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Fire Science & Technology

ASTFE American Society of Thermal and Fluids Engineers

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Contaminant Entrainment in a Liquid Fuel Fire TFESC-12948

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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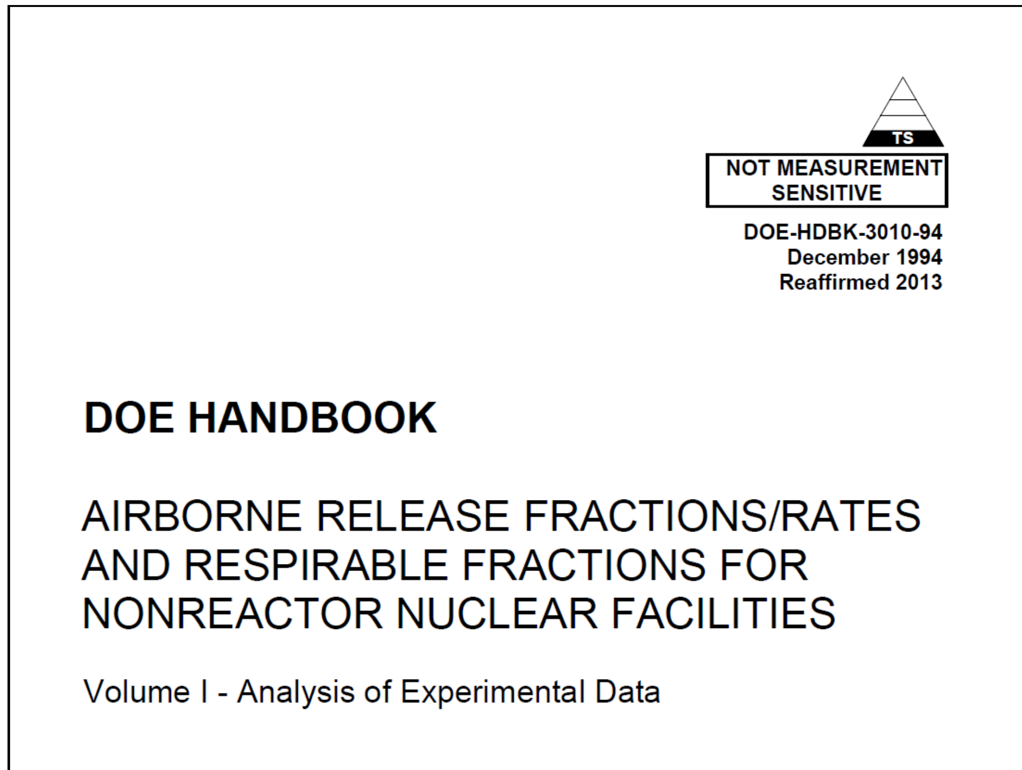
Problem Statement

- DOE handbook 3010 prescribes methods to deal with radioactive release from nonreactor nuclear facilities
- One chapter focuses on the release of contaminants from a fire involving hazardous solids
  - Dated experiments
  - Old correlation methods
  - Difficulty applying results to some problems
- We propose using CFD to enhance the interpretation of the handbook data



