The Next Twenty-Five: Insights from and Opportunities for Applications of MACCS in DOE Nuclear Safety Analysis

Kevin O'Kula
AECOM N&E Technical Services, LLC

2018 U.S. Nuclear Regulatory Commission Regulatory Information Conference
Recent Research and Applications of Severe Accident Offsite Consequence Analysis

Wednesday, March 14, 2018
Rockville, Maryland

AECOM Imagine it. Delivered

Outline of Discussion

- Transition to Nonreactor Nuclear Facilities in early 1990s
- Context for application of MACCS in Nonreactor Nuclear Facility Safety
- Key lessons learned and insights over the last 25 years
- Opportunities
- Conclusions

Transition in Application of Consequence Analysis Codes: Late 1980s/Early 1990s

- NUREG-1150, *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants (1990)*
- DOE production and research reactor mission decisions
  - N Reactor (1987), K Reactor (1992), FFTF (1992), HFBR (1996), TSR (2001), D&D of CP-5, others
- Application of PRA consequence methodology to Nonreactor Nuclear Facilities
  - Defense Waste Processing Facility (DWPF), Pantex, and others
- Issuance of SEN-35-91 (later DOE P 420.1, Nuclear Safety Policy)
- DOE/DP Defense Survey Report (1993)
- DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses (1994)*

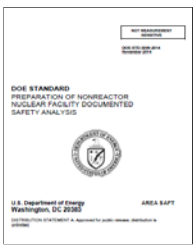
DWPF – Savannah River Site (Aiken, South Carolina)

Pantex Plant, (Amarillo, Texas)

Context for DOE Accident and Consequence Analysis

1. Documented Safety Analysis (DSA) Methodology: DOE-STD-3009-2014
2. Dose Quantification in DOE Documented Safety Analysis
3. Protocol for Calculating Documented Safety Analysis Doses
4. MACCS2 – DOE DSA Modules Executed Through Acute Phase

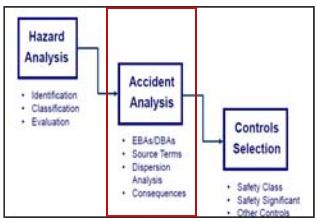
1. Documented Safety Analysis Methodology: DOE-STD-3009-2014



DOE STANDARD
PREPARATION OF NONREACTOR NUCLEAR FACILITY DOCUMENTED SAFETY ANALYSIS

U.S. Department of Energy
Washington, DC 20585

AREA SAFT



- "Safe harbor" Nuclear Safety Rule, 10 CFR 830
- Includes key requirements for
  - Chapter 3 (Hazard and Accident Analyses)
  - Chapter 4 (Control Selection)
- DOE-HDBK-3010-1994 and Hazard & Accident Analysis Handbook
- Approach similar Nuclear Fuel Cycle Facility Accident Analysis Handbook, NUREG/CR-6410

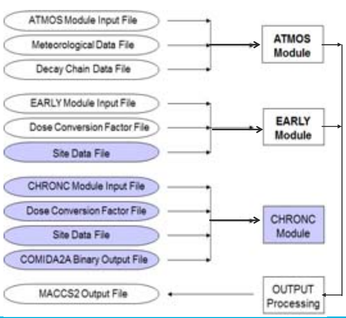
2. Dose Quantification in DOE Documented Safety Analyses

- **Identify major bounding and representative events for identification of control set**
- **For each postulated event, estimate dose consequence from:**
  Dose (rem) = Dose (rem) = Source Term x **χ/Q x BR x DCF**
- **Dose = Total Effective Dose (TED): Integrated committed dose (Adult)**
- **Accounts for direct exposure + 50-year organ commitment**
  - ST = Source Term = Material-at-Risk x Damage Ratio x ARF x RF x Leak path Factor
  - χ/Q = Atmospheric relative concentration (NRC Regulatory Guide 1.145, R1)
  - BR = Breathing Rate (light-activity adult)
  - DCF = Dose Conversion Factor
    - Onsite DCFs: ICRP Publication 68, Collocated Worker (CLW)
    - Offsite DCFs: ICRP Publication 72, Maximally Exposed Offsite Individual (MOI)
- **MACCS and other DOE DSA Consequence codes perform "PAVAN+" function**

3. Protocol for Calculating Documented Safety Analysis Doses

- DOE-STD-3009-2014 standardizes evaluation of the atmospheric dispersion of radiological source term with one of three graded approach options:
- Option 1: NRC Reg. Guide 1.145
  - Simplest, most conservative; often spreadsheet execution
  - Methodology based on Regulatory Guide 1.145 with site-specific meteorology
- Option 2: Use of DOE Central Registry Software with default parameters
  - Usually ATD model with default inputs and assumptions
- Option 3: Site/Facility specific modeling protocol
  - Most accurate, reasonably conservative
  - ATD model is applied
  - Apply site-specific methods and parameters as defined in a site/facility protocol approved by DOE

