CHIEF OF NUCLEAR SAFETY

CNS

TECHNICAL PAPER

TO SHARE AND DISCUSS NUCLEAR SAFETY ISSUES OF INTEREST

Dry-Deposition Velocity Assumptions Used in Consequence Modeling at the Hanford Waste Treatment Plant

Background:

The Chief of Nuclear Safety has been evaluating an emerging issue at the Hanford Waste Treatment Plant (WTP) associated with implications of using dry deposition velocity (DV) values that are incorporated into unmitigated dose consequence analysis. DV is a simplified factor used in calculations representing plume depletion and is directly affected by the size distribution of particles released, wind speed, and the roughness of the surface upon which the plume is traveling.

Methods for Estimation of Leakages and Consequences of Releases (MELCOR) Accident Consequence Code System, version 2 (MACCS2) and other atmospheric dispersion and radiological consequence codes are used in analyzing atmospheric dispersion and the subsequent radiological consequence of accidental releases of radioactivity from postulated accident conditions. Codes of this type of are used primarily to calculate the appropriate dilution factor for atmospheric transport of puffs or plumes and ultimately quantify the radiological dose that is received by the maximally exposed offsite individual. The 95th percentile of the distribution of doses to the maximally exposed offsite individual is the comparison point for assessment against the evaluation guideline. Consequently, the importance of these accident analysis codes on safety is related to their contribution in selecting safety-class systems, structures, and components.

In June 2004, the Department issued *DOE MACCS2 Computer Code Application Guidance for Documented Safety Analysis* (Ref. 1) in response to Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 2002-1, *Quality Assurance for Safety-Related Software*, specifying a deposition velocity of 1 cm/s. The MACCS2 model conservatively estimates exposures for unmitigated releases using 1 cm/s for DV and mitigated releases using 0.1 cm/sec. The 1 cm/sec value is that provided to support dose consequences for unmitigated releases from DOE facilities. This value was consistent with the methodology being applied by Nuclear Regulatory Commission (NRC) licensees and was generally accepted among DOE and DNFSB accident analysis experts at the time.

The WTP incorporated a DV of 1 cm/s, consistent with recommendations from the MACCS2 code guidance. The DNFSB staff raised a concern that this value was not conservative, based on measured values associated with a specific 1985 Hanford Tank Farm radiological release incident, as well as on modeling assumptions cited in NUREG/CR-3332, *Radiological Assessment: A Textbook on Environmental. Dose Analysis*. The DNFSB comments proposed that a value of 0.1 cm/s would be more conservative and would therefore be appropriate.

Issue:

Provide the technical basis supporting DOE's technical approach to accident analysis using MACCS2 and a DV of 1 cm/sec. Demonstrate that the WTP is consistent with that approach in executing its safety analysis.

Technical Basis:

A review of the NRC requirements, technical papers, WTP waste data and calculations, and DOE MACCS2 code guidance provides the technical basis for DV as follows:

- Correlation of a DV to a value of 0.15 cm/s based on actual data calculated from a 1985 Hanford Tank Farm radiological release could be misleading based on the following factors (Ref. 3):
  - The 0.15 cm/s value was backcalculated from the measured deposition of cesium and strontium and was a "mitigated" event (i.e., with cover blocks in place that would inhibit release of the larger particles), and therefore would not be analogous to the unmitigated analysis described in the WTP Severity Level Calculations. The measured DV is similar to values recommended for filtered releases, which involve smaller particle sizes.
  - The Hanford report calculated eight data points from Table 1, where DVs of 0.08 to 1.3 cm/s were calculated. However, the 0.15 cm/s DV is the average of only seven of these values and does not include the eighth data point of 1.30 cm/s. If it were included, the average is closer to 0.3 cm/s.
- A deposition velocity of 0.1 cm/s, as discussed in NUREG/CR-3332, is associated with <u>filtered</u> effluents for which a particle size of 1 µm and a DV of 0.001 m/s are appropriate. Based on WTP-RPT-153, Rev. 0, *Estimate of Hanford Waste Insoluble Solid Particle Size and Density Distribution,* the representative particle size and density distributions, as derived from Hanford waste data, are expected to be in the range of 6 to 9 µm Aerodynamic Equivalent Diameter (AED).[1]
- The DOE MACCS2 code guidance recognizes that a 0. 1 cm/s deposition velocity is overly conservative for the larger particle size distributions associated with unmitigated releases and recommends a 1 cm/s deposition velocity for unfiltered particulate releases. Implicit in this guidance is the assumption that a filtered release will be composed of mostly submicron-sized particles, while unfiltered releases will be composed of larger particles that are still respirable.
- The bases used to support the DOE MACCS2 guidance report, Sehmel (Ref. 4) and an earlier Sehmel and Hodgson conference paper (Ref. 5), support the use of 1.0 cm/s for large particle sizes that are in the respirable range, less than 10 µm. Reference 4 discusses the dependence of DV on particle size (diameter), surface roughness length (z_0), atmospheric stability, ambient wind velocity, and the friction velocity (Ref. 6). For many fission product species of interest at the WTP, Sehmel's curves show a DV of approximately 1 cm/s for 2 µm-to 5 µm-diameter particles under stable atmospheric conditions (E and F stability categories). Stable atmospheric conditions are those most often associated with 95th percentile dose conditions (Ref. 7). A graphical representation of particle size versus DV is presented in Figure 1, which illustrates that for the particle size of 6 to 9 µm, DVs are in the range of 1.1 to 1.5 cm/s. Therefore, the DV of

