MACCS Code Applicability for Nearfield Consequence Analysis

Presented by
Dan Clayton
Sandia National Laboratories

Presented at European MELCOR and MACCS User’s Group (EMUG) meeting, April 12, 2021
Outline

Introduction/Setup

Code Trends

Code Comparisons

MACCS Updates

Wrap up
1. The adequacy of the MELCOR Accident Consequence Code System (MACCS) in the nearfield is discussed in a non-Light Water Reactor (LWR) vision and strategy report that discusses computer code readiness for non-LWR applications developed by the Nuclear Regulatory Commission (NRC).

2. MACCS currently includes a simple model for building wake effects. The MACCS2 User’s Guide suggests that this simple building wake model should not be used at distances closer than 500 m. This statement raises the first question of whether MACCS can reliably be used to assess nearfield doses, i.e., at distances less than 500 m.
3. MACCS is a highly flexible Gaussian model and the user can choose whether to model a variety of physical phenomena, including such things as building wake effects, plume buoyancy, and plume meander. Furthermore, the user has flexibility in choosing how to model the Gaussian dispersion parameters.

4. So, a second question goes beyond the first question of whether MACCS can be used in the nearfield to the related question of how can MACCS be used to generate results that are bounding of other codes intended for nearfield analysis.
General Arrangement of Flow Zones Near a Sharp-edged Building

Meteorology and Atomic Energy, 1968
Objective

An evaluation of modeling approaches (methods) to estimate nearfield air concentrations and depositions was performed where several candidate codes were ranked for comparison and potential incorporation into the MACCS code.

In this report, it is assumed that the results from the selected codes are all adequate in the nearfield, which is reasonable because these codes are specifically intended to be used in the nearfield.

Hence, by comparing the results of these codes to the results from MACCS, the adequacy of MACCS for assessing exposures in the nearfield can be evaluated, along with determining how MACCS can be used to generate bounding results.
Nearfield Code List

Four candidate codes were selected from the three main methods of atmospheric transport and dispersion (ATD) in the nearfield and evaluated:

- CFD models – OpenFOAM
- Simplified wind-field models – QUIC
- Modified Gaussian models – AERMOD and ARCON96

<table>
<thead>
<tr>
<th>Model</th>
<th>Simplicity</th>
<th>Efficiency</th>
<th>Validation</th>
<th>Conservative Bias</th>
<th>Community Acceptance</th>
<th>Ease of Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpenFOAM</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>QUIC</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>ARCON96</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>AERMOD</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Based on these rankings, QUIC, AERMOD, and ARCON96 and were selected for comparison with MACCS.
# Test Cases

## Two weather conditions
- 4 m/s, neutrally-stable (D stability class) – typical condition
- 2 m/s, stable (F stability class) – reduced dispersion condition

## Three building configurations (HxWxL)
- 20m x 100m x 20m (5:1 W:H) – extreme width to height ratio
- 20m x 40m x 20m (2:1 W:H) – typical building size
- No building (point source) – evaluate differences for elevated releases with no building

## Two power levels (heat content)
- 0 MW – without buoyancy
- 5 MW – with buoyancy

<table>
<thead>
<tr>
<th>Weather/Energy Content</th>
<th>Building HxWxL (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20x100x20</td>
</tr>
<tr>
<td>4 m/s, D stability, 0 MW</td>
<td>Case01</td>
</tr>
<tr>
<td>2 m/s, F stability, 0 MW</td>
<td>Case02</td>
</tr>
<tr>
<td>4 m/s, D stability, 5 MW</td>
<td>Case03</td>
</tr>
<tr>
<td>2 m/s, F stability, 5 MW</td>
<td>Case04</td>
</tr>
</tbody>
</table>
Code Trends
MACCS Results

Building and elevation effects greatly diminished at 800 m downwind

Building significantly increases dispersion at short distances

Dilution for stable conditions generally higher than the corresponding dilution for neutrally-stable conditions

Buoyant plumes that escape building wake produce significantly lower dilution values due to fast plume rise compared with dispersion
ARCON96 Results

**Minimal change** due to inclusion of **building** or **elevated** release within 1 km

Dilution for **stable** conditions generally **higher** than the corresponding dilution for **neutrally-stable** conditions

No plume rise model implemented; buoyant cases were not modeled
AERMOD Results

Building and elevation effects greatly diminished at 500 m downwind

Building significantly increases dispersion at short distances

Dilution for stable conditions generally higher than the corresponding dilution for neutrally-stable conditions

Minor differences due to buoyancy
QUIC Results (1/2)

Building and elevation effects greatly diminished at 1 km downwind.