4. MACCS2 – DOE DSA Modules Executed Through Acute Phase



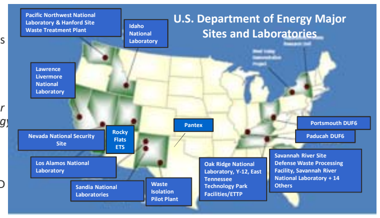
- ATMOS, EARLY, and OUTPUT input & data files are used in DOE safety basis applications
- Long-term consequence analysis not analyzed
  - Analysis covers acute phase plume passage over 24 h
- Shielding and emergency actions (sheltering, evacuation) not credited
- Wet deposition - not modeled
- Resuspension not required

Major Insights From Experience Over Last 25 Years

- Identification of Atmospheric Transport and Dispersion (ATD) Software Applicable for Most Sites and Applications => Central Registry
- Implementation of Graded Approach Methodology for Deposition Velocity (v_{dep})
- Standardization of Dose Conversion Factors (DCFs)
- Specification of a Single χ/Q Basis for Collocated Worker (CW)

Insight 1. Standardizing Set of Software as Regulatory Tools for DOE Nuclear DSA Applications

- 1980s -1990s: Variety of Site and facility developed ATD software
- Unique nuclear facility types with diverse inputs and assumptions
- Disparity in Software Quality Assurance (SQA), Configuration Management and Applications
- Recommendation 2002-1, *Quality Assurance for Safety-Related Software at Department of Energy Defense Nuclear Facilities*
- DOE Central Registry (Toolbox) in 2004 with ATD
  - MACCS
  - GENII
  - HOTSPOT



Ref.: https://www.energy.gov/ehss/safety-software-quality-assurance-central-registry

DOE Central Registry ("Toolbox") Radiological ATD Software

Code	Version	Year Approved	Owner
ALOHA	V5.4.4	2014	National Oceanic and Atmospheric Administration (NOAA)
CFAST	V3.1.7 and V5.1.1	2004	National Institute of Standards and Technology (NIST).
EPIcode	V7.0	2004	Lawrence Livermore National Laboratory
GENII	V2.10.1	2013	Pacific Northwest National Laboratory (PNNL)
HotSpot	V2.07.01	2010	Lawrence Livermore National Laboratory (LLNL)
IMBA	IMBA Expert ™ USDOE Edition V4.0.28	2006	UK Health Protection Agency (HPA)
MACCS2	V1.13.1	2004	Sandia National Laboratories (SNL)
MELCOR	V1.8.5	2004	Sandia National Laboratories (SNL)

- **Each code with SQA gap document**
- **Most with user guidance document**

Ref.: https://www.energy.gov/ehss/safety-software-quality-assurance-central-registry

Insight 2. Revision to Deposition Velocity Input

- **Deposition velocity, v_{dep}, relates flux density deposited to air concentration at some reference height**
- **Fixed input for v_{dep} in MACCS by chemical element or (physicochemical) group**
  - Initial default parameterization challenged: 1.0/0.1 cm/s for unfiltered/filtered release
  - Special case of tritium vapor (HTO)
  - DOE site MOI distances (1 km to ~10 km) & other site characteristics warrant smaller v_{dep}
- **Resuspension accounts for re-entrainment of surface contamination**
  - Upward flux/surface contamination; Units of inverse time => Fixed constant
  - Not required DOE-STD-3009-2014 for particulate aerosols; Limited influence in acute dose
  - HTO modeling requires re-emission $\neq$ resuspension

Deposition Velocity and Resuspension - 2

- Update deposition velocity graded approach with three options, <CD-2 facilities
  - Option 1 - Default values: 0.1 cm/s unfiltered; 0.01 cm/s filtered
  - Option 2 – Calculated site-specific values
  - Option 3 – Use more sophisticated code than MACCS2
- ≥ CD-2 Same as above or provide technical justification
- Some sites opt for "two-computer model" approach
  - Factor in site surface roughness, conservative meteorology, source term characteristics
  - Bulletin guidance: GENII2 informs workhorse code calculations

Deposition Velocity and Resuspension – 3: Special case of Tritium Oxide

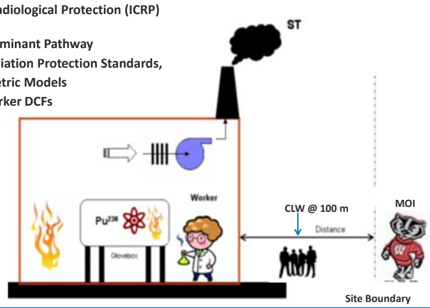
- **Tritium deposition is different from particulate aerosols**
  - Site-dependent: Controlled by atmospheric diffusion and the absorption properties of the soil and vegetation
  - Higher in daytime and lower at night
    - SRS - 0.1-2.8 cm/s (d) and < 0.1 cm/s (n)
    - Re-emission is inversely related to v_{dep}

- **Early use of v_{dep} for HTO in ATD codes based on U.S. and International site experience, and PRA applications (e.g. FUSCRAC)**
  - Typical v_{dep} ranged from 0.2-0.8 cm/s

