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Sandia National Laboratories Fire Science and Engineering

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Sandia National Laboratories

Livermore, CA

Sandia National Laboratories

Exceptional service in the national interest

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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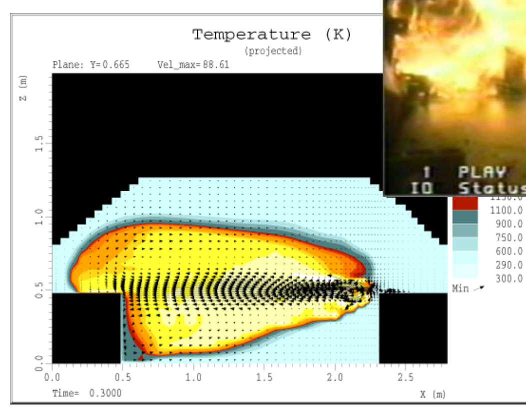
We Solve High Consequence Fire Problems

- 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

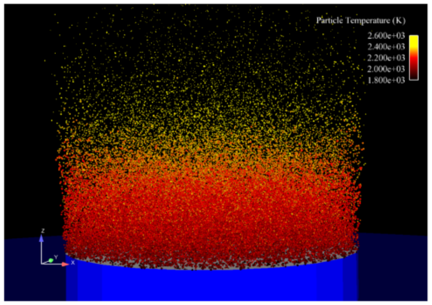


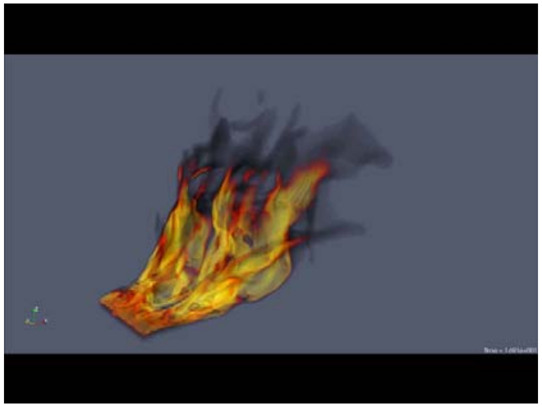
Competencies

- Fire modeling and CFD
  - Sierra/Fuego, Fluent, FDS
  - Pretest fire simulations and DoE
- Thermal and pyrolysis modeling
  - Sierra/Aria, Sierra/Fuego, GPYRO, FDS , Cantera, FlameMaster
- Large-scale fire and thermal environments design and testing
- Thermal test diagnostics and control systems
  - Temperature profiles
  - Heat Flux, Emissivity
  - Photometrics , X-ray
  - Integrated control (PECS)
  - Particle Image Velocimetry, Coherent Anti-stokes Raman Spectroscopy, IR spectroscopy, Laser-Induced Incandescence

Advanced Computing and General Fire/CFD Modeling

- Coupled thermal/electromechanical models for thermal batteries
- Impact/splash modeling (Presto and Fuego coupling)
  - Fuel spread in crash and burn scenario
- Foam decomposition model development
  - Decomposition, transport, pressurization
- Thermal/mechanical code verification
- Composite fire modeling
  - Combustion, heat flux, porous media
- Propellant fire modeling
  - Al particle behavior (transport , reaction, corrosion, melting)
- Hydrocarbon fire characterization
  - Fire whirl
  - Scenario investigation
  - Radiative transfer equation modeling for Fuego
- LNG fire simulations





