Exceptional service in the national interest
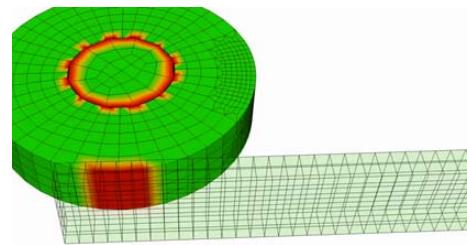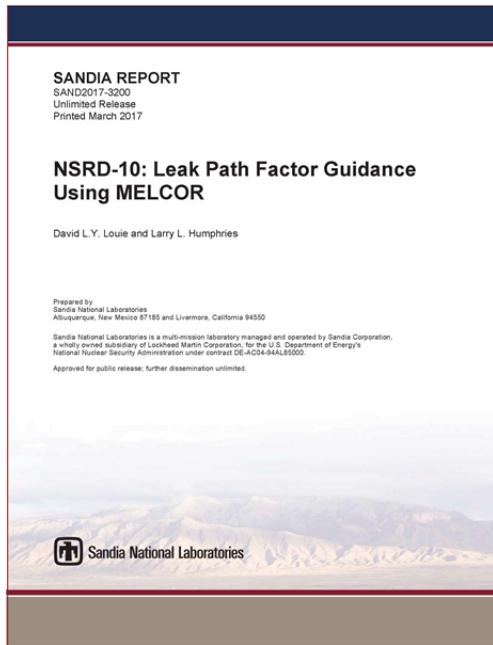
Sandia National Laboratories
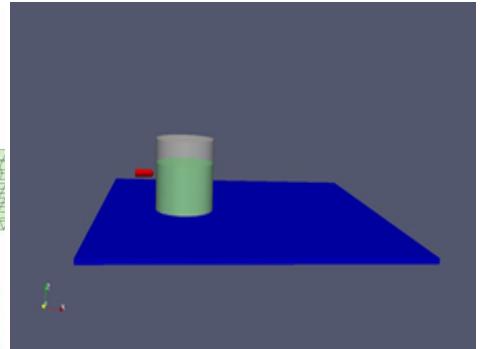
MELCOR Application to Leak Path Factor Analysis

David L.Y. Louie, Ph.D.

MCAP Meeting, September 12-15, 2017

Acknowledgement

- Thanks to many staff within Severe Accident Analysis to review, prepare and run MELCOR validation cases and SAND2017-3200.

- Also thanks to external reviewers for this SAND report from David Gray (KAPL), Terry Foppe, Wendy Reed (NRC) and Alexander Laptev (LANL)

- Thanks the support from DOE HSS's Nuclear Safety Research and Development (NSRD) Project under WAS Project #2015-AU30-SNL-MELCOR, and overseen by Alan Levin and Patrick Frias (AU-30)

- Also expresses thanks to those involved in preparation and review of NSRD-6, NSRD-11, and NSRD-15 projects relating to the use of Sandia's Sierra Code Suite

Outline

- What is Leak Path Factor (LPF)?

- History of Using MELCOR for LPF Analysis and Other Applications

- What is needed for LPF analysis?

- What improvement over the obsolete LPF MELCOR report?

- MELCOR 2.1 validations

- Best Practices

- Summary and future expectations
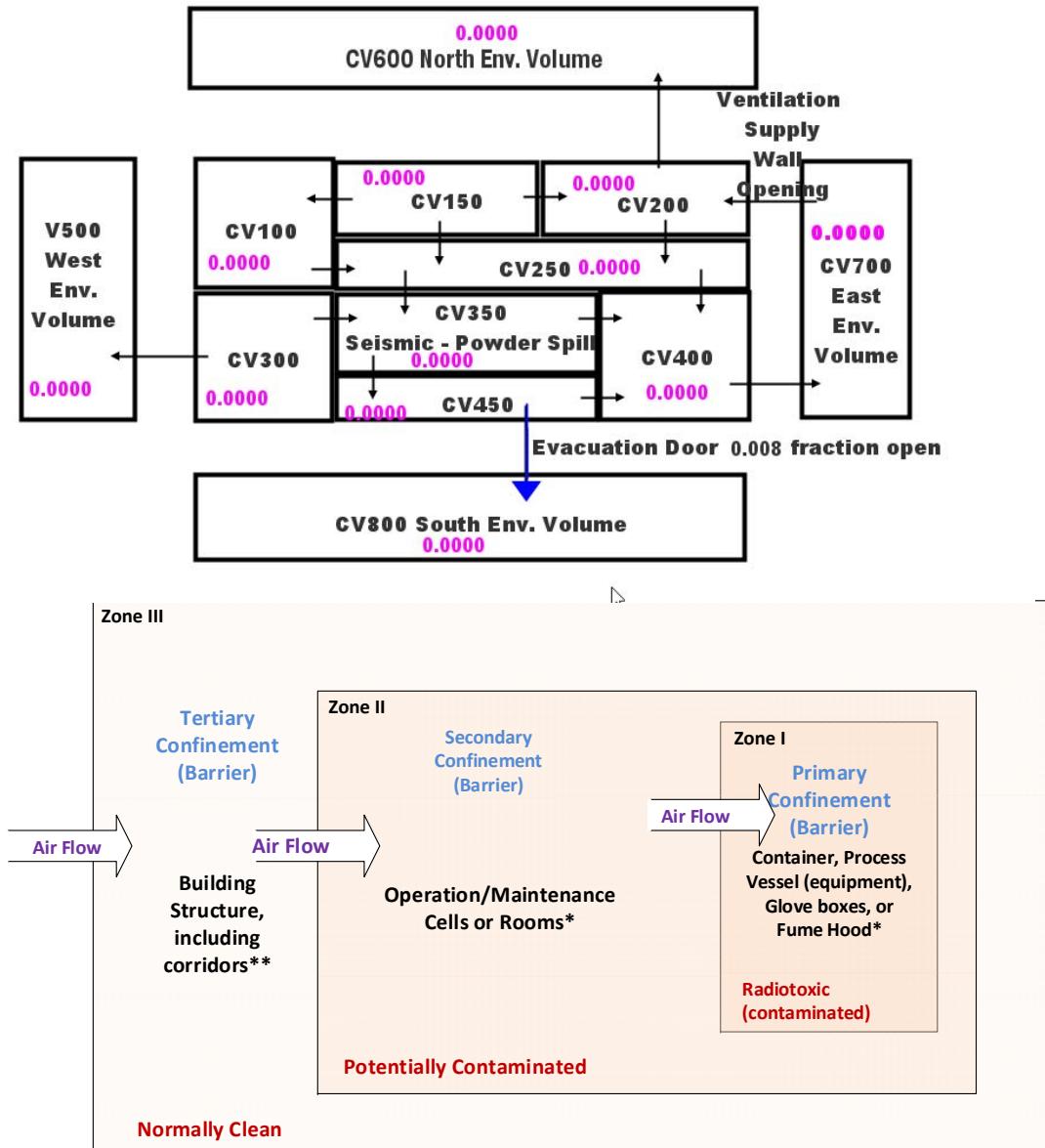
What is Leak Path Factor?

- Five Factor Formula

  - $ST = MAR \cdot DR \cdot ARF \cdot RF \cdot LPF$

    - MAR - material at risk, DR – damage ratio, ARF – airborne release fraction, RF – respirable fraction & LPF – leak path factor

- Derived data (i.e., ARF & RF) from DOE-HDBK-3010-94

  - DOE funded Sandia for substantiating these data for 4 years - Sandia's SIERRA Code Suite: NSRD-6, NSRD-11, NSRD-15 and NSRD-16

- LPF estimates the fraction of the ST that is released from the facility

*This barrier/confinement may contain its own ventilation system that includes off-gas treatment
**This barrier/confinement may require airlock for personnel to enter the secondary confinement

Sandia's SIERRA High Fidelity Code Suites

- SIERRA Framework
- Thermal/Fluid Dynamics
  - Fuego – low Mach, fire & reacting flow capabilities, particles
  - Aria – multi-physics, chemistry, fluid, free surface (no particle)
- Solid Mechanics
  - Adagio –Quasi-static (implicit)
  - Presto – Transient (explicit), can handle explosions (ITAR)
  - Both codes have SPH to model particles

5
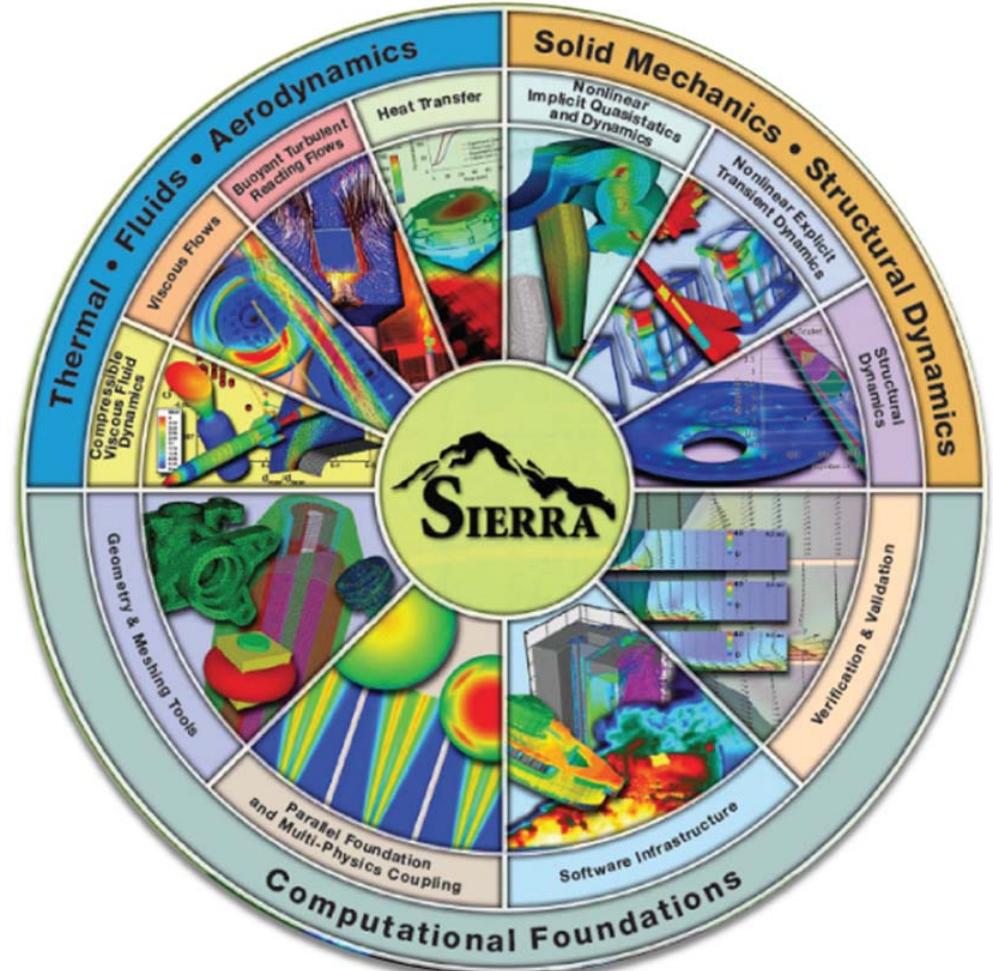
History of Using MELCOR

- LPF Analysis
  - Codes used: MELCOR, CONTAIN, FIRAC, GASFLOW, KBERT, FATE and FSSIM
  - MELCOR 1.8.5 is a safety code listed in DOE Central Registry
  - MELCOR used in LPF analyses at DOE facilities:
    - LANL: TA-55, WCRRF, DVRSF, CMRR, BTF
    - NNSS: DAF, G Tunnel
    - LLNL: Plutonium facility
    - Pantex: Assembly cells
    - SRNL: K Area SF storage facility

