DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

August 26, 2010

The Honorable Kristina M. Johnson
Under Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Mr. Glenn S. Podonsky
Chief Health, Safety and Security Officer
Office of Health, Safety and Security
U.S. Department of Energy
HS-1, Germantown Building
1000 Independence Avenue, SW
Washington, DC 20585-1290

Dear Under Secretary Johnson and Mr. Podonsky:

The Defense Nuclear Facilities Safety Board (Board) has been evaluating the Department of Energy's (DOE) revised safety strategy for the Waste Treatment and Immobilization Plant (WTP) at the Hanford Site. In the revised safety strategy, DOE has changed the assumptions regarding the transport of a radioactive plume following a potential accident at the plant. The revised WTP transport analysis uses the default transport value for dry deposition velocity (1 cm/sec) that was adopted for use in DOE's atmospheric dispersion model in 2004. The Board believes this is not a *reasonably conservative input parameter* for dry deposition velocity as specified in DOE Standard 3009, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses.* Based on review of the pertinent literature and what the Board judges to be conservative values for particle-size, wind speed, and surface roughness at the Hanford Site, the Board has concluded reasonably conservative values for dry deposition velocity for that site are 0.2 cm/sec and 0.01 cm/sec for coarse and fine particles, respectively.

In a letter to you dated May 21, 2010, the Board questioned the technical justification for using a dry deposition velocity of 1 cm/sec. The Board noted that its staff had reviewed published data and believed that a value between 0 cm/sec and 0.3 cm/sec could be technically justified as a dry deposition velocity for aerosols at the Hanford Site. Before DOE revised the safety strategy, the transport analysis for WTP was based on conservative applications of dispersion models and used a dry deposition velocity of 0 cm/sec in the dose consequence analysis. The Board has continued its study of dry deposition velocity and believes the values reported above are technically defensible. The Board also believes that a conservative dose consequence analysis can be obtained by using a single value for dry deposition velocity by selecting the bounding value within the range between zero and the predicted deposition velocity for the median particle-size. The resulting single value for WTP would equate to a deposition velocity of 0.1 cm/sec for Hanford high-level waste. Details of the analyses performed by the Board's staff are contained in the enclosed report.

Sincerely,

Peter S. Winokur, Ph.D.
Chairman

Enclosure

c: The Honorable Inés R. Triay
Mr. Dale Knutson
Mr. Richard H. Lagdon, Jr.
Dr. Don F. Nichols
Mrs. Mari-Jo Campagnone

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

August 18, 2010

MEMORANDUM FOR: T. J. Dwyer, Technical Director

COPIES: Board Members

FROM: A. P. Poloski, R. E. Kasdorf, S. A. Stokes

SUBJECT: Technical Basis for Estimating Deposition Velocities, Hanford Site

Abstract

In 2006,[1] the Department of Energy (DOE) established a policy of using a dry deposition velocity of 1 cm/sec for determining atmospheric dispersion conditions during accident scenarios for safety analyses described in DOE Standard 3009.[2] DOE applies this default deposition velocity across the DOE complex regardless of the characteristics of the site location and process. Deposition velocity varies as a function of several site-specific conditions, such as wind speed, terrain, and size of the particles or type of gas released. The selection of deposition velocity can have a significant impact on calculated dose consequences to the public, which DOE uses to determine the need for and safety classification of structures, systems, and components. Such determinations can have a significant impact on facility design. In this paper, we present an analysis of dry deposition velocity predictions for aerosols at the Hanford Site. We show that when determining the downwind dilution factor from atmospheric dispersion (χ/Q), a technically defensible deposition velocity for the Hanford Site can be developed by considering two particle-size bins for coarse and fine particles, with deposition velocities of 0.2 cm/sec, and 0.01 cm/sec, respectively. One can obtain a conservative χ/Q by using a single value for dry deposition velocity if it ranges between zero and the predicted deposition velocity for the median particle-size, corresponding to 0.1 cm/sec for Hanford high-level waste.

Introduction

DOE established its default dry deposition velocity, 1 cm/sec, based on the work of Sehmel and Hodgson (1976).[3] The relevant data from this paper are represented by the blue diamond symbols in Figure 1. This curve corresponds to a surface roughness of 3 cm and a friction velocity, U^*, of 100 cm/sec. As seen in Figure 1, if the 1976 curve is used, selection of a dry deposition velocity of 1 cm/sec would be a bounding value. Sehmel and Hodgson revised

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[1] U.S. Department of Energy, Memorandum for Distribution from Dr. Inés Triay, "Interim Guidance on Safety Integration into Early Phases of Nuclear Facility Design," July 18, 2006.

[2] 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

[3] Sehmel, G. A., and Hodgson, W. H., "Predicted Dry Deposition Velocities," pp. 399-419, *Atmosphere-Surface Exchange of Gaseous Pollutants*, Proceedings of a symposium held at Richland, WA, September 4-6, 1974, U.S. Energy Research and Development Administration, 1976.

their 1976 model with additional empirical data in 1978.[4] Figure 1 also shows curves from Figures 6 and 10 of Sehmel and Hodgson (1978) corresponding to friction velocities, U^*, of 100 cm/sec (red squares) and 30 cm/sec (green triangles), respectively. The actual figures from Sehmel and Hodgson (1976 and 1978) are reproduced in Appendix A.

Friction velocity is a correlation of wind speed and surface roughness, which is provided by equation 2.15 of Till and Meyer's NUREG/CR-3332.[5] Friction velocity is the square root of the ratio of shear stress from the wind on the ground to the density of air. Friction velocity is a significant factor for determining dry deposition velocity, which makes wind speed and aerodynamic surface roughness important meteorological factors that influence dry deposition velocity. Using a surface roughness of 3 cm, which is appropriate for the Hanford landscape,[6] the wind speed for these curves corresponds to about 32 and 10 mi/hr, respectively. In Figure 1, comparing the curve with blue diamonds and the curve with red squares, which are under identical conditions, we see that the revised 1978 model predicts significantly lower deposition velocities than the 1976 model. Considering a wind speed of 10 mi/hr and a corresponding friction velocity of 30 cm/sec, the deposition velocity decreases further to the values indicated by the curve with green triangles.

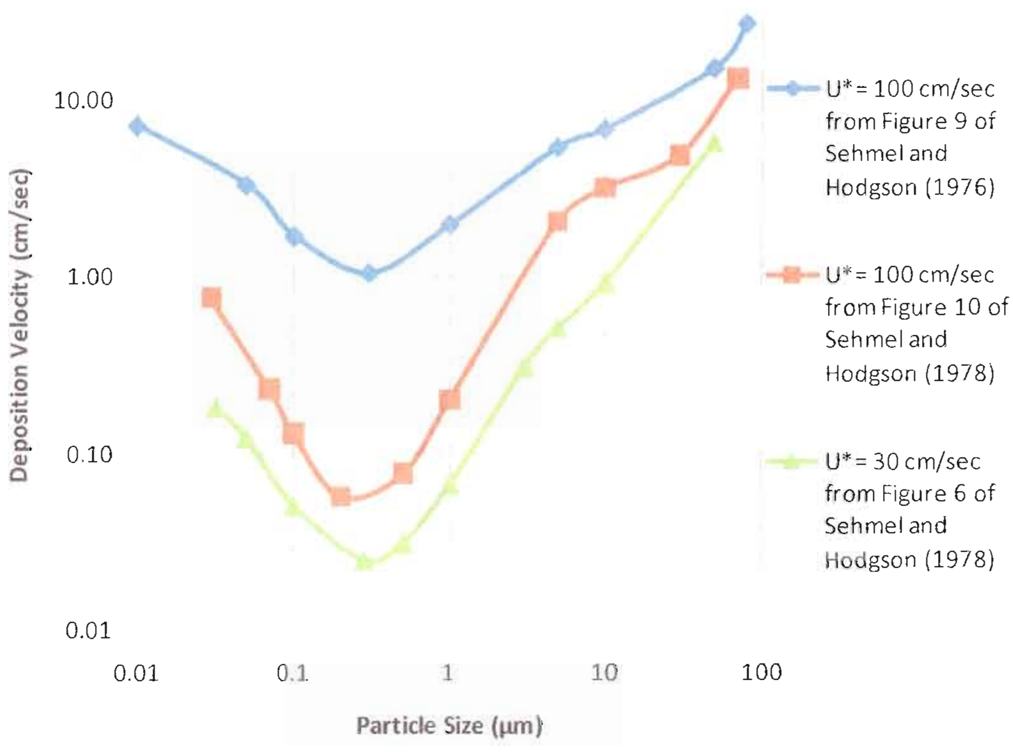

Figure 1. Selected deposition velocity curves from Sehmel and Hodgson (1976, 1978).

