



# Independent Verification of MACCS Air Dispersion and Dose Models

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# Acknowledgments



- Project sponsored by the US Nuclear Regulatory Commission (NRC)
  - Office of Nuclear Regulatory Research
  - Division of Systems Analysis
  - Accident Analysis Branch
- This presentation describes work performed by the CNWRA for the NRC under Contract No. 31310018D0002
- This project is an independent product of the CNWRA and it does not necessarily reflect the views of the NRC. The NRC staff views expressed herein are preliminary as part of an ongoing MACCS testing project
- Appreciation extended to Daniel Clayton and Jennifer Leute of Sandia National Laboratories for generous support to the testing project

# Outline

3



Testing approach



Salient issues in MACCS 4.0  
(addressed in MACCS 4.1)



Examples of testing results



Remarks

# Testing approach

- Independent testing from software developers
- Examination of extreme and limiting cases (e.g. very high source point, very broad plumes) with closed form solutions
- Simple system: one plume segment, constant windspeed, one cohort staying in place (not evacuating nor relocating), no decay chains, one long-lived isotope, uniform population density
- Testing exposed non-intuitive trends, which required exploration
- Identified issues were addressed in the latest MACCS Version 4.1 release

# Three stage testing

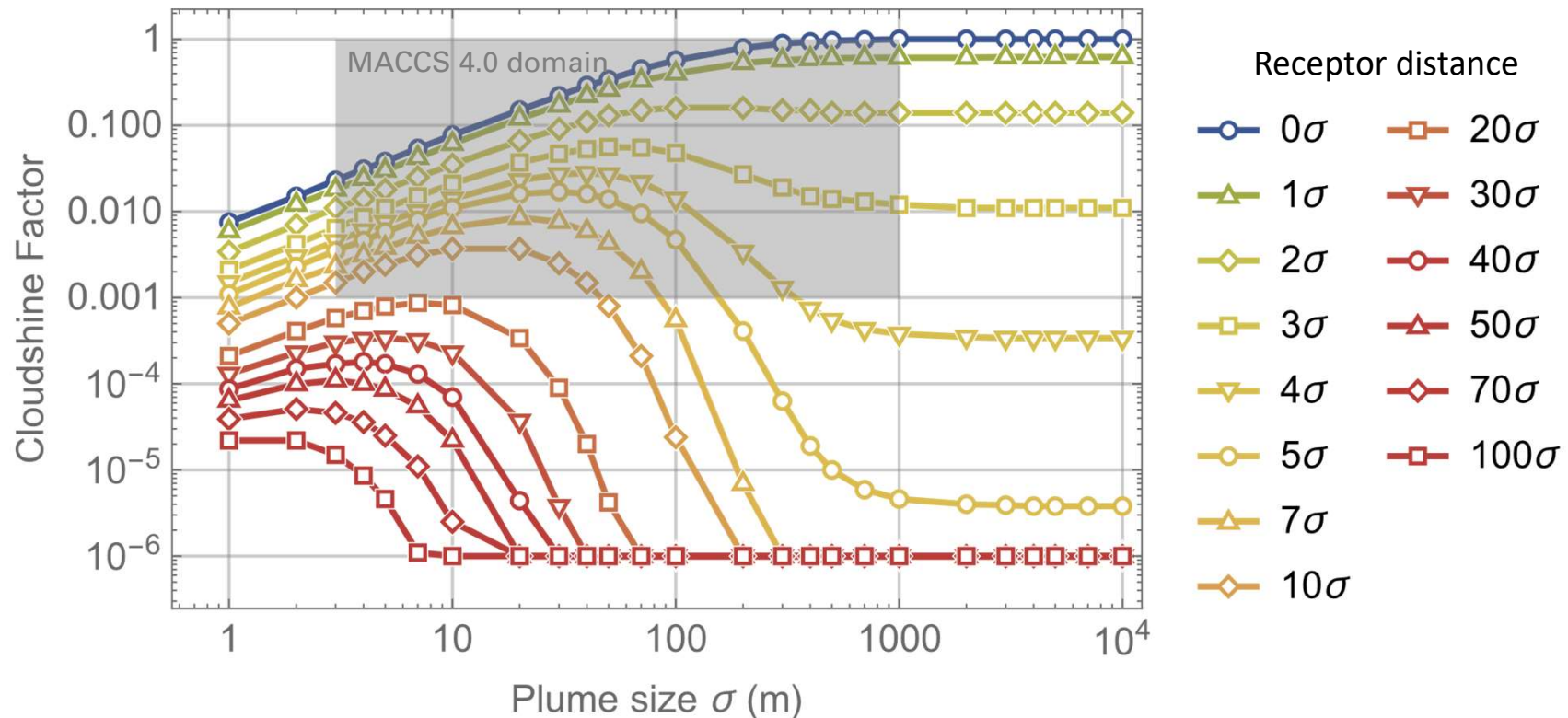
- Compute benchmark concentrations (plume centerline, air concentration at the ground level, ground concentration) from Gaussian steady-state air concentration equations and ground deposition models
- Given concentrations reported in MACCS outputs, compute benchmark doses (inhalation, cloudshine, groundshine, and skin deposition)
- Given MACCS doses, compute benchmark health effects



# Three salient issues in MACCS Version 4.0

- Computation of the cloudshine factor, by interpolation of a lookup table, to establish a cloudshine dose
- Computation of concentrations in broad plumes
- Narrow plume approximation to convert polar to Cartesian coordinates

