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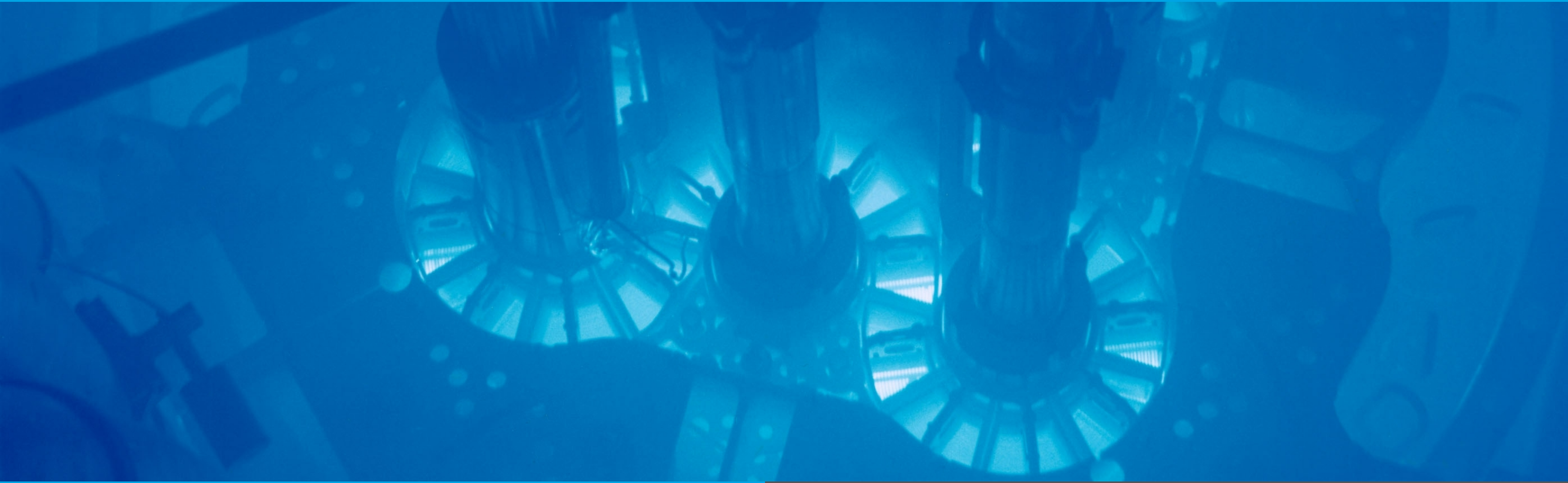

Modeling of Aerosol Depletion in Spent Nuclear Fuel Dry Storage

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Extended Storage Collaboration Program

