



U.S. DEPARTMENT *of* ENERGY

Office of Environmental Management

Hanford Field Office

Alternate Method of Estimating Peak Airborne Ash Concentration when an Ash Cloud from a Volcanic Eruption is Over the Hanford Site

Presented to: 2026 Biennial Natural Phenomena Hazards Workshop
U.S. Nuclear Regulatory Commission Headquarters

CFA-2026-NPH-03

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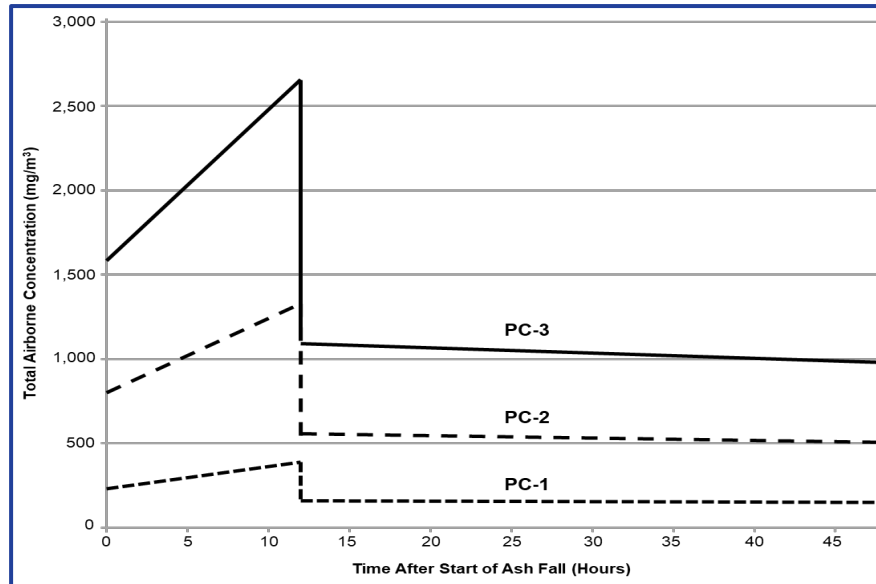
September 23, 2026



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Current Airborne Ash Concentration Curves (2012)



Total airborne ash concentration, first 48 hours

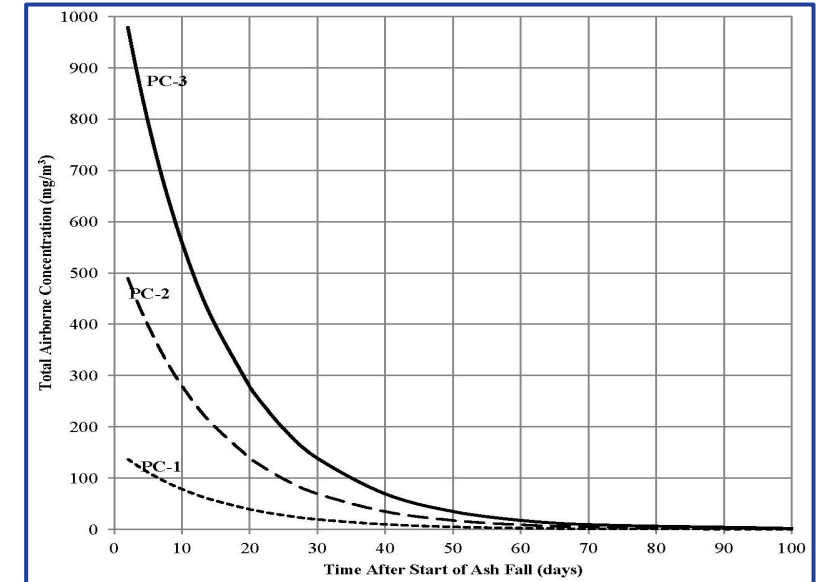
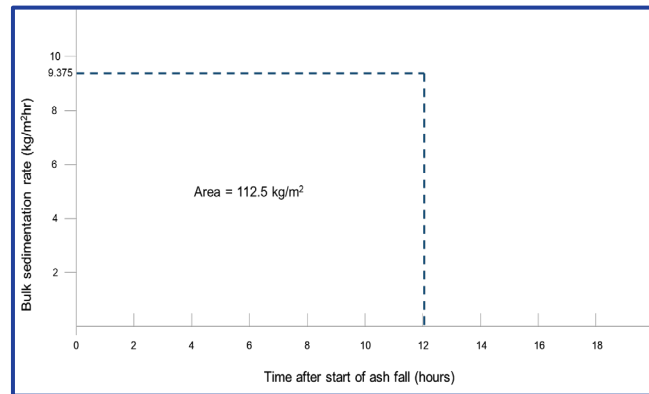
Total Peak Ash Concentrations (t=12 hours)

- PC-3: 2,650 mg/m³
- PC-2 : 1,325 mg/m³
- PC-1: 370 mg/m³

Top two curves from HNF-SD-GN-ER-501, 2017, *Natural Phenomena Hazards, Hanford Site, Washington*, Rev. 3, Washington River Protection Solutions LLC, Richland, Washington, October 24.

Design Basis Criteria: The probability (annual probability of exceedance) of a tephra or ash deposit thickness of at least 10 cm at a given distance (~200 km of a MSH eruption) is 1 in 10,000 years using an average ash density of 1125 kg/m³.

