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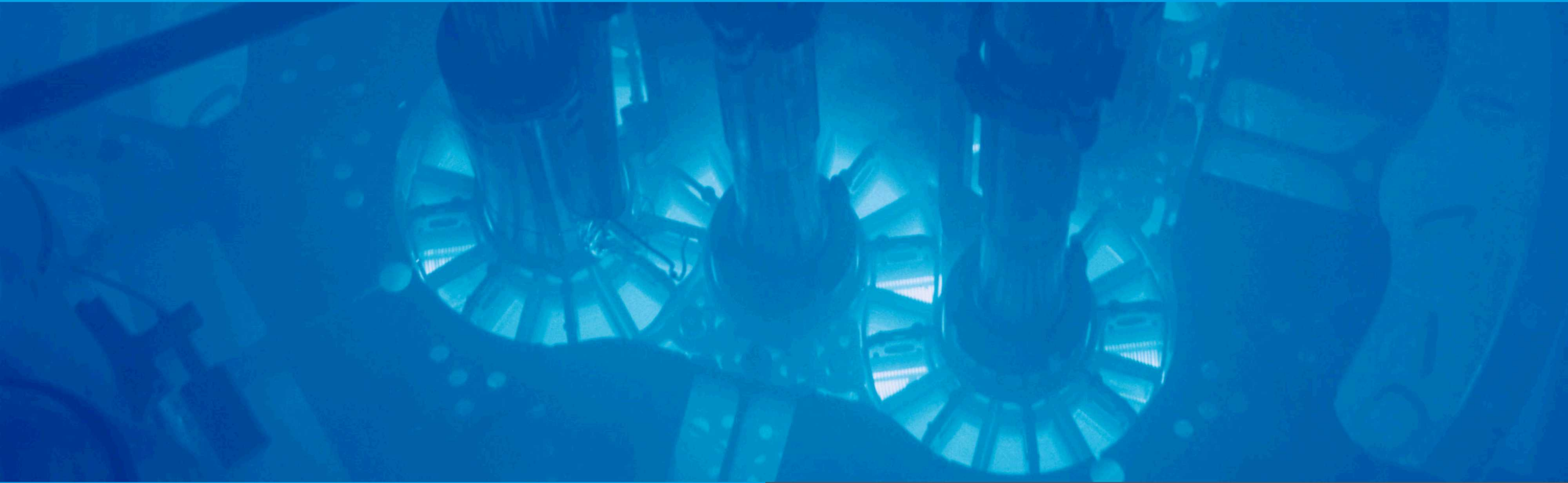

Characterization of Through-Wall Aerosol Transmission for SCC-Like Geometries

International High-Level Radioactive Waste Management

Knoxville, TN

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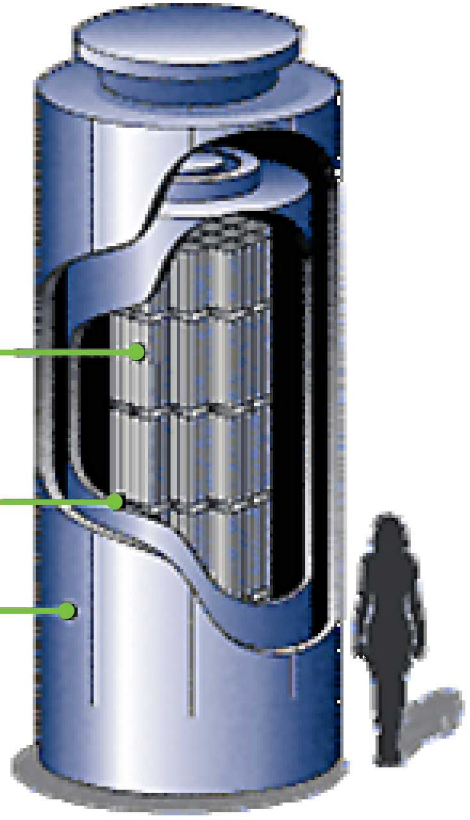
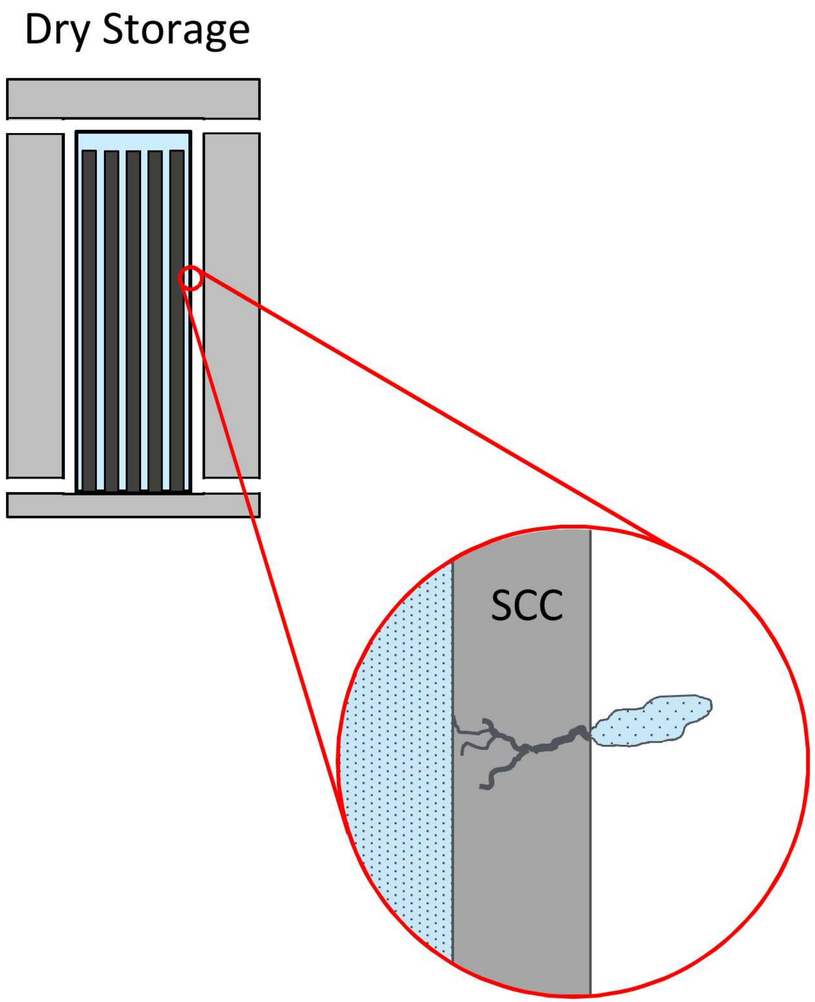
Overview



