Department of Energy
Washington, DC 20585

November 5, 2010

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The Honorable Peter S. Winokur
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, DC 2004-2901

Dear Mr. Chairman:

On May 21, 2010, you requested that the Department of Energy (DOE) provide a technically defensible basis for the complex-wide use of a default value (or values) to be specified in the DOE MELCOR Accident Consequences Code Systems (MACCS2) Computer Code Application Guidance for Documented Safety Analysis and the final deposition velocity to be used in accident calculations for the Waste Treatment and Immobilization Plant (WTP).

In response to your request, the Chief of Nuclear Safety and the Office of Health, Safety and Security (HSS), with the support of industry experts in atmospheric sciences and accident analysis, have performed detailed analyses of the basis for the deposition velocity value used in accident calculations for the generic value specified in the MACCS2 code (enclosed). As a result of this analysis, we have concluded that the default deposition velocity value (1 cm/sec) for unmitigated accident conditions is not a conservative estimate of the deposition velocity for all DOE sites and accident scenarios. Although the MACCS2 code guide needs to be updated, the analysis concludes that conservatism in the other elements of the accident calculations compensate for this specific non-conservatism.

Therefore HSS will develop and issue an Information Notice and provide long-term plans for revising the guidance for MACCS2 or successor codes, as well as interim guidance to ensure appropriately conservative control selection decisions are made. The Information Notice and revised guidance will:

- Take into account conservatism in the MACCS2 code (i.e., straight-line Gaussian plume model with many conservative inputs),
- Address options available to use other codes or calculate site-specific deposition velocity values to ensure that resulting dose calculations are appropriately conservative, and
- Address the applicability of the new guidance to DOE facilities at various stages of design (consistent with the approach the Department adopted for implementation of new design criteria in DOE Standard 1189, *Integration of Safety into the Design Process*).

With regard to the value of deposition velocity values to be used for WTP accident calculations, the Office of Environmental Management has directed that the specified interim guidance will apply to WTP. Pending finalization of the interim guidance, to be issued by the end of calendar year 2010, WTP will prepare to use a site-specific deposition velocity value, anticipated to be on the order of 0.3 cm/sec, in the MACCS2 code, as a conservative means of ensuring safety.

If you have any questions, please contact Mr. Kenneth G. Picha, Jr, Acting Deputy Assistant Secretary for Safety and Security, Office of Environmental Management, at (202) 586-5151 or Dr. James O'Brien, Director, Office of Nuclear Safety Policy and Assistance, at (301) 903-3331.

Sincerely,

Cathy Zoi
Acting Under Secretary of Energy

Glenn S. Podonsky
Chief Health, Safety and Security Officer
Office of Health, Safety and Security

Enclosure

Enclosure

Technical Analysis of
Dry Deposition Velocity Assumptions
Used in DOE Consequence Modeling

1. INTRODUCTION

The purpose of this analysis is to determine whether Department of Energy (DOE) guidance for the Deposition Velocity (DV) value to use in the accident analysis code, *Methods for Estimation of Leakages and Consequences of Releases (MELCOR) Accident Consequence Code System, version 2 (MACCS2)*, is appropriate to support calculations of the impacts of airborne releases of radioactive materials from severe accidents at DOE facilities on the surrounding public.

DV is the speed at which radioactive material is deposited out of a radioactive plume. The DV is one of several inputs to the MACCS2 code used to calculate doses to the public from potential accidents at DOE nuclear facilities in order to identify controls needed to prevent or mitigate the accidents.

2. OVERVIEW OF TECHNICAL ANALYSIS

The analysis covers several areas related to DOE requirements and processes for performing accident analyses focusing on consequence modeling (including model inputs) and, in particular, the technical basis for and sensitivity of the DV model input parameter.

This report is structured as followed:

Section 3: Discusses DOE accident analysis requirements and processes including how MACCS2 code supports DOE's accident analysis and the use of DV value in MACCS2.

Section 4: Discusses the technical basis for the DV value used in MACCS2 and expert reviews of this technical basis.

Section 5: Discusses the sensitivity of accident analysis calculations to variations in the DV value and discusses overall conservatisms in DOE accident analysis calculations.

Section 6: Provides conclusions and recommendations.