- Other Applications of MELCOR
  - Trade-off studies
  - Decontamination studies
  - Facility Design
  - Spent fuel reprocessing facilities

# What improvement over the obsolete LPF MELCOR report?

- Replace the obsolete MELCOR 1.8.5 LPF Guidance Report in DOE Central Registry
  - MELCOR 1.8.5 or 1.8.6 is not supported by Sandia
  - Only verification tests included
- MELCOR 2.1 Guidance Report development include:
  - Validation tests
    - reactor and non-reactor experiments, particularly for aerosol physics
    - Analytical tests
  - Verification tests
    - Version to version comparison - MELCOR 1.8.5, 1.8.6 and 2.1
    - Additional verifications other than those in MELCOR 1.8.5 guidance report
  - Best practices for common accident scenarios encountered at DOE facilities – explosions, fires, spills, and criticalities
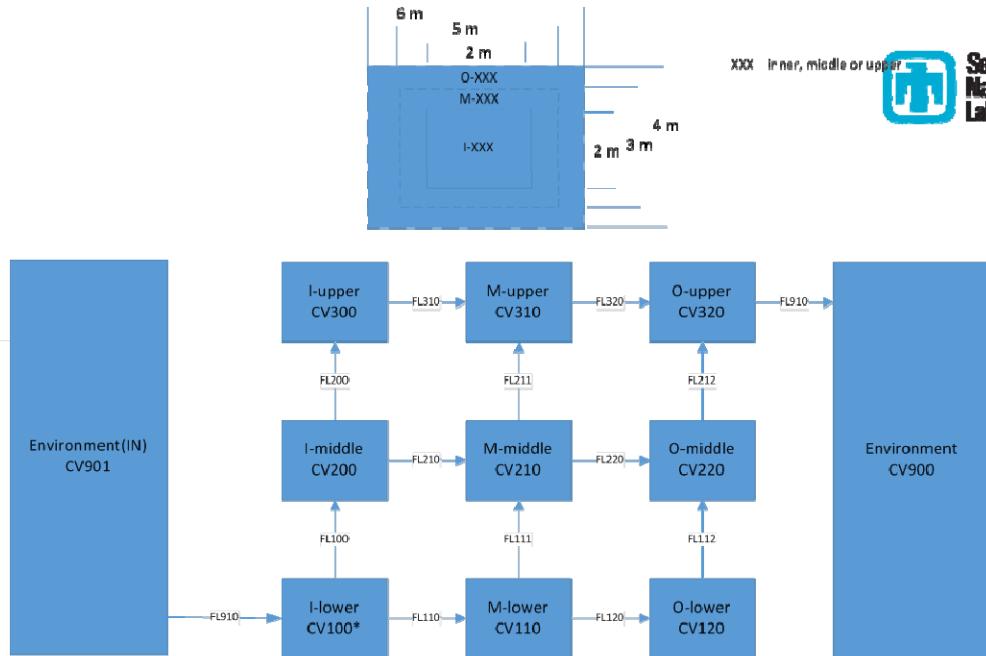
LPF Verification and Validation Tests

- In addition to those experiments identified from MELCOR Assessment Report [SAND2015-6693 R]

- We have identified:
  - Fire test –LLNL Enclosure Fire – from Validation document of CFAST
  - Aerosol resuspension test – STORM SR-11 Test
  - Additional experiments from DOE-HDBK-3010-94
    - Wind Tunnel Gasoline pool fire tests conducted at the RART facility
    - Spills and Pressurized Release Tests conducted in RART

- Verification tests
  - Sample problems in Obsolete MELCOR 1.8.5 guidance report
  - Specific fire problem extracted from LA-UR-03-7945
  - Version-to-version comparison: MELCOR 1.8.5, 1.8.6 and 2.1

[LA-UR-03-7945]
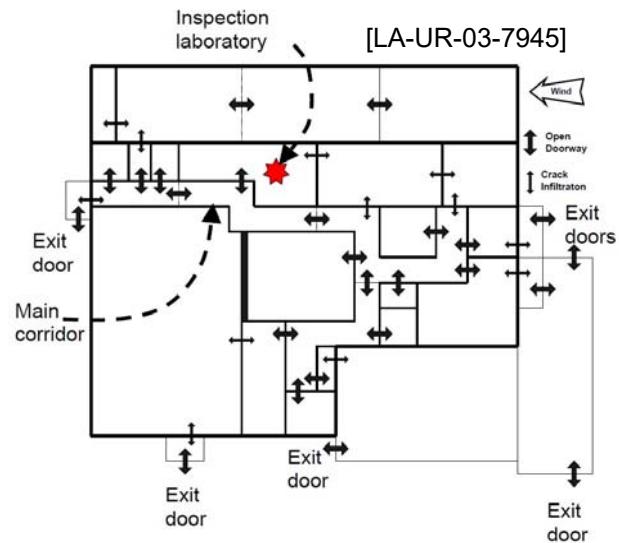
LLNL Enclosure Fire Test (CFAST)

Ceiling intentionally removed. All values refer to inner dimension.
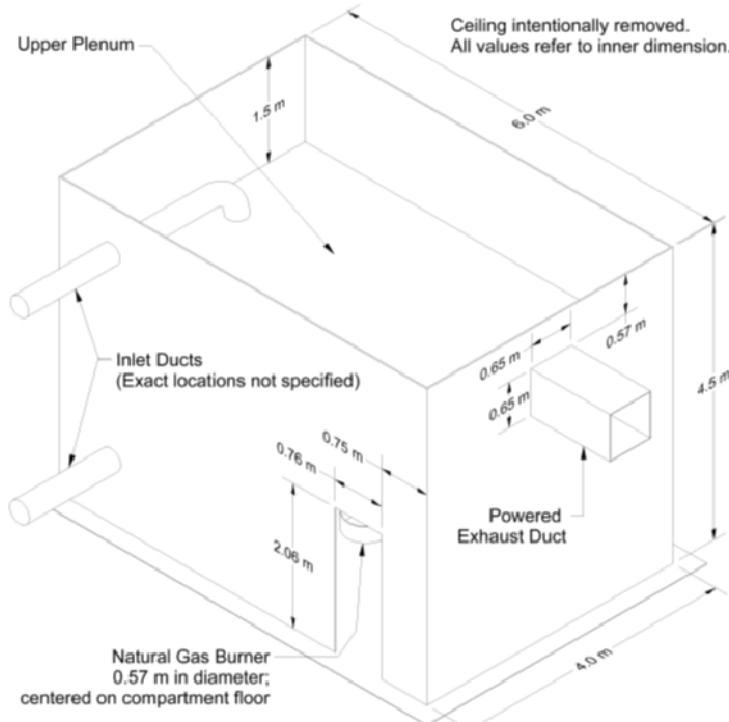
[Peacock 2016]

*The burner is located in this volume. The external sources (CO2 and H2O) and sink (O2) will be modeled. Appropriate control functions to model the combustion are modeled in addition to the specific flow rate of the air flow and combustible power for the tests.

Test 9 https://github.com/firemodels/cfast/blob/master/Validation/LLNL_Enclosure/Experimental_Data/LLNL_09.csv.

Time (s)	Air Flow (kg/s)	Fuel Flow (kg.s)	O₂ Fraction	ΔP (Pa)	CO₂ Fraction	West Upper TC (K)	West Middle TC (K)	West Bottom TC (K)
0	0.565	0.0	0.208	-398	0.0005	302.15	302.15	302.15
500	0.491	0.0041	0.185	-297	0.0140	399.15	386.15	332.15
1000	0.474	0.0040	0.1822	-292	0.0156	413.15	398.15	339.15
2000	0.463	0.0042	0.1809	-287	0.0159	425.15	413.15	346.15
3000	0.464	0.0039	0.1824	-278	0.0154	427.15	413.15	399.15
4000	0.461	0.0040	0.1819	-261	0.0157	434.15	419.15	405.15

Test 11 https://github.com/firemodels/cfast/blob/master/Validation/LLNL_Enclosure/Experimental_Data/LLNL_11.csv.

| Time (s)	Air Flow (kg/s)	Fuel Flow (kg.s)	O2 Fraction	ΔP (Pa)	CO₂ Fraction	West Upper TC (K)	West Middle TC (K)	West Bottom TC (K)
0	0.240	0.0	0.2098	-75	0.0004	292.15	292.15	292.15
500	0.222	0.0040	0.1705	-42	0.0220	408.15	394.15	339.15
1000	0.221	0.0040	0.1546	-39	0.0289	422.15	408.15	349.15
2000	0.210	0.0040	0.1486	-45	0.0325	437.15	421.15	360.15
3000	0.207	0.0040	0.1473	-38	0.0326	444.15	429.15	366.15
4000	0.204	0.0040	0.1460	-31	0.0335	452.15	436.15	373.15

