SAND2015-8834C

Exceptional service in the national interest

Sandia National Laboratories

Fire Science & Technology

ARL/TARDEC Fire Protection Information Exchange Meeting

October 14-15, 2015, ARL Conference Center 4503, Aberdeen, MD, USA

Overview of Sandia Fuel Fire Capabilities

Alexander L. Brown; albrown@sandia.gov; (505)844-1008

John C. Hewson; jchewso@sandia.gov; (505)284-9210

Fire Science and Technology Department

SAND2015-???? C

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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.

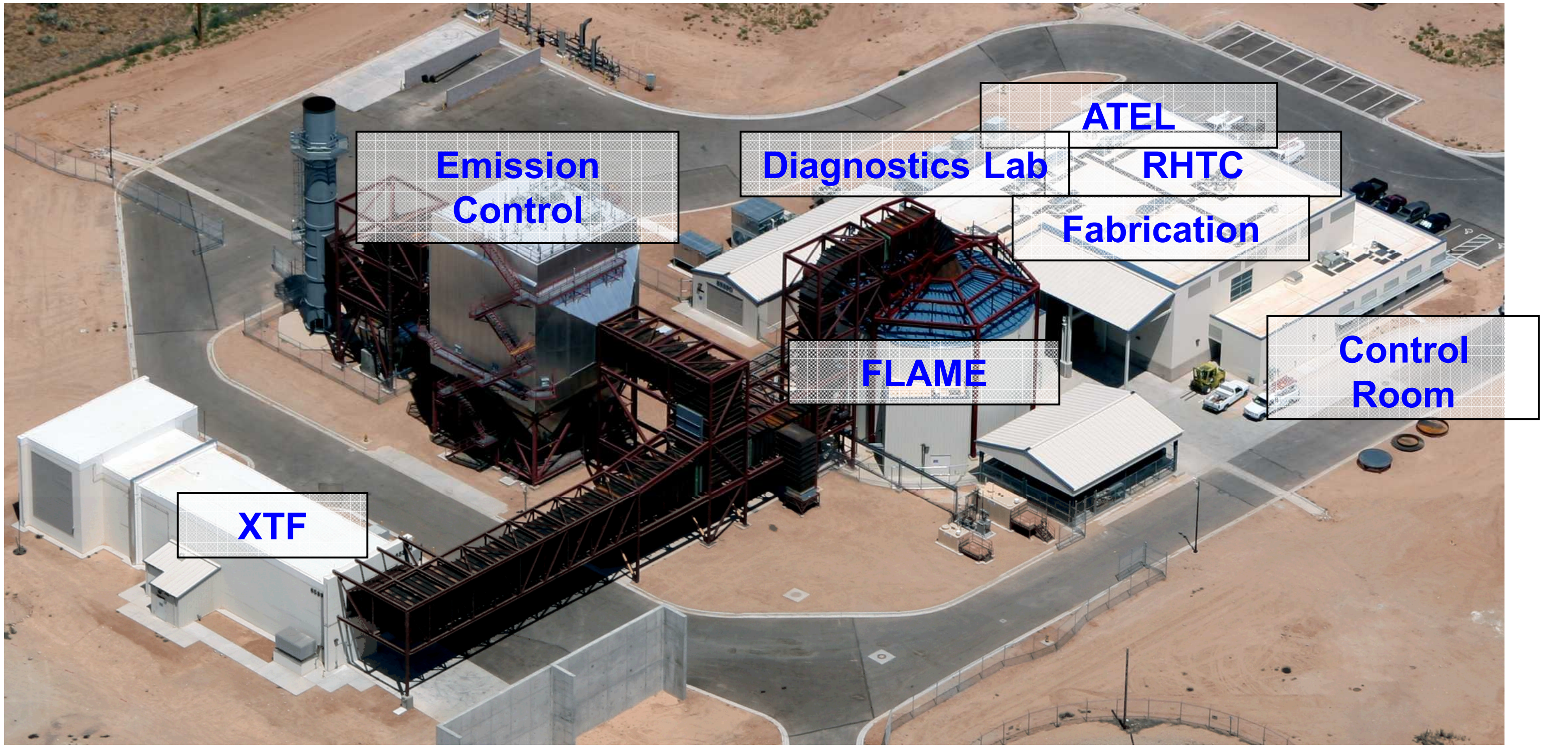
Outline

- Introduce Sandia National Labs Fire Programs (3 min)
  - Programmatic Focus
  - Thermal Test Complex (TTC)
  - Burnsite
- Experimental Work (8 min)
  - Diagnostics
  - V&V Role
  - Some specific project results
- Modeling Efforts (8 min)
  - Unique modeling tools
  - Suppression, solid materials in fires,

