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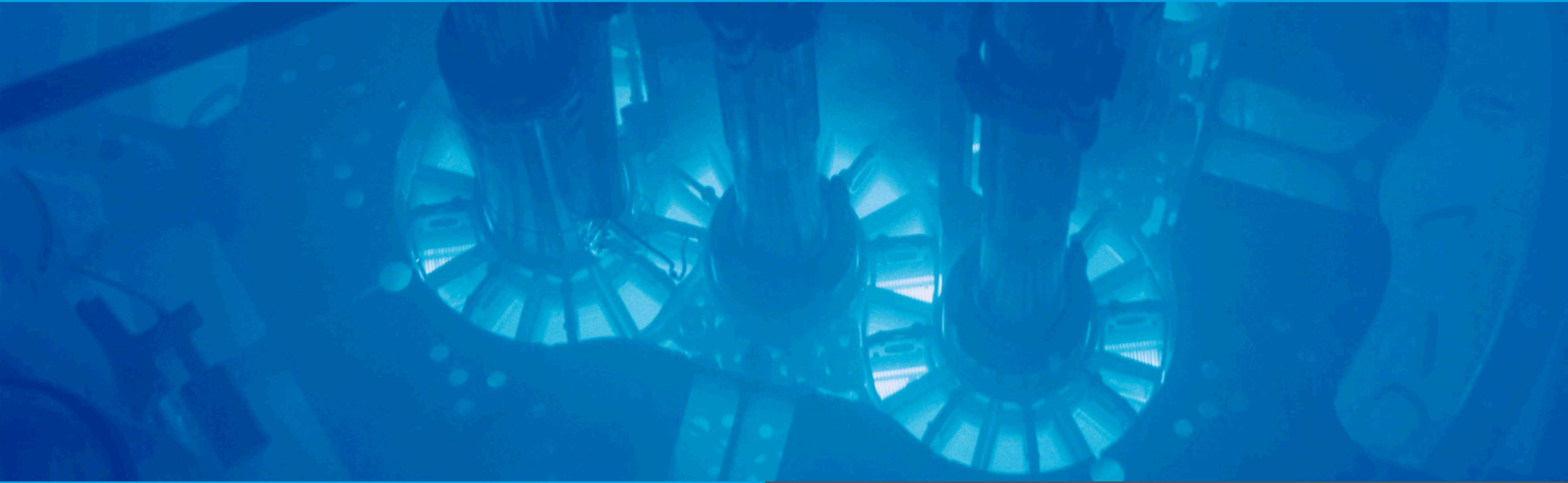

Characterization of Through-Wall Aerosol Transmission for SCC-Like Geometries

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EPRI Extended Storage Collaboration Program

Charlotte, NC

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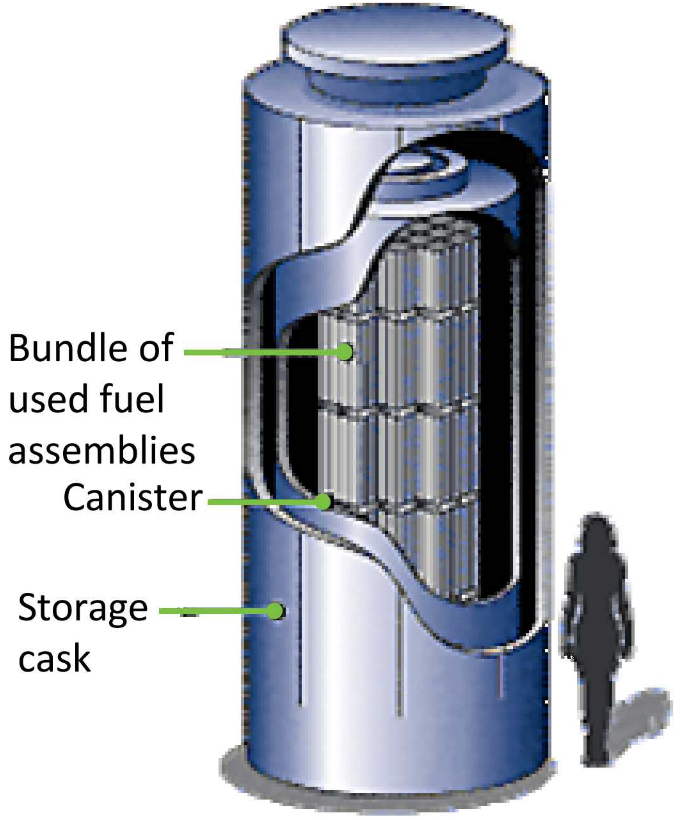
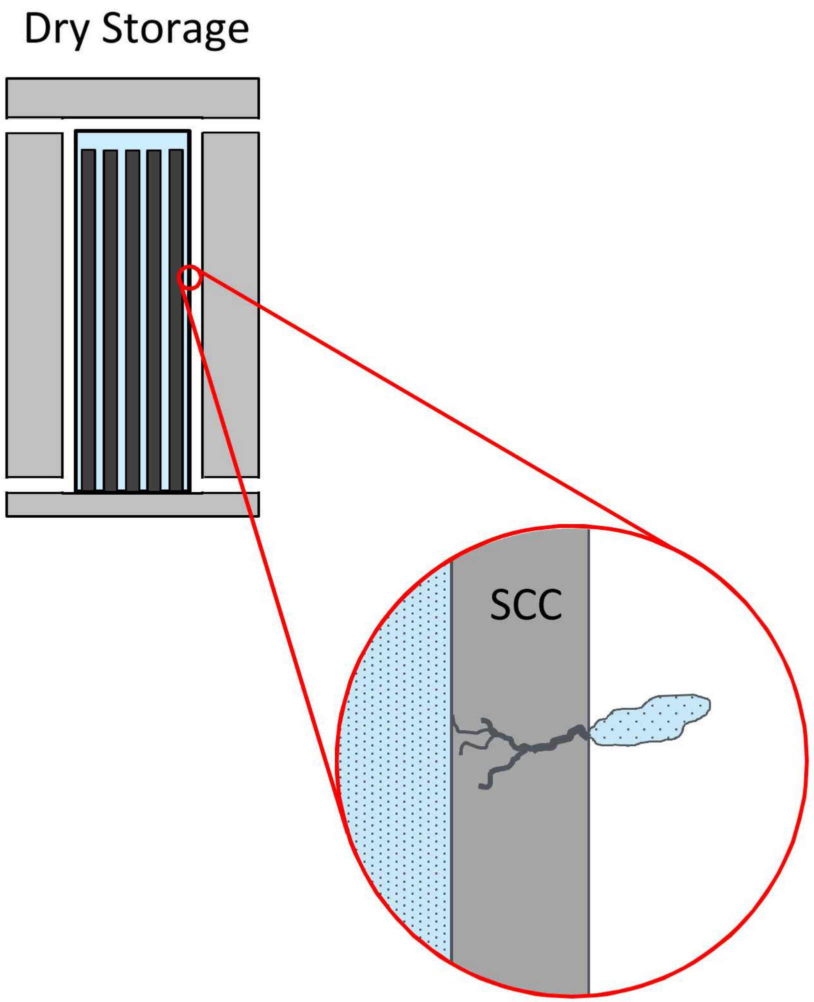
Overview