PC-3: 10 cm
PC-2: 5 cm
PC-1: 1.4 cm



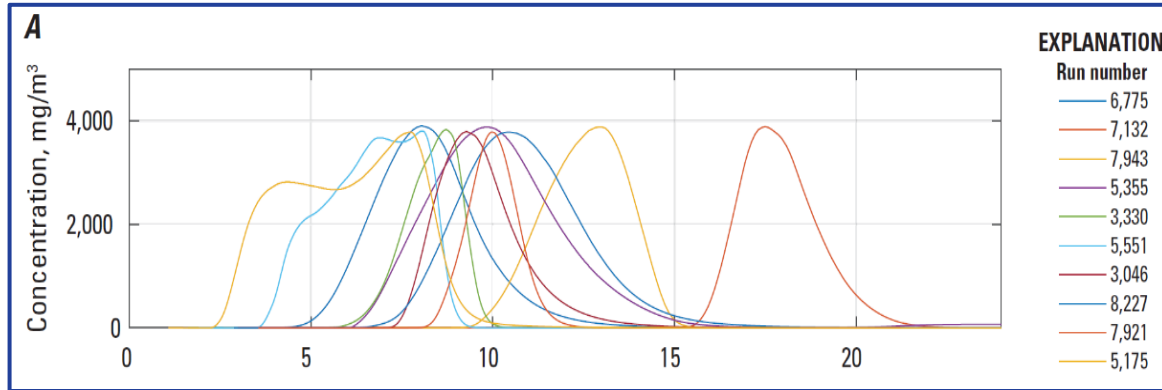
Resuspended airborne ash concentration, after day 2

- PC-3 (VDC-3): 1 in 10,000 years
- PC-2 (VDC-2): 1 in 2,000 years
- PC-1 (VDC-1): 1 in 1,000 years

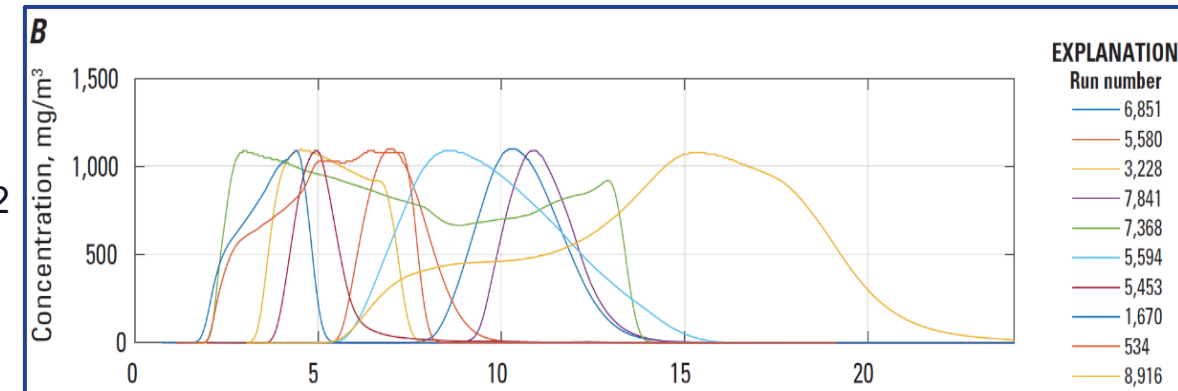
Technical Support Document: WHC-SD-GN-ER-30038, 2012, *Volcano Ashfall Loads for the Hanford Site*, Rev. 2, Washington River Protection Solutions LLC, Richland, Washington, July 23.

Peak Airborne Ash Concentrations Vs Time from Simulated Mount St. Helens Eruptions (2020)

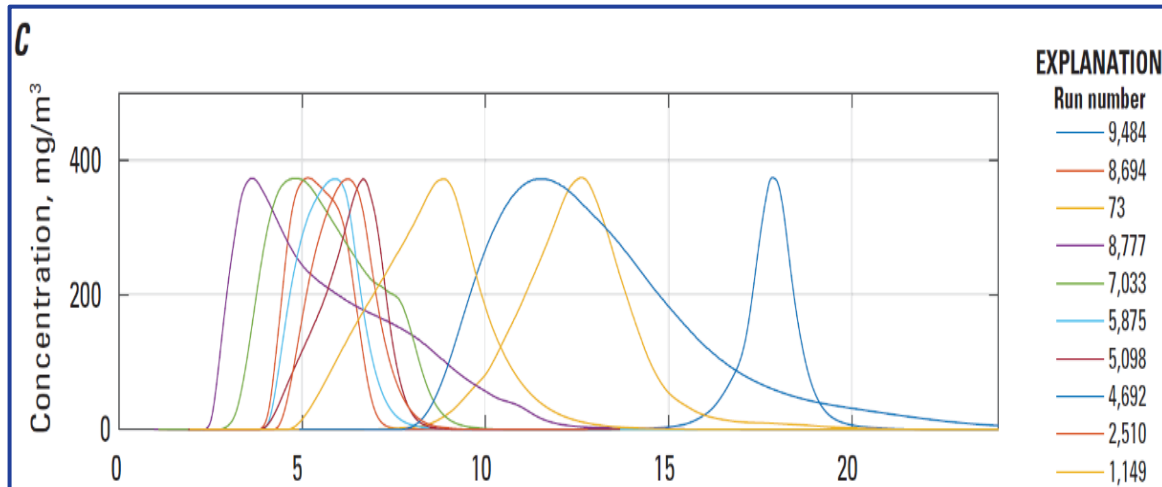
PC-3



PC-2



PC-1



- Graphics use the Ash3d model.
- Falling and suspended ash concentrations.
- USGS Open-File Report 2020-1133, 2020, *A probabilistic assessment of tephra-fall hazards at Hanford, Washington, from a future eruption of Mount St. Helens*, U.S. Geological Survey, Reston, Virginia, December 22.



