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ANALYSIS OF THE VOLCANIC ASHFALL HAZARD AT THE HANFORD SITE, U.S.A.

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ABSTRACT

The U.S. Department of Energy (DOE) commissioned an analysis of the volcanic ashfall hazard at the Hanford Site in Washington State. Hanford, home to nuclear decommissioning and waste cleanup activities, sits about 200 km downwind of historically active Mt. St. Helens (MSH). The 1980 eruption of MSH deposited several millimeters of ash on the Hanford site. DOE requirements call for the highest hazard facilities on site to meet the performance goal of failure from natural phenomena hazards with an annual frequency less than 10^{-4}. Thus, the new analysis, completed in 2018, focused on ashfall events with an expected recurrence of 1 in 10,000 years. The analysis has three segments. First, U.S. Geological Survey (USGS) volcanologists used their atmospheric transport model, Ash3d, to calculate the ashfall deposit thickness and airborne concentration associated with a 1 in 10,000 year event (Mastin et al., 2018). Staff with the Desert Research Institute (DRI) analyzed the threshold wind speed for ash resuspension following an ashfall event, which serves as an input for modeling wind resuspension of ash (Etyemezian et al., 2018). The third part of the analysis, performed by staff with the National Oceanic and Atmospheric Administration (NOAA), used the HYSPLIT atmospheric transport and dispersion modeling system to model the transport of resuspended ash in the weeks following an ashfall event (Crawford et al., 2018).

The USGS analysis considered the frequency of MSH eruptions over the past 500 years, the likely range of eruption volumes, and historical wind patterns in modeling ash dispersal and deposition at the Hanford site. The modeling found that with a 10^{-4} annual frequency, Hanford can expect an ash deposit just over 5 cm thick. This is about half the thickness estimated in a prior USGS analysis (Hoblitt and Scott, 2011). The average airborne concentration during such a 10^{-4} frequency ashfall event would be about 1500 mg/m^3. The DRI analysis examined the resuspension potential of volcanic ash both in the laboratory and in the field using the wind tunnel-type device known as PI-SWERL. Laboratory tests examined ash deposit emissivity as a function of wind speed, under multiple moisture conditions. The DRI results provided ash deposit particle emission rate as a function of particle size and relative humidity. The analysis identified a threshold friction velocity for volcanic ash of approximately 0.4 m/s, increasing slightly with humidity. These results served as input to the HYSPLIT model, along with regional meteorological data from the Weather Research and Forecasting model. HYSPLIT uses this information to model the transport and dispersion of material once it is lofted from the surface. Results from HYSPLIT come with considerable uncertainty, but the best estimates are a 10^{-4} frequency event could produce a 1-hour average resuspended concentration of several hundred mg/m^3. Such a value is higher than concentrations observed in historical resuspension events, which are in the tens of mg/m^3.

At this time, DOE is still working to incorporate the ashfall hazard results into Hanford Site design standards.

INTRODUCTION

The Hanford Site in eastern Washington, U.S.A., is operated by the DOE. The site has ongoing remediation activities to decontaminate soil and groundwater, as well as to treat and dispose of legacy wastes from Cold War plutonium production. The most challenging task remaining is the treatment of approximately 56 million gallons of radioactive waste stored in underground storage tanks. Most of the tank waste is expected to be treated through a vitrification process beginning in 2022. The vitrification facilities under construction are known collectively as the Waste Treatment and Immobilization Plant (WTP). These facilities are expected to operate for several decades, and per DOE nuclear safety requirements, they must be designed to withstand credible natural hazards. Facility safety systems that protect the public and workers must fail at a frequency no greater than 1 in 10,000 years, or a 1E-4 annual frequency of exceedance, due to natural events such as earthquakes and volcanic eruptions.