[4] Sehmel, G. A., and Hodgson, W. H., *A Model for Predicting Dry Deposition of Particles and Gases to Environmental Surfaces*, Battelle Pacific Northwest Laboratories, Richland, WA, PNL-SA-6721, 1978.
[5] 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.
[6] Sehmel, G. A., and Hodgson, W. H., *A Model for Predicting Dry Deposition of Particles and Gases to Environmental Surfaces*, Battelle Pacific Northwest Laboratories, Richland, WA, PNL-SA-6721, 1978.

As seen in Figure 1, dry deposition velocity varies as a function of several site-specific conditions such as wind speed, terrain, and size of the particles. The remainder of this report focuses on developing a methodology for determining a reasonably conservative input value for deposition velocity at the Hanford Site based on these considerations.

Establishment of Input Parameters for Analyses

Wind Speed. From our analysis of the Sehmel and Hodgson (1976, 1978) data, we see that wind speed is a significant variable in determining dry deposition velocity. As wind speed increases, more turbulence occurs, which tends to increase the dry deposition velocity. DOE Standard 3009 states that χ/Q values for safety classification should be determined in accordance with the method described in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.145, *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants*. This method produces a single χ/Q value for 95th percentile meteorological conditions; this value could correspond to multiple combinations of atmospheric stability classes and wind speed. We can estimate an upper bound for wind speed at the 95th percentile meteorological conditions through equation (1), for Gaussian plume centerline concentration for a continuous, ground level release, without plume meander:[7]

$$U = \frac{1}{\pi\left(\frac{\chi}{Q}\right)\sigma_y\sigma_z} \tag{1}$$

where

U	is the wind speed corresponding to 95th percentile meteorological conditions (m/sec);
$\frac{\chi}{Q}$	is the atmospheric dispersion factor at 95th percentile meteorological conditions without dry deposition (s/m^3);
σ_y	is the horizontal dispersion coefficient for Pasquill stability class F at the site boundary (m); and
σ_z	is the vertical dispersion coefficient for Pasquill stability class F at the site boundary (m).

(Note that wind speed, U, is not friction velocity, U*)

Typically, wind speeds at 95th percentile meteorological conditions are low. As reported by Hanford meteorological stations,[8] wind speeds at the 200 Area at the Hanford Site are below 3 mi/hr 24–38 percent of the time. For the Waste Treatment and Immobilization Plant (WTP) at the Hanford Site, several atmospheric dispersion parameters have been documented by Schulz and Lanning (2009).[9] The atmospheric dispersion factor at 95th percentile meteorological conditions without dry deposition has been determined to be 1.52×10^{-5} s/m^3. The horizontal and vertical dispersion coefficients for Pasquill stability class F at the site boundary (about 9.3 km) are 277 m and 45 m, respectively. According to equation (1), wind speed corresponding to 95th percentile meteorological conditions at the Hanford Site is 1.7 m/s or about 4 mi/hr.

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[7] Turner, D. B., *Workbook of Atmospheric Dispersion Estimates: An Introduction to Dispersion Modeling*, 2nd Edition, CRC Press, ISBN 1-56670-023-X, 1994.

[8] Duncan, J. P., et al., *Hanford Site National Environmental Policy Act (NEPA) Characterization*, Pacific Northwest National Laboratory, PNNL-6415 Rev. 18, September 2007.

[9] Schulz, J., and Lanning, R., *Atmospheric Dispersion Factors at the Public Boundary*, Bechtel National, Inc, 24590-WTP-Z0C-W14T-00022, June 11, 2009.

Particle Size. To account for the variability of deposition velocity with particle-size, we selected three particle-size cases for further analysis. The three cases represent particle-size distributions of the respirable fraction of Hanford high-level waste particles by a single-bin, two-bins, or five-bins, respectively. We present the characteristic diameters for each particle-size case in Table 1; details on how we determined these values are presented in the paragraphs below.

Table 1. Characteristic Diameters for Three Particle-Size Cases

Description	Single-bin	Two-bin		Five-bin				
Physical Size (μm)	2.0	0.3	3.0	0.1	0.5	1.1	2.6	5.0
Aerodynamic Equivalent Diameter (μm)	3.4	0.5	5.0	0.3	0.9	1.8	4.6	8.6

Note: the aerodynamic equivalent diameter is the diameter of a sphere, with density of 1 gm/cm^3, that has the same settling velocity due to gravity as the particle under consideration.

$$d_{AED} \approx d_p\sqrt{\rho}$$

where

d_{AED} is the aerodynamic equivalent diameter of a particle, μm;
d_p is Stokes' diameter of a spherical particle with the same density and settling velocity as the particle, μm; and
ρ is the density of the particle, gm/cm^3, or specific gravity (SG) x 1 gm/cm^3.

For the two-bin case, we selected particle-size bins that correspond to size classifications of the U.S. Environmental Protection Agency's (EPA) designation of particulate matter (PM). EPA states that particles less than 10 μm in diameter (PM_{10}) pose a health concern because they can be inhaled into and accumulate in the respiratory system. Particles less than 2.5 μm in diameter ($PM_{2.5}$) are referred to as fine particles and are believed to pose the greatest health risk. Because of their small size, fine particles can lodge deeply in the lungs. The coarse particle-size range corresponds to particles between 2.5 and 10 μm aerodynamic equivalent diameter (AED), the lower and upper bounds of the thoracic fraction (i.e., $PM_{2.5}$ to PM_{10}). The thoracic fraction is the percentage of respirable particles penetrating beyond the larynx; typically this will represent particles with a mean aerodynamic diameter of less than 10 μm. The fine particle-size range corresponds to particles between 0.1 and 2.5 μm AED, the upper and lower bounds of the ultrafine and thoracic fraction (i.e., UF and $PM_{2.5}$, respectively). From these particle-size boundaries and the definition of AED, we can determine the geometric mean of each of these particle-size fractions through equations (2) and (3). In the derivation of these equations, we assume that all other variables in this conversion to AED are unity (e.g., aerodynamic shape factor and ratio of Cunningham slip factors).

$$d_{coarse} = \sqrt{\frac{10\ \mu m}{\sqrt{SG}} \cdot \frac{2.5\ \mu m}{\sqrt{SG}}} = \frac{5\ \mu m}{\sqrt{SG}} \tag{2}$$

$$d_{fine} = \sqrt{\frac{2.5\ \mu m}{\sqrt{SG}} \cdot \frac{0.1\ \mu m}{\sqrt{SG}}} = \frac{0.5\ \mu m}{\sqrt{SG}} \tag{3}$$

where

d_{coarse}	is the characteristic particle-size corresponding to the coarse fraction of particulate matter between $PM_{2.5}$ to PM_{10} (µm);
d_{fine}	is the characteristic particle-size corresponding to the fine fraction of particulate matter between UF to $PM_{2.5}$ (µm); and
SG	is the specific gravity of the particulate material.