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

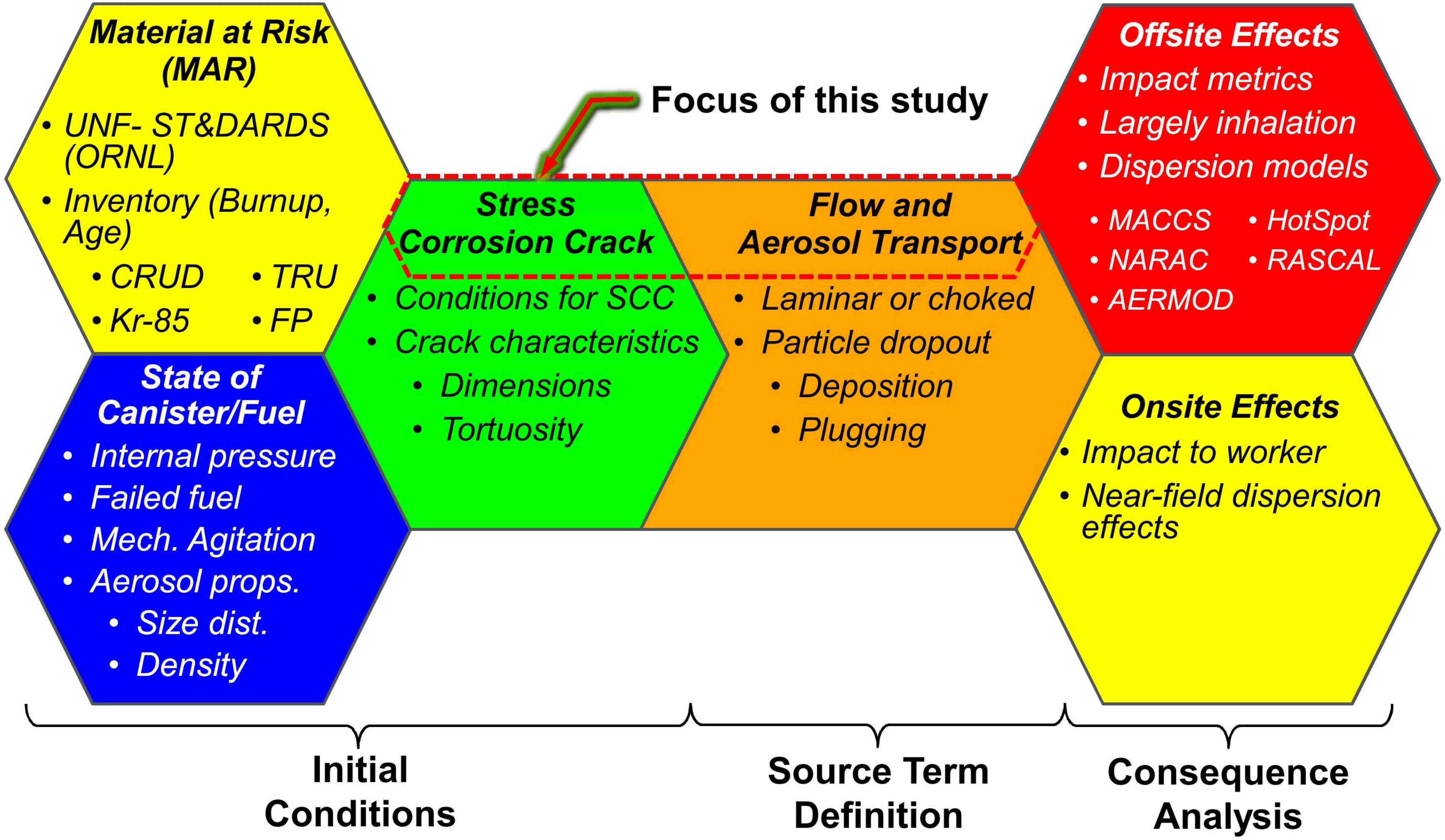
- Mimic aerosol transport through a stress corrosion crack (SCC)
  - Pressure-driven flow
    - Prototypic canister pressures
    - Near-prototypic canister volume
- Explore flow rates and aerosol retention of an engineered microchannel
  - Characteristic dimensions similar to those of SCCs
    - Microchannel: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