High-Fidelity Modeling Provides Insight on Thermal Response of Components

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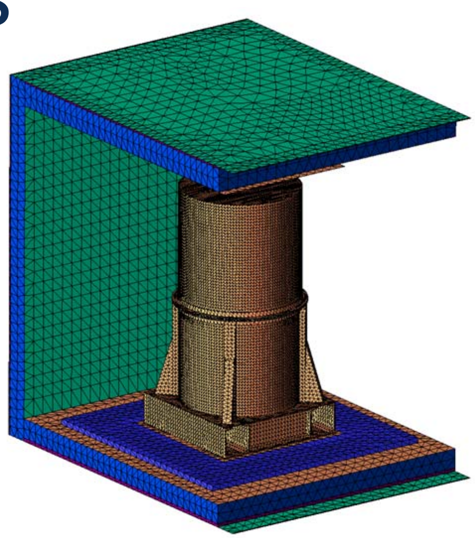
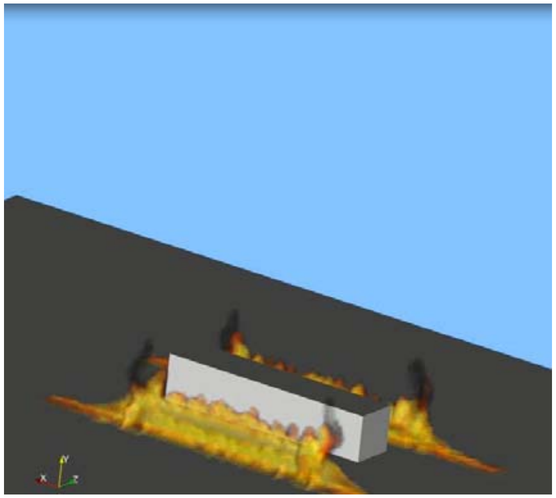
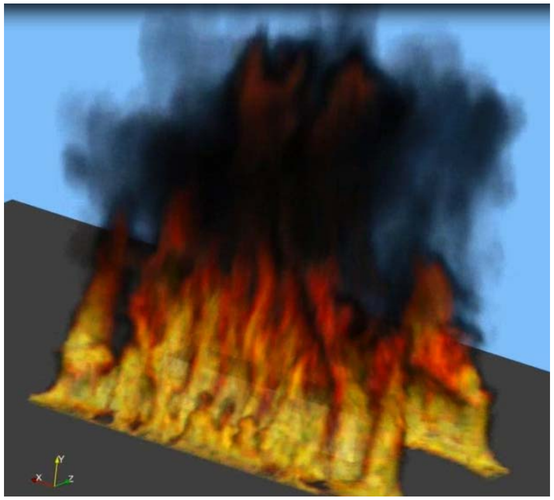
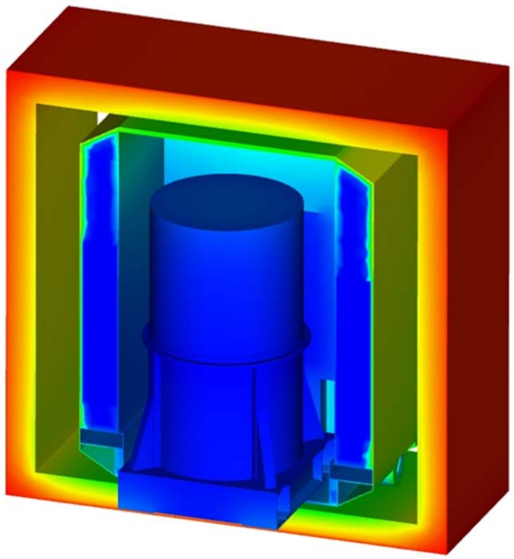