For WTP, an estimate for the average density of the Hanford waste solids is approximately 3 g/cm^3. This value is documented by Wells et al. (2007).[10] Using equations (2) and (3), we calculated the characteristic particle-sizes for the coarse and fine fractions to be about 3 µm and 0.3 µm, respectively.

Figure 2 shows an example of particle-size binning of coarse and fine particles with a specific gravity of unity. In this example, the characteristic particle-size of the coarse fraction of particles is 5 µm, and the corresponding dry deposition velocity is about 0.4 cm/sec. For the fine fraction of particles, the characteristic particle-size is 0.5 µm, and the corresponding dry deposition velocity is about 0.03 cm/sec. We note that the minimum value of dry deposition velocity predictions typically occurs for particle sizes between 0.1 to 1 µm and, depending on the particle density, the characteristic diameter of the fine fraction falls between 0.1 to 0.5 µm. Since the characteristic particle diameter of fine particles falls near the minimum value on the dry deposition velocity curve (see Figure 1), the corresponding dry deposition velocity for the fine particles is a conservative value.

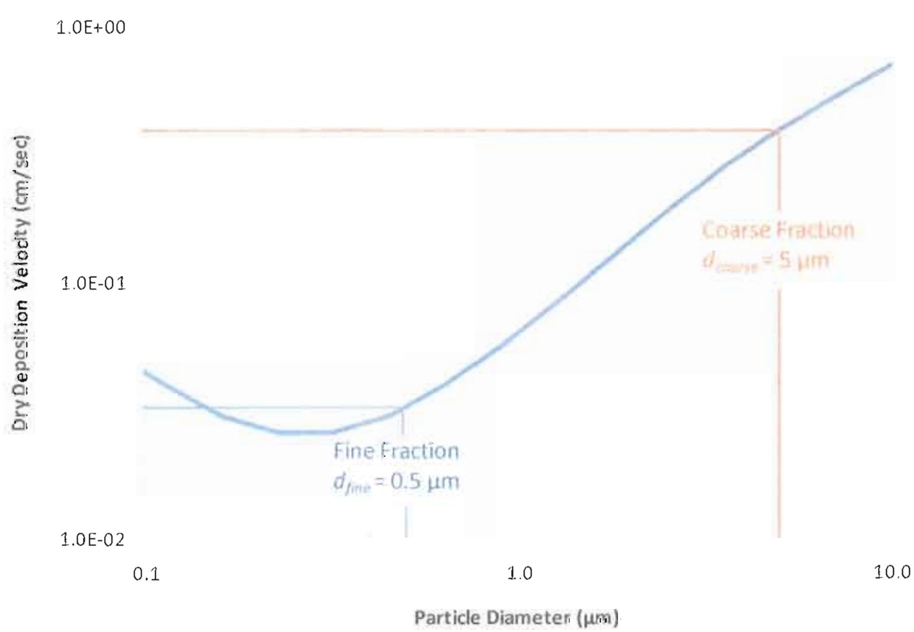

Figure 2. Example showing two particle-size bins for coarse and fine particles with a specific gravity of unity.

[10] Wells, B. E., et al., *Estimate of Hanford Waste Insoluble Solid Particle-size and Density Distribution*, Battelle–Pacific Northwest Division, PNWD 3824, Richland, WA, 2007.

The single-bin case, however, simply utilizes the characteristic diameter corresponding to the median particle-size of the respirable fraction of Hanford high-level waste. In Appendix B, we determined the median size of the respirable fraction to be 3.4 μm AED. This corresponds to a physical diameter of approximately 2 μm.

The five-bin case uses the particle-size distribution of the respirable fraction of Hanford high-level waste shown in Appendix B to represent five particle-size bins between 0.1 μm and 10 μm AED. The characteristic diameters for each bin are geometrically centered between the points on the original distribution.

Terrain—Surface Roughness. DOE guidance for surface roughness height mandates the use of 3 cm. We believe this value is suitable, as Sehmel and Hodgson (1978) found this value to be appropriate for the open topography of the Hanford Site.[11] Additionally, this value is close to the 5 cm surface roughness value provided for "underdeveloped, wasteland" land use type in Table 2-2 of EPA-454/R-94-015.[12]

Staff Analysis

In developing the analysis approach, we initially considered the DOE methodology, which used the data from Sehmel and Hodgson (1976). We evaluated the more recent Sehmel and Hodgson (1978) data but also looked beyond this data to determine if more recent studies had been performed anywhere in industry. We found that EPA had completed a comprehensive evaluation in 1994,[13] which presented several algorithms for estimating dry deposition velocity. From the EPA evaluation, we selected one recommended model to calculate dry deposition velocity for site-specific conditions at the Hanford Site. We also analyzed even more recent NRC data on dry deposition velocity from expert elicitation. We compared the NRC data against the model we selected for calculating dry deposition velocity to further assess the appropriateness of using this model for the Hanford Site. Lastly, we compared our calculations of dry deposition velocity against the deposition velocity determined using in situ data collected following an accidental release at the Hanford Site in 1985.

Sehmel and Hodgson Research Papers. As wind speed increases, more turbulence occurs, which tends to increase dry deposition velocity. As previously determined, the appropriate wind speed for the 95th percentile meteorological conditions at the Hanford Site would be about 4 mi/hr. The lowest wind speed presented by Sehmel and Hodgson (1976, and 1978) corresponds to the lowest friction velocity of 30 cm/sec. The wind speed at this friction velocity for Hanford Site conditions is about 10 mi/hr. We note that the Sehmel and Hodgson (1978) wind speed of 10 mi/hr (30 cm/sec friction velocity) will bias the deposition velocities higher than would be calculated using the 95th percentile meteorology.

Nonetheless, referring to Figure 1, the green triangle curve (wind speed of 10 mi/hr) shows that 0.03 cm/sec would be a lower-bound deposition velocity. Using the characteristic particle-sizes for the coarse and fine fractions of the two-bin particle-size case (about 3 μm and

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[11] Sehmel, G. A., and Hodgson, W. H., *A Model for Predicting Dry Deposition of Particles and Gases to Environmental Surfaces*, Battelle Pacific Northwest Laboratories, Richland, WA, PNL-SA-6721, 1978.
[12] U.S. Environmental Protection Agency, *Development and Testing of a Dry Deposition Algorithm* (Revised), Office of Air Quality Planning and Standards, EPA-454/R-94-015, Research Triangle Park NC, 1994.
[13] Ibid.

0.3 μm, respectively), one could reasonably select a deposition velocity of 0.03 cm/sec for fine particle fractions and 0.3 cm/sec for coarse particle fractions.

Environmental Protection Agency Algorithms. EPA performed a statistical assessment of several algorithms for estimating dry deposition velocity.[14] Of the ten algorithm variants analyzed, EPA concluded that three models—the Urban Airshed Model (UAM 2), the Acid Deposition and Accident Model (ADOM 1), and the California Air Resources Board Model (CARB 3)—appear to have one or more performance characteristics that make them superior to the rest of the models. After examining these three models, we focused our analysis on the CARB 3 model, because it is based on a model originally developed by Sehmel and Hodgson (1978) and Sehmel (1980).[15]

Using the method described in section 2.1.2 of EPA-454/R-94-015, we determined the dry deposition velocities using CARB 3. This allowed us to determine dry deposition velocity for conditions specific to the Hanford Site and beyond the conditions in the Sehmel and Hodgson (1976, and 1978) data. For example, we determined the dry deposition velocity at a wind speed of 4 mi/hr, surface roughness of 3 cm, particle density of 3 g/cm^3, and particle-sizes of 3 μm and 0.3 μm. To ensure we performed the calculations appropriately, we benchmarked our calculation against published EPA results under identical conditions as shown in Appendix C, Figure C-2. The results we obtained agreed with the EPA data, and we concluded that the CARB 3 equations were properly transcribed and implemented.