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Issue and Proposed Alternate Method

- **Issue:**

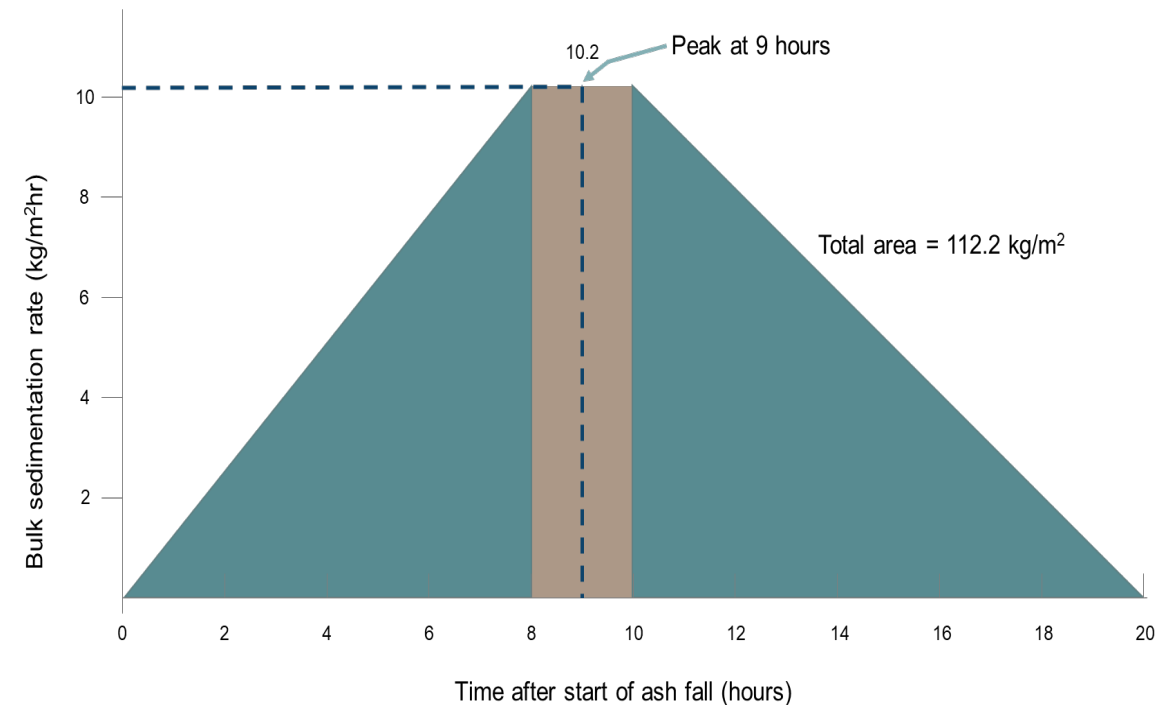
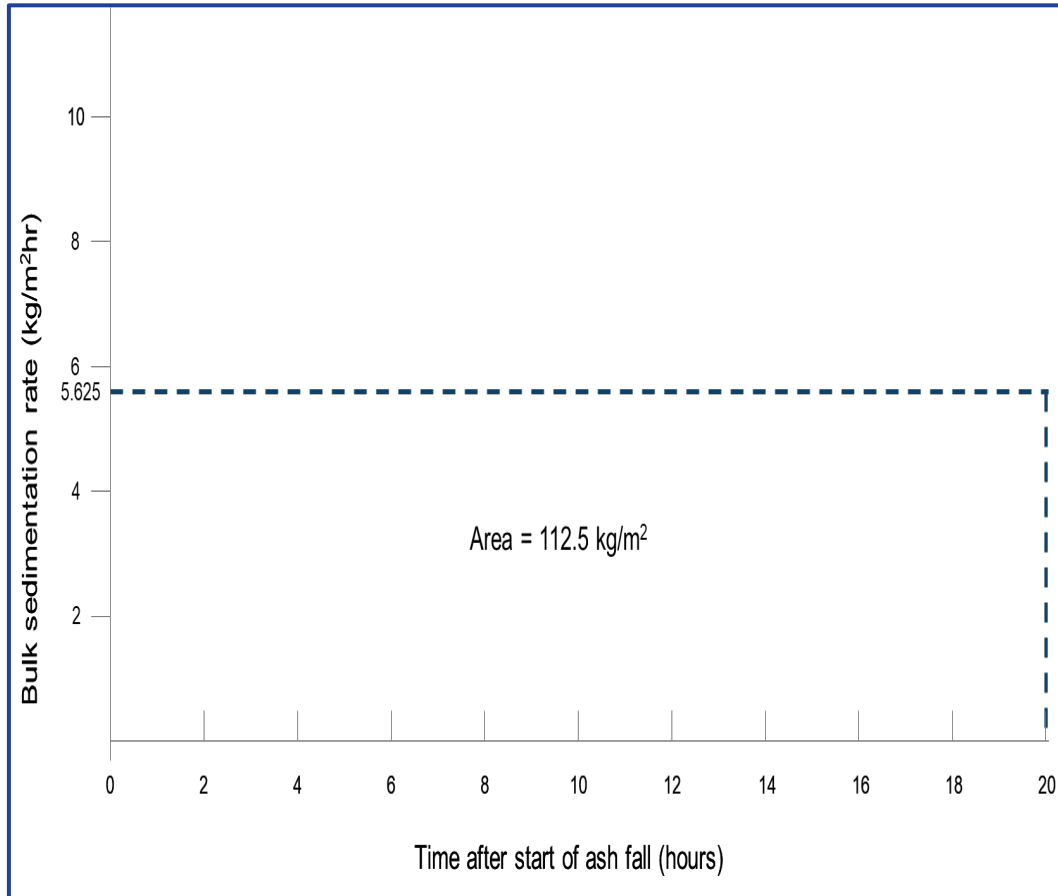
- Falling ash from the descending ash cloud over the Hanford Site is not uniform. Using an average falling-ash concentration for the entire ash-fall period masks short duration peak effects. Likewise, relying on resuspended ash (42% at $t = 12$ hours)) to estimate peak airborne ash concentrations underestimates the total peak ash concentration. The current approach uses an average bulk particle fall velocity of 1.7 m/s derived from an assumed ash plume height elevation
- Document WHC-SD-GN-ER-30038, states, “the derived average fall velocity has many aspects of uncertainty. It might be argued that is biased on the high side, representing only the first falling ash particles may be larger, heavier, and faster than the average.” And that “the average fall velocity does not consider variation with altitude. The concentration of interest is near the ground level, and it is not known how well the average fall velocity represent this final velocity at the ground.”

