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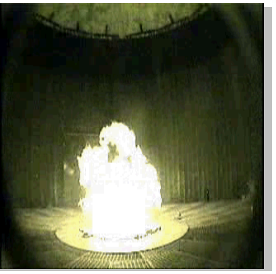
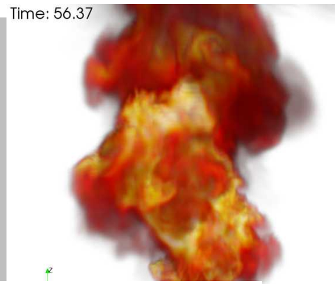
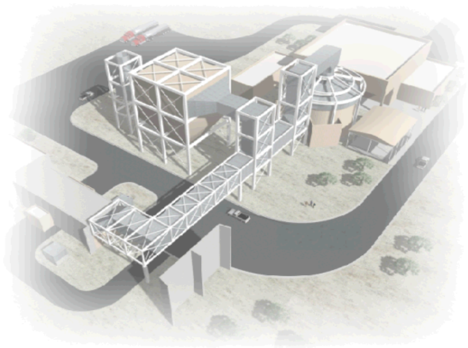






An overview of Sandia National Laboratories recent fire science and related work

John Hewson, Carlos Lopez, Amanda Dodd

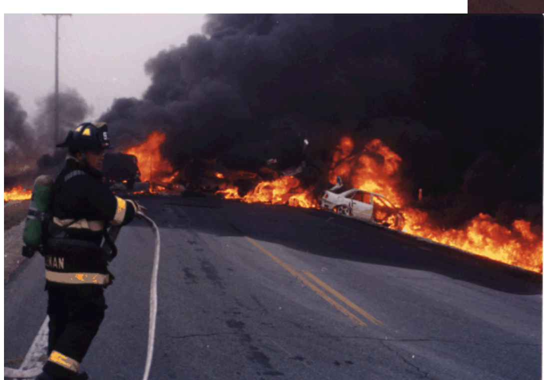
International FORUM of Fire Research Directors Annual Meeting

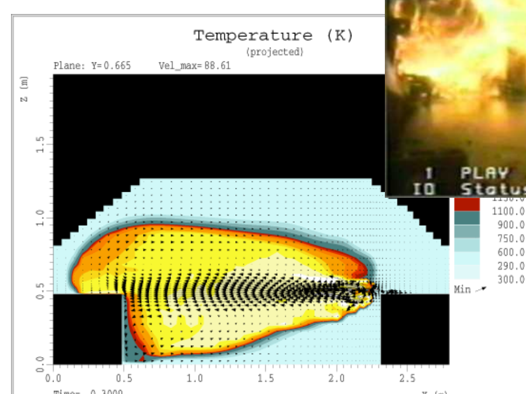
10/1/2017

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

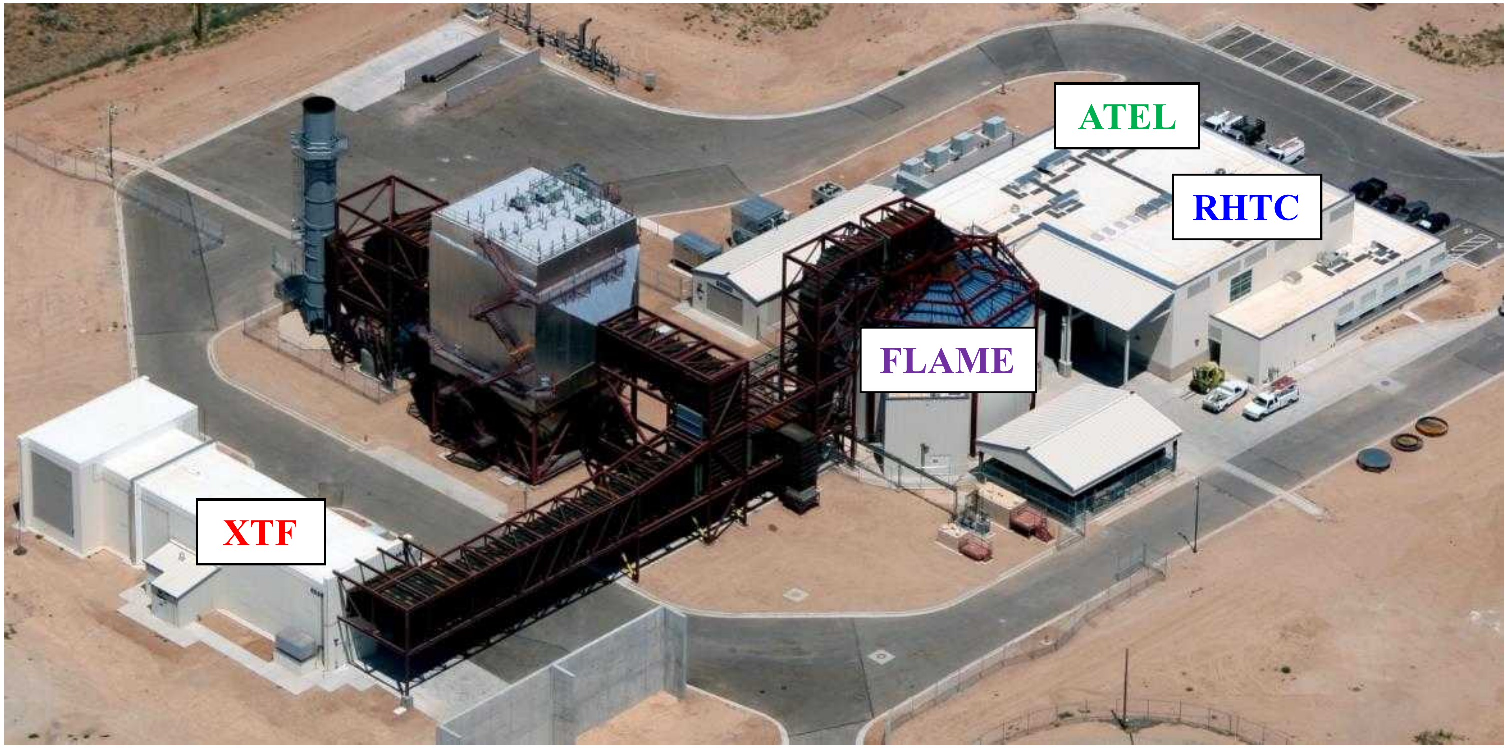
We Solve High Consequence Fire Problems

- Improved Confidence in Nuclear Weapon Safety
  - Assessments identify fire as a potential concern in the transportation & storage of weapons (DOE, DTRA)
  - Qualification required for Stockpile Life Extension
- Unique Capabilities to Problems of National Interest
  - NRC, DoD, DoT, DHS, DOE, NASA
  - Close Collaboration with Risk Assessment





Thermal Test Complex

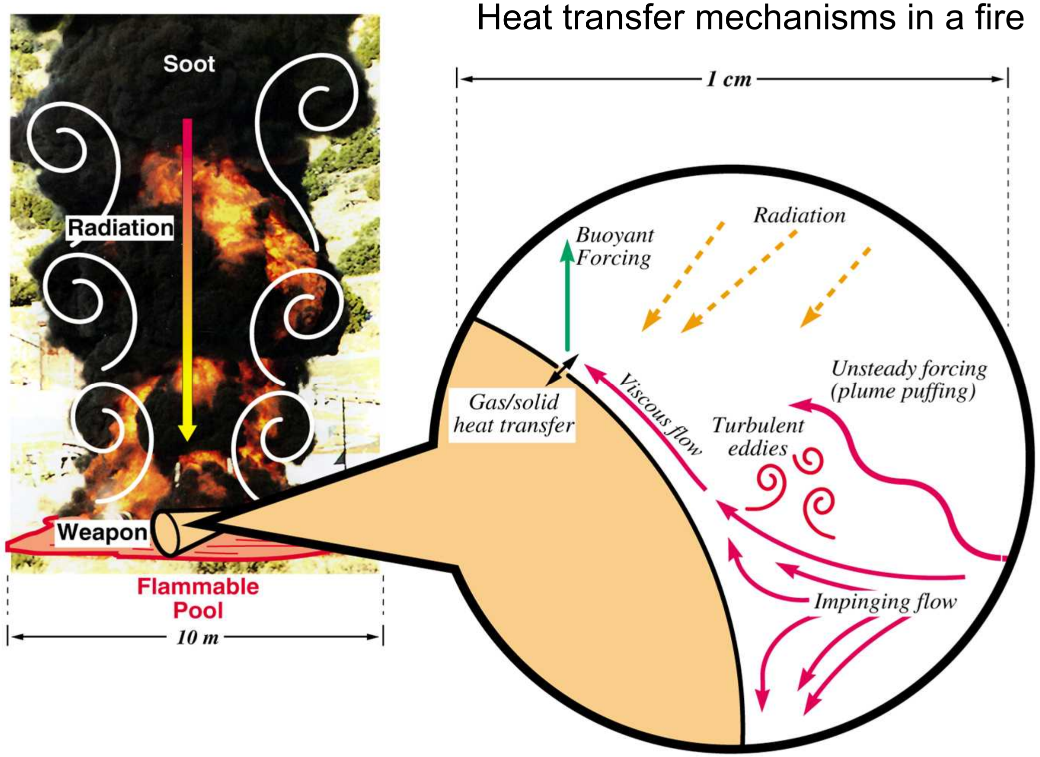


- FLAME – Vertical Wind Tunnel for Fires in Calm Conditions (18.3m dia. x 12.2m high)
- XTF – Horizontal Wind Tunnel for Fires in Cross Wind (7.6m x 7.6m x 25m long)
- RHTC – Full Scale Radiant Heat (Fire Loading Simulator) Lab (5.2MW total power)
- ATEL – Abnormal Thermal Environment Lab (small-scale fire tests)
- Plus, the Burn Site for remote, large scale outdoor fire tests

Sandia Multiphysics Computational Tools Suitable for Fire Environment and System Response

- Sierra-Mechanics integrated simulation tools developed at Sandia
  - Original purposes included safety analysis of weapons in fire scenarios
  - Product of DOE-NNSA investments via Advanced Scientific Computing (ASC) program
- Focus on multi-physics coupling including conjugate heat transfer between fire and objects in fires.