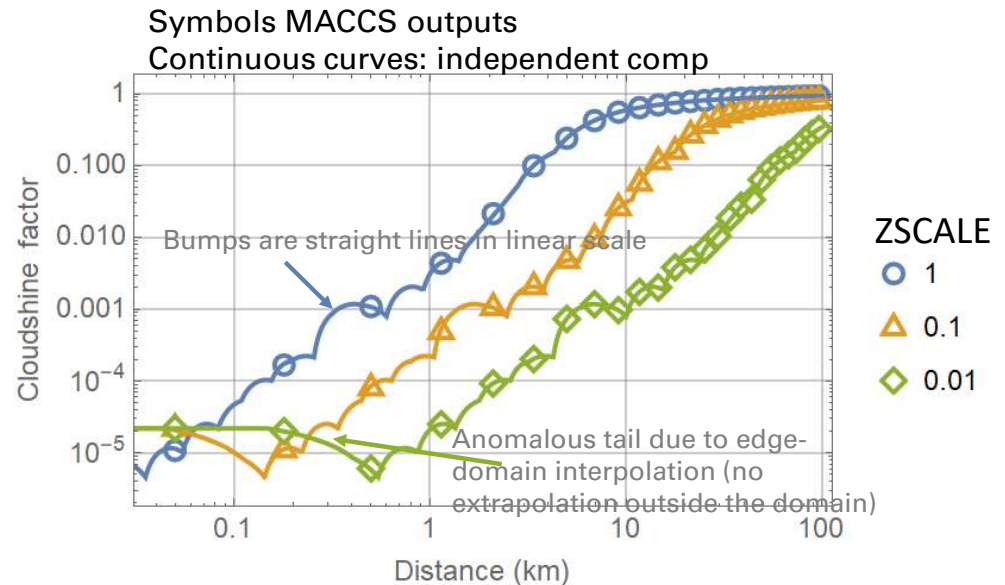
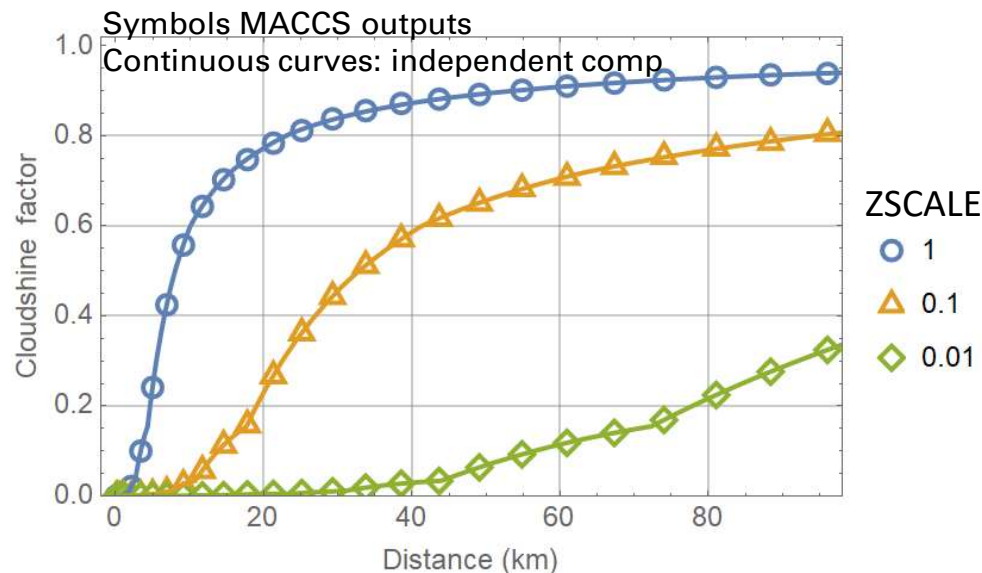
# Cloudshine factor lookup table



- Factor to compute immersion doses as a function of plume centerline concentrations, based on work by Healy (1984)