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

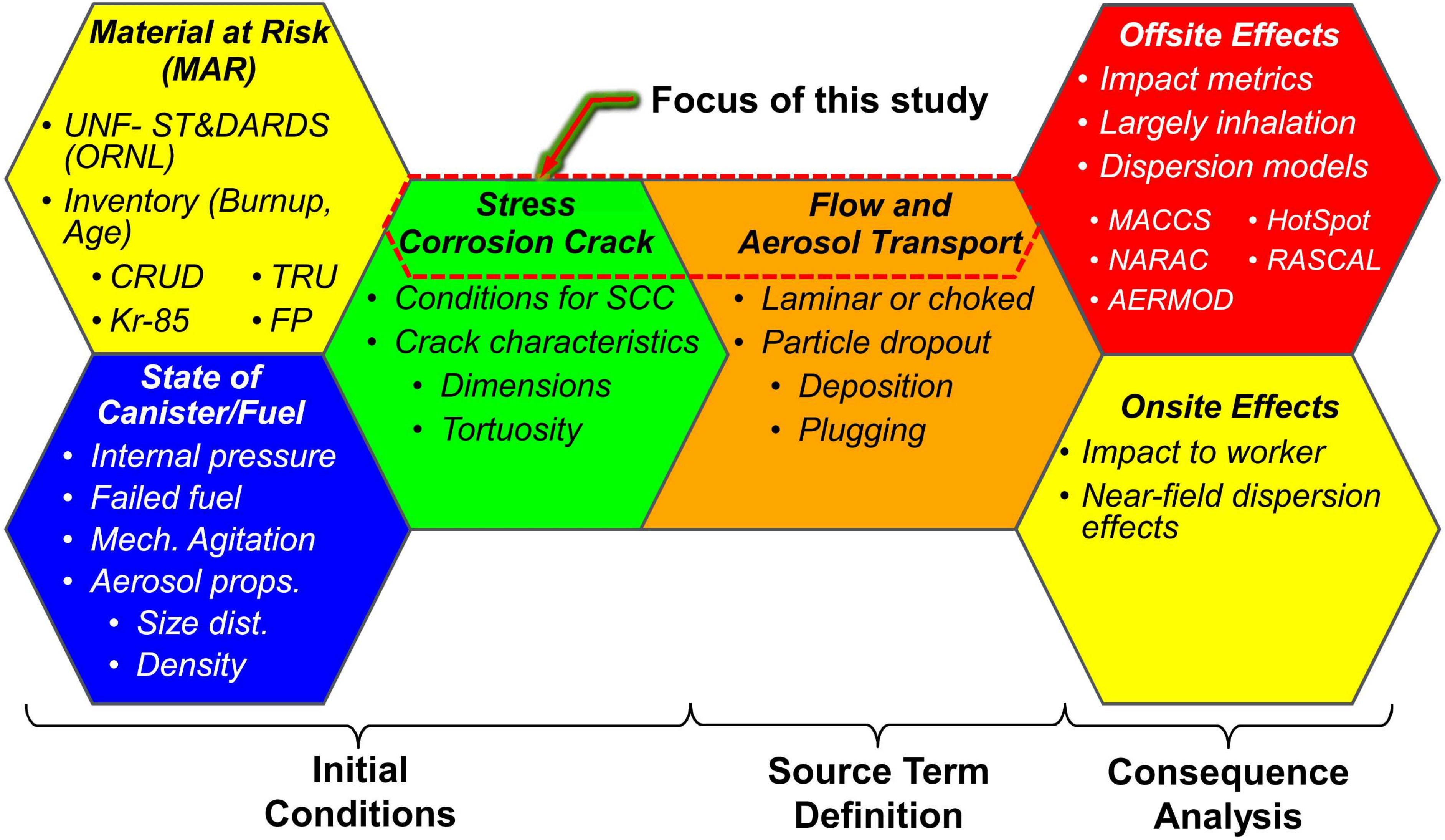
- Mimic aerosol transport through a stress corrosion crack (SCC)
  - Pressure-driven flow
    - Prototypic canister pressures
    - Near-prototypic canister volume
- Explore flow rates and aerosol retention of an engineered microchannel
  - Characteristic dimensions similar to those of SCCs
    - Microchannel: 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

