DOE contractors began a review of the ashfall hazard analysis in 2010. Coincident with this review, the DNFSB staff raised questions with the 10^{-4} AFE, 10 cm ashfall value in the site-wide standard. The staff believed that by considering additional worldwide ashfall thickness data, the ashfall thickness at Hanford with a 10^{-4} AFE could be much greater than 10 cm. This led to a careful review of the USGS reports on which the site-wide standard was based, and during this review several minor technical errors were discovered. The USGS volcanologists who worked on the original Hanford ashfall characterization agreed to perform a new ashfall hazard analysis for the site. This study (Hoblitt and Scott, 2011) benefitted from some additional ashfall data, and it considered the latest Mt. St. Helens eruption probabilities and wind data. Hoblitt and Scott (2011) again calculated that WTP can expect an ashfall thickness of about 10 cm with AFE of 10^{-4} . However the 2011 thickness estimate was based on analyzing compacted ash deposits, which had ramifications for the structural loading of a 10 cm ashfall.

During the 2010 review of the technical basis for the Conrads (1996) values, DOE staff also investigated the basis supporting WTP design values for ashfall event duration (20 hours) and airborne ash concentration (220 mg/m³) during an ashfall event. These WTP design values did not appear in Conrads (1996), but were derived from the safety analysis documentation for the Columbia Generating Station (CGS) commercial nuclear reactor located on the Hanford site. Although located on DOE land, this facility is unaffiliated with DOE operations and is regulated by the U.S. Nuclear Regulatory Commission. Extensive research into the eruption duration and airborne ash concentration values in the CGS safety analysis revealed no solid technical basis. Moreover, these values did not consider potential ash re-suspension due to wind or other disturbances. The CGS safety analysis assumes airborne concentration remains at essentially zero once the 20-hour fallout completed. In defense of CGS, the reactor safety systems do not have a continuous need for compressed air, extending days after a plant shutdown, as does WTP.

Soon after the release of the Hoblitt and Scott (2011) analysis, DOE asked the Pacific Northwest National Laboratory to review all natural hazard analyses for the Hanford site. Snow and Ross (2011) performed this review and concluded that the increased structural loading resulting from Hoblitt and Scott (2011), and the absence of a reliable airborne concentration value, warranted an update to the site-wide ashfall design standard. DOE commissioned this update, and a new ashfall design standard was published (Snow and Nelson, 2012). Snow and Nelson (2012) calculated significant increases in the ashfall hazard. Although the 10⁻⁴ AFE ashfall of 10 cm was essentially unchanged from 1996, the increase in ashfall density considered, as well as the potential for added loading from rainfall, increased the static load design value from 12.5 to 23.5 pounds per square foot. Snow and Nelson (2012) derived an airborne concentration of 1500 mg/m³ for the 10⁻⁴ AFE ashfall event, and unlike the previous estimate, also considered the possibility of ash re-suspension due to wind or other mechanical agitation. With re-suspension, the value increased to 2600 mg/m³, and they predicted significant ash could remain airborne for 60 days after the ashfall event. The airborne concentration estimates are significantly higher than the 220 mg/m³ in the WTP design basis. The airborne concentration and re-suspension calculations invoked several conservative assumptions, but at the time DOE had no reason to question the figures.

IMPACT OF INCREASED ASHFALL

In late 2012, DOE asked BNI for an estimate of the cost and schedule impact to WTP, if DOE were to incorporate the ashfall values of Snow and Nelson (2012) into the BNI contract as new design values. BNI estimated that the increased structural load requirements would require some re-analysis, but no significant re-design. However, the increased airborne ash concentration value was highly problematic. Given the much higher airborne concentration, and that significant re-suspended ash may linger for 60 days, the need for just 4400 cubic feet per minute of ash-free, compressed air to maintain tank mixing would require tremendous upgrades to facility infrastructure. Additional filters, air compressors, chillers, and emergency electrical generators to provide the compressed air under these conditions would be cost prohibitive. The high impact estimate was due in part to lingering uncertainties surrounding WTP tank mixing issues still under investigation. The amount of safety-related mixing air required for operation has not been firmly established. Therefore, early in 2014, DOE directed BNI to suspend their analyses for mitigating the high ashfall airborne concentrations.