LLNL Fire Test Results

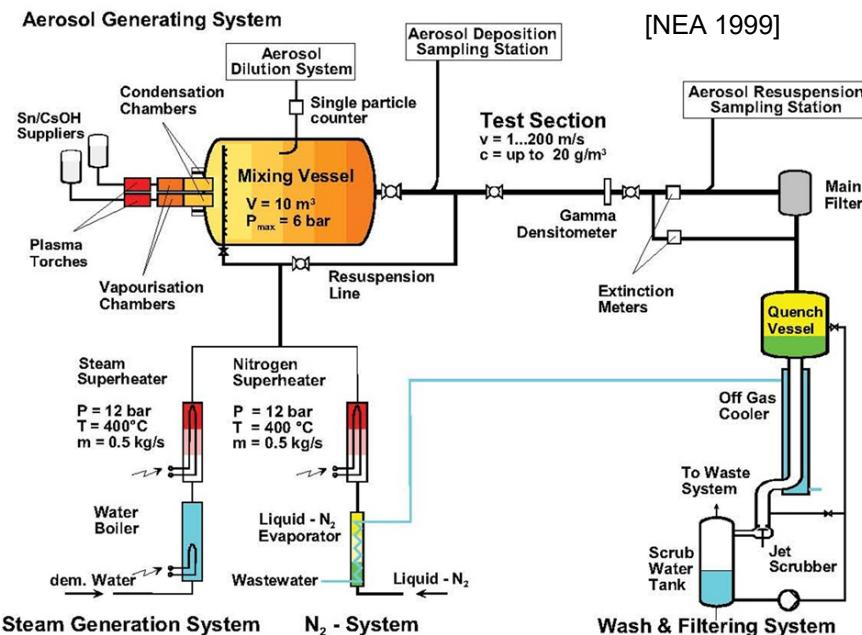**Test 9**
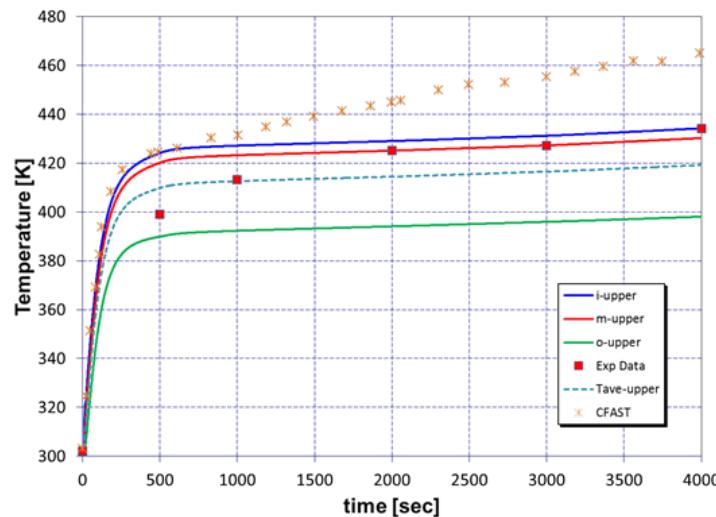
**Test 11**
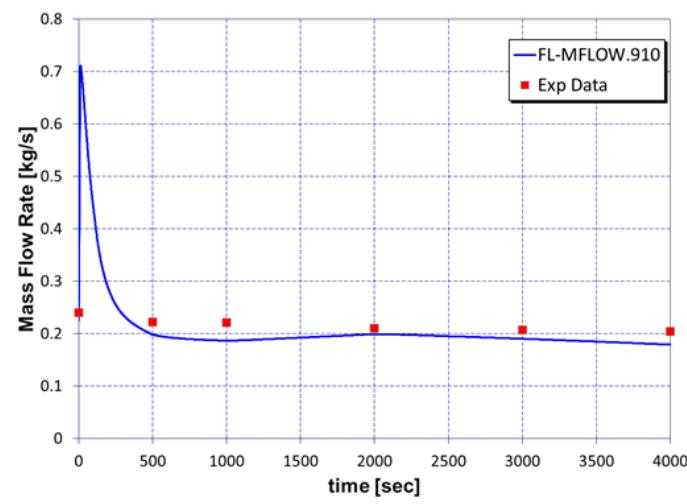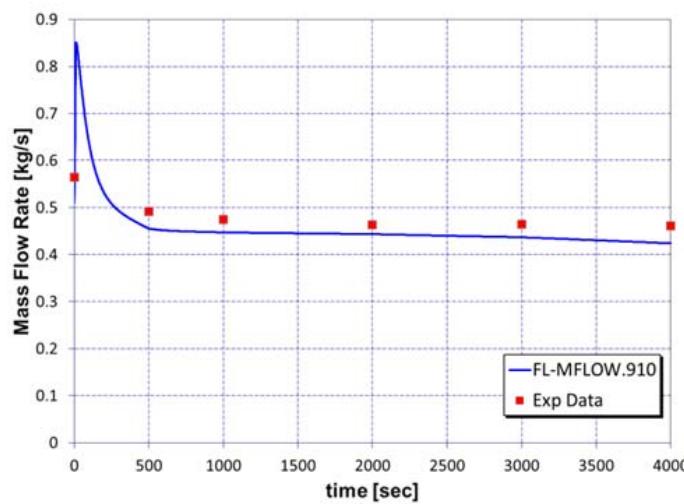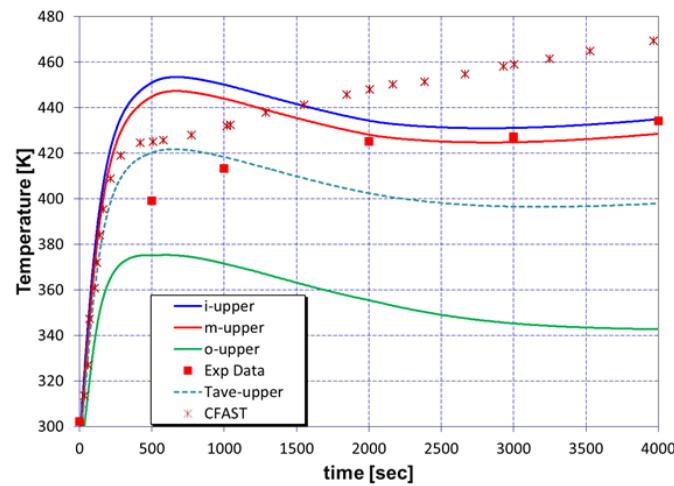
STORM SR-11 Resuspension Test

[NEA 1999]
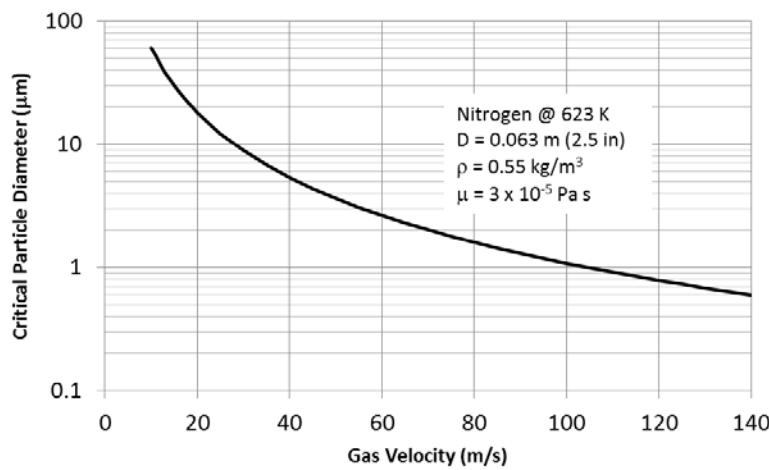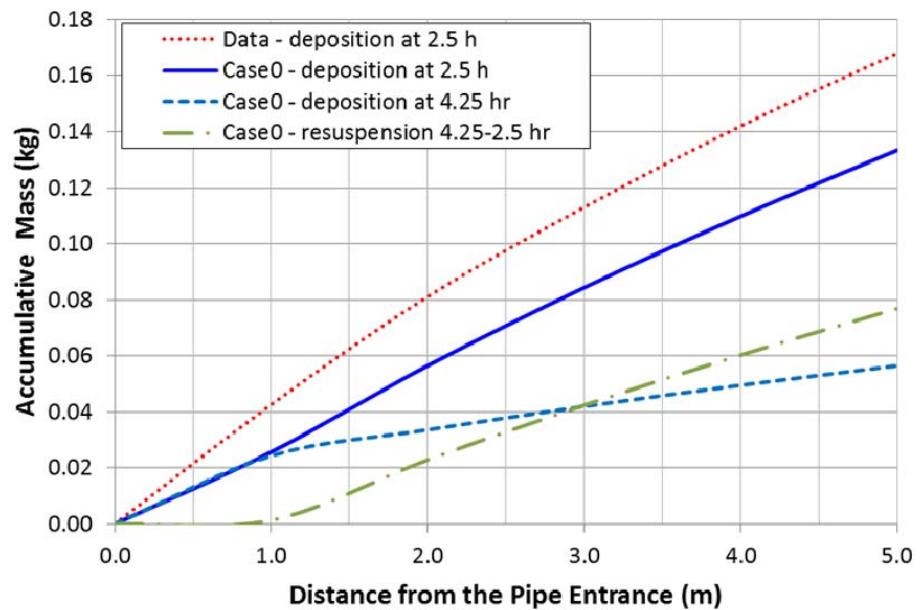
MELCOR predicted 88.3 g versus experimental result of 113.3 g for SnO_2

Gasoline Pool Exp (Mishima/Schwendiman 1973)

- Experiment distributed UO$_2$ in a stainless steel fuel pan, added one gallon of gasoline, and performed the test in a wind tunnel

- Air drawn in at ~1 m/s for the duration of the fire

- Filters downstream collected entrained contaminants

- Filters replaced at 9 minutes and air flow continued for 4.8 hours to collect resuspended particles

- Four natural entrainment mechanisms
  - Evaporation induced
  - Surface agitation by wind
  - Surface agitation by boiling
  - Residue entrainment
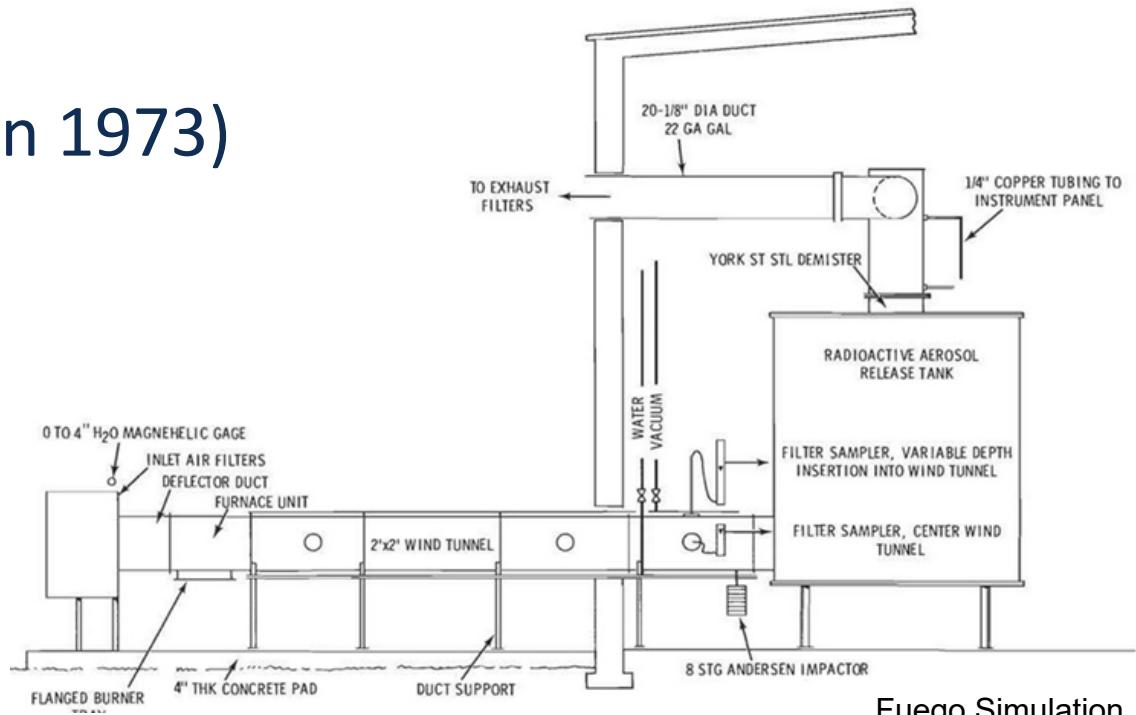
Fuego Simulation [SAND2016-12167]
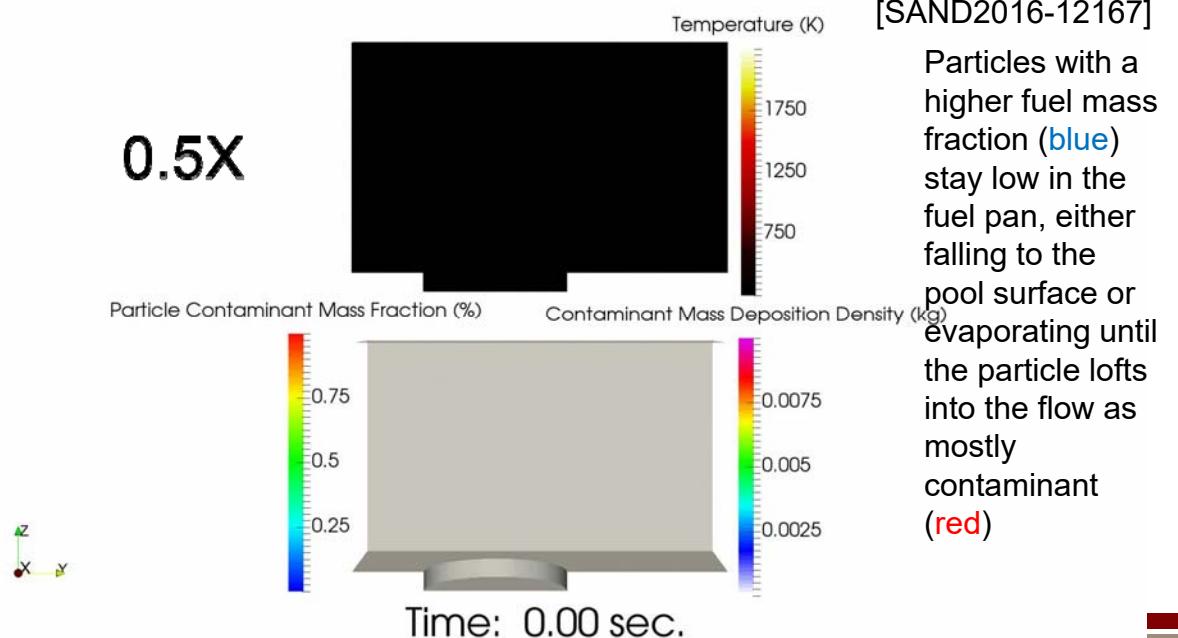
Particles with a higher fuel mass fraction (blue) stay low in the fuel pan, either falling to the pool surface or evaporating until the particle lofts into the flow as mostly contaminant (red)
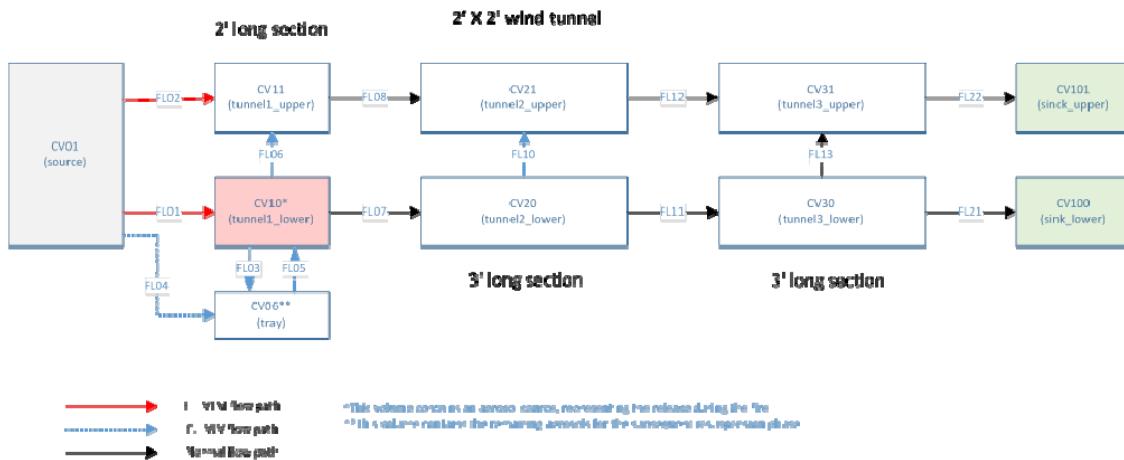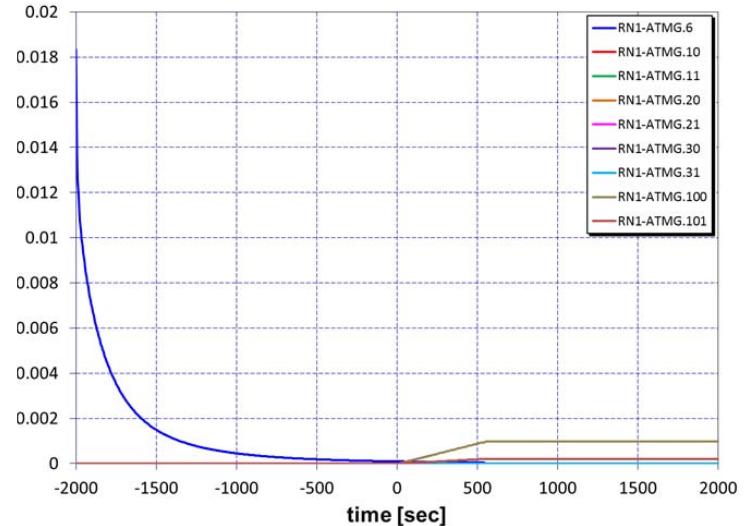
Gasoline Pool Fire Results