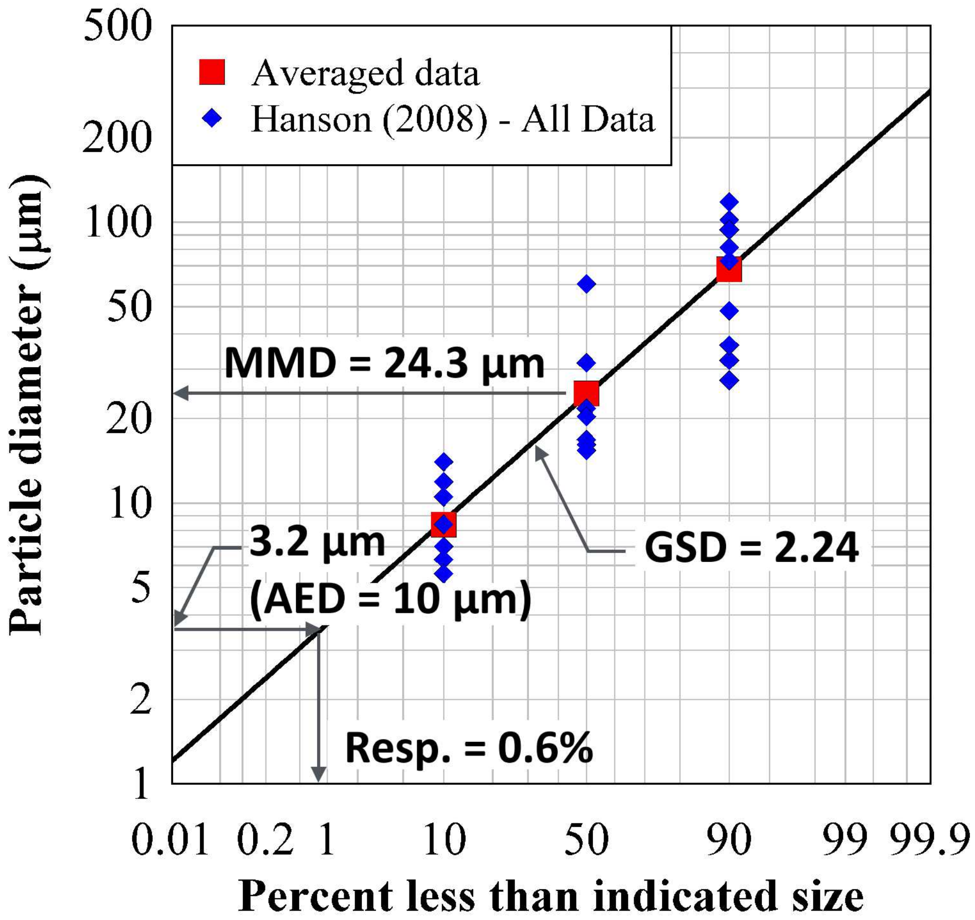


- What is the potential impact of a through-wall stress corrosion crack (SCC)?
  - Relatively low availability of mobile radionuclides under normal storage and transportation
- Significant amount of literature on aerosol transport through idealized leak paths
  - Primarily for moderate pressure differentials
- 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



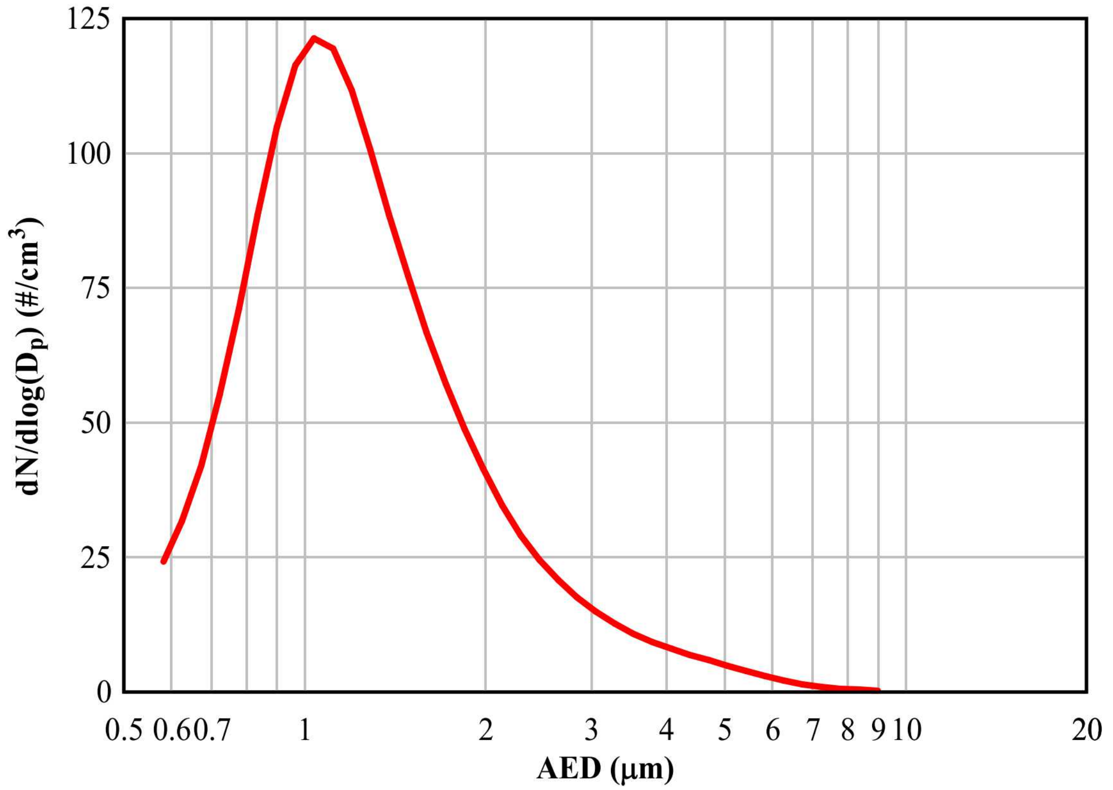
Hanson, B.D., et al., "Fuel-In-Air FY07 Summary Report," Pacific Northwest National Laboratory, PNNL-17275, September 2008.

