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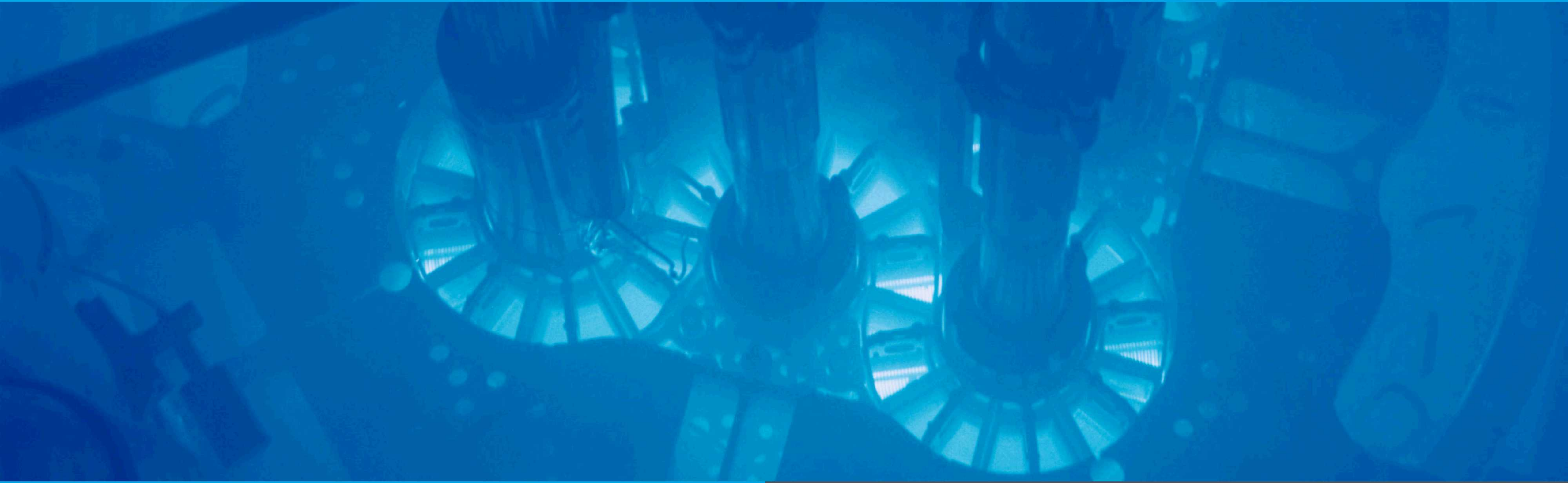

Measurement of Through-Wall Aerosol Transmission for SCC-Like Geometries

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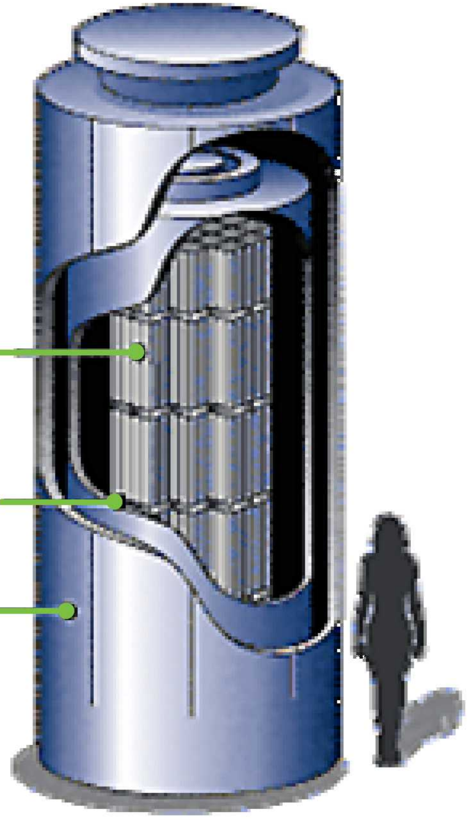
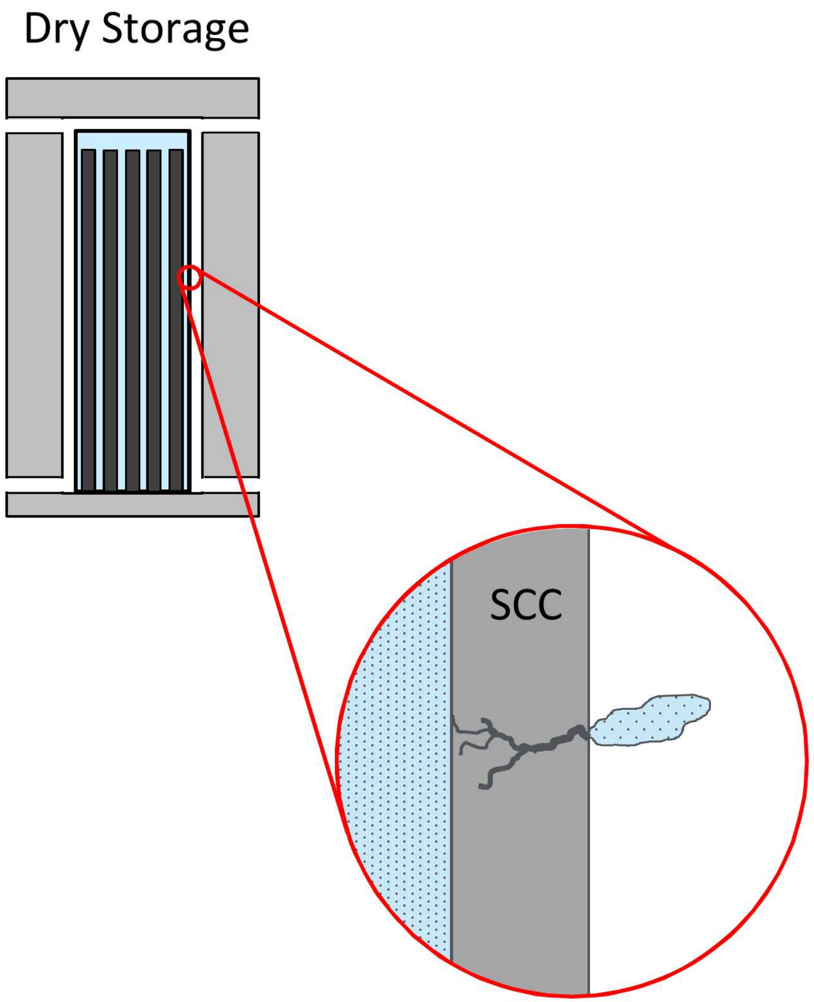
Overview



