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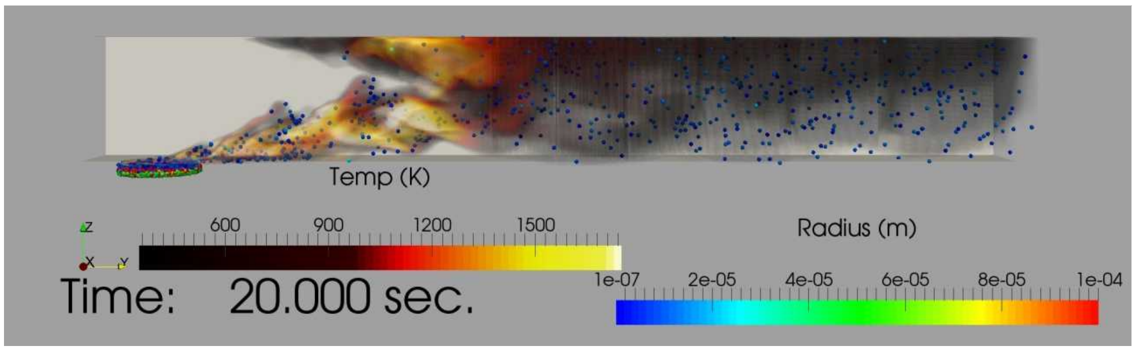

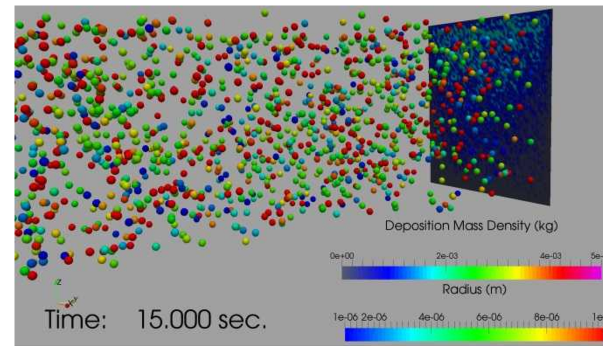

Evaluating a Historical Airborne Release Test with Modern Modeling Methods

American Nuclear Society

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Background & Motivation

- Contaminant entrainment is a safety concern during transportation accidents involving radioactive particles and fuel fires. Knowing an accurate source term important
- DOE-HDBK-3010[1] gives guidelines for potential releases
  - Several experiments performed by Mishima and Schwendiman to study contaminant entrainment
  - Experiment in 1973, UO_2 particles released in a gasoline pool fire.
  - Determined the amount of particles entrained in the flow, **Airborne Release Fraction (ARF)**
- Computational capabilities now exist enabling the simulation of the relevant physics in these experiments
  - Modeling helps interoperate potentially incomplete physical data, and can provide insight into untried scenarios

1. Department of Energy, "DOE HANDBOOK: Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities", Volume 1 and 2, U.S. Department of Energy, DOE-HDBK-3010-94, Reaffirmed 2013, (2013).

Background & Motivation

- Simulating an experiment performed by Mishima and Schwendiman in 1973[1]
  - Studied particle release in a gasoline pool fire
- Experiment distributed uranium dioxide 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

1. Mishima, J., Schwendiman, L.C., “Some Experimental Measurements of Airborne Uranium (Representing Plutonium) in Transportation Accidents, BNWL-1732, August, 1973.