[1] From DOE-HDBK-3010-94, $D_{AED} \approx D_g \times (\rho)^{0.5}$,where D_{AED} is the aerodynamic equivalent diameter, sphere of unit density, D_g is the geometric diameter and ρ is the material density.

1 cm/s used in the WTP safety analysis is conservative.

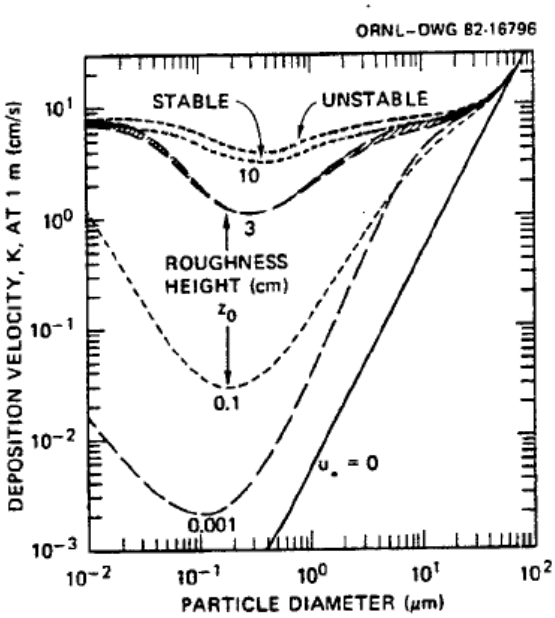

Figure 1. Deposition Velocity vs. Particle Diameter (from NUREG-CR/3332)

- NUREG/CR-2300, *PRA Procedures Guide* (Ref. 8) in its discussion in Chapter 9, states, "For particles, v_d [i.e., DV] depends on a variety of parameters: the chemical properties of the material being deposited, the size and shape of the particles, the surface-roughness length z_0, the nature of the vegetation, the atmospheric stability category, and so on." As a result, a survey of published data on the value of v_d produces figures varying between 0.0001 and 20 cm/sec (Hosker, 1974) (Ref. 9). Since this remains an area of great uncertainty, it is discussed in some depth in Appendix D, where it is shown that, for particulate matter emitted in the aftermath of a reactor accident, it is reasonable to expect v_d, to be in the range of 0.1 to 10 cm/sec. Appendix D states, "In the Reactor Safety Study, the dry-deposition velocity was judged to lie in the range 0.1 to 10 cm/sec, with 1 cm/sec taken as the expected average. In the light of the foregoing discussion, the recent reviews by Sehmel and Slinn (see Refs. 10 and 11) have produced no reason for changing this estimate."

- Two relevant dual-tracer studies were conducted at the Hanford Site for which publications exist. The first, by Nickola and Lee (Ref. 12) evaluated deposition on snow, while the second by Doran and Horst (Ref. 13) was conducted over the desert grasses and 1- to 2-m dry steppe sagebrush. The DV values measured at 0.8 and 1.6 km over the smooth snow surface are more than an order of magnitude below those determined through mass balance techniques over the same field grid when dry. However, the Doran and Horst DV values of 1.5 to 5.4 cm/sec applied to the total surface, including the 1- to 2-m tall sagebrush and lower vegetation.

