HSS
Office of Health, Safety and Security

Safety Bulletin

Accident Analysis Parameter Update

No. 2011-02 **May 2011**

Purpose

To inform U.S. Department of Energy (DOE) and contractor personnel of an update in guidance for the default value for the dry deposition velocity (DV) parameter used in accident dose consequence calculations.

DV is the speed at which radioactive material settles out of a radioactive plume. The DV is one of several inputs to the DOE *Methods for Estimation of Leakages and Consequences of Releases Accident Consequences Code System Version 2* (MACCS2) computer code used to calculate hypothetical radiation doses to the public from potential accidents at DOE nuclear facilities. This calculated dose is used to identify controls to prevent or mitigate the potential accidents.

Background

On February 1, 2010, the DOE Office of Environmental Management (EM) informed the DOE Office of Health, Safety and Security (HSS) about concerns raised by the Defense Nuclear Facilities Safety Board (DNFSB) regarding the default DV values used in the MACCS2 computer code. EM requested guidance from HSS on whether the accident dose calculations using the DOE-specified DV values were reasonably conservative, consistent with DOE Standard (STD) 3009-94, *Preparation Guide for DOE Nonreactor Nuclear Facility Documented Safety Analyses*.

On May 21, 2010, the DNFSB requested that DOE provide a better technical basis for default DV values in the *MACCS2 Computer Code Application Guidance for Documented Safety Analysis Final Report*. On November 5, 2010, DOE provided a response to the DNFSB that included a technical analysis of the assumptions behind the DV values used in DOE consequence modeling.

Analysis

The DOE Chief of Nuclear Safety and HSS, with the support of industry experts in atmospheric sciences and accident dose consequences analysis, performed detailed analyses of the basis for the DV values used in the MACCS2 computer code. As a result of these analyses, DOE concluded that the MACCS2 default DV values of 1 centimeter/second (cm/s) for unfiltered/unmitigated releases and 0.1 cm/s for filtered/mitigated releases may not be reasonably conservative for all DOE sites and accident scenarios.

Actions to be Taken

Until DOE formally revises the *MACCS2* guidance to address this issue, HSS recommends the following actions to calculate conservative results for accident dose consequence estimates when using MACCS2. For new projects that have not reached Critical Decision-2 (CD-2), use one of the three options below:

1) Use default DV values of 0.1 cm/s for unmitigated/unfiltered particulate releases and 0.01 cm/s for mitigated/filtered particulate release; or
2) Calculate site-specific DV values for unmitigated/unfiltered and mitigated/filtered particulate releases (refer to Attachment 1 for additional information); or
3) Use a more sophisticated computer code than MACCS2 to determine the 95^{th} percentile dose at the site boundary.

For new projects beyond CD-2 and existing facilities, in which the Documented Safety Analysis (DSA) accident analysis utilized the MACCS2 code with a DV of 1 cm/s:

1) Use one of the three options stated above, or
2) Provide a technical justification that demonstrates the existing DSA accident dose calculation is reasonably conservative and meets the methodology by which the DSA was developed.

The results of any revised accident analyses should be evaluated to determine whether they indicate that additional safety controls (or changes to classification of existing controls) are warranted consistent with the DSA development methodology utilized for the facility.

Attachment 2 provides additional information regarding the technical basis for these recommended actions.

Additional Sources of Information

Contact your Program Secretarial Office representative or Mark Blackburn, Office of Nuclear Safety, at 301-903-8396 or mark.blackburn@hq.doe.gov.

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Attachment 1

Approach for Making Site-Specific Calculations of Deposition Velocity

The choice of a model to calculate deposition velocity (DV) parallels the methodology by which dispersion is calculated – namely, using reasonably conservative values for the input parameters, meteorological parameters that result in a 95th percentile result, and an appropriate methodology. In selecting an appropriately conservative site-specific value of DV to be used in unmitigated/unfiltered accident analysis calculations, three main parameters are necessary: local wind speed and stability, site-specific particle characteristics, and the surface roughness of the site. The use of a dilution factor that is not exceeded for more than 5 percent of the total hours in the data set (Nuclear Regulatory Commission [NRC], 1983) provides the conservatism in the meteorology portion of the dispersion modeling analysis. Since the local meteorology plays a key role in determining the DV, using the site-specific wind speed and stability class from the 95th percentile meteorology as input into a DV model calculation ensures an appropriate level of conservatism. The site-specific choices for surface roughness, particle size, and particle density should also reflect reasonably conservative values for these parameters, in accordance with U.S. Department of Energy (DOE) Standard 3009-94, Appendix A, with the particle size and density reflecting the particles that are within the respirable fraction (< 10 micrometers [µm] aerodynamic equivalent diameters [AED]) used in the accident analysis.