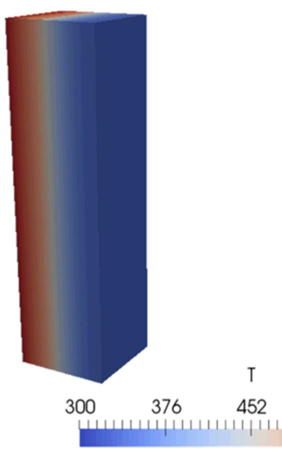
Heat transfer mechanisms in a fire

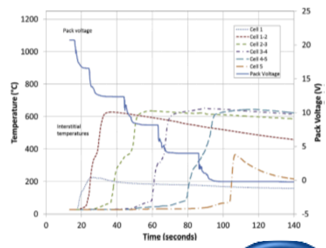


ESS Safety tied into industry to effect maximum impact

Objective: ESS safety R&D initiated with objectives determined by industry priorities from our diverse working group.

Thermal runaway experiments and modeling

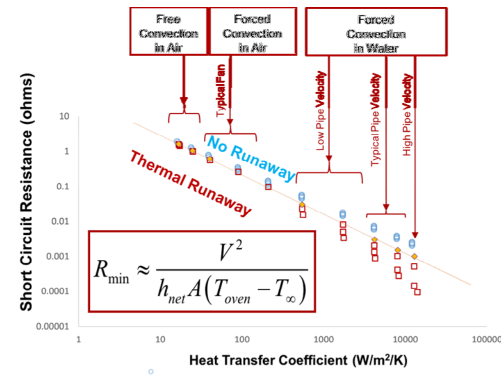


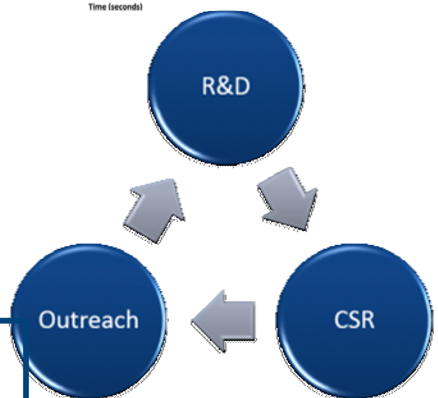


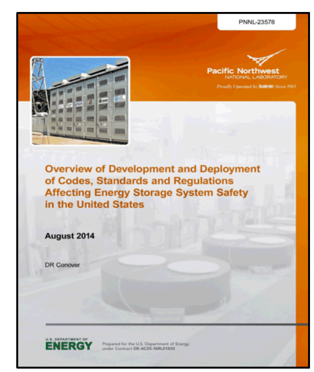
- **Fire Suppression testing** and analysis
- **Thermal runaway and mitigation** research
- **System scale burn test and modeling**

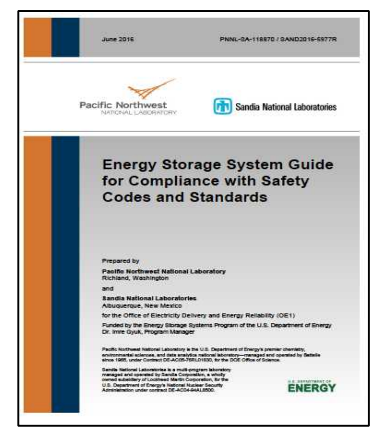
Commodity classification development

Fire and vent gas modeling and analysis

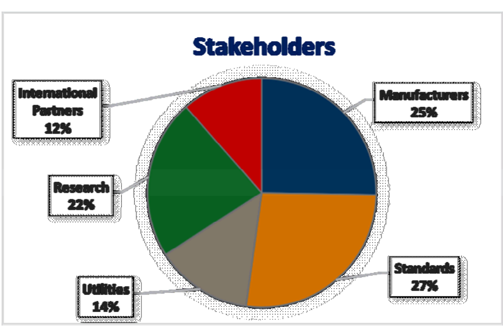








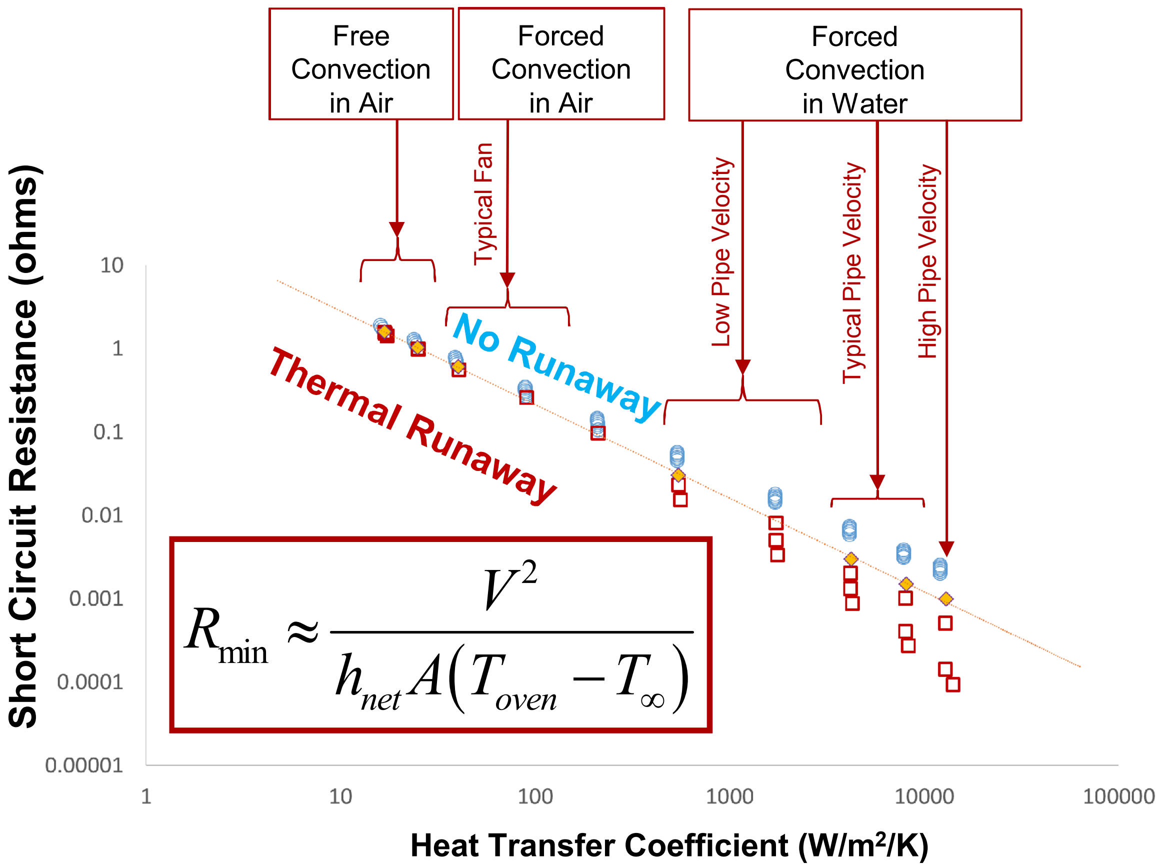
Objective: Provide awareness to first responders and authorities with jurisdiction; metering perception of risks with reality.

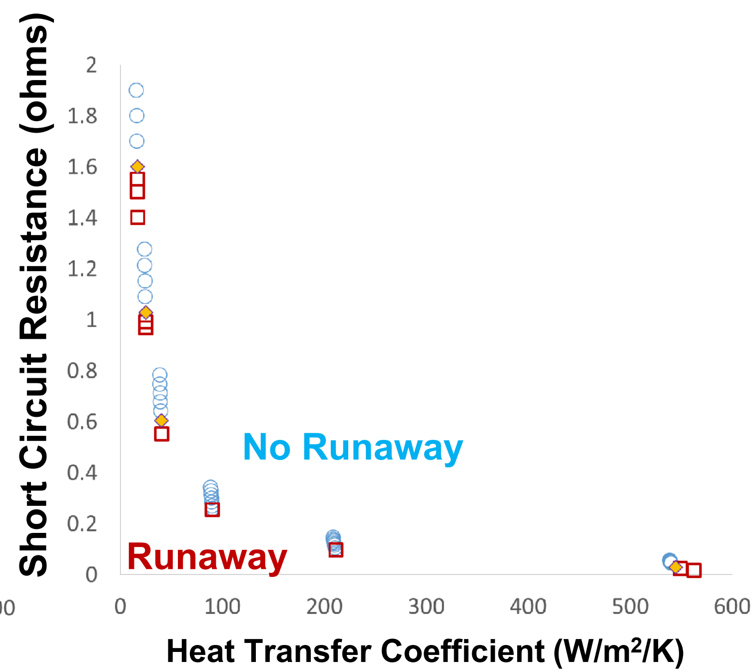


Objective: Distill codes and regulations, providing common sense feedback to code bodies while identifying gaps to facilitate safe and efficient adoption.