Volcanic eruption is a credible hazard at the Hanford Site. The site lies about 200 km downwind of MSH, a stratovolcano in the Cascade Range, and currently the most active volcano in the contiguous United States. The 1980 eruption of MSH deposited several millimeters of ash on the Hanford Site, but nearby areas along the central axis of ash deposition received over 40 mm (Sarna-Wojcicki et al., 1981). MSH has displayed intermittent periods of activity since 1980, but with eruptions orders of magnitude smaller than the May 18, 1980 event.

The Hanford Site is far enough from MSH that lava flows and lahars pose no threat; ash deposits and airborne ash are the only hazards that can affect nuclear facility safety. Thick ash deposits, especially if compounded with water and/or ash drifting, can challenge the limits of roof structural design. More important to the safe operation of the WTP facilities is the ash suspended in air. This includes the airborne material during the initial ashfall event, as well as that resuspended by wind or mechanical disturbance in the days and weeks following an ashfall. Some WTP facilities require large volumes of ash-free, fresh air for the treatment process, so high airborne concentrations can be problematic if they overwhelm plant filtration systems. Designing facility air filtration systems to remove high concentrations of ash from large volumes of air can be quite expensive and operationally challenging, especially if filters need frequent replacement. A reliable analysis of the airborne concentrations likely to occur at the site is important, so facility filtration capability can be properly designed, and/or alternate ventilation system operating strategies implemented.

ASHFALL HAZARD

Ashfall was recognized as a hazard to nuclear facilities in the Northwest U.S.A. even prior to the 1980 MSH eruption (U.S. NRC, 1977). The first volcanic hazard analysis focused on DOE facilities at the Hanford Site was completed in 1996 (Conrads, 1996). This analysis provided estimates of the ashfall deposit thickness at various return periods, but it did not address airborne concentrations during or after an ashfall event. The ashfall hazard was re-analyzed by the USGS with additional data in 2011 (Hoblitt and Scott, 2011). The 2011 effort derived an estimated ashfall thickness at the Hanford site of about 10 cm with a 1E-4 annual frequency of exceedance, similar to the 1996 analysis. However, this analysis was expanded to consider airborne concentration values as well. Snow and Nelson (2012a) used Hoblitt and Scott (2011) results to calculate airborne ash concentrations during a 10 cm ashfall event as high as 1500 mg/m^3. The calculation made basic assumptions about eruption duration and particle fall velocity, and it has considerable uncertainty. They also examined airborne concentrations due to resuspension in the days following deposition, arriving at resuspension concentrations in excess of 1000 mg/m^3, decaying to near zero about 60 days after deposition.

DOE accepted the Snow and Nelson (2012a) results and incorporated them into the Hanford site-wide standard for natural phenomena hazard design (Snow and Nelson, 2012b). The airborne ash and resuspension concentrations proved to be very difficult for the WTP to accommodate as a design requirement. Additional equipment and infrastructure to accommodate those values over a 60-day time period would have been cost-prohibitive. As a result, DOE chartered a team of experts to review aspects of both the ashfall hazard analysis and the facility design, and recommend options to reduce the projected cost. In this review, the team identified shortcomings in the airborne concentration and resuspension analyses (Diaz and Hamel, 2014). One team recommendation, which DOE accepted, was to commission a new analysis of the Hanford ashfall hazard. DOE established a formal project with a quality assurance plan and procedures for executing the analysis. The new analysis was completed in late 2018. The analysis was divided into three segments: the initial ashfall deposition; the resuspension of ashfall deposits; and the transport and resulting airborne concentration from resuspended ash. The USGS was contracted to model the ashfall thickness and airborne concentration during an ashfall event from MSH. The Desert Research Institute (DRI) collected empirical data on the resuspension of ash deposits as a function of wind speed and other variables. Finally, the National Oceanic and Atmospheric Administration (NOAA) modeled the concentrations of resuspended ash using Hanford-specific meteorology conditions.