- 19.5 g UO_2 in 1 Gallon gasoline
  - 6% sourced into tunnel at 0 s according to Fuego
 - 94% sourced into pan before start of resuspension phase
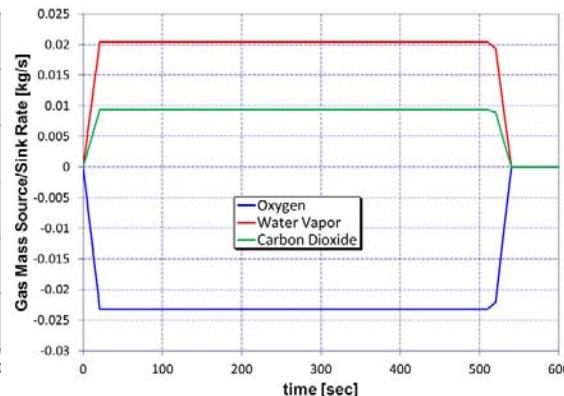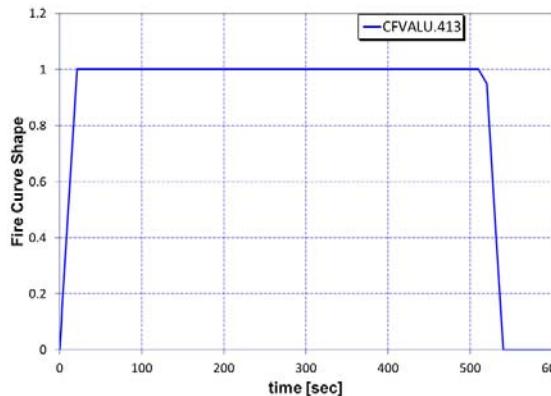
UO_2 Airborne Release Masses in Volumes

Experimental Data	MELCOR 2.1
During Fire – ARF=0.0012 Mass=2.34E-05 kg	During Fire – ARF= 0.0606 1.1836E-03 kg (Adjust to total area of the sampling*) Mass=2.94E-05 kg
During Resuspension- ARF=9.0E-4 Mass=1.755E-05 kg	During Resuspension (after fire gone) ARF=0.0 Mass=0.0 kg

*Total sampling cross section fraction to the wind tunnel cross section area of 0.025

Powder Release Experiment from PNL
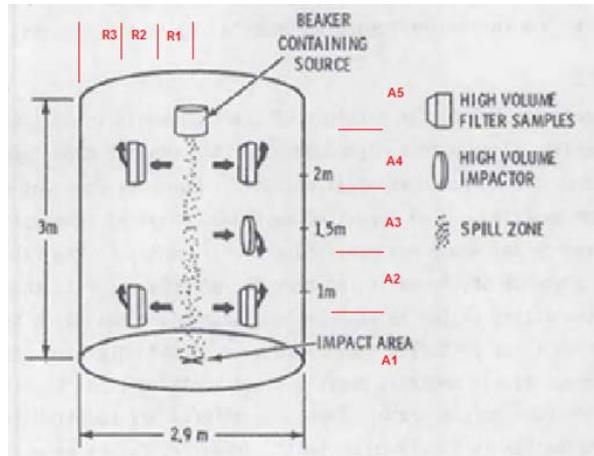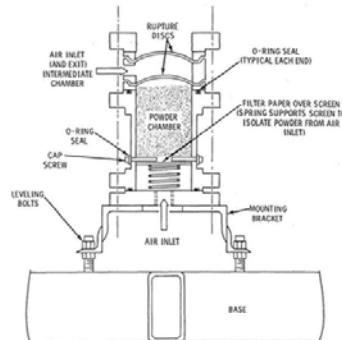

[Sutter 1981]
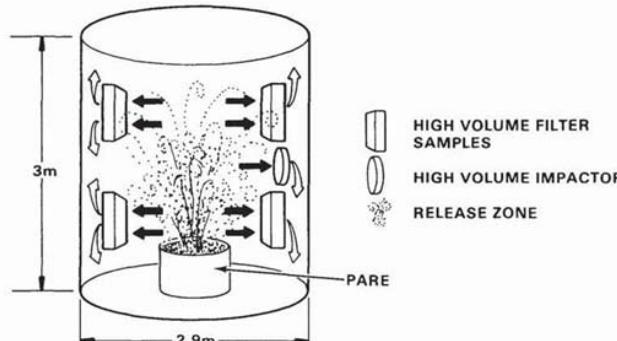
[Sutter 1983]

Parameter	MELCOR
Dimension	
PARE or beaker volume	862 cm^3
RART model	3 m × 2.9 m dia.
1-volume (1V)	1V
5-vol: A1 to A5 in Fig. 1	5V
15-vol: A1 to A5 × R1 to R3 in Fig. 1	15V
Assumptions	
Aerosol min and max diameters	0.8 and 50 μm
Pressurized Case	
Rupture disk timing	0.001 s
Aerosol source timing	< 0.001 s
Spill Case	
Aerosol source timing	0.05 s
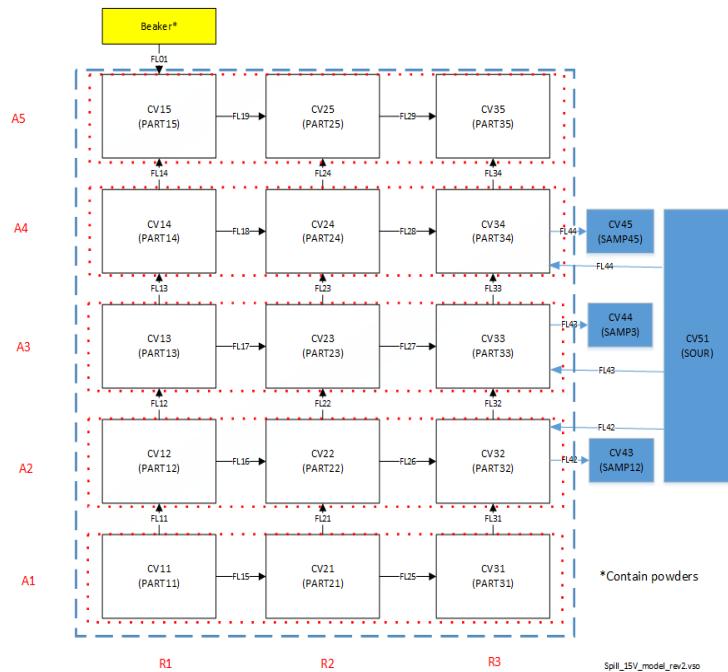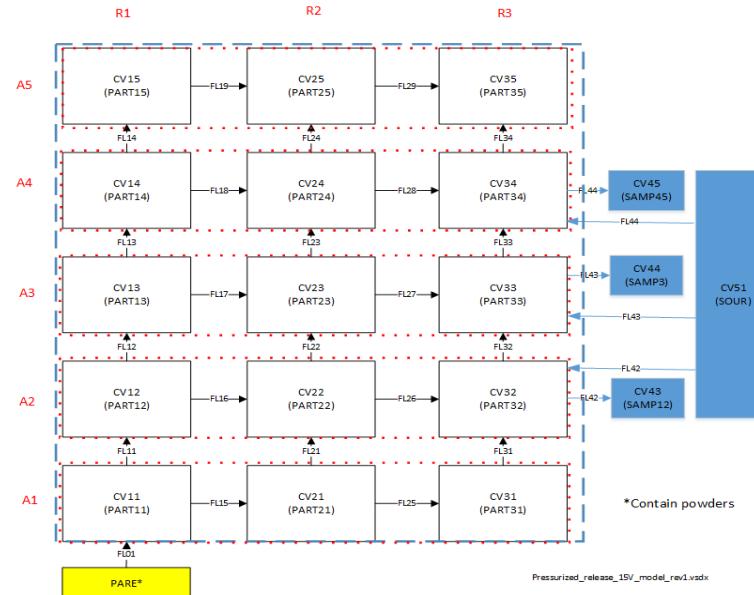
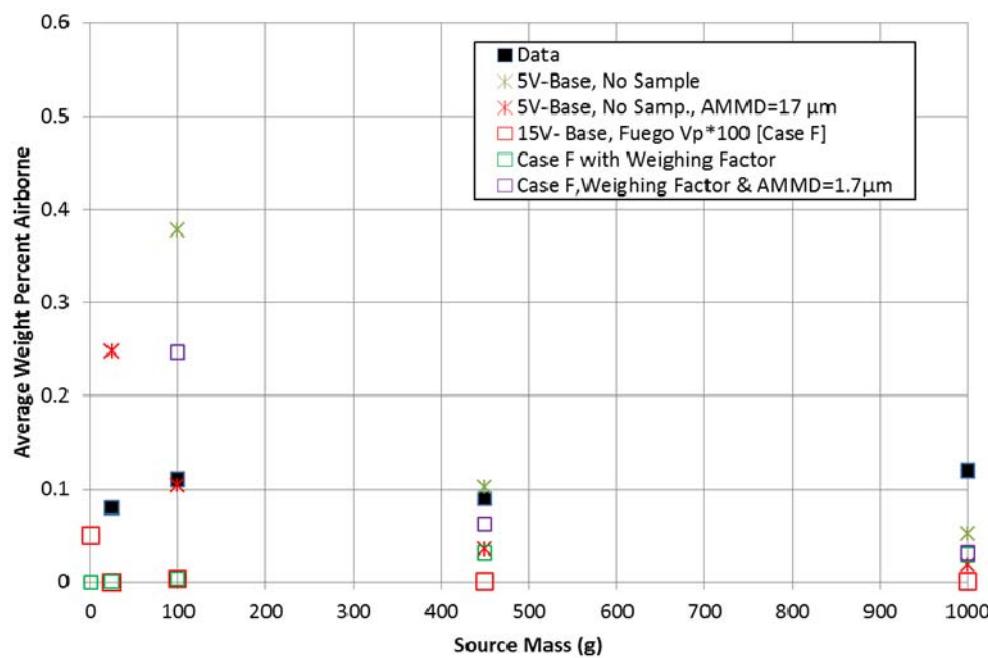[Sutter 1983]