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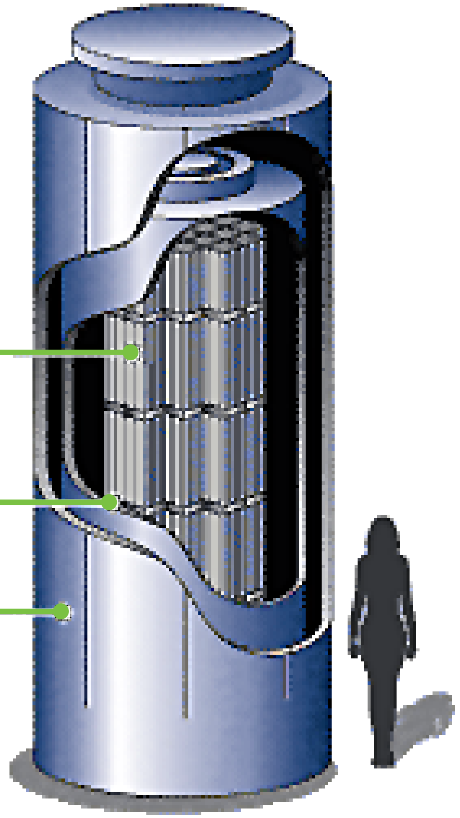
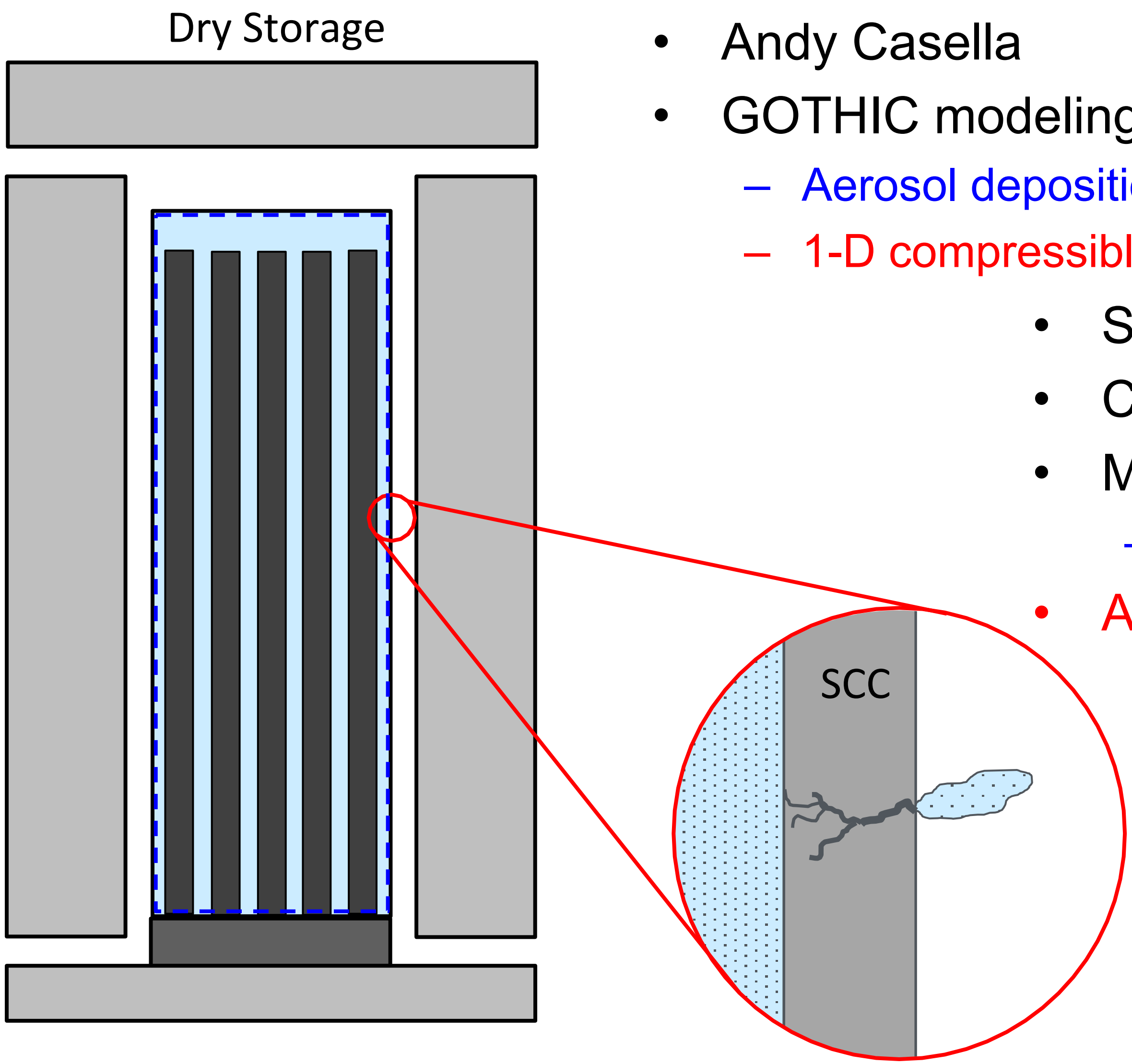
Objective



Source: www.nrc.gov/waste/spent-fuel-storage/diagram-typical-dry-cask-system.html

- **Model aerosol transport inside a spent fuel canister**
  - Fuel released into canister interior
    - Fuel failure from unspecified event
    - No path to external environment
  - Vertical, convective type system
    - Steady-state thermal-hydraulics
    - Relatively strong recirculation of backfill gas
- **Explore aerosol depletion as function of time**
  - Treat fuel release parametrically
    - Quantity: Initial aerosol mass concentration
    - Size distributions: Monodisperse, bi-disperse, and lognormal
      - Initial sizes: Initial mass median diameter (MMD_o)