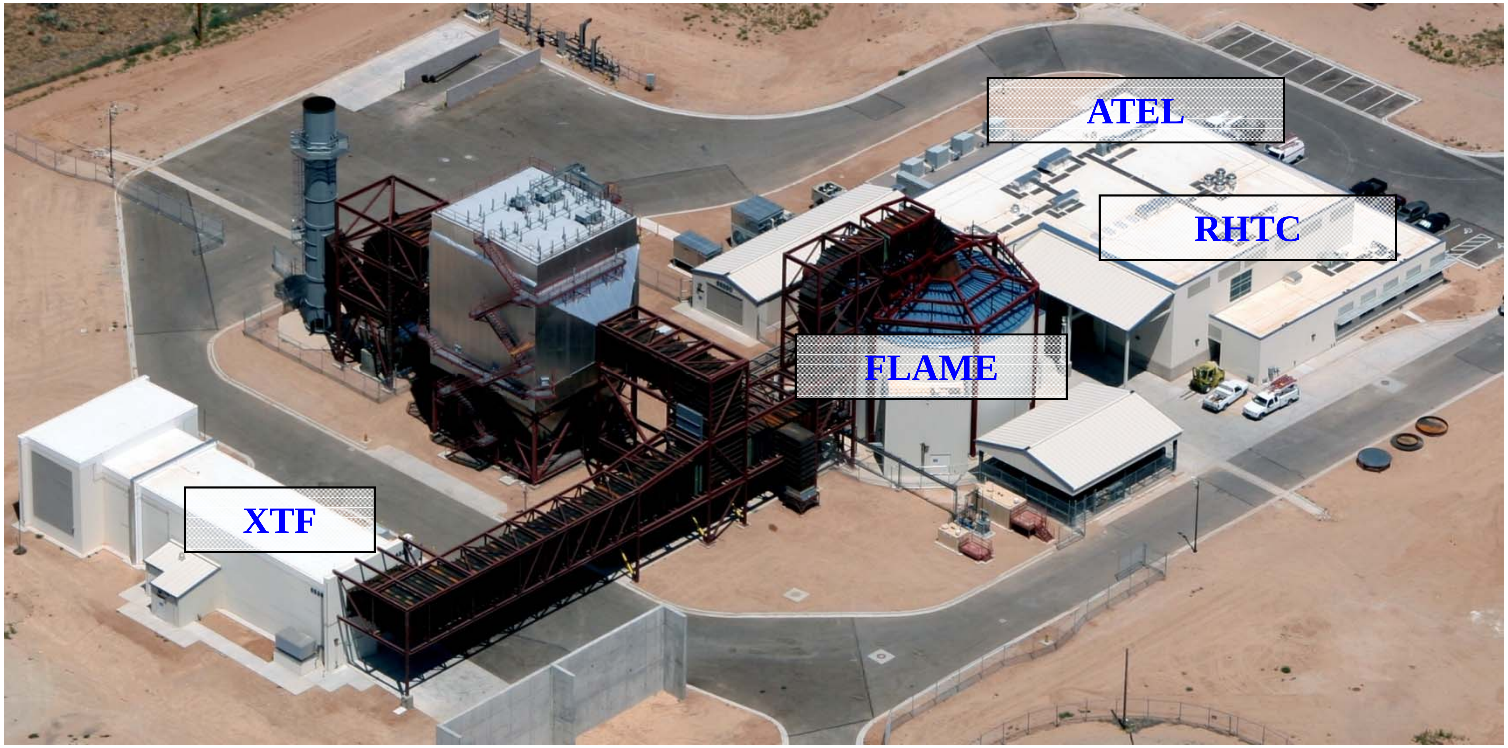
- Fire modeling provides boundary conditions (i.e., fire flux) for thermal response simulations
- Thermal model includes shipping container in various configurations
- Multiple accident scenarios explored computationally







Thermal Test Complex Experimental Capabilities



- XTF – Horizontal Wind Tunnel for Fires in Cross Wind
- FLAME – Controlled Environments Laboratory for Fires in Calm Conditions
- RHTC – Full-Scale Radiant Heat (Fire Loading Simulator) Lab
- ATEL – Abnormal Thermal Environment Lab, bench-scale testing
- Burnsite – Facility for outdoor, full-scale fires

Large-scale Fire and Thermal Environments

- Thermal/Mechanical Failure: Pressurization and breach
- Organic Material Decomposition: Foam decomposition and flow dynamics
- Composite Fires
- Rocket Propellant Fires (metal particle combustion dynamics)
- Fire Dynamics and Jet Flame turbulence/soot model development and validation (ISF workshop engagement)
- Fire Whirl
- Emissivity and Enclosure Radiation
- LNG dispersion and fire

FTIR Mid-IR IntegratIR Integrating Sphere
Spectral range – 2 - 20 μm

Propellant Fire

Intermediate Scale
Composite Fire Test

T/M failure of a unit at
Temp and Pressure

Advanced Diagnostics Development:

- Local Gas Temperature and species concentrations Measured with CARS (Coherent Anti-Stokes Raman Scattering)
- Soot Concentration Measured with Laser-Induced Incandescence (LII)

Outer wall of FLAME

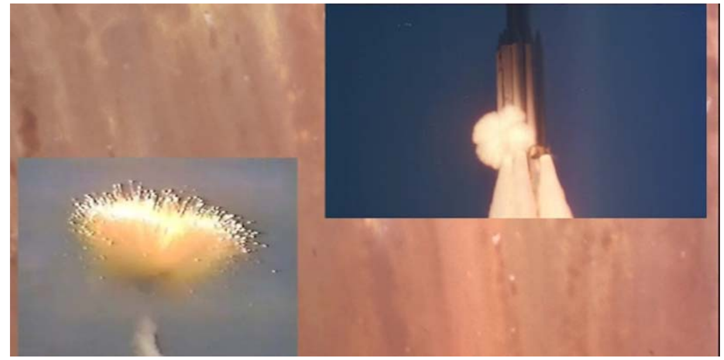
Optical access ports through the FLAME wall

CARS laser

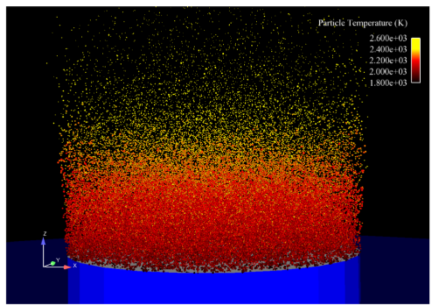
The gas temperature is determined from the spectral content of the CARS signal generated in an interrogation volume in which two frequency-tuned laser beams cross, exciting rotational-vibrational Raman transitions

Recent Research in Fire Science and Engineering

1. NASA/JPL-DOE Solid Propellant Fires and Launch Safety



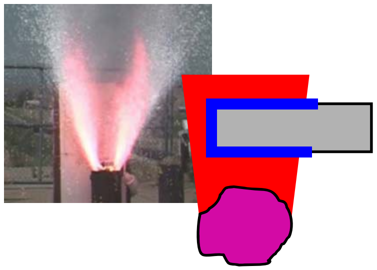
NASA space missions involving radiological power sources are subjected to a rigorous risk assessment performed by the DOE.



For the launch accident propellant fire environment, Sandia has been tasked in a 3 year program to:

- Define and test an interface between the SNL physics-based computational model of the fire environment and the DOE radiological response model.
- Improve and validate the physics representation in the propellant fire environment model.
- Develop experimental data to validate the physics-based model for NASA launch safety environments.

Our experimental and modeling capabilities cover the range of interest for rocket propellants



← Fire Simulator →

← Strand Burner → ← Flame Spray →

← Large Scale Integral Experiments →

	Propellant	Plume	Interface	System
Experimental Measurements	• Burn Rate • Aluminum Particle Size and Production	• Velocities • Temperature • Gas Species • Heat Flux • Rx Particle Morphology	• Deposition rates • Heat transfer	• Incident Heat Fluxes • Wall Temperatures
Diagnostics	• Spectrometry • Strand Burner • Image Analysis	• Particle Sampling • Calorimetry • Spectrometry • Image Analysis	• Interrupted Exposure	• Calorimetry
Modeling	• Energetic Materials Models	• Particle Transport Models • Combustion • Radiation	• Particle Deposition w/ Phase Change	• *SIERRA/ARIA* • Phase Change

II. Aluminum Melt/Reactivity Research supports Design-of-Experiments for Weapon Qualification

	Environment	Response
Expt'l Application	-Al droplet size distribution - Strand burner - Flame sprays - Heat flux, temperatures	Full scale Aero-shells Weapon Case Bench scale Properties
Model	Al spray combustion	Oxide skin formation Metal Dissolution rates
Code	FUEGO	ARIA
UQ/ V&V	Start FY15	UQ in parameter estimates