3. DOE ACCIDENT ANALYSIS REQUIREMENTS, PROTOCOLS, AND TOOLS

3.1 DOE Standard 3009

10 Code of Federal Regulations (CFR) 830 Subpart B, *Safety Basis Requirements,* requires DOE to analyze hazards of its nuclear facilities and establish hazard controls. For the majority of its nuclear facilities, the manner in which this is performed is prescribed in DOE Standard (STD) 3009, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses.*

DOE-STD-3009 outlines an approach for ensuring that all hazardous materials are identified, as well as all events that could cause the release of the hazardous material to the environment. It then provides directions on how to calculate the consequences of unique and representative accidents. These calculated consequences are compared to an "Evaluation Guideline (EG)[1]" to support a determination on the type and reliability of controls and technical safety requirements needed to prevent or mitigate the accidents.

DOE-STD-3009 states that the accident analysis calculations should be *based on reasonably conservative estimates of the various input parameters.* The input parameters are[2]:

Material at Risk (MAR) –	The amount of hazardous material
Damage Ratio (DR) –	The fraction of material at risk that is impacted by the accident generating conditions
Airborne Release Fraction (ARF) –	The fraction of material at risk impacted by the accident that is released into the air during an event
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

All of these input parameters are multiplied together to determine a **"source term"** which is the amount of radioactive material, in grams 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 which calculates the dose that could be received by a "Maximally Exposed Offsite Individual" (MOI) (member of the public located at the site boundary for a period of two hours).

The manner in which this calculation is made is dictated by DOE-STD-3009, which 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.*

[1] The EG is 25 Rem Total Dose Equivalent. The EG is not considered an acceptable public exposure. It is, however, a value indicative of no significant health effects (i.e., low risk of latent health effects and virtually no risk of prompt health effects). DOE Standards and Guides direct the consideration of the use of safety class controls when the calculated dose "challenge the EG or are in the rem range" which is interpreted as radiological doses equal to or greater than 5 rem TEDE but less than 25 rem.

[2] These parameters are further discussed in Section 5.2.2 of this report.

The method used should be consistent with the statistical treatment of calculated χ/Q values described in regulatory position 3 of NRC Regulatory Guide 1.145 for the evaluation of consequences along the exclusion area boundary.

χ/Q is a parameter that represents the dilution of the radioactive plume via dispersion and deposition as it travels from the facility during a postulated accident.

3.2 MACCS2 Code

MACCS2 is a general-purpose tool applicable to reactor and nonreactor facilities licensed by the Nuclear Regulatory Commission (NRC) or operated by DOE or the Department of Defense (NRC 1998). It was developed by Sandia National Laboratory (Chanin, 2005) to evaluate the impacts of airborne releases of radioactive material from severe accidents on the surrounding public. It contains a Gaussian plume dispersion model that provides as its output χ/Q values that can then, in conjunction with other factors (discussed in the next paragraph), be multiplied by the source term to calculate the 95th percentile of the distribution of doses for a given accident type (e.g., fire event). This is performed in accordance with NRC Guide 1.145 (NRC 1983c), and involves calculating a χ/Q value for each hour of a year based upon measured meteorological data for that hour and then choosing the χ/Q that is exceeded 5 percent of the time.

Inputs to the code include:

- Meteorological Data (stability class and wind speed)
- Surface roughness (e.g., height of vegetation in the areas between the facility and the site boundary)
- Deposition velocity (the speed at which aerosols are deposited from the plume)

In 2004, DOE selected MACCS2 as a dose calculation code for the "DOE Toolbox." The Toolbox comprises the set of computer codes designated by DOE as being appropriate for use in supporting the authorization basis of nuclear facilities. Concurrently with adoption of MACCS2 for the DOE Toolbox and in response to DNFSB Recommendation 2002-1, *Software Quality Assurance,* in June 2004, the Department issued guidance on how it is to be applied at DOE (DOE, 2004).

3.3 Deposition Velocity Use in MACCS2 Code

DV is a MACCS2 input parameter. It is a complex and highly variable parameter that is impacted by many factors. The primary factors that control DV are atmospheric conditions (e.g., wind speed), surface roughness, and the size and density distribution of the particles.

DOE's MACCS2 guide (DOE 2004) cites three DV values as appropriate for specific release scenarios. These values, shown below, cite Sehmel and Hodgson (1978) as the data source:

- A DV of 0.1 cm/sec is appropriate for filtered (e.g., mitigated) releases into the atmosphere.
- A DV of 0.5 cm/sec is an approximate value for tritiated water vapor.