How Much Cooling to Suppress Runaway with Internal Short Circuit?

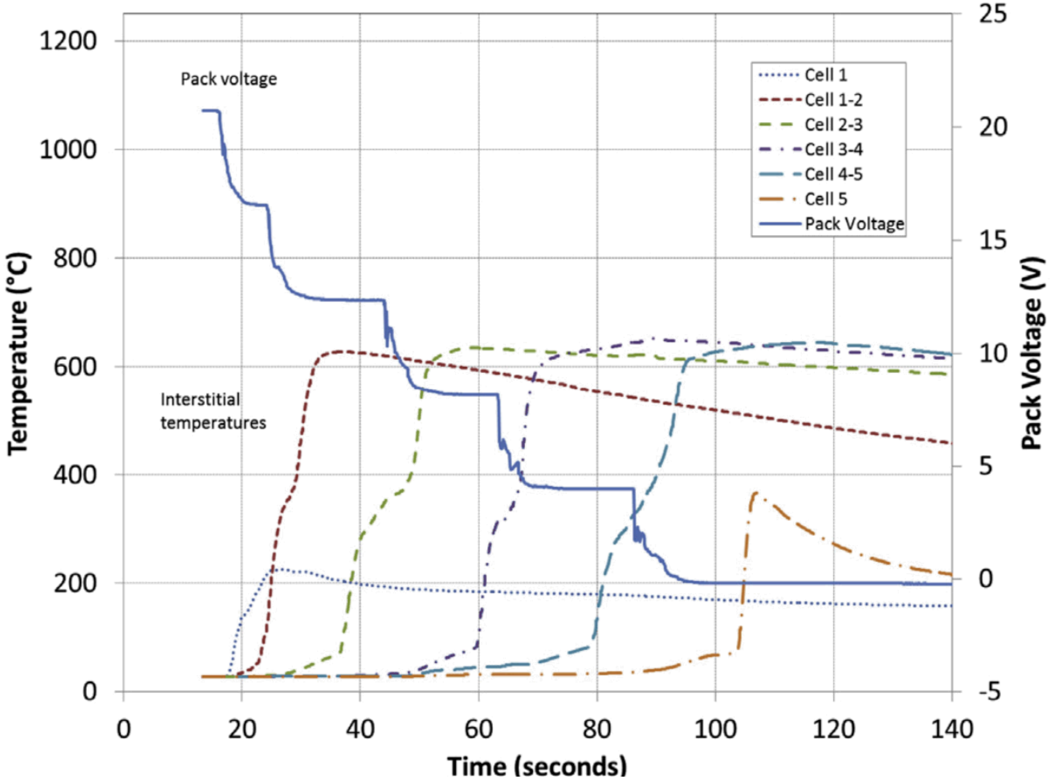
$$T_{eff} = T_\infty + P / h_{net} A \qquad P = \frac{V^2}{R}$$

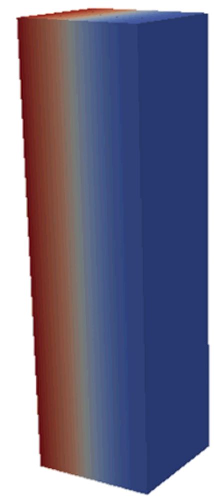


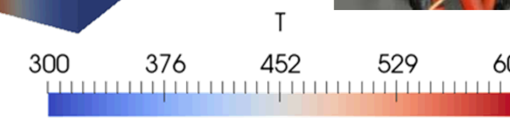


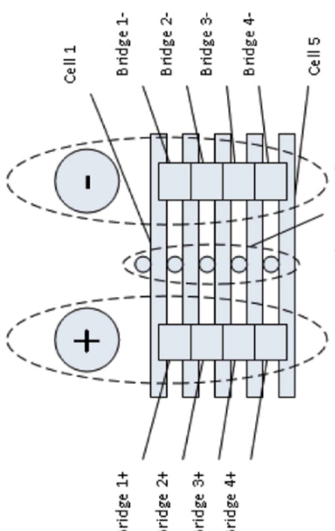
- Models can be used to estimate cooling requirements
  - Simulation shows homogeneous heating of 18650 cells (varying short resistance and cooling)
  - Internal temperature variation will be worse for large format systems and localized shorts

Cascading Propagation Observed in Li-Ion Packs



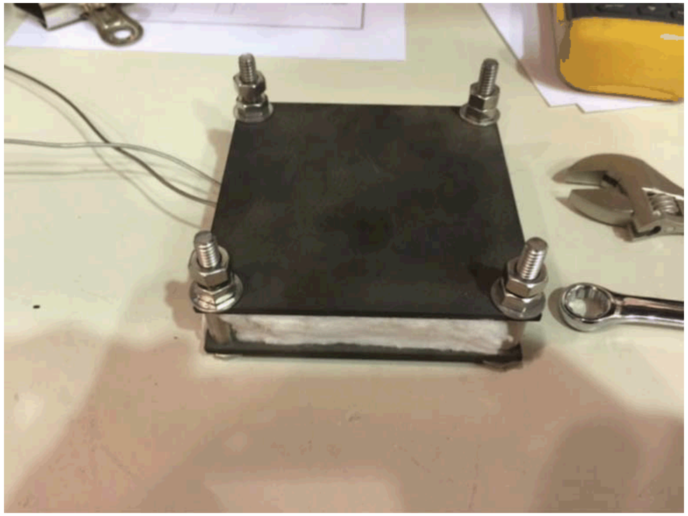






- Experimental propagation in 5 stacked pouch cells at Sandia
- Investigating effects of
  - State of charge
  - Intermediate layers
  - Cell geometry
- Good pack-scale model validation cases

Test standards for heat flux in fires



Designation: E3057 – 16

Standard Test Method for Measuring Heat Flux Using Directional Flame Thermometers with Advanced Data Analysis Techniques[1]

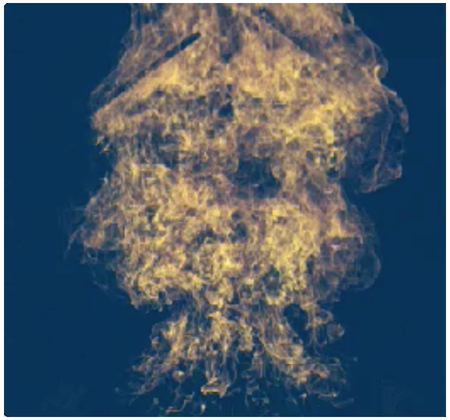
This standard is issued under the fixed designation E3057; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

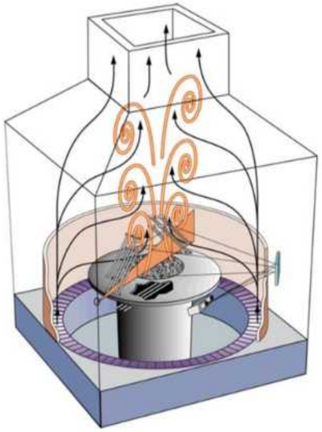
INTRODUCTION

This test method describes a technique for measuring the net heat flux to one or both surfaces of a sensor called a Directional Flame Thermometer. The sensor covered by this standard uses measurements of the temperature response of two metal plates along with a thermal model of the sensor to determine the net heat flux. These measurements can be used to estimate the total heat flux (aka thermal exposure) and bi-directional heat fluxes for use in CFD thermal models.

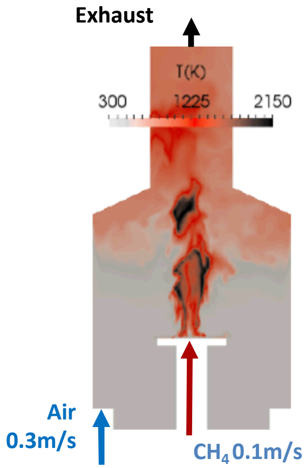
Measurements and Computation of Fire Phenomena

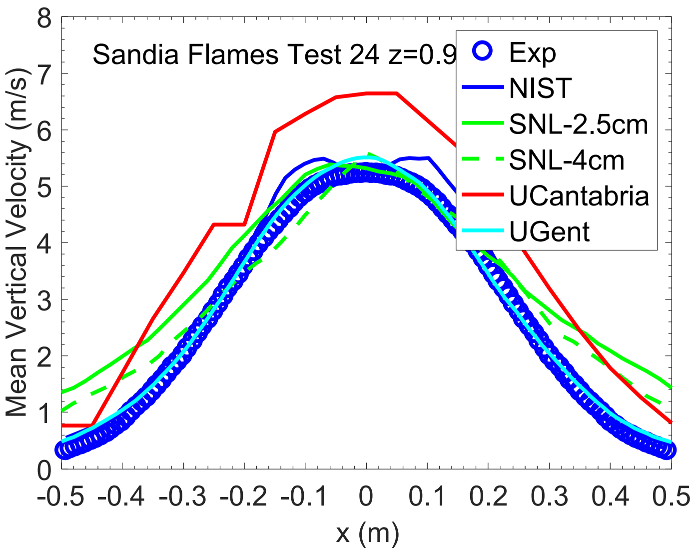
- Workshop held in conjunction with IAFSS meeting.
- Methane fire and helium plume validation cases based on Sandia measurements.