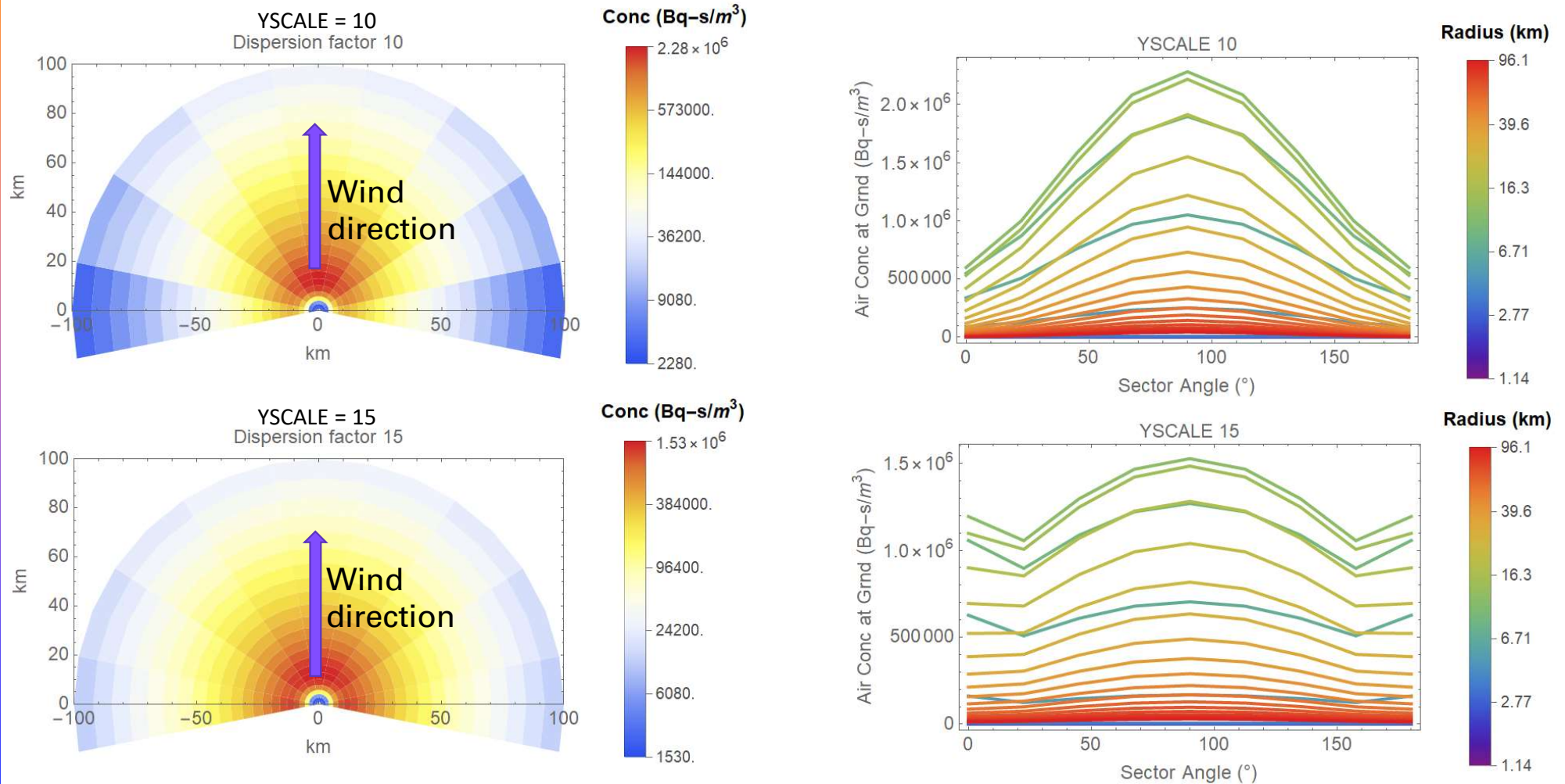
# Verification of the cloudshine factor



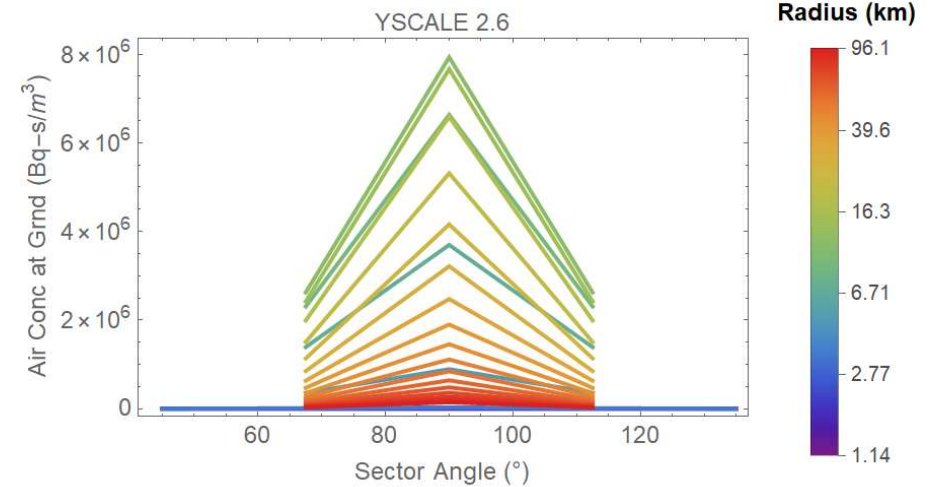
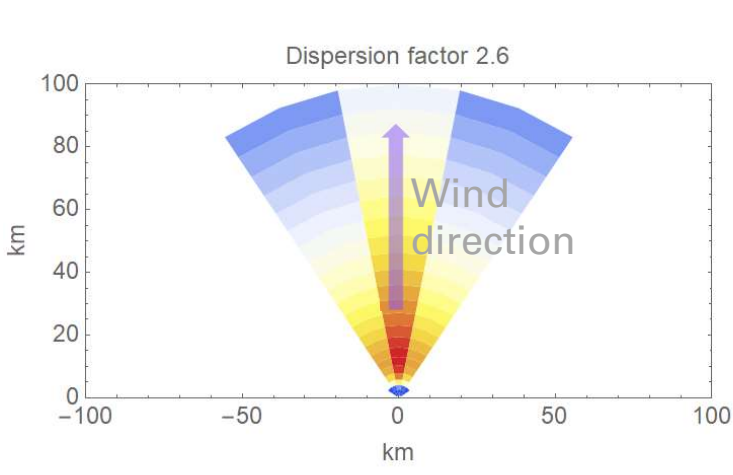
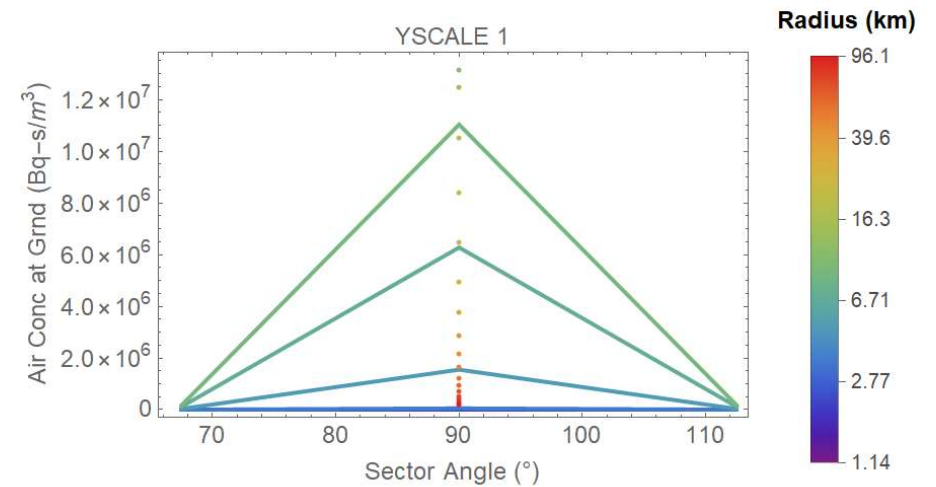
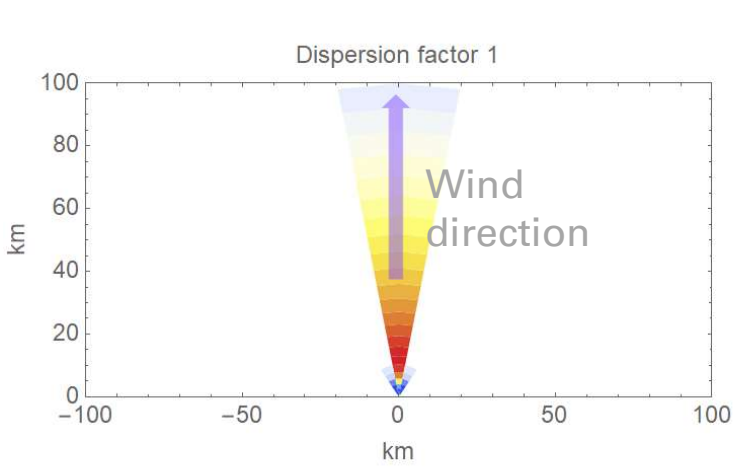
- The curves represent different cases of vertical plume spread (ZSCALE factor acting on  $\sigma_z$ )