TS

NOT MEASUREMENT SENSITIVE

DOE-HDBK-3010-94
December 1994
Reaffirmed 2013

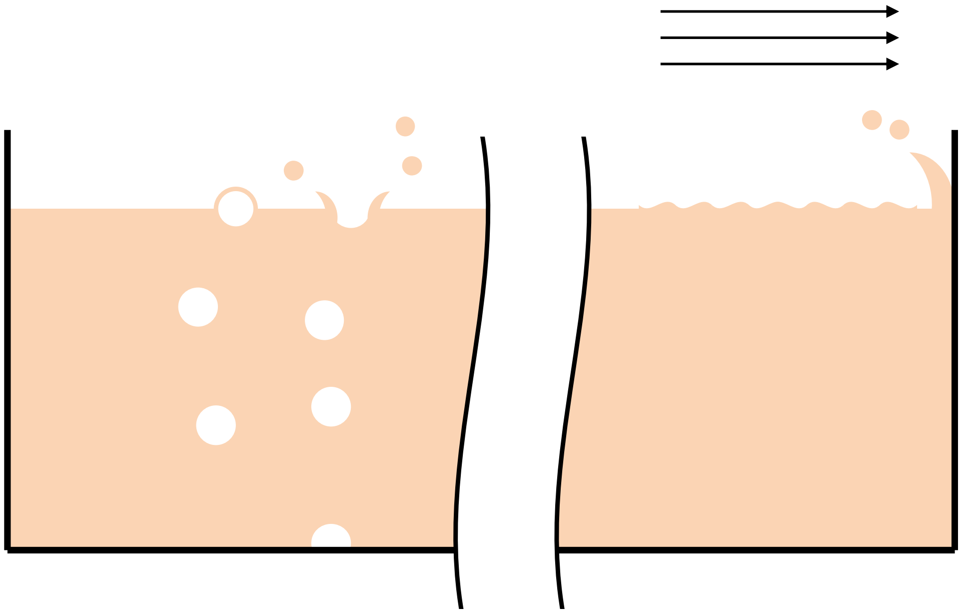
DOE HANDBOOK

AIRBORNE RELEASE FRACTIONS/RATES AND RESPIRABLE FRACTIONS FOR NONREACTOR NUCLEAR FACILITIES

Volume I - Analysis of Experimental Data

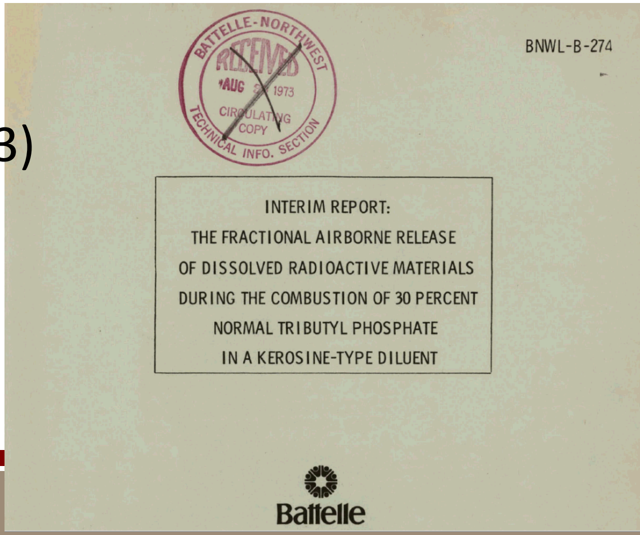
Relevant Phenomena

- Based on historical work there are four main entrainment mechanisms:
  - Evaporation Induced Entrainment
  - Surface Agitation by Wind
  - Surface Agitation by Boiling
  - Residue Entrainment (resuspension)
- The image on the right illustrates two of these mechanisms