Table 2 shows the results of our CARB 3 calculations for the particle-size cases considered in our analysis. In Appendix C, we provide details on the input parameters used in these calculations. Under these conditions, the selection of atmospheric stability has only a minor effect on the values obtained. The results show a wide variation in deposition velocity with particle-size. For example, the two-bin model has deposition velocities of 0.2 cm/sec and 0.01 cm/sec for the coarse and fine fraction, respectively. For the single-bin model, we obtained a deposition velocity of 0.1 cm/sec. For example, the two-bin model has deposition velocities of 0.2 cm/sec and 0.01 cm/sec for the coarse and fine fractions, respectively. Appendix B explains how the weight fraction associated with each particle-size bin was determined from the particle-size distribution of the respirable fraction of Hanford high-level waste. In Figure B-1, for example, about 40 weight percent of the particles are below 2.5 μm AED. Therefore, in the two-bin model we use 60 weight percent and 40 weight percent for coarse and fine particles, respectively.

[14] U.S. Environmental Protection Agency, *Development and Testing of a Dry Deposition Algorithm* (Revised), Office of Air Quality Planning and Standards, EPA-454/R-94-015, Research Triangle Park, NC, 1994.
[15] Sehmel, G. A., "Particle and Gas Dry Deposition: A Review," *Atmospheric Environment*, Volume 14, pp. 983–1011, 1980.

Table 2. CARB 3 Predicted Range of Deposition Velocity (cm/sec) for Wind Speed of 4 mi/hr										
Description	DOE Default Value	No Deposition Velocity	Single-bin	Two-bin (coarse and fine)		Five-bin				
Physical size (µm)	n/a	n/a	2.0	0.3	3.0	0.1	0.5	1.1	2.6	5.0
Aerodynamic equivalent diameter (µm)	n/a	n/a	3.4	0.5	5.0	0.3	0.9	1.8	4.6	8.6
Weight fraction of respirable particles	n/a	1.0	1.0	0.4	0.6	0.02	0.07	0.35	0.45	0.11
CARB 3 deposition velocity (cm/sec)	1.0	0	0.1	0.01	0.2	0.02	0.02	0.04	0.1	0.4

Note: n/a = not applicable

Nuclear Regulatory Commission Expert Elicitation. In its report NUREG/CR-6244,[16] the NRC documents an expert elicitation of dry deposition velocity data for the purpose of obtaining probability distributions for use in the MELCOR Accident Consequence Code System (MACCS) atmospheric dispersion code. The NRC experts were asked to provide three percentile values—5^{th}, 50^{th}, and 95^{th}—from the cumulative distribution function for the dry deposition velocity. The probability distributions produced by the NRC consist of expert data on dry deposition for a number of wind speeds, particle-sizes, and ecological conditions. Figures 3 and 4 provide the results of this effort for eight expert responses at the median and lower 5^{th} percent quantiles, respectively, over a 0.1 to 10 µm particle-size range at a wind speed of 4.5 mi/hr and a surface roughness of 5 cm. For comparison purposes, the figures also show the CARB 3 predictions for deposition velocity under the same conditions. The 50^{th} percent quantile would represent the median value of expert opinions, indicating confidence that the value specified would be not be exceeded 50 percent of the time. The lower 5^{th} percent quantile would represent the reasonably conservative value expected according to DOE Standard 3009, which would not be exceeded 95 percent of the time.

The results show that the CARB 3 model produces results that are within the range of median values from the NRC expert elicitation and above (less conservative than) the lower 5^{th} percent quantile data. This indicates that the CARB 3 model is more representative of median than of the lower 5^{th} percent quantile values for deposition velocity. If we were to use solely the expert elicitation data as presented, the deposition velocity selected for the Hanford Site would be lower than ultimately believed to be a reasonably bounding value. The NRC constrained this expert elicitation to spherical particles with a specific gravity of unity (density = $1 g/cm^3$). For this reason, direct use of the NRC expert elicitation data is limited to low-density particulate releases. Because of this limitation, we do not believe it is appropriate to use the lower 5^{th} percent quantile data from NRC as a reasonably conservative input value. The data do support that the dry deposition velocity predicted by CARB 3 should not be exceeded when one is determining a reasonably conservative value. Accordingly, we will rely on the calculations from the CARB 3 model even though it appears to be more representative of median values of dry deposition velocity based on the expert elicitation data. If NRC releases an updated correlation

[16] Harper, F. T., Hora, S. C., Young, M. L., Miller, L. A., Lui, C. H., McKay, M. D., Helton, J. C., Goossens, L. H. J., Cooke., R. M., Pasler-Sauer, J., Kraan, B. C. P., and Jones, J. A., *Probabilistic Accident Consequence Uncertainty Assessment: Dispersion and Deposition Uncertainty Assessment*, NUREG/CR-6244, EUR 15855EN, SAND94-1453, Vols. 1-3, 1994.

for dry deposition data at different probability quantiles that considers particle density, we would reconsider this choice.

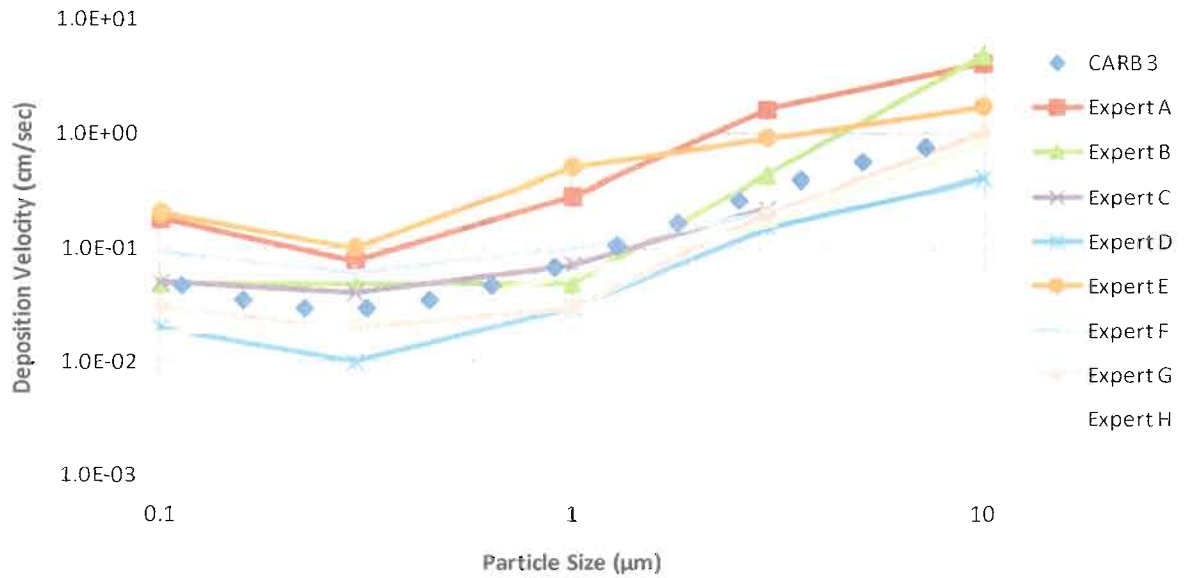

Figure 3. Comparison of CARB 3 deposition velocity calculations and NRC expert elicitation data corresponding to median quantiles at a wind speed of 4.5 mi/hr and surface roughness of 5 cm.