- MACCS cloudshine factor computed from the cloudshine centerline dose, centerline concentration, and the radionuclide-specific dose conversion factor



# MACCS Version 4.0: concentrations in broad plumes



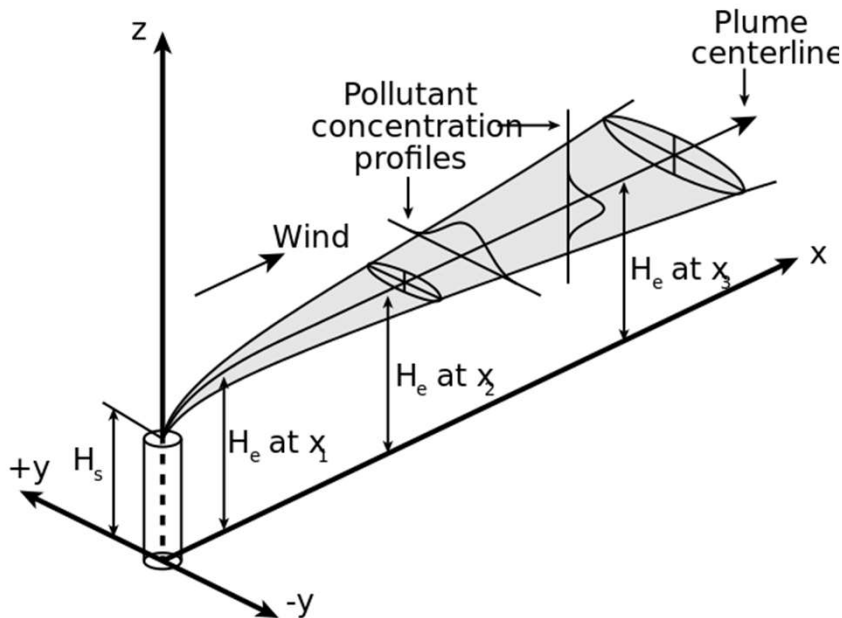
# MACCS Version 4.1: concentrations in broad plumes