Soon after the 2011 ashfall study was completed, USGS volcanologists developed Ash3d, a tool for modelling volcanic ash transport and deposition (Mastin et al., 2013). This tool can probabilistically model ashfall deposition using a Monte Carlo procedure to capture the range of various input parameters. The Hanford study included eruption source parameters such as MSH eruption frequency, volume, duration, and plume height; physical parameters such as particle shape, density, and vertical distribution within the ash cloud; and meteorological parameters (Mastin et al., 2018). The meteorological inputs considered conditions from 1980-2010 using data from the European Community's Medium-Range Weather Forecasting (ECMWF) Interim-ERA model. The Ash3d analysis predicts that with an annual frequency of 1E-4, the Hanford site can expect an ashfall deposit thickness of 5.1 cm. This is about half the thickness predicted by the two previous studies, largely because Mastin et al. (2018) used recent, more reproducible estimates of volumes for MSH eruptions over the last 10,000 years. Moreover, they used best estimates for eruption parameters and secondary source parameters, with no intent to add conservatism. As a result, the model estimated a smaller 10,000-year ashfall event at Hanford.

Ash3d has the added benefit of predicting airborne concentrations of particles as an ashfall event occurs. The model calculates airborne concentration at the surface during each simulation time step, as well as an average over the duration of the ashfall event. For a 1E-4 ashfall event, it predicted a peak concentration of 3819 mg/m^3, but with an average of 1513 mg/m^3 over the duration (Mastin et al., 2018). This average value agrees very well with the Snow and Nelson (2012a) estimate of 1500 mg/m^3 during a 1E-4 ashfall event.

RESUSPENSION ANALYSES

The Snow and Nelson (2012a) ash resuspension calculation was the first attempt to quantify the hazard of ash resuspended after a major Hanford Site ashfall event. As part of the 2014 expert team review, the model used to estimate ash resuspension was found to be a poor fit for that application, and hence the Snow and Nelson (2012a) estimates may have significantly overestimated the ash resuspension hazard. A major motivation for the new analysis was a more rigorous examination of how much ash can resuspend in various conditions, what airborne concentrations would affect the facilities, and the duration of those concentrations. DOE chose to contract with DRI to make empirical measurements of ash deposit resuspension, as they have experience with a wind tunnel-type device known as PI-SWERL (Etyemezian et al., 2007) that is well-suited for such measurements.

Empirical Measurements

DRI measured threshold shear velocity for particle transport (u_{*t}), and emissivity of volcanic ash deposits, both in the field and the laboratory (Etyemezian et al., 2018). They collected ash representative of an MSH eruption from two different deposits: one composed of MSH 1980 ash near the volcano, and one composed of ash from the Valley of Ten Thousand Smokes (VTTS) 1912 eruption in Alaska. The VTTS ash is considered a suitable analogue, since it is similar to MSH ash in terms of physical, mineralogical, and chemical characteristics (Etyemezian et al., 2018). Field measurements with the PI-SWERL device were taken at the VTTS sample location. The field results are less reliable because of the inability to control ash moisture, so they were not used to estimate threshold velocity and emissivity.

Laboratory measurements were made under variable humidity and ash moisture conditions. Threshold velocity and emissivity were measured at relative humidities ranging from 15 to 90 percent, which adequately represents the range of humidity likely to accompany a fresh ash deposit at Hanford. Etyemezian et al. (2018) measured the minimum shear velocity to achieve particle transport (u_{*t}) as 0.32 meters/second for the slightly older ash material, and 0.36 meters/second for the younger ash. The younger ash is likely more representative of a future MSH ash deposit at Hanford. The PI-SWERL measurements suggest a slight increase in u_{*t} with relative humidity, but given the measurement uncertainties, any correlation is modest (Etyemezian et al., 2018). Emissivity, however, shows a clear decrease with increasing humidity. Particle size distribution of ash deposits also affects u_{*t} and emissivity, but the relationship is complicated and hard to characterize, as Etyemezian et al. (2018) discuss.