Collaborative Modeling and Testing



- Andy Casella
- GOTHIC modeling (Mark Lanza)
  - Aerosol deposition in canister
  - 1-D compressible flow model for SCC

- Sam Durbin
- CFD internal flows (Fred Gelbard)
- MELCOR modeling (Jesse Phillips)
  - Aerosol deposition in canister
- Aerosol transmission testing

- Yadu Sasikumar
  - Previous efforts by Stylianos Chatzidakis
- 1st principles modeling of aerosol transport/depletion in microchannels

Independent Modeling

Two independent thermal-hydraulics codes, originally written for analysis of nuclear power plants, have been configured to examine aerosol transport inside of a vertical spent fuel storage canister.

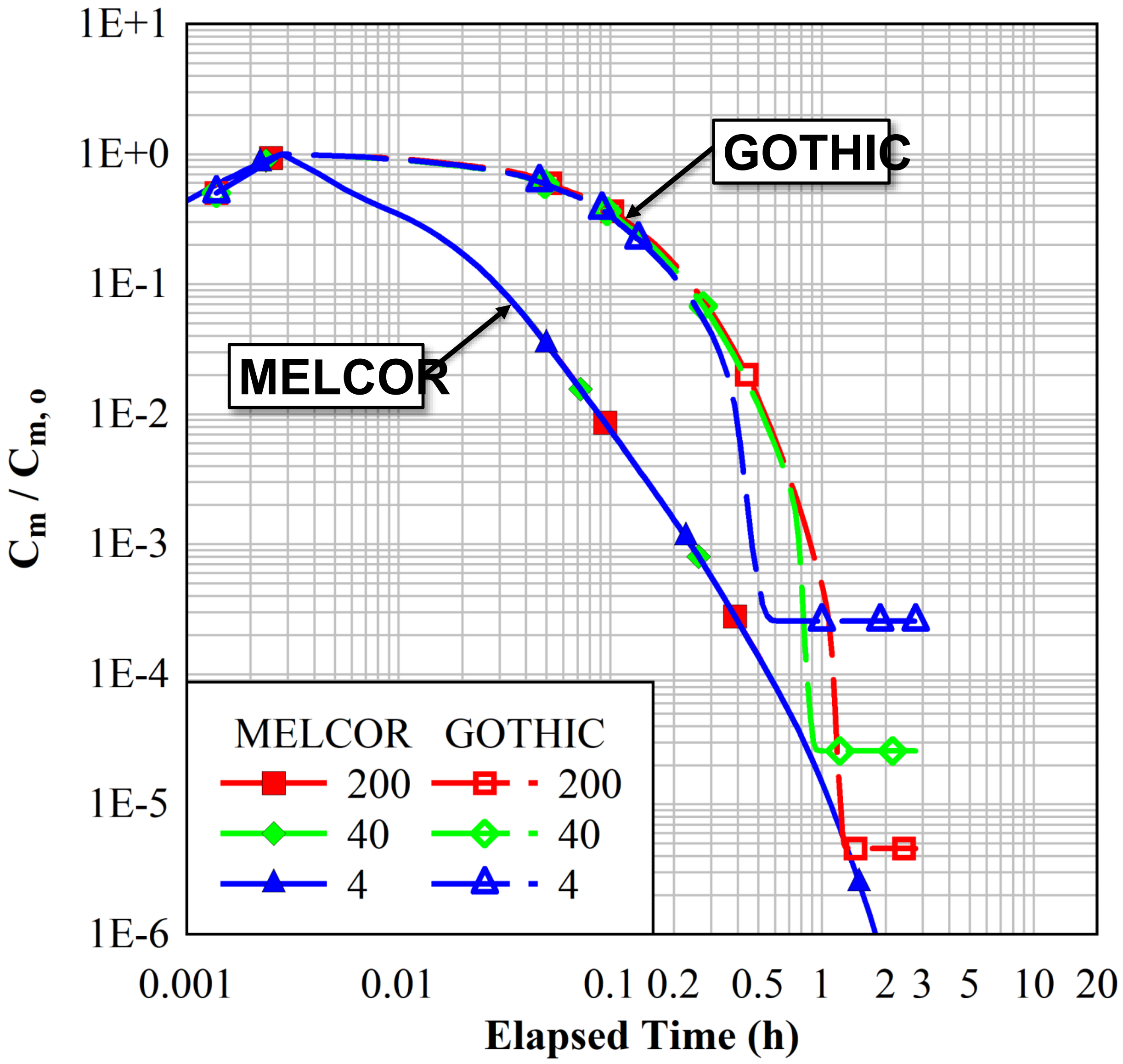
GOTHIC

- Generation of Thermal Hydraulic Information in Containment
- Integrated finite volume, general-purpose thermal-hydraulics code
  - Used for design, licensing, safety, and operating analysis of nuclear power plants and components
  - Lumped and multidimensional geometries
  - Tracks evolution of multiple drop/aerosol fields based on transport, phase change, and interactions with other fields and surfaces

MELCOR

- Coupled thermal-hydraulic and risk-significant phenomena modeling in a system-level accident code
  - Developed at SNL for USNRC
