Overview of Upgrades to MACCS Dispersion Modeling Capabilities

2019 NRC Regulatory Information Conference

Atmospheric Transport and Dispersion Modeling for Severe Accident Consequence Analysis

K. Compton*, J. Barr*, N. Bixler**, and D. Clayton**

*U.S. Nuclear Regulatory Commission
**Sandia National Laboratories
Outline

– Severe accident consequence analysis with the MELCOR Accident Consequence Code System (MACCS)
– Overview of current MACCS atmospheric transport and dispersion (ATD) model capabilities
– Ongoing dispersion model enhancements
– Potential near-field dispersion model enhancements
Overview of Severe Accident Consequence Analysis

- Typically includes modeling the radioactive release to the atmosphere

- Analyses typically estimate the doses and health effects from inhalation, cloudshine, groundshine, skin deposition, and ingestion (e.g., water, milk, meat, crops), as well as costs and other impacts associated with protective actions to reduce exposure
Considerations for Severe Accident Assessments

• Severe accident probabilistic consequence assessments
  – Realistic assessment
  – Prospective analysis
  – Multiple figures of merit
  – Wide temporal and spatial scales

• Computational efficiency needed for modeling multiple possible prospective weather conditions

• Traditional ATD approach for probabilistic consequence analysis is to use a Gaussian plume segment model
MACCS Modules

• ATMOS
  – Source term definition
  – Weather sampling algorithms
  – Atmospheric transport, dispersion, and deposition

• EARLY (1 to 40 days)
  – Doses as modified by emergency phase countermeasures such as sheltering, evacuation, relocation, and potassium iodide ingestion
  – Allows modeling of multiple population cohorts
  – Acute and latent health effects from early acute exposure

• CHRONC (1 week to >50 years)
  – Doses as modified by intermediate and recovery phase protective actions such as relocation, temporary and permanent interdiction, and decontamination
  – Latent health effects from chronic exposure to deposited material
  – Economic impact from early and late phase protective actions
ATMOS: Meteorological Data

- MACCS ATMOS Gaussian plume segment model typically reads data from a file containing 1 year’s worth of observed hourly meteorological data (8,760 observations)
  - Wind speed (at 10 meters)
  - Wind direction (sector into which wind is blowing)
  - Stability class (typically based on lapse rate)
  - Accumulated precipitation
- Each plume segment uses up to 1,000 hours of meteorological data from meteorological file
- Up to 500 plume segments can be defined
- Typical practice is to sample approximately 1,000 different accident initiation times from the 8,760 potential hourly start times
ATMOS

ATD Model Plume Dispersion

• Straight-line Gaussian plume segment model
• User-specified plume dispersion parameterization
  – Distance-based power law formulation
    \[ \sigma_y = a \cdot x^b \quad \sigma_z = c \cdot x^d \]
  – Distance-based lookup tables: allow formulations that do not fit a simple power law (e.g., Briggs or Eimutis and Konicek formulations)
• Horizontal and vertical scaling factors (YSCALE and ZSCALE)
  – ZSCALE typically used to account for surface roughness effects on vertical dispersion
• Long-range dispersion: time-based plume growth model
  \[ x > CYDIST: \sigma_y = \sigma_{y,CYDIST} + a \cdot t \]
ATMOS

*Gaussian Plume Model Modifications*

**Virtual source model**
- Accounts for building wake effects and time-varying meteorological conditions
- User can specify initial plume dimensions to simulate initial dispersion from wake effects

**Plume Meander**
- User-selectable model applies corrections to transverse dispersion coefficients
- Original model (accounts for sampling time)
- Alternative model based on NUREG/CR-2260 (accounts for wind speed and stability)

**MACCS also includes modifications to account for plume rise, wet deposition, and dry deposition**
ATMOS (Gaussian Plume Segment): Air Concentration

- Illustration showing how plume segments move with wind shifting from northwest to northeast
- Each segment has its own width depending on the amount of dispersion that has occurred as it experiences varying weather conditions
- Each segment has a unique length depending on wind speed
- Wet and dry deposition (not shown) results in plume depletion and buildup of ground concentration
Accuracy of MACCS

- Probabilistic consequence analysis applications generally require the generation of the statistical distribution of consequence values over annual weather data (i.e., weather-averaged calculations)
- ATD model fidelity for probabilistic consequence analysis is traditionally considered less significant than for emergency response tools because of the statistical nature of probabilistic consequence analyses
- However, questions about the adequacy of the Gaussian plume model for probabilistic consequence analyses have been raised since at least the 1980s
- A previous study (NUREG/CR-6853) showed that MACCS is generally within a factor of two of the National Atmospheric Release Advisory Center’s Lagrangian Operational Dispersion Integrator (LODI) code for weather-averaged calculations
Evaluation Attributes for Potential Alternative ATD Codes

• Essential features
  – Treats Lagrangian particles
  – Code executable files can be distributed to users (either by Sandia National Laboratories or directly from the developer)
  – Source code available in case modifications are required for integration
  – Code has adequate quality assurance (QA)
  – Treats three-dimensional (3-D) wind field (gridded data)

• Desirable features
  – Can model both puffs and particles
  – Supports a variety of gridded weather data formats
  – Facilitates graphical postprocessing
## Features of Potential Alternative ATD Codes