Entrainment Mechanisms

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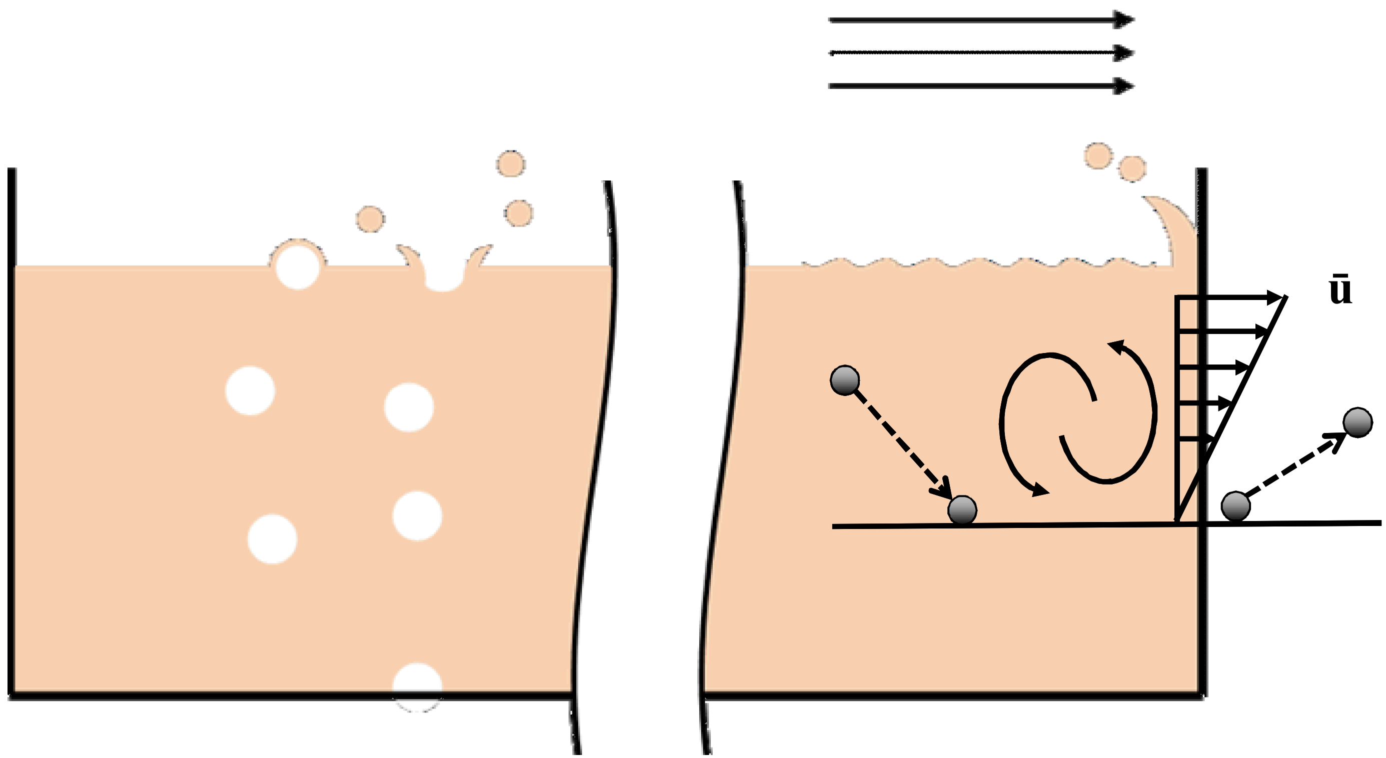
- Four natural mechanisms were identified
  - Evaporation Induced Entrainment [E]
    - Particles ejected from pool by evaporating fluid
  - Surface Agitation by Wind
    - Strong winds create waves which suspend particles upon breaking
  - Surface Agitation by Boiling [B]
    - Droplets become suspended as the gases rupture the liquid surface
  - Residue Entrainment (Resuspension) [R]
    - After liquid has been consumed, remaining solid particles can erode by persisting flow conditions
- An external mechanism also exists
  - Impact Entrainment
    - Droplets (i.e. rain, water from suppression devices) can impact and disturb the fuel surface