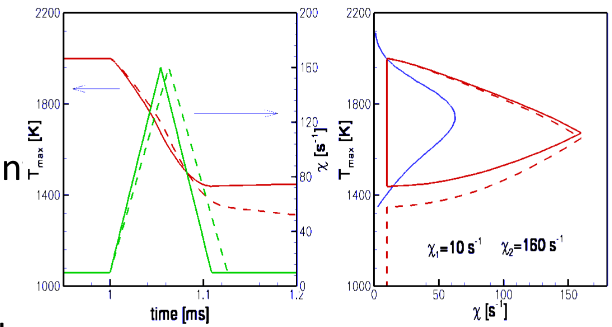
- Separately addressing sensitivities:
  - mesh resolution,
  - turbulence and combustion model
  - boundary condition sensitivity



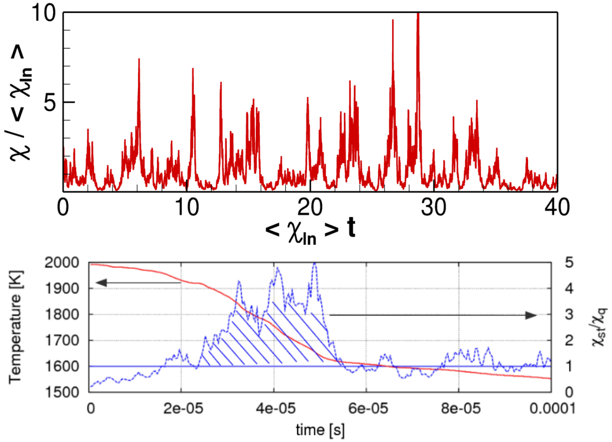


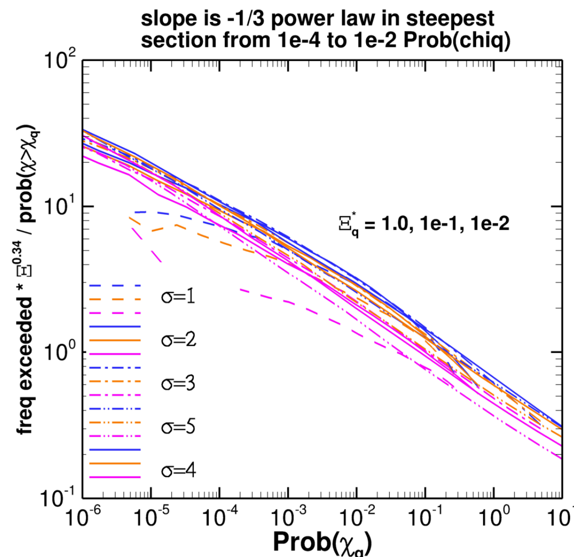
Stochastic modeling of unsteady extinction

- Flame extinction is generally based on unsteady stochastic events.
  - Magnitude of event leading to extinction given by recen extinction impulse, Ξ_q.
  - Rate of occurrence examined using stochastic approaches to develop scaling laws.



Hewson, Comb. Flame, 160:887-897, 2013



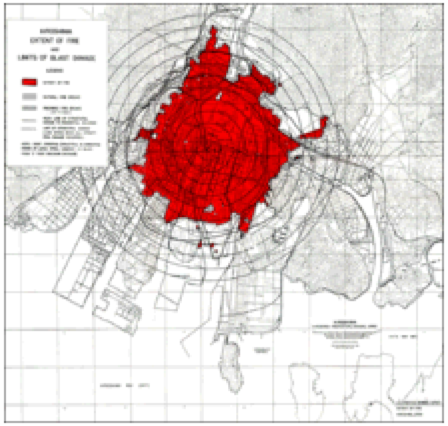


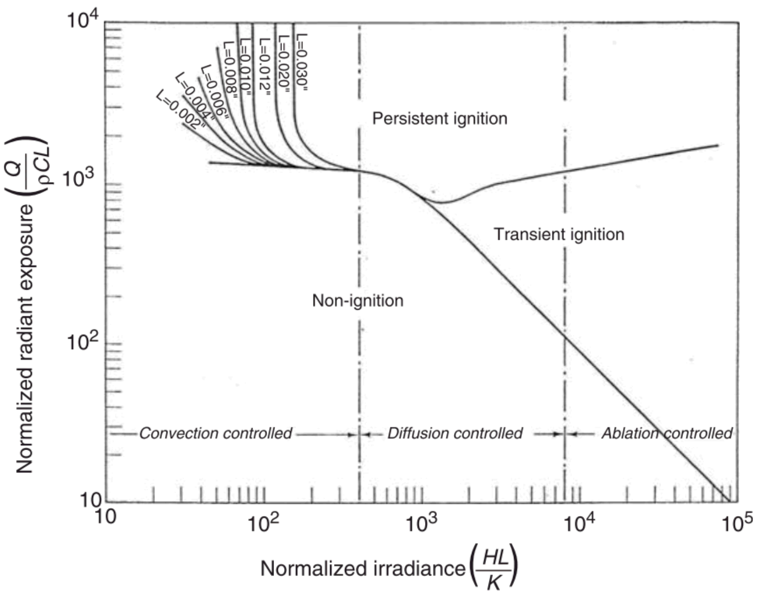
Lackman, Hewson, et al. *Proc. Comb. Instit.*, 13:1677-1684, 2017.

- Extinction frequency: leading order scaling by $\text{Prob}(\chi > \chi_q)$ (cumulative distribution) as measure of time when $\chi > \chi_q$.
- Also decreasing with $\text{Prob}(\chi_q)$-– crossing frequency.

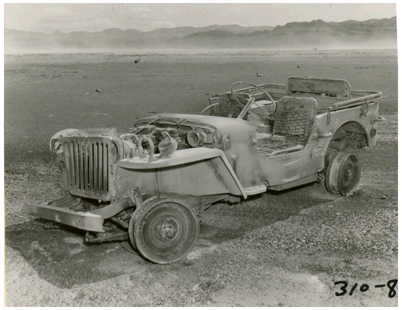
High Heat Flux Ignition

- Why we care?-we seek to be able to adequately plan, predict and respond to NW events
- Prior testing to replicate the environment at lab scale
  - S.B. Martin and collaborators, USN tests, mostly 1950-1970
  - Some blast-fire interaction work 1975-1985
- Martin's Regimes of Ignition





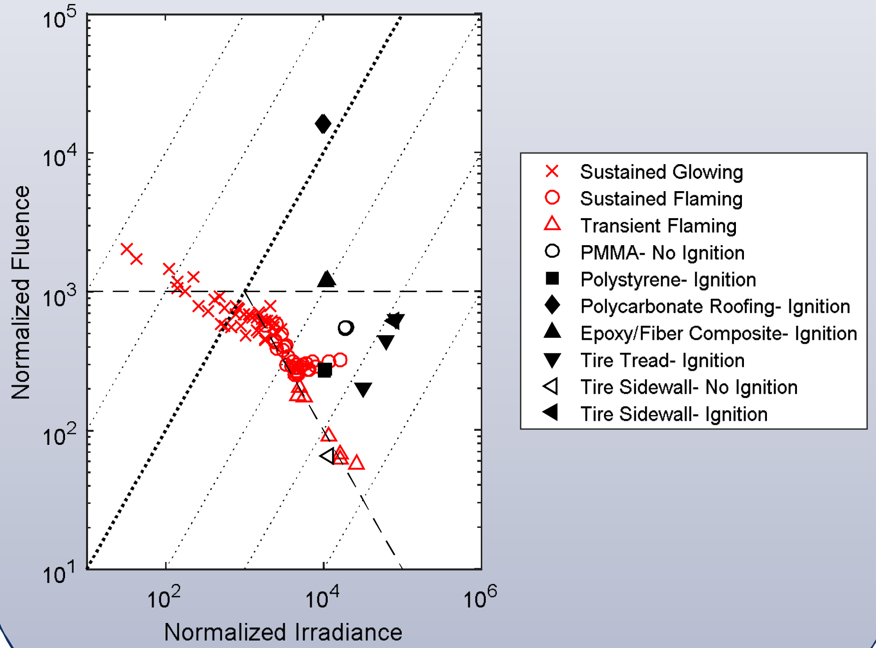
- Maps ignition regimes for cellulose
- Recommended in the SFPE handbook
- Diagonal lines (45º) are constant Fourier numbers



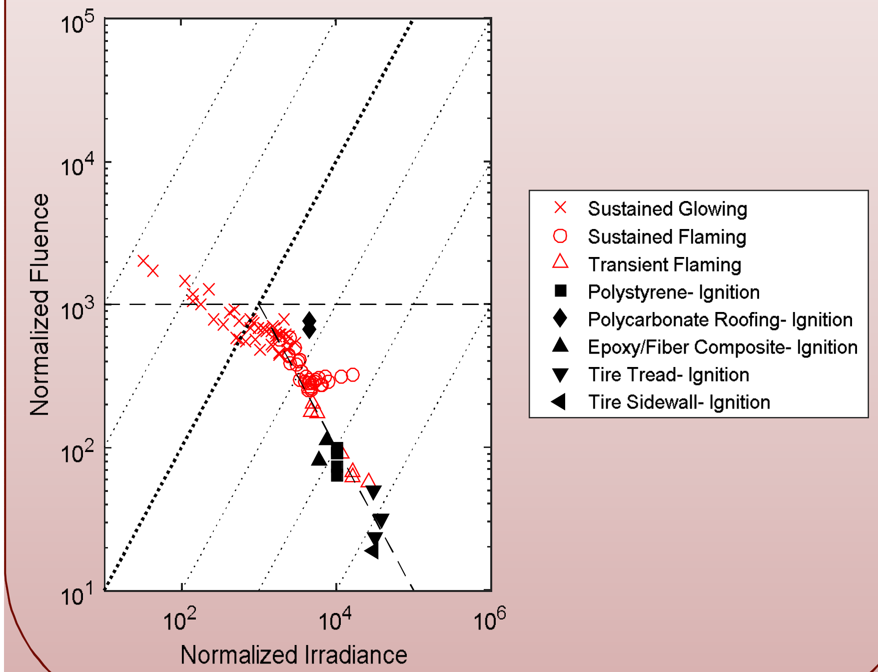
Martin S.B., Diffusion-controlled ignition of cellulosic materials by intense radiant energy. In Symposium (International) on Combustion 1965 (Vol. 10, pp. 877-896).