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

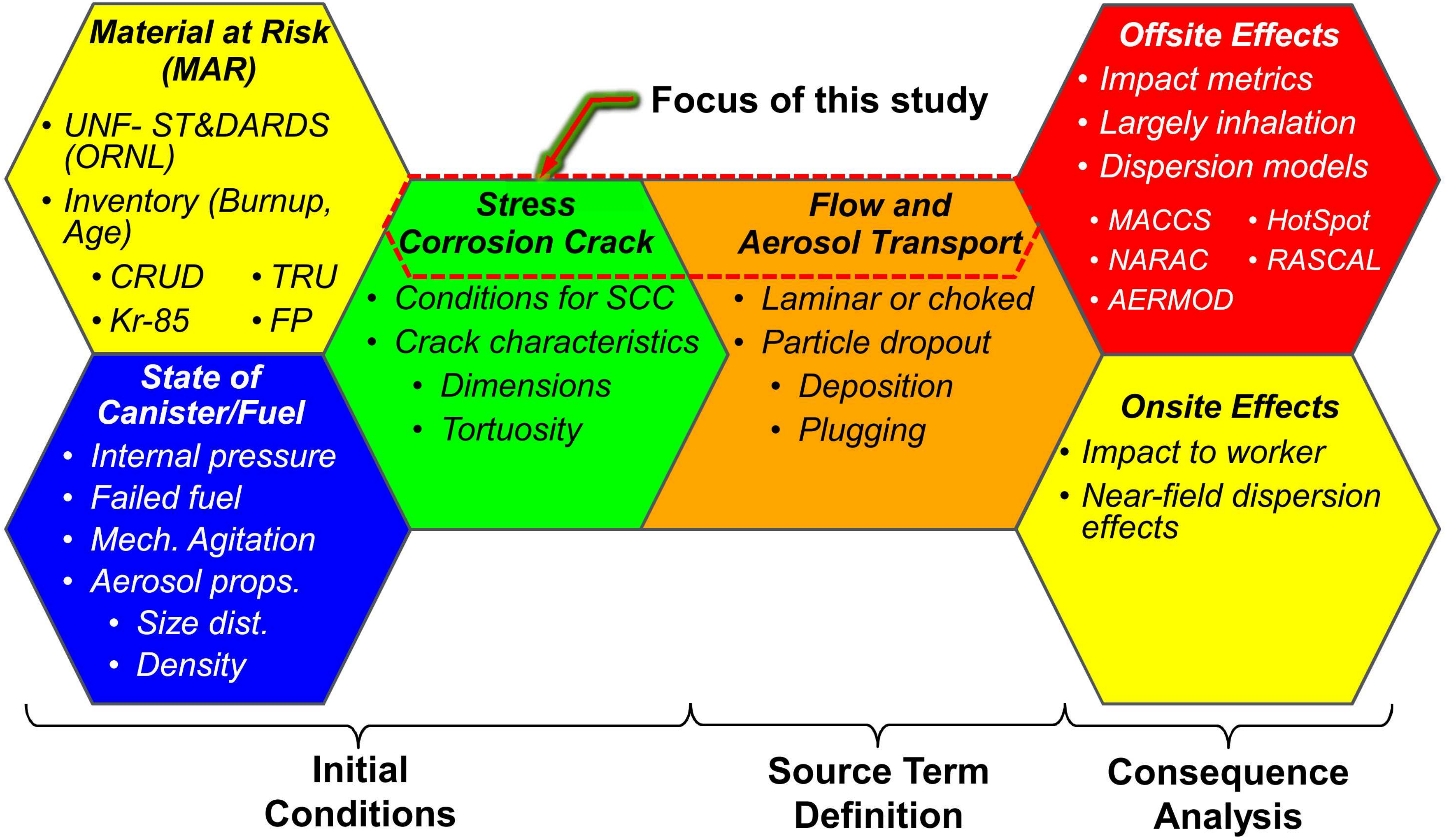
- Mimic aerosol transport through a stress corrosion crack (SCC)
  - Pressure-driven flow
    - Prototypic canister pressures
    - Near-prototypic canister volume
- Explore flow rates and aerosol retention of an engineered microchannel
  - Characteristic dimensions similar to those of SCCs
    - Microchannel: 28.9 μm (0.0011 in.) deep x 12.7 mm (0.500 in.) wide
    - Flow length: 8.86 mm (0.349 in.) long
- Measure mass flow and aerosol concentration
  - Upstream and downstream of microchannel
  - Simplified geometry with well-controlled boundary conditions