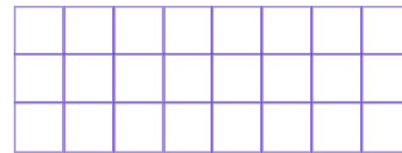
# Basic equations expressed in Cartesian coordinates

$$\chi(x, y, z) = \frac{Q}{u \sqrt{2\pi} \sigma_y(x)} \exp\left(-\frac{1}{2} \frac{y^2}{\sigma_y(x)^2}\right) \psi(x, z)$$

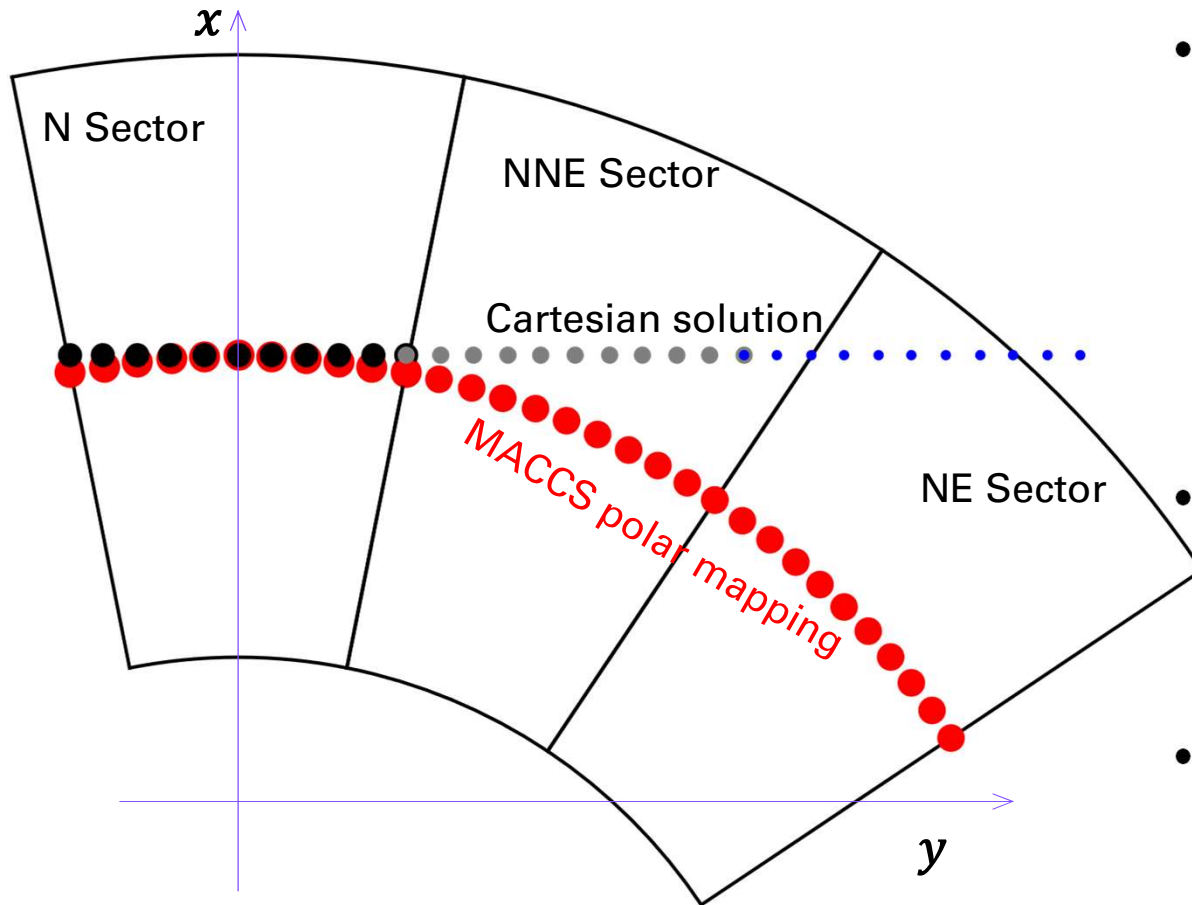
$$\psi(x, z) = \frac{1}{\sqrt{2\pi} \sigma_z(x)} \sum_{n=-N}^N \left\{ \exp\left[-\frac{1}{2} \frac{(z - h + 2nH)^2}{\sigma_z(x)^2}\right] + \exp\left[-\frac{1}{2} \frac{(z + h + 2nH)^2}{\sigma_z(x)^2}\right] \right\}$$



- Gaussian concentration equations correspond to steady-state solutions in Cartesian coordinates