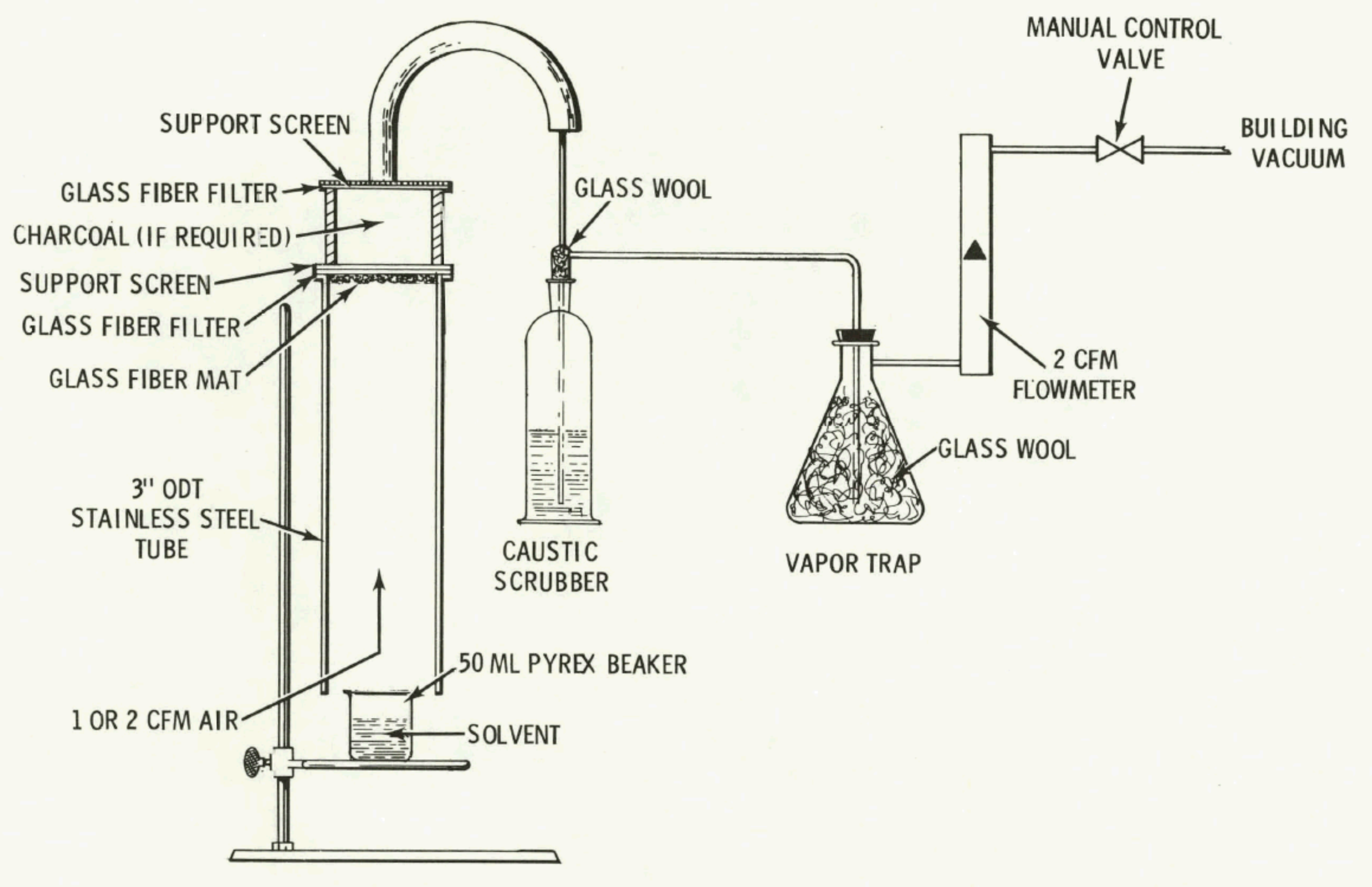
Approach

- Even though CFD codes do not have the ability to define a release from a contaminated fuel fire, we could improve on existing methods by modeling what we could:
  - Existing multi-component evaporation models were inadequate
  - Direct particle source terms not possible (i.e. heat flux or temperature at pool surface leads to a particle yield)
  - Forced to use correlations for source terms
- Selected a HDBK 3010 recommended dataset for comparison
  - Mishima and Schwendiman (1973)
  - Simple conditions, pre-CFD experiments
  - Used source terms from Kataoka and Ishi (1983)
  - Evaluated Aria/CDFEM to help with boiling



Test Configuration (M-S 1973)

- The test simulated involved a solvent (kerosene with 30% TBP) heated to the boiling point and ignited.



Entrainment Theory

- Kataoka and Ishii (1983) suggest entrainment can be described:

$$E_{fg} = 4.84 \times 10^{-3}\left(\frac{\rho_g}{\Delta\rho}\right)^{-1.0}$$

$$E_{fg} = \frac{\rho_f j_{fe}}{\rho_g j_g}$$

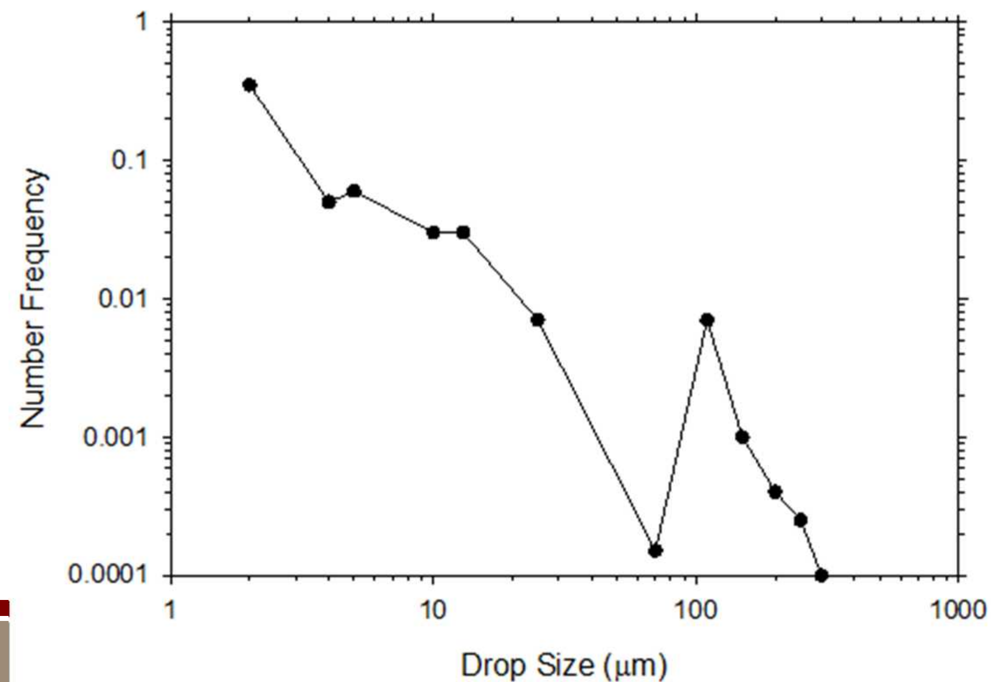
Valid for: $0 \le h^* \le 1.038 \times 10^3 j_g^* N_{\mu g}^{0.5} D_H^{*0.42}\left(\frac{\rho_g}{\Delta\rho}\right)^{0.23}$