DRI simulated the effects of rain on ash deposits by wetting the surfaces and allowing them to dry for several days. Emissivity generally declined in the days following surface wetting and then rebounded, but the two sources of ash behaved differently. Emissivity from the slightly older, more weathered ash sample was more affected by the addition of water (Etyemezian et al., 2018).

HYSPLIT Calculations

The NOAA Air Resources Laboratory analyzed the airborne concentrations of resuspended ash using their HYSPLIT atmospheric transport and dispersion model. This work relied on inputs from the USGS and DRI analyses, as well as historical meteorological data for the region. Specifically, NOAA used data from the Weather Research and Forecasting (WRF) model as input to the analyses (Crawford et al., 2018). The WRF provided surface friction velocities and precipitation through time, which in combination with the DRI results, yielded ash emission at a given location. HYSPLIT then used WRF wind data to model the transport and dispersion of ash once lofted from the surface.

Crawford et al. (2018) made a number of assumptions in the HYSPLIT modelling. Some key assumptions include:

- Meteorological conditions from only the 1980-2010 time span were considered. Results could vary if this time span is not adequately representative for the region.
- No ash is emitted from a surface if precipitation provided by the WRF exceeds 0.01 mm in an hour. Once precipitation ends, resuspension can immediately resume.
- Resuspension occurs for only 60 days after an ashfall occurs; the deposit is considered too weathered after this time to allow significant ash emission.
- WRF velocities are provided for grid cells 27 km square, so a given friction velocity is applied uniformly to each grid cell.
- Some momentum is transferred to non-erodible surface elements, but quantifying that portion requires a partitioning scheme. This work uses no such scheme, so ash emissions are likely over-estimated.

HYSPLIT was used to calculate hourly airborne ash concentration at the Hanford site for various eruption scenarios, with each scenario run for 60 days past the eruption time. With wind speeds highly variable hour-by-hour, Crawford et al. (2018) established “averaging times” over which to average airborne concentrations. In addition to the hourly calculations, they averaged concentrations over 6, 12, 48, 168, 336, and 720 hours. As airborne concentrations closely correlate with wind velocity, and high wind events tend to last for just hours or tens of hours, longer averaging times have lower concentrations. The NOAA modelling approach assumed that the highest concentrations of ash will result from episodic strong winds. Crawford et al. (2018) found that concentrations varied by over an order of magnitude depending on which mass flux relationship was used to model deposit emissivity. Other parameters such as threshold velocity, threshold deposit thickness at which emission begins, and particle size distribution had a much smaller effect on results.

For a resuspension event with an expected 1E-4 annual frequency, the simulations of Crawford et al. (2018) calculated one-hour airborne concentrations between 61 and 8600 mg/m^3. For a 24-hour average, the range drops to 18-2300 mg/m^3, and for a week, to 6-700 mg/m^3. These ranges obviously show considerable uncertainty in concentrations, and Crawford et al. (2018) discuss reasons that the upper end values may be very conservative. Their estimates of the duration of resuspension events have far less uncertainty than the concentration estimates. Airborne concentrations in the g/m^3 range are significantly higher than concentrations measured in ash resuspension events around the world, which are in the range of several mg/m^3. However, given that Etyemezian at al. (2018) found fresh MSH ash to be highly emissive and subject to resuspension, Crawford et al. (2018) suggest that concentrations in the hundreds of mg/m^3 could be reasonable for Hanford. Both DRI and NOAA suspect the lack of momentum partitioning in the HYSPLIT analyses is the primary cause of the high-end values. Momentum partitioning considers terrain aerodynamic roughness length. Crawford et al. (2018) did not characterize roughness lengths for the Hanford non-erodible surfaces (e.g., shrubland and vegetation), as that was beyond the scope of this study. Applying momentum partitioning could reduce modeled concentrations by one to three orders of magnitude. Moreover, other factors not examined could limit the mass of re-suspended ash in a volume of air. Considering the uncertainties and conservatisms in the analyses, Crawford et al. (2018) conclude that “a more realistic estimate of the 1 hour average concentration of a 1 in 10,000 year event would be more in the range of a few hundred mg m^{-3}. This modified estimate still appears conservative in comparison to measurements that have been made of resuspended ash.”