- Hanson (2008) quantified releases from SNF rods
  - Forced air through segmented fuel
- New data may become available from High Burnup Demonstration Project
  - Sister rod testing
- Average of all data
  - CMD = 3.46 µm, GSD = 2.24
  - Release fraction = 1.9×10^{-5}
    - 4.8×10^{-6} cited in NUREG-2125
      - Assumes 100% respirable
- Derived quantities of interest
  - MMD = 24.3 µm
    - Resp. fraction = 6×10^{-3} {for particles < 3.2 µm (or 10 µm AED)}
    - ***Resp. release fraction = 1.1×10^{-7}***
      - ***Normalized to mass of fuel***

Initial Aerosol Density

- Respirable particles with an AED < 10 μm
- Hanson *et al.*, 2008
  - Respirable release fraction = 1.1×10^{-7}
- Estimate hypothetical aerosol density available for transport
  - 37 PWRs
  - 520 kg UO_2 per assembly
  - Assume 10% fuel rod failure
  - Assume no deposition
  - Initial pressure 800 kPa (116 psia)
  - Assume canister free volume of 6 m^3
  - Target aerosol density: $\dfrac{0.10 \times 37\text{PWRs} \times 5.20 \times 10^{8}\ \text{mg} \times 1.1 \times 10^{-7}}{\left(\frac{300\ \text{K}}{460\ \text{K}}\right) \times \left(\frac{800\ \text{kPa}}{100\ \text{kPa}}\right) \times 6\ \text{m}^3} \approx 7\ \text{mg/m}^3$

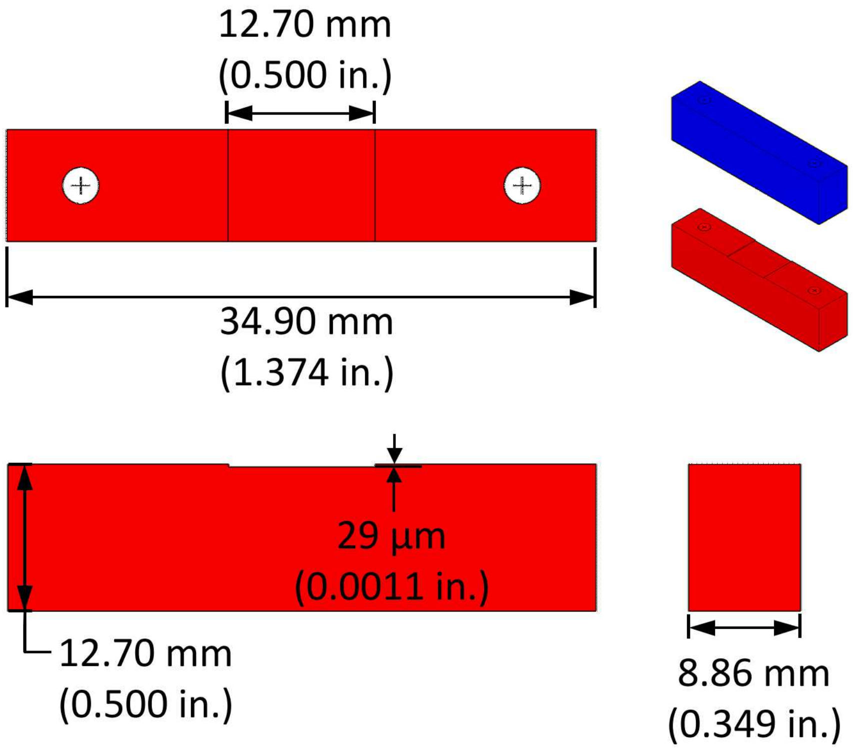
Surrogate Selection

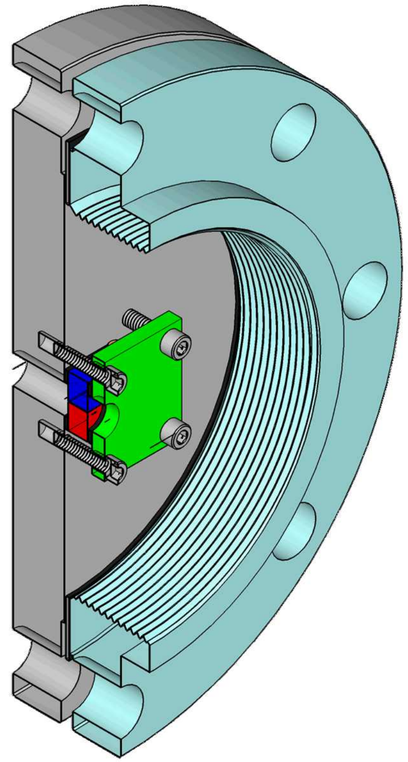


Particle size distribution (PSD) of the cerium oxide surrogate

- Cerium oxide (CeO_2) chosen as surrogate
  - ρ_{CeO_2} = 7.22 g/cm^3
  - ρ_{SNF} ≈ 10 g/cm^3 (Spent fuel)
- Aerosol PSD characteristics
  - Mass median diameter (MMD)
    - MMD = 4.1 μm
  - Geometric standard deviation (GSD)
    - GSD = 1.88