- Designed to simulate reactor, auxiliary equipment, and other nuclear components
- Uses a “control volume” approach to solve thermal-hydraulics
  - Tracks fuel and fission product release and transport

Aerosol Depletion in SNF Canister



- Normalized depletion nearly independent of initial mass concentration ($C_{m,\,o}$)
  - 1% fuel failure → ~200 mg/m^3
    - ~50 mg/m^3, STP
- Lognormal particle size distribution
  - MMD_o = 3.46 μm and GSD_o = 2.24
    - Based on measurements from Hanson, *et al.*, 2008
  - Plateauing GOTHIC results from imposition of minimum count density
- **Nearly 6 orders of normalized aerosol mass depletion in less than 2 hours**

Hanson, B.D., et al., "Fuel-In-Air FY07 Summary Report," Pacific Northwest National Laboratory, PNNL-17275, September 2008.

Aerosol Dynamics/Mechanisms

Agglomeration	**GOTHIC**	**MELCOR**
Gravitational	Yes	Yes
Brownian	Yes	Yes
Turbulent, shear	Yes	Yes
Turbulent, inertial	No	Yes
Condensation/Evaporation	Yes	Yes

Deposition		
Gravitational settling	Yes	Yes
Impaction	Yes	Yes
Diffusion	Yes	Yes
Thermophoresis	Yes	Yes
Turbulent Diffusion	Yes	Yes
Diffusiophoresis	Yes	Yes

Re-entrainment

If re-entrainment were generally effective at removing settled particulates, one could simply clean their car by driving around.