$$j_g^* = \frac{j_g}{(\sigma g \Delta\rho/\rho_g^2)^{1/4}} \qquad h^* = \frac{h}{(\sigma/g\Delta\rho)^{1/2}} \qquad N_{\mu g} = \frac{\mu_g}{\left[\rho_g \sigma (\sigma/g\Delta\rho)^{1/2}\right]^{1/2}}$$

$$D_H^* = \frac{D_H}{(\sigma/g\Delta\rho)^{1/2}}$$

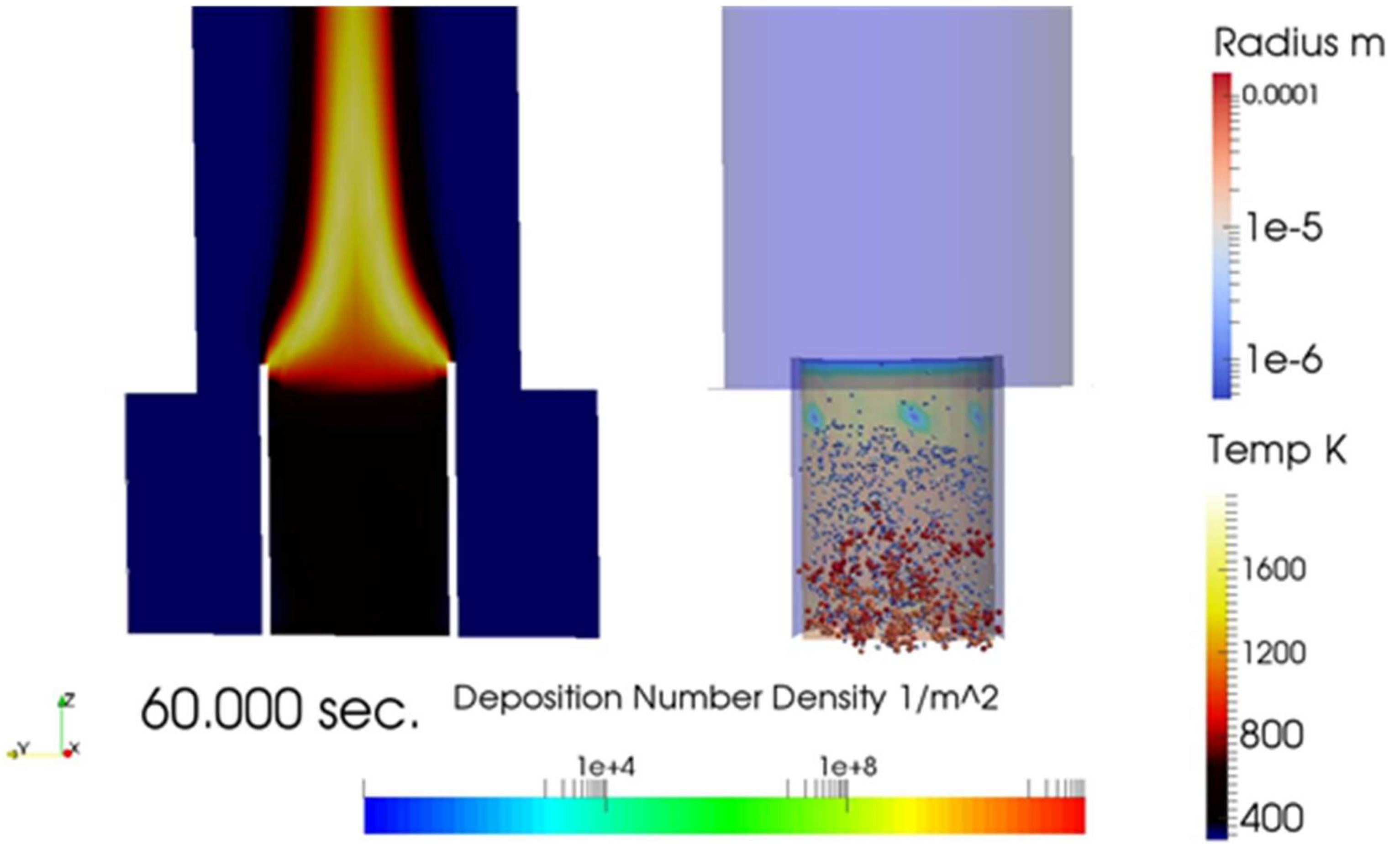
- Borkowski et al. (1986) measured the particle distribution from a boiling scenario:

- Primary entrainment includes all drops formed by surface boiling, but most drops fall back to the surface