Concern with the project risk posed by ashfall, as well as questions from the DNFSB staff about ashfall, led DOE to establish an ashfall planning team (APT) in September 2014. This team, representing several organizations within DOE as well as outside experts, was chartered to develop options to ensure WTP operational safety in light of the ashfall hazard posited by Snow and Nelson (2012). The team was allowed great latitude, to include reviewing the basis of the new ashfall hazard analysis and re-

considering some fundamental WTP design and operational assumptions. The APT produced a report of its findings in December of 2014 (Diaz and Hamel, 2014).

ASHFALL MITIGATION OPTIONS

The DOE APT consulted with USGS volcanologists on the latest techniques for estimating ashfall hazard and airborne concentrations during an ashfall event. The USGS volcanologists do not believe the 10 cm value for an ashfall with AFE of 10^{-4} is likely to change much with further analysis. The APT also reviewed recent volcanology literature for measurements of airborne ash concentrations during ashfall events. Most measurements were far below the 1500 mg/m³ value of Snow and Nelson (2012); mass concentrations of the same magnitude were measured only very close to a volcanic vent while an ash cloud still contained particles up to 20 mm diameter (Rose et al., 2001). Ash particles that fell 200 km downwind of Mt. St. Helens after the May 18, 1980 eruption were almost exclusively below 0.2 mm diameter (Fruchter et al., 1980). The absence of modern measurements similar to 1500 mg/m³, from eruptions similar to a large Mt. St. Helens eruption, at a similar distance from a volcanic vent, casts doubt on the validity of this figure. The Snow and Nelson (2012) value assumed the 10 cm ashfall event occurred over 12 hours, and their airborne concentration is highly sensitive to the event duration and average particle fall velocity. They acknowledged conservative assumptions and great uncertainty in their estimate. During discussions with the USGS, they informed the APT of a new ashfall model known as Ash3d (Schwaiger et al., 2012) that can provide estimates of airborne ash concentration during an ashfall event, as well as refined estimates of ashfall accumulation at Hanford. The APT recommended commissioning the USGS to use Ash3d for such an analysis. This work is expected to begin in 2015.

The APT also consulted with a re-suspension expert, who raised serious questions about the re-suspension analysis of Snow and Nelson (2012). Another recommendation of the APT is to commission modeling of ash re-suspension in the days following an ashfall event. This modeling could consist of laboratory-scale, empirical measurements of volcanic ash re-suspension in a wind field, combined with one or more existing models of dust suspension. These modeling efforts can make use of Hanford site-specific wind velocity data to arrive at more realistic estimates of ash re-suspension in the days following an ashfall event. As of April 2015, DOE is still considering these modeling options.

While discussing Mt. St. Helens with the USGS, the APT also inquired about possible advance warnings of a Mt. St. Helens eruption. With the current monitoring network around Mt. St. Helens, the USGS is confident that at least seven days of warning could be provided to Hanford prior to an eruption that could produce a major ashfall. This amount of warning time would allow WTP operators to suspend waste feed into the plant and reduce the amount of waste in process vessels. Such proactive measures may greatly reduce the need for mixing air to mitigate hydrogen buildup. As plant safety analyses are re-considered, this warning period prior to an ashfall event may be credited to help ensure plant safety after an ashfall event.

Finally, the APT found that implementing certain operation controls on WTP, or modifying the plant waste acceptance criteria, could play an important role in ensuring plant safety after an ashfall event. The current WTP design criteria assume a worst-case radiological inventory for the tank waste, a level that only a small percentage of the waste approaches. This relatively small volume of concentrated tank waste could possibly be processed in smaller batches, or pre-mixed with waste containing fewer radionuclides. The hydrogen buildup after a loss of mixing air may then be gradual enough that accident scenarios become incredible. In short, reducing the allowable material-at-risk in the WTP process vessels may allow operations to remain safe over an extended period of airborne ash and loss of mixing air.