- A 1 cm/s deposition velocity is consistent with the NRC regulatory analysis documented in NUREG-1140, *A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licensees* (Ref. 14). NUREG-1140 is cited in Appendix A to DOE-STD-3009-94 on the airborne pathway being of primary interest in the dose estimation process for nonreactor nuclear facilities. Work documented in a 2004 report comparing various complex atmospheric transport and dispersion (ATD) computer models using meteorological conditions recorded for a Federal site located in the U.S. Midwest (Kansas and Oklahoma) (Ref. 15). In this study, the models were compared for a 30-minute release of a "non-depositing species" of 10^{16} Bq, simultaneously with a "depositing species" of 10^{16} Bq. For the depositing species,

all computer models used a 1 cm/s deposition velocity input.

Conclusion:

The DV value of 1 cm/s is a conservative value to use in unmitigated consequence modeling for the WTP. The historical data, industry guidance, and WTP's average particle size support the DV used in the analysis. Other values proposed by specific studies are associated with small particle sizes or limiting meteorological conditions that are not consistent with DOE's approach to unmitigated consequence modeling (i.e., 95 percent meteorological conditions). Such conservatism does not provide assurance that the accident can be analyzed properly under most conditions.

The effect of numerous other conservative assumptions related to modeling of seismically induced explosions at WTP should also be considered in the overall acceptance of severity level calculation results. These include an assumed simultaneous explosion of 28 tanks, the use of a conservative TNT-equivalent method for modeling all explosions, an extensive duration of 1,000 hours for calculating vessel potential to exceed the Lower Flammability Limit (LFL), and the optimization of tank liquid level to ensure maximum hydrogen generation. Together, these conservatisms substantially increase the magnitude of consequence estimates. Using a DV of 0.1 cm/s would further increase consequences by an approximate factor of four.

Table 1 presents an additional discussion of conservatisms contained in the analysis.

Table 1, Sample Conservatisms found in WTP Severity Level Calculations and Assumptions for Seismic Hydrogen Detonations

WTP Severity Level Calculations/Assumptions	Basis	Level of Conservatism	Sensitivity on Safety Analysis
The source terms for vessels with hydrogen accumulation between 4 and 8 percent by volume following DBE are calculated in the same manner as vessels with more than 8 percent volume (i.e., TNT-equivalent method)	The source term factors and modeling for hydrogen deflagration events involving liquids are not well established with DOE-HDBK-3010. However, modeling of source term from Deflagration to Detonation Transition to Detonation (DDT) is described in the Handbook using a TNT equivalent methodology (Section 3.2.2.1 of DOE-HDBK-3010, which states that a respirable release of inert mass equal to the TNT equivalent for the detonation is considered bounding)	Minor conservatism when compared to the source term calculations results from prior deflagration modeling. The reason is that the specific vessels previously subjected to deflagration assumption have a small contribution to overall dose (whether modeled as deflagration or DDT method) due to MAR involved.	Minor impact on the analysis when compared with initially proposed deflagration source term calculations (less than .1 rem in MOEI dose calculation). However, a given MAR that is subjected to deflagration stresses would generally be expected to produce a much smaller source term than if subjected to DDT stresses.
Twenty-eight vessels are subject to a simultaneous detonation following a DBE.	The source term calculation included any vessel that accumulated hydrogen to levels greater than LFL over the 1,000-hour period assumed following a DBE. Any vessel that fits this criterion was included in the source term calculation.	Major conservatism. The calculation does not account for factors such as the initiator for such an event. Simultaneous DDT is not plausible.	Modeling of the worst-case single vessel (HLP-VSL-00028) would result in a dose of 0.73 rem (factor of roughly 6 less than total dose of 4.37 rem calculated from multiple vessels).

WTP Severity Level Calculations/Assumptions	Basis	Level of Conservatism	Sensitivity on Safety Analysis
Use of TNT-equivalent model is used for detonation source term modeling	The TNT equivalent model is described in Section 3.2.2.1 of DOE-HDBK-3010 and is considered a conservative approach to determining a respirable source term involving detonation impacts on liquids.	Major conservatism. The assumption that a respirable release of inert mass is equal to the TNT equivalent for a detonation conservatively bounds Steindler and Seefeldt correlations described in DOE-HDBK-3010, which are based on experiments conducted with explosives embedded or contiguous to the material affected. In the case of WTP, the detonation occurs above the liquid and therefore isn't subject to similar forces described in DOE-HDBK-3010. Furthermore, the Mass Ratio for this event far exceeds the usable range for the Steindler and Seefeldt correlation.	Potentially significant, though difficult to quantify the impacts since an alternate approach hasn't been presented or modeled.
The duration for recovery from loss of hydrogen purge on the PTF vessels after the DBE is assumed to be 1,000 hours (i.e., time used for calculating vessel potential to exceed the LFL)	The 1,000 hours is a WTP chosen criteria to be consistent with the time allowed for using specific administrative controls in lieu of engineered features for vessels that can exceed the LFL in less than 1,000 hours.	Major conservatism. The assumed time period is much greater than is assumed at other DOE sites. For example, SRS assumes 4 to 7 days for similarly modeled events. This is based on the amount of fuel available for diesel generators to operate without intervention. This correlates to as much as a factor of 10 less.	Most of the PTF vessels (28) are assumed to exceed the LFL in the 1,000-hour period. This number of vessels and the corresponding TNT equivalence would be reduced significantly if assuming a time frame consistent with assumptions used at SRS.