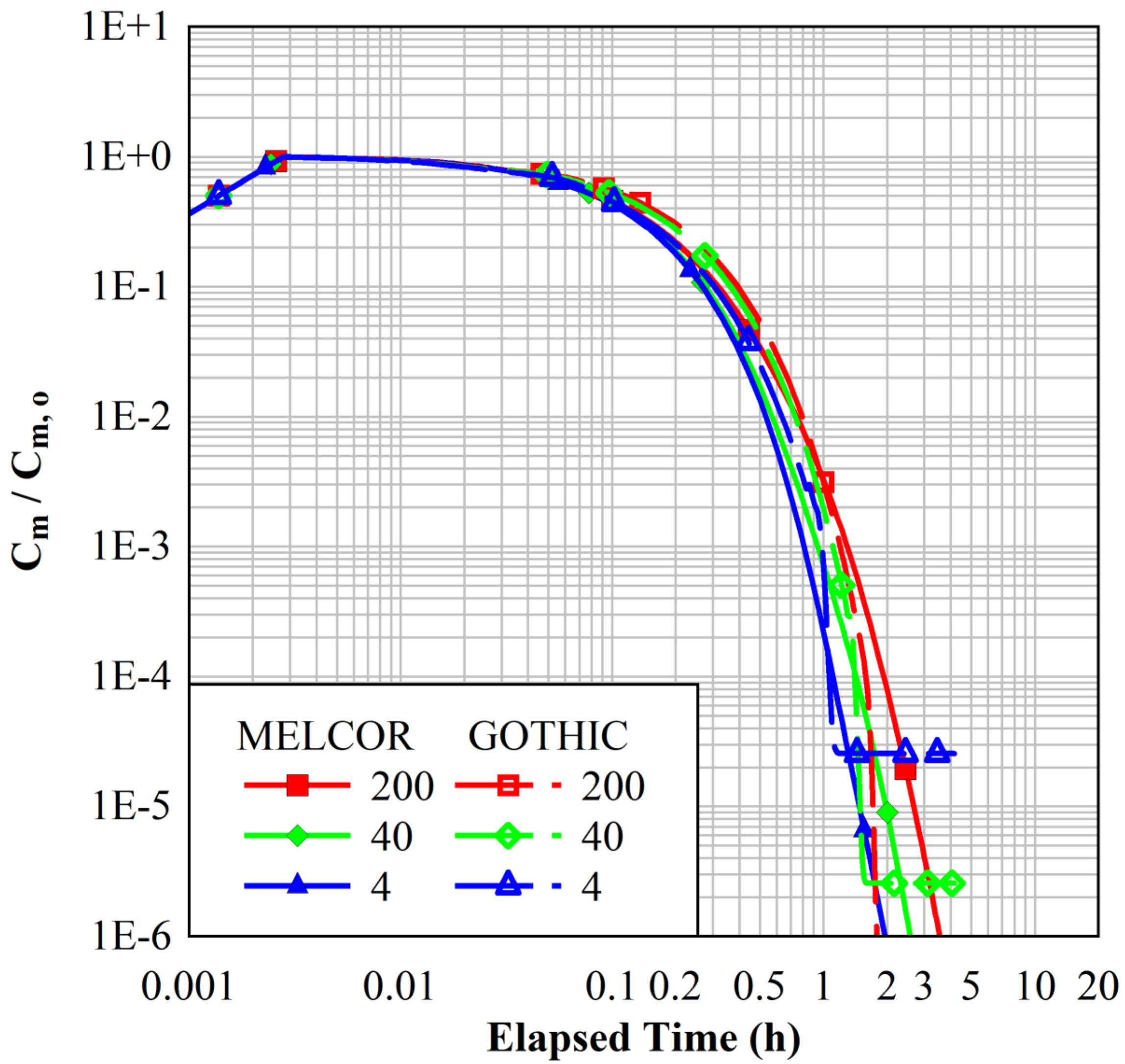
GOTHIC

- Drop entrainment
  - User-specified
  - Dripping
  - Entrainment from wavy interfaces on Films and Pools
- Currently no dry particle entrainment model