- A DV of 1 cm/sec is appropriate for unfiltered (e.g., unmitigated) releases directly into the environment.

Using a single one of these three values is a simplified approach. A more sophisticated approach would be to calculate the DV for each specific type event (based upon the density and size distributions of released particles for that event) and hourly meteorological condition. DOE chose not to utilize a more sophisticated code because this level of accuracy is not needed to serve DOE needs for estimating the dose consequence for the purpose of hazard controls. Furthermore, data on the appropriate DV value did not support evaluation at this level of detail. This is discussed further in Sections 4 and 5.

4. TECHNICAL BASIS FOR DEPOSITION VELOCITY USED IN MACCS2 CODE

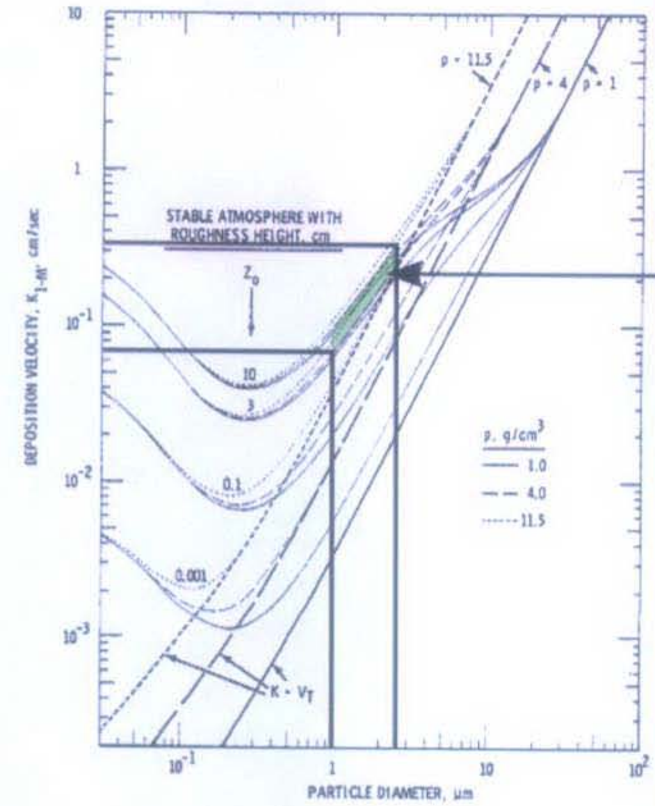
To support this analysis, DOE (1) performed a critical review of DV research, (2) performed a detailed review of DV calculations from the Defense Nuclear Facilities Safety Board (DNFSB) Staff Issue Report (including running of confirmatory calculations), and (3) contracted with outside subject matter experts to perform modeling studies. Each of these efforts is discussed in detail below.

4.1 Critical Review of DV Research

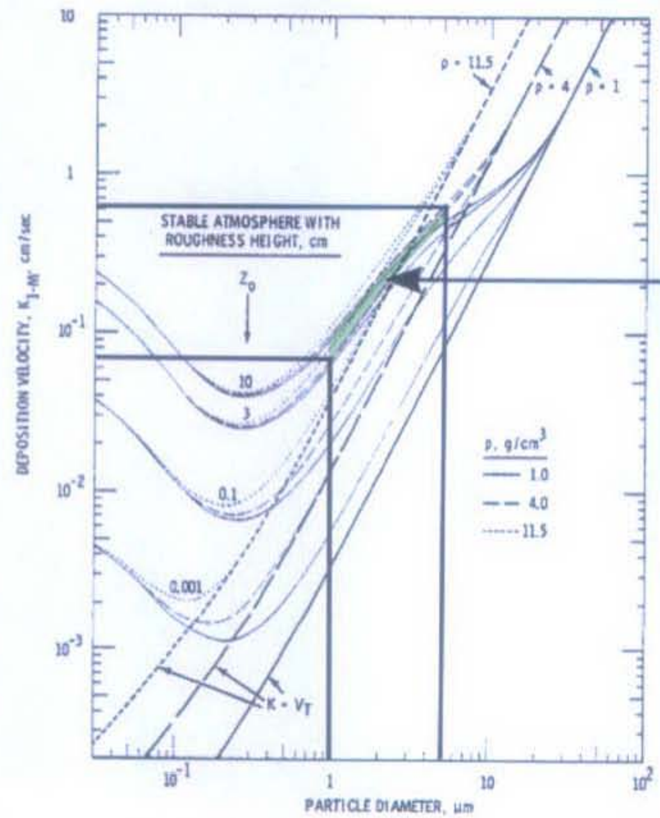
Over 30 years ago, Sehmel and Hodgson created a model for predicting DV (Sehmel and Hodgson 1976 and 1978). Their model was developed from observational data derived from wind tunnel experiments. It is clear from this early work that predicting DV is not a simple exercise. Over 50 variables exist that can influence the magnitude of the rate of dry deposition removal. These can be categorized as micrometeorological, the nature of the depositing material itself, and surface variables. A graph of DV versus particle size was provided in the NUREG/CR-3332, *Radiological Assessment: A Textbook on Environmental Dose Analysis, September 1983*, (NRC 1983a) using Sehmel and Hodgson's original data. This graph indicated that for the expected roughness height found in ambient conditions, the DV exceeded 1 cm/sec for all respirable particle sizes. The value of 1 cm/sec for DV had already been in use for decades (Hilsmeier and Gifford, 1962). Later publications by Sehmel refined and modified his calculations of DV (Sehmel and Hodgson, 1978; Sehmel, 1980). The data from these publications were incorporated into NUREG/CR-2300, *PRA Procedures Guide* (NRC, 1983b). Specifically, using data from Sehmel 1980, the PRA Procedures Guide appendix defining DV stated:

> "In the Reactor Safety Study, the dry deposition velocity was judged to lie in the range of 0.1 to 10 cm/sec, with 1 cm/sec taken as the expected average. In conclusion, for the consequence models that use a single deposition velocity for particulate matter released during a reactor accident, it is reasonable to assume that v_d is in the range of 0.1 to 1 cm/sec. Over rough or heavily vegetated surfaces, deposition velocities of up to 10 cm/sec may be appropriate."

As seen in the figures below and as noted in NUREG/CR-2300, the DV can change from 0.1 to 10 cm/sec, depending on particle size. This change occurs over a particle size range of 0.1 to 30 microns which corresponds to an aerodynamic equivalent diameter (AED) of 0.2 to 60 microns for particles with a density of 4 g/cm^3. Within the 2 to 5 micron AED (which roughly corresponds to the 1 to 2.5 microns range that defines a MACCS2 unmitigated release), NUREG/CR-2300 indicates that the DV varies from 0.07 to 0.30 cm/sec.



The area in green encompasses the range of deposition velocities expected for particle sizes of 1 - 2.5 microns, and a surface roughness of 3 - 10 cm. The resulting deposition velocity varies from 0.07 - 0.30 cm/sec.



The area in green encompasses the range of deposition velocities expected for particle sizes of 1 - 5 microns, and a surface roughness of 3 - 10 cm. This corresponds to a AED of 2-10 microns, which is the respirable range. The resulting deposition velocity varies from 0.07 - 0.60 cm/sec.

4.2 DNFSB Staff Issue Report: *Technical Basis for Estimating Deposition Velocities at Hanford*

The DNFSB Staff Issue Report enclosed in the DNFSB's August 26, 2010, letter (DNFSB, 2010b) uses the CARB3 model to evaluate what would be an appropriate DV value for the Hanford Site. The research performed by Sehmel formed the basis for DV modeling efforts by the California Air Resource Board (CARB). The CARB3 model attempted to incorporate the best understanding of the key physical factors controlling DV, while also using parameterizations to ensure that the results matched the observed experimental data presented in the Sehmel publications (EPA, 1994).

The DNFSB Staff Report presents results using low wind speeds (2 m/sec) and surface roughness heights (5 cm). Low values for those factors correspond to low values for DV and thus represent conservative input assumptions. The DNFSB Staff Issue Report results were presented for two cases, a single bin case that calculated a DV using an average particle size of 2 μm, and a two bin case that used fine particles (0.3 μm) and coarse particles (3 μm). For the single bin case (2 μm particle size), the DNFSB Report concluded that 0.1 cm/sec was appropriate for the DV. For a two bin approach, the report concluded that 0.01 cm/sec was the appropriate DV for the fine particles (0.3 μm), and 0.2 cm/sec was appropriate for the coarse particles (3 μm).

DOE performed confirmatory calculations utilizing the equations from the CARB3 model to validate the DNFSB results and to determine the sensitivity to parameters such as wind speed, particle size, and particle density. The results from these analyses were consistent with the DNFSB results and for the range of particles sizes for the unmitigated case identified in the MACCS2 code guide (i.e., 2 to 4 μm) and showed that a DV on the order of 0.1 cm/sec was appropriate.