Problem Statement

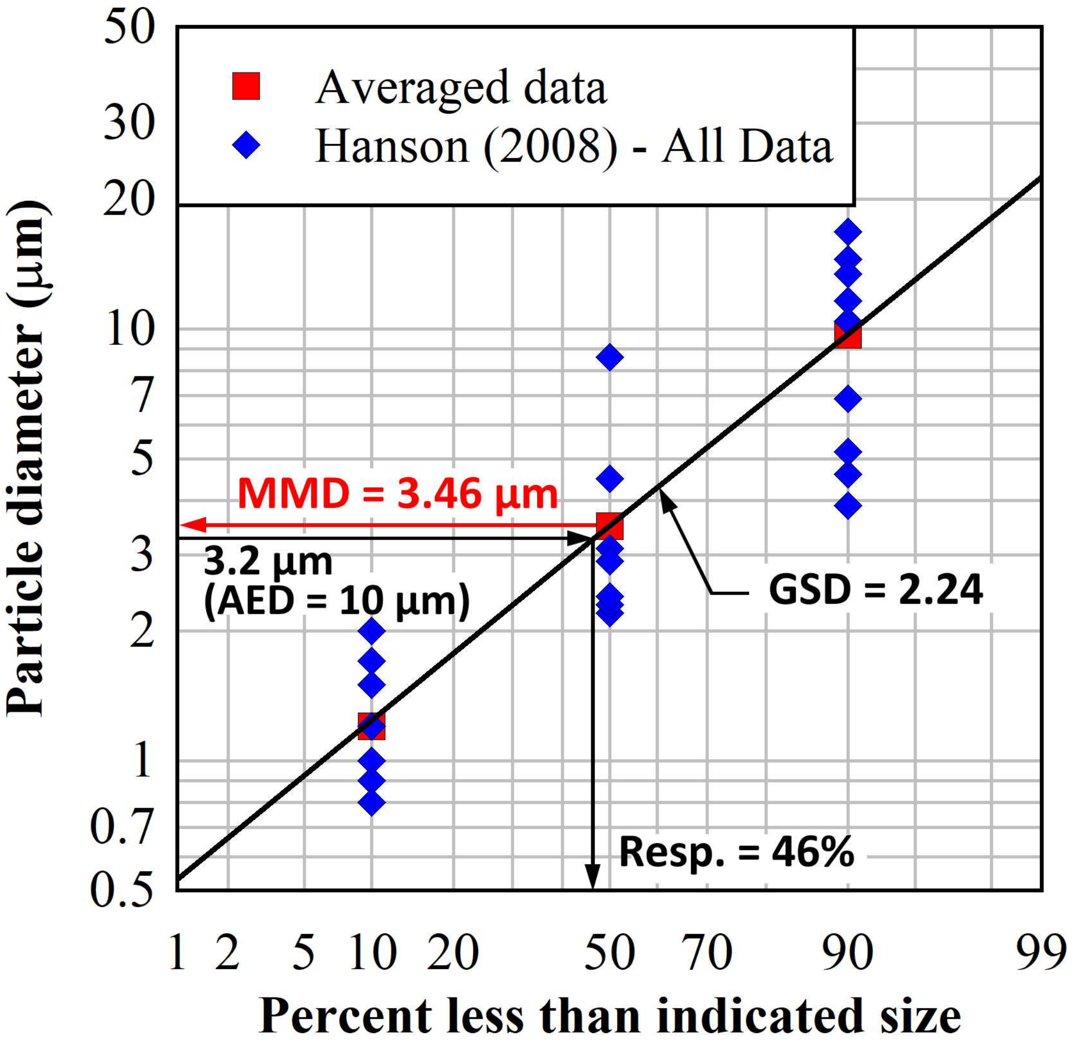


- What is the potential impact of a through-wall stress corrosion crack (SCC)?
  - Relatively low availability of mobile radionuclides under normal storage and transportation
- Significant amount of literature on aerosol transport through idealized leak paths
  - Primarily for moderate pressure differentials
- Information for combined analysis needed from following topics
  - Available source term inside canister
  - Characteristics of SCC
  - Flow and particle transport through prototypic SCC's

Organization of Analyses



Spent Fuel Release Data



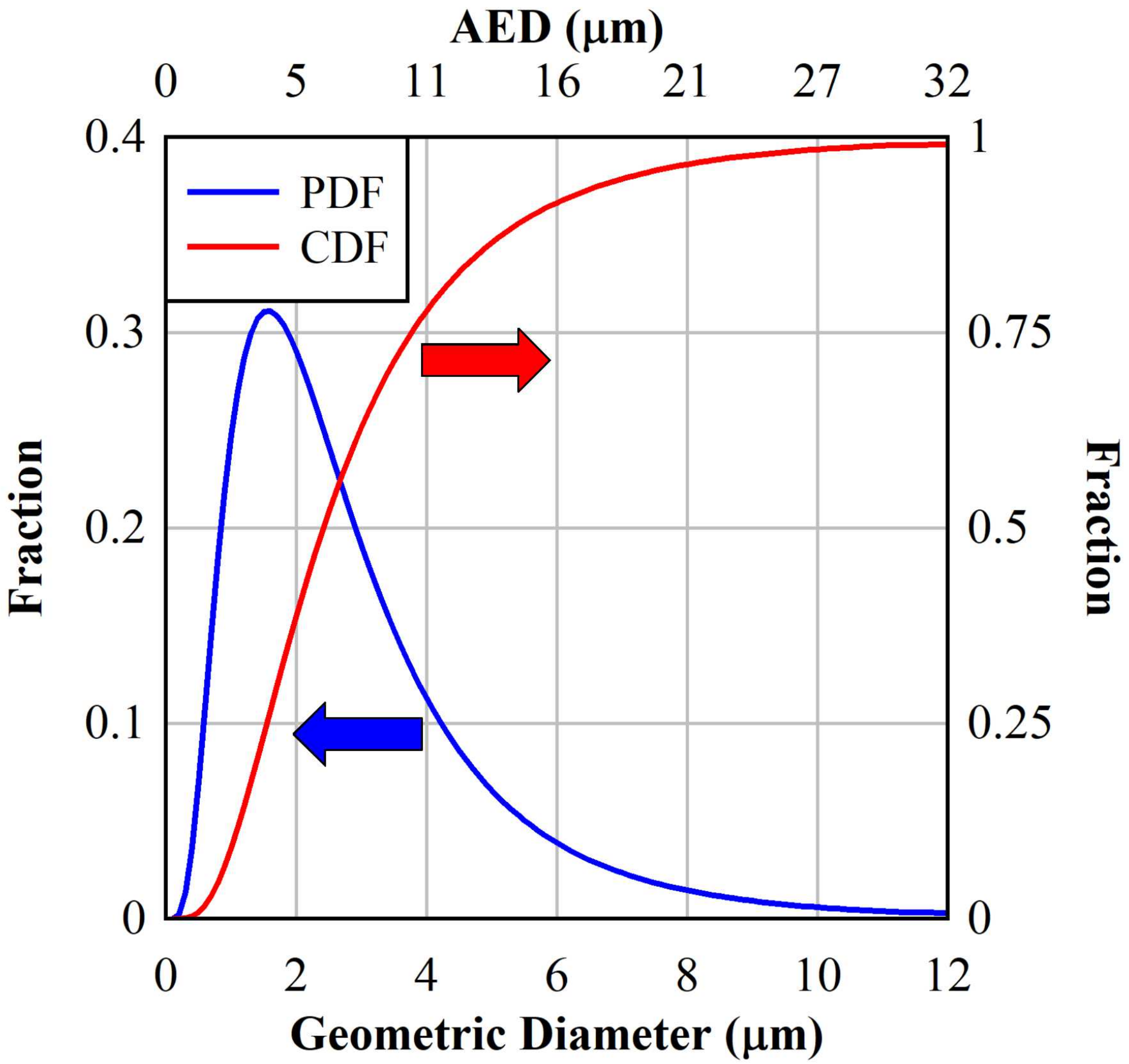
Hanson, B.D., et al., "Fuel-In-Air FY07 Summary Report," Pacific Northwest National Laboratory, PNNL-17275, September 2008.