MELCOR

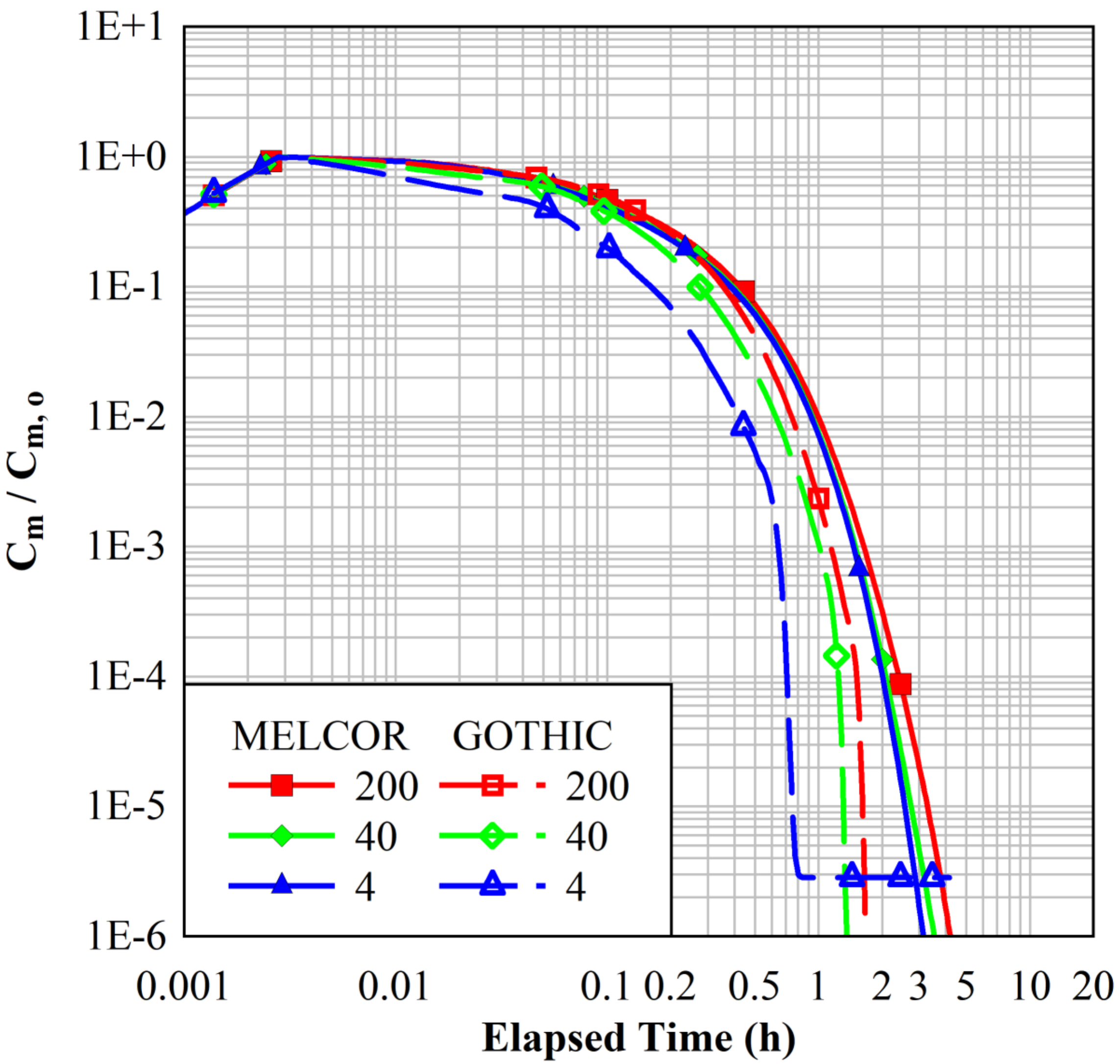
- Current model allows for re-entrainment via vaporization from surfaces
  - Temperatures in storage model not sufficient for vaporization
- New LOFT model allows for sweeping of particles below critical size
  - Not used in present results
  - Being considered for future work

Monodisperse Aerosol Distributions



- 1 µm aerodynamic equivalent diameter (AED)
  - Simplified modeling options for each code.
    - Better aligned phenomenological models.
    - Improved agreement observed for each computer code/simulation than prior reported values.
  - Smaller aerosol sizes promote longer airborne duration.
    - Concentration still reduced by several orders of magnitude within a few hours.
    - Similar overall duration as other sensitivities.

Bi-disperse Aerosol Distributions



- Mass equally divided into AED 0.5 and 5 μm
  - Good agreement is observed and similar large reductions in overall concentrations results within a few hours.
  - Default, best-practice code use shows slight differences, suggesting agglomeration modeling differences
    - But again, small differences
  - Compared to the 1.0 μm results:
    - GOTHIC computes a slightly reduced overall duration
    - MELCOR computes a slightly increased overall duration

Future Work

- Aerosol transport calculations are very complicated with a large number of variables potentially impacting a particular system
- Software packages for addressing aerosol system evolution are also very complicated and there are numerous areas in which diverging solutions can be generated.
- This fiscal year, the MELCOR and GOTHIC teams will be focusing on executing a parametric study of physical and modeling parameters and comparing the results for the two codes.
- This study will identify parameters of high impact and solidify the solutions generated for the aerosol system of interest.
  - Rank mechanisms of depletion (fallout, diffusion, thermophoresis, etc.)
  - Characterize settled distribution and particle sizes of settled aerosol

Summary

- Independent aerosol transport modeling showed **significant depletion in less than 2 hours** from fuel-to-canister release
- The calculated depletion times are similar in all cases to date with polydisperse systems having slightly shorter depletion times than mono-disperse systems.
- Enough differences have been identified between different system definitions (particle size distribution, etc.), treatment of different physical parameters in the two codes, and methods employed by the two codes, that a detailed parametric study is needed to further elucidate remaining uncertainty and increase confidence in the calculations.