2500C

Aluminum burning

Molten Metal Reactions with Other Metals

1000 C

Molten Metal Flow in Alumina Shell

635 C

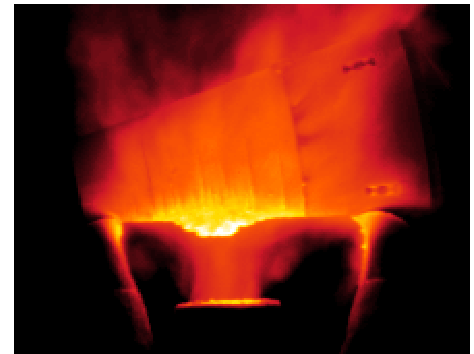
Mushy Metal

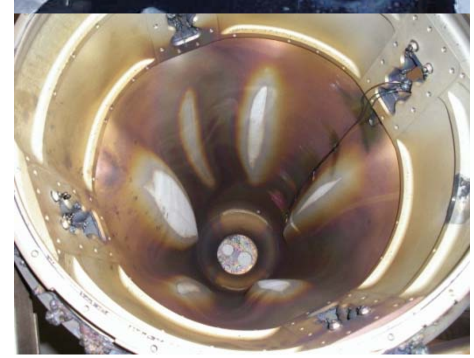
477 C

Plastic Flow

High Thermal Expansion

20 C

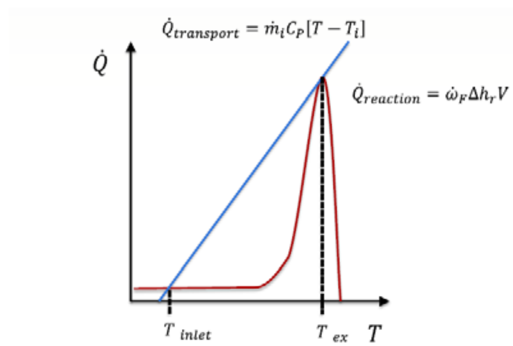


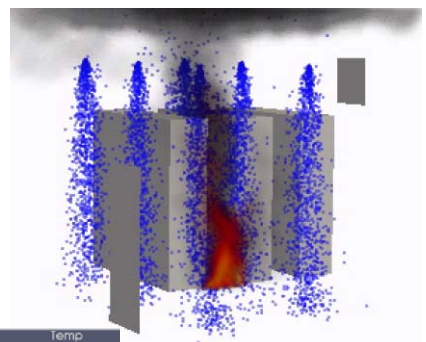


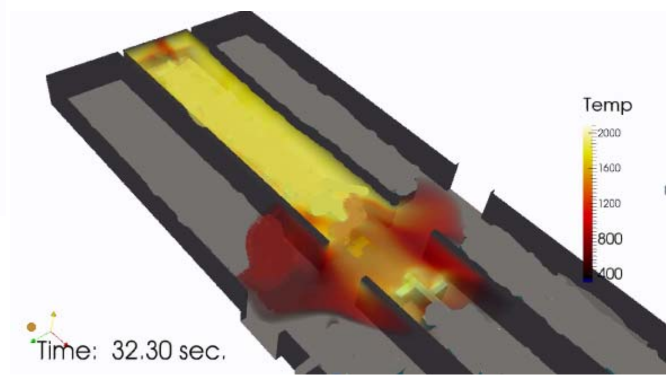
Future focus on experiments and models for V&V

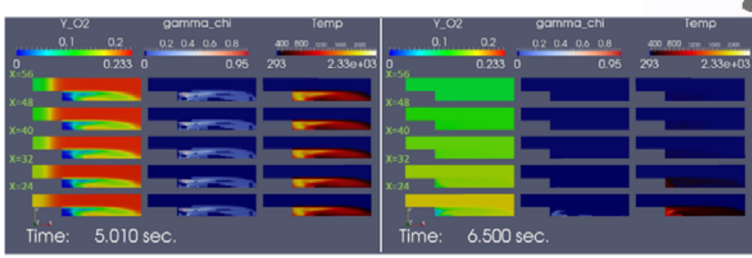
Fire Hazard Assessment

- Assessment of fires in storage scenarios with coupled heat transfer to geometrically detailed systems
- Included:
  - Suppression with an EDC reaction model based on a Perfectly Stirred Reactor model
  - Multiple materials contributing to fire loading
    - Wood, hydraulic oil, polyurethane foam, chairs,
    - curtains, polystyrene foam
    - >500lbs material