Spill Simulation (Fuego)
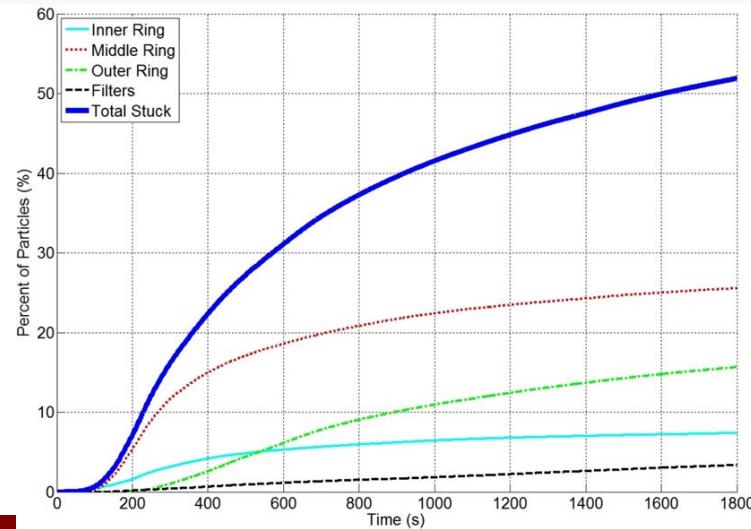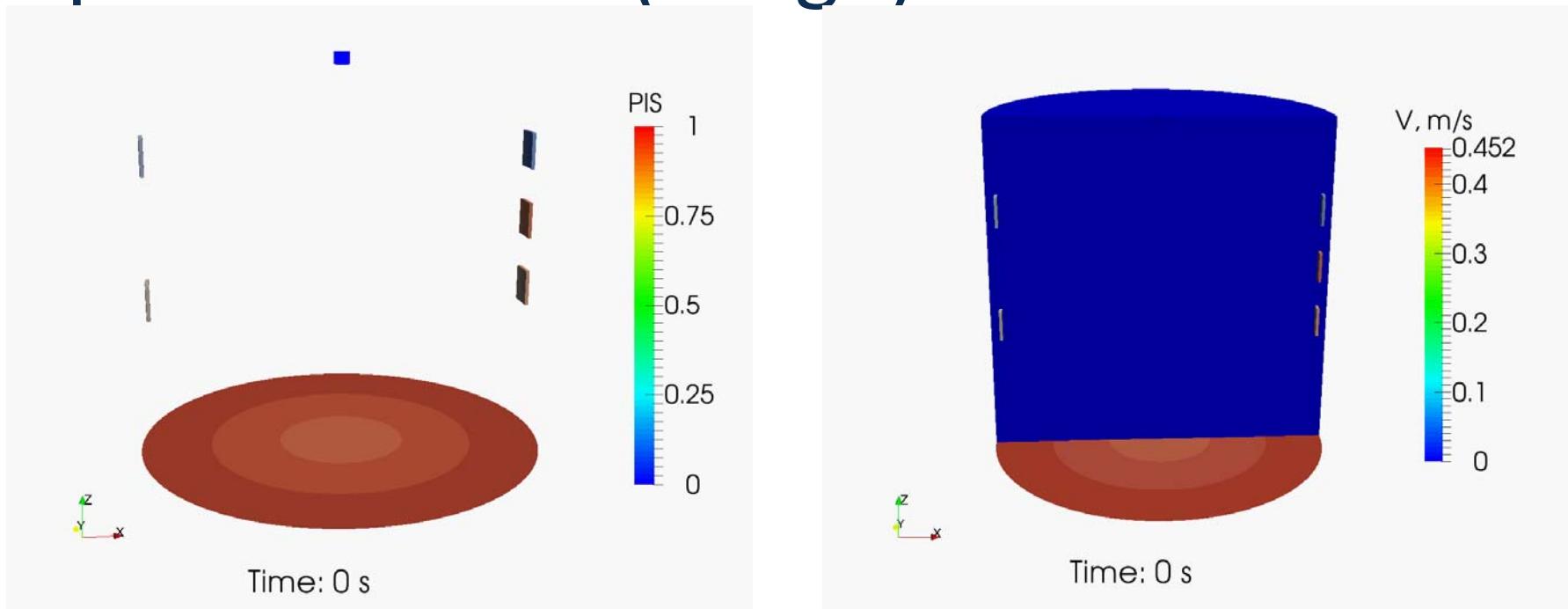
Particle "clusters" comprised of the larger particles first reached the bottom of the chamber at around 50 s.

The lighter particles first reached the floor at 200 s and continued settling on the floor for the duration of the transient.
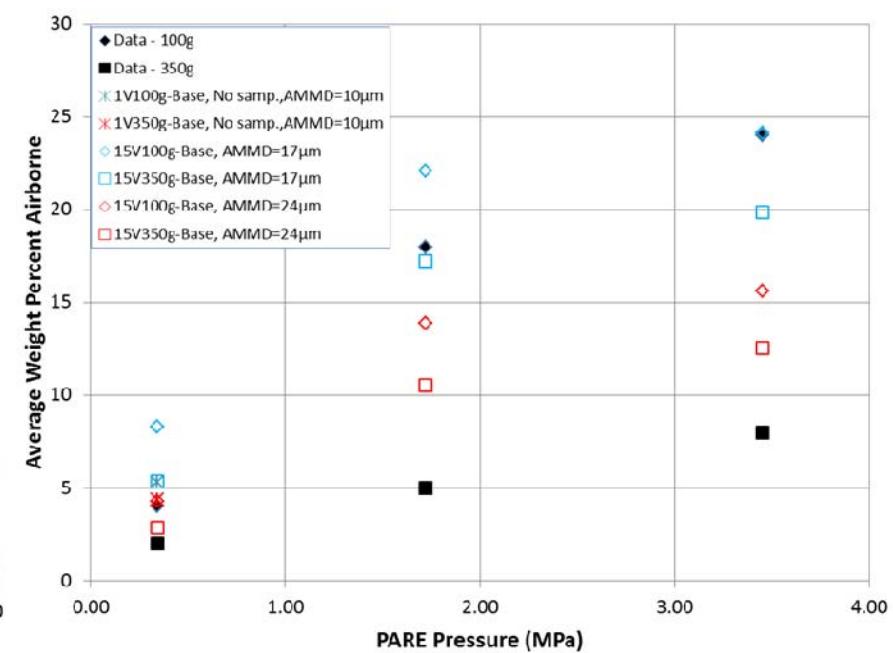
Powder Release Results

Gravitational Spill at 3 m
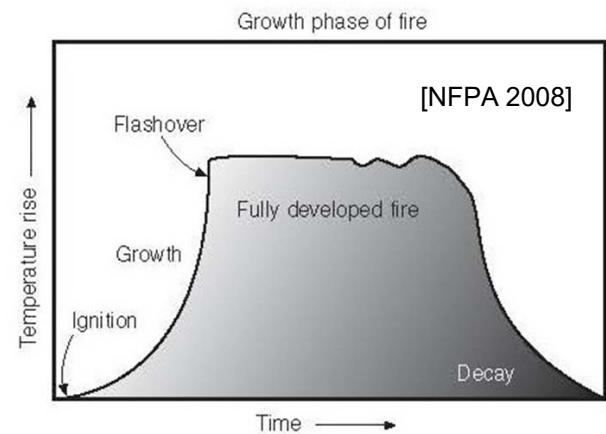
Pressurized Release

Best Practices

- Cover major accident scenarios in using MELCOR

  - Explosions
    - Analytical approach using control functions
    - Computational approach using BLASTX
    - Proper accounting for product gas generation and energies
  - Fires
    - Use Control function package to fire (demonstrated in here)
    - Results are encouraging, compared well with CFAST
  - Inadvertent of nuclear criticality
    - Similar approach as in explosion, except no by-product gas generation
    - 10^{18} fissions ~ 32 MJ.
  - Spills
    - Demonstrated in the validation tests shown here

- Specified models

  - Default values
  - Environment volume modeling – time-independent volume
  - Aerosol modeling
 - Counter-Current Flow Model for Fire

TOMSK-7 Explosion

IAEA-TOMSK-7

Growth phase of fire

[NFPA 2008]

Flashover

Fully developed fire

Growth

Ignition

Decay

Temperature rise

Time

17

Counter Current Flow Model Applications

- It has been applied to model natural recirculation of hot and cold gas exchange during a severe accident condition
  - With the use of CFD results, the results should match better

- Similarly, it can be applied to model the doorway between the fire room and a cooler corridor
  - It is only applicable for the horizontal flow paths
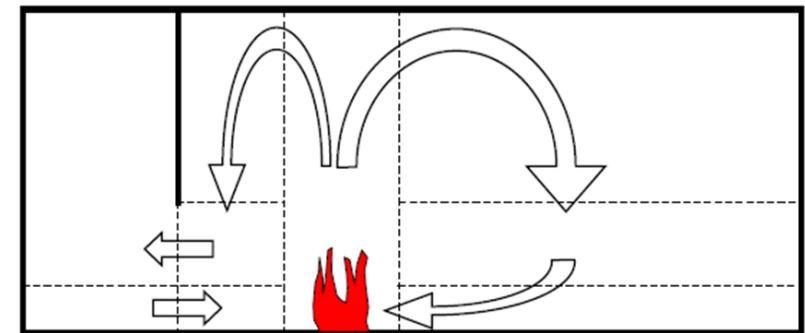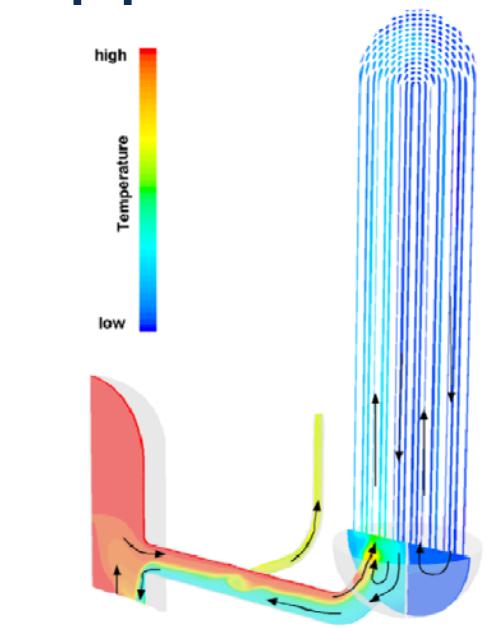
# Summary and Future Expectation