CONCLUSION

DOE has chosen to pursue in parallel several options for mitigating the impact of an ashfall on WTP operations. DOE is revisiting at least two parameters in the ashfall hazard analysis, anticipating that more rigorous analyses will reduce the airborne ashfall hazard. DOE is also examining operational changes that will eliminate potential accident scenarios if a major ashfall event does occur.

Periodic reviews of NPH analyses, as required by DOE Order 420.1, are prudent. In the case of volcanic ashfall, a periodic review identified some minor errors and was one factor that led to a re-analysis of the ashfall hazard. The resulting 2012 Snow and Nelson re-analysis encompassing ashfall, airborne concentration, and re-suspension, and the potential impact on WTP operations led to the DOE decision to convene a multi-disciplinary team to critically examine all facets of the ashfall hazard. The results of this team analysis provided several fruitful options for mitigating the ashfall hazard and should lead to a considerable long-term cost savings.

REFERENCES

- Conrads, T. J. (1996). *Volcano Ashfall Loads for the Hanford Site*, Westinghouse Hanford Company, WHC-SD-GN-ER-30038, Rev. 0, 25 p.
- Diaz, E. N., and Hamel, W. F. (2014). *Evaluation of Alternatives to Address Volcanic Natural Phenomena Hazards at the Waste Treatment and Immobilization Plant*, U. S. Department of Energy, Office of River Protection document number DOE/ORP-2014-07, Rev. 0, 216 p.
- Fruchter, J. S., Robertson, D. E., Evans, J. C., Olsen, K. B., Lepel, E. A., Laul, J. C., Abel, K. H., Sanders, R. W., Jackson, P. O., Wogman, N. S., Perkins, R. W., Van Tuyl, H. H., Beauchamp, R. H., Shade, J. W., Daniel, J. L., Erikson, R. L., Sehmel, G. A., Lee, R. N., Robinson, A. V., Moss, O. R., Briant, J. K., Cannon, W.C., (1980). "Mount St. Helens Ash from the 18 May 1980 Eruption: Chemical, Physical, Mineralogical, and Biological Properties," *Science*, 209 1116-1125.
- Hoblitt, R. P., and Scott, W. E. (2011). *Estimate of Tephra Accumulation Probabilities for the U.S. Department of Energy's Hanford Site, Washington*, U. S. Geological Survey Open-File Report 2011-1164, 15 p.
- Hoblitt, R. P., Scott, W. E., and Miller, C. D. (1987). *Volcanic Hazards with Regard to Siting Nuclear-Power Plants in the Pacific Northwest*, U. S. Geological Survey Open-File Report 87-297, 196 p.
- Rose, W. I., Bluth, G. J. S., Schneider, D. J., Ernst, G. G. J., Riley, C. M., Henderson, L. J., and McGimsey, R. G. (2001). "Observations of Volcanic Clouds in Their First Few Days of Atmospheric Residence: The 1992 Eruptions of Crater Peak, Mount Spurr Volcano, Alaska," *Journal of Geology*, 109 677-694.
- Schwaiger, H. F., Denlinger, R. P., and Mastin, L. G. (2012). "Ash3d: A finite-volume, conservative numerical model for ash transport and tephra deposition," *Journal of Geophysical Research*, 117, B04204, doi: 10.1029/2011JB008968.
- Scott, W. E., Iverson, R. M., Vallance, J. W., and Hildreth, W. (1995). *Volcano Hazards in the Mount Adams Region, Washington*, U. S. Geological Survey Open-File Report 95-492, 11 p.
- Snow, R. L., and Nelson, E. A. (2012). *Volcano Ashfall Loads for the Hanford Site*, Washington River protection Solutions, WHC-SD-GN-ER-30038, Rev. 2, 40 p.
- Snow, R. L., and Ross, S. B. (2011). *Review of Natural Phenomena Hazard (NPH) Assessments for the DOE Hanford Site*, Pacific Northwest National Laboratory report PNNL-20684, Rev. 1, 14 p.
- U. S. Department of Energy. (2012). *DOE-STD-1020-2012, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*. Washington, DC, USA.
- U. S. Department of Energy. (2015). *DOE Order 420.1C, Change Notice 1, Facility Safety*. Washington, DC, USA.