Comparison to Martin: Polymers

Total Quantities
-Preliminary-



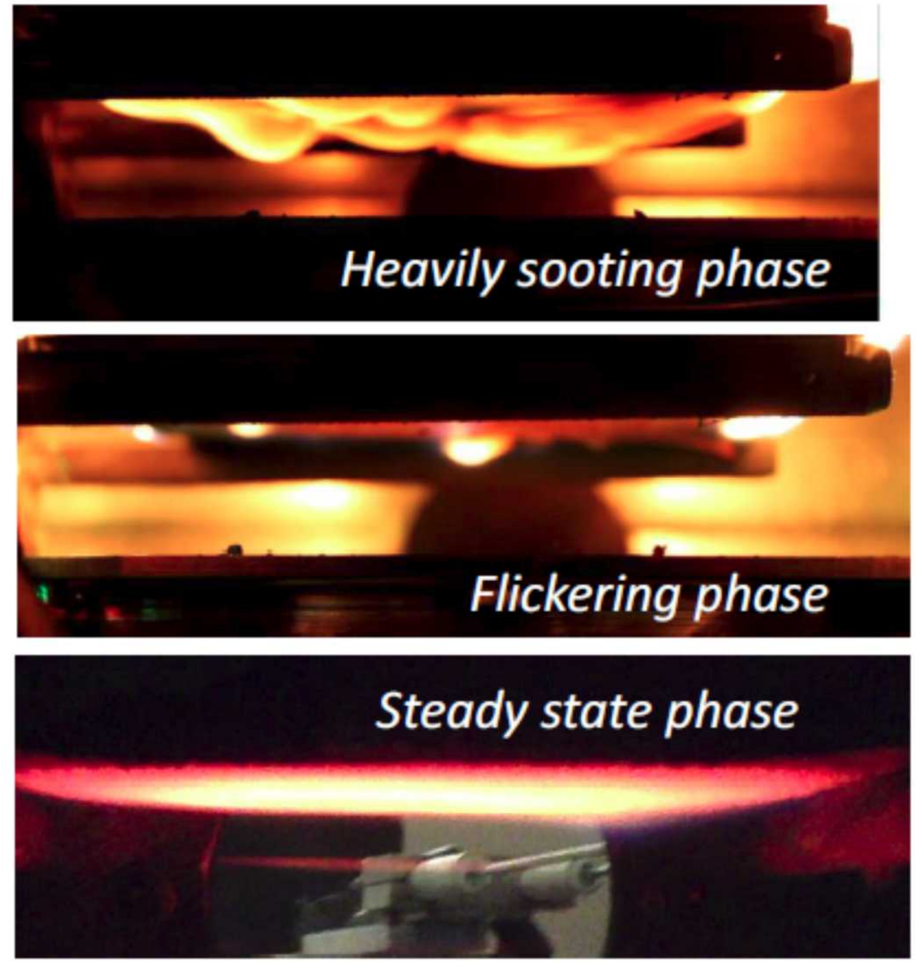
Time-of-Ignition Quantities
-Preliminary-



- PMMA is more difficult to ignite
- Many ignite similar to cellulose
- All data points are for transient flaming

Composite airframe material fire studies

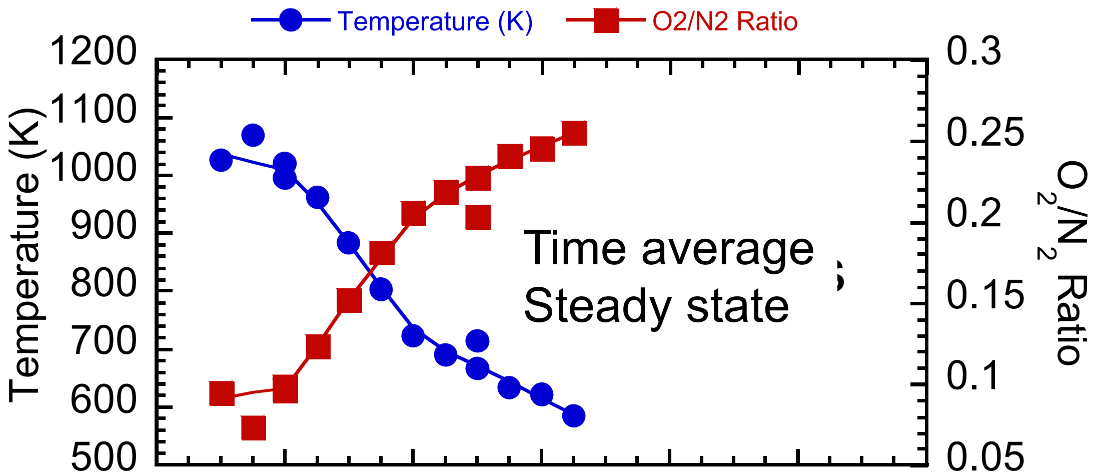
- Behavior of composite fires not well characterized.
- Prior work on decomposition pyrolysis and oxidation.
- Gas-phase measurements and forthcoming condensed-phase temperature measurements.
  - CARS temperature and O2/N2

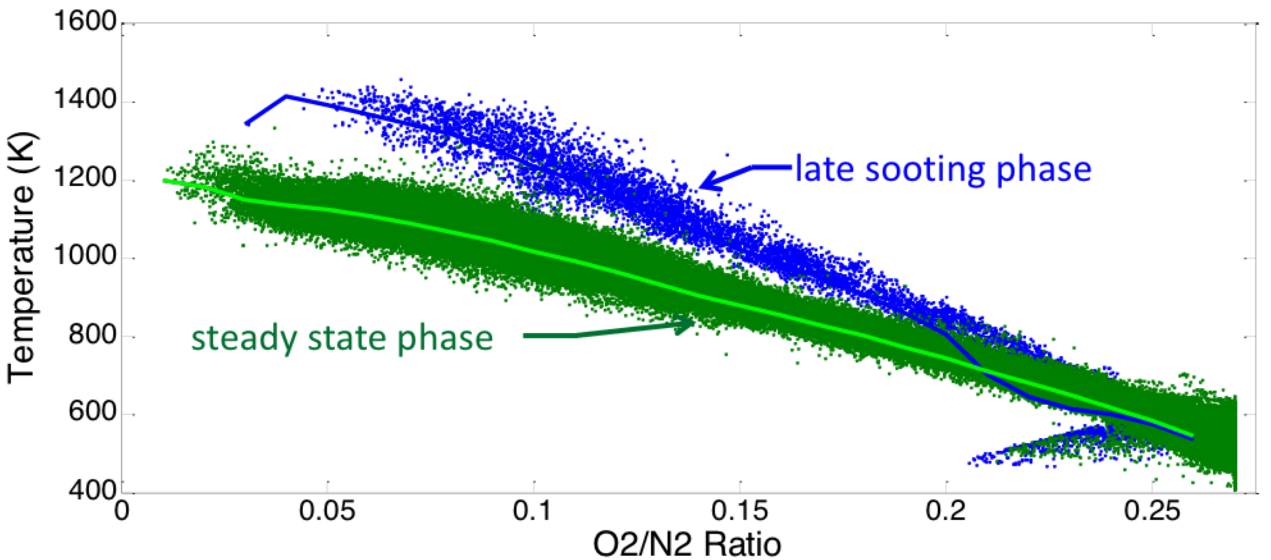


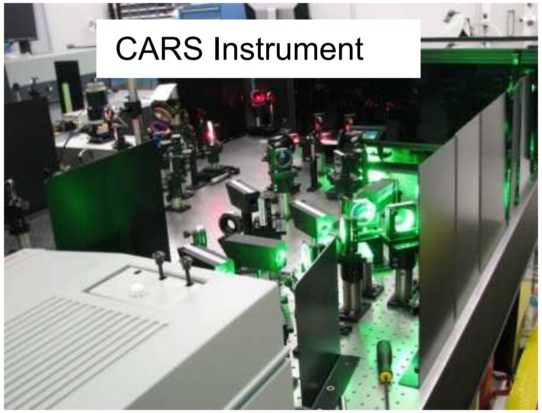
From Kearney et al. SAND2015 – 0343C

Gas-phase temperature and O2/N2 in Composite airframe material fires

- Coherent Anti-Stokes Raman Scattering.
- Composites here, C2H4 jet flame and ethanol-toluene pool fires also.