- **Proposed Alternate Method:**

- Intent is to retain simplicity without making estimations overly computationally intensive
- To maintain consistency with the conservative design criteria in USGS Open-File Report 2011-1064 mass loads (derived from the conservative compacted ash density value of 1125 kg/m^3) for PC-3, PC-2, and PC-1 events are converted to sedimentation rates ($\text{kg/m}^2 \text{ hour}$) using **20 hours** vice 12 hours
- The alternate method uses a **composite curve** of varied sedimentation rates to encompass all eruption events
- The alternate method considers an alternative, yet conservative **average bulk fall velocity at or near ground level** in lieu of the current average bulk particle velocity

Proposed Alternate Method – First Step for the PC-3 Event

Vary the sedimentation rate (kg/m^2 hour) over the event period

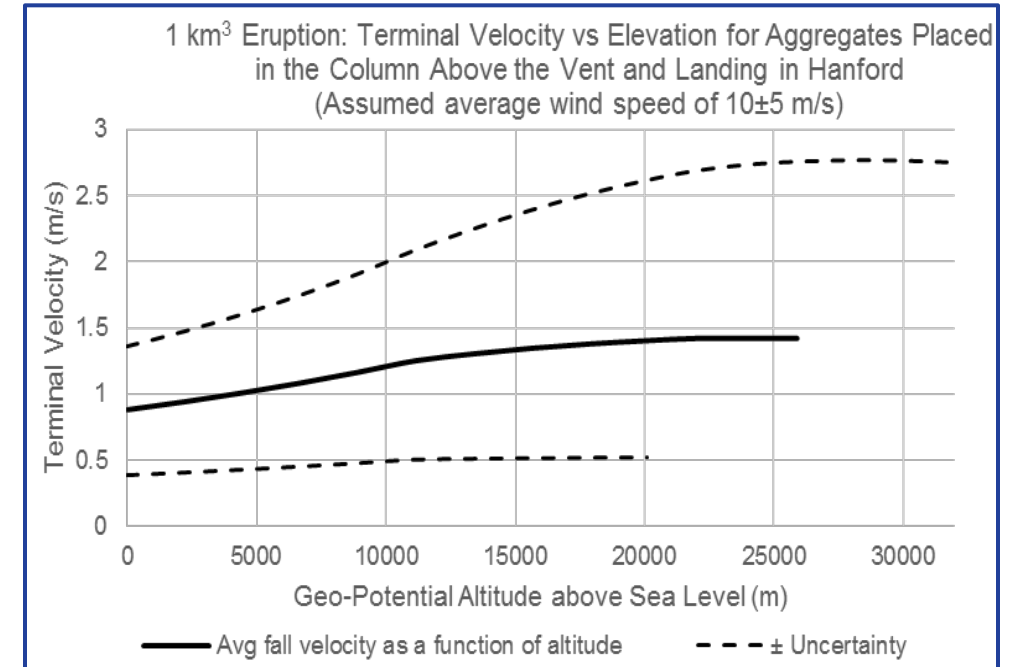


Second Step – Estimation of Fall Velocity

- An estimate of the fall velocity of ash particles or aggregates—as an average bulk value or expressed as a range of velocity values—has aspects of uncertainty on a particle falling from elevations of 12 to 15 km, including:
 - Temperature differences affecting atmospheric density and viscosity variation with elevation, liquid in the ash cloud, freezing of liquid in the ash cloud, aggregate formation in the ash cloud, and particle shape
- The Ash3d model from USGS Open-File Report 2020-1133 assumes fine ash aggregates formed in the eruption plume do not undergo further aggregation in the ash cloud as they are carried downwind of the eruption. Approximately 60 percent (by mass fraction) of fine ash aggregates are 63 μm or less (deposit from the 1980 Mount St. Helens [MSH] eruption). The U.S. Geological Survey (USGS) used a range of fall velocities of 0.35 to 0.85 m/s (average of 0.6 m/s) in the Ash3d model
