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Perspectives on DOE Consequence Inputs for Accident Analysis Applications

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INTRODUCTION

Department of Energy (DOE) accident analysis for establishing the required control sets for nuclear facility safety applies a series of simplifying, reasonably conservative assumptions regarding inputs and methodologies for quantifying dose consequences. Most of the analytical practices are conservative, have a technical basis, and are based on regulatory precedent. However, others are judgmental and based on older understanding of phenomenology. The latter type of practices can be found in modeling hypothetical releases into the atmosphere and the subsequent exposure. Often the judgments applied are not based on current technical understanding but on work that has been superseded.

The objective of this paper is to review the technical basis for the major inputs and assumptions in the quantification of consequence estimates supporting DOE accident analysis, and to identify those that could be reassessed in light of current understanding of atmospheric dispersion and radiological exposure. Inputs and assumptions of interest include:

- Meteorological data basis
- Breathing rate
- Inhalation dose conversion factor.

A simple dose calculation is provided to show the relative difference achieved by improving the technical bases.

TECHNICAL BASIS REVIEW

A generalized, simplified version of the consequence terminology used in most DOE accident analysis is

$$\text{Dose (Sv)} = \text{Source Term (Bq)}\ \chi/Q\ (\text{s/m}^3)\ \text{BR}(\text{m}^3/\text{s})\ \text{IDCF (Sv/Bq)} \quad (1)$$

In Eq. 1, the source term represents the amount of respirable radiological material that is driven airborne to the environment by an imposed accident stress. The source term is often evaluated using the five-factor formula, and is based on conservatively evaluating radiological inventories, accident types, facility information, and typically references DOE-HDBK-3010-94. [1] The remaining three terms are the primary areas of interest: (1) atmospheric transport dilution factor (χ/Q) based on meteorological conditions; (2) breathing rate (BR); and (3) inhalation dose conversion factor (IDCF). It should be noted that while Eq. 1 is broadly applicable to nonreactor nuclear facilities, it is best applied to non-criticality source terms where the dominant radiological hazard is due to radionuclides that are important through the inhalation pathway.

Table I is a listing of the three categories of input or parameter values and the corresponding regulatory or technical basis. The table summarizes key bases for DOE consequence analysis.

Table I. Major Input Requirements and Regulatory Basis

Input or Parameter	Value or Prescriptive Guidance	Regulatory/ Technical Basis
A. Meteorological Basis		
1. statistical basis	95th percentile	DOE-STD-3009-94, App. A; Reg. Guide 1.145
2.a stability categorization	• ΔT • sigma-azimuth	Regulatory Guide 1.23 (Draft)
2.b stability categorization	• sigma-azimuth • solar radiation delta-T	EPA-454/R-99-005
3.a surface roughness length	site evaluation through surface feature characterization	Rules of thumb in most consequence software applications
3.b surface roughness length	z_o=3 cm; ~Prairie Grass Experiments	DOE-STD-5506-2007
B. Breathing rate		
1. point value	Public/Worker: 3.33E-04 m^3/s	DOE-STD-5506-2007; DOE G 440.1-3

Input or Parameter	Value or Prescriptive Guidance	Regulatory/ Technical Basis
2. range	Worker:3.33E-04 - 4.69E-04 m^3/s	ICRP 66
C. Dose conversion factors		
1. Dose terminology	Prescriptive dose evaluation guidance	10 CFR 835
2. Weighting factors; biokinetics model	-	ICRP 60
3. Respiratory tract model	-	ICRP 66
4. Particle size distribution*	Physicochemical grouping	ICRP 68; ICRP 71
5. DCFs	Worker DCFs; Public DCFs	ICRP 30; ICRP 68; ICRP 72; also DOE-STD-5506-2007 and DOE-STD-1189-2008
*The particle size also establishes the deposition velocity, which affects quantification of χ/Q.		