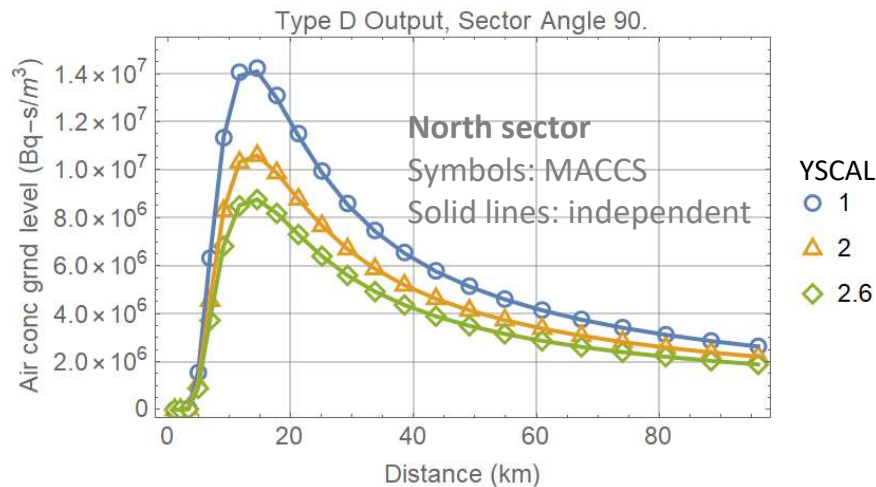


# MACCS polar mapping (narrow plume approximation)

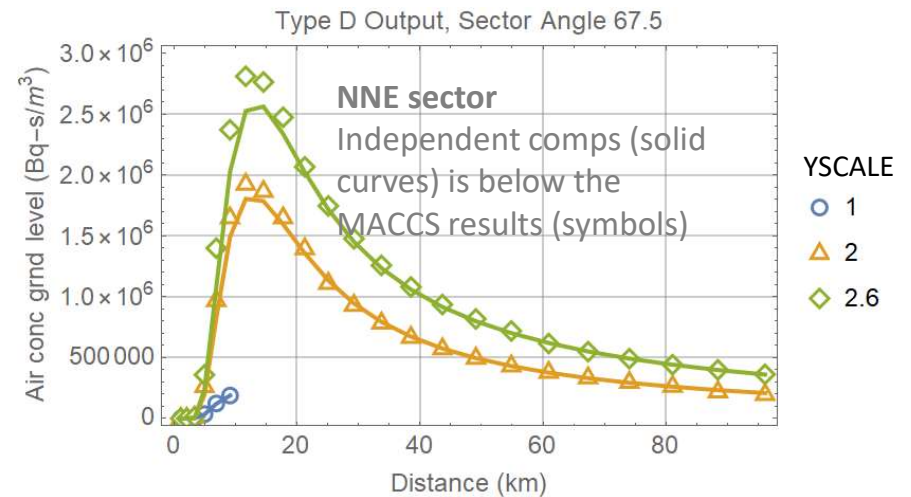
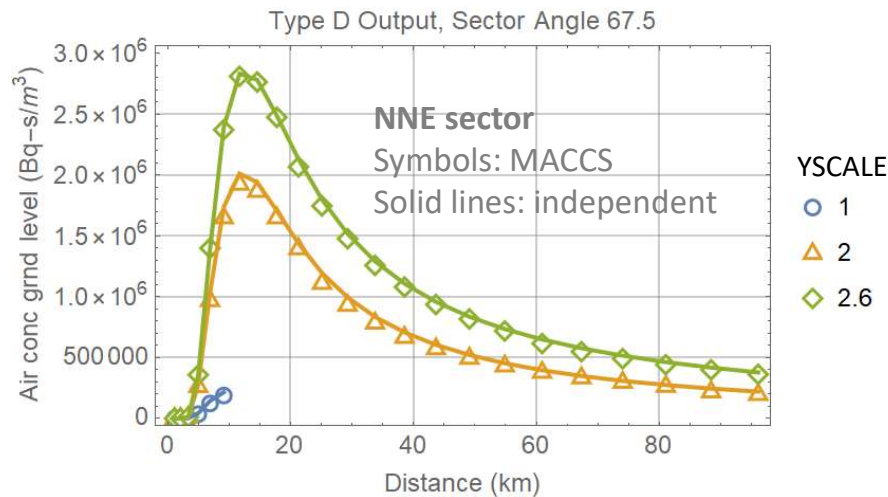


- The concentration  $\chi(x, y)$  in Cartesian coordinates is mapped by MACCS along the arc of constant radius (red points)
  - $x \rightarrow r$
  - $y \rightarrow r \theta = \text{arc length}$
- The average concentration along the arc defines the average concentration of the sector
- Average concentrations are used to compute population doses and health effects

# Comparison to independent computations

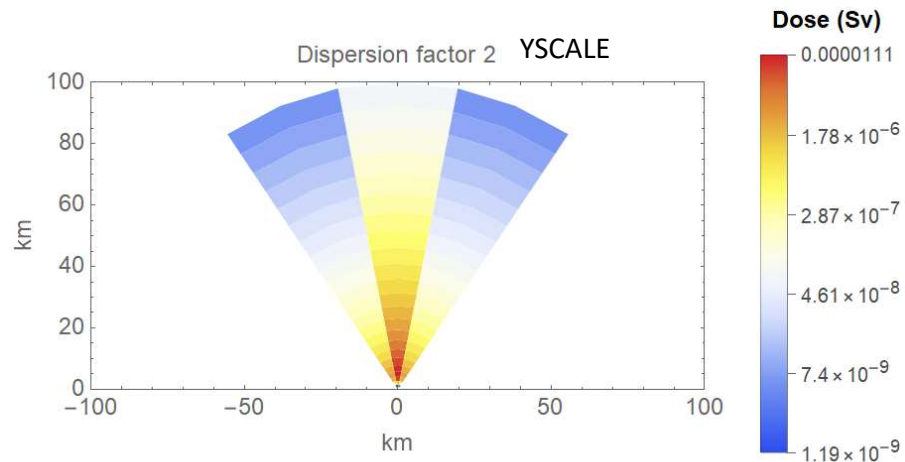


Independent computations below: proper Cartesian coordinate solution along constant-radius arcs