- Durant et al. (2009) proposed that aggregation of fine ash particles appears to be highly affected by precipitation effects (e.g., the amount of water in the form of raindrops or ice particles/crystals present in the high-altitude ash cloud)
- Presence of these hydrometeors causes icing of ash particles/aggregates to settle faster
- Carey and Sigurdsson (1982) concluded that particle aggregation in the presence of moisture and condensation caused these fine particles to stick together (i.e., hydro-bonds acting as a binding agent) into larger, heavier clusters
- Electrostatic particle attraction is typically prevalent with fine ash particles
- Fall velocities may be in the range of 1.0 to 2.0 m/s

Estimating Average Fall Velocity

- USGS estimate of average fall velocity at ground level
- Calculation used the drag coefficient expression by Wilson and Huang (1979) and the 1976 U.S. Standard Atmosphere Model for air density and viscosity as function of elevation to calculate terminal (fall) velocities as function of elevation
- Average diameter of rounded aggregates with density of 600 kg/m³
- **Hanford ground level fall velocity** estimated at **0.9 m/s** plus or minus 0.5 m/s; model used a 250-micron aggregate diameter and windspeed of 15.1 m/s
- Likely range from 0.57 to 1.04 m/s
- **Summary:** To account for moisture-initiated aggregation and electrostatic attraction effects tending to drive fall velocities higher (i.e., greater than 1 m/s), and fine particle/aggregate distributions having lower fall velocities (i.e., less than 1 m/s), the alternate approach selected an **average bulk fall velocity** (biased to the ground level) of **1 m/s**; considered conservative with respect to its average ash density of 1,125 kg/m³



$$Re = \frac{\rho_{air} u D}{\mu_{air}}$$

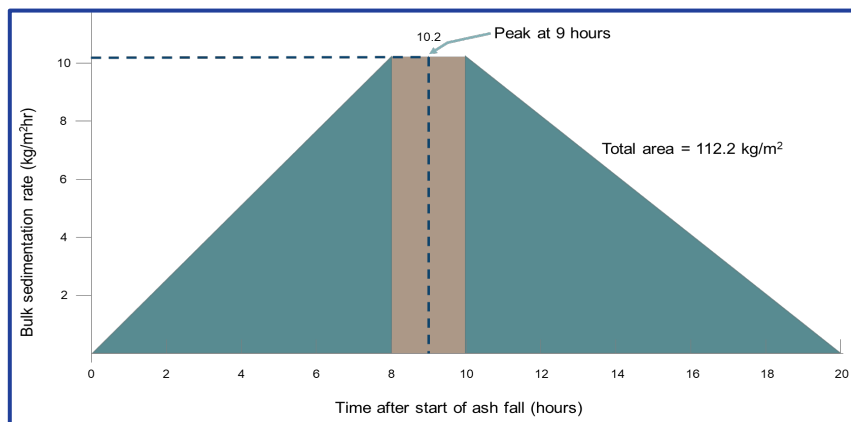
$$C_D = \frac{24}{Re} F^{-0.828} + 2\sqrt{1.07 - F}$$

$$u_{Terminal} = \sqrt{\frac{4gD(\rho_{agg} - \rho_{air})}{3C_D\rho_{air}}}$$

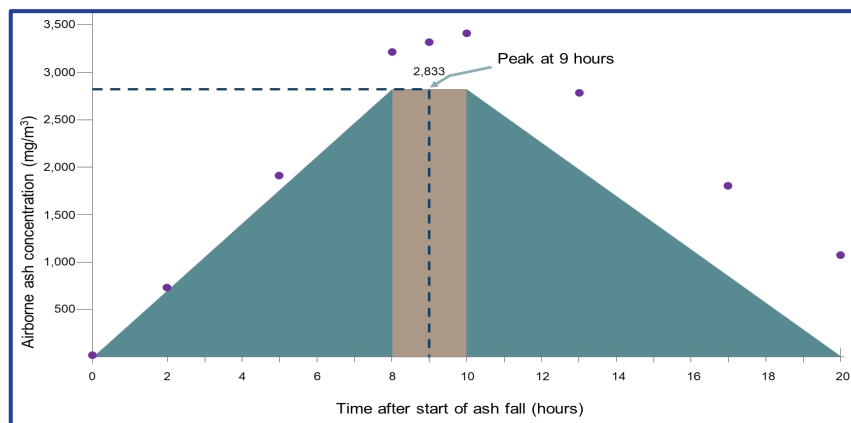
Alternate Method: Continuous Composite Configuration (Triangle Method)