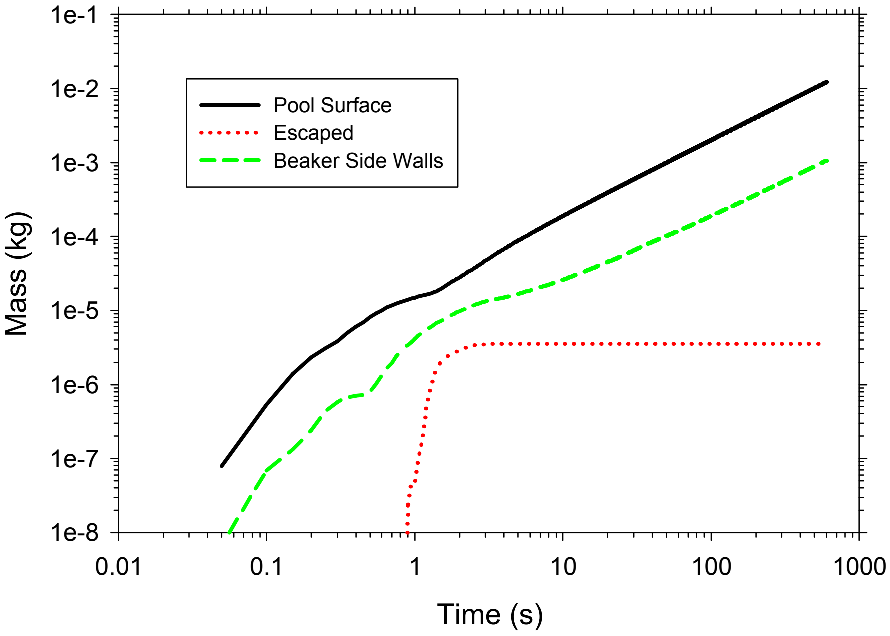
Evaluated Particle Fate

- Below image illustrates typical behavior

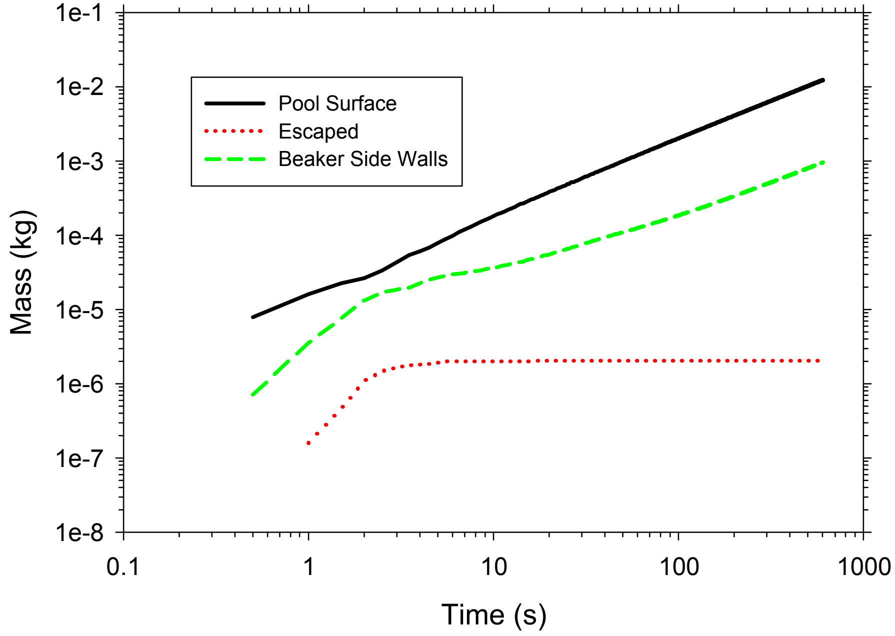


Initial Finding (mass)

- Mass was almost all released during ignition
- Subsequent was minimal, small particles
- Pool height was varied to capture the effect of the change