Sandia Fire Science Department

- Sandia is a FFRDC laboratory managed by LMC for the US DOE
  - Around 10,000 employees, a wide range of program areas
  - Major locations in Albuquerque, NM and Livermore, CA
- The NM Fire Science and Technology Department is in the Engineering Sciences Center, and supports a range of missions with cutting-edge technologies and capabilities
  - Located on Kirtland AFB
  - Around 30 full-time employees varying from research staff to technologists
  - Fire research includes staff in other complimentary departments at Sandia, mostly in part-time roles
- Primary role is in support of the US weapon stockpile
  - Nuclear weapon components safety, normal and abnormal thermal environments
  - Sandia has large energy programs, also leading to significant project work
  - We support DOD and other government agencies, some commercial work
- We normally do work that can't be done elsewhere

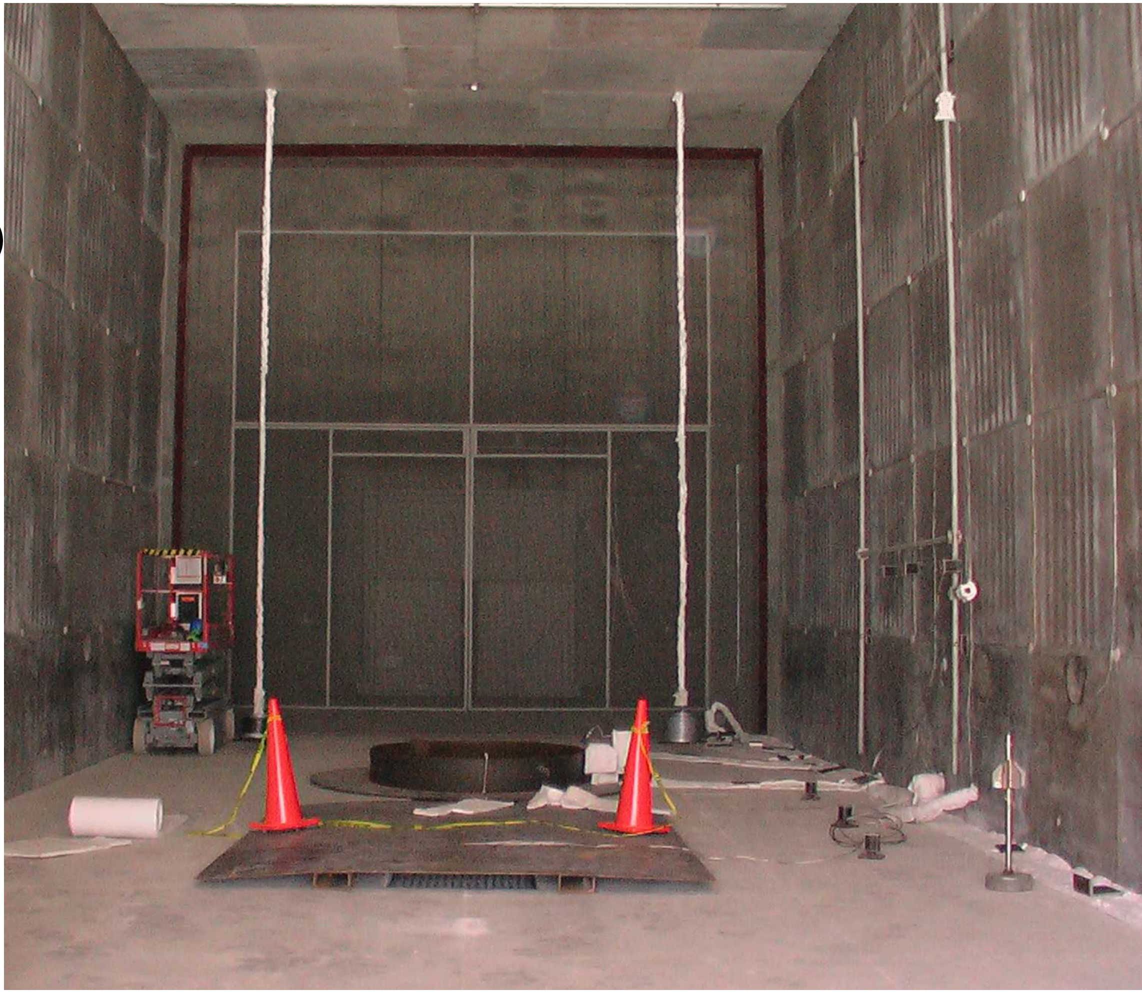
Thermal Test Complex



- XTF – Horizontal Wind Tunnel for Fires in Cross Wind
- FLAME – Vertical Wind Tunnel for Fires in Calm Conditions
- RHTC – Full Scale Radiant Heat (Fire Loading Simulator) Lab
- ATEL – Abnormal Thermal Environment Lab
- Supporting infrastructure
  - Diagnostics development and instrumentation labs
  - Control room