- Two right triangles on both sides of one peak center column
- Geometry makes estimations of airborne ash concentration straightforward and simple
- Configuration is supposed to be a **composite** encompassing all MSH volcanic eruptions over a 20-hour period
- Peak time was set constant for all annual probabilities of exceedance. Peak column is 2 hours ($t = 8$ to $t = 10$ hours)
- Objective is to estimate a peak maximum ashfall concentration of the ash cloud (falling and suspended ash) over the Hanford Site
- Safety basis assumption requires nuclear facilities to be placed in a safe shutdown configuration within 2 hours of notification of a volcanic eruption
- Total mass loads for PC-3, PC-2, and PC-1 events using the triangle method are approximate
- Sedimentation rate at any time is determined by the height of the intermediate triangle and the corresponding ash concentration is calculated by dividing the average fall velocity for the given height. Calculating peak column height reduces to a simple expression
- Accumulated mass load (kg/m^2) at time t , based on area under the composite configuration. Total mass load is accumulated over the 20-hour period
- Dots shown on the airborne ash concentration curves represent resuspension values and are calculated using the Maxwell and Anspaugh equation for **resuspended ash concentration** (currently used) defined as the resuspension factor (units of m^{-1}):
 - $S_f = [10^{-5} \exp(-0.07t) + 7 \times 10^{-9} \exp(-0.002t) + 10^{-9}]$ $S_f = X / D$ $t = \text{days}$
 - $X = \text{airborne air concentration (mg}/\text{m}^3)$ or $X = S_f \times D$
 - $D = \text{total areal deposition (kg}/\text{m}^2) - \text{same as mass load}$
- Resuspended ash concentration value is added to the falling ash value for the total airborne ash concentration; the D or total areal deposition (kg/m^2) is the accumulated mass load used in the resuspension equation. **Peak airborne ash concentration value occurs at $t = 10$ hours**

Continuous Composite Configuration – PC-3 Event



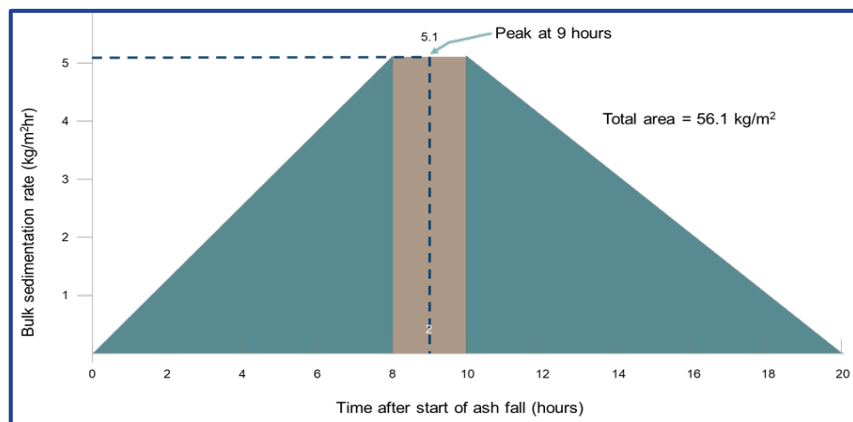
Sedimentation rate at kg/m² hour



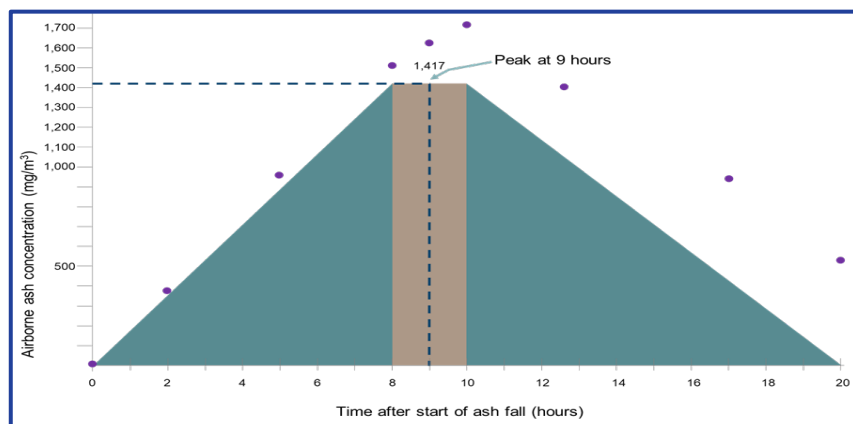
Total airborne ash concentration mg/m³

Time (hours)	Accumulated Mass Load (kg/m ²)	Falling Ash Concentration (mg/m ³)	Resuspended Ash Concentration (mg/m ³)	Total Ash Concentration (mg/m ³)
0	0	0	0	0
2	2.55	708.3	25.4	734
5	15.94	1770.8	157.2	1928
8	40.8	2833.3	398.9	3232
9	51	2833.3	497.2	3331
10	61.2	2833.3	594.9	3428
13	87.21	1983.3	840.3	2,824
17	107.61	850	1024.9	1875
20	112.2	0	1059.3	1059
24	112.2	0	1047	1047
36	112.2	0	1011.1	1011
48	112.2	0	976.3	976