The input parameters are used to calculate DV using the widely accepted resistance methodology in modern dispersion models, such as GENII2 (Napier et al., 2009), American Meteorological Society/Environmental Protection Agency (EPA) Regulatory Model (AERMOD), and California Puff (CALPUFF) (using Acid Deposition and Oxidant Model [ADOM1] to calculate DV). While a number of variations in the resistance models are available, the methodology used in the GENII2 code allows for the incorporation of site-specific parameters without an extensive independent modeling effort. In addition, the Office of Health, Safety and Security's recommendation to use a model like GENII2 for unmitigated/unfiltered releases is based on the model's ability to accurately assess the minimum DV found at low wind speeds and smooth surface conditions, while simultaneously being able to predict variations in DV consistent with observed and theoretical patterns that arise from changes in surface roughness and light wind speeds. Given the light winds typically associated with the meteorology that results in the 95th percentile impact, the selected model needs to perform well in these conditions. Further, because the input value for surface roughness significantly affects the results from site to site, a model that can account for variations in surface roughness is also needed. Moreover, the EPA approved the use of GENII2 for calculating radiation dose and risk from radionuclides released to the environment. If sites choose to use the GENII2 model, a calculated site-specific value for DV for particulates can then be used as input for the Methods for Estimation of Leakages and Consequences of Releases Accident Consequence Code System, Version 2 (MACCS2) computer code, replacing the default recommended value of 0.1 centimeter/second (cm/s).

The ADOM1 model that was adapted for use in AERMOD and CALPUFF cannot predict an unmitigated/unfiltered DV value for particles 2-4 µm AED in excess of simple gravitational settling in the light wind speed conditions expected in the 95th percentile meteorology. The California Air Resources Board Model 3 (CARB3) model was developed using smooth surfaces and was not designed to handle variations in surface roughness (EPA, 1994). Similarly, the AERMOD (method 2) model cannot account for differences in surface roughness, given the light wind speed conditions. To demonstrate the differences in the models, the model results for varying wind speeds and surface roughness are shown in Table 1, on the following page.

As the table shows, the DV calculated by the GENII2 model for the conditions in the default DOE complex-wide calculation (1 m/s wind speed, 3 cm surface roughness) is smaller than that calculated by both the CARB3 and AERMOD (method 2) methodologies. The Sehmel curves (Sehmel and Hodgson, 1978) for light wind speed and smooth surfaces (10 cm/s friction velocity) indicate DV values in the 0.1-0.3 cm/s range, demonstrating that there is reasonably good agreement among the Sehmel curves and the CARB3, GENII2, and AERMOD (method 2) models, but not with the ADOM1 model.

Table 1 and Figures 1 and 2 demonstrate that the ADOM1, CARB3, and AERMOD (method 2) models cannot predict changes in DV resulting from changes in the surface roughness. The agreement among the models for the default DOE complex-wide input values for the 2-4 µm AED range is shown in Figure 1. Figure 2 shows the impact of changing the surface roughness from a value of 3 cm to 100 cm, representing a shift from smooth grassland to a forested canopy. The DV calculations from AERMOD (method 2) and CARB3 are essentially identical to those from Figure 1, while the GENII2 DV calculation is able to predict the expected increase.

Attachment 1

Approach for Making Site-Specific Calculations of Deposition Velocity

This attachment describes an approach for making site-specific calculations of deposition velocity and provides recommendations regarding computer codes and models to utilize and other supporting technical information to support these calculations.