During Fire

After Fire

Focus of this study

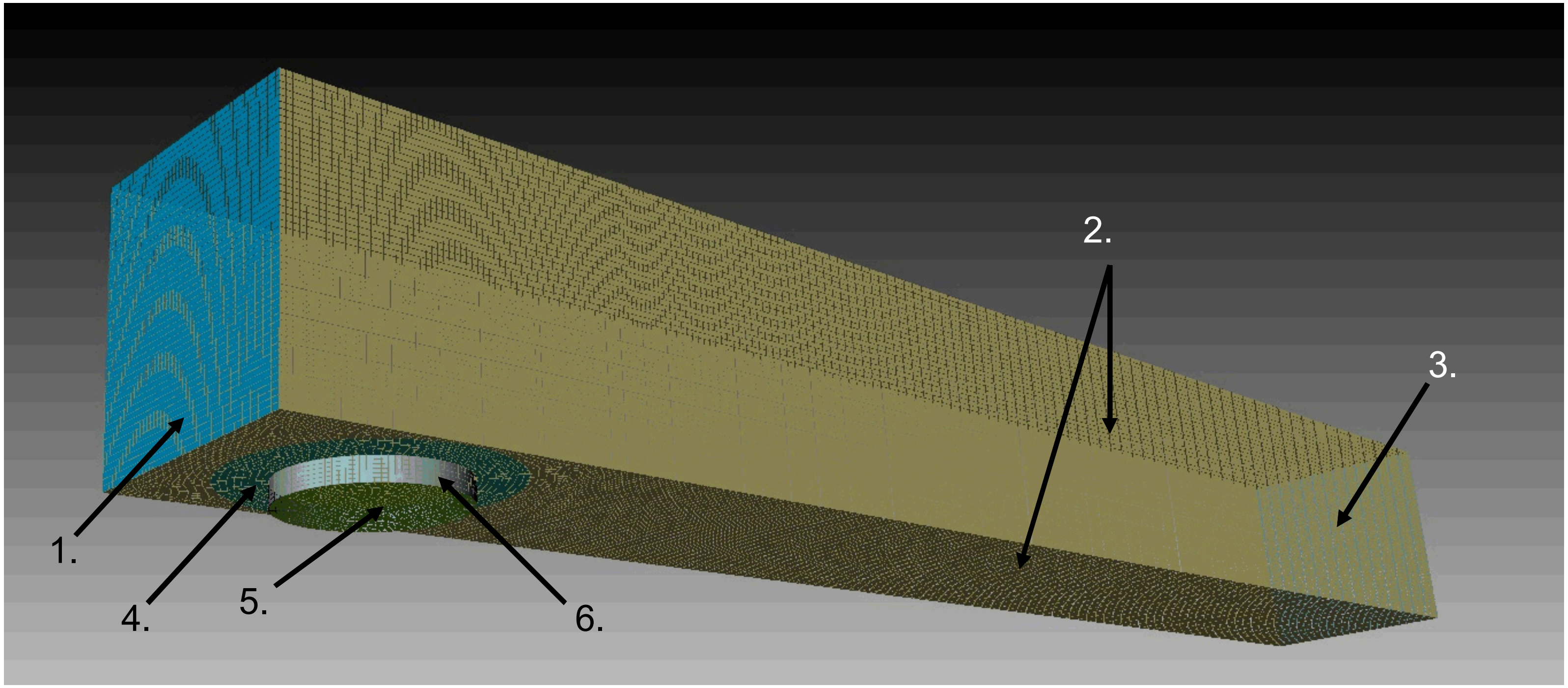
An Illustration of Two Mechanisms



Surface Agitation by Boiling
Involves pinch and rupture of bubbles

Resuspension
Involves adhesion to surface and subsequent turbulent resuspension into flow

Geometry & Mesh Features



1. Air inflow BC, 1 m/s
2. Stainless steel walls
3. Outflow BC, “Filter” location
4. Dirt ring
5. Embedded stainless steel fuel pan, fuel surface, particles dispersed here prior to addition of fuel
6. Steel pan lip

Dimensions:

Tunnel Height: 0.66 m
Tunnel Width: 0.66 m
Tunnel Length: 4.57 m
Fuel Pan Diameter: 0.381 m
Empty Pan Lip Height: 51 mm
Elements: 709,856

Selected Entrainment Mechanisms

- Expanding upon previous work[1], Boiling and Resuspension were selected to study using SIERRA Fluid Mechanics codes
  - Recently implemented model capabilities are important code improvements that allow models to better predict the physics of this type of scenario
    - Multi-component evaporation
    - Particle resuspension
  - Baseline scenarios incorporating each mechanism were chosen, and variations were formed to study sensitivity to parameters, and to account for uncertainty in certain experimental parameters
  - Unknown parameters include the duration of the boiling regime, an accurate characterization of the turbulence, and tuned resuspension parameters

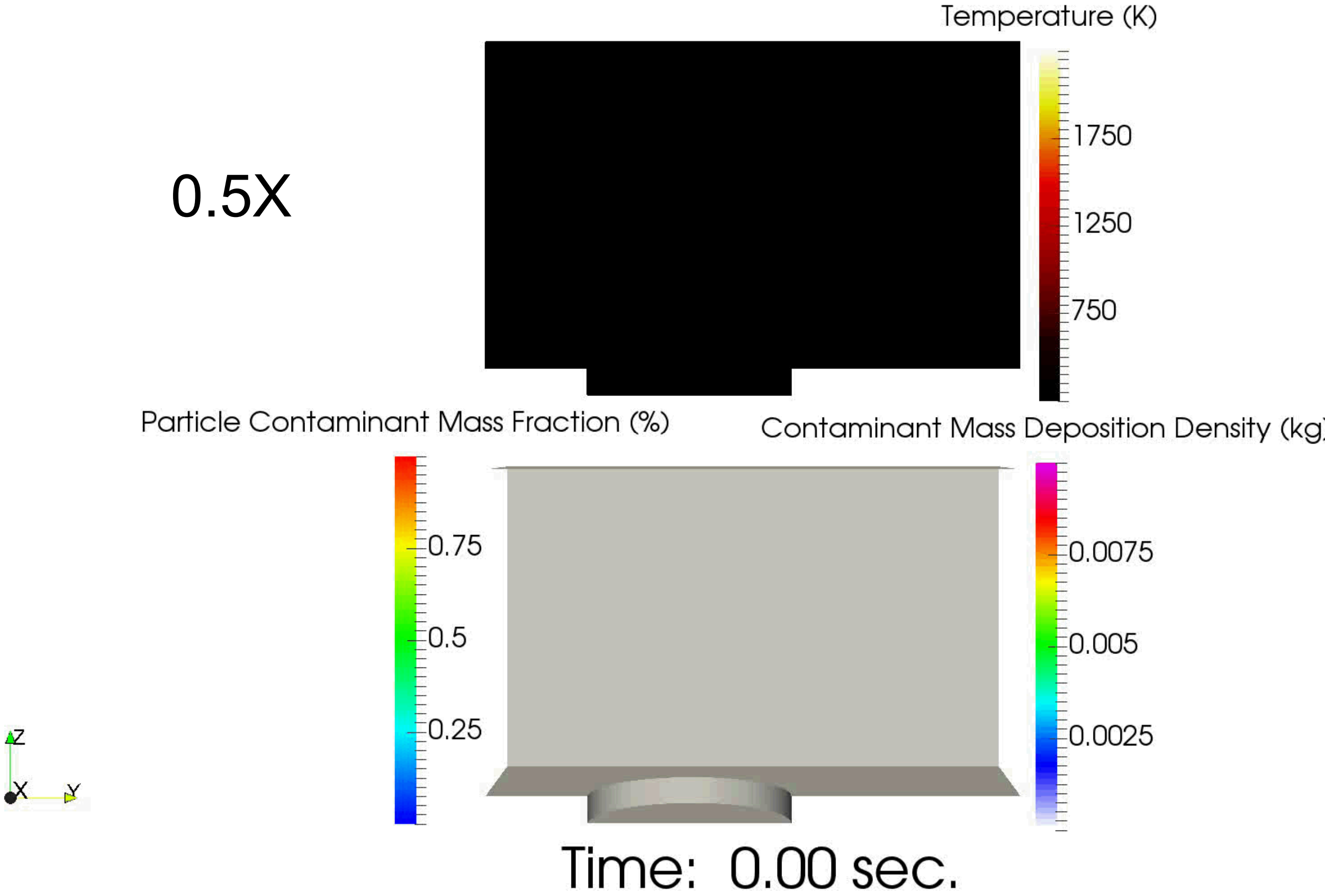
1. Brown, A. L., Zepper, E. T., Louie, D. L. Y., Restrepo, L. “Contaminant Entrainment from a Gasoline Pool Fire,” SAND2015-7185C, September 2015, Sandia National Laboratories.