- Hanson (2008) quantified releases from SNF rods
  - Forced air through segmented fuel
- New data currently being collected from High Burnup Demonstration Project
  - Sibling pin testing
- Average of all data
  - Mass Median Diameter (MMD) = 3.46 µm
  - Geometric Standard Deviation (GSD) = 2.24
  - Total release fraction = 1.9×10^{-5}
    - 4.8×10^{-6} cited in NUREG-2125
    - 3×10^{-5} cited in SAND90-2406
      - Assumes 100% respirable
- Derived quantities of interest
  - Resp. fraction = 4.6×10^{-1} [for particles < 3.2 µm {or 10 µm Aerodynamic Equivalent Diameter (AED)}]
    - ***Resp. release fraction = 8.9×10^{-6}***
      - ***Normalized to mass of fuel***

Initial Aerosol Density

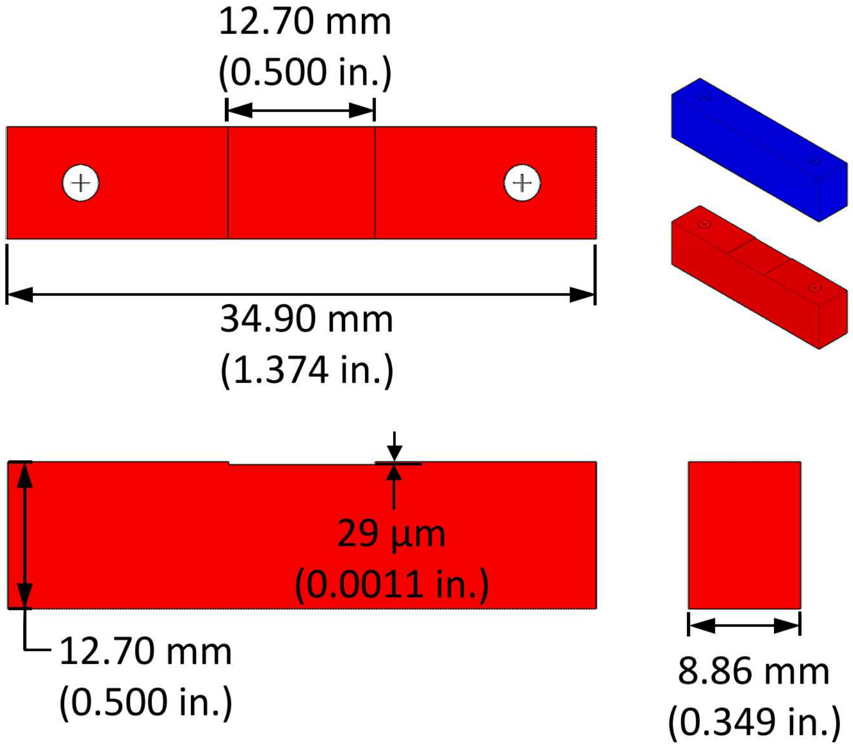
- Respirable particles with an AED < 10 μm
- Hanson *et al.*, 2008
  - Respirable release fraction = 8.9×10^{-6}
- Estimate hypothetical aerosol density available for transport
  - 37 PWRs
  - 520 kg UO_2 per assembly
  - Assume 1% fuel rod failure
  - Assume no deposition
  - Initial pressure 800 kPa (116 psia)
  - Assume canister free volume of 6 m^3
  - Reference aerosol density: $\dfrac{0.01 \times 37\ \text{PWRs} \times 5.20 \times 10^{8}\ \dfrac{\text{mg}}{\text{PWR}} \times 8.9 \times 10^{-6}}{\left(\dfrac{300\ \text{K}}{460\ \text{K}}\right) \times \left(\dfrac{800\ \text{kPa}}{100\ \text{kPa}}\right) \times 6\ \text{m}^3} \approx 54\ \text{mg/m}^3$

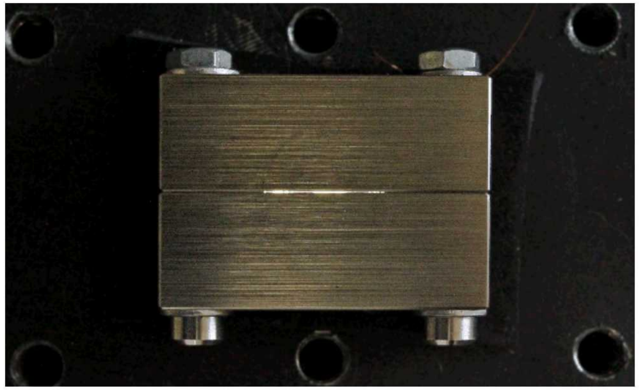
Surrogate Selection

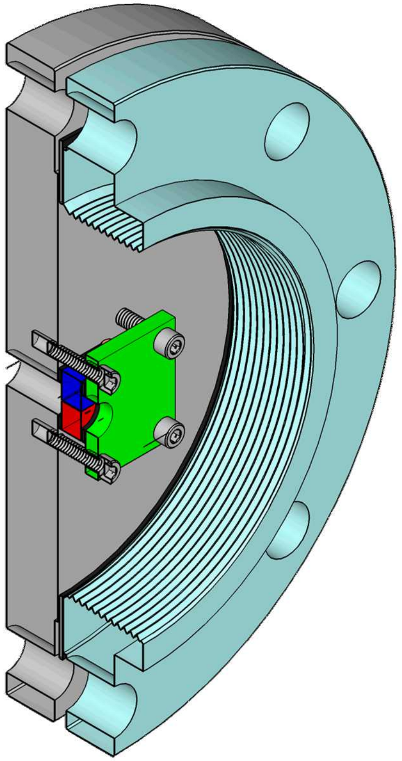


- Cerium oxide (CeO_2) chosen as surrogate
  - $\rho_{CeO_2} = 7.22$ g/cm^3
  - $\rho_{SNF} \approx 10$ g/cm^3 (Spent fuel)
- Particle size distribution
  - Mass median diameter (MMD)
    - MMD = 2.4 µm
  - Geometric standard deviation (GSD)
    - GSD = 1.9
  - ~75% particles (by mass) respirable
    - AED < 10 µm

