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NEARFIELD MODEL UPDATES

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European MELCOR/MACCS User Group (EMUG) meeting

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MACCS
Accident Consequence Model

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INTRODUCTION

Motivation: Resolve the technical issues with the adequacy of MACCS in the nearfield (i.e., at distances less than 500 m) that are identified 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)

The **purpose** of this presentation is threefold:

- **Summarize** the technical issues associated with the use of MACCS in the nearfield and approach used to resolve them
- **Alert** users that improved nearfield modeling capabilities have been added to MACCS
- **Familiarize** users with the improved nearfield capabilities available in MACCS

BACKGROUND

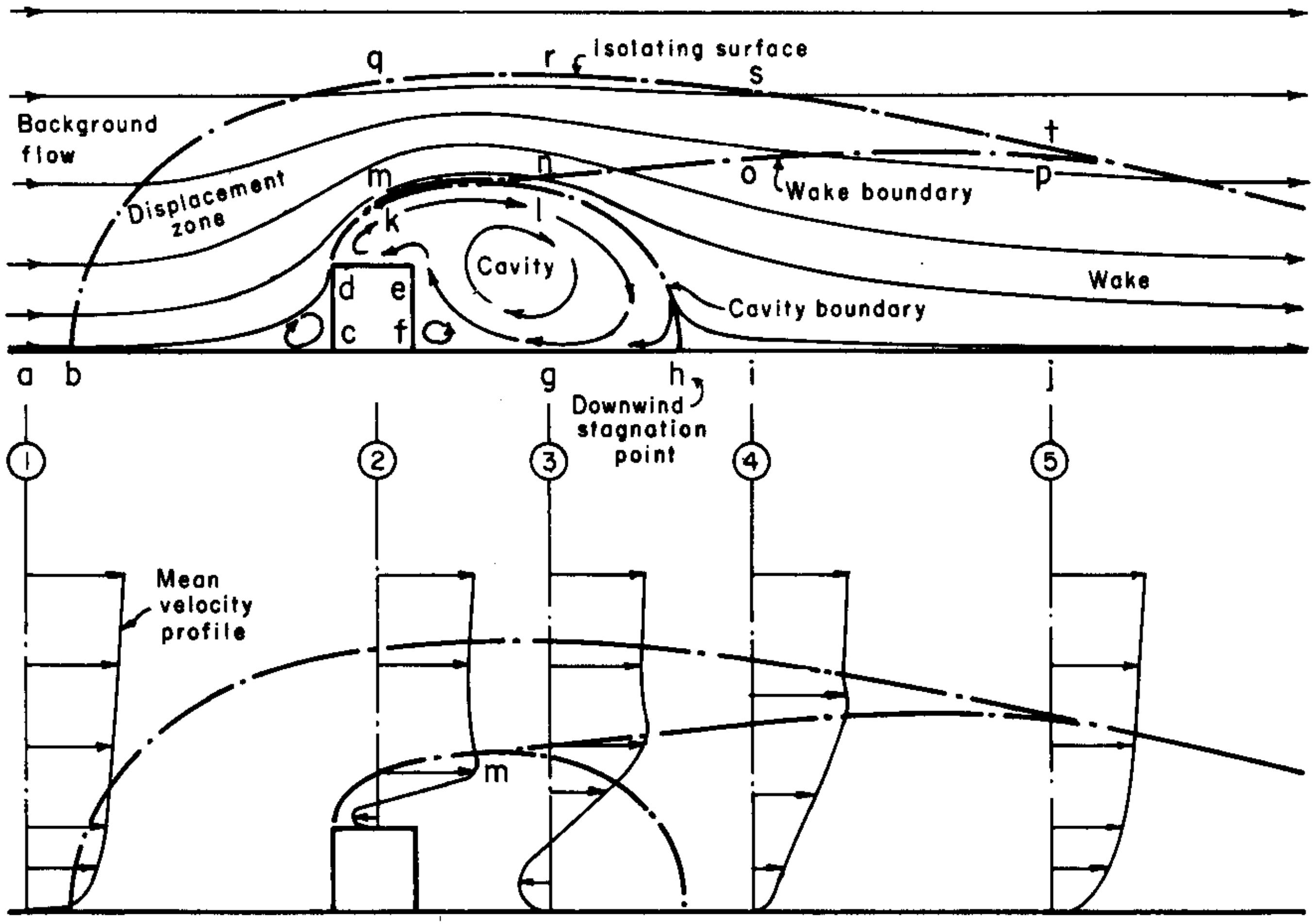
MACCS Accident Consequence Model

MACCS 4.0 uses the general **gaussian plume equation** with reflective boundaries and includes **models** for **plume meander** and **building wake effects** based on building dimensions

$$C = \frac{\dot{Q}}{2\pi\sigma_y\sigma_z u}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\sum_{n=-\infty}^{\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{2nh-H-z}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{2nh+H-z}{\sigma_z}\right)^2\right]\right\}$$

Previous (4.0 and earlier) versions of MACCS include only a **simple model** for building wake effects. The MACCS User's Guide suggests that this simple building wake model **should not be used at distances closer than 500 m**. This statement raised the question of **whether MACCS can reliably be used to assess nearfield doses**, i.e., at distances less than 500 m

GENERAL ARRANGEMENT OF FLOW ZONES NEAR A SHARP-EDGED BUILDING



Meteorology and Atomic Energy, 1968

APPROACH

Identify candidate **codes** considered **adequate** for use in nearfield modeling

Benchmark MACCS 4.0 nearfield results against results from candidate codes

Identify model **input** recommendations or **code updates** for improved nearfield modeling

Implement the code **updates** in MACCS

Verify that the **MACCS** code **updates** adequately reflect the results from the candidate codes

Exercise new capabilities in **MACCS**

NEARFIELD CODE LIST

MACCS
Accident Consequence Model

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

	Model Characteristics					
Model	Simplicity	Efficiency	Validation	Conservative Bias	Community Acceptance	Ease of Implementation
OpenFOAM	3	3	1	2	1	3
QUIC	3	2	1	2	2	3
ARCON96	1	1	2	2	1	1
AERMOD	1	1	1	2	1	2

Based on these rankings, **QUIC**, **AERMOD**, and **ARCON96** were selected for **comparison with MACCS** 4.0

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

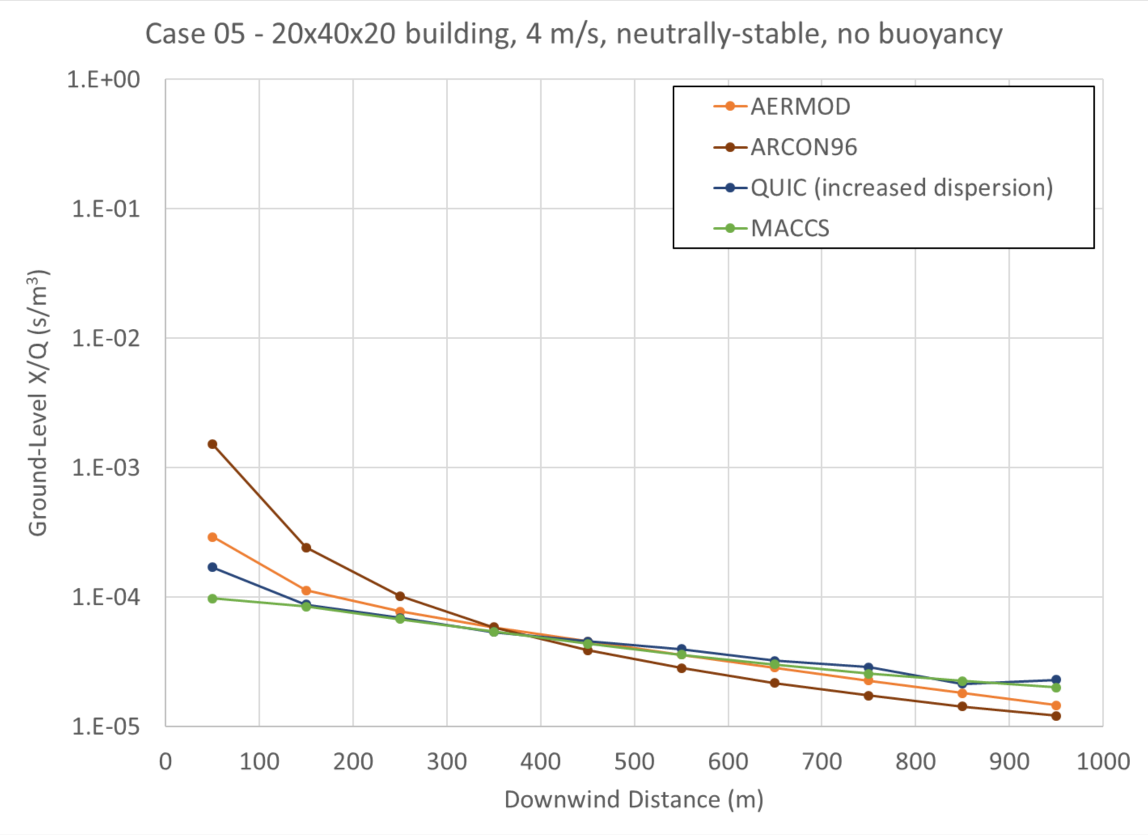
Weather/Energy Content	Building HxWxL (m)		
	20x100x20	20x40x20	None
4 m/s, D stability, 0 MW	Case01	Case05	Case09
2 m/s, F stability, 0 MW	Case02	Case06	Case10
4 m/s, D stability, 5 MW	Case03	Case07	Case11
2 m/s, F stability, 5 MW	Case04	Case08	Case12