Simulation Scenarios

Run	Sim. Time (s)	Mechanism Duration† (min)	Injected Mass (kg/s)	Particle Size (um)	Turbulence	Injection Height (mm)	Particle Temp.
1B*	25	0.28	8.3E-3 [2%]	Distribution	Normal	10	370
2B*	35	0.45	8.3E-3 [2%]	Distribution	Normal	10	370
3B*	25	0.28	8.3E-3 [2%]	Distribution	High	10	370
4B*	25	0.28	4.15E-3 [2%]	Distribution	Normal	10	370
5B*	25	0.28	1.25E-2 [2%]	Distribution	Normal	10	370
6B*	25	0.28	8.3E-3 [2%]	Distribution	Normal	5	370
7B*	25	0.28	8.3E-3 [2%]	Distribution	Normal	5	361
1R**	50	288	8.3E-3	Distribution	Normal	10	370

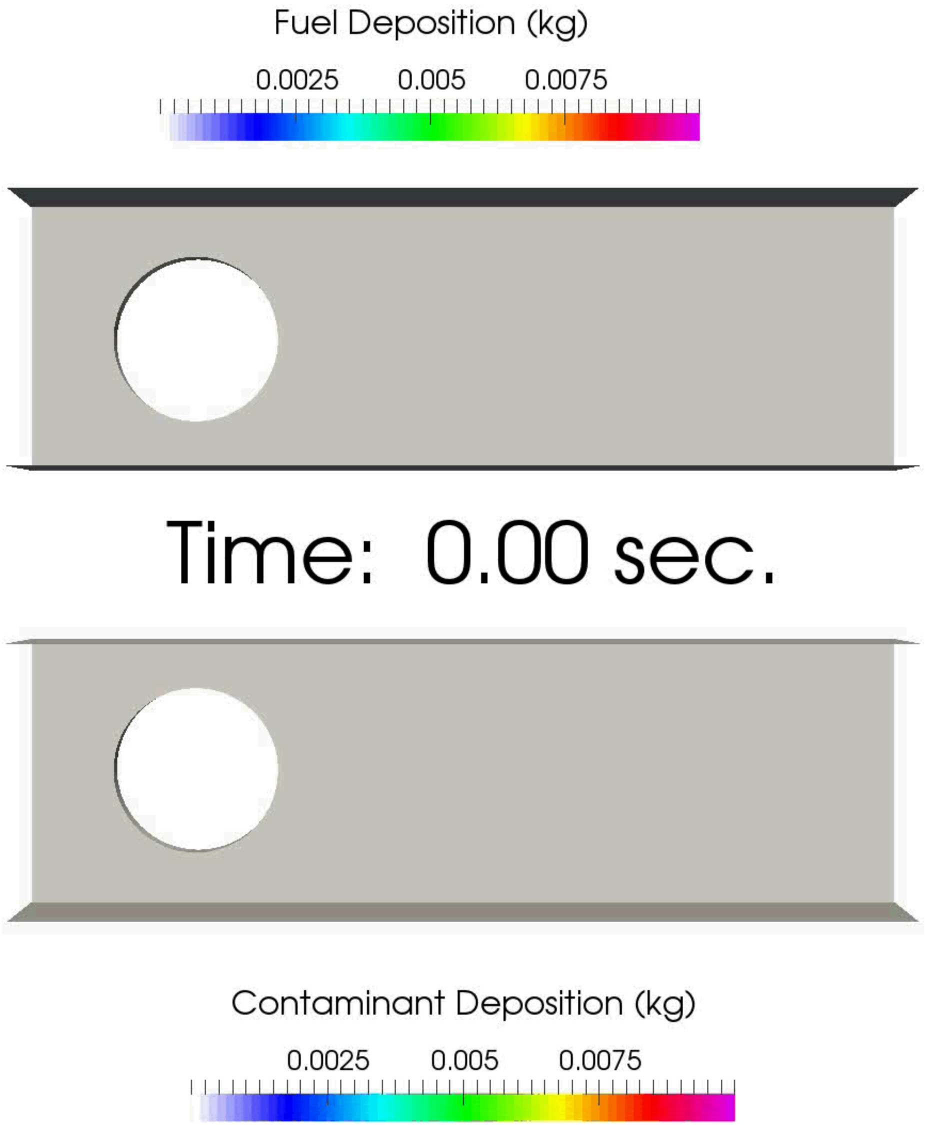
* = Multi-component Fuel & Contaminant
** = Combined Fuel & Contaminant
†= Note: Duration for Resuspension [R] denotes the entire time for the post-burn flow, and does not use the multi-component particle model. The duration for Boiling [B] denotes the portion of the burn when the fuel was assumed to be boiling. The Resuspension scenario includes the particle birthing and deposition time (~20 sec) from the boiling scenario.