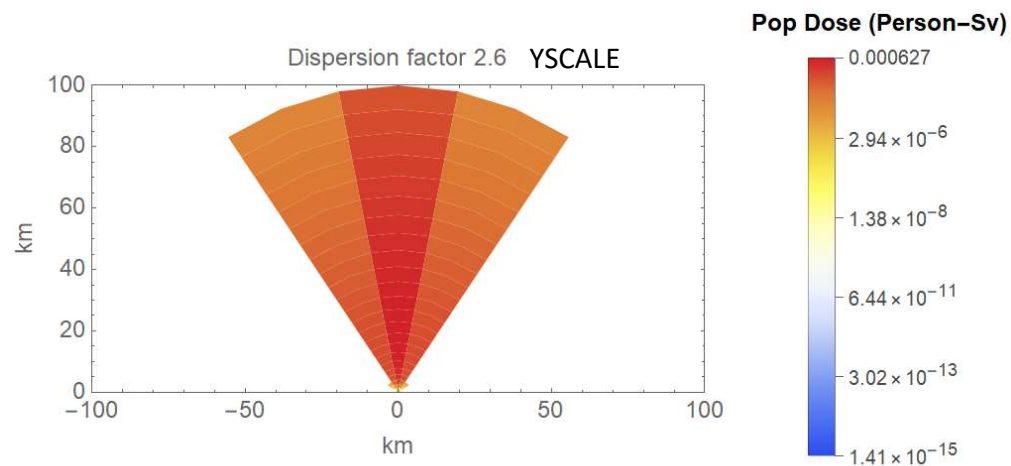
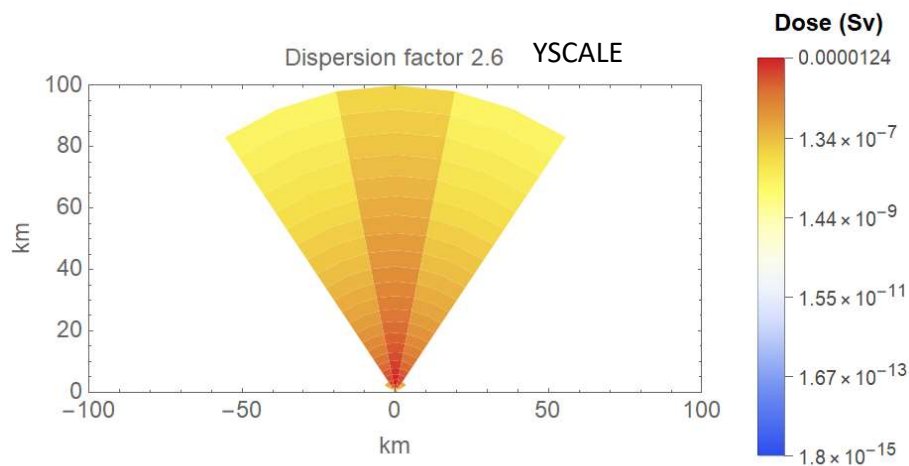
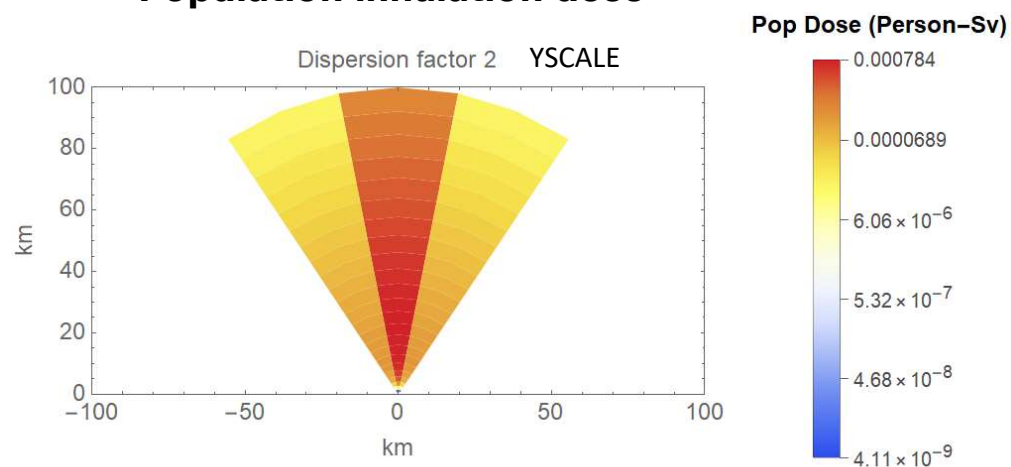




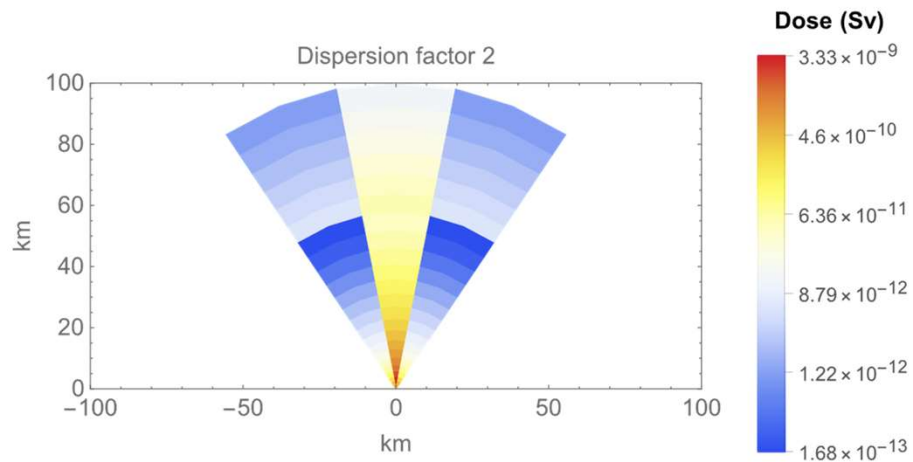
## Inhalation dose



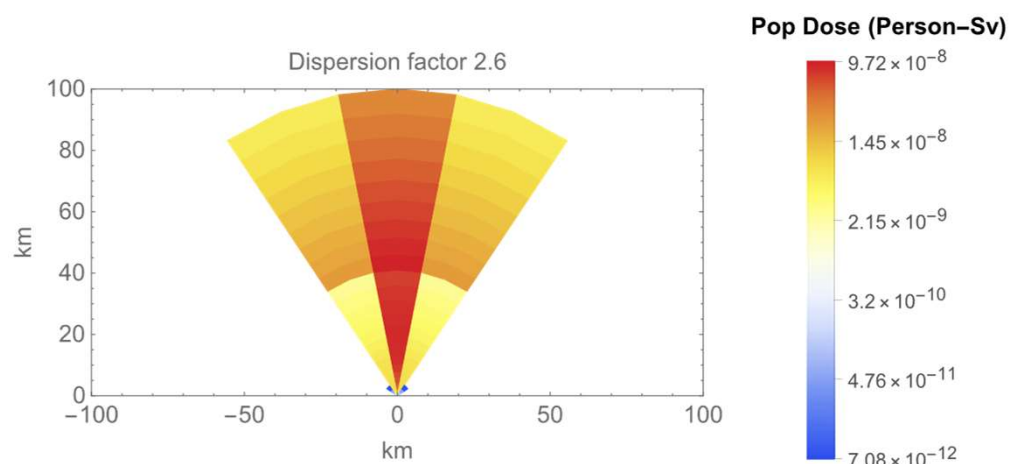
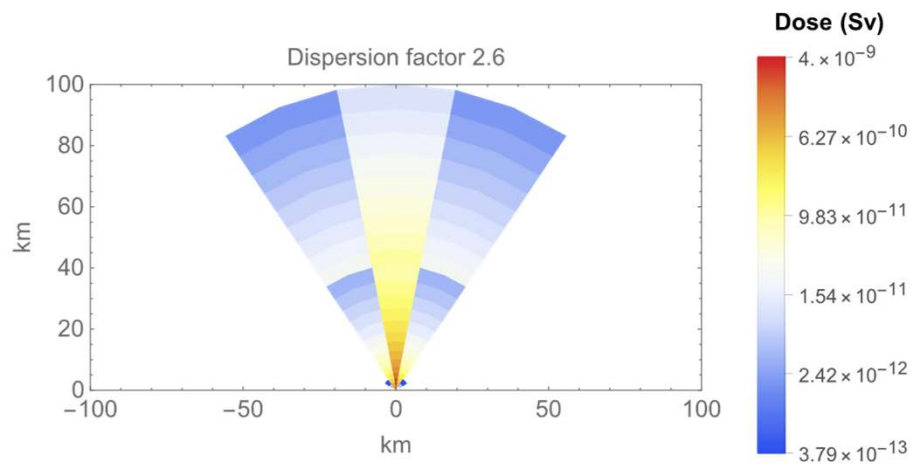
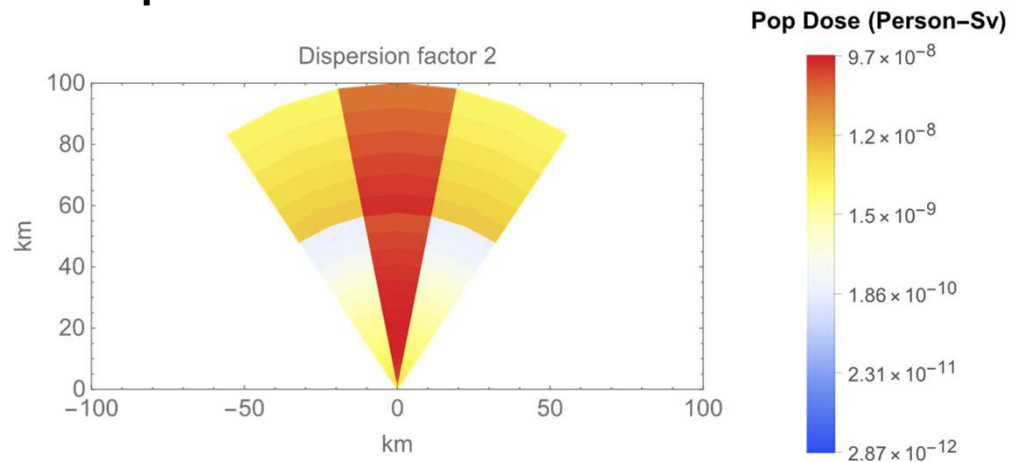
## Population inhalation dose