Meteorological Basis

The meteorological basis for the consequence calculation is the 95th percentile, direction-independent level of consequence (χ/Q) is summarized in Appendix A to DOE-STD-3009-94.[2] Data for forming the basis for the 95th percentile is often processed using Regulatory Guide 1.23 – including the technique for determining the stability category for the set of meteorological data. [3] Depending on site surface characteristics and meteorological data collection instrumentation, the methodology can be inaccurate in assigning data to stable categories. More accurate techniques are provided by the EPA. [4] A second factor that can be identified is the surface roughness length (z_o), a measure of the mechanical turbulence introduced by surface features. A recent DOE Standard specifies z_o = 3 cm for all facility dose evaluations, characteristic of dispersion tests over relatively flat, treeless terrain. [5]

An area of uncertainty in the meteorological phase of the analysis is the physicochemical characteristics of the radiological material during dispersion. Current, working assumptions can be generalized as follows: (1) the radiological material in transport is the same form as what existed pre-accident; and (2) particle size and related deposition characteristics are based on a monosize assumption. A deposition velocity of 1 cm/s is typically specified based on a particle size of 2-4 microns AED.

Breathing Rate

The breathing rate is a point value in consequence analysis and is tied to respiratory considerations. For recommendations for both worker and public receptors, the most authoritative guidance is ICRP 66. [6] The recommendation for the breathing rate in DOE-STD-5506-2007 is consistent with the ICRP guidance, and specifies the same value as derived in DOE G 440.1-3. [7] A point of departure is that a range of light to heavy activity breathing rate is recommended for the worker in Ref. 6, rather than a single breathing rate. A range of values is also recognized for the public receptor and is based on age, gender, and activity level. [6]

Dose Conversion Factors

With issuance of 10 CFR 835, DOE radiological assessments are to implement the newer biokinetics model and weighting factors, as well as the updated respiratory model. [8, 9] The radiological dose conversion factors that complement the improved models are contained in ICRP 68 and ICRP 72 for worker and general public receptors. [10, 11] This information reflects our current state of knowledge and is an advance over previous IDCFs. [12] An area of uncertainty is the particle size, and the default value is generally applied (1 μm or 5 μm activity median aerodynamic diameter (AMAD)) for the inhalation pathway for unmitigated analysis. [13]

Upon review of the three categories of input specification and guidance, the meteorological aspect is technically less accurate. The factors in this category that could be technically improved are stability category basis and the surface roughness length. The IDCF data upgrade is already reflected in current-day standards.

RESULTS

To better estimate the overall effects of the current updated inputs and assumptions with those less accurate, a sample calculation is performed using the MACCS2 code for a postulated Savannah River Site release. [14] The baseline case is a ground-level three-minute release of one curie of ^{239}Pu and the dispersion analysis is performed with z_o = 3 cm. The meteorological data set is prepared using a Ref. 3 approach for analyzing stability categories. The analysis is repeated with a more accurate (Ref. 4) method of binning stability categories. A dose comparison is shown with the percentage change as a function of distance in Table II. The second half of the table repeats both cases with z_o = 100 cm (forest surface cover). A third identified input, deposition velocity, is constant at 1 cm/s. The dose estimates shown in Table II provide a sense of the dose change with more accurate models and assumptions for stability class and surface roughness length.

Table II. Comparison of 95th Percentile Doses for Data Processed with Two Methods of Stability Categorization and Two Surface Roughness Lengths (3 cm and 100 cm)

Distance (km)	95th Percentile Dose (Sv), (1997-2001)	95th Percentile Dose (Sv), (2002-2006)	Difference (%)
z_o= 3 cm			
0.1	2.17E+00	1.75E+00	-19.4
0.6	1.59E-01	1.21E-01	-23.9
1.7	2.44E-02	2.06E-02	-15.6
5.2	4.12E-03	3.32E-03	-19.4
9.2	1.36E-03	1.08E-03	-20.6
11.5	9.08E-04	7.37E-04	-18.8
z_o= 100 cm			
0.1	1.23E+00	9.51E-01	-22.7
0.6	8.65E-02	7.26E-02	-16.1
1.7	1.58E-02	1.20E-02	-24.1
5.2	2.55E-03	2.15E-03	-15.7
9.2	9.47E-04	7.82E-04	-17.4
11.5	6.84E-04	5.42E-04	-20.8

CONCLUSIONS

A review of the three primary categories of inputs to a generalized consequence analysis for DOE safety analysis has been performed. The least reflective of current, state-of-the-art understanding of radiological atmospheric release and exposure from accident conditions are those in the meteorological area. Key uncertainties include particle deposition velocity and the particle size distribution associated with inhalation pathway.

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