U.S. Department of Energy (DOE) Standard (STD) 3009-94, *Preparation Guide for DOE Nonreactor Nuclear Facility Documented Safety Analyses,* specifies that a 95th percentile of the distribution of doses to the Maximally Exposed Offsite Individual (MOI) should be calculated and that the method for calculation this should be consistent with the statistical treatment of calculated χ/Q values described in regulatory position 3 of Nuclear Regulatory Commission (NRC) Regulatory Guide 1.145 for the evaluation of consequences along the exclusion area boundary.

In selecting an appropriate site-specific input value of DV to use as part of this calculation, three main parameters should be addressed: meteorological addressed meteorological conditions (local wind speed and stability), the surface roughness of the site, and site-specific particle characteristics. Appropriate conservatism in local meteorology is provided by using the site-specific wind speed and stability class from the 95th percentile meteorology, and using a dilution factor that is not exceeded for more than 5 percent of the total hours in the data set (NRC 1983.NRC 1983 The site-specific choices for surface roughness, particle size, and particle density should also reflect reasonably conservative values for these parameters, in accordance with DOE Standard 3009-94, Appendix A, with the particle size and density reflecting the particles that are within the respirable fraction (< 10 micrometers [μm] aerodynamic equivalent diameters [AED]) used in the accident analysis.

The input parameters can be used to calculate DV using the widely accepted resistance methodology in modern dispersion models, such as GENII2 (Napier et al., 2009), American Meteorological Society/Environmental Protection Agency (EPA) Regulatory Model ([AERMOD), (method 2] and California Puff (CALPUFF). CALPUFF and AERMOD (methods 1 and 2) use a form of the Acid Deposition and Oxidant Model (ADOM1) to calculate DV.

While a number of variations in the resistance models are available, the Office of Health, Safety and Security (HSS) recommends using a model like that in GENII2. The benefits of a model like the GENII2 code include:

- It allows incorporating site-specific parameters without an extensive independent modeling effort.
- It can accurately assess the minimum DV found at low wind speeds and smooth surface conditions, while simultaneously predicting variations in DV consistent with observed and theoretical patterns that arise from changes in surface roughness and light wind speeds. This is well suited to the light winds typically associated with the meteorology that results in the 95th percentile impact and variations in surface roughness
- The EPA approved the use of GENII2 for calculating radiation dose and risk from radionuclides released to the environment.

If sites choose to use the GENII2 model, a calculated site-specific value of DV for particulates can then be used as input for the *Methods for Estimation of Leakages and Consequences of Releases Accident Consequence Code System, Version 2* (MACCS2) computer code, replacing the recommended default value of 0.1 centimeter/second (cm/s).values.

HSS cautions against use of the ADOM1 model because it cannot predict an unmitigated/unfiltered DV value for particles 2-4 μm AED in excess of simple gravitational settling in the light wind speed conditions expected in the 95th percentile meteorology. Likewise, the California Air Resources Board Model 3 (CARB3) model was developed using smooth surfaces and was not designed to handle variations in surface roughness (EPA, 1994). Similarly, the AERMOD (method 2) model cannot account for differences in surface roughness, given the light wind speed conditions. To demonstrate the differences in the models, the model results for varying wind speeds and surface roughness are shown in Table 1, on the following page.

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Table 1. DV (cm/s) for 3 µm AED.

Model	**Wind Speed** 1 meter (m)/s **Surface Roughness** 3 cm	**Wind Speed** 3 m/s **Surface Roughness** 3 cm	**Wind Speed** 1 m/s **Surface Roughness** 100 cm	**Wind Speed** 3 m/s **Surface Roughness** 100 cm
Gravitational Settling	0.03	0.03	0.03	0.03
ADOM1	0.03	0.03	0.03	0.03
CARB3	0.21	0.19	0.20	0.19
GENII2	0.14	0.30	0.24	0.48
AERMOD (method 2)	0.20	0.21	0.21	0.23