- **MACCS2 resuspension model not applicable**
  - 2012 DOE recommendation: Apply 0.0 cm/s deposition velocity

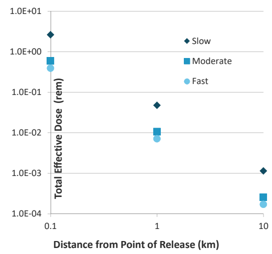
Insight 3. Internal Dose Conversion Factor (IDCF) for Some Radionuclides

- **International Commission on Radiological Protection (ICRP) recommendations in 1990s**
  - **Focus placed on Inhalation-Dominant Pathway**
- **ICRP 60 (1991), 66 (1994) – Radiation Protection Standards,**
  - **Revised Biokinetic and Dosimetric Models**
- **ICRP 68 (1994) – Collocated Worker DCFs**
  - **5 μm particles**
- **ICRP 71 (1995), 72 (1996)**
  - **General Public DCFs**
  - **1 μm particles**
- **Ambiguity in Absorption Type**
  - **Fast (F)**
  - **Moderate (M)**
  - **Slow (S)**
- **Example of Sr-90**



Example: Strontium Dose Conversion Factors

Radiological Dose Receptor	Basis: Activity Median Aerodynamic Diameter (AMAD)	Absorption Type	DCF (Sv/Bq)	Ratio to Lowest DCF for Receptor
Onsite Worker	5 µm	Fast (ICRP 68)	3.0E-08	1.0
	5 µm	Slow	7.7E-08	2.6
General Public (MOI)	1 µm	Fast	2.4E-08	1.0
	1 µm	Moderate (ICRP 71/72)	3.6E-08	1.5
	1 µm	Slow	1.6E-07	6.7



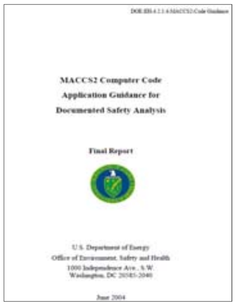
Insight 4. Establishing Onsite χ/Q for Collocated Worker

- Previously, wide and varied application of ATD models to estimate onsite doses to inform control selection for onsite worker
- Appendix A of DOE Standard (STD) 1189-2008, *Integrating Safety into the Design Process*,
  - Now prescribed in DOE-STD-3009-2014
- Use χ/Q of 3.5 x 10^{-3} sec/m^3 for collocated worker (100 m)
  - Ground-level release
  - Removed input of site-specific meteorology and region-of-transport information
- Basis: NUREG-1140 (1988): No buoyancy, F-stability, 1.0 m/sec wind speed at 100 m, influenced by building wake of small building size [10 m x 25 m], and v_{dep} = 1 cm/s
- Alternate value: DSA shall provide a technical basis supporting need for alternate and value selected

Opportunity -1: Establish MACCS Version for DOE DSA Applications

- **Current DOE Central Registry Version of MACCS2: 1.13.1 (early 2000s)**
- **Supported software, MACCS Version 3.10.1.2/WinMACCS Version 3.10.0**
- **Consider MACCS, DOE-specific version with simplified, acute phase modeling capabilitie**s
  - Maintain “research grade” version
  - Define limited capability version for DOE DSA applications
- **Suggested model additions and modifications:**
  - Tritium model with simple algorithm for time-dependent deposition and re-emission
  - Sensible energy emitted in source terms (Briggs models (1971, 1972) and (1975))

Opportunity -2: Upgrade MACCS DOE User's Guide & Related Code Support


MACCS2 Computer Code
Application Guidance for
Documented Safety Analysis

Final Report

U.S. Department of Energy
Office of Environment, Safety and Health
1000 Independence Ave., S.W.
Washington, DC 20585-2040

June 2004

- **Revise User Guidance as appropriate for DOE MACCS version**
- **Revise SQA issue document(s)**
  - DOE O 414.1D *Quality Assurance*
  - Update SQA compliance with DOE G 414.1-4
- **Update code application training**
  - National Training Center (Sandia National Laboratories)
  - EFCOG Nuclear and Facility Safety Workshop
- **Communication**

Conclusions

- **Last 25 years mark transition to more nonreactor nuclear support in DOE Complex by MACCS and other consequence analysis software**
- **Robust methodology infrastructure in place to support DSA process and use of consequence analysis software**
- **Lessons learned and insights include those relating to**
  - Standardization of software (Central Registry)
  - Clarification of deposition velocity input values
  - Dose Conversion Factor bases: aerosol size, absorption type, receptor
  - Single point value for onsite worker χ/Q
- **Opportunities to promote DSA-applications in the next 25 years**
  - Establish MACCS Version for DOE DSA Applications
  - Upgrade User's Guide and Related Code Infrastructure

The presenter acknowledges
Maeley Brown and Dave Thoman of AECOM TS for their support of this discussion.

Thank you for your attention.

AECOM Imagine it. Delivered.

Kevin O'Kula
AECOM N&E Technical Services, LLC
+1.803.640.2572 (m); +1.803.502.9620 (o)
kevin.okula@aecom.com