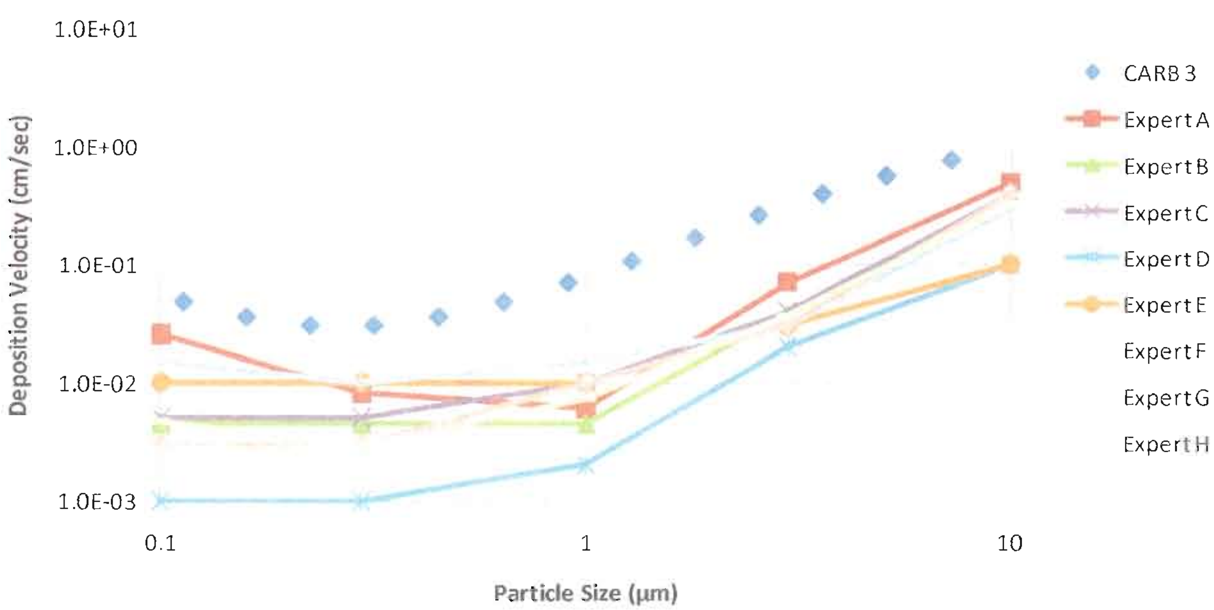

Figure 4. Comparison of CARB 3 deposition velocity calculations and NRC expert elicitation data corresponding to lower 5 percent quantiles at a wind speed of 4.5 mi/hr and surface roughness of 5 cm.

Comparison of Results from Accidental Release. In this section we compare measured deposition velocities from a 1985 accident with the CARB 3 model predictions. We present a description of the data in Appendix D and the CARB 3 inputs for this scenario in Appendix C. Using the CARB 3 model, we predict a deposition velocity of 0.1 cm/sec for the median value of respirable particles for the Hanford tank waste, approximately 3.4 μm AED. The predicted value corresponds well with the measured value of 0.15 cm/sec from the 1985 release. However, investigators used analysis of samples taken from snow several days after the release to calculate the measured deposition velocities, and the size/density of the released particles is unknown. Redistribution of contaminated snow due to drifting and comingling with background contamination could lead to uncertainty in the results. For these reasons, we consider the 1985 deposition velocity data to be interesting but only circumstantial.

Discussion. Using the MACCS 2 atmospheric dispersion code and 2004 Hanford Site meteorological data, we compare the resulting 95 percent quantile χ/Q for each particle-size case and for the DOE default deposition velocity and zero deposition velocity. Table 3 presents these data for a downwind distance of 9.0–9.5 km, which is near the Hanford Site boundary.[17] Using a single value for deposition velocity of 1 cm/sec with plume meander, we find that the 95 percent quantile χ/Q near the site boundary is approximately 2.47×10^{-6} s/m^3. With no deposition (i.e., zero deposition velocity), this value is 1.23×10^{-5} s/m^3. These results are consistent with the estimates from WTP analysts Shultz and Lanning (2009).[18]

In Table 3, we also compare the χ/Q for the undepleted plume (i.e., zero deposition velocity) with the depleted plume values (i.e., with particle deposition). From these data, we see that near the Hanford Site boundary, the DOE default value reduces the χ/Q by a factor of about 5.1 relative to the zero deposition velocity case. The single-bin, two-bin, and five-bin particle-size cases reduce the χ/Q by a factor of about 1.3 relative to the zero deposition velocity case. In addition, the two-bin, and five-bin particle-size cases show a slightly greater reduction in χ/Q relative to the single-bin case. We postulate that the reason for this behavior is that MACCS2 is capturing the deposition of coarse particles closer to the source location, resulting in a slightly greater amount of plume depletion. Since the two-bin and five-bin particle-size cases show nearly identical behavior, we conclude using two particle-size bins for coarse and fine particles, respectively, is sufficient to capture plume depletion mechanisms and leads to a reasonably conservative input value for accident scenario analyses.

Lastly, if we divide the airborne and ground radionuclide concentrations calculated from MACCS 2, we can determine an overall dry deposition velocity. These data are also shown in Table 3, and indicate that the overall deposition velocities for the two-bin and five-bin particle-size cases are slightly larger than the single-bin case. For all particle-size cases, the overall dry deposition velocity is approximately 0.1 cm/sec, which is about an order of magnitude lower than the DOE default value of 1 cm/sec.

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[17] Schulz, J., and Lanning, R., *Atmospheric Dispersion Factors at the Public Boundary*, Bechtel National, Inc, 24590-WTP-Z0C-W14T-00022, June 11, 2009.
[18] Ibid.

Table 3. Comparison of 95 Percent χ/Q, Ratio of Undepleted to Depleted χ/Q, and Overall Dry Deposition Velocity Calculated from MACCS 2 Data Using 2004 Hanford Site Meteorological Data for a Downwind Distance of 9.0–9.5 km					
Description	DOE Default Value	No Deposition Velocity	Single-bin	Two-bin (Coarse & Fine)	Five-bin
χ/Q (s/m^3)	2.47×10^{-6}	1.26×10^{-5}	9.81×10^{-6}	9.56×10^{-6}	9.56×10^{-6}
(Undepleted χ/Q) / (depleted χ/Q)	5.10	1.00	1.28	1.32	1.32
Overall deposition velocity (cm/sec)	1.0	0	0.10	0.10	0.10

Conclusion. The selection of deposition velocity can have a significant impact on calculated dose consequences to the public, which DOE uses to determine the safety classification of structures, systems, and components. We found that using the CARB 3 model for predicting dry deposition velocities is technically defensible. We presented methods for determining input values for the CARB 3 model based on site-specific conditions at the Hanford Site for wind-speed, surface roughness, and particle-size. From our analyses, we found that when determining χ/Q, a technically defensible deposition velocity for Hanford high-level waste can be derived by considering two particle-size bins for coarse and fine particles, with deposition velocities of 0.2 cm/sec and 0.01 cm/sec for each bin, respectively. However, one can gain additional accuracy by performing the MACCS2 simulations with more than two particle-size bins. Alternatively, one can obtain a conservative χ/Q by using a single value for dry deposition velocity if it ranges between zero and the CARB 3 predicted deposition velocity for the median particle-size, corresponding to 0.1 cm/sec for Hanford high-level waste.

Appendix A

Deposition Velocity Curves from Sehmel and Hodgson (1976, 1978)

Figure 1 in the main body of this report replicates the curves in Figures A-1 to A-3 with a surface roughness of 3 cm, which is appropriate for the Hanford Site. We highlighted the replicated curves by the addition of green lines to the original figures.