MACCS
Accident Consequence Model

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

Order changes with distance

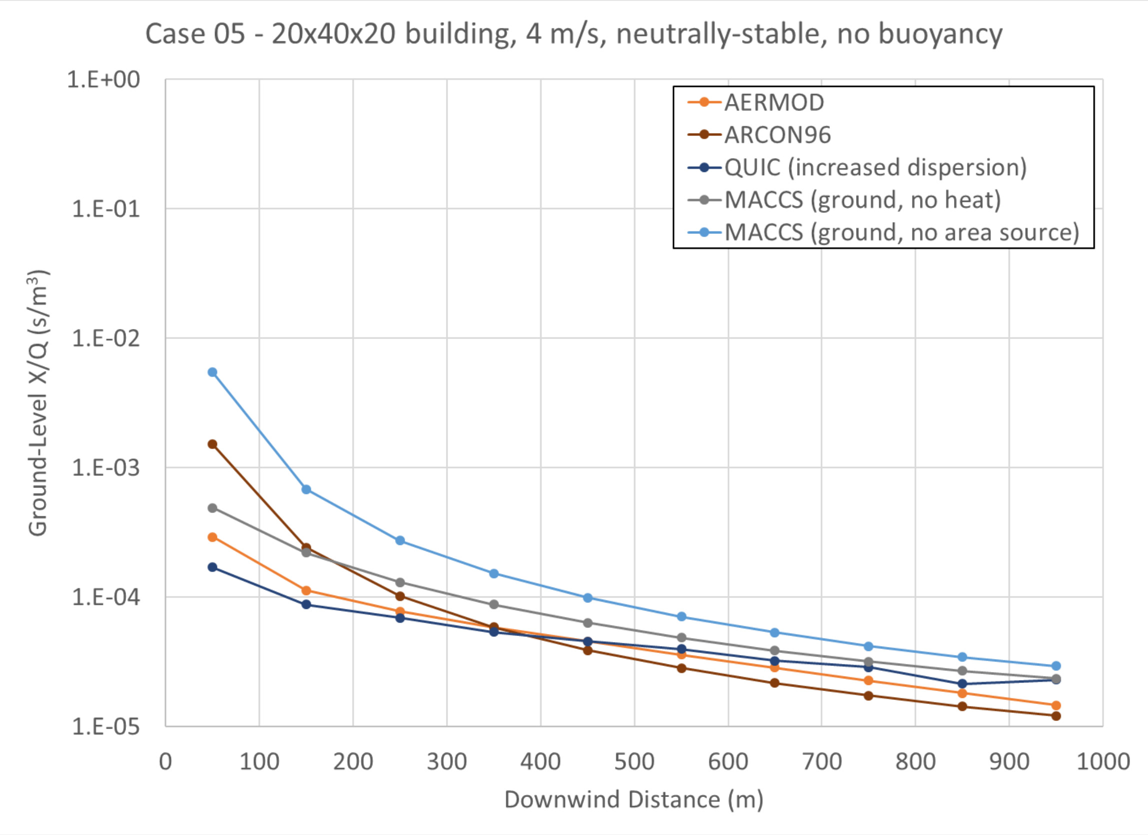
- ARCON96 shifts from highest to lowest
- AERMOD shifts from 2nd highest to 2nd lowest
- Relative order between QUIC and MACCS is consistent



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 ENHANCEMENTS

Add two **new capabilities** in **MACCS** to facilitate **simulating** or **bounding** nearfield calculations performed with **other codes:**

- Implemented **Ramsdell and Fosmire** wake and meander algorithms used in ARCON96
- Updated existing meander model to fully implement wake and meander model equations from **US NRC Regulatory Guide 1.145** as implemented in PAVAN

Maintain existing MACCS capabilities to bound results with AERMOD and QUIC

MACCS
Accident Consequence Model

Ramsdell and Fosmire meander model used in ARCON96

US NRC Regulatory Guide 1.145 meander model as implemented in PAVAN

Plume Meander

- (selected) US NRC Regulatory Guide 1.145 (MNDMOD=NEW)
- Ramsdell and Fosmire (MNDMOD=RAF)
- Original MACCS (MNDMOD=OLD)
- None (MNDMOD = OFF)

Ramsdell and Fosmire

$$\Sigma_y = (\sigma_y^2 + \Delta\sigma_{y1}^2 + \Delta\sigma_{y2}^2)^{1/2}$$

$$\Sigma_z = (\sigma_z^2 + \Delta\sigma_{z1}^2 + \Delta\sigma_{z2}^2)^{1/2}$$

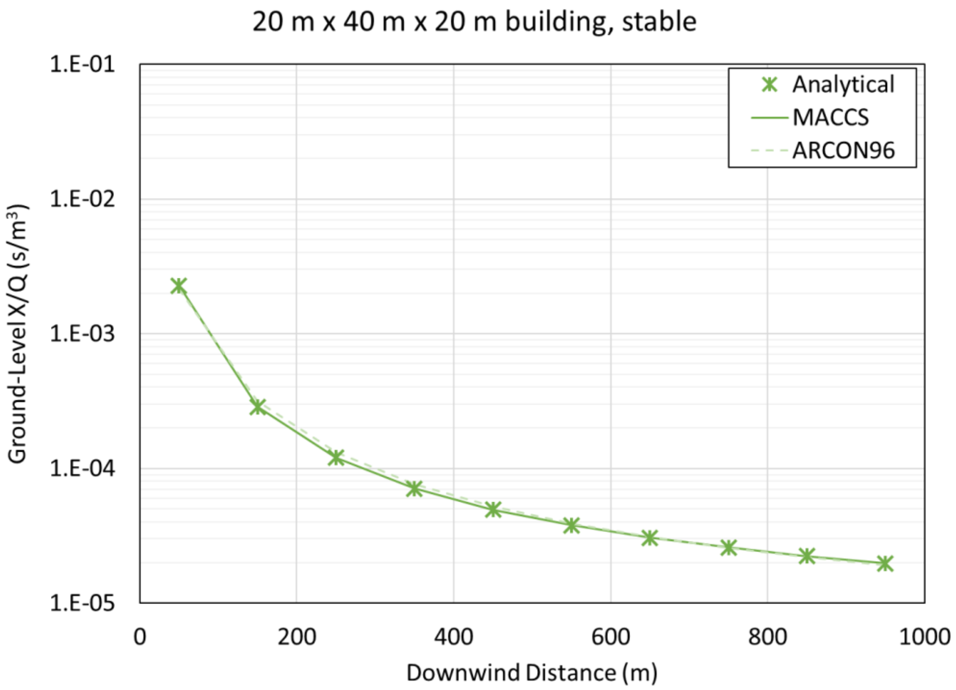
Reg. Guide 1.145

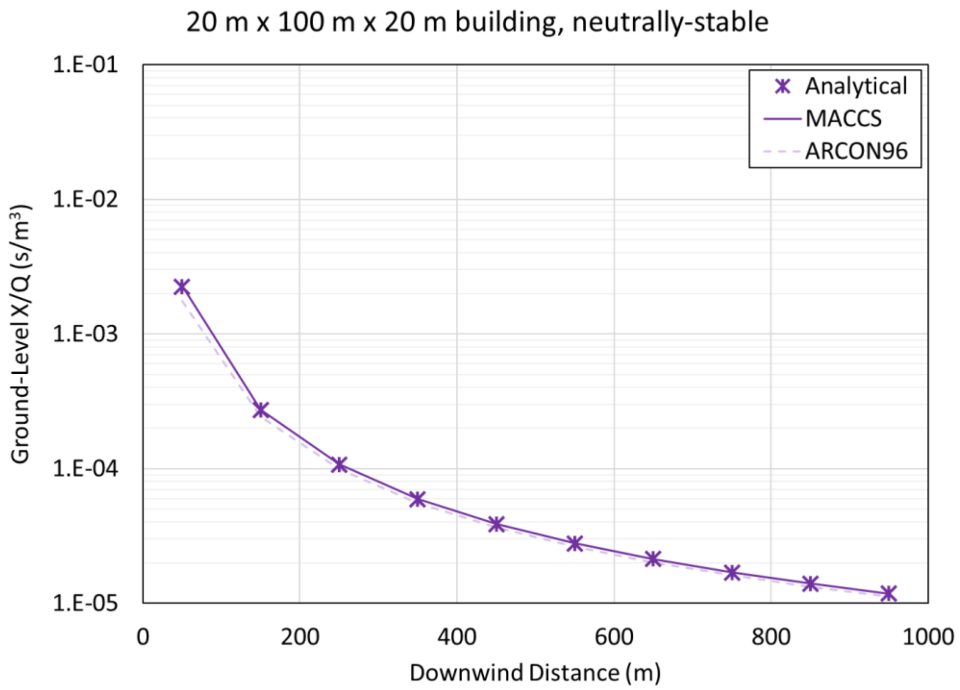
$$\chi/Q = \frac{1}{\bar{U}_{10}(\pi\sigma_y\sigma_z + A/2)} \quad (1)$$