Continuous Composite Configuration – PC-2 Event



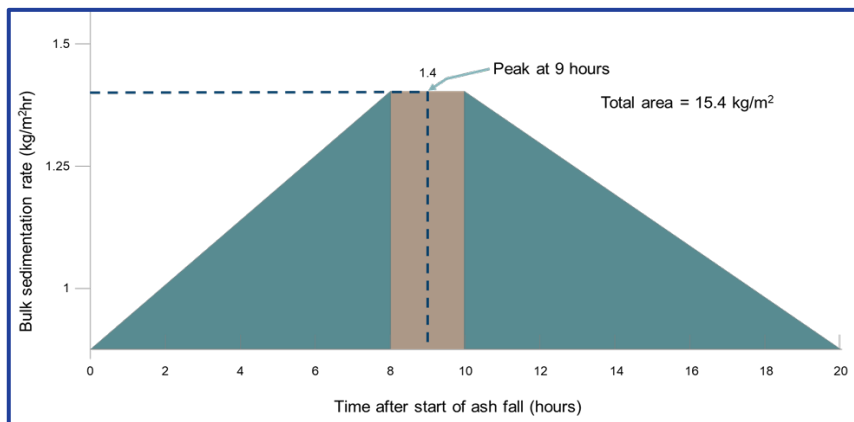
Sedimentation rate at kg/m² hour



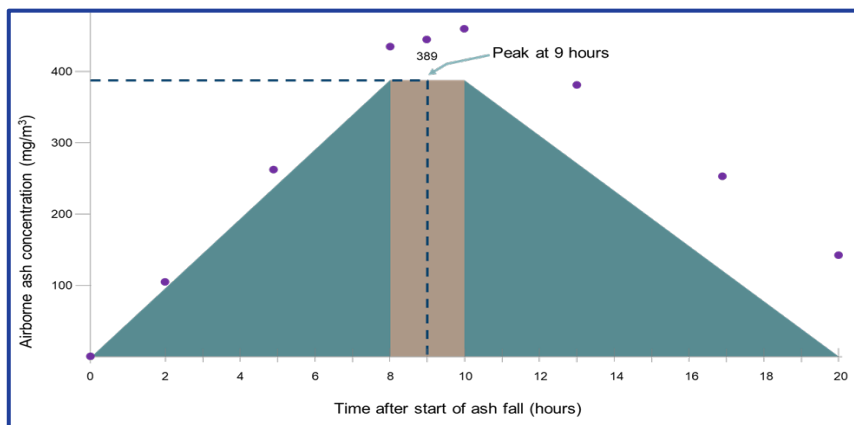
Total Airborne Ash Concentration mg/m³

Time (hours)	Accumulated Mass Load (kg/m ²)	Falling Ash Concentration (mg/m ³)	Resuspended Ash Concentration (mg/m ³)	Total Ash Concentration (mg/m ³)
0	0	0	0	0
2	1.28	354.2	12.7	367
5	7.97	885.4	78.6	964
8	20.4	1416.7	199.5	1,616
9	25.5	1416.7	248.6	1,665
10	30.6	1416.7	297.4	1,714
13	43.61	991.7	420.2	1,412
17	53.81	425	512.5	938
20	56.1	0	529.7	530
24	56.1	0	523.5	524
36	56.1	0	505.5	506
48	56.1	0	488.2	488

Continuous Composite Configuration – PC-1 Event



Sedimentation Rate kg/m²



Total Airborne Ash Concentration mg/m³

Time (hours)	Accumulated Mass Load (kg/m ²)	Falling Ash Concentration (mg/m ³)	Resuspended Ash Concentration (mg/m ³)	Total Ash Concentration (mg/m ³)
0	0	0	0	0
2	0.35	97.2	3.5	101
5	2.1875	243.1	21.6	265
8	5.6	388.9	54.8	444
9	7	388.9	68.2	457
10	8.4	388.9	81.7	471
13	11.97	272.2	115.3	388
17	14.77	116.7	140.7	257
20	15.4	0	145.4	145
24	15.4	0	143.7	144
36	15.4	0	138.8	139
48	15.4	0	134.0	134

Results and Discussion

- Results for PC-3, PC-2, and PC-1 using conservative design criteria indicate about 30 percent higher than current total airborne ash concentrations
- How can we improve on these highly conservative ash concentration values?

Sensitivity evaluation:

- Increase fall velocity?
 - Can reduce the falling ash concentration to a point, but defending a higher fall velocity may be technically challenging
- Use different ash density values?
 - Evaluate falling ash concentration as a function of ash density

Application of the Triangle Method – PC-3

Peak ash concentrations using 10 cm thickness and fall velocity of 1 m/s

Ash Density kg/m ³	Mass Load kg/m ² (Total)	Peak Falling Ash Concentration mg/m ³ at T = 10 hours	Resuspended Ash Conc. mg/m ³ at T = 10 hours	Total Peak Ash Conc. mg/m ³
1,125	112.5	2,833	595	3,428
900	90	2,278	478	2,756
800	80	2,014	423	2,437
770	77	1,944	408	2,352
700	70	1,764	370	2,134
620	62	1,567	329	1,896
600	60	1,514	318	1,832
500	50	1,264	265	1,529
450	45	1,139	239	1,378

Peak falling ash concentration values corresponding to average concentration values at 1,125 kg/m³ density are achieved at lower ash density at 620 kg/m³ using same ash thickness values. Ash densities representing freshly fallen ash better represent the ash downfall period rather than compacted ash density of 1,125 kg/m³. Conservatism is maintained using the design basis thickness. Reduction in total peak ash concentration is achieved because of the lower accumulated mass load used to estimate resuspended ash concentration. Overall reduction is nearly 30 percent lower over current value. Overall reduction also applies to PC-2 and PC-1 events.