CONCLUSION

The USGS, DRI, and NOAA analyses did not recommend to DOE specific airborne concentration values to use in facility design; they simply provided the best, technically credible estimates they could develop within the project scope. DOE is still considering how to incorporate the new ashfall hazard analysis into the Hanford site-wide design requirements, as well as the specific WTP design requirements. The new analysis is clearly preferable for facility design, as it confirms that high airborne ash concentrations will last at most several days, not potentially weeks, as per the Snow and Nelson (2012a) analysis. However, even the NOAA estimate of a few hundred mg/m^3 of resuspended ash for an hour or more could be problematic for facility air filtration systems. Therefore, as design of some WTP facilities continues, and others approach commissioning, DOE will likely consider options for suspending certain operations in the event of a major ashfall event. Suspending operations, where feasible, may be more cost-effective than designing facility systems to endure high ash concentrations.

REFERENCES

Conrads, T. J. (1996). “Volcano Ashfall Loads for the Hanford Site,” Westinghouse Hanford Company, WHC-SD-GN-ER-30038, Rev. 0, 25 p.

Crawford, A., Loughner, C., and Stein, A. (2018). "Modeled concentrations of volcanic ash due to resuspension at Hanford: Final Report," prepared for the U.S. Department of Energy, Office of River Protection, AFP-NOAA-REPORT-03, Revision 1.

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.

Etyemezian, V., Nikolich, G., Ahonen, S., Pitchford, M., Sweeney, M., Gillies, J., and Kuhns, H. (2007). "The Portable In-Situ Wind Erosion Laboratory (PI-SWERL): a new method to measure PM_{10} windblown dust properties and potential for emissions," *Atmospheric Environment*, v. 41, No. 18, 3789-3796.

Etyemezian, V., Gillies, J. A., and Nikolich, G. (2018). "Measurement of resuspension of volcanic ash by wind erosion: Final Report," prepared for U. S. Department of Energy, Office of River Protection, AFP-DRI-REPORT-02, Revision 1.

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 2011-1064, 15 p.

Mastin, L. G., Randall, M. J., Schwaiger, H. F., and Denlinger, R. P. (2013). "User's Guide and Reference to Ash3d: A 3-D Eulerian Atmospheric Tephra Transport and Deposition Model," U. S. Geological Survey Open-File Report 2013-1122, 48 p.

Mastin, L. G., Van Eaton, A. R., and Schwaiger, H. F. (2018). "A probabilistic assessment of tephra-fall hazards at Hanford, Washington, from a future eruption of Mount St. Helens," prepared for the U.S. Department of Energy, Office of River Protection, AFP-USGS-REPORT-01, Revision 1.

Sarna-Wojcicki, A. M., Shipley, S., Waitt Jr., R. B., Dzurisin, D., and Wood, S. H. (1981). "Areal Distribution, Thickness, Mass, Volume, and Grain Size of Air-fall Ash From the Six Major Eruptions of 1980," *The 1980 Eruptions of Mount St. Helens, WA*, U. S. Geological Survey Professional Paper 1250, 577-600.

Snow, R. L., and Nelson, E. A. (2012a). "Volcano Ashfall Loads for the Hanford Site," Washington River Protection Solutions, WHC-SD-GN-ER-30038, Rev. 2, 43 p.

Snow, R. L., and Nelson, E. A. (2012b). "Natural Phenomena Hazards, Hanford Site, Washington," Washington River Protection Solutions, HNF-SD-GN-ER-501, Rev. 2, 24 p.

U. S. Nuclear Regulatory Commission (1977). "Safety Evaluation for the Construction of the Pebble Springs Nuclear Power Plant," NUREG-0013, Supplement No. 3, Docket Numbers 50-514 and 50-515.