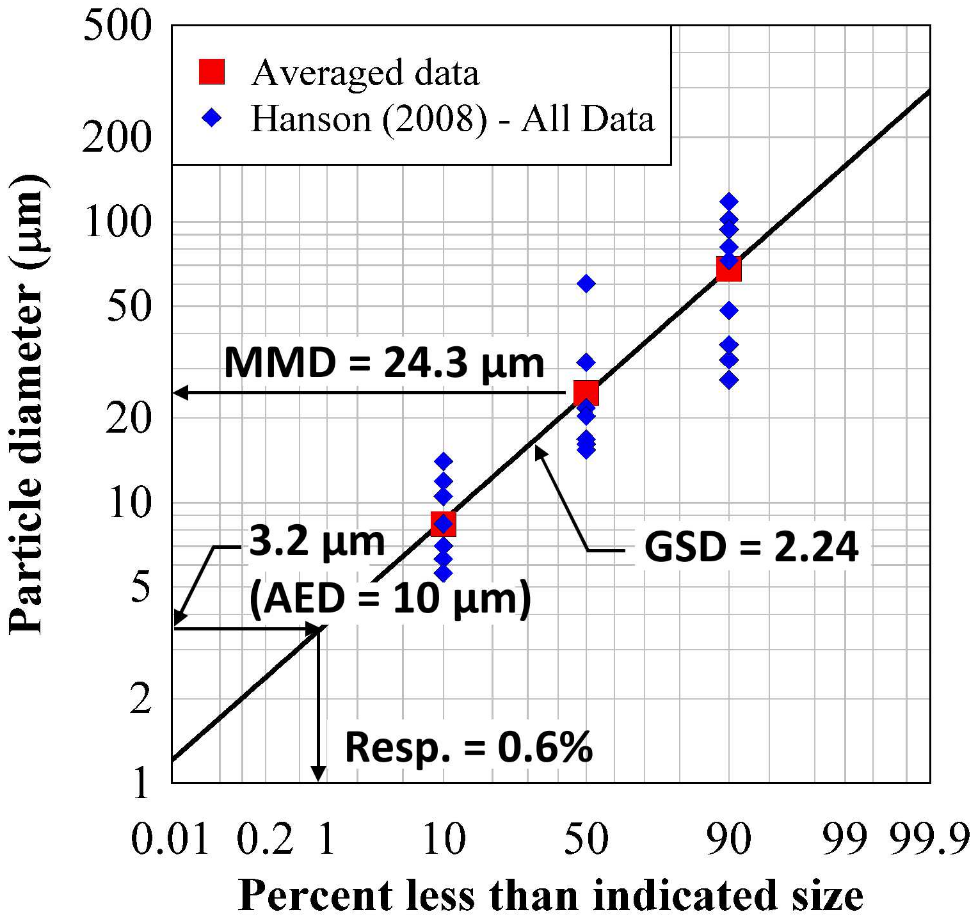


- What is the potential impact of a through-wall stress corrosion crack (SCC)?
  - Relatively low availability of mobile radionuclides under normal storage and transportation
- Significant amount of literature on aerosol transport through idealized leak paths
  - Primarily for moderate pressure differentials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