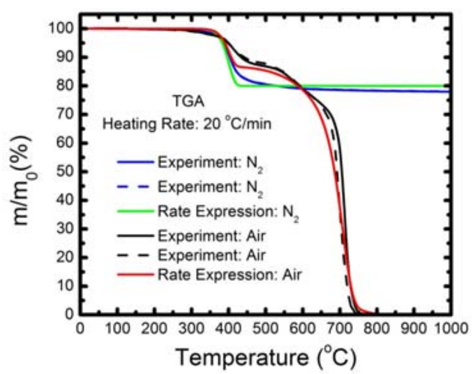


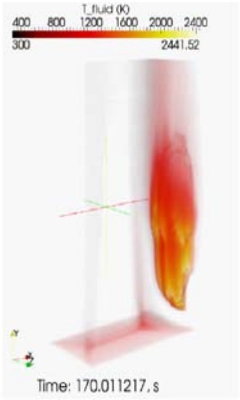


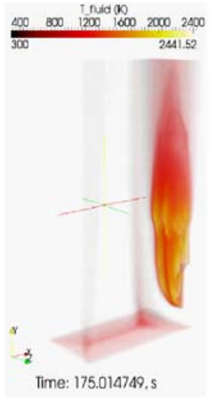
**S. Zhang, M.C. Soteriou, "An analytical model for the determination of the cup-burner minimum extinguishing concentration of inert fire suppression agents," Proc. Combust. Inst., 33, 2505-2513, 2011.

IV. Composite Material Behavior in Fires

- Increased numbers of aircraft with composite materials
- Composite materials behave differently from conventional fuel sources and have the potential to smolder and burn for extended time periods
- Modeling and experimental efforts to examine decomposition behavior, influence on fire, heat transfer through
  - Range of scales of experimental efforts:
    - TGA, DSC, FTIR
    - Cone calorimeter
    - Medium scale (3 test series) to provide validation and behavior assessment
    - Large scale system level
  - Modeling
    - Decomposition and material model development
    - Fire modeling with varying levels of fidelity