$$\chi/Q = \frac{1}{\bar{U}_{10}(3\pi\sigma_y\sigma_z)} \quad (2)$$

$$\chi/Q = \frac{1}{\bar{U}_{10}\pi\Sigma_y\sigma_z} \quad (3)$$

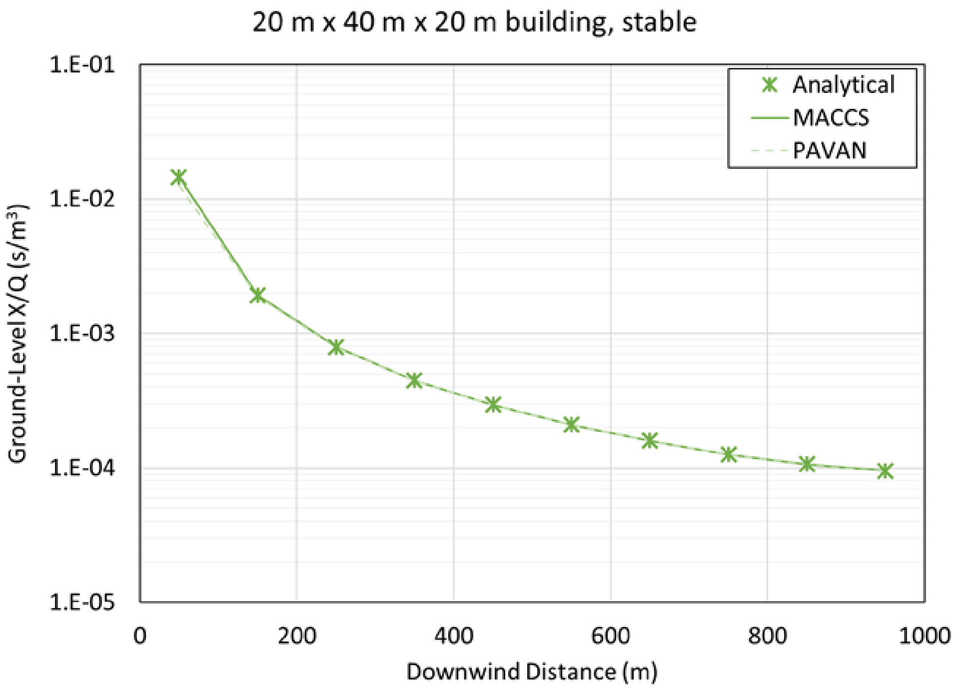
VERIFICATION-RAMSDELL AND FOSMIRE MEANDER MODEL

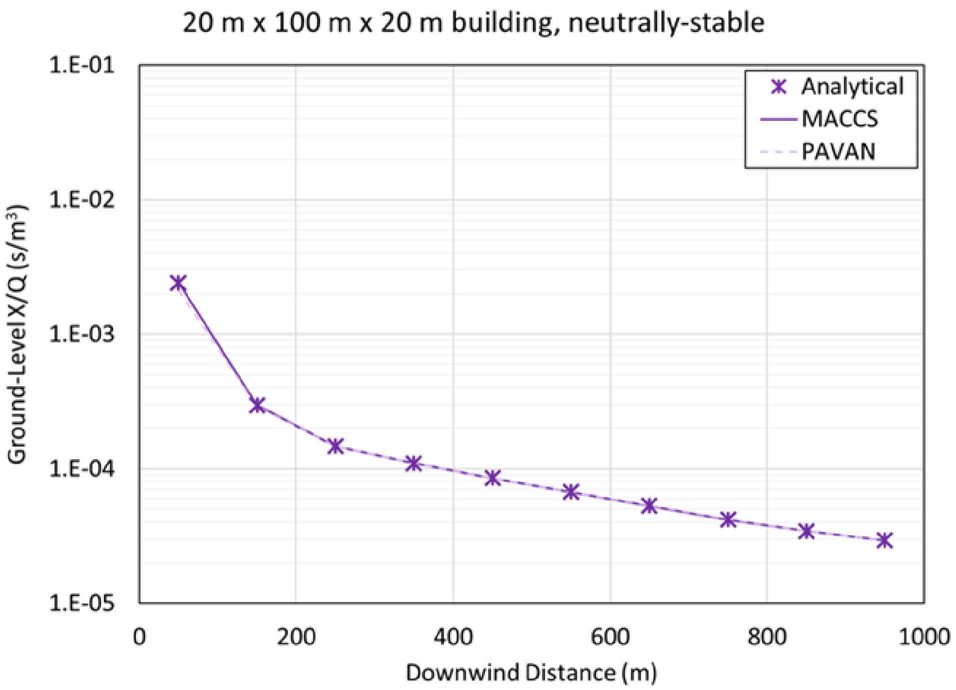




Generate **results comparable** to those from **ARCON96** with MACCS when using the Ramsdell and Fosmire meander model

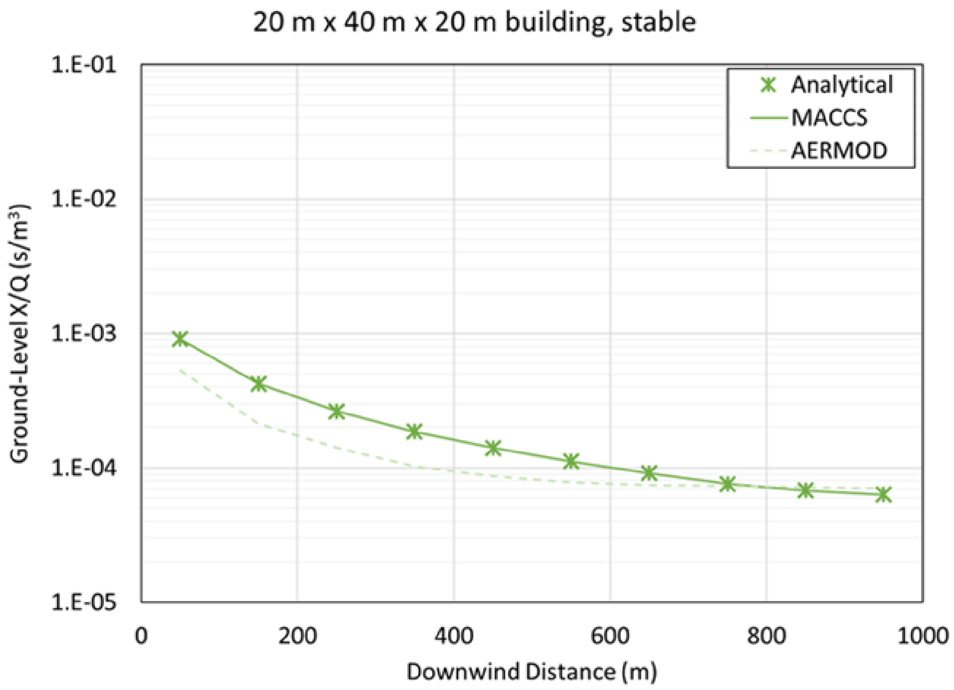
VERIFICATION-US NRC REG GUIDE 1.145 MEANDER MODEL AS IMPLEMENTED IN PAVAN

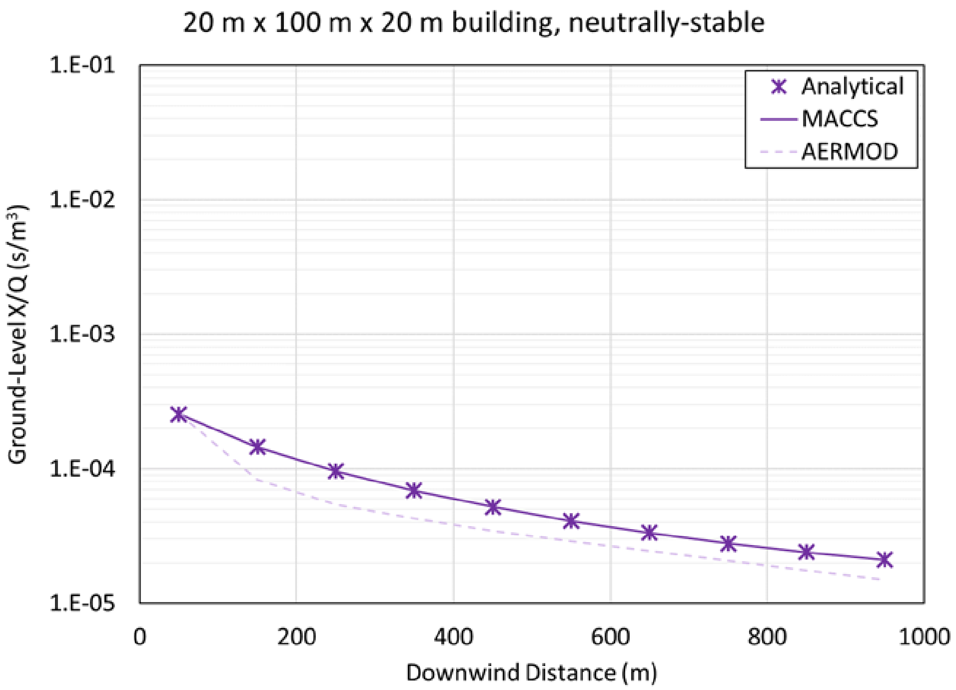




Generate **results comparable** to those from **PAVAN** with MACCS when using the full US NRC Regulatory Guide 1.145 meander model