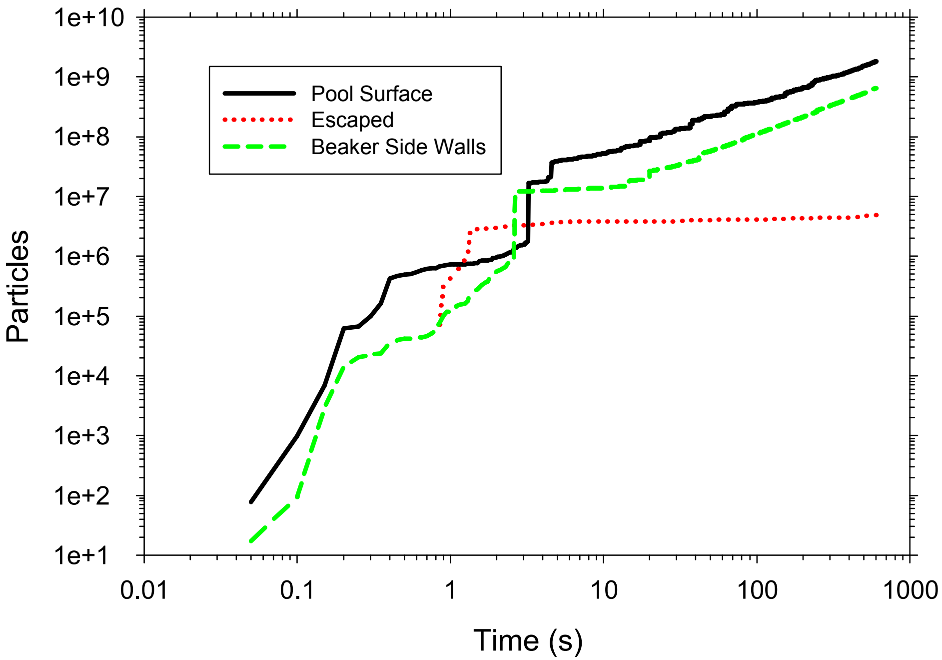
20 mm initial heigh



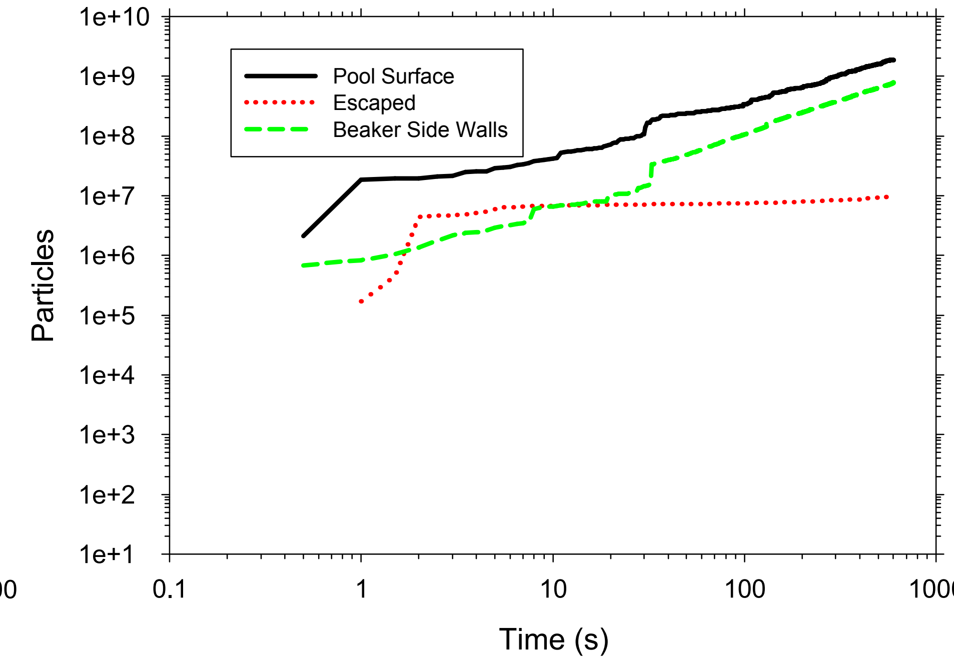
0 mm initial height

Initial Finding (particles)

- Slight upward trend in particle count with time
- Almost all the mass comes out during ignition!