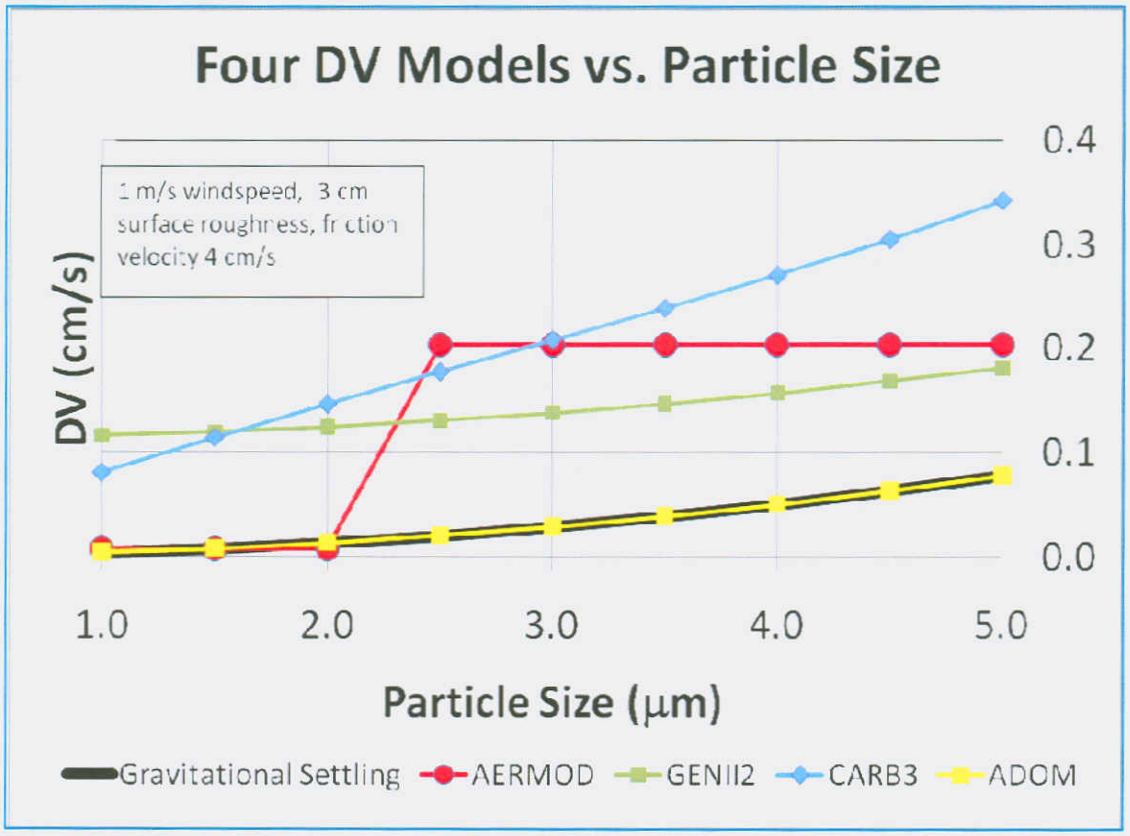

Figure 1. Model Comparison for Surface Roughness of 3 cm.