VERIFICATION-US NRC REG GUIDE 1.145 MEANDER MODEL AS IMPLEMENTED IN MACCS 4.0



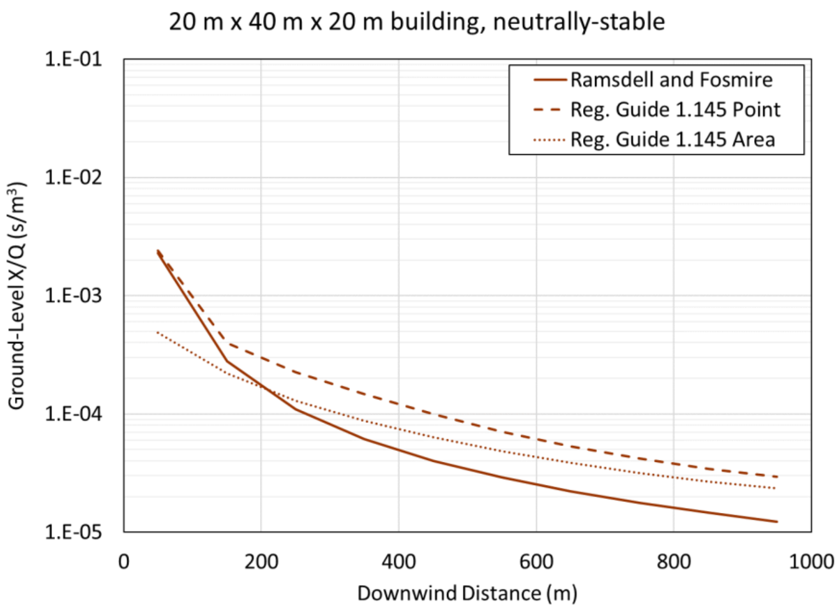


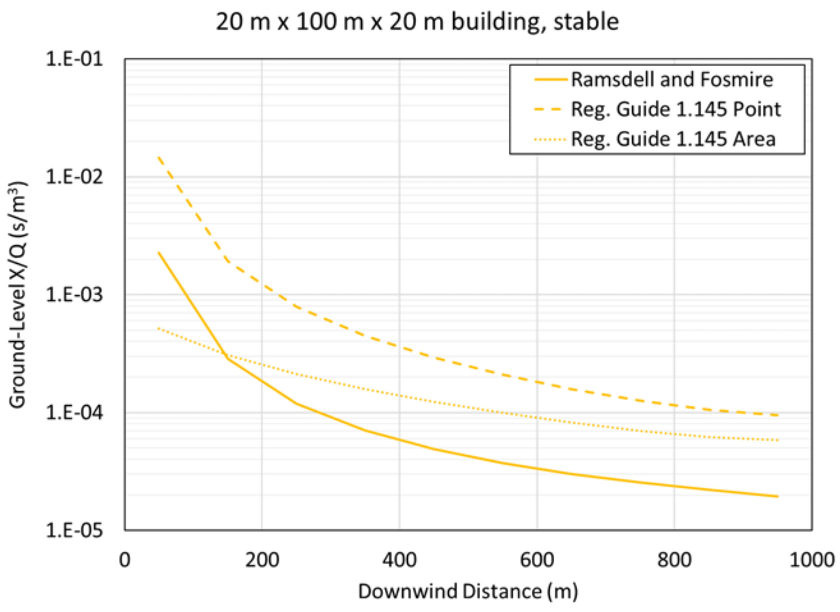
Maintain capability to **bound AERMOD** and **QUIC** results using recommended MACCS parameter choices

MODEL COMPARISONS

When using the full **US NRC Regulatory Guide 1.145 meander model**, the X/Q values for the test cases are **higher** than for the other two models

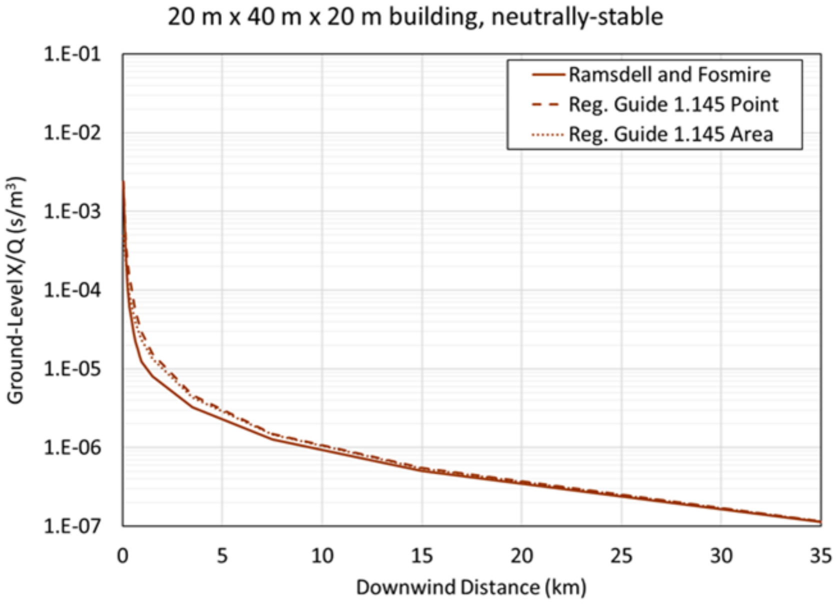
The X/Q values for the test cases with **MACCS Ramsdell and Fosmire plume meander model** are lower than the other two models except at distances of less than 200-300 m

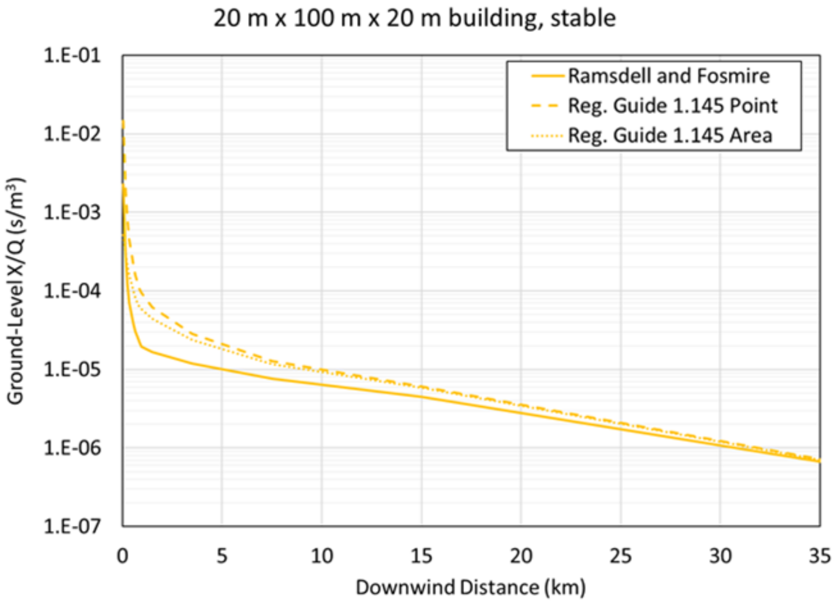




MODEL COMPARISONS CONT.

The three **models converge** with differences on the order of 5-10% at a distance of 35 km





SUMMARY ASSESSMENT OF MACCS

MACCS
Accident Consequence Model

ARCON96, AERMOD, and QUIC selected for **comparison** with **MACCS 4.0** based on initial evaluation

Based on the comparison, **MACCS 4.0 can be used in a conservative manner** at distances significantly shorter than 500 m downwind 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

Additional information available from final technical report (Clayton D.J and N.E. Bixler, “Assessment of the MACCS Code Applicability for Nearfield Consequence Analysis” SAND2020-2609, Sandia National Laboratories, Albuquerque, NM, February 2020, ADAMS Accession Number ML20059M032)

SUMMARY OF NEW MACCS CAPABILITIES

MACCS
Accident Consequence Model

Additional **nearfield meander models** are now **included** with **MACCS**

- Generate results comparable to those from ARCON96 with MACCS when using the Ramsdell and Fosmire meander model
- Generate results comparable to those 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