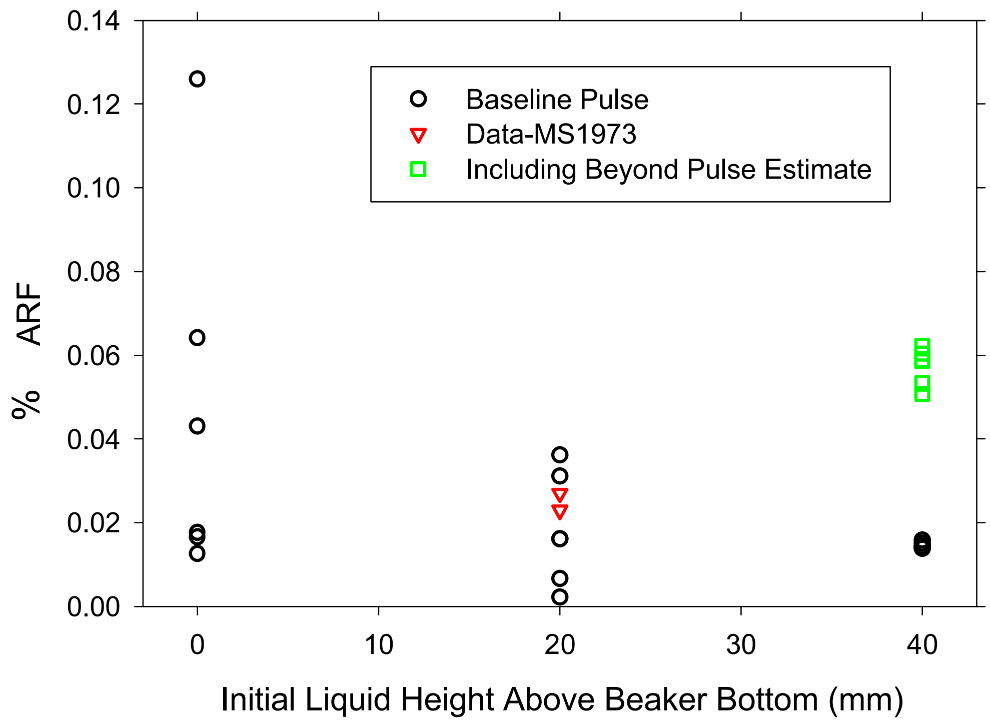
20 mm initial height



0 mm initial height

Initial fuel height significant

- Varying the fuel initial height from what was used in the tests resulted in higher airborne release fraction (ARF)
- Higher initial height resulted in more late-term release of mass
- TEST APPEARS NON-CONSERVATIVE in terms of fuel height
- High liquid height resulted in significant release after ignition

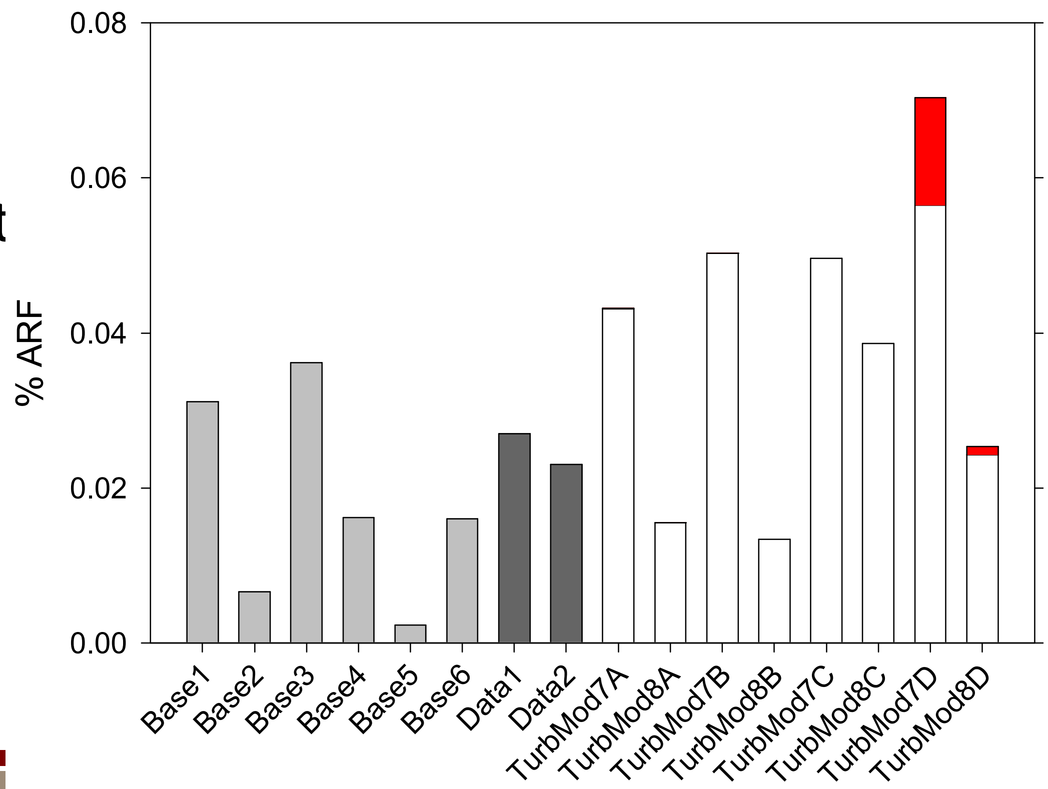


Effect of turbulence (20 mm height)