## Cloudshine dose

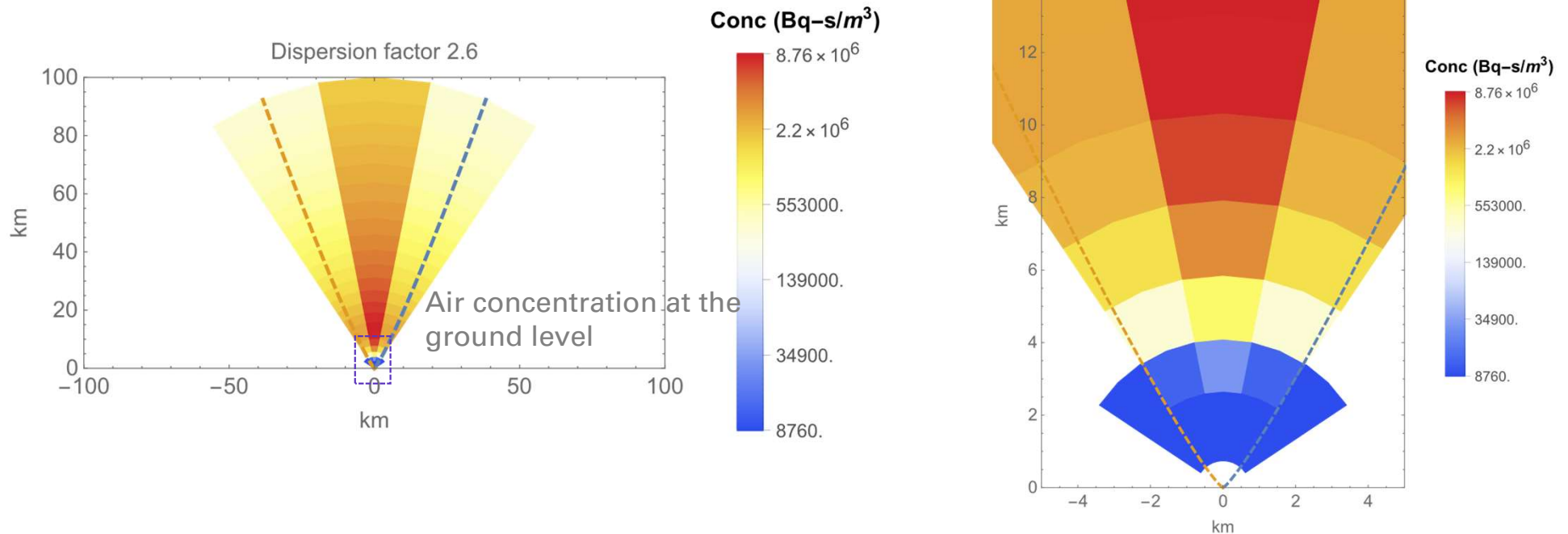


## Population cloudshine dose



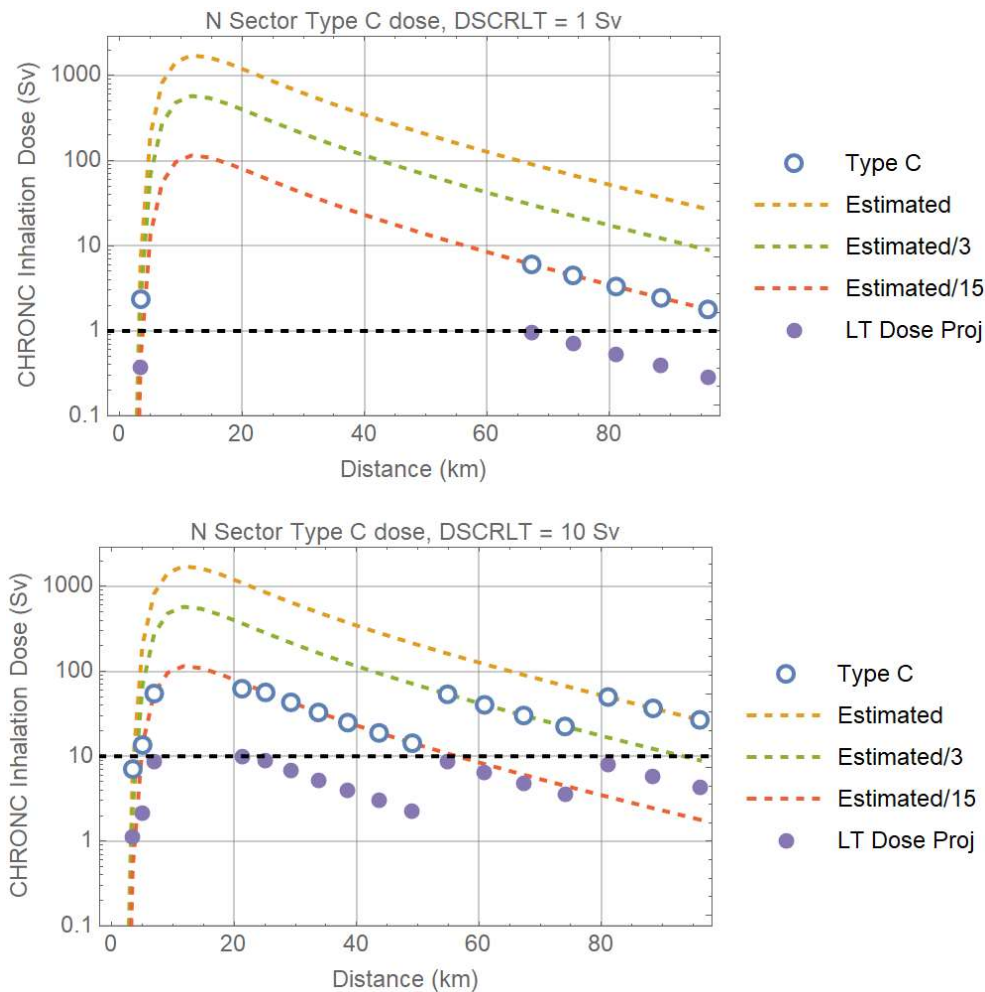


# $\pm 2.15 \sigma_y$ limits for the spread



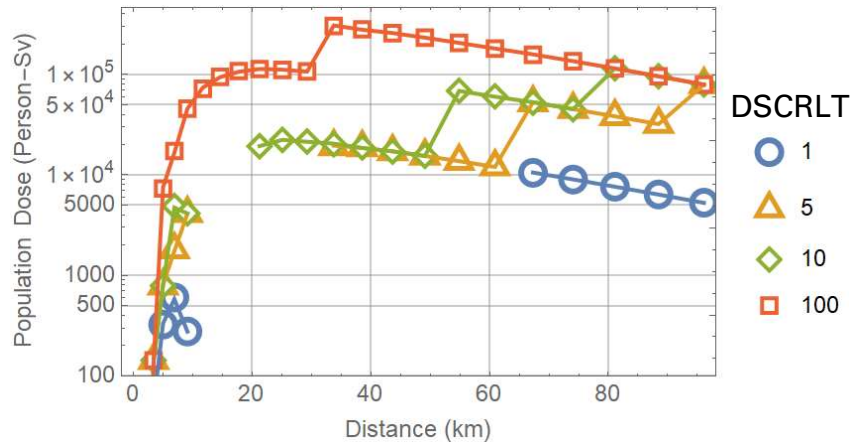
- The last MACCS lateral sector is the sector with boundaries exceeding the  $\pm 2.15 \sigma_y$  line
- The distance  $2.15 \sigma_y(r)$  is measured over an arc

# CHRONC long-term effects (resuspension dose)

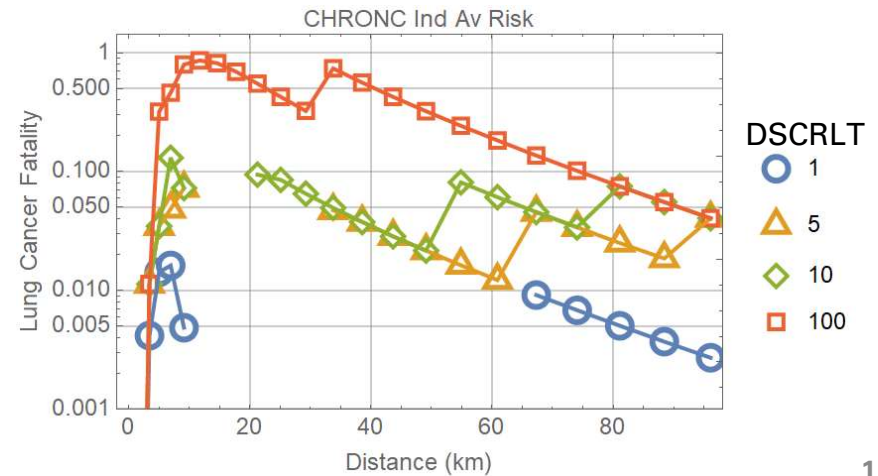
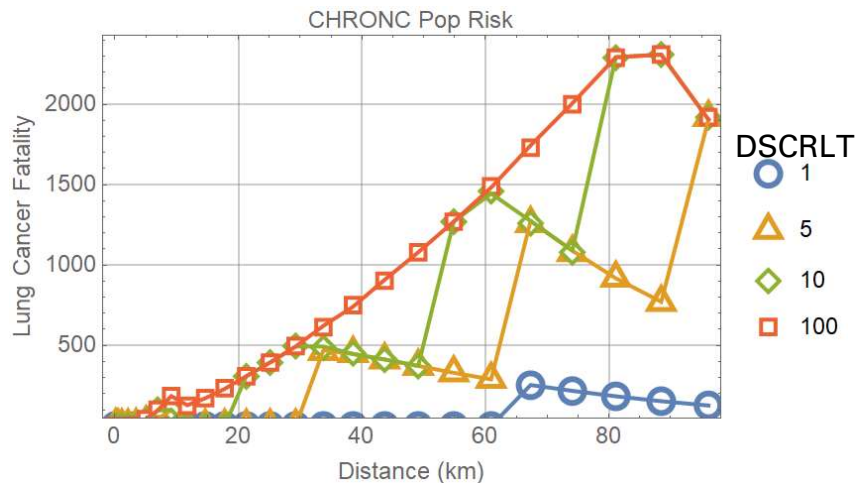


- Exposure period: 50 years
- Two decontamination levels triggered by exceedance of a limit (DSCRLT limit) by the 10-year exposure dose
- The decontamination model causes up-and-down fluctuations with distance away from the source

# CHRONC population dose and health consequences



- Population doses, health consequences, and average individual risk are computed over 360° rings



# Remarks

- Some issues were detected testing MACCS 4.0 that were addressed in the latest MACCS 4.1
  - Extrapolation of cloudshine factor
  - Limits on spread of plume
- MACCS implements a narrow plume approximation to compute concentrations in polar grid sectors
  - The approximation is inaccurate for sectors far from the centerline sectors; however, an accurate polar to Cartesian conversion yields very similar concentrations and doses
  - The approximation tends to overestimate contaminant concentrations in non-central sectors
- No other issues have been discovered
- Testing activities will continue