Comparing the plume meander model **results** shows

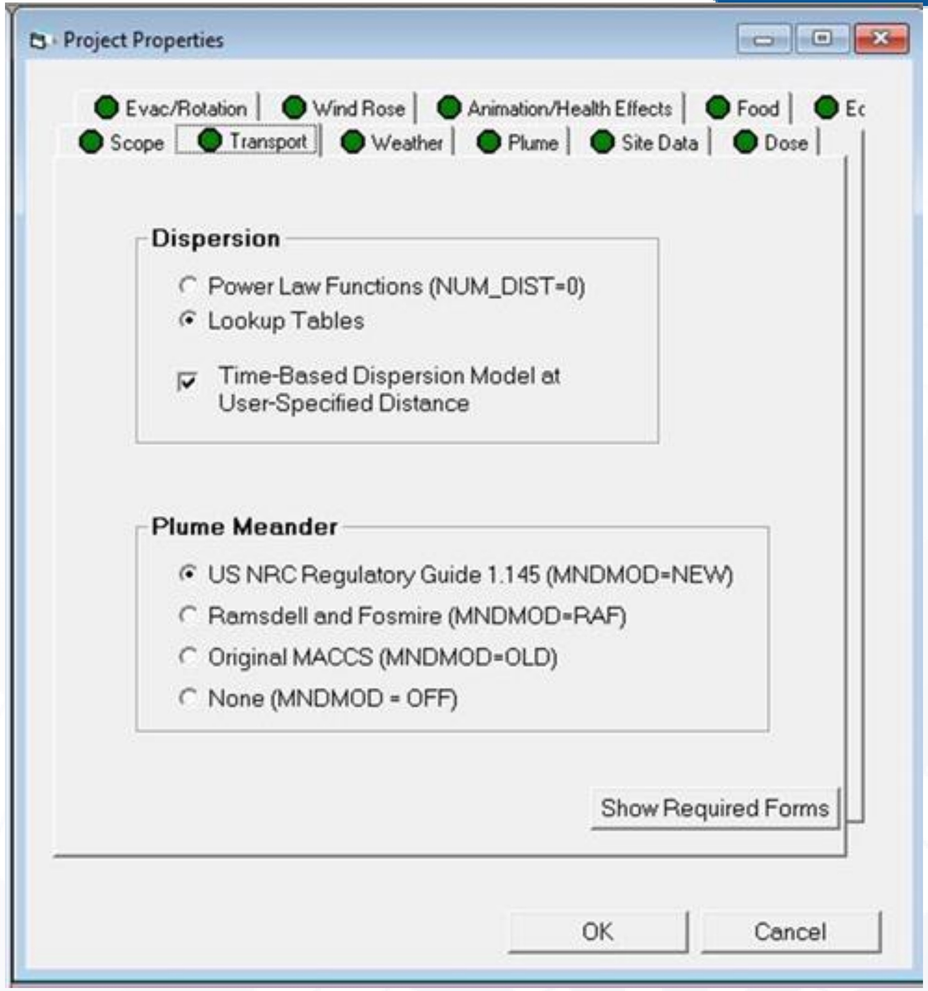
- When using the full **US NRC Regulatory Guide 1.145 meander model**, the X/Q values for the test cases are **higher** than for the other two models
- The X/Q values for the test cases with **MACCS Ramsdell and Fosmire plume meander model** are lower than the other two models except at distances of less than 200-300 m
- Beyond 1 km, **the three models converge** with differences on the order of 5-10% at a distance of 35 km.

Additional information available from final technical report (Clayton D.J, “Implementation of Additional Models into the MACCS Code for Nearfield Consequence Analysis” SAND2021-6924, Sandia National Laboratories, Albuquerque, NM, June 2021)

PROPERTIES FORM CHANGES FOR PLUME MEANDER

In WinMACCS, on the Transport tab of the Project Properties Form, updated the "Plume Meander" model list to containing:

- US NRC Regulatory Guide 1.145 [MNDMOD=NEW]
- Ramsdell and Fosmire [MNDMOD=RAF]
- Original MACCS Meander [MNDMOD=OLD)]
- None [MNDMOD=OFF]



MACCS
Accident Consequence Model

MACCS
Accident Consequence Model

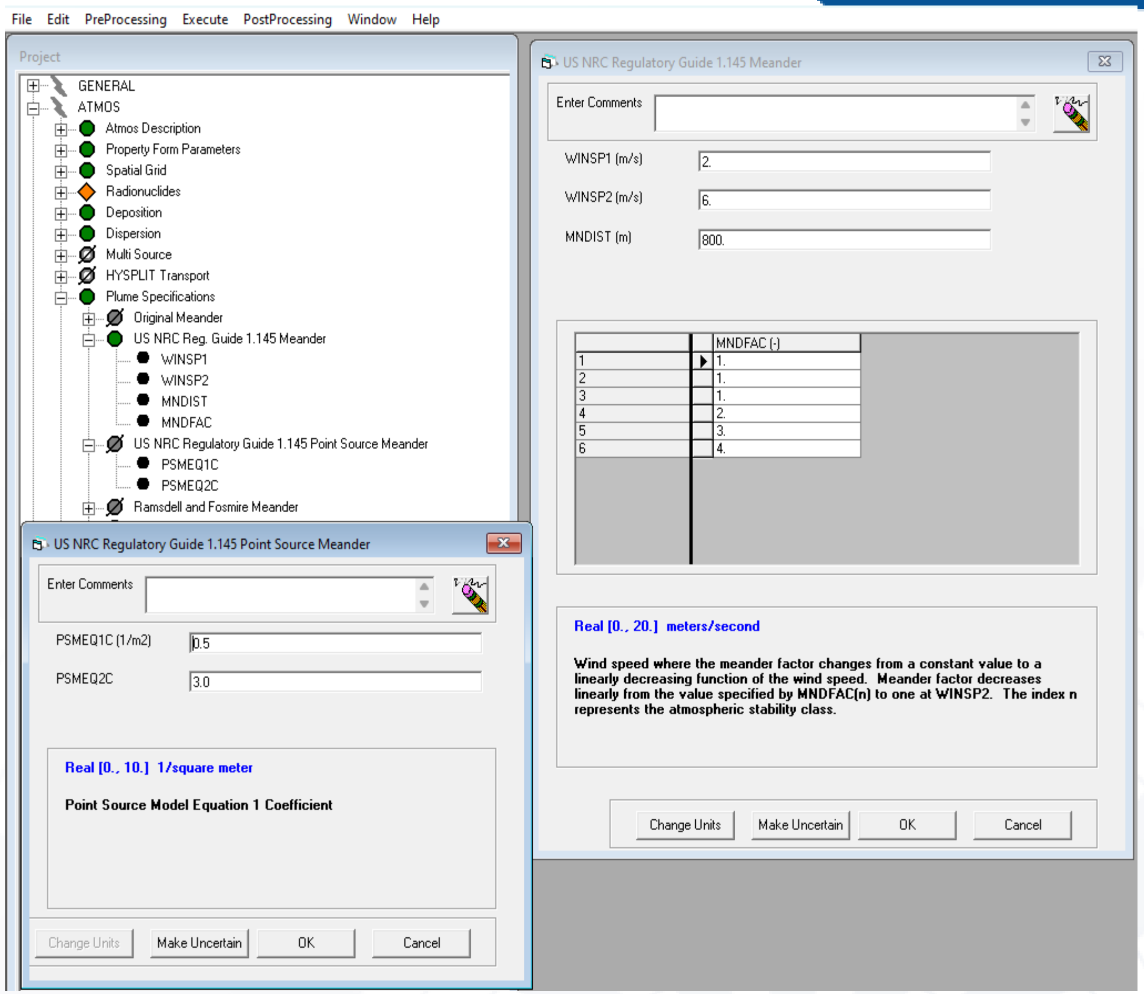
US NRC Reg Guide 1.145 Meander

[WINSP1, WINSP2, MNDIST, MNDFAC]

- Always required
- Function of wind speed, stability class
- Based on 1-hr release duration

US NRC Reg Guide 1.145 Point Source Meander [PSMEQ1C, PSMEQ2C]

- Only needed if point source option selected [SRCMOD=PNT]
- Function of building dimensions



$$f_{ym1} = 1 + \frac{0.5 \cdot A}{\pi \sigma_y(x) \sigma_z(x)}$$

$$f_{ym2} = 3$$

$$f_{ym3} = m_i \cdot f(u)$$

$$f(u) = 1 \qquad u \le u_i$$

$$f(u) = \frac{1}{m_i} exp\left[\left(1 - \frac{ln(u) - ln(u_1)}{ln(u_2) - ln(u_1)}\right) \cdot ln(m_i)\right] \qquad u_1 < u \le u_2$$

$$f(u) = {}^{1}/_{m_i} \qquad u > u_2$$

RAMSDELL & FOSMIRE PLUME MEANDER MODEL

MACCS
Accident Consequence Model

Ramsdell & Fosmire model

[RAFDIST, TIMSCLY1, TIMSCLZ1, TIMSCLY2, TIMSCLZ2, BKGTRBV, BKGTRBW, TRBINCV1, TRBINCW1, TRBINCV2, TRBINCW2]

- Function of wind speed and building dimensions

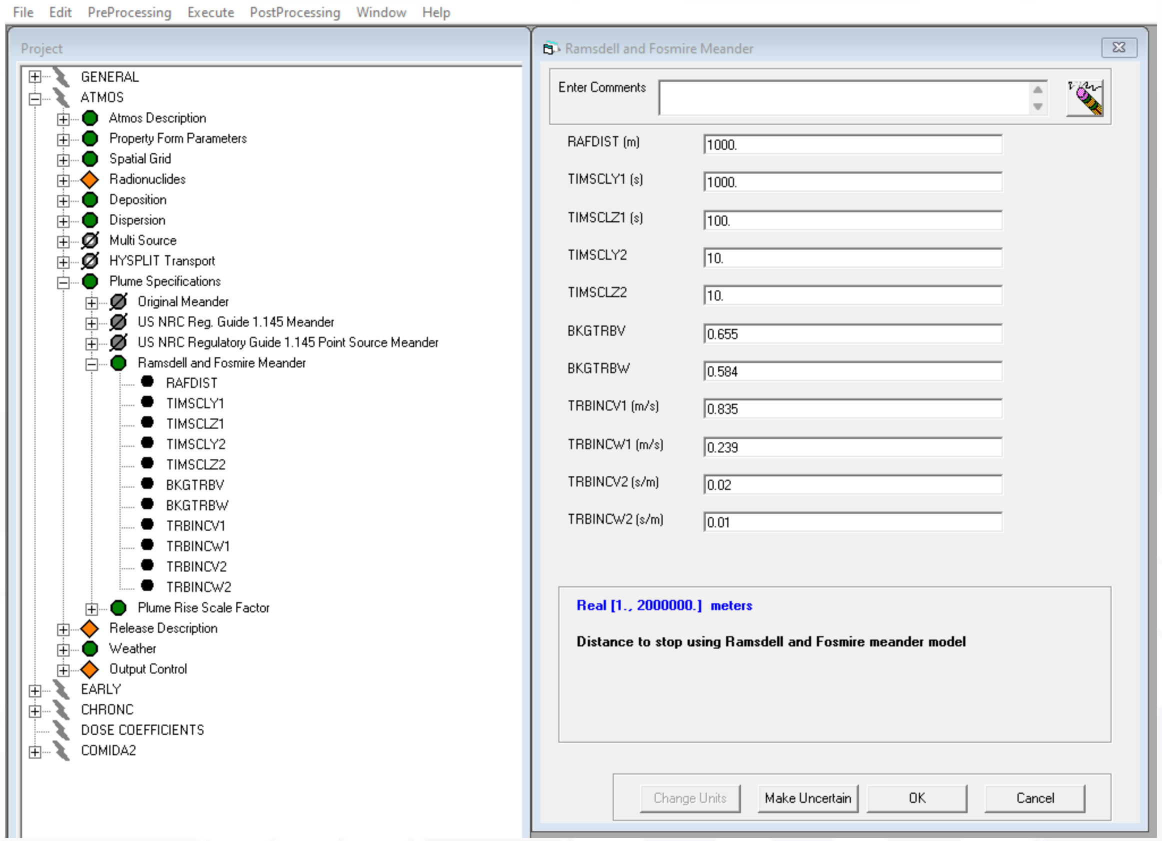
$$f_{ymRF} = \left(1 + \frac{\Delta\sigma_{y1}(x)^2 + \Delta\sigma_{y2}(x)^2}{\sigma_y(x)^2}\right)^{1/2} \qquad f_{zmRF} = \left(1 + \frac{\Delta\sigma_{z1}(x)^2 + \Delta\sigma_{z2}(x)^2}{\sigma_z(x)^2}\right)^{1/2}$$