4.3 External Subject Matter Expert Review

To gain additional perspective, DOE requested input from a nationally recognized DV expert and published textbook author, Dr. John Till. Specifically, DOE requested this expert answer the following question: "Is the MACCS2 code as implemented based on its documentation, assuming 1 cm/sec DV for particles, sufficiently conservative for the Hanford Site such that the target dose to the public is not underestimated at the 95 percentile level?" Dr. Till's results concluded that the MACCS2 code, with 1 cm/sec default value DV value, yielded conservative dose calculations. Dr. Till concluded that this was the case even though the DV value of 1 cm/sec used in MACCS2, based on his analysis, was not a conservative estimate of the DV for an unmitigated release at stable atmospheric conditions. Based on his analysis, he determined that a DV value in the range of 0.1 to 0.3 cm/sec would be more appropriate for the particle size distribution described in MACCS2 Code Guide.

It is noteworthy that Dr. Till's work derives its conclusion based on observational data that are independent of Sehmel's work. His analysis was performed using formulations similar to those used in models such as RATCHET (Ramsdell, et al., 1994) and GENII2 (Napier, et al., 2009). As does CARB3, these formulations utilize physical parameters to determine the DVs used in the code calculations rather than having the user directly input DV values. The specific parameterizations involved use experimental data derived from DV experiments conducted in the 1980s (Droppo, et al. 1983, Droppo, 1985).

Ultimately, Dr. Till concluded that the inherent conservatisms associated with the Gaussian plume model and conservative assumptions in the MACCS2 code more than compensate for the higher plume depletion rate introduced by using a 1 cm/sec DV. Therefore, he concluded the MACCS2 results for the Waste Treatment and Immobilization Plant (WTP) are, in fact, conservative and do not underestimate the target dose to the public.

5. SENSITIVITY EVALUATION AND ACCIDENT ANALYSIS CONSERVATISMS

This section discusses the sensitivity of the calculated doses to the DV parameter and the overall accident analysis conservatisms in order to provide insights into how potential non-conservatisms in the currently recommended DV value impacts DOE's expectation for performing reasonably conservative accident analysis to support decisions on the types and reliability of safety controls.

5.1 Sensitivity of Calculated Doses to DV Parameter

Two sensitivity analyses were conducted to document the effects of changing the existing DOE guidance to a DV value other than the current 1.0 cm/sec (Schulz, et al., 2009 and Henley, et al., 2010).

These studies evaluated several different accident release types at different DV rates. The results showed that, as compared to a DV of 1 cm/sec, the calculated 95th percentile χ/Q value was three times higher for a DV of 0.3 cm/s, four times higher for a DV of 0.15 cm/s, and approximately five (4.6) times higher for a DV of 0.1 cm/s.

5.2 Accident Analysis Conservatisms

5.2.1 Conservatisms in MACCS2 Code

As discussed briefly in Section 3, the MACCS2 code is a Gaussian straight-line model for atmospheric dispersion is a simplistic model that, for DOE accident analyses, typically uses several conservative assumptions:

- No buoyancy of the plume
- No building wake effects
- No wet deposition
- No plume meander
- Representative individual breathing rate of 3.33 x 10^{-4} m^3 s^{-1} (10,406 m^3 y^{-1}) which is on the high end of possible breathing rates in a distribution of the population
- No shelter or movement of representative individual

None of these assumptions are inherent in the MACCS2 code; rather, they are based on DOE guidance for conducting safety analyses and are intended to be conservative. The degree of conservatisms introduced by using these assumptions has not been quantified. This could be done by performing code runs for representative releases, weather, and site conditions while varying the different input assumptions.

The Gaussian plume model, as implemented in the MACCS2 code, also has been shown to be conservative compared to more complex dispersion codes. A comparison was made of several codes in a study by Molenkamp, et al. (2004). The study specifically compared MACCS2 to a fully three-dimensional (3-D) code (which can take into account terrain changes and spatial variability of weather). This code, LODI (Lagrangian Operational Dispersion Integrator), is described as a state-of-the-art, three-dimensional advection dispersion code that uses a Lagrangian stochastic, Monte Carlo method (Nasstrom, et al., 2000). For the closest arc-average results at 10 miles, a distance that would be representative of the general public receptor distance for some of the larger DOE sites, the comparison shows that the MACCS2 result is 58 percent, 41 percent, and 21percent higher for non-depositing exposure, depositing airborne exposure, and deposition exposure, respectively.