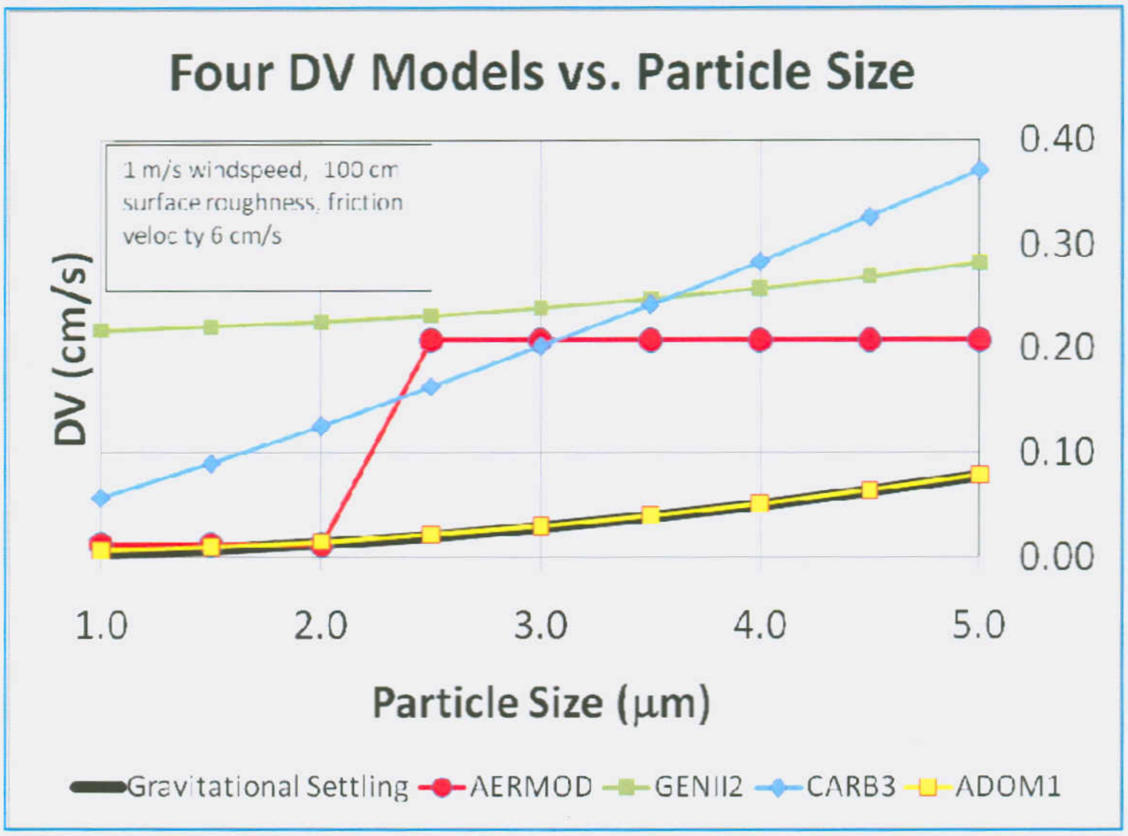

Figure 2. Model Comparison for Surface Roughness of 100 cm.

The GENII2 code does not perform well in the submicron range because the model calculates a constant DV value with respect to particle size and does not match the expected theoretical minimum in the submicron range. A particle size distribution that predominantly contains submicron particles more closely resembles a mitigated or filtered release. If site-specific information indicates that this condition is expected, then the use of the mitigated/filtered DV value of 0.01 cm/s is more appropriate.

References:

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NRC, 1983. NRC Regulatory Guide 1.145, *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants*, Revision 1, February 1983.

Sehmel, G.A. and W.H. Hodgson, 1978. *A Model for Predicting Dry Deposition of Particles and Gases to Environmental Surfaces*, PNL-SA-6721, January 1978.

Attachment 2

Technical Basis for Recommended Actions in Safety Bulletin No. 2011-02

1. Introduction

The following summarizes the technical basis for the actions recommended in Safety Bulletin No. 2011-02. Further context for the recommended changes in the dry deposition velocity (DV) used in the Methods for Estimation of Leakages and Consequences of Releases Accident Consequences Code System, Version 2 (MACCS2) computer code (U.S. Department of Energy [DOE], 2004) is provided in the attachment to DOE's November 5, 2010, memo to the Defense Nuclear Facilities Safety Board (DOE, 2010a). A copy of this memo can be found at http://www.hss.energy.gov/deprep/2010/TB10N05A.PDF. Additional information on the technical basis can be found on the Office of Health, Safety and Security (HSS) webpage under Important Links, Nuclear Safety Information, *Detailed Technical Basis for Default Dry DV Values in Safety Bulletin No. 2011-02.* For the purposes of this attachment, all references to DV are concerned with the process of dry deposition and should not be confused with the process of wet deposition.

2. Technical Basis for Default DV Values

2.1. General Regulatory Basis

Title 10 Code of Federal Regulations 830 Subpart B, *Safety Basis Requirements*, requires DOE to analyze the hazards of its nuclear facilities and establish hazard controls. DOE Standard (STD) 3009-94, *Preparation Guide for DOE Nonreactor Nuclear Facility Documented Safety Analyses* (DOE, 2006), prescribes this process for most DOE nuclear facilities, outlining an approach for identifying all relevant hazardous materials and all events that could cause the release of those materials to the environment. The standard then provides directions on how to calculate the consequences of unique and representative accidents. These calculated consequences are compared to a radioactive dose evaluation guideline (EG) to determine the type and reliability of controls and technical safety requirements needed to prevent or mitigate the accidents.