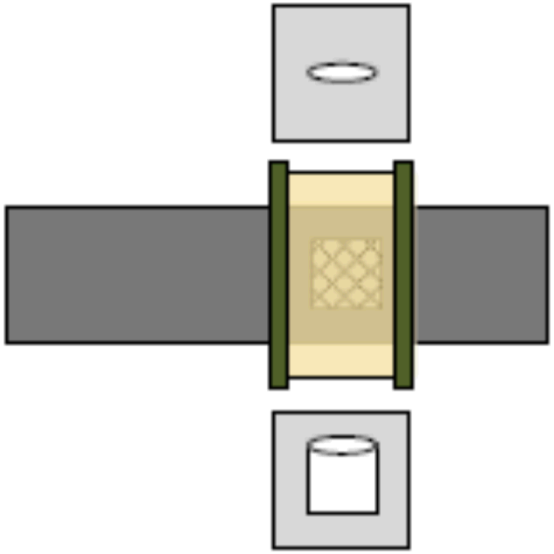




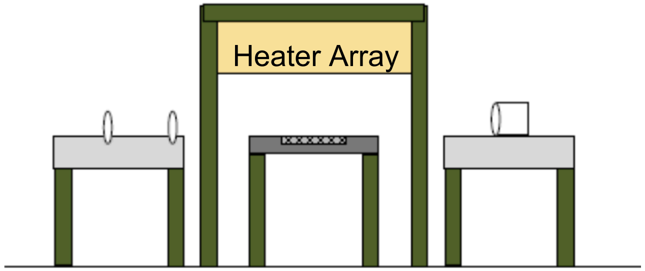


Solid Reacting Materials – Composites and more fundamental materials

- Large-scale Test Design
  - Wind-tunnel-like setup in XTF using long, flat plate to create boundary layer and radiant heating to ignite solid fuels
  - Measurements of mass loss rate, burning surface temperature, air temperature, radiative heat flux, and boundary layer velocity (if possible)



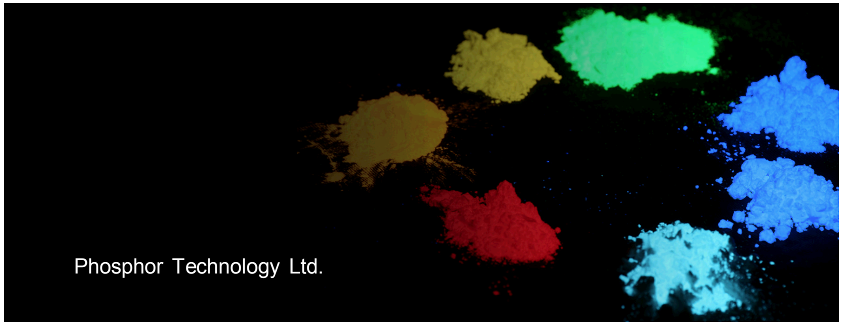
Proposed Setup within XTF

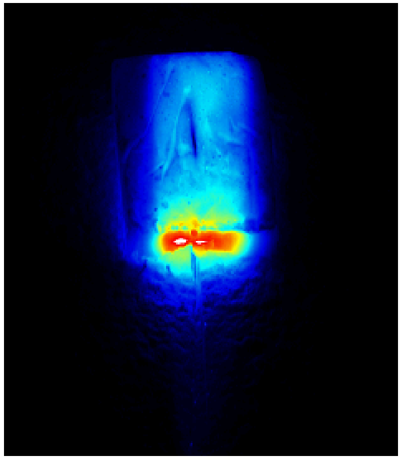


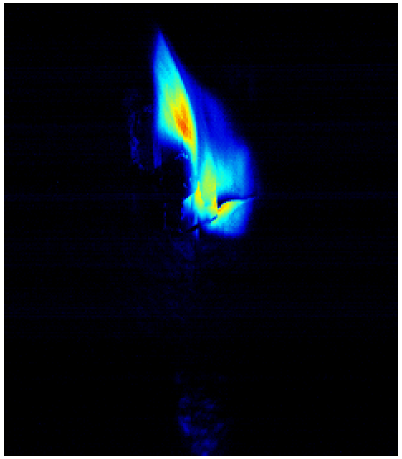
Embedding Thermographic Phosphors in Material

- Mixing phosphor into the reacting material to measure:
  - Surface temperature
  - Burning rates
  - Gas phase temperature/velocity above the surface

- Small-scale Test Results
  - TGA/DTA analysis demonstrating that phosphors do not change burning characteristics of surrogate solid fuels
  - Initial experimental results in surrogate solid fuels
  - Current: Processing initial data to determine feasibility of measuring ignition temperatures of solid fuels



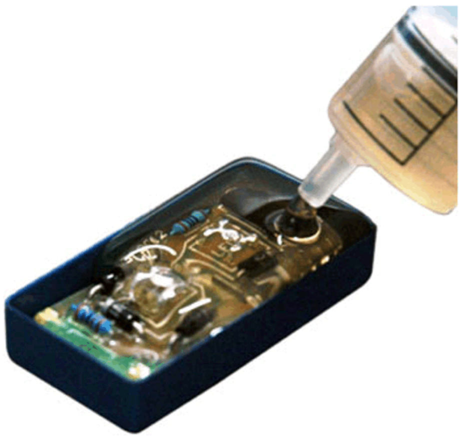




Sample Phosphor-doped Resin Raw Data Images:

Room Temperature (left) After Ignition (right)

Motivation for Studying Foams in Fires

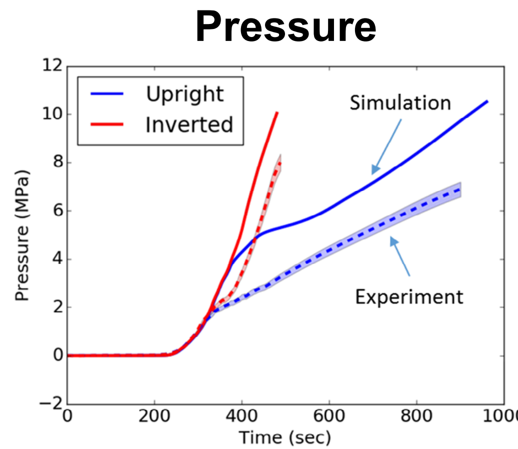


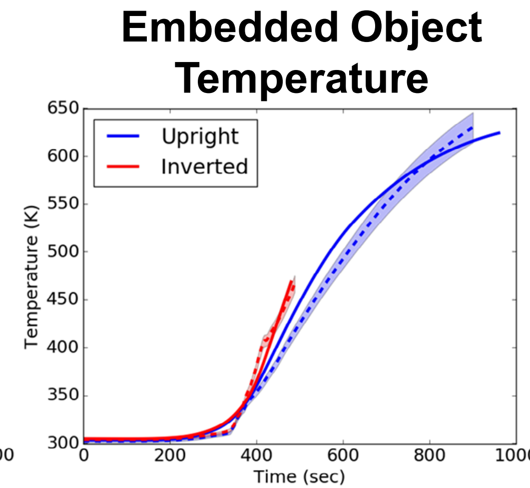
- Electronic devices need protection from mechanical and thermal shocks under normal operating conditions
  - Foams can be used for this purpose
- Foams pyrolyze at relatively low temperatures (250° C – 300° C)
  - In a fire environment and in sealed systems, the foam pyrolysis can cause pressurization

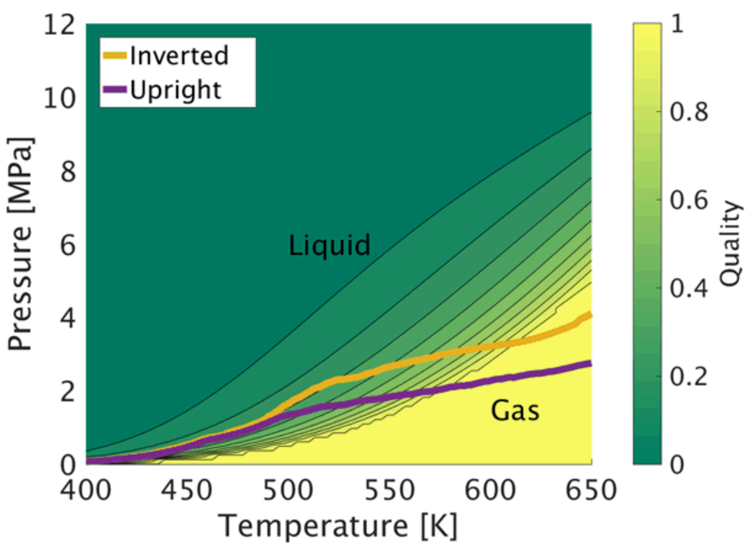
Want to be able to predict pressurization and temperature of an embedded object

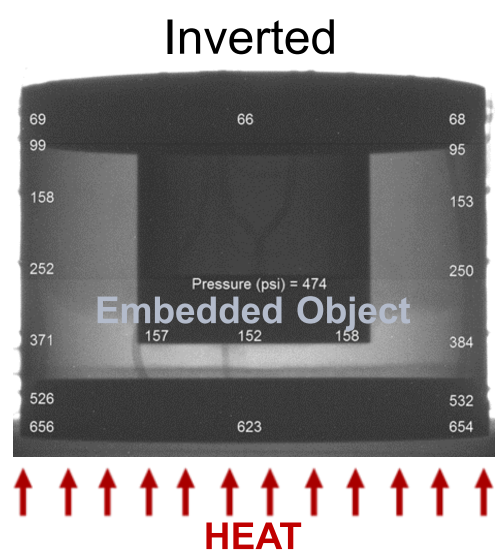
Foam Decomposition Models: Predictions and Measurements