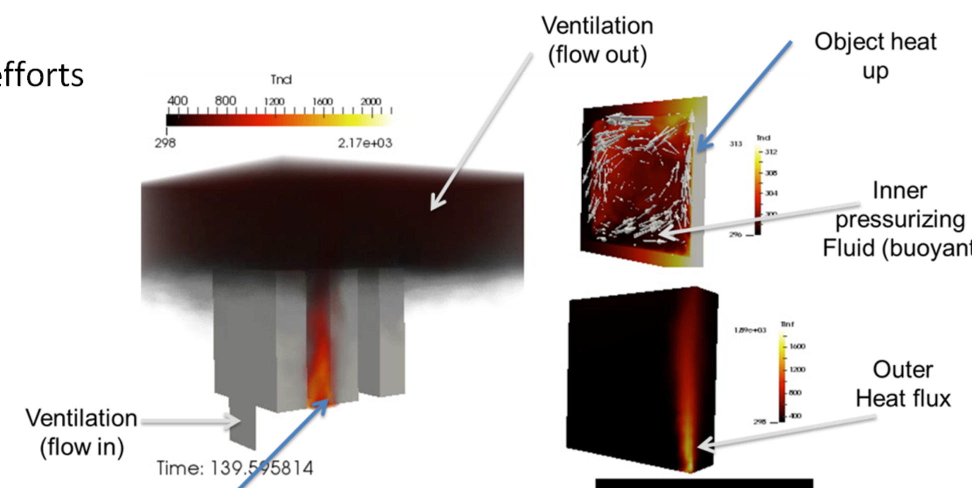






V. Battery Fire Experiments and Modeling

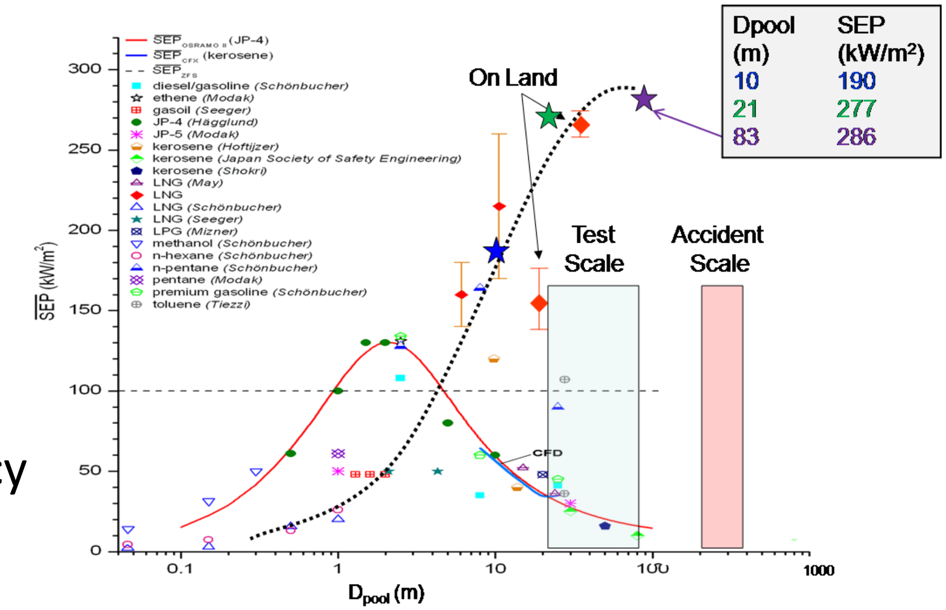
- Experimental
  - NHTSA Rechargeable Energy Storage Safety (RESS) Research Program to understand thermal response of electric vehicle batteries to mechanical insult
  - Test series include 2 battery types subject to sequential levels of crush, each in 3 different orientation, plus repeats (12 total)
- Modeling
  - Use Case: Hawaii Lead Acid Batter System on Fire
    - Racks of lead acid batteries and power conditioning system inside the building
    - No emergency response (Hawaii is a closed water system)
  - Sierra/Fuego modeling
  - Integrate battery response into future efforts



Fire modeled as a combustible hydrocarbon

VI. LNG Safety Research – DOE

- Modeling effort (2004) examining hazard distances based on available data
- Sandia performed the tests under the direction of DOE's Office of Fossil Energy to provide additional evidence
  - 10, 21, and 83m pool diameter
- Requested Data:
  - Surface Emissive Power (SEP)
  - Flame height/width (Viewfactor) for a given spill rate
- Regulatory agencies (USCG, FERC, & PHMSA) have set hazard distance policy based on the data.



Effect of Water Addition on LNG Pool Fires on Water

- SNL LNG pool fire test on water produced less smoke than smaller land based LNG fires, contrary to anticipated trend.
- To investigate possible explanation of trend, simulations were performed to determine the effect of water entrainment on soot formation using ANSYS/Fluent.
- Results indicate that water addition has the potential to reduce soot volume fraction by an order of magnitude for lab scale methane fires.
- For larger fires, results for the limited number of cases performed indicate a 35% reduction in soot volume fraction levels.
- These results provide a plausible explanation for the lack of smoke shielding of LNG pool fires on water.

35 m diameter LNG pool fire on land (Montoir Tests)

83 m diameter LNG pool fire on water (SNL)

- LNG 35 m fire on land produced more smoke than the 83 m fire on water.
- Not anticipated trend.

Summary of Sandia Fire Science Thrusts and Applications

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Technical Thrusts

- Material Decomposition
- Fluid Dynamics
- Gas Phase Combustion
- Soot Formation/Properties
- Particulate Combustion
- Heat Transfer
- Suppression

Apps

- Weapon Safety
- Homeland Security
- Transport Industrial Safety
- Military Systems

Tools

Computational Models - Analysis and Exp. Design
Diagnostics/Facilities - Discovery/Validation/Qualification