DOE-STD-3009-94 also states that the accident analysis calculations should be *based on reasonably conservative estimates of the various input parameters*. The key input parameters are:

Material at Risk (MAR) –	The amount of hazardous material in a given facility being evaluated
Damage Ratio (DR) –	The fraction of the MAR that is impacted by the accident-generating conditions
Airborne Release Fraction (ARF) –	The fraction of MAR that is released into the air by the accident
Respirable Fraction (RF) –	The fraction of material released into the air by the accident that is respirable
Leak Path Factor (LPF) –	The fraction of respirable material that is released from the facility.

The input parameters are multiplied together to determine the "source term," or amount of radioactive material, in grams (g) or curies, released to the air:

Source Term = MAR x DR x ARF x RF x LPF

The "Source Term" is input to a model that calculates the dose that could be received by a "Maximally-exposed Offsite Individual" (MOI), defined as a member of the public located at the site boundary for a period of two hours. DOE-STD-3009-94 dictates how this calculation is made and specifies that:

The 95th percentile of the distribution of doses to the MOI, accounting for variations in distance to the site boundary as a function of direction, is the comparison point for assessment against the EG. The method used should be *consistent with the statistical treatment of calculated χ/Q values described in regulatory position 3 of Nuclear Regulatory Commission (NRC) Regulatory Guide 1.145 for the evaluation of consequences along the exclusion area boundary.*

The parameter χ/Q (chi over Q) represents the dilution of the radioactive plume via dispersion and deposition as it travels from the facility during an accident. Within the plume dilution process, there is a parameterization of the process by which particles settle out from the plume to the ground (i.e., surface deposition). The method for calculating surface deposition involves the concept of a DV value, which is used to determine the flux of deposited material by multiplying the DV by the ground level concentration. DV is considered a useful tool for calculating the amount of surface deposition; however, *it in no way explains the physics of the deposition mechanism, but nevertheless it is a convenient way to express the whole complex and little-understood dry-deposition phenomenon* (Slade, 1968). Although the physical processes that control dry deposition are better understood today, the use of a single DV value to determine plume dilution is still a mathematical construct designed to simulate a highly complex phenomenon.

2.2. Development of Appropriate Values for DV

The calculation of DV has a long history, with initial estimates, based on tracer studies for examining radioactive fallout, in the range of 1 centimeter/second (cm/s) (Slade, 1968). Later efforts attempted to assess the effect of different parameters on DV and determined that wind speed, particle size, and surface roughness played a critical role in controlling the value of DV (U.S. Environmental Protection Agency [EPA], 1994). Methods were developed to directly observe the value of DV, but simulating the full range of ambient conditions continues to prove challenging.

2.2.1. Input Values

The input values of key interest in calculating DV involve the meteorological parameters of wind speed and stability, local terrain surface roughness, and the appropriate particle size distribution. Consistent with NRC Regulatory Guide 1.145 (NRC, 1983), the wind speed and stability are selected to reflect 95th percentile meteorological conditions, while the surface roughness and particle size distribution are chosen to reflect, as required in Appendix A of DOE-STD-3009-94, reasonably conservative assumptions. The friction velocity used in the models is then calculated from these input values.

Wind Speed and Stability

For DOE complex-wide calculations, a wind speed of 1 meter (m)/s and a stability class of F is assumed to represent the meteorological conditions consistent with the 95th percentile dose (NRC, 1988).

Surface Roughness

Modern methods for calculating surface roughness used in dispersion models rely on the use of 30 m resolution land-use data derived from the 1992 National Land Covered Data set. Examples of surface roughness values that correspond to different land uses (EPA, 2008) include:

1) Grasslands, bare rock, and row crops, which represent a very smooth surface roughness that varies seasonally from 1 to 10 cm
2) Industrial/urban presence with a surface roughness of 80 cm
3) Shrub vegetation with a surface roughness of 15 cm.

For DOE complex-wide calculations, a reasonably conservative value of surface roughness (3 cm) is used.