Simulation Visualization



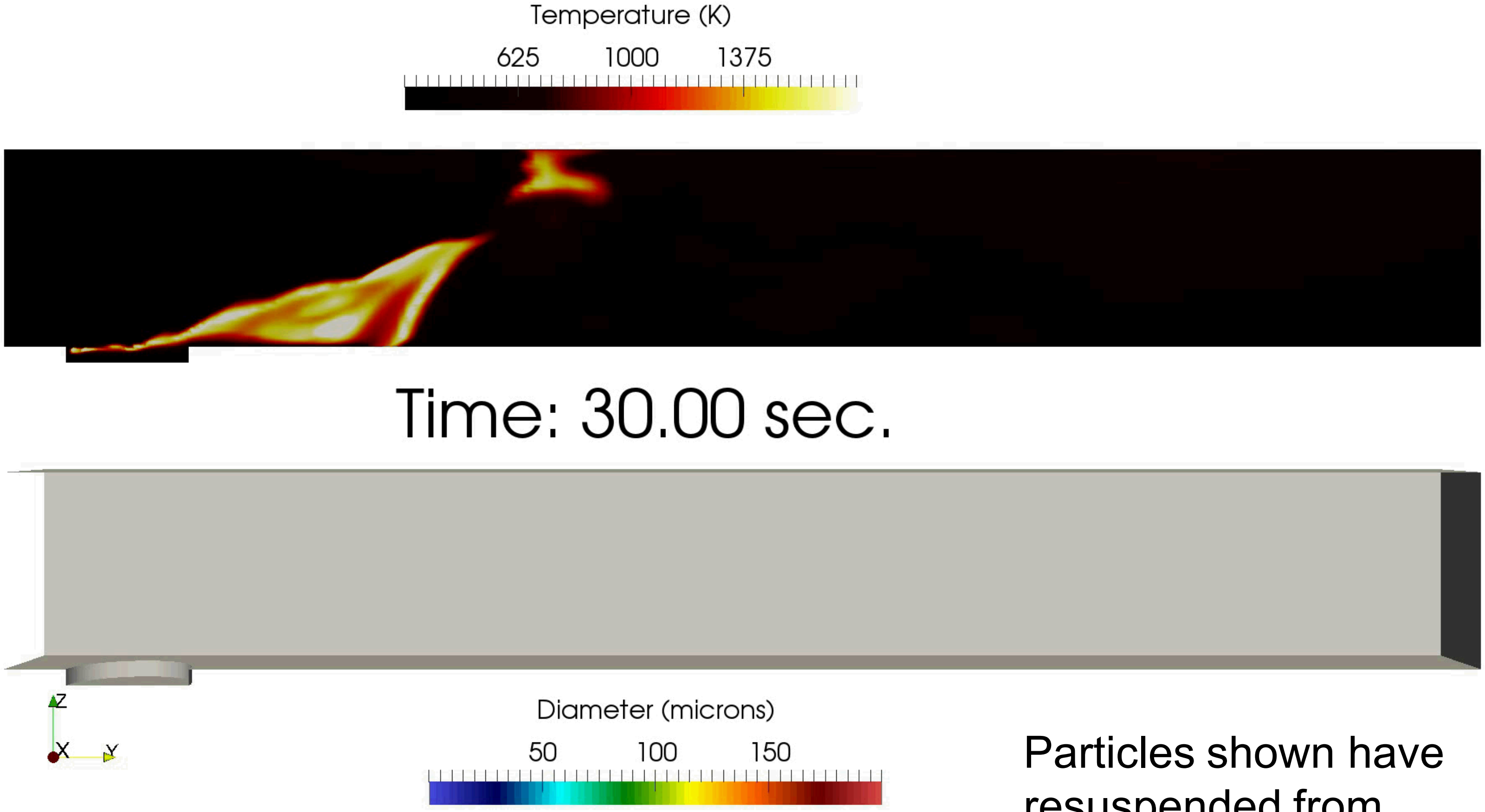
- Particles with a higher fuel mass fraction (blue) stay low in the fuel pan, either falling to the pool surface or evaporating until the particle lofts into the flow as mostly contaminant (red)

Simulation Visualization: Boiling Entrainment Multi-component Evaporation(1B)



The fuel deposits closer to the pool, while the lighter contaminant particles carry further downstream