$$\Delta\sigma_{y1}(x)^2 = 2r_v \Delta\tau_{v1}{}^2 T_{\Delta v1}{}^2 \left[1 - \left(1 + \frac{x}{T_{\Delta v1}\cdot u}\right)\cdot \exp\left(\frac{-x}{T_{\Delta v1}\cdot u}\right)\right]$$

$$\Delta\sigma_{y2}(x)^2 = 2r_v C_{Tv}{}^2 \alpha_{Tv}{}^2 u^2 A \left[1 - \left(1 + \frac{x}{\alpha_{Tv}\cdot\sqrt{A}}\right)\cdot \exp\left(\frac{-x}{\alpha_{Tv}\cdot\sqrt{A}}\right)\right]$$

$$\Delta\sigma_{z1}(x)^2 = 2r_w \Delta\tau_{w1}{}^2 T_{\Delta w1}{}^2 \left[1 - \left(1 + \frac{x}{T_{\Delta w1}\cdot u}\right)\cdot \exp\left(\frac{-x}{T_{\Delta w1}\cdot u}\right)\right]$$

$$\Delta\sigma_{z2}(x)^2 = 2r_w C_{Tw}{}^2 \alpha_{Tw}{}^2 u^2 A \left[1 - \left(1 + \frac{x}{\alpha_{Tw}\cdot\sqrt{A}}\right)\cdot \exp\left(\frac{-x}{\alpha_{Tw}\cdot\sqrt{A}}\right)\right]$$

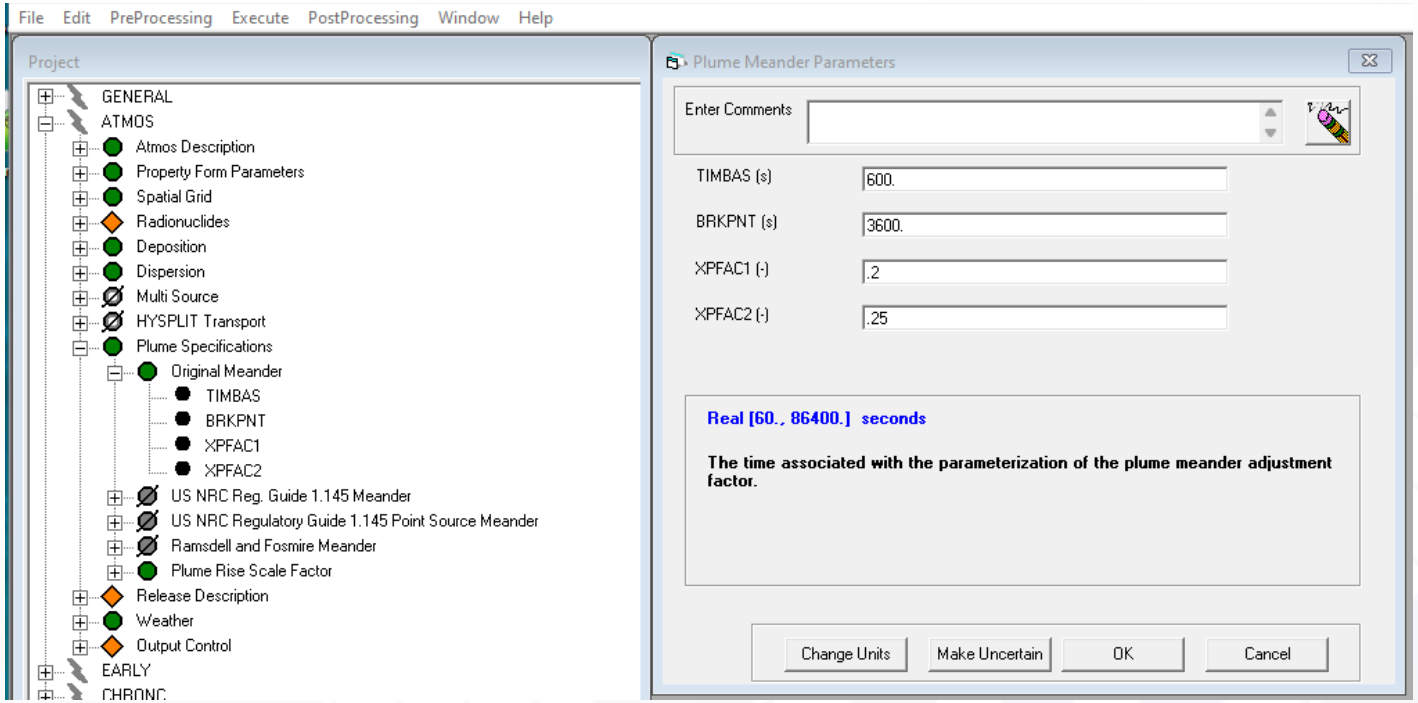


Original meander model

[TIMBAS, BRKPNT, XPFAC1, XPFAC2]

- Function of release duration

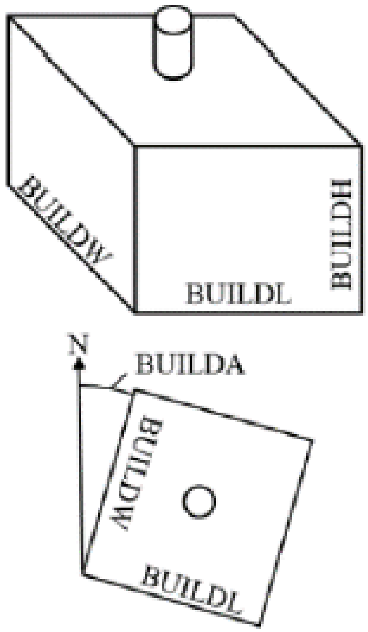
$$
\begin{aligned}
f_m &= 1 & &\text{if} \quad \Delta t_{release} \le \Delta t_0 \\
f_m &= \left(\frac{\Delta t_{release}}{\Delta t_0}\right)^{F_1} & &\quad \Delta t_0 < \Delta t_{release} \le \Delta t_1 \\
f_m &= \left(\frac{\Delta t_{release}}{\Delta t_0}\right)^{F_2} & &\quad \Delta t_1 < \Delta t_{release} \le 10\ hours
\end{aligned}
$$