5.2.2 Conservatism in Source Term

A primary area where DOE makes conservatism assumptions in its accident analysis is related to the calculation of the unmitigated source term. These are briefly discussed below:

Material at Risk (MAR): The MAR is a value representing the maximum quantity of radionuclide present or reasonably anticipated for the process or structure being analyzed. Typically, the theoretical maximum is utilized to ensure that the assumptions in the safety analysis are not invalidated during the life of the facility.

Damage Ratio (DR): The DR is estimated based upon engineering analysis of the response of structural materials and materials-of-construction for containment to the type and level of stress/force generated by the event. Standard engineering approximations are typically used. These approximations often include a degree of conservatism due to simplification of phenomena to obtain a useable model, but the purpose of the approximation is to obtain, to the degree possible, a realistic understanding of potential effects.

Airborne Release Fraction (ARF): The ARF is the coefficient used to estimate the amount of a radioactive material suspended in air as an aerosol and thus available for transport due to a physical stresses from a specific accident. It is determined from data from experiments that is reported in DOE Handbook 3010. The ARFs are based primarily upon experimentally measured values for the specific material (e.g., plutonium, uranium, mixed fission products) or surrogates subjected to the particular type of stress under controlled conditions.

Respirable Fraction (RF): The RF is the fraction of airborne radionuclides as particles that can be transported through air and inhaled into the human respiratory system and is commonly assumed to include particles of sizes of 10-µm Aerodynamic Equivalent Diameter (AED) and less. Measured experimental data for RFs are much more limited but are from the same general sources used for the ARFs. To keep RFs at a reasonable bounding rather than an ultraconservative level, the RF associated with the measured bounding ARF is generally selected rather than the highest RF value measured. The highest RF values are often associated with the smallest ARFs, and when used in conjunction with the bounding ARF, result in ultraconservative estimates of the respirable fraction released. When no measured RF is associated with the maximum measured ARF, but other measured RFs are available for the experimental set, the greatest RFs are generally used. In some cases where significant uncertainty may exist, RFs are arbitrarily set to a value of 1.0 for conservatism. The second figure on page 5 in Section 4.2 illustrates the potential impact on DV range if the 10-µm AED RF particle size range was applied rather than those discussed in Section 4.2.

As stated in DOE Handbook 3010, in most cases, the ARFs and RFs for conditions bounded by the experimental parameters can be defined to one significant digit. The parameter definition process has focused on estimating reasonable bounding values because of the limited quantity and variability of the data. The use of the word "reasonable" is an acknowledgement that the only definitive bounds are ARFs and RFs of 1.0, which can always be postulated if enough synchronous, extreme localized conditions are assumed. Such extreme synchronicity is neither an expected condition nor a practically useful model of reality.

Leakpath Factor (LPF): The LPF is the fraction of the radionuclides in the aerosol transported through some confinement deposition of filtration mechanism. For conservatism, DOE typically assumes a leak path factor of 1 (i.e., no deposition).

6. CONCLUSIONS AND RECOMMENDATIONS

From a review of the technical information, HSS has concluded that a DV value of 0.1 to 0.3 cm/sec is more technically defendable for unmitigated releases of radioactive material from DOE facilities than the current DV value of 1 cm/sec specified in the MACCS2 code guide. Therefore, HSS concludes that, when site specific DV values are not available, a value of 0.1 cm/sec is a more appropriate default input for DV for the MACCS2 code for unmitigated releases in order to provide greater assurance that conservatisms are maintained in the accident analysis calculations.

However, consistent with Dr. Till's conclusion for WTP, HSS concludes that the inherent conservatisms associated with the Gaussian plume model, conservative assumptions in MACCS2 model, and conservatisms in source term assumptions compensate for any potential non-conservatisms introduced by the use of higher plume depletion rate and, therefore, accident analyses that have been performed will still be reasonably conservative. HSS recognizes that further work may be warranted to further evaluate all of the accident analysis conservatisms (including those related to input parameters and the dispersion code itself) to provide better guidance to ensure the level of conservatism does not result in unneeded and costly accident mitigation or prevention controls. Part of this evaluation may include assessing alternatives to utilizing the MACCS2 code.

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