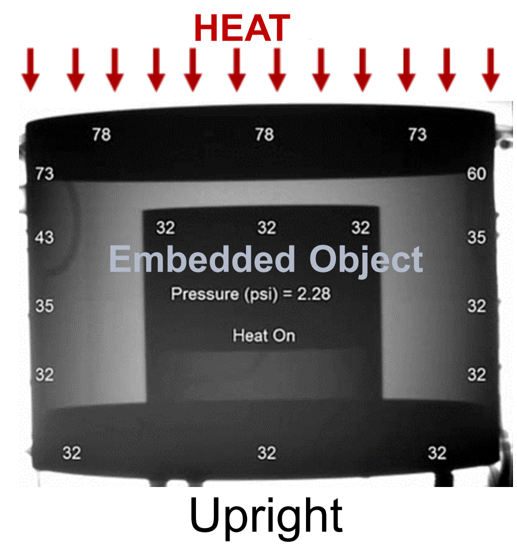
- Decomposition model uses three step reaction to break down foam
- Porous media flow model accounts gravity and generates orientation-dependent pressure response
- Vapor-liquid equilibrium model distinguishes between liquid and gas phases







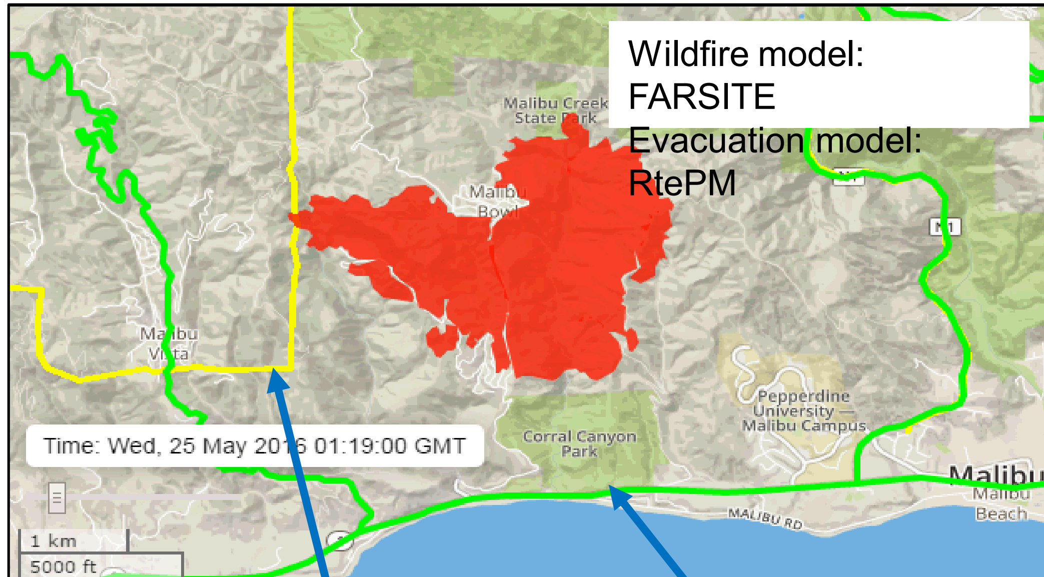




SUMMIT* is a software platform that integrates models and simulations to support emergency planning and exercise, including wildfire, population, critical infrastructure and evacuation models.

Sandia National Laboratories

- Deployed at the California Exercise and Simulation Center in Mather, CA
- Has supported several exercises at CESC
- Web-accessible with account registration



Fire reaches power transmission line at 0119

Fire reaches roadway at 1900

SUMMIT result shows:
- Spread of fire over time
- Population impacted over time
- Time that fire reaches critical assets
- Traffic flow on evacuation routes over time

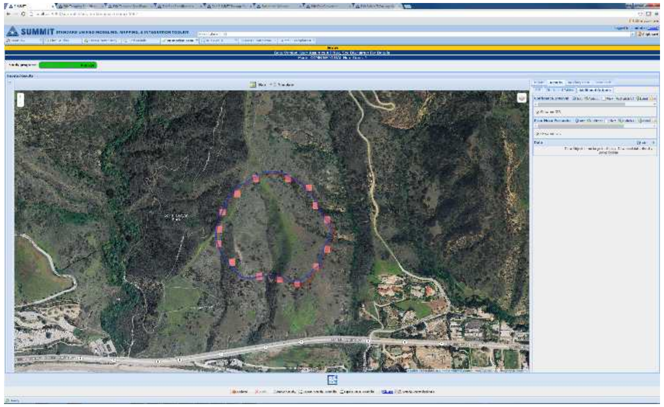
*Standard Unified Mapping and Modeling Integration Toolkit (SUMMIT) was sponsored by the Department of Homeland Security First Responders Group, and developed at

POC: Lynn Yang, liyang@sandia.gov

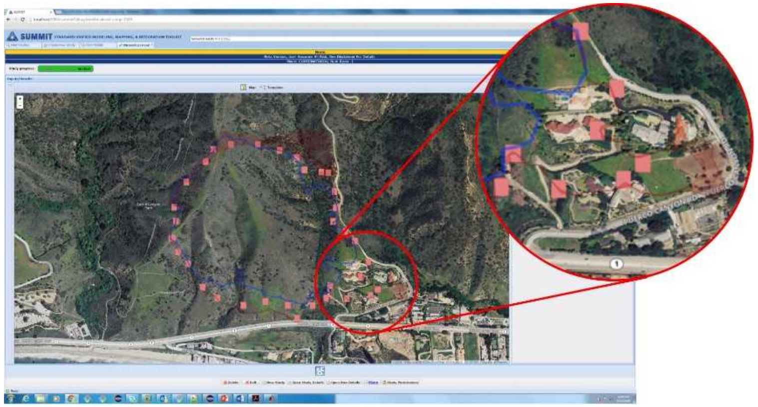
Data assimilation to enhance model accuracy

Sandia National Laboratories

- Objective: Incorporated data assimilation (DA) capabilities into SUMMIT simulation framework for wildfire modeling
- Motivation: Combine predictive models (FARSITE) with observational data to enhance predictive accuracy (similar approach to weather forecasting)
- DA Techniques: Ensemble Kalman filter (EnKF) and (more general) Particle filter
- Illustrative example: Forecast evolution of a *full* fire front + “uncertainty bars”
  - Available tools/data: Noisy/sparse observations of the front’s; uncertain forecast of wind speed and direction; FARSITE wildfire model; static database of vegetation type
  - Numerical specifics: EnKF with 20 ensemble members (FARSITE predictions)



Fire front evolution (3 hrs) , no DA
- Traditional forecast: Blue curve
- Confidence interval: Shaded region
- Noisy observations: square markers

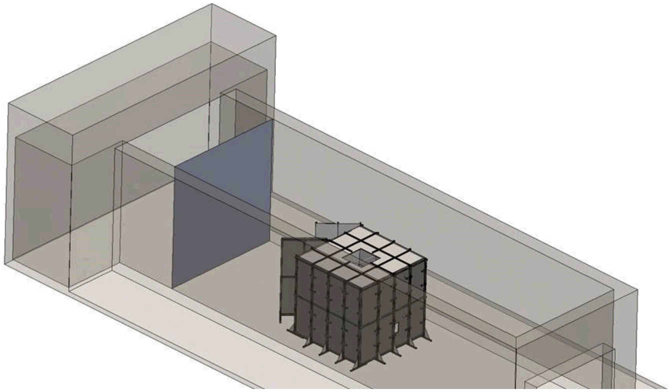


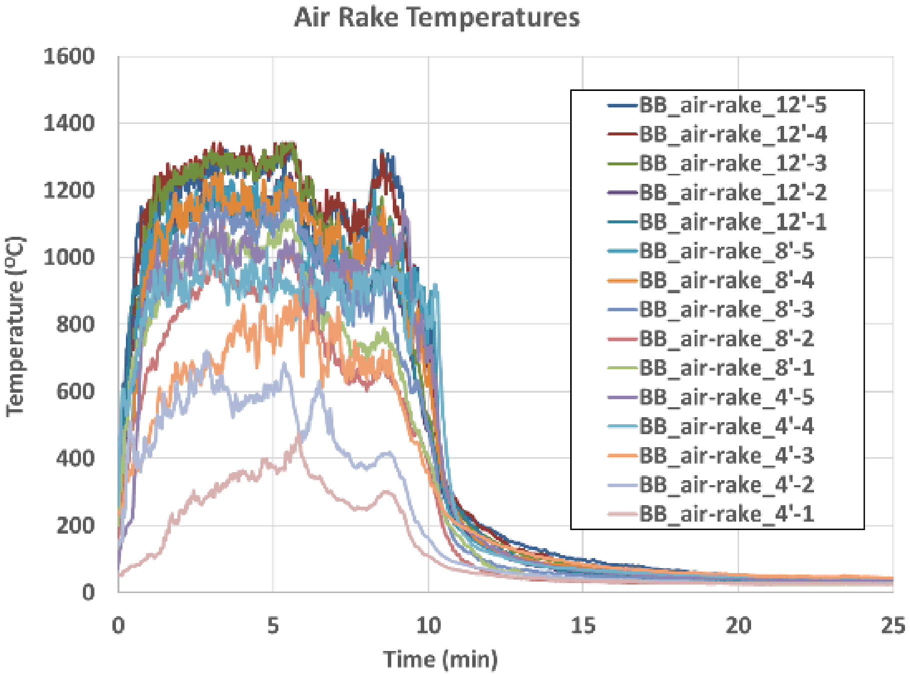
Fire front evolution (5 hrs), with DA
- Traditional forecast: Blue curve
- Confidence interval: Shaded region
- Noisy observations: square markers