Particle Size Distribution

Current guidance for the MACCS2 computer code defines the particle size range for an unmitigated/unfiltered release to reflect particles in the 2-4 micrometers (μm) aerodynamic equivalent diameter (AED) range (DOE, 2004). The documented safety analysis assumes that the entire release of particles is considered to be in the respirable range (< 10 μm AED) and that no particle filtering occurs. The guidance for a mitigated/filtered release is to assume a particle size distribution of 0.2-0.4 μm AED. The HSS considers these to be reasonably conservative ranges for the particle size distributions given the accident analysis calculations assumptions related to the determination of the ARF/RF values for different accident scenarios. Note that HSS considers unmitigated/unfiltered accident analyses to be "parking lot" type releases that do not account for deposition of the plume particles on the building structure. Therefore, HSS assumes that the particle size range, which is not well known, has a uniform size distribution.

Friction Velocity

The friction velocity is calculated as a function of the wind speed, surface roughness, and stability class. Using the meteorology associated with the 95^{th} percentile dose (wind speed of 1 m/s and stability class F) and the reasonably conservative assumption for surface roughness (3 cm), the DOE complex-wide friction velocity is calculated to be 4 cm/s.

2.2.2. Models for Calculating DV

In evaluating the doses associated with a variety of accident analysis scenarios, DOE uses several computer models to help analyze the more than 50 parameters that are applied in the dose calculations. DOE selected the MACCS2 computer code as a "toolbox" code that is appropriate for performing dose calculations. The following discussion focuses on development of new DOE complex-wide default DV values for use as an input parameter in the MACCS2 computer code. The calculation of reasonably conservative DV values relies on a few key input values and uses a variety of methods.

An often-used method for determining DV involves the use of particle size, friction velocity, and surface roughness dependent curves published by George Sehmel (Sehmel and Hodgson, 1978; Sehmel, 1980). The developers of the MACCS2 computer code used the Sehmel curves to determine the DV. Figure 1, on the following page, shows the Sehmel curves (Sehmel, 1980) that best approximate the chosen DOE complex-wide conservative input parameters. A particle size range of 1-2 µm and a density of 4 g/cm^3 correspond to the 2-4 µm AED recommended in the MACCS2 guidance (DOE, 2004). For this range of parameters, the DV is estimated to fall within the range of 0.1-0.2 cm/s.

Additionally, calculations performed using the GENII2 model (Napier, et al., 2009), the California Air Resources Board Model 3 (CARB3) model, and the American Meteorological Society/EPA Regulatory Model (AERMOD) method 2 model calculate an unmitigated/unfiltered DV value in the range of 0.1-0.2 cm/s. Therefore, HSS recommends using 0.1 cm/s as an appropriately conservative DOE complex-wide DV value for the unmitigated/unfiltered case in the MACCS2 computer code. For the case of a mitigated/filtered release, the models frequently have difficulty predicting accurate DV values for the submicron particles that dominate this type of release (EPA, 1994), and phoretic effects (small-scale forces) predominate. These phoretic effects provide a minimum estimated DV value of 0.01 cm/s. Consequently, HSS recommends a DV value of 0.01 cm/s for a mitigated/filtered release.

3. Technical Basis for Recommendations on Application of the New Default DV Values

HSS's recommendation to use one of the three options in Safety Bulletin 2011-02 for new projects that have not reached Critical Decision-2 (CD-2) is consistent with DOE-STD-1189-2008, *Integration of Safety into the Design Process* (DOE, 2008). For such projects, the preliminary design is incomplete and warrants use of a reasonably conservative set of values to determine the appropriate safety control set. This approach is in keeping with DOE-STD-1189-2008 expectations for making reasonably conservative decisions early in the project design and is consistent with DOE-STD-3009-94 (DOE, 2006). As described in Attachment 1, a project may choose to calculate site/facility-specific values of DV rather than using the default values.

For new projects beyond CD-2 and existing facilities, in which the Documented Safety Analysis (DSA) accident analysis utilized the MACCS2 code with a DV of 1 cm/s:

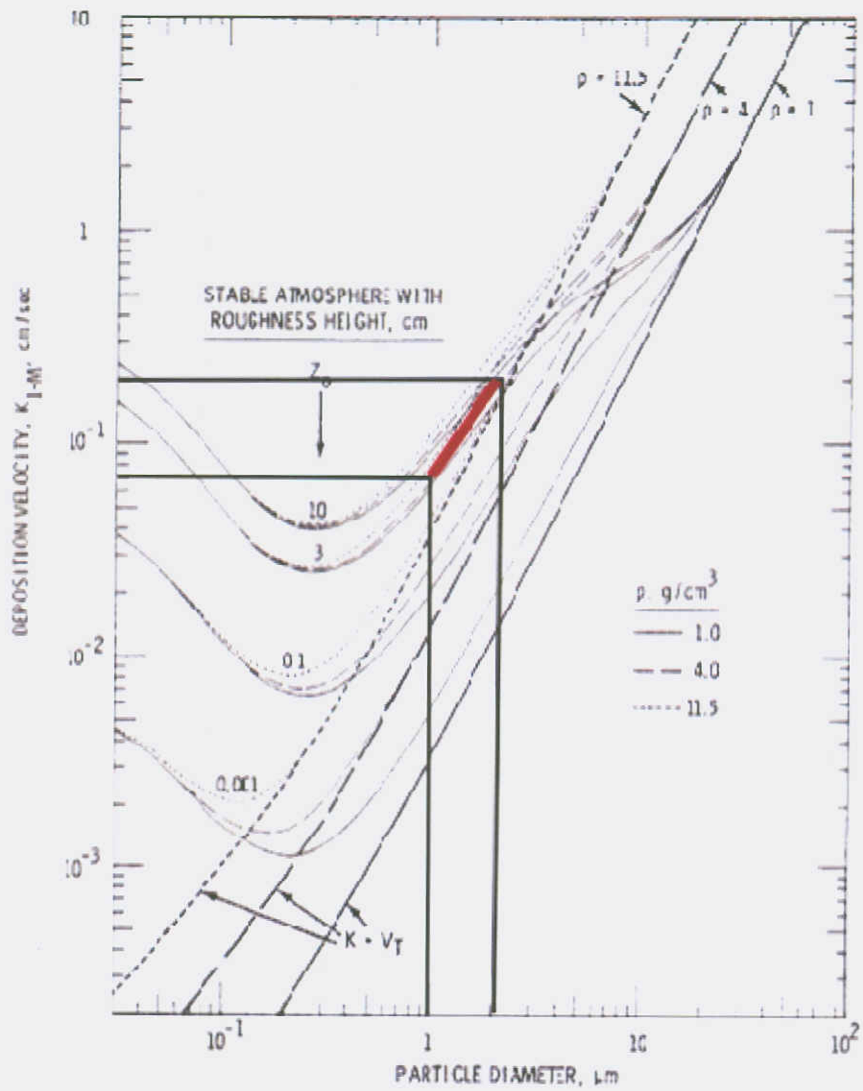
1) Use one of the three options in Safety Bulletin 2011-02, or

2) Provide a technical justification that demonstrates the existing DSA accident dose calculation meets the approved DSA methodology by which they were developed (e.g., DOE Standard 3009 which requires a 95^{th} percentile dose calculation). The results of any)Any revised accident analyses should be evaluated to determine whether they indicate that addition safety controls (or changes to classification of existing controls) are warranted consistent with the DSA development methodology utilized. The appropriate DOE Program

Office should provide direction on evaluating the cost impact and safety benefit for any proposed changes to safety controls.

For existing facilities, DOE sites should consider actions recommended in this Safety Bulletin as constituting "new requirements," per Section 2.4 of DOE Guide 424.1-1B, *Implementation Guide for Use in Addressing Unreviewed Safety Question (USQ) Requirements* (DOE, 2010b). DOE Guide 424.1-1B states that:

The USQ process does not apply to documented safety analysis upgrades in response to new requirements or to the use of new or different analytical tools during the upgrade process. However, the USQ process does apply when there is reason to believe that the current safety basis may not be bounding or may be otherwise inadequate.



The range enclosed encompasses the deposition velocities expected for particle sizes of 1 - 2 microns, and a surface roughness of 3 cm. For particles with a density of 4 g/cm3, this corresponds to a AED of 2-4 microns The resulting deposition velocity is 0.1 - 0.2 cm/sec.

Figure 1. Sehmel curves (Sehmel, 1980).

4. References

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DOE, 2006. DOE-STD-3009-94, *Preparation Guide for DOE Nonreactor Nuclear Facility Documented Safety Analyses*, Change Notice No. 3, March 2006.

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