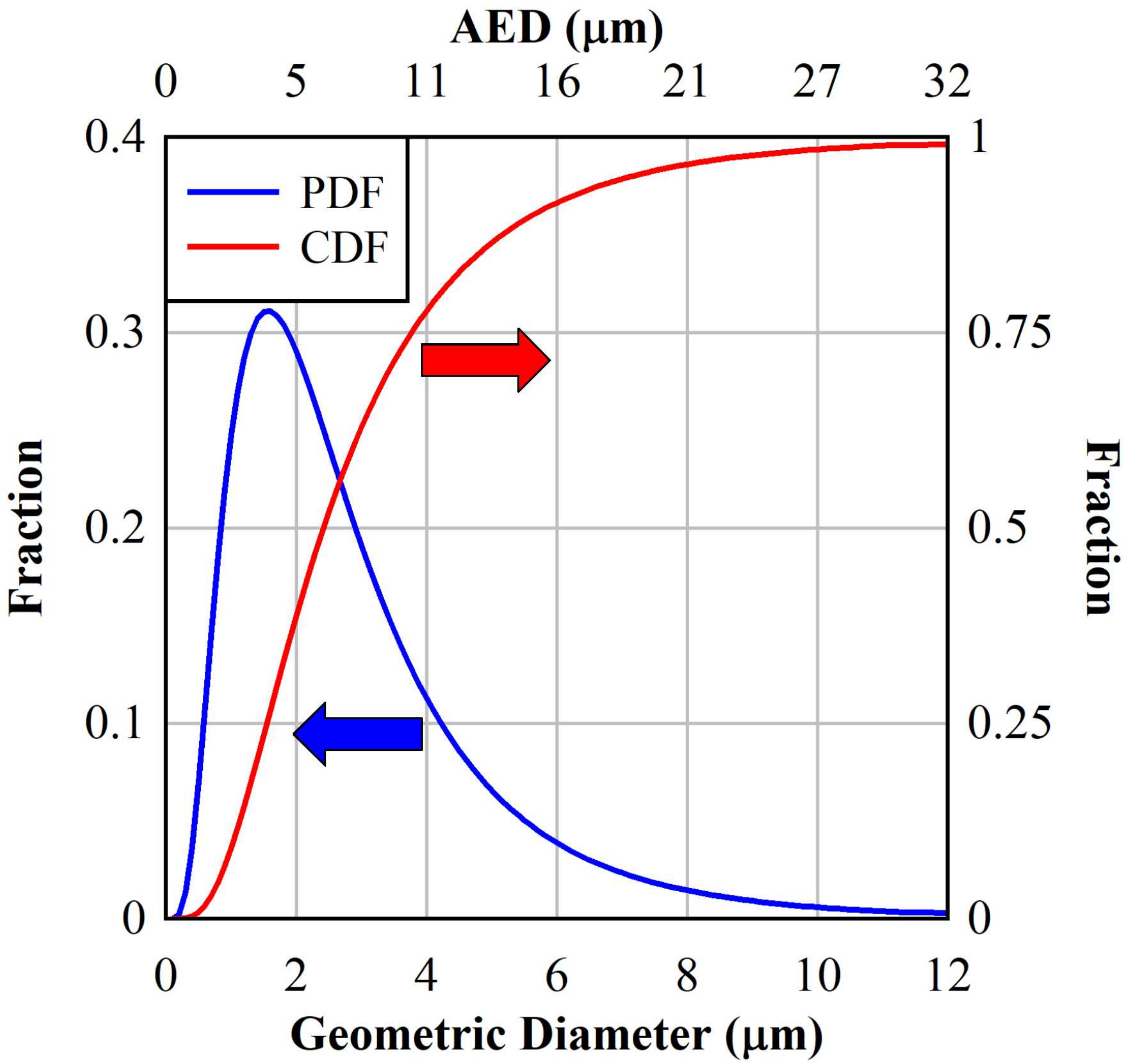
Hanson, B.D., et al., "Fuel-In-Air FY07 Summary Report," Pacific Northwest National Laboratory, PNNL-17275, September 2008.

- 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
    - 3×10^{-6} cited in SAND90-2406
      - 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

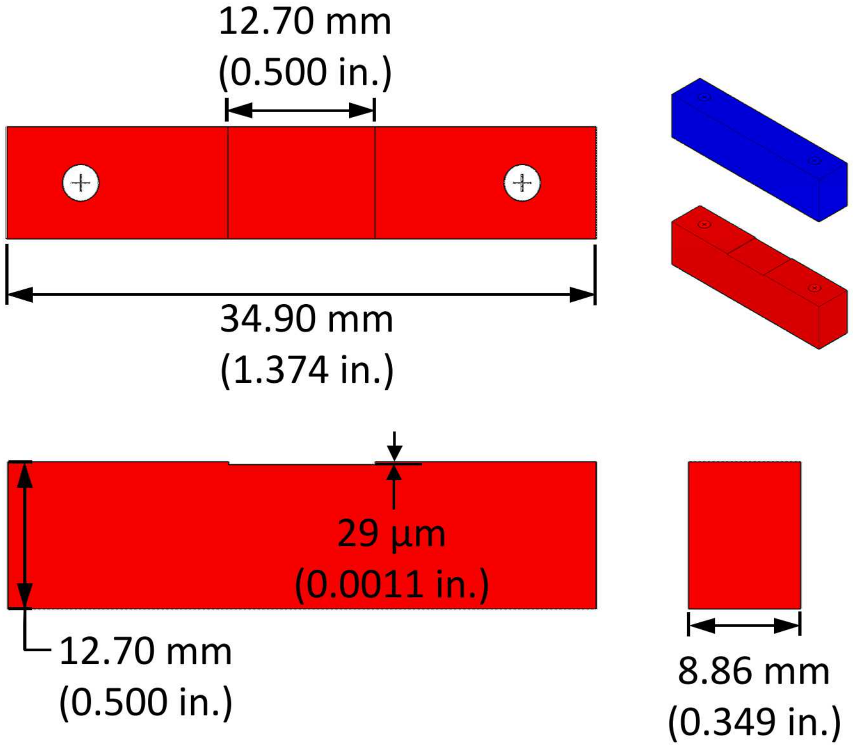
- Respirable particles with an AED < 10 µm
- Hanson *et al.*, 2008
  - Respirable release fraction = 1.1×10^{-7}
- Estimate hypothetical aerosol density available for transport
  - 37 PWRs
  - 520 kg UO_2 per assembly
  - Assume 10% fuel rod failure
  - Assume no deposition
  - Initial pressure 800 kPa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