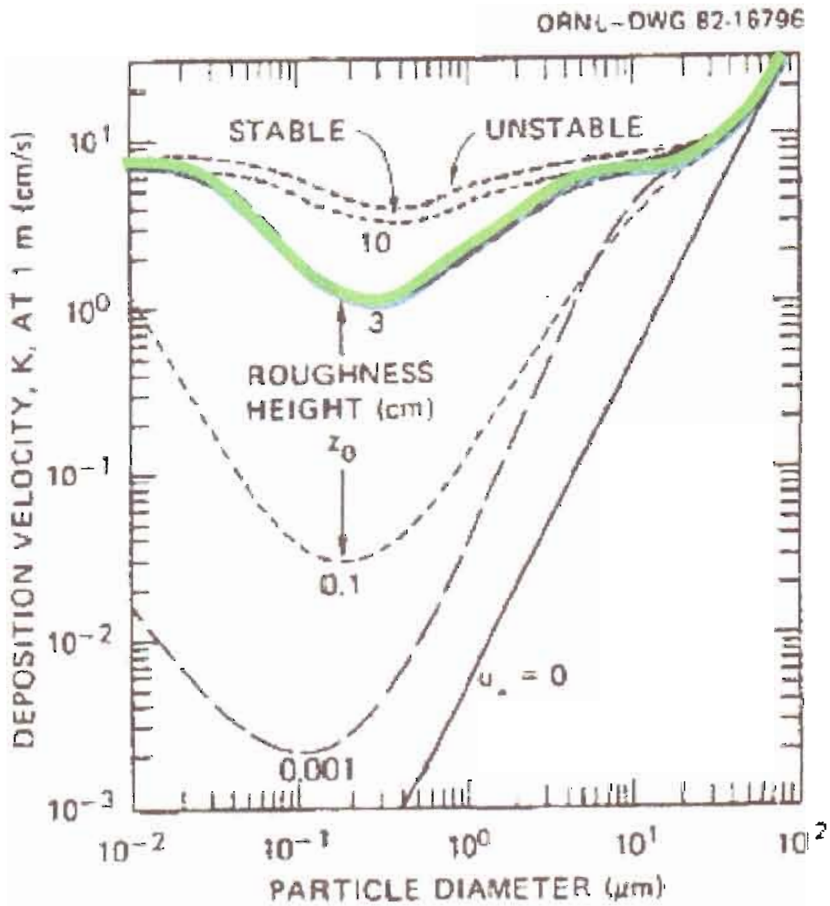
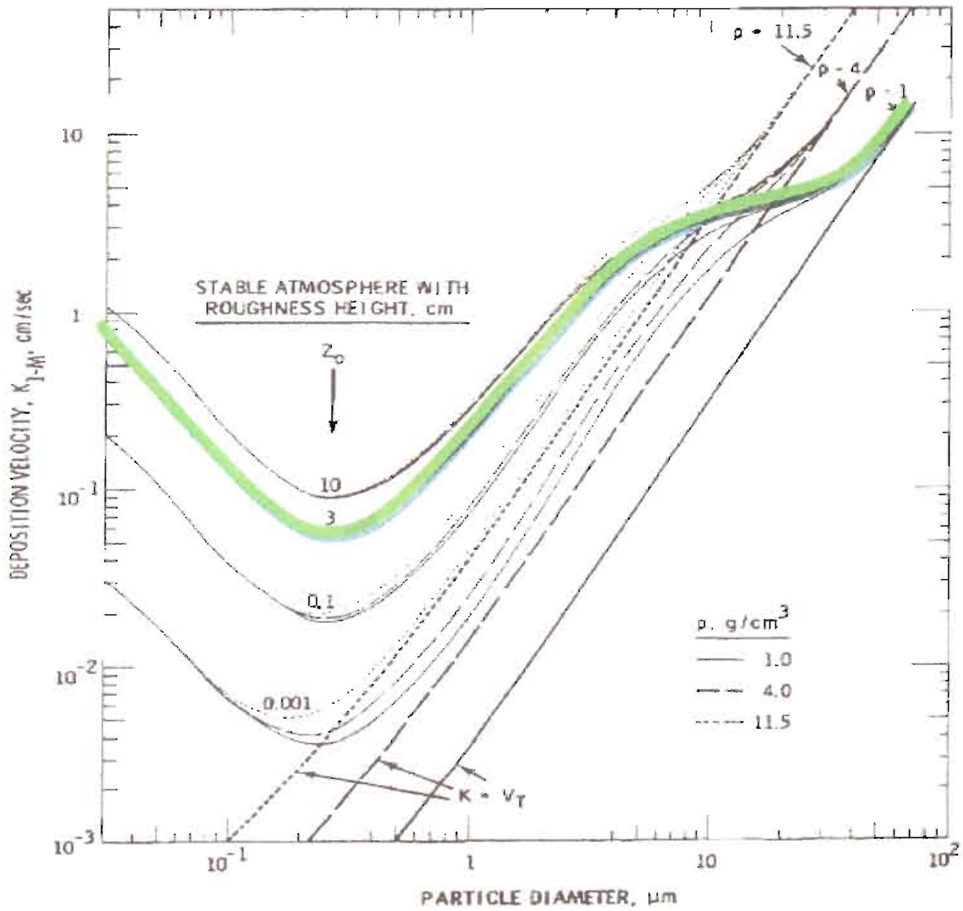


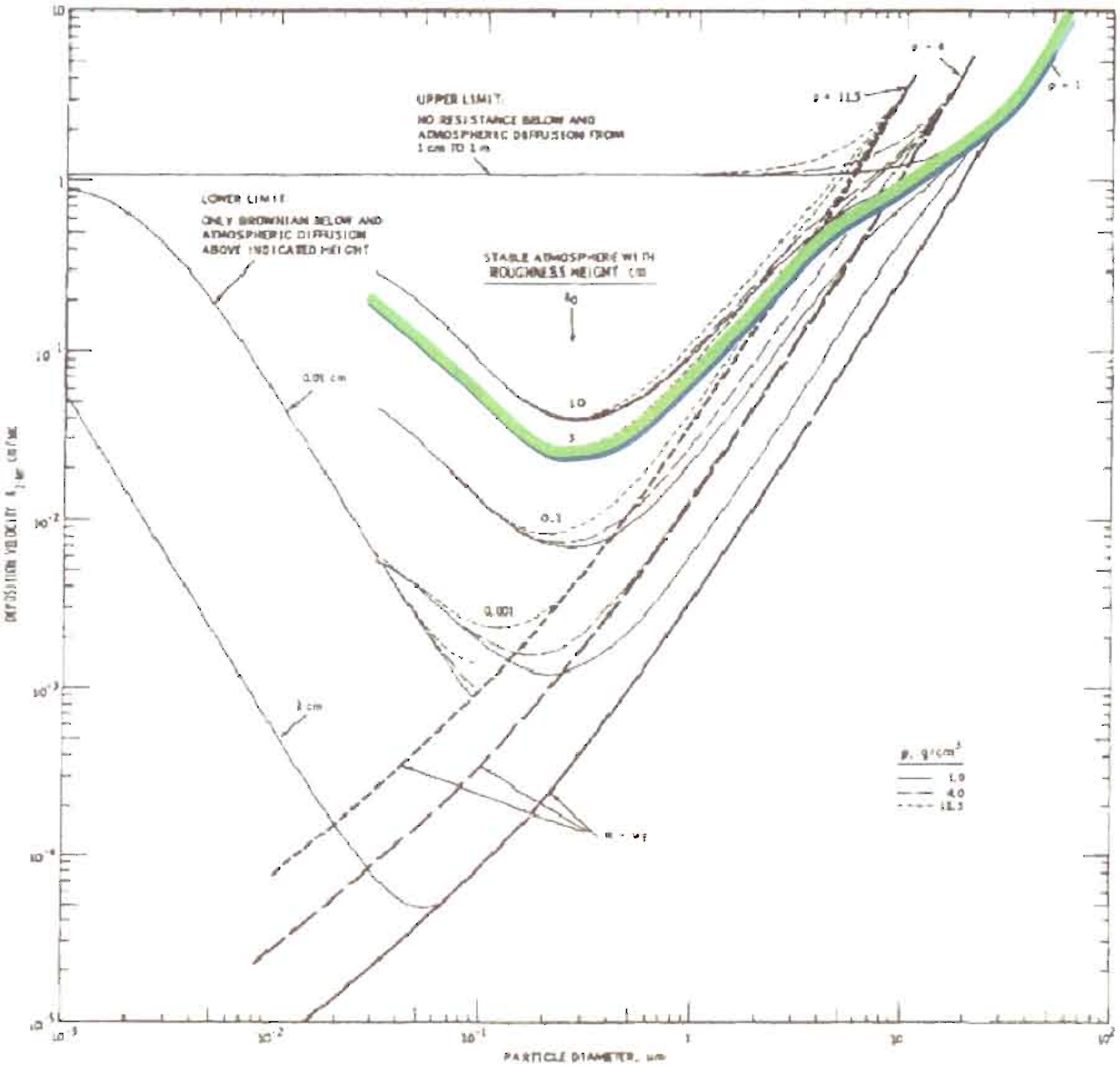
Figure A-1. Deposition velocity vs. particle diameter from Sehmel and Hodgson (1976) (friction velocity, U^*, of 100 cm/sec).