Building significantly increases dispersion at short distances.

Dilution for stable conditions generally higher than the corresponding dilution for neutrally-stable conditions.

No straightforward way to implement buoyancy; buoyant cases were not modeled.
QUIC Results (2/2)

Horizontal and vertical slices for a 4 m/s, neutrally-stable weather condition with a non-buoyant, elevated release from a 20 m x 100 m x 20 m building (Case 01)
Code Comparisons
Comparison Results

At 50 m, order from highest to lowest dilution is ARCON96, AERMOD, QUIC, MACCS

Order changes with distance

• ARCON96 shifts from highest to lowest
• AERMOD shifts from 2nd highest to 2nd lowest
• Relative order between QUIC and MACCS is consistent
Potential Modifications to MACCS Input

1. Specify a **ground-level release**, instead of a release at the height of the building
   - *ARCON96* model showed **little dependence on elevation** of release
   - *Wake-induced building downwash* observed in QUIC output
   - *Regulatory Guide 1.145* discusses releases less than 2.5 times building height should be modeled as **ground-level releases**

2. Specify **no buoyancy** (plume trapped in building wake)
   - *AERMOD* model showed **little dependence on buoyancy**

3. If **additional conservatism** needed or desired, model as a point source
   - *ARCON96* model showed **little dependence on building size**
   - *DOE* approach used for **collocated workers**
   - If point source **too bounding**, use an **intermediate building wake size**
Updated Comparison Results

**MACCS input modified** to reflect a ground-level (1), non-buoyant (2), release (grey) **bounds** AERMOD and QUIC up to 1 km and ARCON96 from 200 m up to 1 km

**MACCS input modified** to reflect a ground-level (1), non-buoyant (2), point-source (3) release (light blue) **bounds all three** up to 1 km
MACCS Updates
MACCS Update Plan

Provide additional capabilities in MACCS to facilitate simulating or bounding nearfield calculations performed with other codes

- Ramsdell and Fosmire meander model used in ARCON96
- US NRC Regulatory Guide 1.145 meander model as implemented in PAVAN
- Maintain existing MACCS capabilities
Initial Testing Results (1/2)

Ramsdell and Fosmire meander model

20 m x 100 m x 20 m building, 4 m/s, D stability

US NRC Reg Guide 1.145 meander model as implemented in PAVAN

US NRC Reg Guide 1.145 meander model as implemented in MACCS 4.0
Initial Testing Results (2/2)

20 m x 40 m x 20 m building, 2 m/s, F stability

Ramsdell and Fosmire meander model

US NRC Reg Guide 1.145 meander model as implemented in PAVAN

US NRC Reg Guide 1.145 meander model as implemented in MACCS 4.0
Wrap up
Summary (1/4)

ARCON96, AERMOD, and QUIC selected for comparison with MACCS based on initial evaluation

Test cases developed to give a broad range of conditions, not to be exhaustive

• Two weather conditions
• Three building configurations
• Two buoyancy variations
Summary (2/4)

MACCS calculations configured with point-source, ground-level, nonbuoyant plumes provide conservative nearfield results that bound the centerline, ground-level air concentrations from ARCON96, AERMOD, and QUIC.

MACCS calculations with ground-level, nonbuoyant plumes that include the effects of the building wake (area source) provide nearfield results that bound the results from AERMOD and QUIC and the results from ARCON96 at distances >200 m.

If using a point-source is too conservative and it is desired to bound the results from all three codes, another alternative is to use area source parameters in MACCS that are less than the standard values, i.e., an area source intermediate between the standard recommendation and a point source.
Summary (3/4)

**MACCS can be used** at distances significantly shorter than 500 m downwind (50 – 200 m) from a containment or reactor building.

However, the MACCS user needs to **select** the MACCS **input parameters appropriately** to generate results that are adequately conservative for a specific application.

A **conservative nearfield result** may be obtained using the following **MACCS parameter choices**:

- The parameterization of Eimutis and Konicek for the dispersion model.
- The plume meander model based on Regulatory Guide 1.145. This model is selected by setting the value of the MACCS parameter MNDMOD to NEW.
- The release modeled as a point-source, ground-level, nonbuoyant plume.

Summary (4/4)

Additional **nearfield meander models** to be **included** with **MACCS 4.1**

- Simulate results from ARCON96 with MACCS when using the Ramsdell and Fosmire meander model
- Simulate results from PAVAN with MACCS when using the full US NRC Regulatory Guide 1.145 meander model
- Maintain capability to bound AERMOD and QUIC results using recommended MACCS parameter choices