Engineered Microchannel

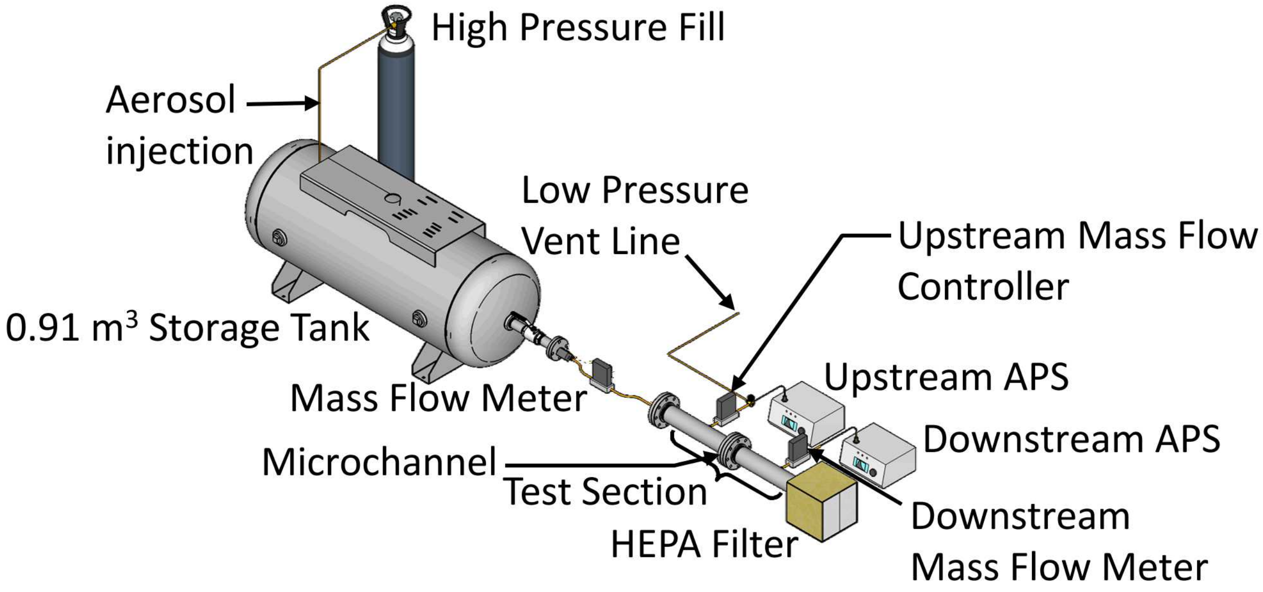


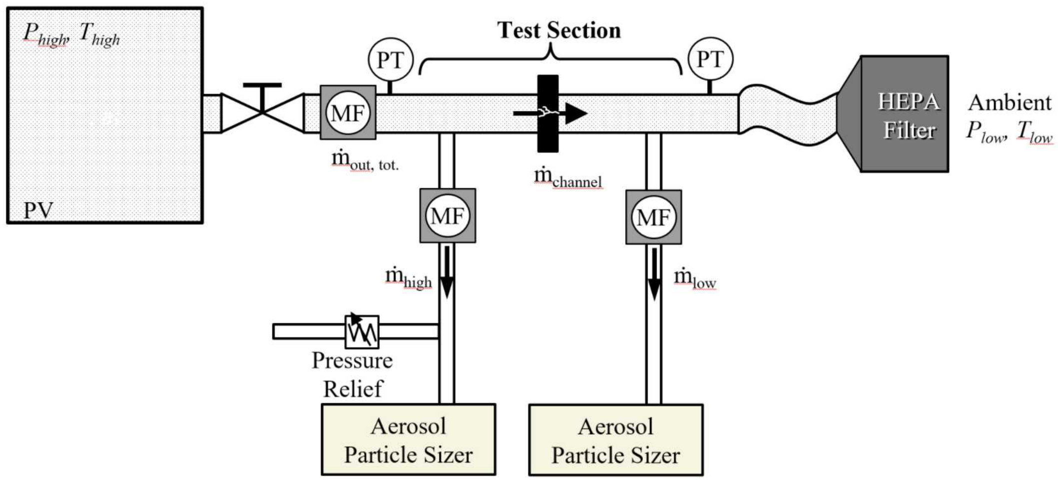


Isometric view of mounted microchannel on upstream side

- 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
- Bolted together to form microchannel
- Replaceable test section
  - Ultimately conduct experiments with representative SCC's