WTP Severity Level Calculations/Assumptions	Basis	Level of Conservatism	Sensitivity on Safety Analysis
Liquid level in each vessel is varied between HGR operating level and 10 percent vessel capacity when calculating number of hydrogen moles generated for determining hydrogen concentrations	The content of each tank is optimized to generate the maximum hydrogen concentration	Major conservatism. No consideration is given to realistic operating volumes anticipated.	Varying the liquid level of the vessel to optimize hydrogen generation maximizes the source term. This affects the TNT equivalence assumed to be involved in explosion events.

References:

1. *DOE MACCS2 Computer Code Application Guidance for Documented Safety Analysis,* DOE-EH-4.2.1.4-MACCS2-Code Guidance, U.S. Department of Energy, 2004.

2. Till, John E. and Meyer, H. Robert. *Radiological Assessment, A Textbook on Environmental Dose Analysis.* U.S. Nuclear Regulatory Commission. NUREG/CR-3332 / ORNL 5968. September 1983.

3. *Refined Radiological and Toxicological Consequences of Bounding Spray Leak Accidents in the Tank Farm Waste Transfer Pits*, HNF-SD-WM-CN-096, 1996.

4. Sehmel, 1978, G.A. Sehmel and W.H. Hodgson, *A Model for Predicting Dry Deposition of Particles and Gases to Environmental Surfaces*, Battelle Pacific Northwest Laboratories, Richland, WA, PNL-SA-6721.

5. Sehmel, G.A., and Hodgson, W.H., 1976: *Predicted Dry Deposition Velocities*, Proceedings of the symposium on Atmospheric-Surface Exchange of Particulates and Gaseous Pollutants, September 4-6, 1974, Richland, Washington. CONF-740921, NTIS, Springfield, VA, pp. 399-422.

6. S. R. Hanna and R. E. Britter, *Wind Flow and Vapor Cloud Dispersion at Industrial and Urban Sites*, Center for Chemical Process Safety, AIChE, New York, NY, 2002.

7. U.S. Department of Energy Standard, DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, Change Notice. 3, Washington, DC, March 2006.

8. *PRA Procedures Guide,* NUREG/CR-2300, U.S. Nuclear Regulatory Commission, January 1983.

9. Hosker, R. P., Jr., 1974. "Estimates of Dry Deposition and Plume Depletion over Forests and Grassland," in *Physical Behavior of Radioactive Contaminants in the Atmosphere,* IAEA STI/PUB/354, International Atomic Energy Agency, Vienna, Austria, p. 291.

10. Sehmel, G. A., 1980. "Particle and Gas Dry Deposition—A Review," *Atmospheric Environment*, Vol. 14, pp. 983-1011.

11. Slinn, W. G. N., 1978. "Parameterizations for Resuspension and for Wet and Dry Deposition of Particles and Gases for Use in Radiation Dose Calculations," *Nuclear Safety*, Vol. 19, pp. 205-219.

12. P. W. Nickola and R. N. Lee, *Direct Measurements of Particulate Deposition on a Snow Surface*, BNWL-1950, PT3, February 1975.

13. J. C. Doran and T. W. Horst, "An Evaluation of Gaussian Plume-Depletion Models with Dual-Tracer Field Measurements," *Atmospheric Environment*, Vol. 19, No. 6, pp. 939-951, 1985.

14. U.S. Nuclear Regulatory Commission, *A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licensees*, Final Report, January 1988.

15. Mollenkamp, C.R., N.E. Bixler, C.W. Morrow, J.V. Ramsdell, Jr., and J.A. Mitchell, *Comparison of Average Transport and Dispersion Among a Gaussian, a Two-Dimensional, and a Three-Dimensional Model*, Lawrence Livermore National Laboratory, Atmospheric Science Division, Livermore, CA. NUREG/CR-6853, October 2004.