- A final report of MELCOR guidance for LPF applications has been completed and published

  - Document applicable reactor experiment data, and additional validation experiments from DOE-HDBK-3010

  - Provided additional specific validations:
    - Fire experiment with CFAST – LLNL Enclosure Fire
    - STORM Resuspension Phase Experiment
    - Gasoline pool fire experiment at PNNL
    - Powder release experiments

  - Developed a number best practice on modeling explosion, fire, nuclear criticality and spill accidents

- Expected future works:

  - DOE to award the final QA process to bring MELCOR 2.2 to the DOE Central Registry as a safety analysis tool

  - MELCOR 2.2 is ready to be used in DOE LPF analysis, replacing the old LPF analysis using obsolete versions of MELCOR
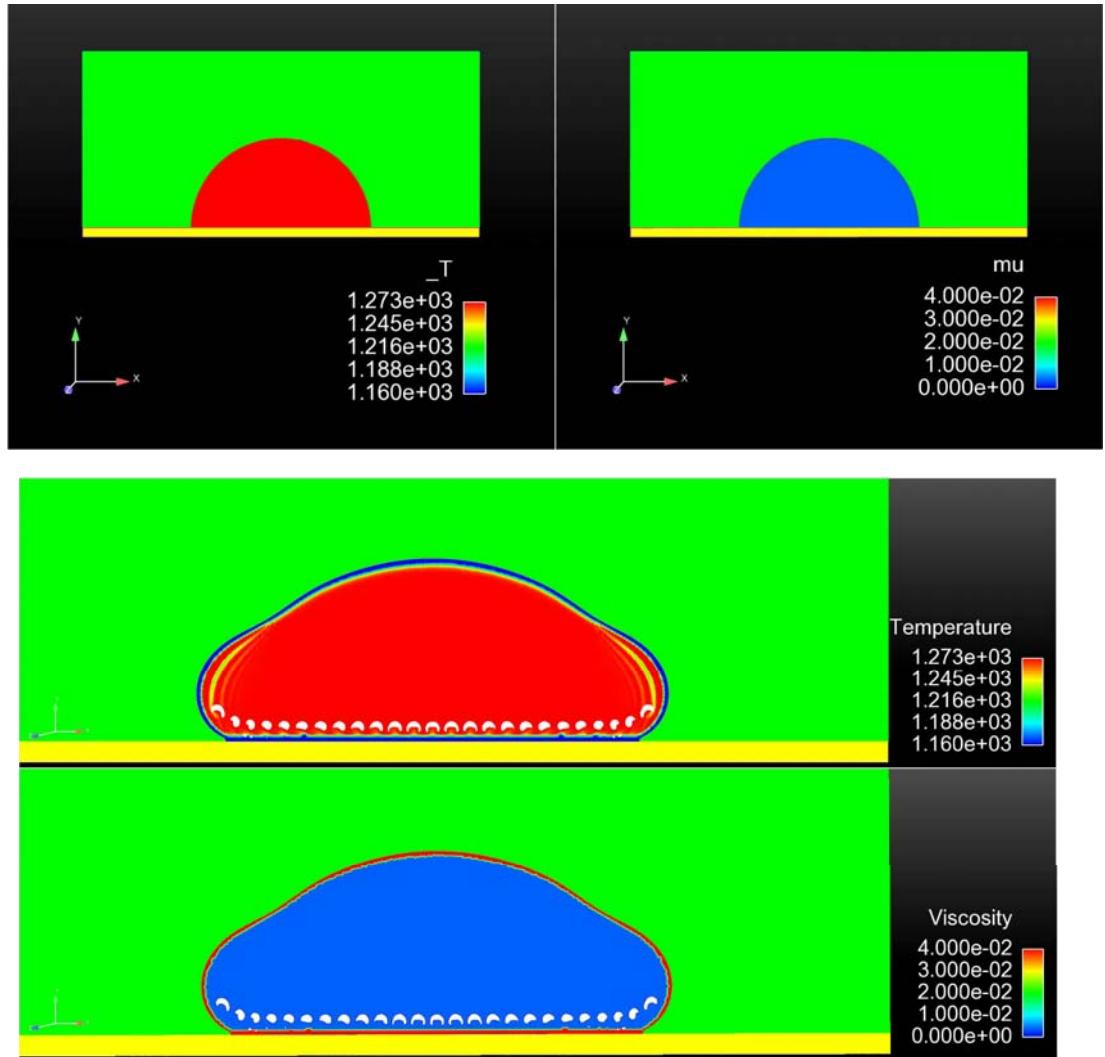
BACK UPS

Aria Capability – Corium Spreading

[Journeau 2003]
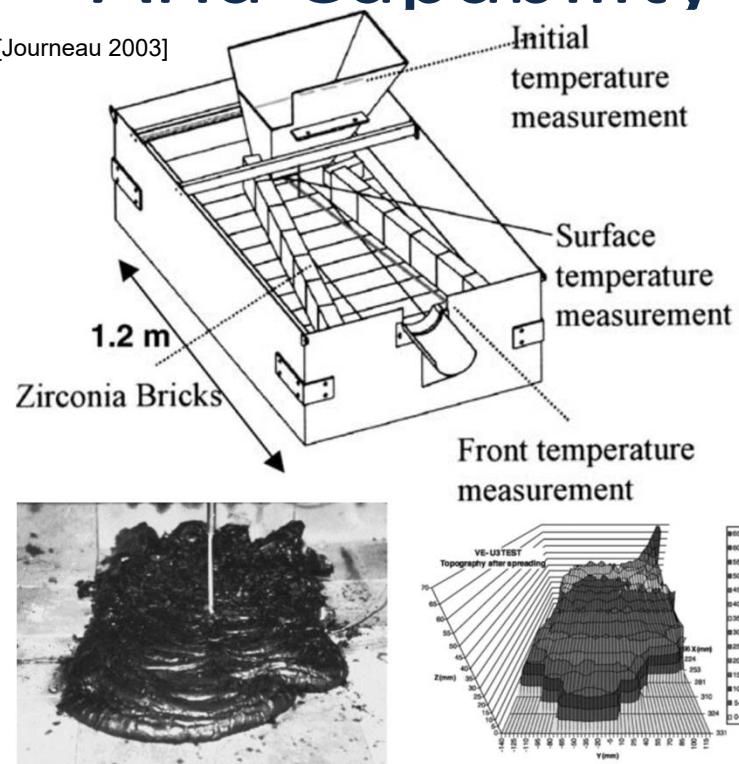
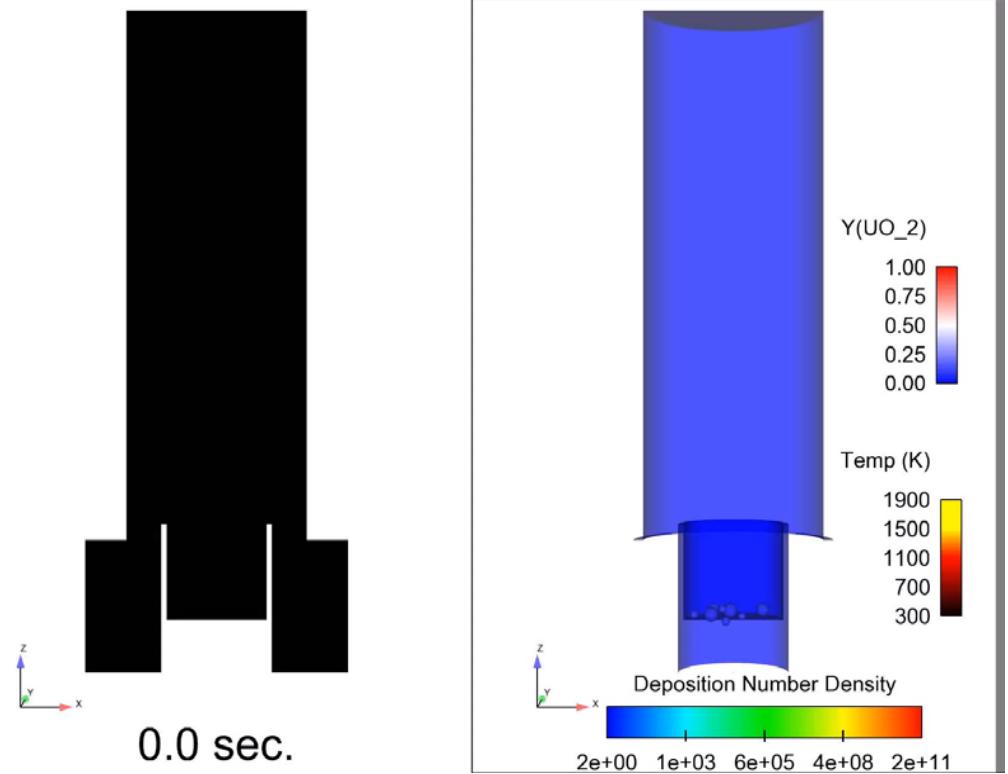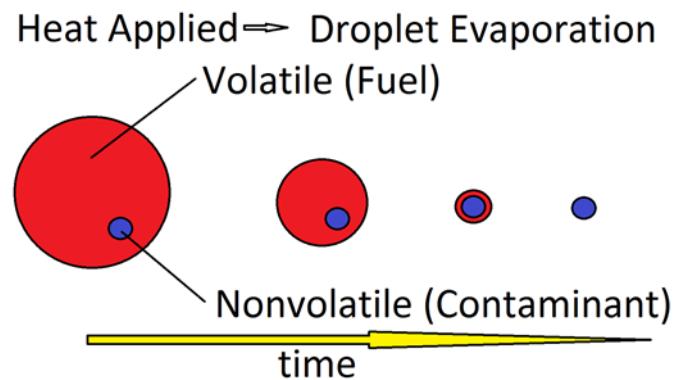2-D simulation of Surrogate Corium Spreading and Bubbling

# Fuego Capability – Fire/Aerosol

[Mishima 1973]
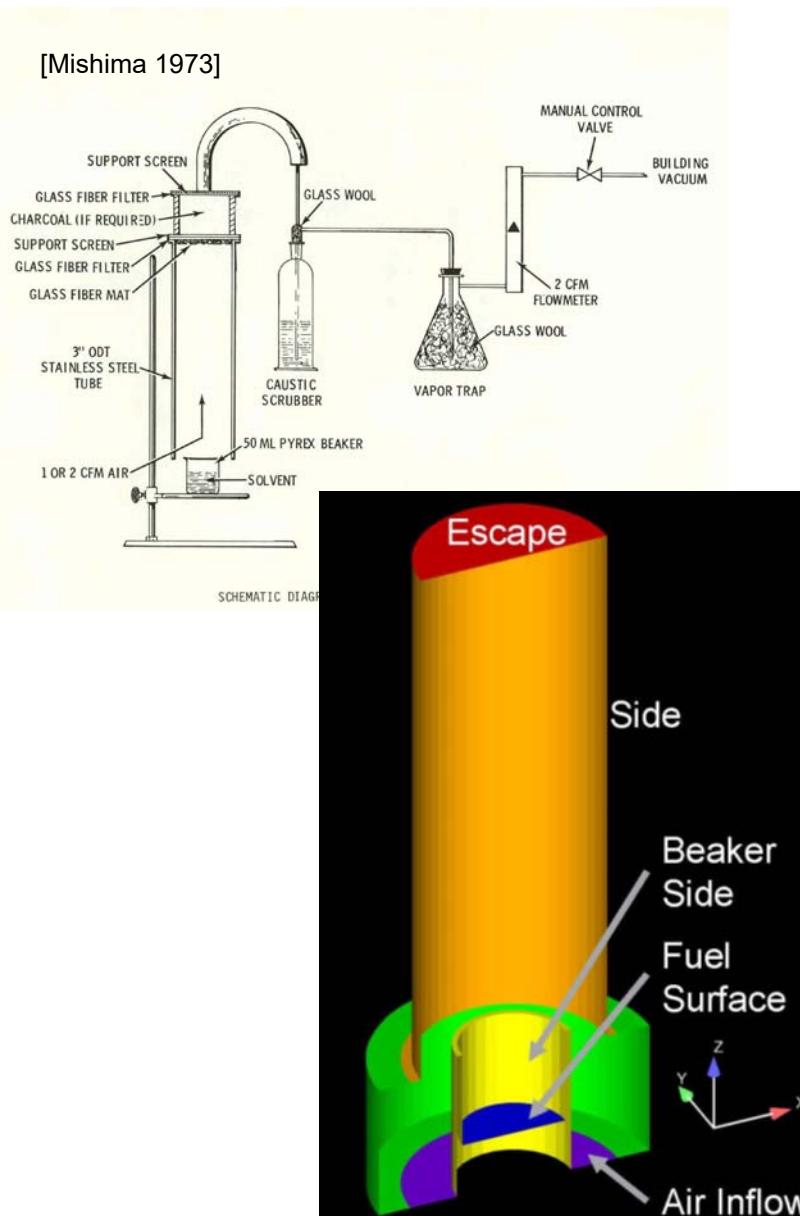
Fuego Application to Resuspension