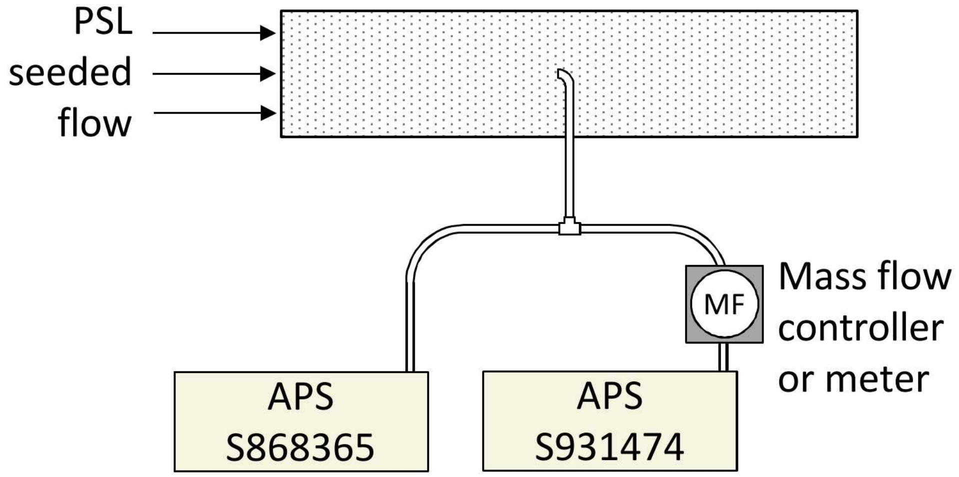
Preliminary Experimental Approach





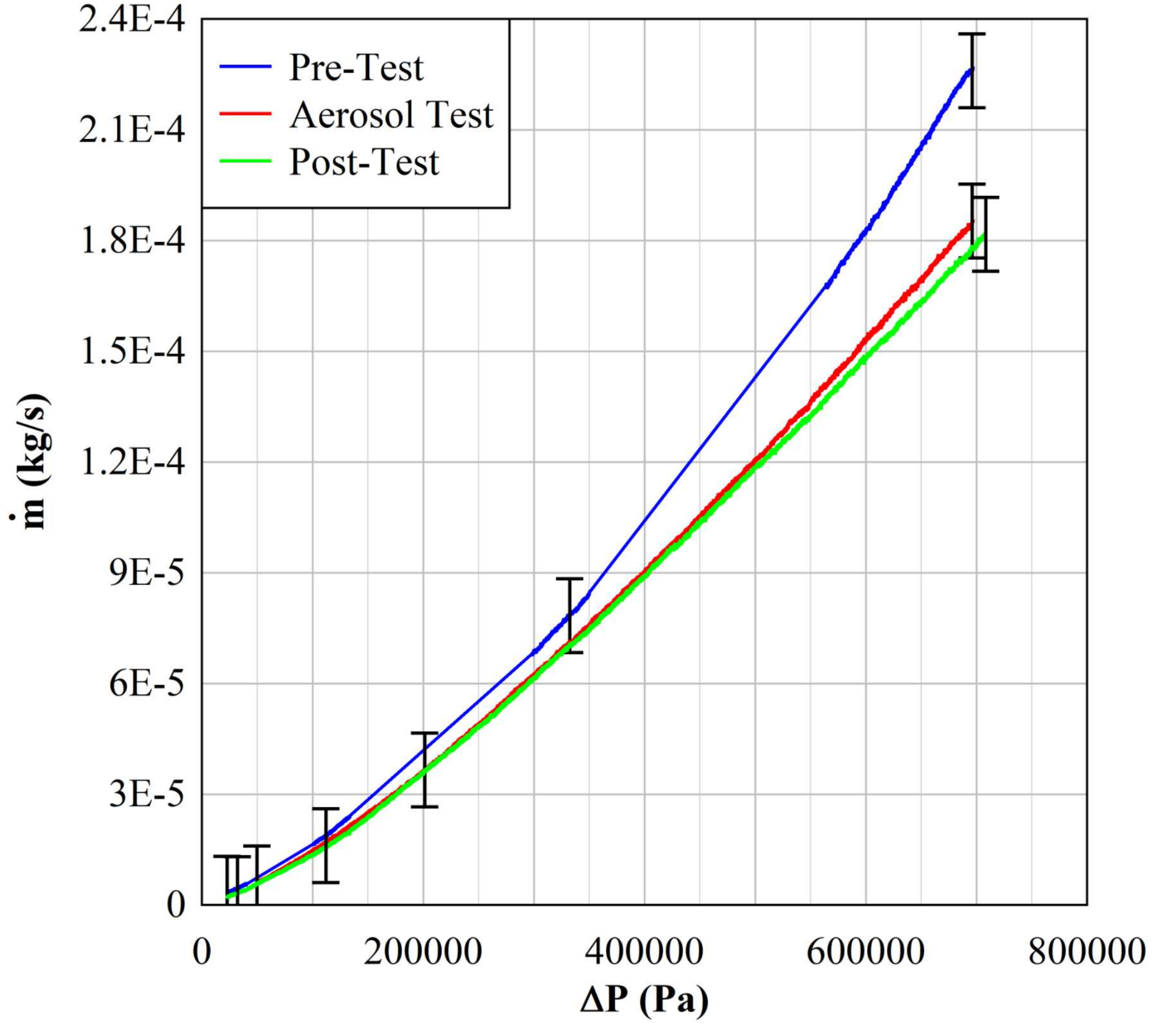
- Simulate blowdown of a pressurized canister using a 0.91 m^3 (240 gal) pressure tank
  - Prototypic canister free volume ~ 6 m^3
  - Seeded with CeO_2 surrogate aerosols
- Simulate SCC with engineered microchannel
  - Simplified representation with typical dimensions
- Quantify the aerosols upstream and downstream of the microchannel
  - During transient blowdown
  - Aerosol particle concentration and size
- Measure the air mass flow rate into and out of test section
  - Determine crack flow rate