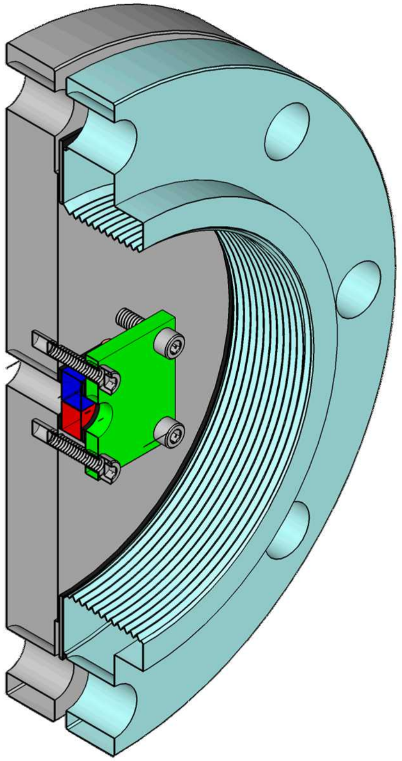
Surrogate Selection



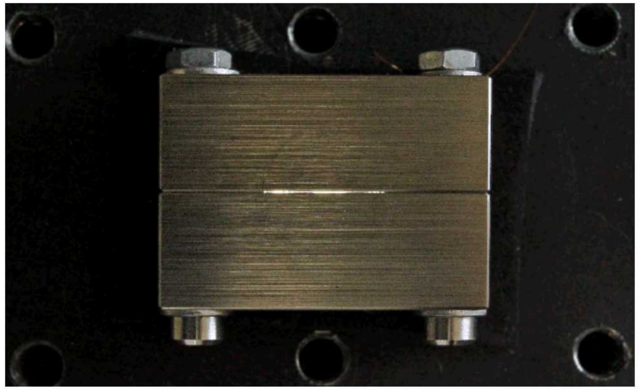
- Cerium oxide (CeO_2) chosen as surrogate
  - $\rho_{CeO_2} = 7.22$ g/cm^3
  - $\rho_{SNF} \approx 10$ g/cm^3 (Spent fuel)
- Particle size distribution
  - Mass median diameter (MMD)
    - MMD = 2.4 μm
  - Geometric standard deviation (GSD)
    - GSD = 1.9
  - ~75% particles (by mass) respirable
    - 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 (5.7×10^{-4} in^2)
- Bolted together to form microchannel
- Replaceable test section
  - Ultimately conduct experiments with representative SCC's