- Including turbulence effects results in minor ARF increase

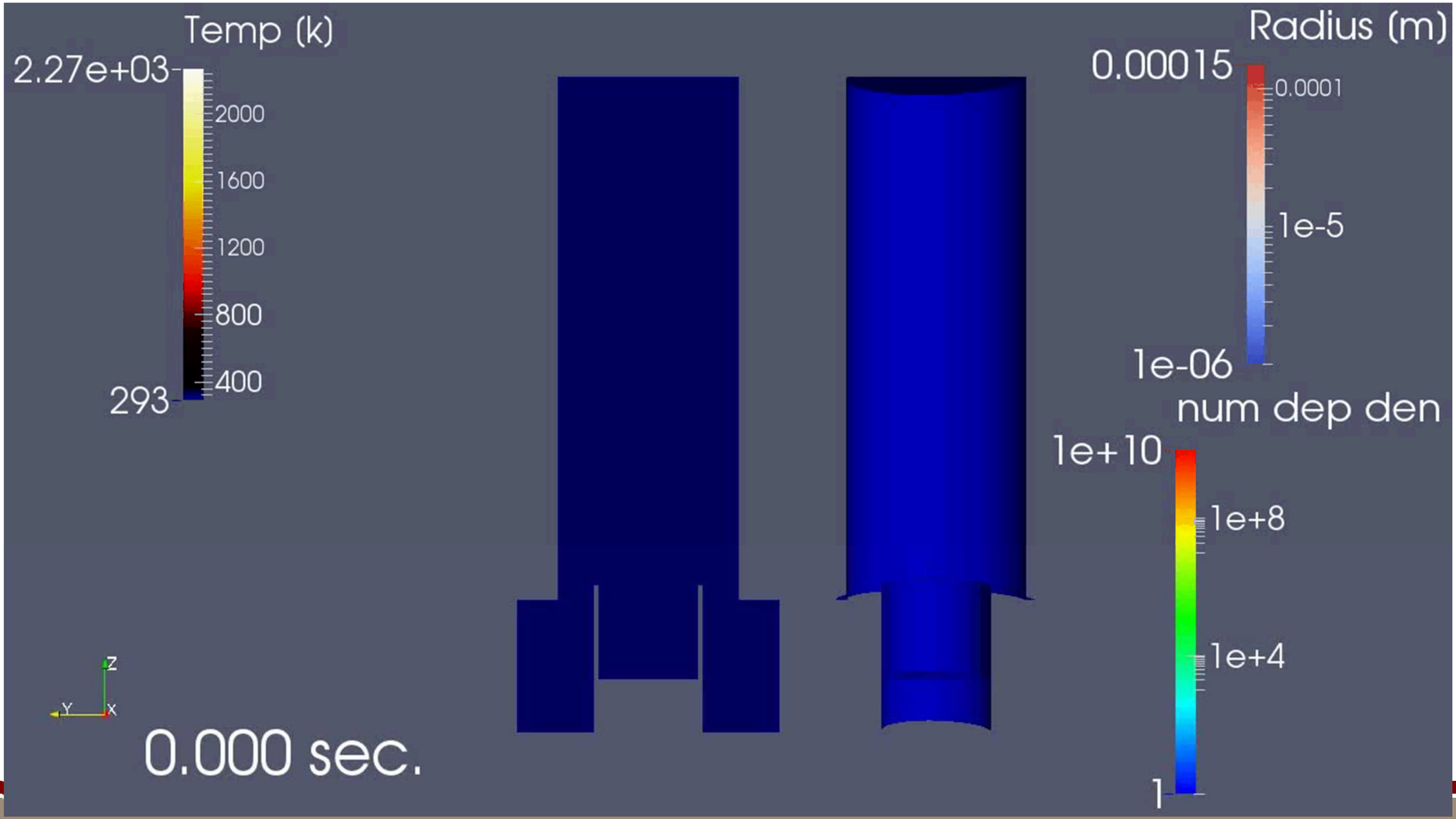
Runs	k [m²/s²]	epsilon [m²/s³]	Corresponding length scale [m]	Corresponding turbulence intensity [%]
Baseline	5.95e-7	4.56e-7	1.7×10^{-4}	100
A variation	5.95e-5	1.53e-4	5×10^{-4}	1000
B variation	5.95e-5	1.92e-6	4×10^{-2}	1000
C variation	5.95e-3	1.53e-1	5×10^{-4}	10000
D variation	5.95e-3	1.92e-3	4×10^{-2}	10000

- Varied particle input file distribution
- Red is after pulse contribution



Video Results

- Varied the liquid height in the beaker
- Varied turbulence parameters



Selected findings (summary)

- Code development needs to better simulate this problem:
  - Resuspension, multi-component particle evaporation, volumetric flow BC, film deposit flow and evaporation, improved reaction model, regressing liquid surface, multi-component pool model
- Issues with experiments:
  - No temporal resolution, no indication of ignition methods, no variation of initial fluid height and liquid level below lip, no turbulence data, no data on distillation, no observations on liquid behavior
- Major findings:
  - The release was mostly during start-up in the simulation
  - Sensitivity to turbulence parameters was slight
  - Initial liquid level was a significant parameter, non-conservative

Follow-on work

- Finishing out the year analyzing a larger scale scenario
- Second year project involves
  - Include model development to allow prediction of resuspension of particles
  - Additional scenario work
- Experimental report postulates side-wall deposition may be significant
- Further develop modeling methods to better resolve physical phenomena in this scenario

Acknowledgements

- Major contributors to the code efforts including David Glaze, Stefan Domino, Flint Pierce, John Hewson, David Noble, Sam Subia, Amanda Dodd, Rekha Rao, Vern Nicolette, Anay Luketa

Extra Viewgraphs

Level-set methods

- CDFEM methods were evaluated for resolving level-set multi-fluid interfaces
- The below video exhibits a 2-D prediction of a boiling drop rupturing on the surface of a liquid