Engineered Microchannel



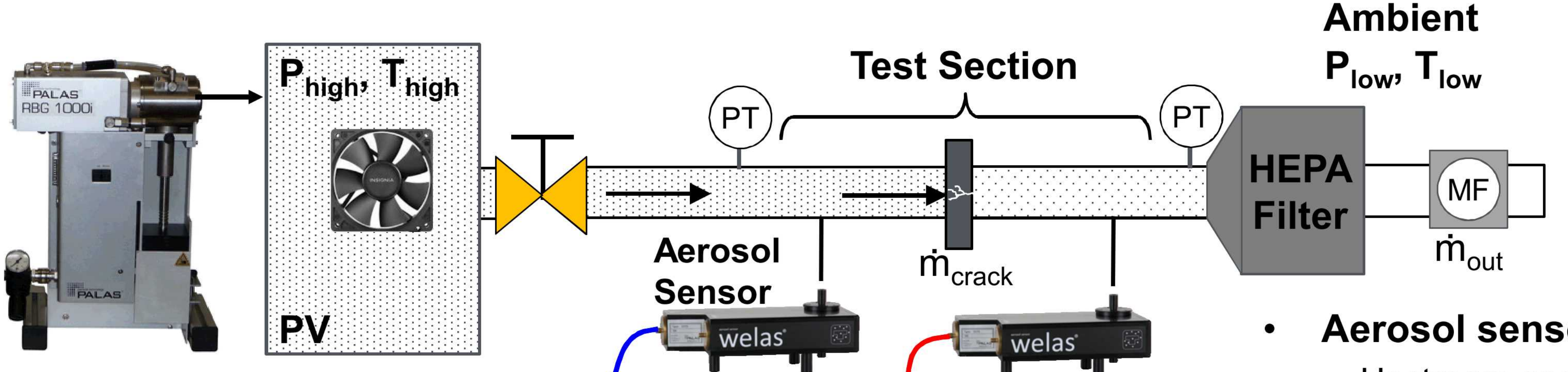


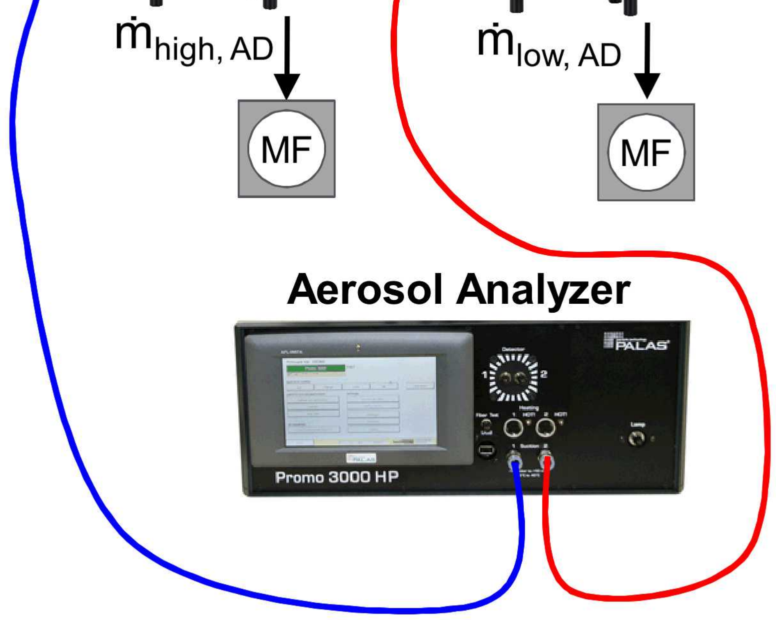


Isometric view of mounted microchannel on upstream side

- Microchannel formed with paired blocks
  - High-precision gauge blocks
  - Electrical discharge machined to form channel
  - Dimensions
    - Microchannel: 28.9 µm (0.0011 in.) deep x 12.7 mm (0.500 in.) wide
    - Flow length: 8.86 mm (0.349 in.) long
    - Flow area: 0.37 mm^2 (5.7 $\times 10^{-4}$ in^2)
- Bolted together to form microchannel
- Replaceable test section
  - Ultimately conduct experiments with representative SCC's