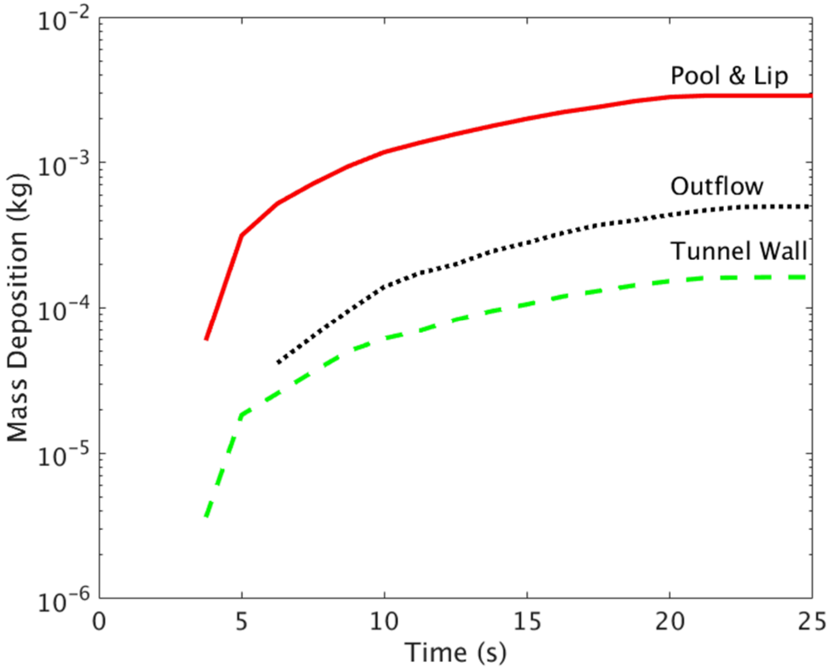
Simulation Visualization: Resuspension Entrainment (1R)



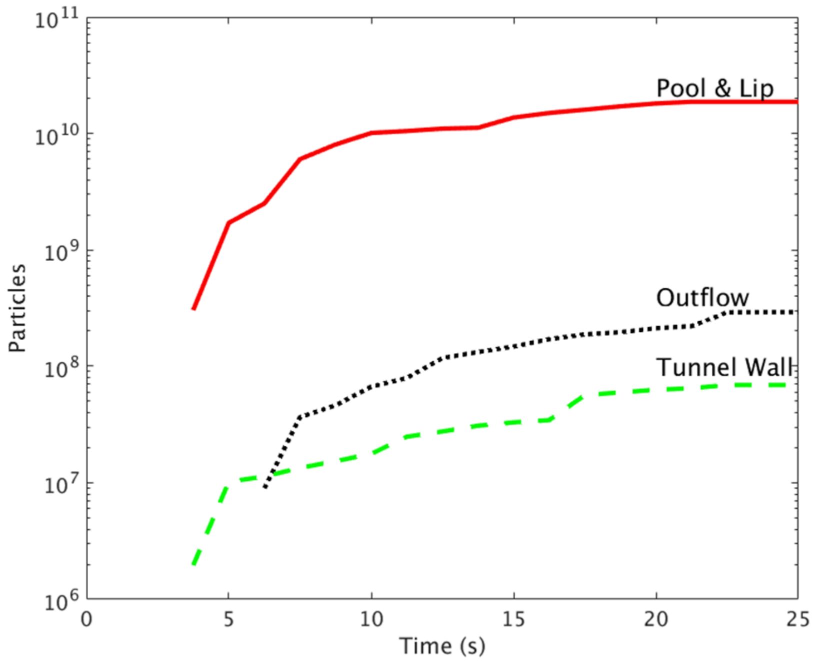
Particles shown have resuspended from surfaces

Deposition Reaches Steady State

Boiling: Predicted Mass Deposition vs Time (1B)

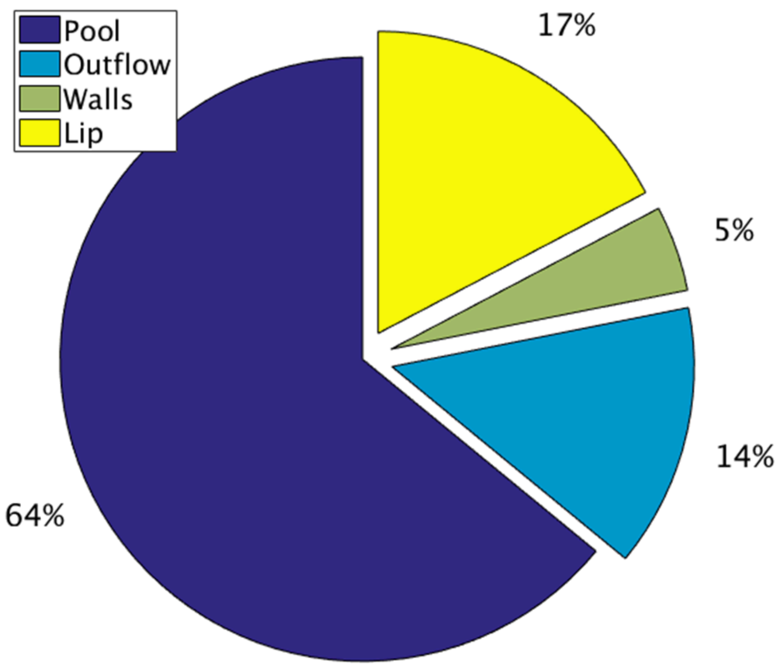


Boiling: Predicted Number Deposition vs Time (1B)