<table>
<thead>
<tr>
<th></th>
<th>HYSPLIT</th>
<th>FLEXPART</th>
<th>LODI</th>
<th>CALPUFF</th>
<th>RASCAL</th>
<th>SCIPUFF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dispersion</strong></td>
<td>Lagrangian/</td>
<td>Lagrangian</td>
<td>Lagrangian/</td>
<td>Gaussian</td>
<td>Gaussian</td>
<td>Gaussian</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td></td>
<td>Gaussian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Developer/Primary</strong></td>
<td>NOAA &amp; Aus.</td>
<td>Norwegian Inst.</td>
<td>LLNL/DOE</td>
<td>TRC/</td>
<td>PNNL/</td>
<td>Titan/</td>
</tr>
<tr>
<td><strong>Customers</strong></td>
<td>Bureau of Met./</td>
<td>for Air Research/</td>
<td></td>
<td>EPA</td>
<td>NRC</td>
<td>DTRA, U.S. Army</td>
</tr>
<tr>
<td></td>
<td>NASA, Universities,</td>
<td>Europe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weather Data</strong></td>
<td>Any gridded data</td>
<td>WRF, MM5</td>
<td>WRF, ADAPT</td>
<td>CALMET, MM5, etc.</td>
<td>Surface data</td>
<td>Surface or</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>gridded data</td>
</tr>
<tr>
<td><strong>Surface Roughness</strong></td>
<td>User input at any</td>
<td>User input at any</td>
<td>User input at any</td>
<td>User input at</td>
<td>User input at</td>
<td>Unknown</td>
</tr>
<tr>
<td></td>
<td>resolution, or 1</td>
<td>resolution</td>
<td>resolution</td>
<td>any resolution</td>
<td>any resolution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>degree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Availability/Source Code</strong></td>
<td>NOAA/Yes</td>
<td>Norwegian Inst.</td>
<td>Only via Web/No</td>
<td>TRC/No</td>
<td>NRC/Yes</td>
<td>Titan/No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for Air Research/</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Europe/Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>QA/Verification and Validation</strong></td>
<td>Yes, open literature</td>
<td>Open literature</td>
<td>Yes, open</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>literature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Platforms</strong></td>
<td>Unix/Linux, PC, Mac</td>
<td>Unix/Linux, PC</td>
<td>Unix/Linux</td>
<td>PC</td>
<td>PC</td>
<td>PC</td>
</tr>
<tr>
<td><strong>Graphics</strong></td>
<td>Yes</td>
<td>User plots output</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Computer Time</strong></td>
<td>Can be high/needs multiple processors</td>
<td>Can be high/needs multiple processors</td>
<td>Can be high/needs multiple processors</td>
<td>Can be high</td>
<td>Moderate</td>
<td>Can be high</td>
</tr>
</tbody>
</table>
Selected Alternative ATD Code: HYSPLIT

- Selected for integration into MACCS as a modern alternative to the Gaussian plume segment model
- Developed and maintained by the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory
- Can compute trajectories as well as complex transport, dispersion, chemical transformation, and deposition
- Accepts a wide variety of publicly available gridded meteorological data, including both North American and global datasets
- Models dispersion using either puffs or particles:
  - “[P]uffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass.” *
  - “[A] fixed number of particles are advected about the model domain by the mean wind field and spread by a turbulent component.” *

*https://www.arl.noaa.gov/HYSPLIT_info.php
Potential MACCS Enhancements for Non-Light-Water Reactors (Non-LWRs)

• Evaluating potential code development needs for design-specific issues
  – Radionuclide screening
  – Radionuclide chemical form
  – Aerosol size
  – Aerosol shape factor
  – Radionuclides with complex transport characteristics (e.g., tritium)

• Evaluating potential code development needs for site-related issues
  – Near-field atmospheric transport
  – Decontamination modeling
Near-Field Atmospheric Transport

- MACCS currently has a simple virtual source model for building wake effects; its user guide (NUREG/CR-6613) cautions against use closer than 500 meters
- Licensees for non-LWRs (and small modular reactors) desire a smaller emergency planning zone and site boundary than for large LWRs; therefore, better modeling of near-field phenomena may be beneficial

Near-Field Atmospheric Transport

- Various options for addressing near-field ATD
  - Modifications to Gaussian plume segment ATD model
  - Lagrangian particle tracking ATD using simplified 3-D wind field models
  - Lagrangian particle tracking ATD using CFD modeling of 3-D wind field
- Considerations for evaluating options
  - Extent of practical acceptance in the user community
  - Simplicity of use
  - Computational efficiency
  - Cost and time efficiency
  - Accuracy
  - Feasibility for probabilistic application

Example QUIC-URB simulation of wind vectors
Example QUIC-PLUME simulation of urban transport and dispersion

QUIC Factsheet, Los Alamos National Laboratory
Summary

• The current version of MACCS is an efficient and highly flexible probabilistic consequence analysis tool with many user-configurable options
• Code enhancements are nearing completion to introduce results computed by HYSPLIT into MACCS
• Examining the applicability of current and potential approaches for modeling near-field dispersion phenomena where building wakes may be important
ACRONYMS AND REFERENCES

Acronyms

- ATD: Atmospheric Transport and Dispersion
- FLEXPART: FLEXible PARTicle Dispersion Model
- HYSPLIT: Hybrid Single Particle Lagrangian Integrated Trajectory Model
- LODI: Lagrangian Operational Dispersion Integrator
- MACCS: MELCOR Accident Consequence Code System
- NOAA: National Oceanic and Atmospheric Administration
- QUIC: Quick Urban & Industrial Complex Dispersion Modeling System

References