POC: Moe Khalil, mkhalil@sandia.gov

Fire whirls in partial enclosures

- 3-m diameter equivalent square pan was placed in the center of the enclosure and doors parallel to 3.1 m/s wind.
- Fire whirl developed due to enclosure configuration

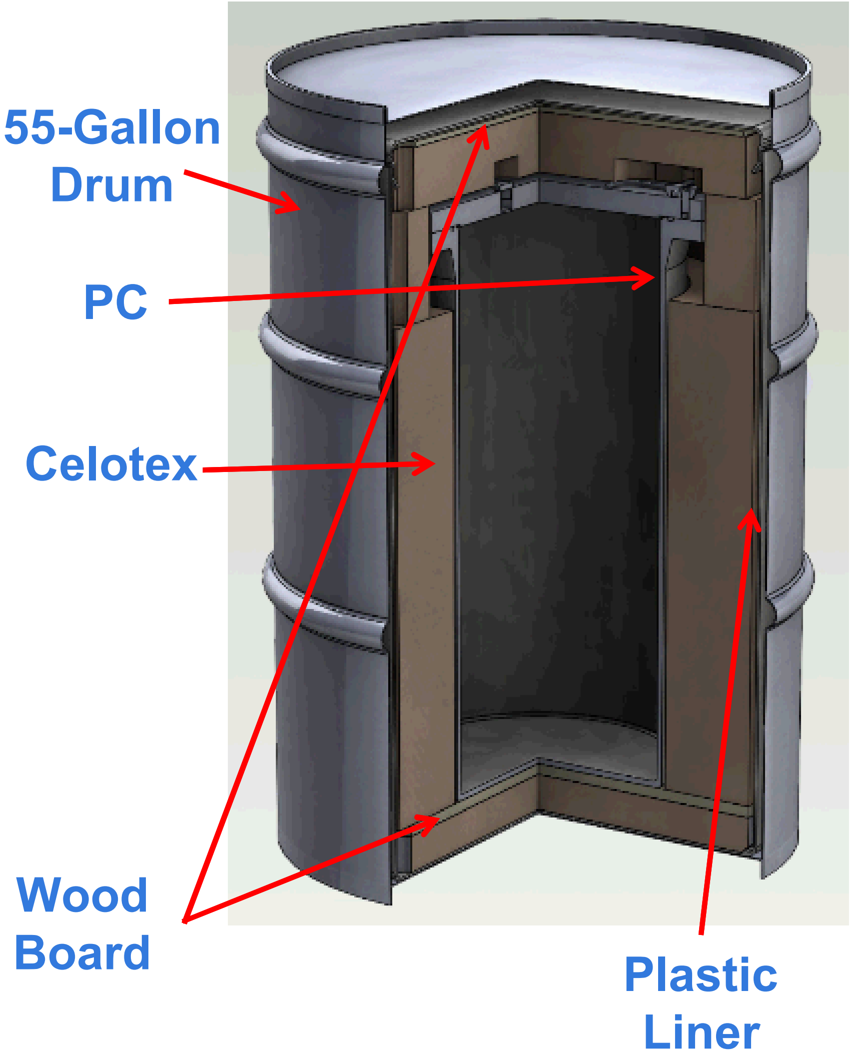




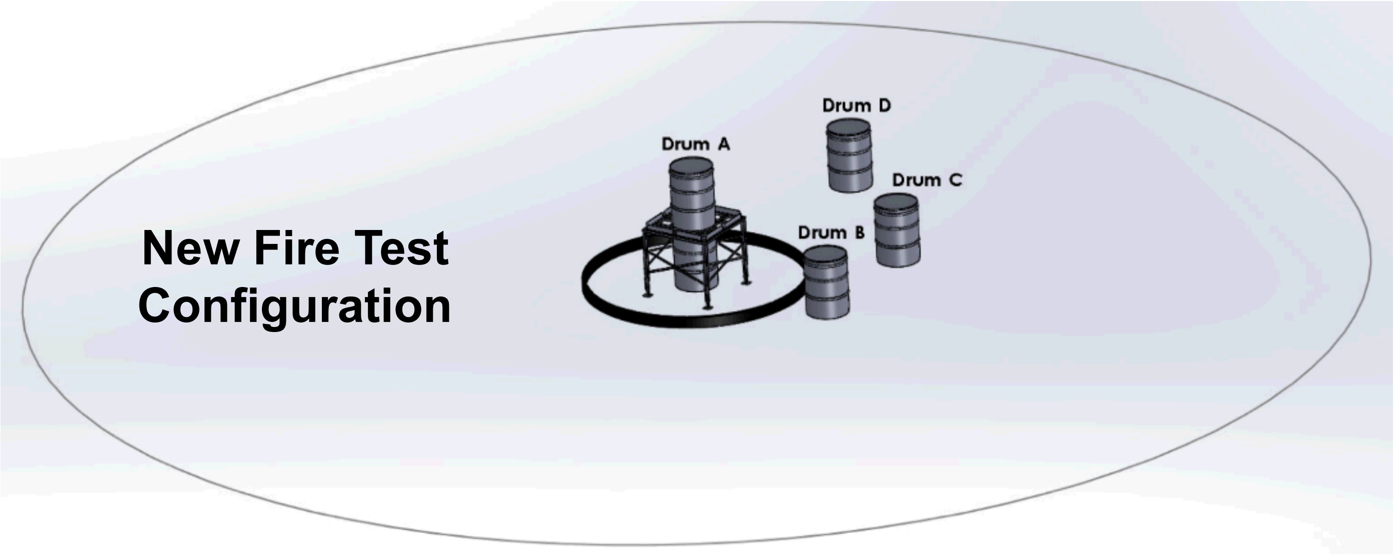
- Temperatures of almost 1400°C and heat flux levels of 400 kW/m^2 occurred within enclosure.

Pipe Overpack Container Fire Testing

- The Pipe Overpack Container (POC) was developed at Rocky Flats to transport nuclear waste residues (waste containing higher hazard levels than standard TRU waste) to WIPP for disposal.
- The pipe overpack container was designed to
  - maintain separation of fissile material
  - provide shielding from radiation



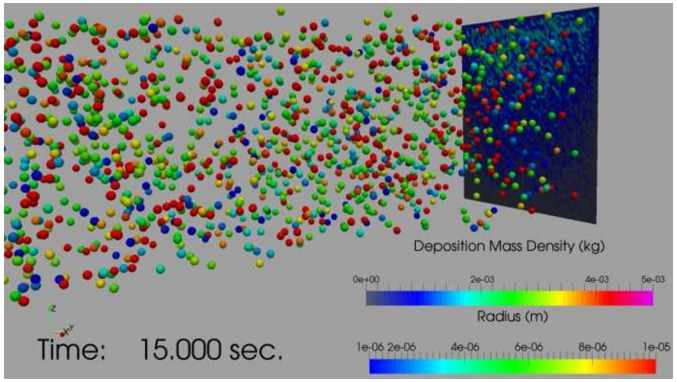
Setup for Indoor Fire Test – 1st Phase

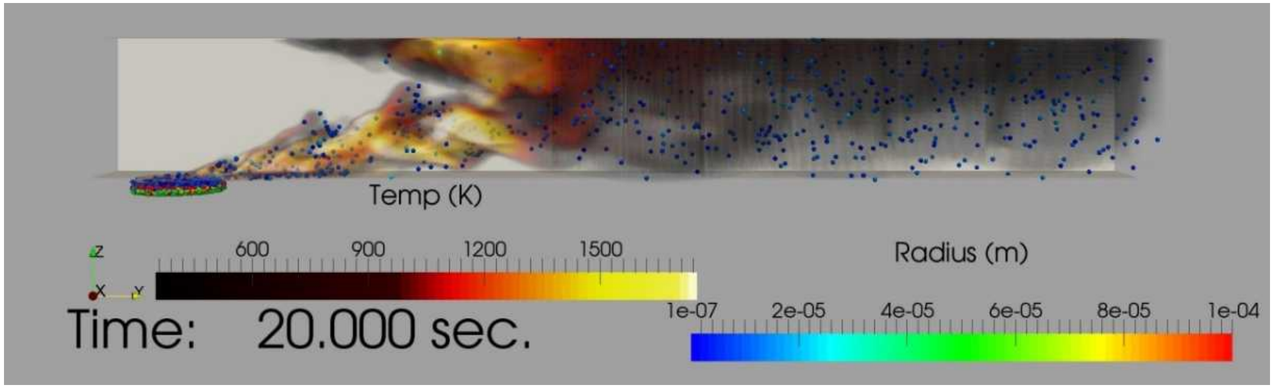


Typical Test Conditions in 1st Phase

Contaminants entrained in fires

- Modeling and measurement (over various projects) of contaminant released from fires
- Supporting the DOE-HDBK-3010, which gives guidelines for potential releases
- Demonstrated capability to model multi-component particle evolution.
- Parametric analysis revealed pool boiling duration to be the most sensitive parameter





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

THANK YOU

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