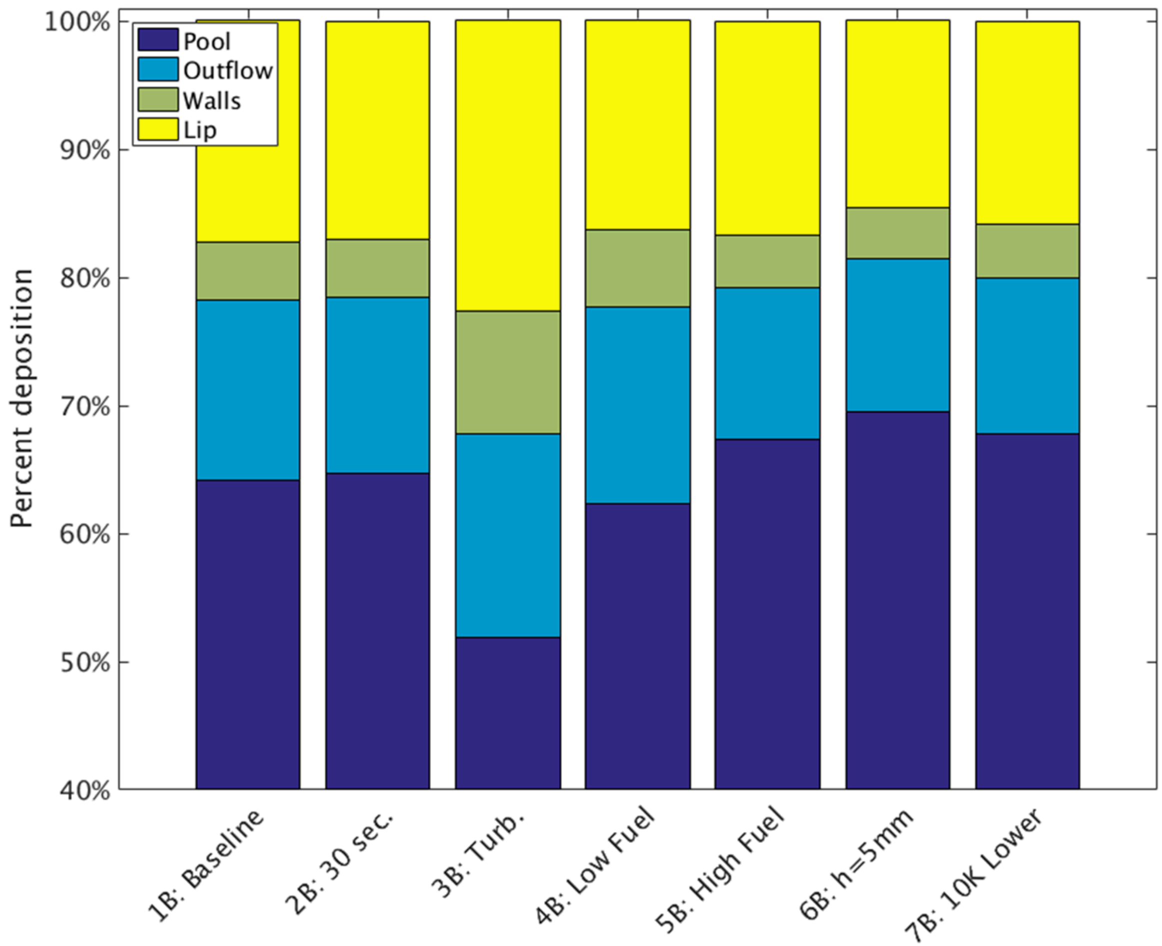
Boiling (1B) Final Mass Fate

- Contaminant (1B)