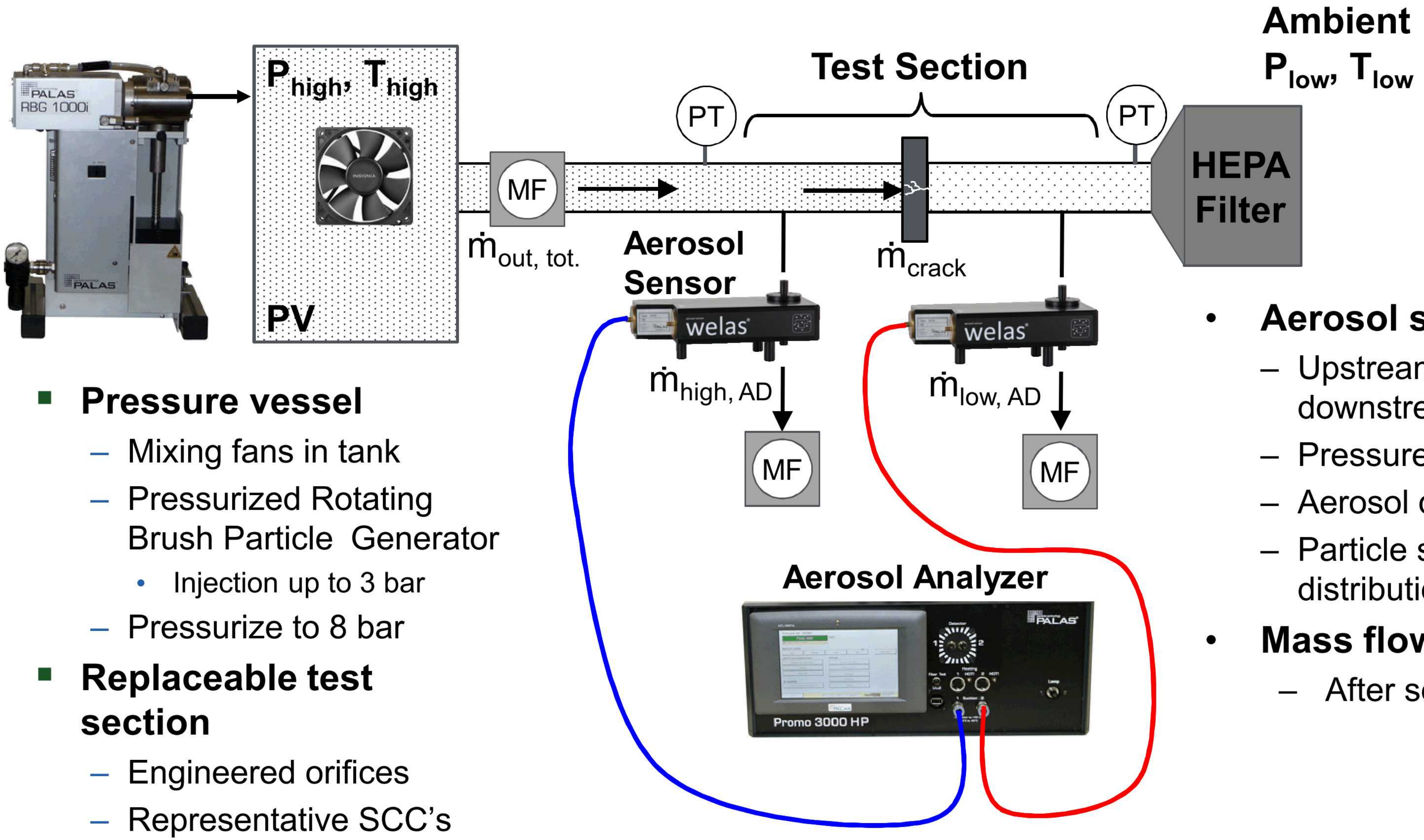
Experimental Improvements in FY19

- Dual high pressure sensors
  - Near simultaneous upstream and downstream
    - Virtually eliminates instrumentation bias
  - Up to 1 MPa (145 psi)
  - Light scattering
    - Aerosol concentration
    - Geometric size distribution

- High pressure rotating brush particle generator
  - Loads particles up to 300 kPa (43.5 psi)

- Four mixing fans inside of pressure tank
  - Aerosols lofted for extended time period