Test System Schematic

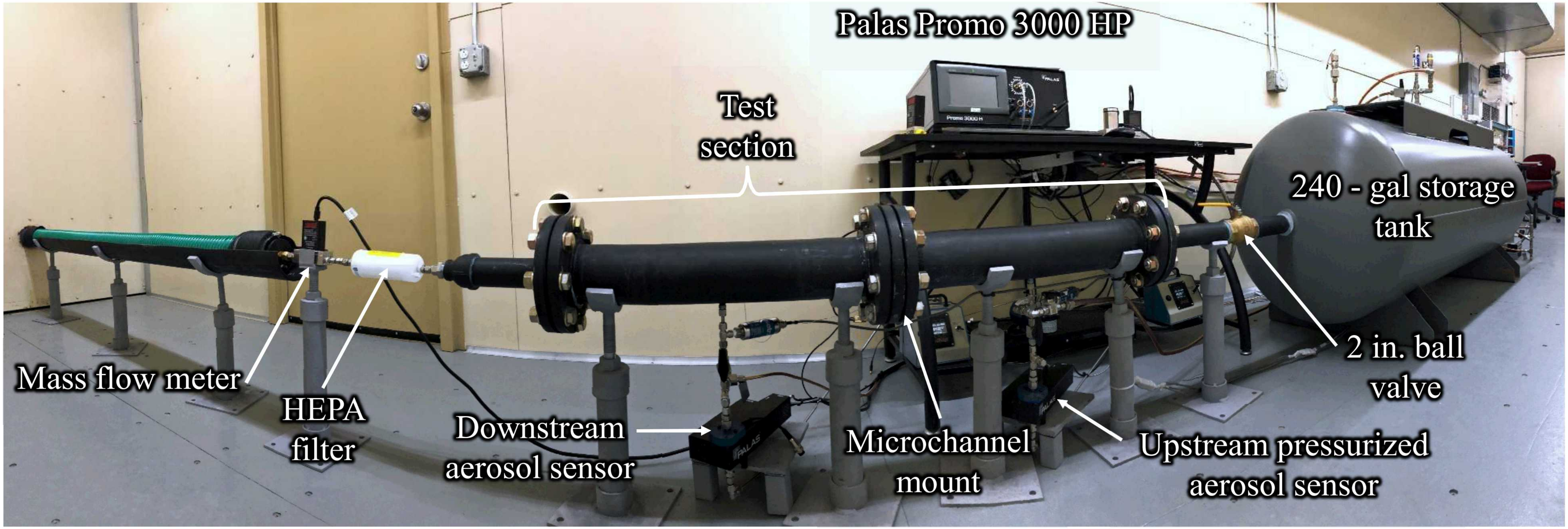




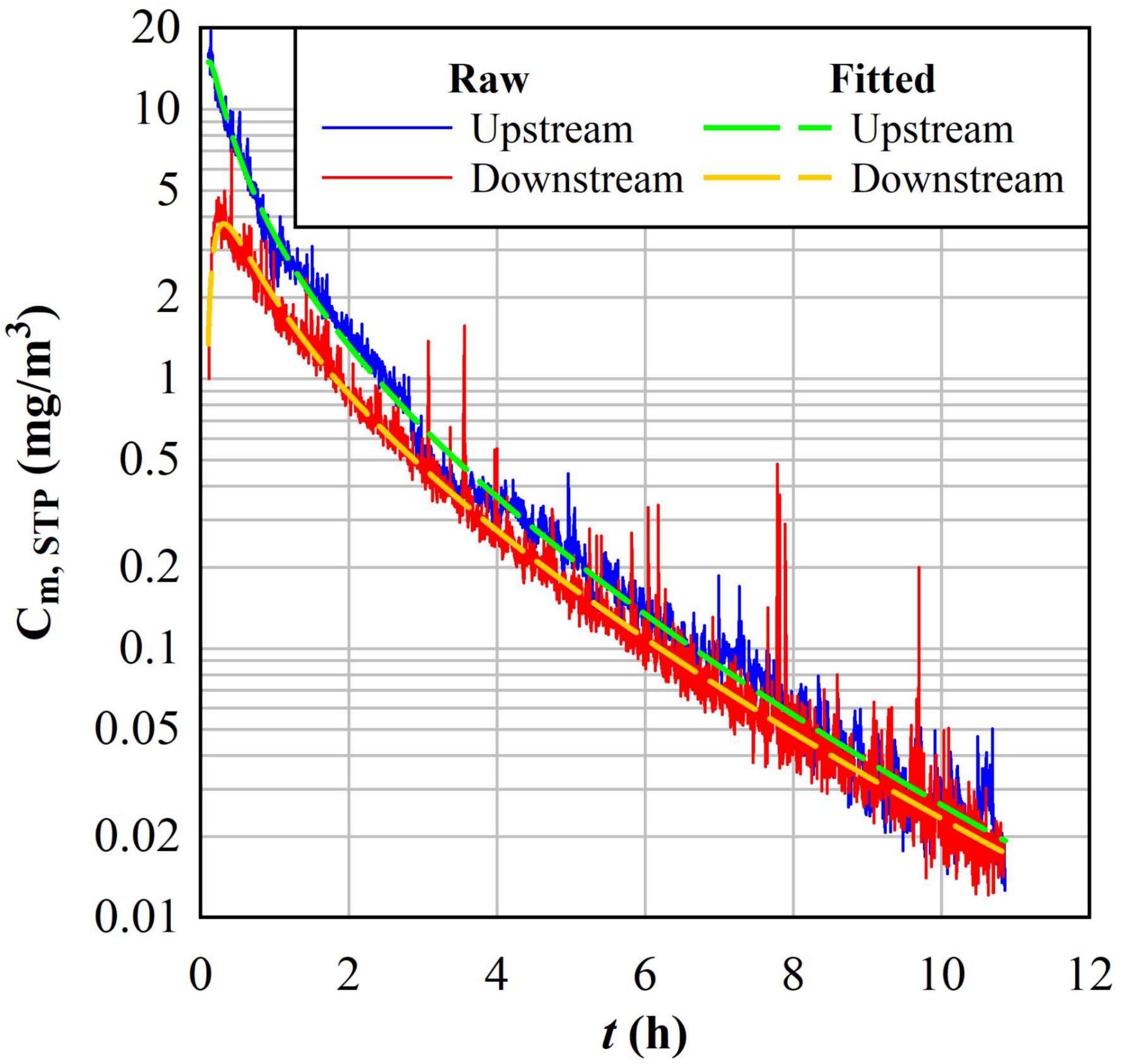
- **Pressure vessel**
  - Mixing fans in tank
  - Pressurized Rotating Brush Particle Generator
    - Injection up to 300 kPa
  - Pressurize up to 800 kPa
- **Replaceable test section**
  - Engineered orifices
  - Representative SCC's

- **Aerosol sensors**
  - Upstream and downstream
  - Pressure
  - Aerosol density (AD)
  - Particle size distribution
- **Mass flow rates**
  - After sensors