- 8'x8'x12' room

- ZnS particles dispersed on floor using 2.44x10^{-6} particles/cm2, 3.1 µm, 4.1 g/cc

- Simulation
  - Floor was divided into 24 BCs of equal surface area (mimic person walking and sweeping)
  - 100,000 particles modeled
  - Various boundary conditions are used
  - Simulated time of 24 s for vigorous human activity, 600 s time simulation
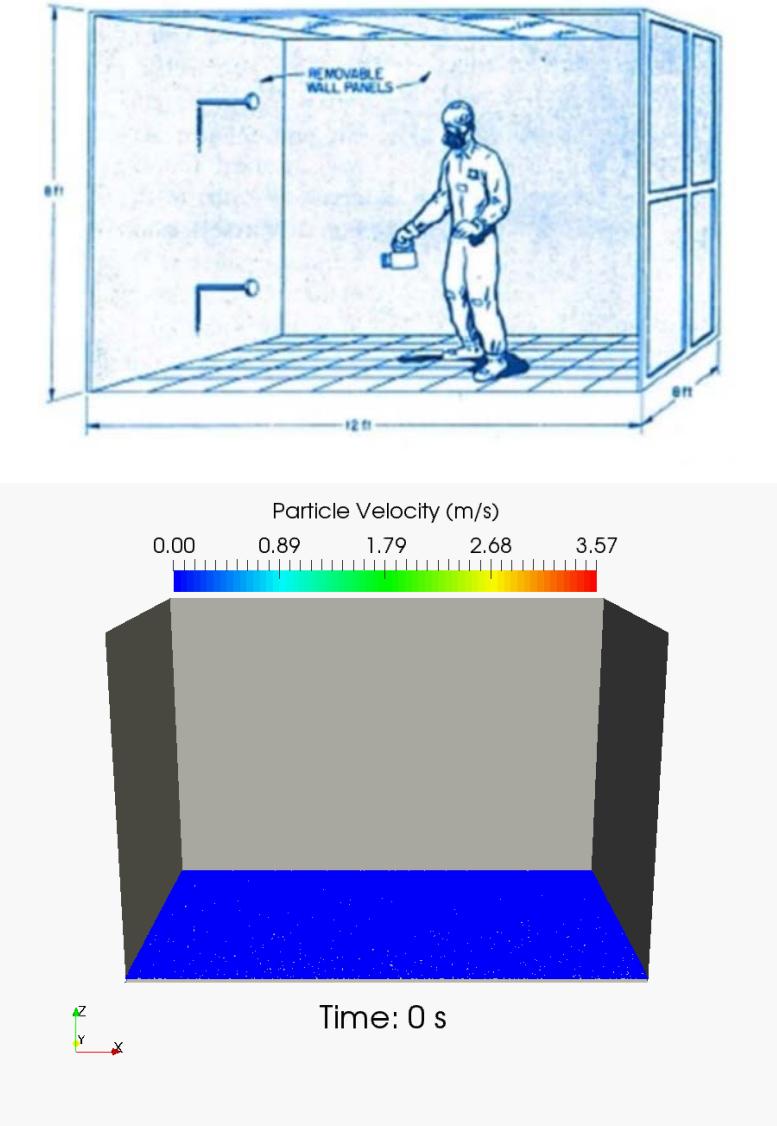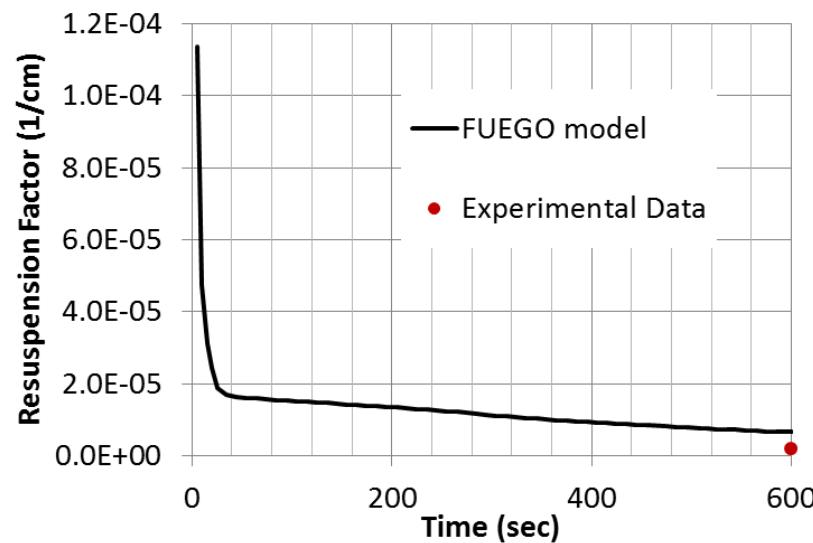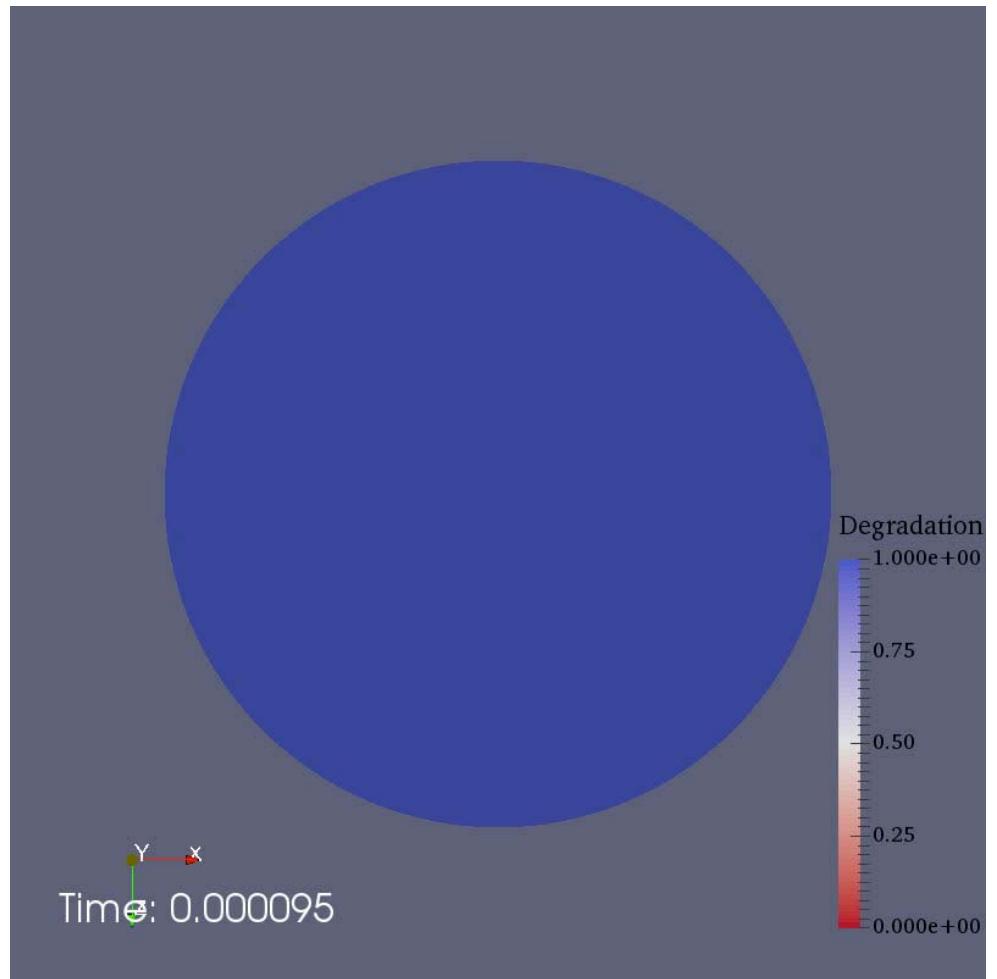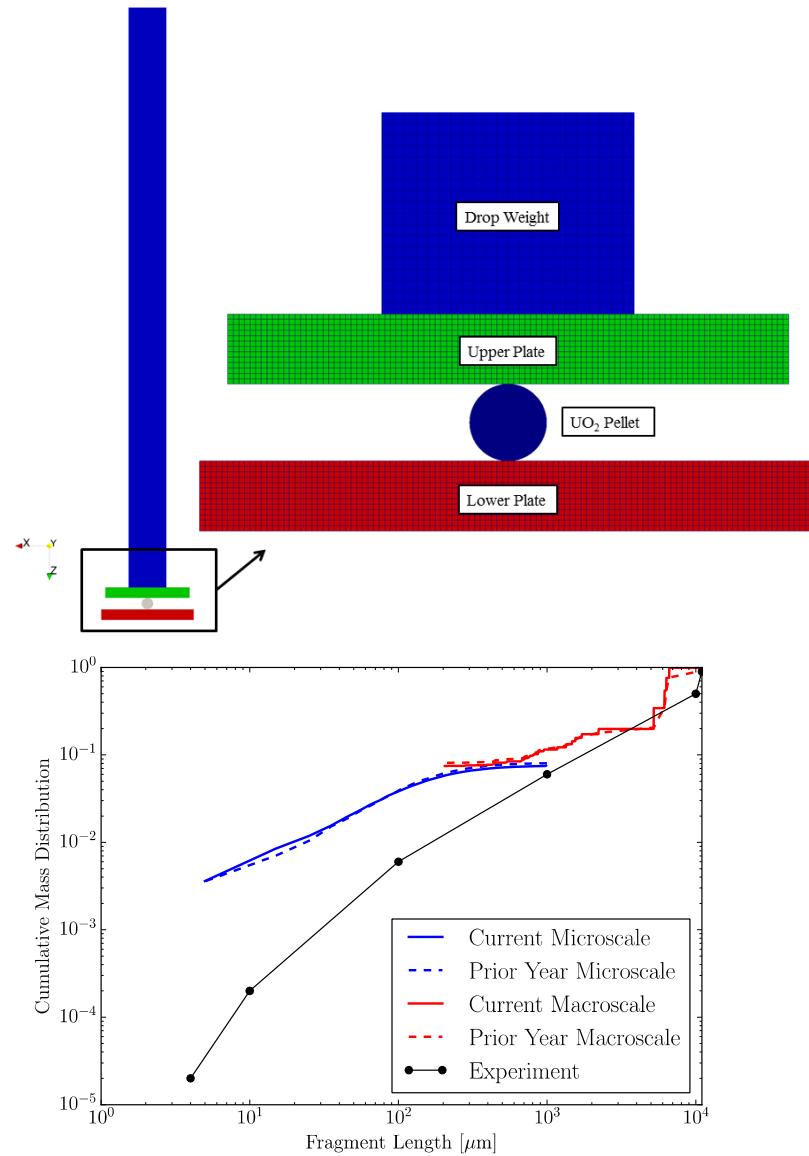
250 psig Adagio/Fuego Simulation
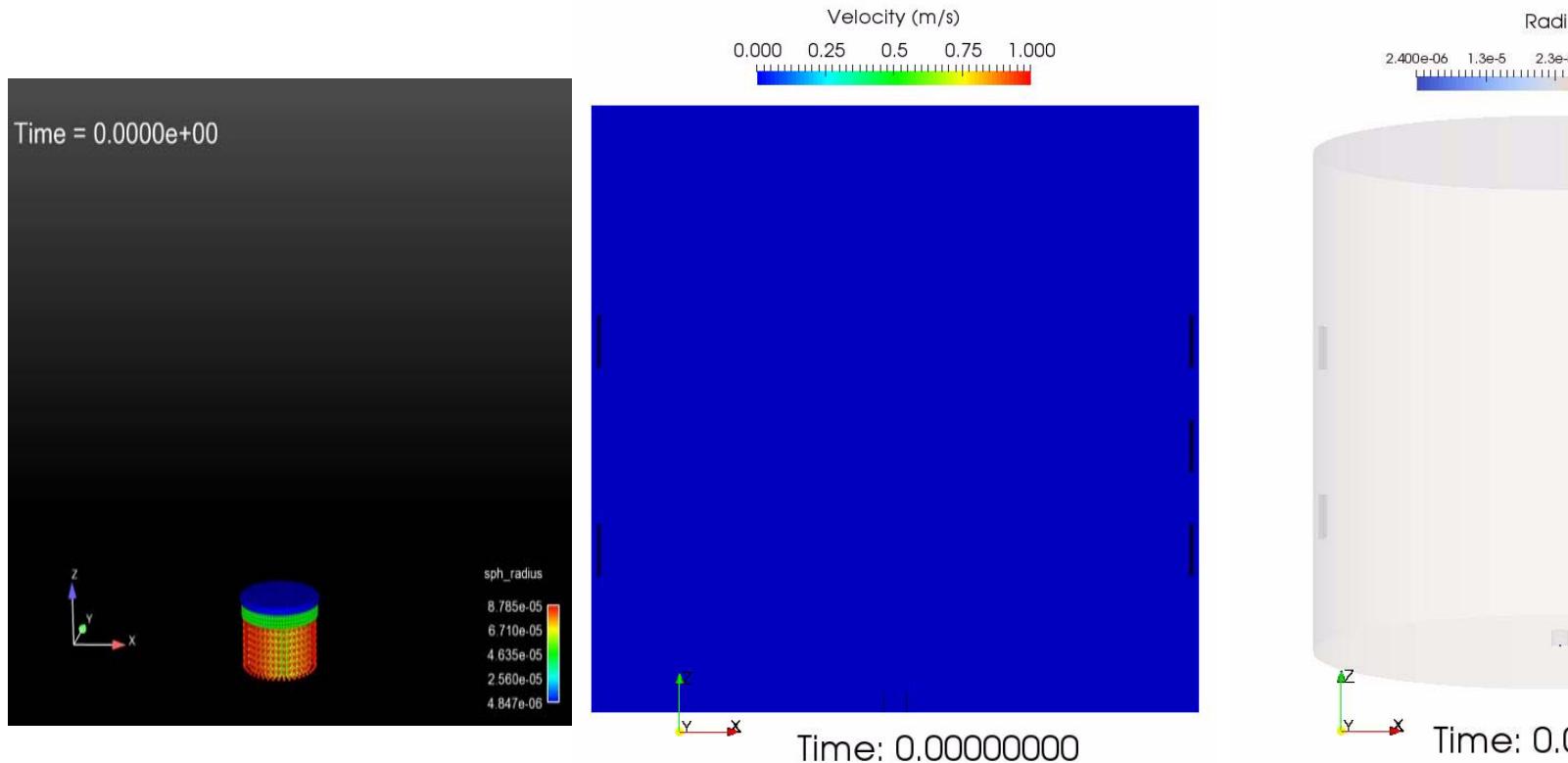
- Multi-SPH models used for Adagio to create sufficient particle flows
- One way couple method use: Adagio results translate into Fuego inputs
- This capability is demonstrated so that particles lose kinetic energy to induce fluid flow