Line Loss Characterization

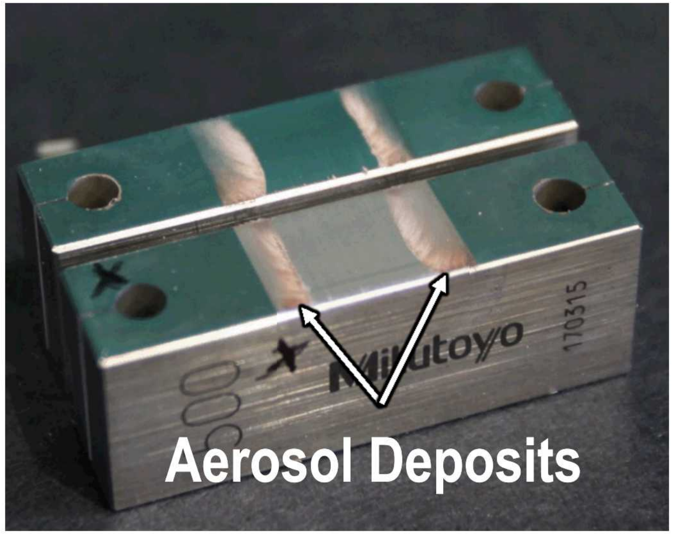


- Correct for presence of mass flow instrumentation
- Unpressurized tests
  - Monodisperse polystyrene latex (PSL) beads
    - 1.0, 3.1, and 4.8 µm
- Simultaneous measurement
  - Upstream and downstream
  - With and without flow controller
- Line losses based on aerosol density (mg/m^3)
  - Upstream (Mass flow *controller*)
    - $\frac{\text{With}}{\text{Without}} = 0.47$
  - Downstream (Mass flow *meter*)
    - $\frac{\text{With}}{\text{Without}} = 0.82$

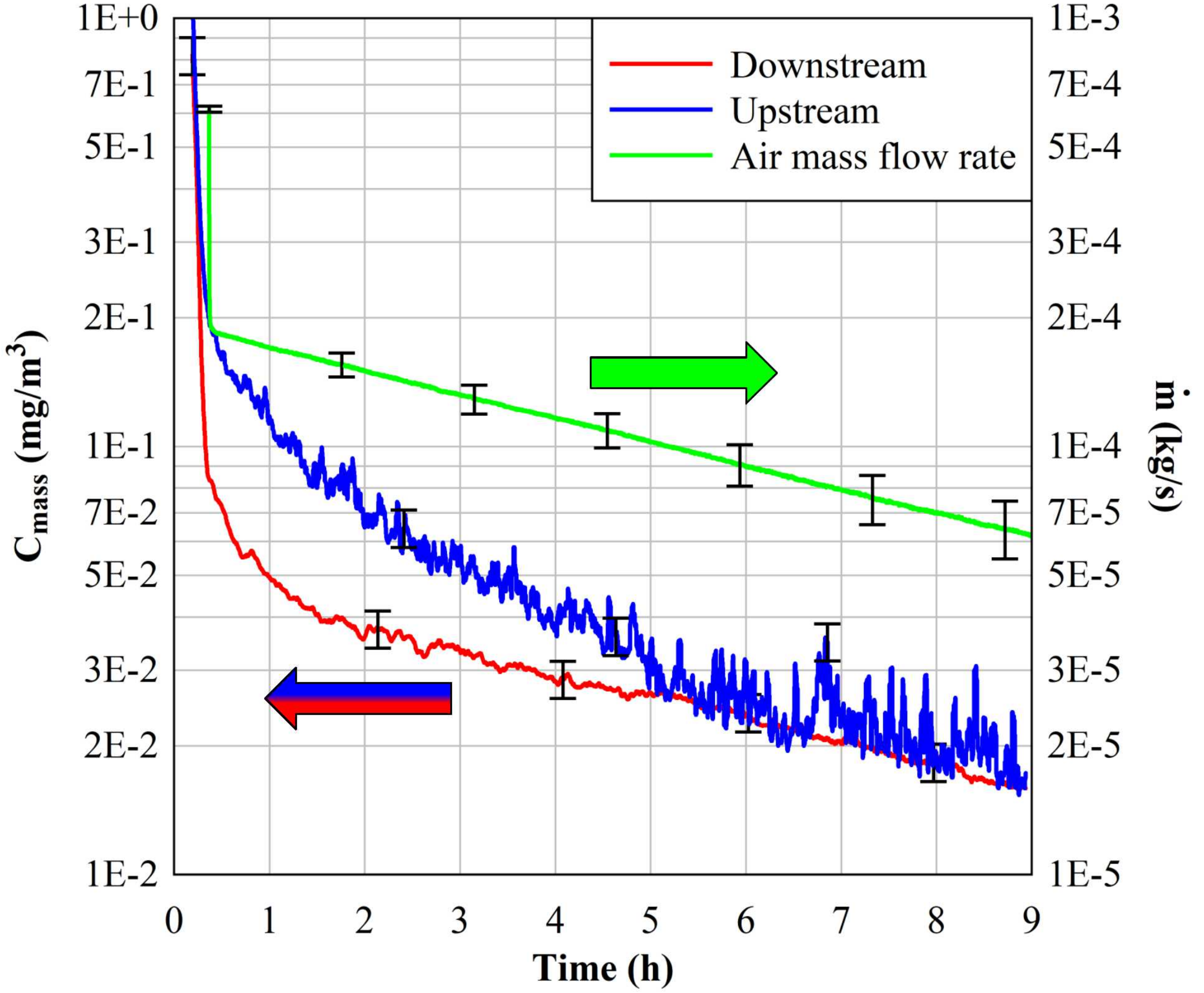
Gas Flow Measurements



- Pre-Test
  - Air only
  - Clean microchannel
- Aerosol Test
  - Aerosol laden air
- Post-Test
  - Clean air
  - Aerosol accumulations on microchannel
  - Similar flow rates for Aerosol Test and Post-Test
    - Indicates microchannel particle deposition occurred early in test