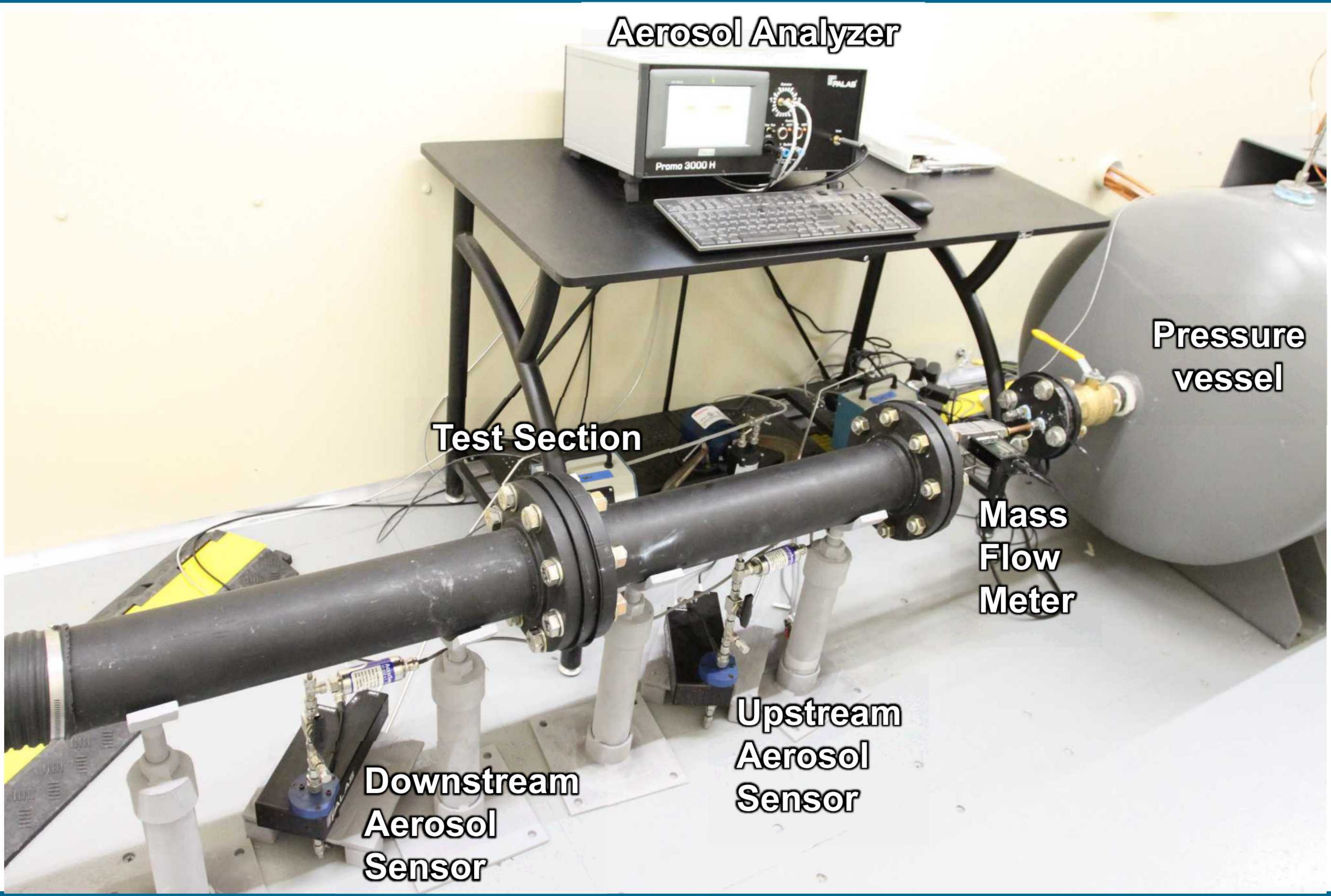
Test System Schematic



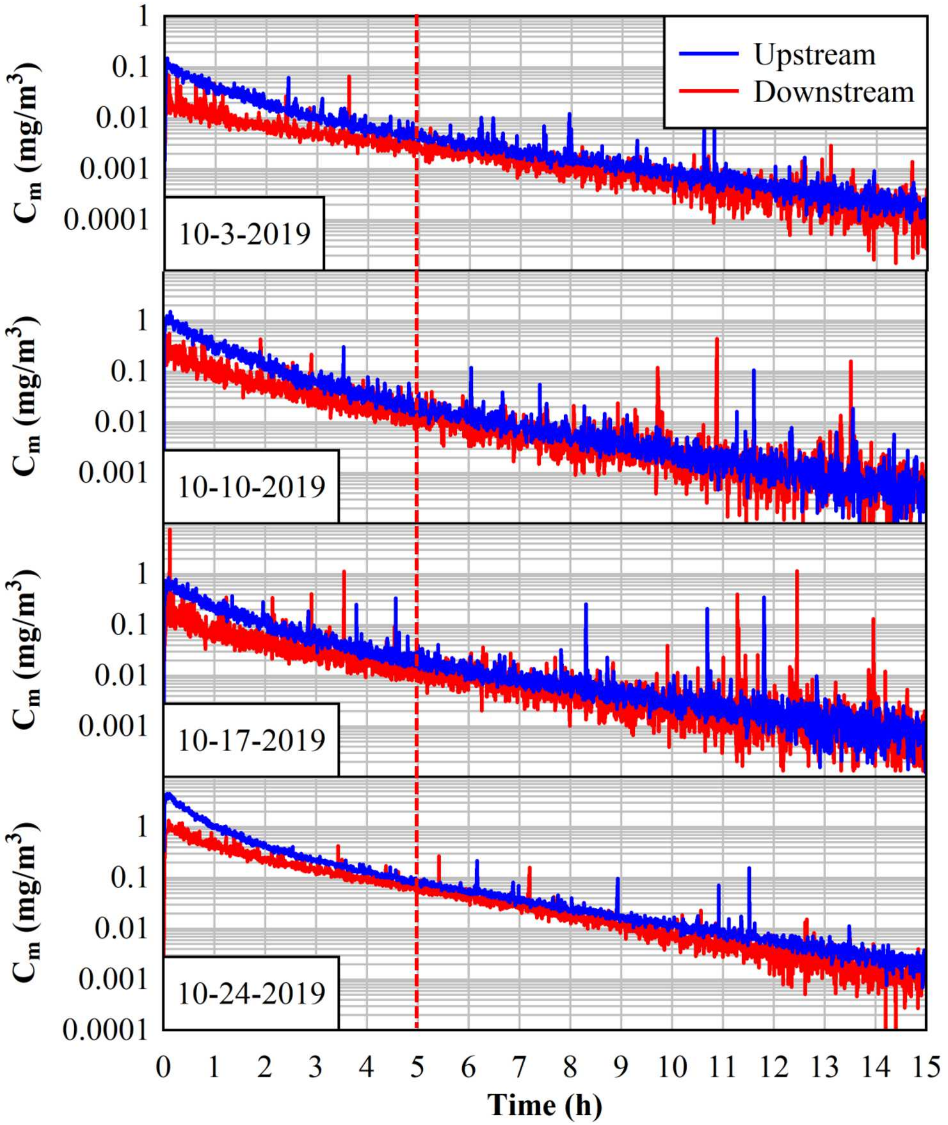
- **Pressure vessel**
  - Mixing fans in tank
  - Pressurized Rotating Brush Particle Generator
    - Injection up to 3 bar
  - Pressurize to 8 bar
- **Replaceable test section**
  - Engineered orifices
  - Representative SCC's