Neg 7712644-4

FIGURE 10. Model-1977W - Predicted Deposition Velocities at 1M for $U_* = 100$ cm/sec and Particle Densities of 1, 4 and 11.5 g/cm^3

Figure A-2. Deposition velocity vs. particle diameter from Sehmel and Hodgson (1978) (friction velocity, U^*, of 100 cm/sec).



Neg 7711495-2

FIGURE 6. Model-1977W - Predicted Deposition Velocities at 1M for U_* = 30 cm/sec and Particle Densities of 1, 4 and 11.5 g/cm3

Figure A-3. Deposition velocity vs. particle diameter from Sehmel and Hodgson (1978) (friction velocity, U^*, of 30 cm/sec).

Appendix B

Estimate of Particle-Size Distribution in the Respirable Fraction for Hanford Tank Waste

We determined the median value by noting that ^{241}Am dominates the dose consequences to the public from airborne releases of Hanford high-level waste. This isotope exists predominantly in the solid phase. For these solid particles that precipitated intank as a result of neutralization, actinide chemists have shown that the actinides have a tendency to either adsorb on the surface of particles or coprecipitate throughout the matrix of the waste solids.[19] Hanford tanks SY-102 and TX-118 are exceptions to this statement as they contain plutonium species from the Hanford Plutonium Finishing Plant (PFP). Since actinides do not typically exist as discrete particles, their density is not relevant to this calculation. Hanford scientists estimate 3 g/cm^3 as the average density of the Hanford waste solids. We convert the particle-size and density distribution of the Hanford waste solids from Wells et al. (2007) [20] to AED by multiplying the diameter of the solids by the square root of this density. We assume that all other variables in this conversion to AED are unity (e.g., aerodynamic shape factor and ratio of Cunningham slip factors). In addition, accident analysts account for the respirable fraction in modeling the initial release, so we can discount the fraction of particles greater than 10 μm AED. This produces a median AED estimate of about 3.4 μm. Figure B-1 shows the particle-size distribution of the respirable Hanford solids on an AED basis.

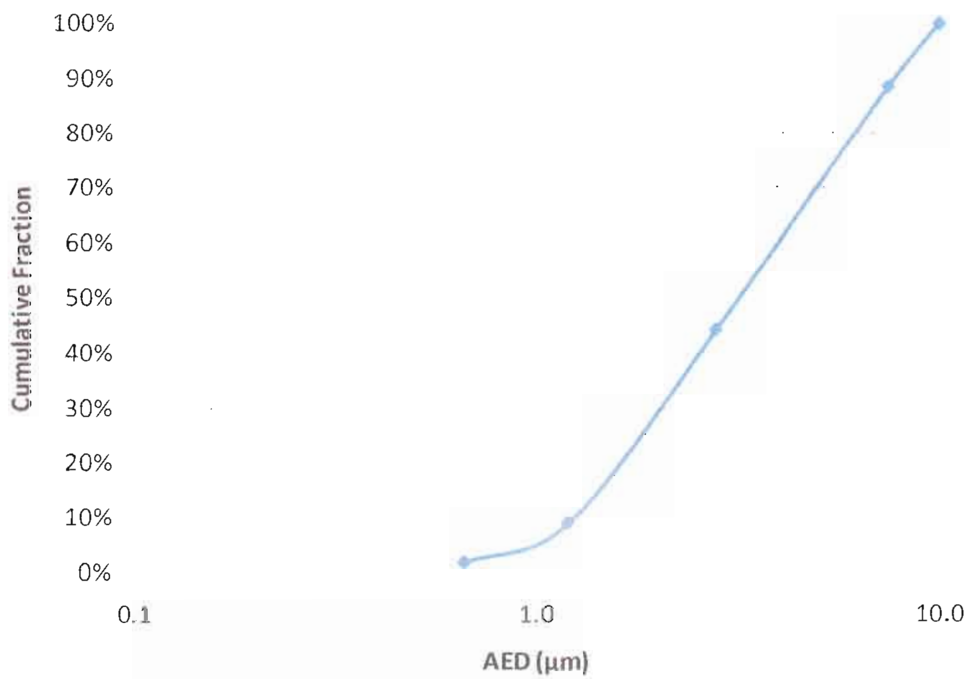


Figure B-1. Estimate of particle-size distribution in the respirable fraction for Hanford high-level waste.

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[19] Hobbs, D. T., "Precipitation of Uranium and Plutonium from Alkaline Salt Solutions," *Nuclear Technology*, Vol. 129, 103–112, October 1999.
[20] Wells, B. E., et al., *Estimate of Hanford Waste Insoluble Solid Particle-size and Density Distribution*, Battelle–Pacific Northwest Division, PNWD-3824, Richland, WA, 2007.

Appendix C

CARB 3 Calculation Details for Deposition Velocity Modeling at the Hanford Site

This appendix establishes the input parameters specific to the Hanford Site for the CARB 3 model. We estimated the Monin-Obukhov mixing length based on Pasquill atmospheric stability criteria as shown in Figure C-1. For each range of Monin-Obukhov mixing lengths at a surface roughness of 3 cm, we selected the midpoint value for our analysis. We selected the leaf area index (LAI) as 0.1, which corresponds to the "desert shrubland" category for all conditions without snow in Table 2-5 of EPA-454/R-94-015.[21]

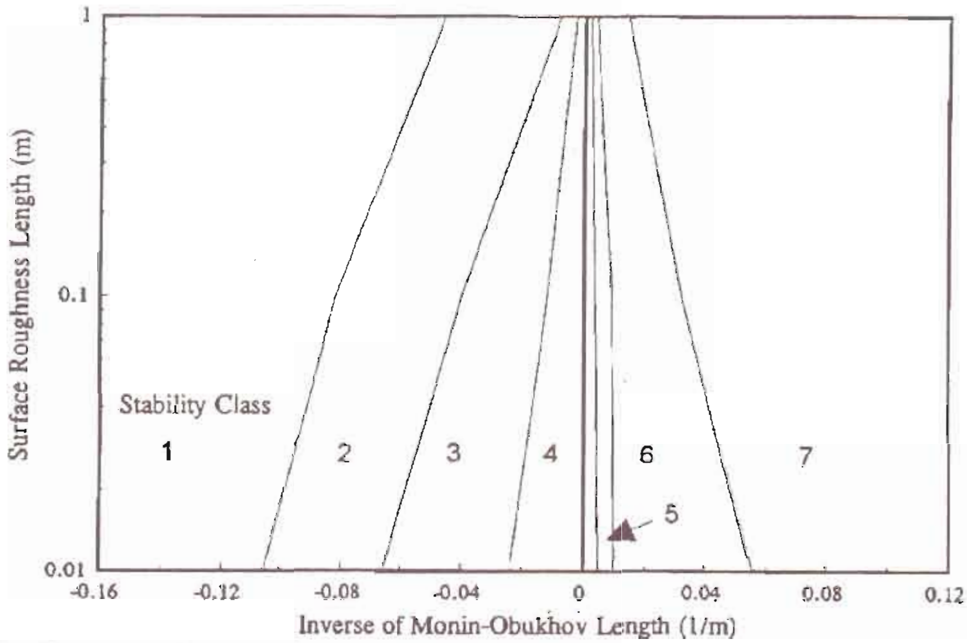

Figure C-1. Estimate of Monin-Obukhov mixing length under different atmospheric stability classes.[22]