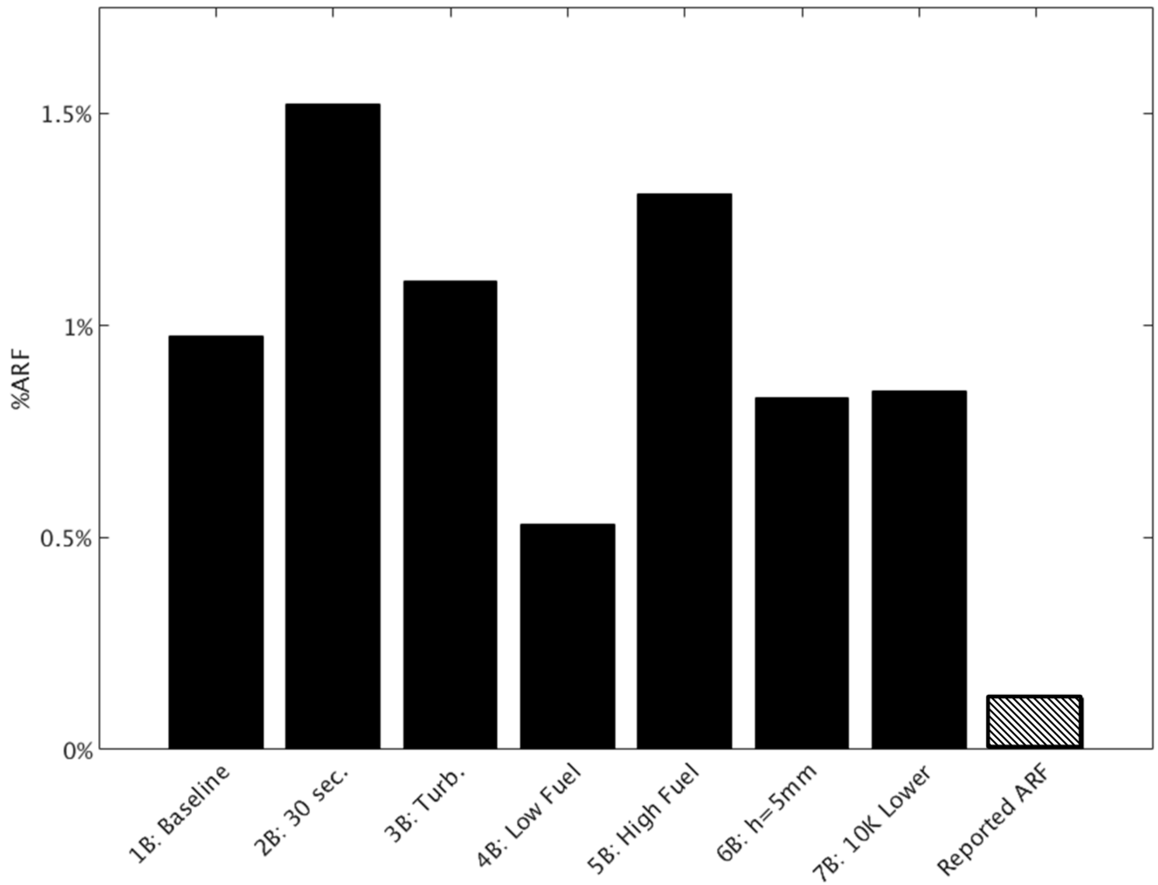
- Boiling: Most entrained particles fall back into the pool
- Resuspension: No additional resuspended mass reached the outflow during the simulation time

Boiling Final Deposition



- Varying the turbulence intensity (3B) had the largest impact to the final deposition distribution
- Varying the initial particle temperature does not significantly alter the release and deposition

Boiling Predicted and Reported Particle ARF



- Simulations including multi-component particle evaporation physics indicate a higher Airborne Release Fraction than reported by the experimental data
- Comparisons between experimental and simulation data for the Resuspension mechanism not made as additional contaminant release was not seen in the simulations

Future Work

- Distribution of particles in gasoline pool will affect the ARF
  - Pool distribution of contaminant assumed to be homogeneous; lacking a more accurate model.
  - Large difference in particle and fuel density, 11,000 and 680 kg/m^3
    - Suggests settling would occur
    - Alters the ARF.
- Tuning of a resuspension model
- Improved boiling models
  - Specific to fuels
  - Respective of the burn-out dynamics

Summary and Conclusions

- Multiple mechanisms contribute to the entrainment of particles in a fuel fire, two of which were the focus of this study.
- Methods exist to simulate particle entrainment in a fuel fire using CFD codes.
- The addition of multiple species evaporation and deposition for particles provided new insight to the entrainment dynamics.
- The volatile fuel was seen to evaporate rapidly in the fire above the pool surface, increasing the likelihood that the remaining non-volatile solid contaminant would transport down the wind tunnel and reach the outflow.
- Practical assumptions for the turbulence boundary conditions result in significant uncertainty in the ARF, as the release is most sensitive to this parameter.
- The boiling duration was found to be the most significant factor in predicting the ARF. Improved modeling of particle entrainment from pool boiling will help quantitative accuracy of this type of modeling.

Acknowledgements

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Extra Viewgraphs

Simulation Variations

- Boiling Multi-Component Entrainment

Case	Variation from Baseline
1B	Baseline. 25 second simulation, 10 mm particle injection height, particle size distribution, empty pan (high lip) mesh, 370 K particle injection temperature, and gas velocity representing the fuel pool.
2B	Simulated for 35 seconds with particle injections from 3 to 30 seconds.
3B	Turbulence parameter increased to 100%
4B	Fuel pool height lowered to 1 mm.
5B	Fuel pool height increased to 3 mm.
6B	Particles injected at 5 mm above the bottom of the fuel pan.
7B	Particle injection temperature decreased to 361 K

- Resuspension Entrainment

Case	Variation from Baseline
1R	Resuspension mechanism. 50 second simulation 1D pool model, 2 mm fuel height, 50 µm surface roughness.

Mesh comparison/ convergence