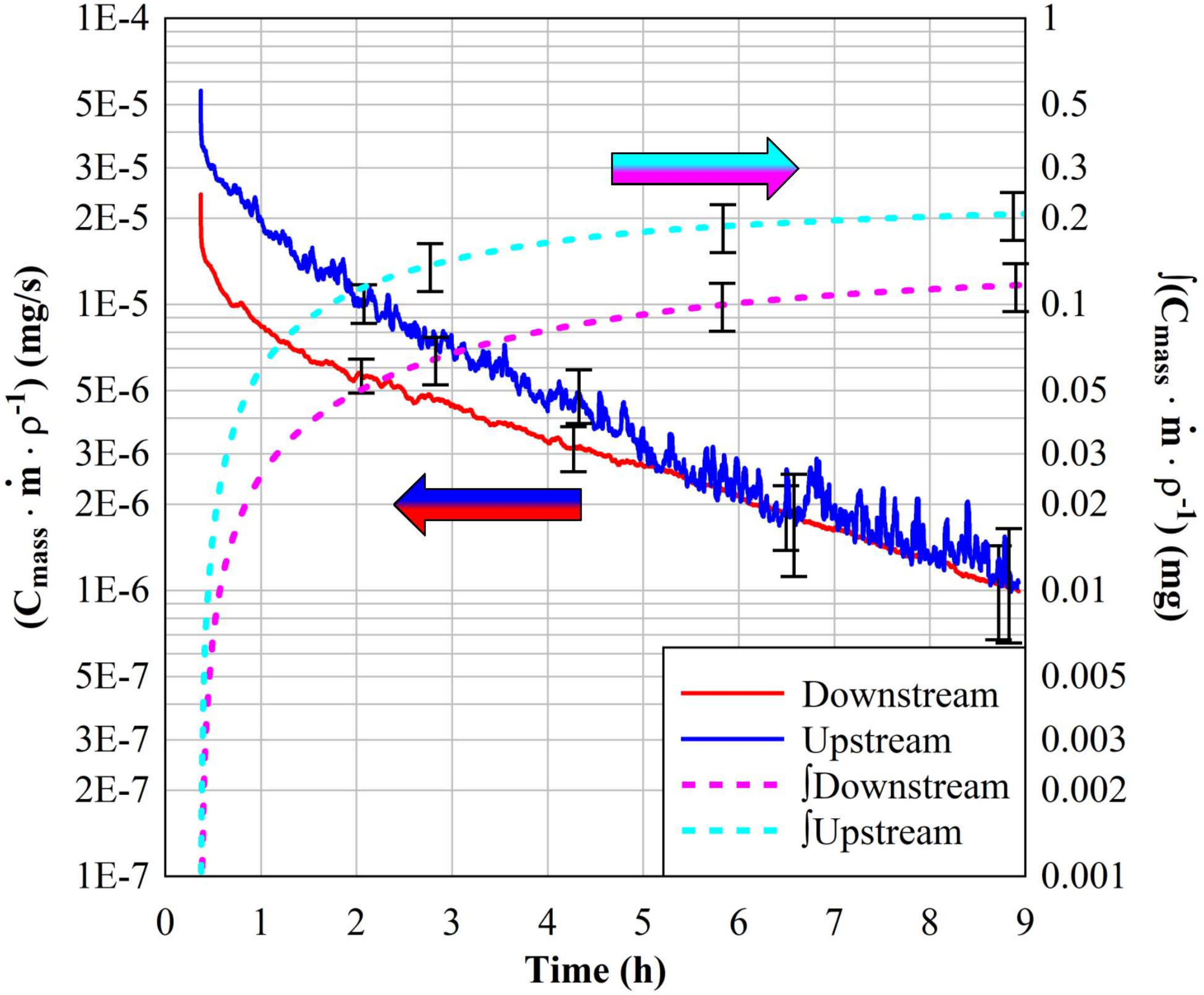


Aerosol Measurements
(Aerosol Mass Concentration)



- Aerosol mass concentration
  - Initial value of 1+ mg/m^3
    - Target value of C_{mass} = 7 mg/m^3
  - Upstream greater than downstream
    - Significant difference in first 5 hours
    - Convergence after 5 hours
  - 9 hour average concentration
    - Upstream: 0.048 mg/m^3
    - Downstream: 0.030 mg/m^3

Aerosol Measurements
(Aerosol Mass Flow)



- Aerosol mass flow
  - Product of aerosol mass concentration and volumetric air flow rate
- Integrated aerosol mass
  - Upstream: 0.21 mg
  - Downstream: 0.12 mg
- Overall retention 44%

Summary

- Explored flow rates and aerosol retention in an engineered microchannel
  - First step to characterize hypothetical 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
    - 800 kPa (116 psia)
  - 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 first 5 hours
  - Integrated aerosol mass
    - Upstream 0.21 mg
    - Downstream 0.12 mg
  - 44% retention

Future Work

- Improve aerosol analysis capabilities
  - Dual sensor single analyzer system
  - New aerosol particle sizer designed for pressure
    - Eliminate mass flow instrumentation losses
- Additional tests of existing microchannel
  - Different initial pressures
  - Different initial aerosol concentrations
  - Repeatability tests
- Mixing of aerosols in pressure tank
- More complex microchannels
  - Work up to mountable, lab-grown SCC
  - Characterize geometry for code validation