For modeling the conditions specific to the 1985 accidental release at the Hanford Site, we made several changes. For example, we used values from Stupka et al. (1986), which states that the wind speed during the 1985 accidental release at the Hanford Site was approximately 3 mi/hr.[23] From temperature profile measurements, they determined that the atmosphere near the ground (under 30 m) was unstable, and they used Pasquill classes A and B to model the dispersion near the point of release. They modeled atmospheric dispersion at distances far from the point of release with Pasquill classes C and D, as they expected the plume to rise above 30 m and into a more stable atmospheric zone. Lastly, we selected an LAI of 0.05, which corresponds to the "desert shrubland" category for all conditions with snow in Table 2-5 of EPA-454/R-94-015.[24]

[21] U.S. Environmental Protection Agency, *Development and Testing of a Dry Deposition Algorithm* (Revised), Office of Air Quality Planning and Standards, EPA-454/R-94-015, Research Triangle Park, NC, 1994.
[22] Napier, B. A., Strenge, D. L., Ramsdell, J. V. Jr., Eslinger, P. W., and Fosmire, C. J., *GENII Version 2 Software Design Document*, Pacific Northwest National Laboratory, PNNL-14584, Richland, WA, 2004.
[23] Stupka, R. C., Kephart, G. S., and Rittmann, P. D., *Environmental Contamination from a Ground-Level Release of Fission Products*, DOE/NRC Nuclear Air Cleaning Conference, RHO-QA-SA-25 P, Seattle, WA, August 17, 1986.
[24] U.S. Environmental Protection Agency, *Development and Testing of a Dry Deposition Algorithm* (Revised), Office of Air Quality Planning and Standards, EPA-454/R-94-015, Research Triangle Park, NC, 1994.

CARB 3 Calculation Benchmark

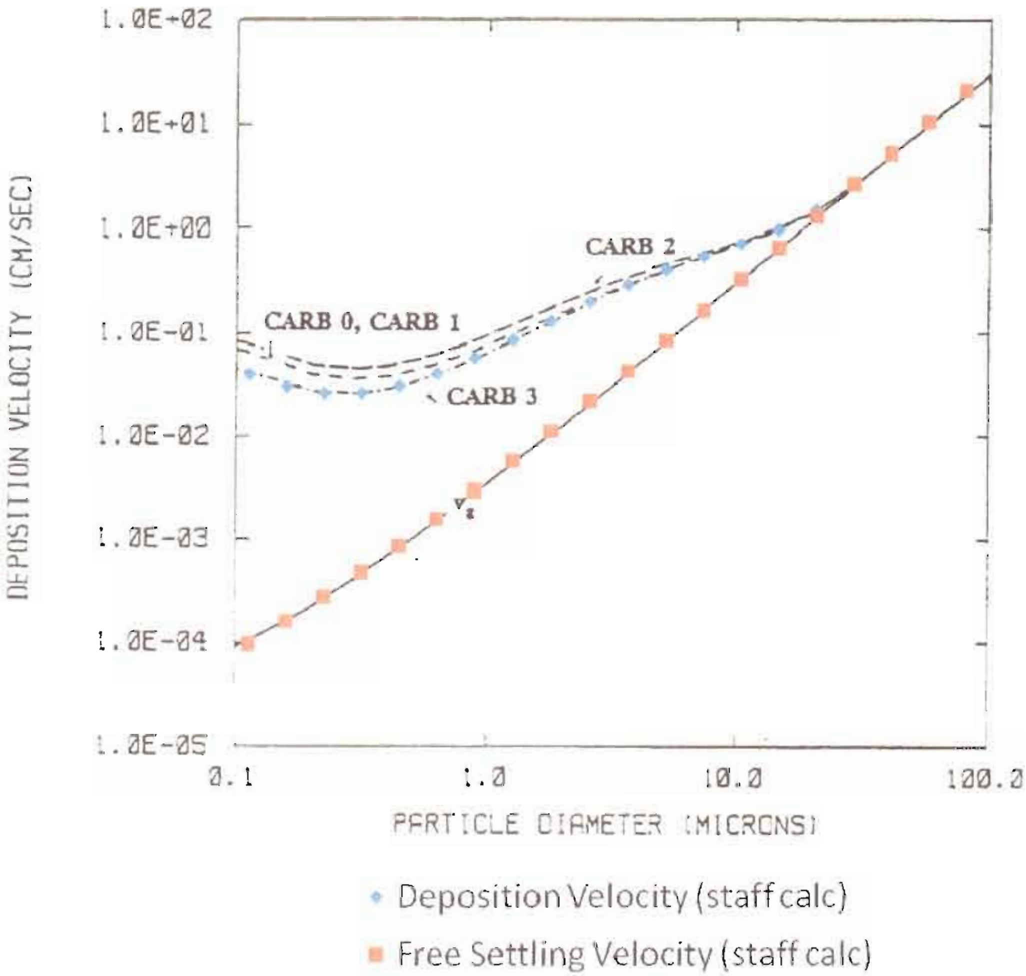

Figure C-2. Benchmarking of calculations by the Board's staff against results of EPA deposition velocity prediction methods outlined in Figure D-1 of EPA-454/R-94-015.

The staff calculations are overlaid on the original figure from the EPA report. Calculation conditions are a friction velocity of 10 cm/sec, surface roughness of 10 cm, leaf area index (LAI) of 1.0, density of 1 g/cm^3, and neutral atmospheric stability. Our calculations are shown by the blue triangles and red squares, while the EPA results are shown by the black lines. We find that our results agree with the EPA data indicating that the CARB 3 equations were properly transcribed and implemented.

Appendix D

Analysis of Deposition Velocities—1985 Accidental Release at the Hanford Site

Stupka et al. (1986)[25] document an accidental release of radioactive aerosols that occurred at the Hanford Site in 1985. The purpose of their report was to estimate the source term of the release and the potential dose to the public. The release was estimated to have occurred from 1 p.m. through 3 p.m. on Friday, January 11, 1985. By 3:30 p.m., investigators had determined the airborne contamination by analyzing the first of the air sampler systems. Hanford workers analyzed several additional air sampler systems to determine the concentration of airborne radionuclides. Additionally, they determined the level of ground contamination by taking samples of the snow near the air sampling stations. The investigators took snow samples on the Monday following the incident, January 14, 1985. They took the surface samples across a 1 m^2 area and took care not to disturb the soil under the snow so as to avoid cross-contamination. With these data, Stupka et al. (1986) determined deposition velocity for the 1985 incident using equation D-1.

$$V_d = \frac{C_{surface}}{\bar{\chi} \cdot t_{sample}} \qquad \text{(D-1)}$$

where

V_d	is the deposition velocity (cm/sec);
$C_{surface}$	is the surface concentration from the snow (Ci/cm^2);
$\bar{\chi}$	is the average airborne activity from the air samplers (Ci/cm^3); and
t_{sample}	is the air sampling time (sec).

Using this equation, an analyst can calculate the deposition velocity directly from measured or known data. Stupka et al. (1986) estimated the deposition velocity to be 0.15 cm/sec.

[25] Stupka, R. C., Kephart, G. S., and Rittmann, P. D., *Environmental Contamination from a Ground-Level Release of Fission Products*, DOE/NRC Nuclear Air Cleaning Conference, RHO-QA-SA-25 P, Seattle, WA, August 17, 1986.