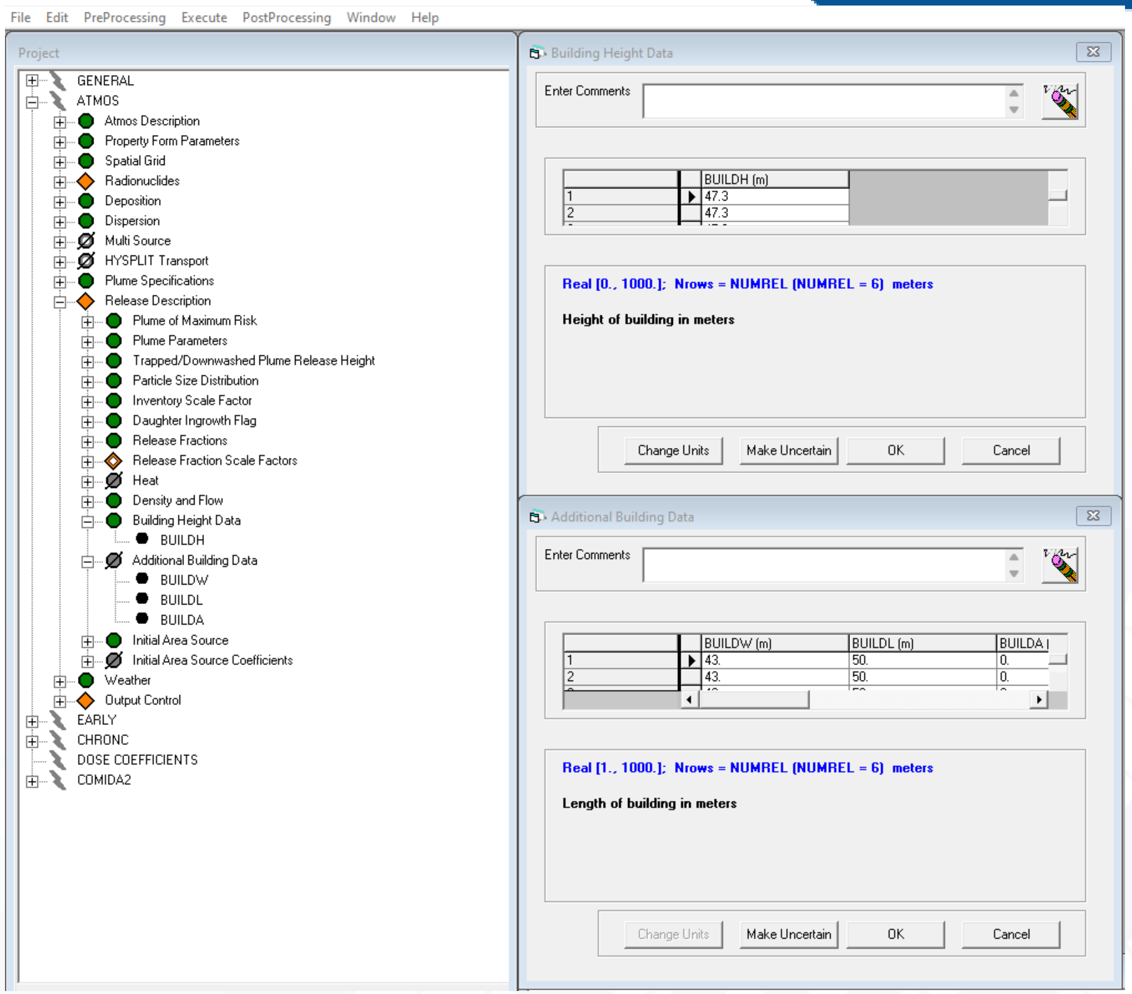


BUILDING DESCRIPTION

Building Height Data
[BUILDH]
- Always needed
- Building height can be 0

Additional Building Data
[BUILDW, BUILDL, BUILDA]
- Only needed when using models that require full building information

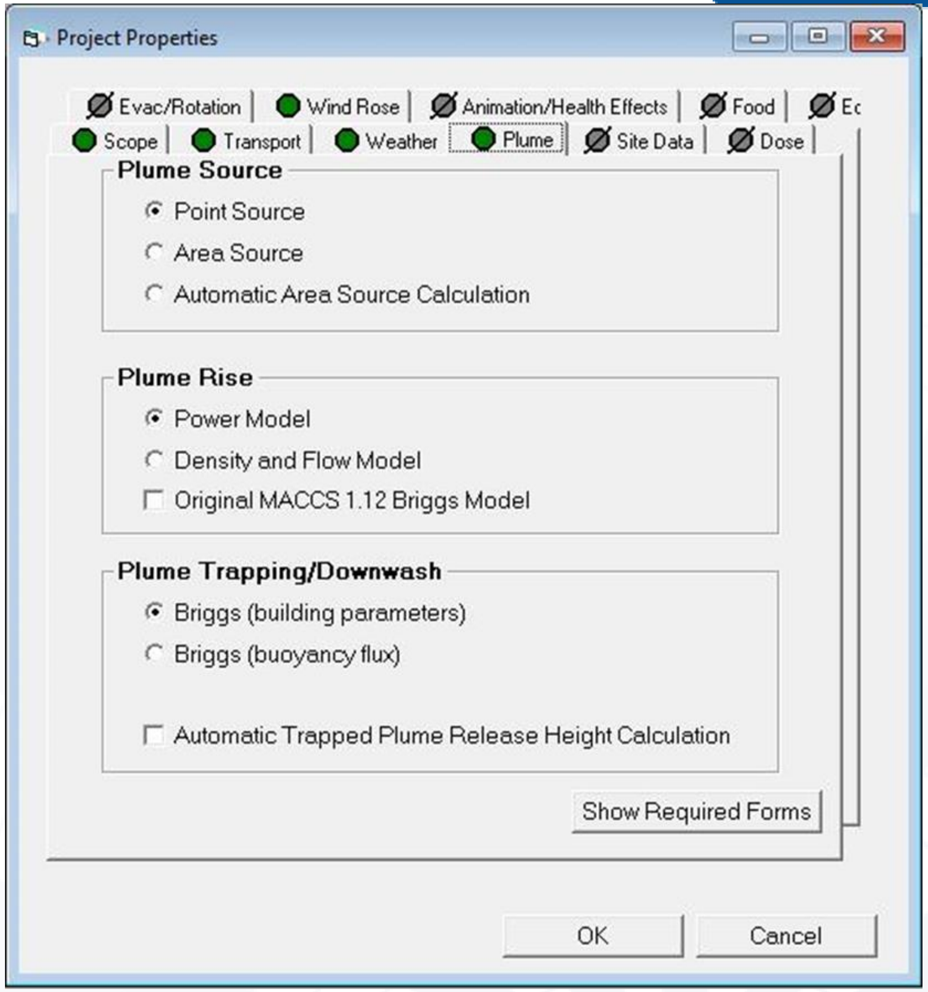




PROPERTIES FORM CHANGES FOR PLUME SOURCE

In WinMACCS, on the Plume/Source tab of the Project Properties Form, added a “Plume Source” model list containing:

- Point source [SRCMOD=PNT]
- Area source [SRCMOD=AREA]
- Automatic area source calculation [SRCMOD=AUTO]



PLUME SOURCE MODEL

Point Source [SRCMOD=PNT]

- Assumes a value of 0.1 m for σ_y and σ_z

Area Source [SRCMOD=AREA]

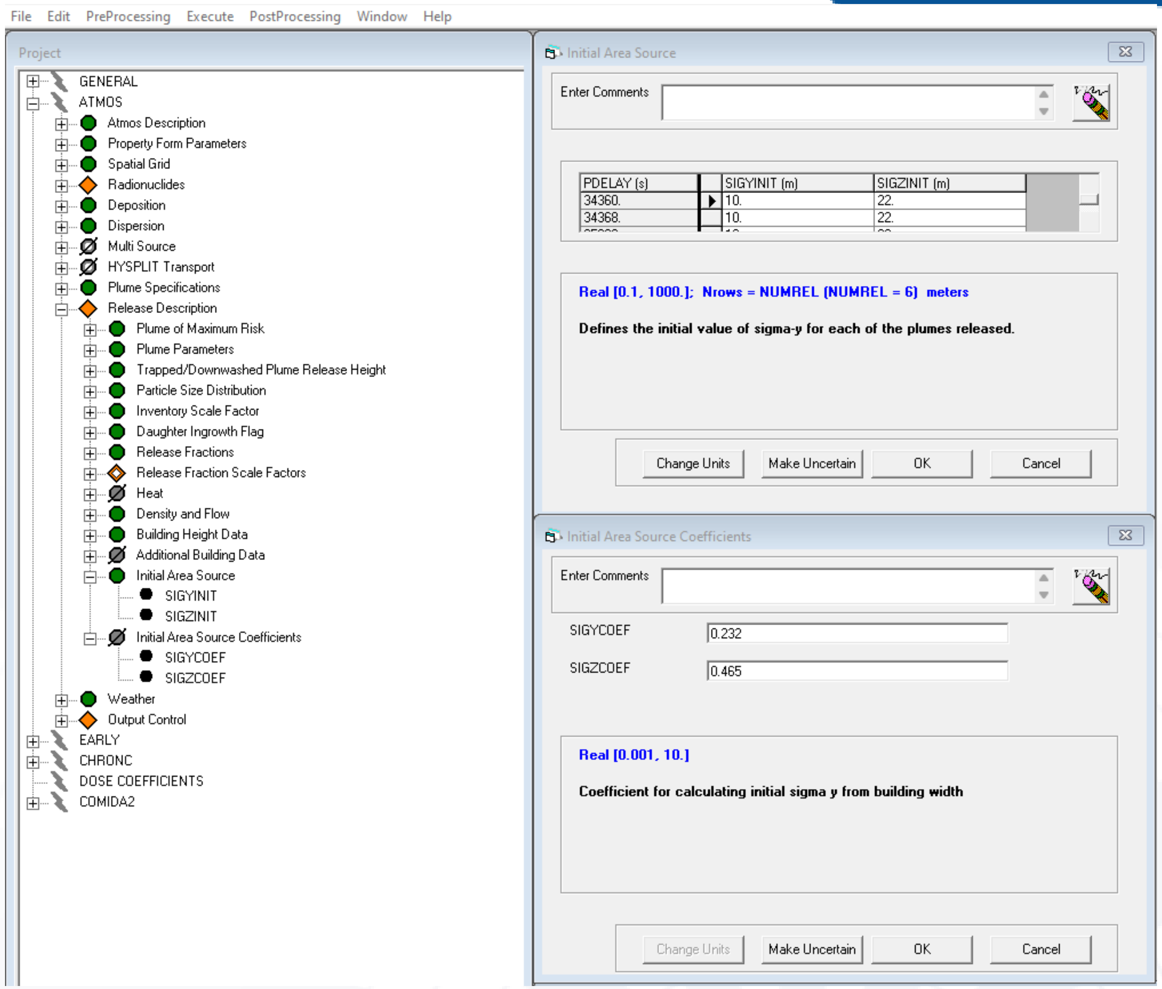
- Uses specified value of initial source [SIGYINIT, SIGZINIT]