Test System Photograph

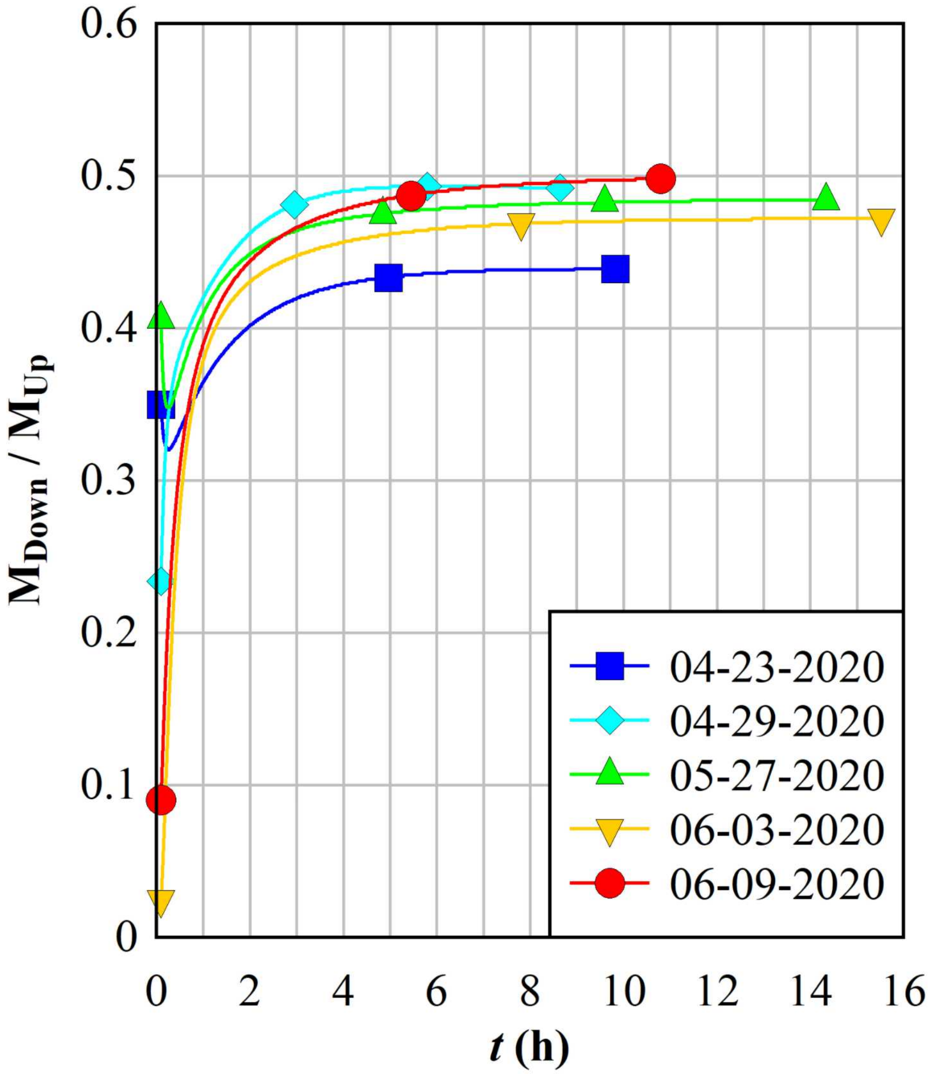


Aerosol Measurements
(Aerosol Mass Concentration)



- Aerosol mass concentration
  - Results shown for test on 06-09-2020
  - Five tests show similar behavior
    - Initial reference value of $C_{m, STP} = 54$ mg/m^3
  - Upstream greater than downstream
    - Convergence with time
    - Downstream spikes likely caused by dislodgement of agglomerates
  - Integrated aerosol mass
    - $M = \int_{t_o}^{t} Q_{STP}(t) \cdot C_{m, STP}(t)\, dt$
      - Where Q_{STP} is the instantaneous gas flow rate through the microchannel

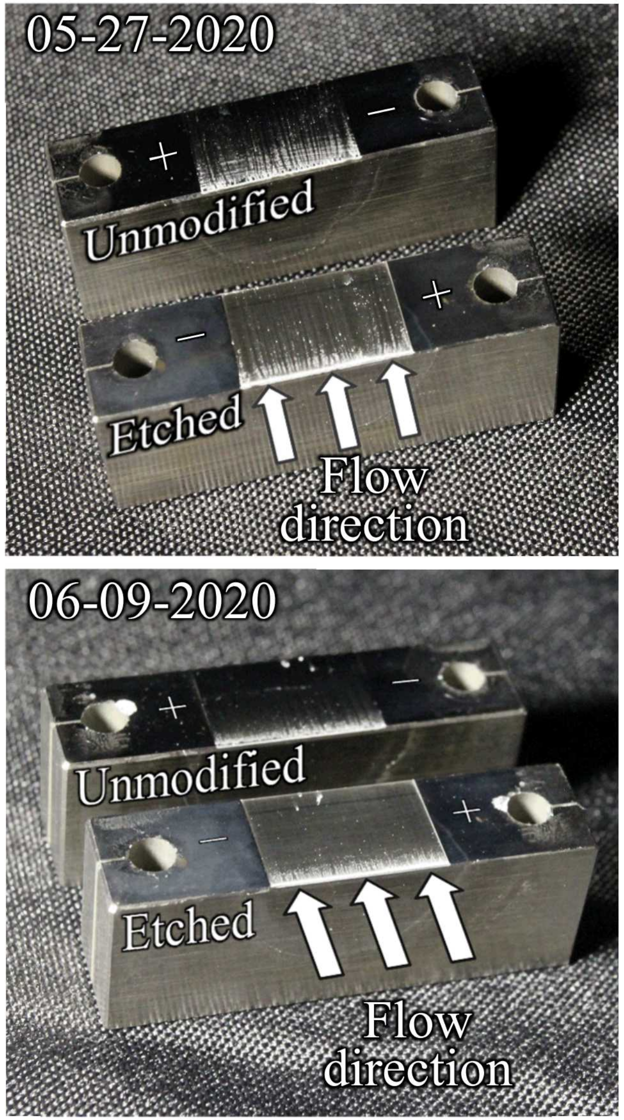
Aerosol Transmission



- Integrated aerosol masses (M)
- Transmission = M_{Down} / M_{up}
  - Average = 0.48

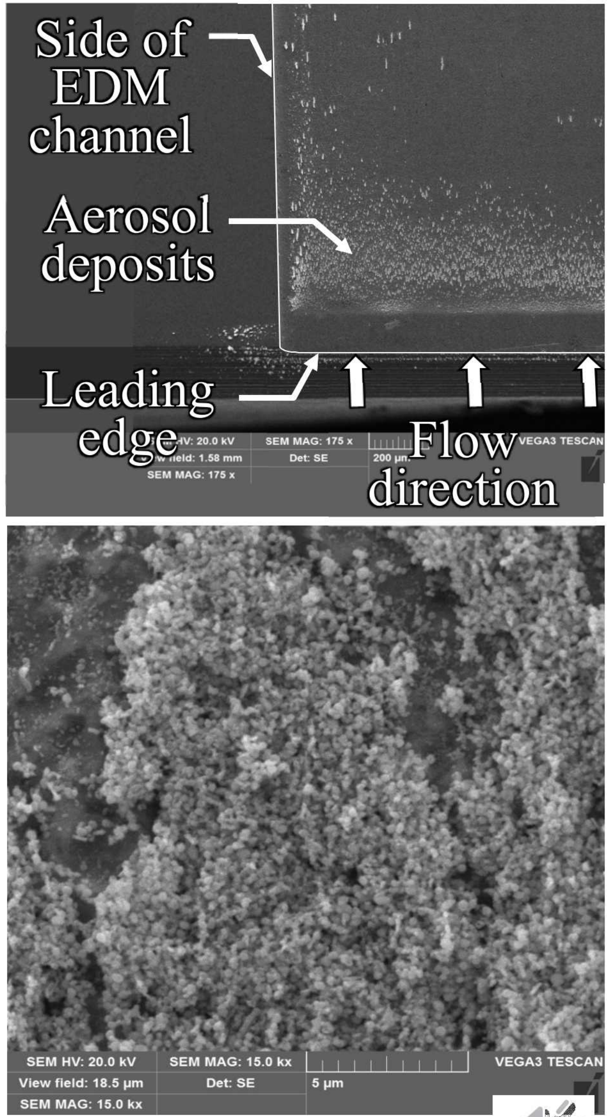
Date	Test Type	Initial Upstream Conditions		Filtering Characteristics	
		ΔP (kPa)	$C_{m, STP}$ (mg/m³)	Transmission	Retention
4/23/2020	Blowdown	125	49.2	0.44	0.56
4/29/2020	Blowdown	121	81.0	0.49	0.51
5/27/2020	Constant Press.	116	52.4	0.48	0.52
6/3/2020	Constant Press.	120	54.8	0.47	0.53
6/9/2020	Constant Press.	118	14.3	0.50	0.50