Application of the Triangle Method – PC-2

Peak ash concentrations using 5 cm thickness and fall velocity of 1 m/s

Ash Density kg/m ³	Mass Load kg/m ² (Total)	Peak Falling Ash Concentration mg/m ³ at T = 10 hours	Resuspended Ash Conc. mg/m ³ at T = 10 hours	Total Peak Ash Conc. mg/m ³
1,125	56.25	1,417	297	1,714
900	45	1,139	239	1,378
800	40	1,014	213	1,227
770	38.5	972	204	1,176
700	35	889	187	1,076
620	31	783	165	948
600	30	758	159	917
500	25	639	134	773
450	22.5	569	120	689

Application of the Triangle Method – PC-1

Peak ash concentrations using 1.4 cm thickness and fall velocity of 1 m/s

Ash Density kg/m ³	Mass Load kg/m ² (Total)	Peak Falling Ash Concentration mg/m ³ at T = 10 hours	Resuspended Ash Conc. mg/m ³ at T = 10 hours	Total Peak Ash Conc. mg/m ³
1,125	15.75	389	82	471
900	12.6	317	67	384
800	11.2	278	58	336
770	10.8	272	57	329
700	9.8	247	52	299
620	8.7	219	46	265
600	8.4	211	44	255
500	7	176	37	213
450	6.3	158	33	191

Results and Discussion (continued)

Additional Sensitivity:

Total peak ash concentration effect (at $t = 10$ hours) if fall velocity were increased to 1.1 m/s with ash density at 620 kg/m^3 . Conservatism is still maintained

- **PC-3:** 1752 mg/m^3 (1423 + 329)
- **PC-2:** 877 mg/m^3 (712 + 165)
- **PC-1:** 246 mg/m^3 (200 + 46)

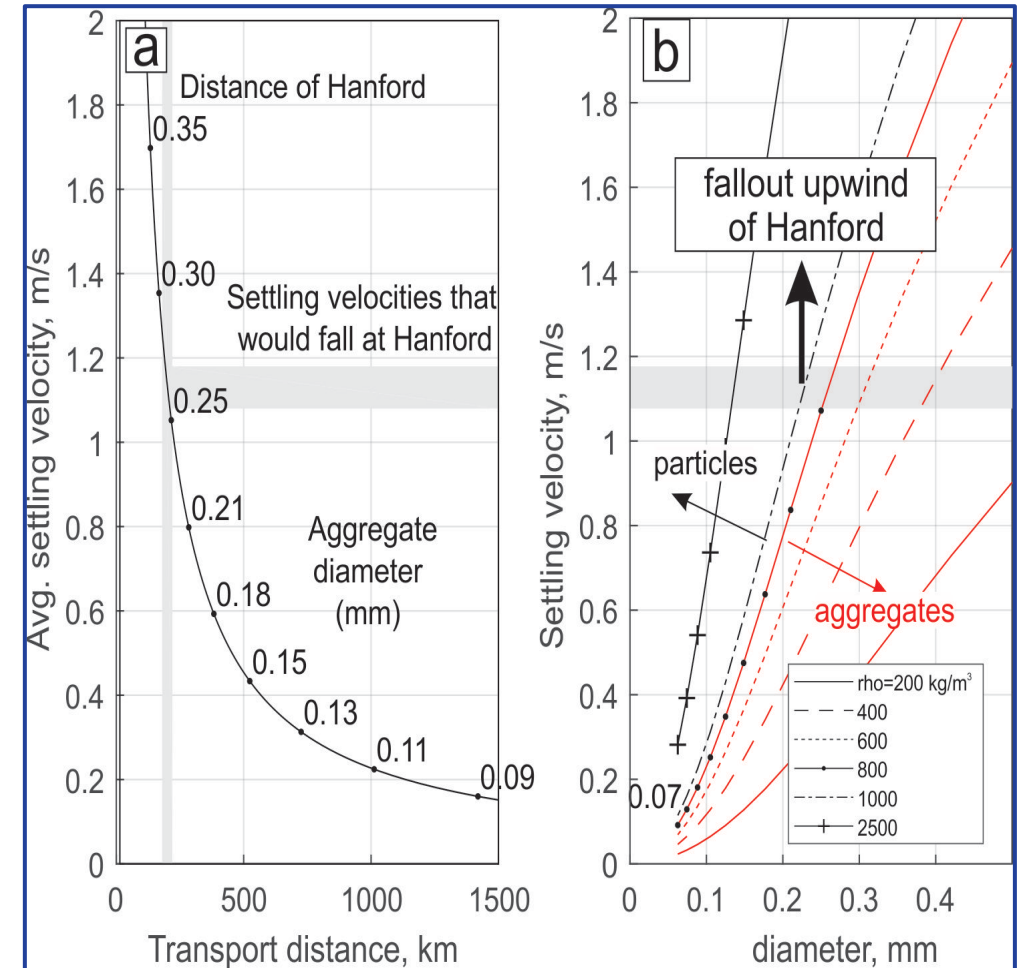
Reduction of about 34% over current peak concentration values

Questions?



Back-Up Slide: Settling Velocity Estimates at the Hanford Site

- Left graph (shaded gray bar) represents the average fall velocity of particles/aggregate falling from the plume's peak (15 km) would land at the Hanford Site
- Average diameter of rounded aggregates with density of 600 kg/m^3 for given average fall velocities
- Aggregate diameters above 0.25mm (250 μm) settle upwind of the Hanford Site.
- Distance between MSH to the Hanford Site is approximately 210 km



USGS estimates for the Hanford Site (USGS Open-File Report 2020-1133)