Automatic Source [SRCMOD=AUTO]

- Calculates initial source based on building dimensions and wind direction [SIGYCOEF, SIGZCOEF]

$$\sigma_y = C_y W_B$$

$$\sigma_z = C_z H_B$$



In WinMACCS, on the Plume/Source tab of the Project Properties Form, added a "Trapping/Downwash" model list containing:

- Briggs (building parameters) [TDWMOD=BRGBLD]
- Briggs (buoyancy flux) [TDWMOD=BRGFLX]
- Check box for automatic calculation [TDWAUTO=TRUE,FALSE]

Briggs (building parameters) [TDWMOD=BRGBLD]

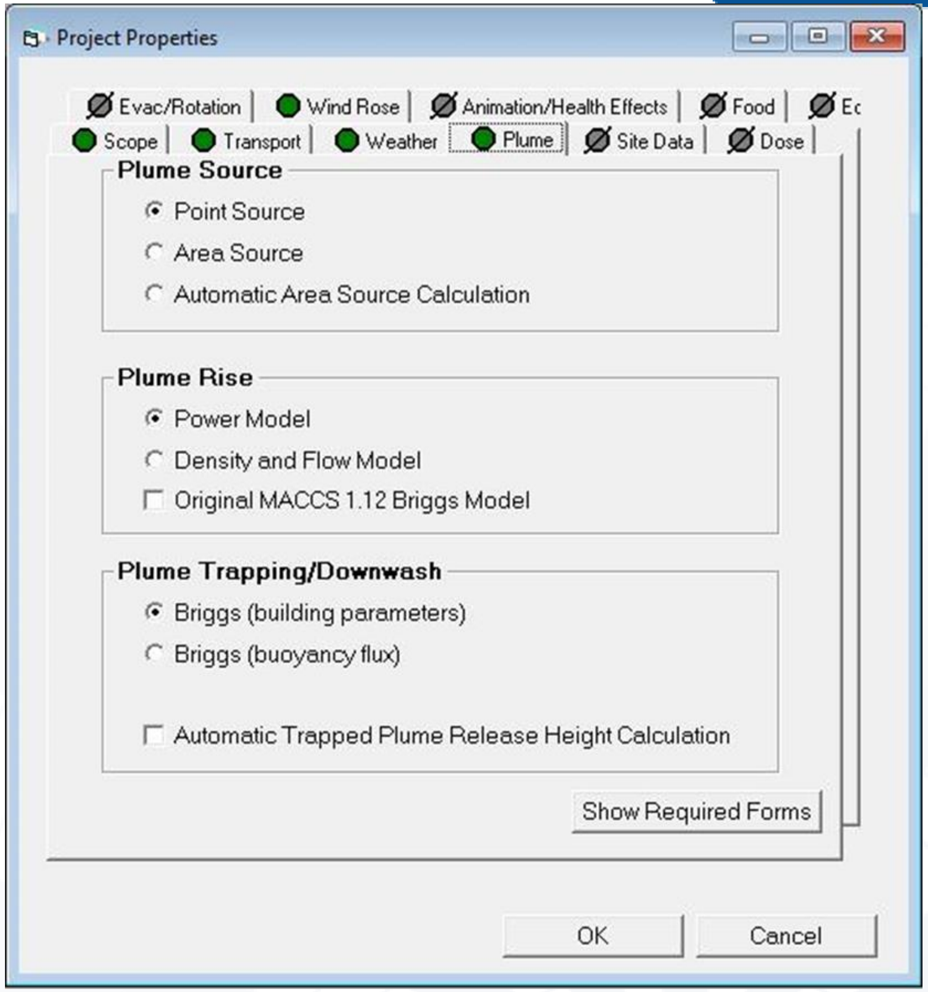
- Plume segment is calculated as trapped (influenced by wake region) based on building parameters

$$H_{Plume} < H_b + 1.5 * x$$

Briggs (buoyancy flux) [TDWMOD=BRGFLX]

- Plume segment is calculated as trapped based on wind speed and buoyancy flux

$$u_c = \left[\frac{9.09F}{H_b}\right]^{\frac{1}{3}}$$

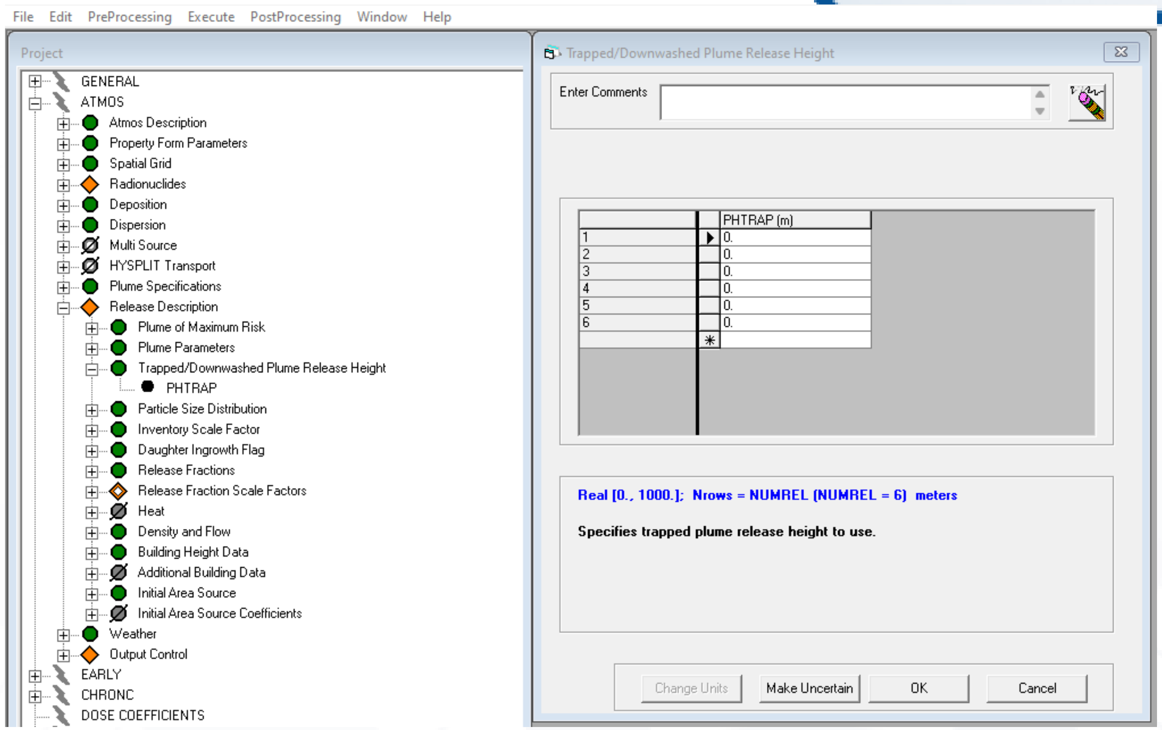


TRAPPING/DOWNWASH MODEL

MACCS
Accident Consequence Model

Trapped/Downwashed Plume Release Height [PHTRAP]

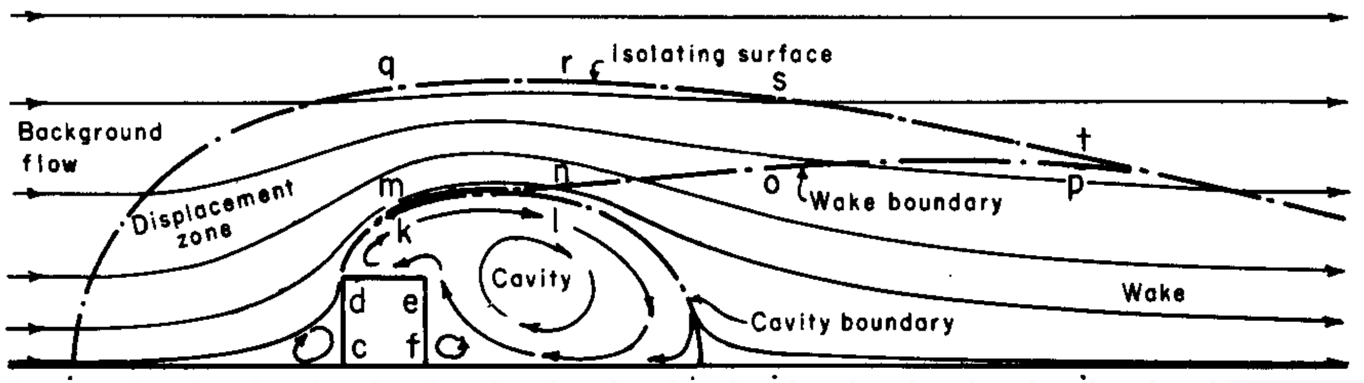
- Post wake region plume centerline height
- If automatic calculation is off, use value specified on form [TDWAUTO=FALSE]
- If automatic calculation is on, use the following [TDWAUTO=FALSE]



$$H_{Trap} = 2 * H_{Plume} - (H_b + 1.5 * x) \qquad H_b < H_{Plume} < H_b + 1.5 * x\,,$$

$$H_{Trap} = H_{Plume} - 1.5 * x \qquad H_{Plume} < H_b$$

If $H_{Trap} < 0.5 * x$, then $H_{Trap} = 0$



QUESTIONS?

BACKUP

QUIC RESULTS

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)