Using SIERRA/SM to fragmentation

Drum Fire Failure Simulation

- Estimate airborne release fraction (ARF) and respirable fraction (RF) using SIERRA analysis tools for a type 7A waste drum exposed to a fire accident scenario.

Thermal-Fluid Response
(SIERRA Thermal/Fluids) → Material Temperatures Internal Pressure → Thermal-Mechanical Response
(SIERRA Solid Mechanics)

Heat flux from fire

Time: 0.00 sec

Time: 0 Seconds

Time: 1000 Seconds
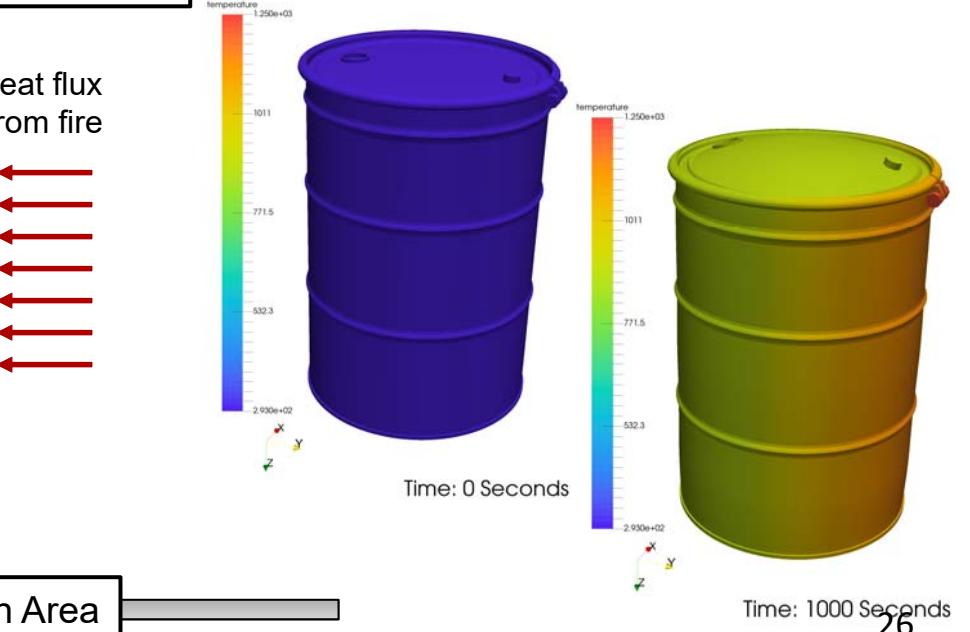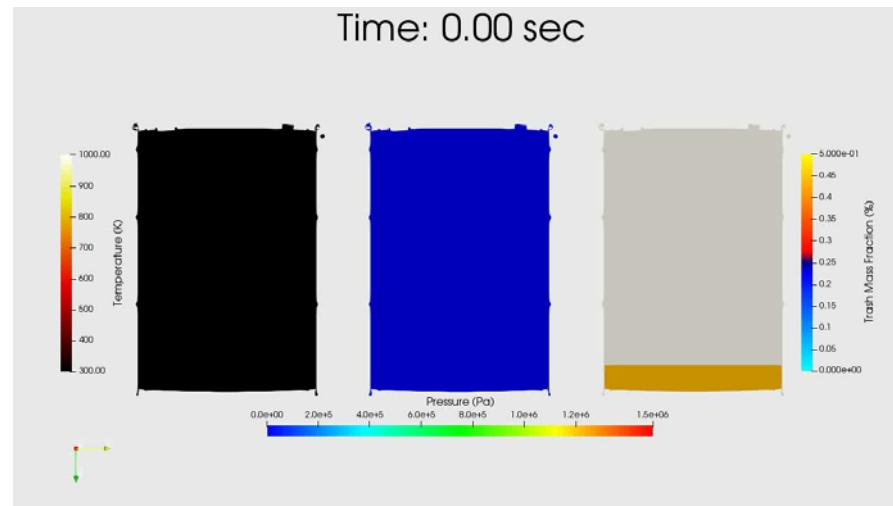
← Breach Area

NSRD-15

Simulation Visualization: Resuspension Entrainment (1R)

Temperature (K)

625   1000   1375

Time: 30.00 sec.

Diameter (microns)

50   100   150
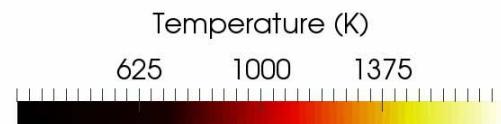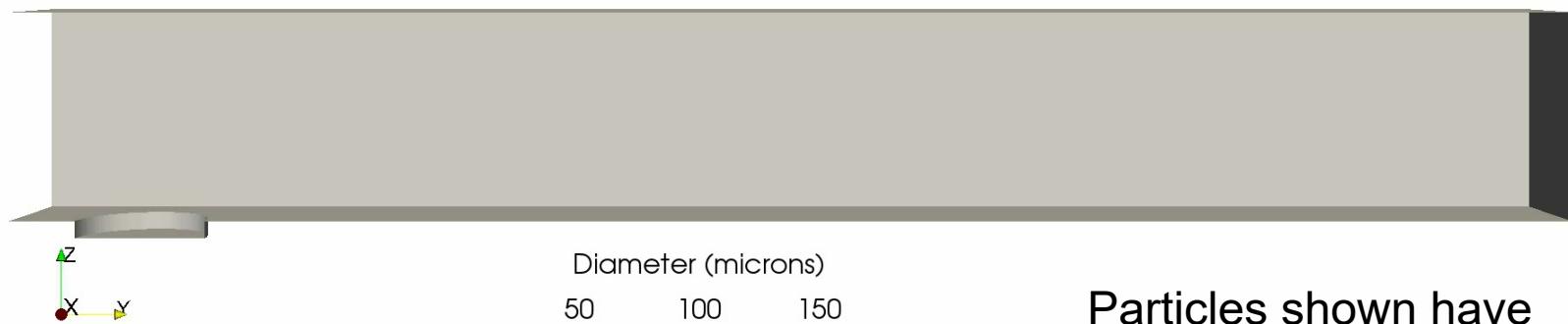
Particles shown have resuspended from surfaces

SAND2016-12167

MELCOR Model for Barnwell Plant

- Facility model: 202 CVs, 335 FLs and 290 HSs.
  - Main building includes hot cells (UPC, ILC, HLC, HILC and PPC), SAC and filter niche, piping galleries (FPIG, LPIG and TPIG) – FP release likely
  - Other buildings – FRSS, WTEG, PNSL are not included extensively
  - Environments – 4 CVs
  - Exhaust air filters and ducts - 35 CVs
  - Supply air ducts - 10 CVs

- Model airflows and pressures
  - Main building flow – hot cells (from top and out at bottom)
  - Control room area (CRA) – independent HVAC
  - FRSS and WTEG have their own HVAC
  - Gloveboxes are not simulated
  - Pressure zones – three
    - Hot cells, RPC, RMSC cells, FN and SAC : - 2 inches (-498 Pa)
    - CEMG, including FPIG, LPIG and TPIG (including HTG/PEG, VFS and AFS at -0.5 inches (-125 Pa)
    - Remainders are at -0.25 inches (-62 Pa)
  - Flow controlling dampers