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

Test System Photograph



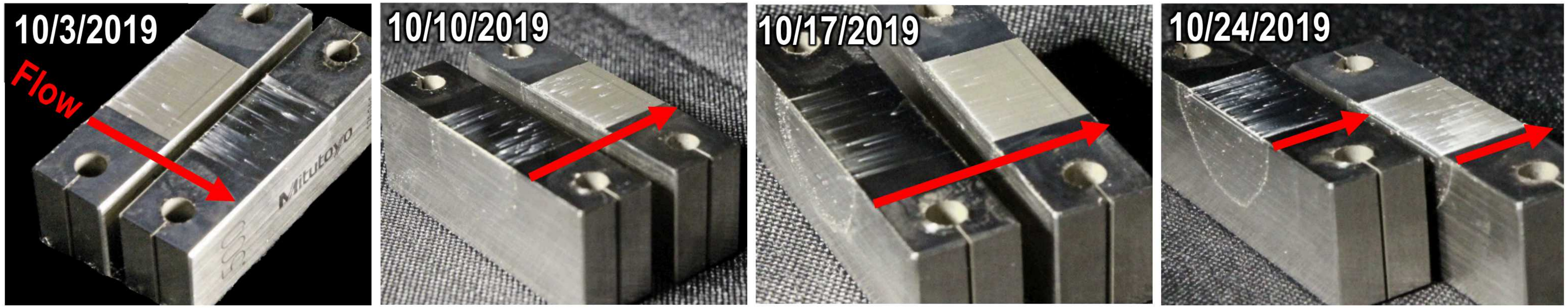
Aerosol Measurements
(Aerosol Mass Concentration)



- Aerosol mass concentration
  - Four tests show similar behavior
    - Target value of C_m = 7 mg/m^3
  - Upstream greater than downstream
    - Significant difference in first 5 hours
    - Convergence after 5 hours

Test Date	Initial Upstream Aerosol Characteristics			Filtering Characteristics	
	MMD (µm)	GSD (-)	C_m (mg/m^3)	Transmission (-)	Retention (-)
Oct. 3, 2019	2.3	2.0	0.12	0.30	0.70
Oct. 10, 2019	2.5	1.8	1.14	0.33	0.67
Oct. 17, 2019	2.0	1.9	0.66	0.36	0.64
Oct. 24, 2019	2.8	2.1	5.03	0.40	0.60

Aerosol Deposits



C_m (mg/m^3)	**0.12**	**1.14**	**0.66**	**5.03**
Retention (-)	**0.70**	**0.67**	**0.64**	**0.60**

- Aerosol deposits on microchannel
  - Four tests show similar behavior
    - Streaking
    - “Snowball” accumulation
  - Upstream leading edge
    - More accumulation

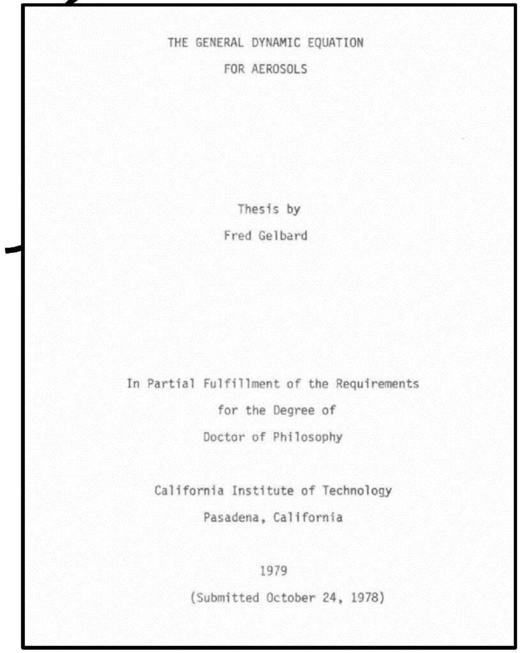
Summary

- 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
  - Average transmission (release fraction) measured as 0.34
    - Additional work needed to quantify uncertainty and repeatability

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


THE GENERAL DYNAMIC EQUATION
FOR AEROSOLS

Thesis by
Fred Gelbard

In Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy

California Institute of Technology
Pasadena, California

1979
(Submitted October 24, 1978)

Future Work

- Eliminate upstream mass flow measurement
  - Move flow measurement downstream
    - After HEPA filter
    - Prevent flow instrument damage by particles
- Additional tests of existing microchannel
  - Different initial pressures
  - Different initial aerosol concentrations
  - Repeatability tests
- More complex microchannels
  - Work up to mountable, lab-grown SCC
  - Characterize geometry for code validation