Aerosol Deposits



Photographs

- Aerosol deposits on microchannel
  - Five tests show similar behavior
    - Streaking
    - “Snowball” accumulation
  - Upstream leading edge
    - More accumulation
  - Streaking due to agglomerate migration
    - Spikes in downstream mass concentration
      - Believed to be from occasional breakthrough



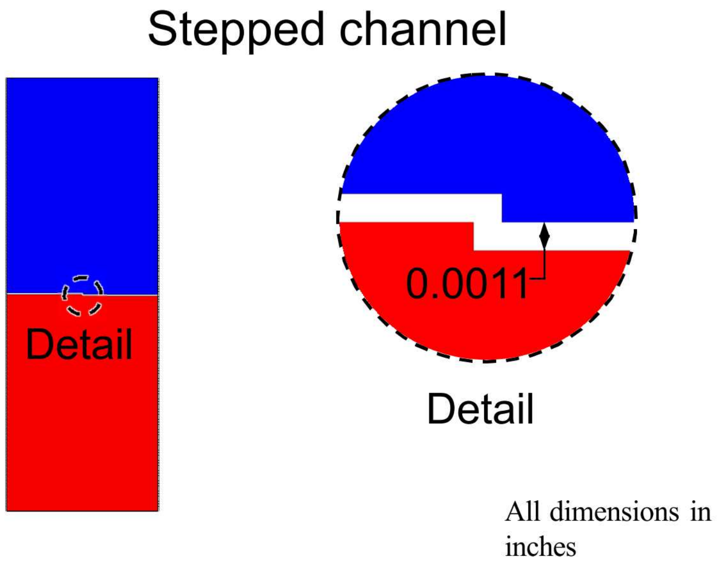
SEM Images

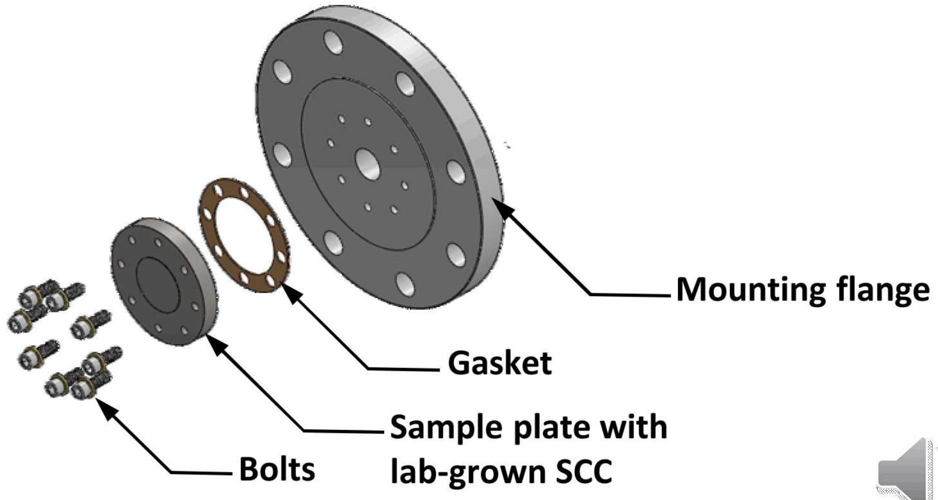
Summary

- Explored flow rates and aerosol retention in an engineered microchannel
  - First step to characterize hypothetical aerosol-laden flow through an SCC
  - Characteristic dimensions similar to SCCs
    - 29 μm (0.0011 in.) channel by 12.7 mm (0.500 in.) wide and 8.86 mm (0.349 in.) long
  - Prototypic maximum canister pressure
    - 200 kPa (29 psia) this work
    - 800 kPa (116 psia) in progress
  - Aerosol concentration measured upstream and downstream of microchannel
  - Results demonstrate a viable capability to measure aerosol transport under conditions of interest
- Preliminary results
  - Upstream concentration greater than downstream for over 10 hours
  - Average transmission (release fraction) measured as 0.48
    - Additional work needed to quantify uncertainty and repeatability

Future Work

- Additional tests of existing microchannel
  - Different initial pressures
  - Prototypic gas backfills (helium)
  - Different initial aerosol concentrations
  - Repeatability tests
- More complex microchannels
  - Stepped channel to add tortuosity
  - Work up to mountable, lab-grown SCC
  - Characterize geometry for code validation
- Simpler tube flow microchannels
  - Compare to analytic solution





Modeling Activities

- Parallel modeling activities ongoing
  - Oak Ridge National Laboratory – Stylianos Chatzidakis
    - Numerical model based on general dynamic equation for aerosols and Navier-Stokes
    - Gain insight into aerosol transport and retention in leak paths
  - Pacific Northwest National Laboratory – Andrew Casella
    - Generation of Thermal Hydraulic Information in Containment (GOTHIC) modeling to simulate aerosol transport in spent fuel storage under conditions of interest
  - Sandia National Laboratories – Fred Gelbard
    - Explore the effect of internal convection on aerosol depletion using MELCOR
  - Electric Power Research Institute – Shannon Chu

Coupled validation exercises with SNL testing