  - Fabrication areas
  - Emission Control

XTF Capabilities

- **Test Cell Dimensions**
  - 25 ft x 25 ft by 83 ft long
  - (7.6 m x 7.6 m by 25 m long)
- **Fuel Sources**
  - Liquid
    - JP-8 – 10 ft dia. (20 MW)
  - Gas source easily added
- **Heat Sources**
  - Radiant Heat Panels
    - 2.88 MW
- **Air Sources**
  - Full Cross Section
    - 8 ft/sec (2.4 m/s)
  - Limited Cross Section (~1/4)
    - 34 ft/sec (10 m/s)
- **Explosives**
  - <106 lbs (damage/no-injury)



New FLAME Facility

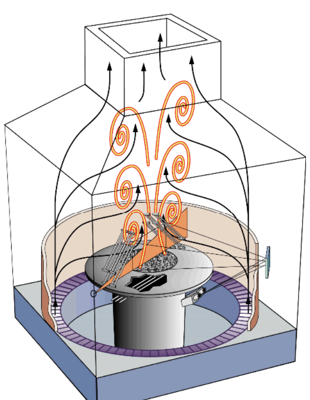
- **Test Cell Dimensions**
  - 60 ft dia. x 40 ft high
  - (18.3 m dia. x 12.2 m high)
- **Fuel Sources**
  - Liquid
    - JP-8/Ethanol
    - 10 ft (3.05 m) dia. (20 MW)
  - Gas
    - $CH_4/H_2/N_2$
    - 10 ft (3.05 m) dia. (20 MW)
- **Heat Sources**
  - Radiant Heat Panels
    - 5.2 MW
- **Air Sources**
  - Push/Pull Fan Arrangement
    - 150,000 cfm
    - Annular/Central flow
- **Walls**
  - Water Cooled

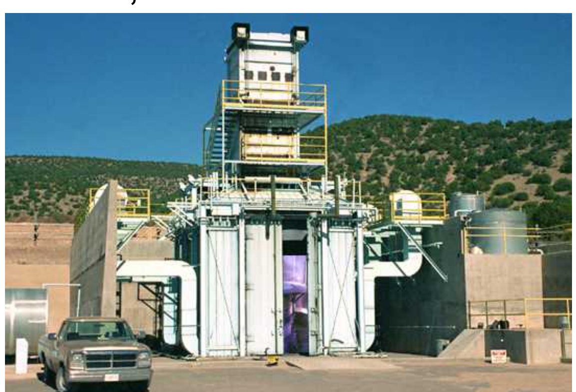
Burnsite and Other Areas

- **Burnsite: Open Pool**
  - 10 meter diameter fires
  - Large jet fuel reservoir

- **Burnsite: Igloo**
  - 54’ x 26’ x 14’ bunker for fire testing
  - Ceiling vents and one sided entry

- **Burnsite: Old FLAME facility**
  - 6 m internal square test section
  - Water cooled walls, remote site



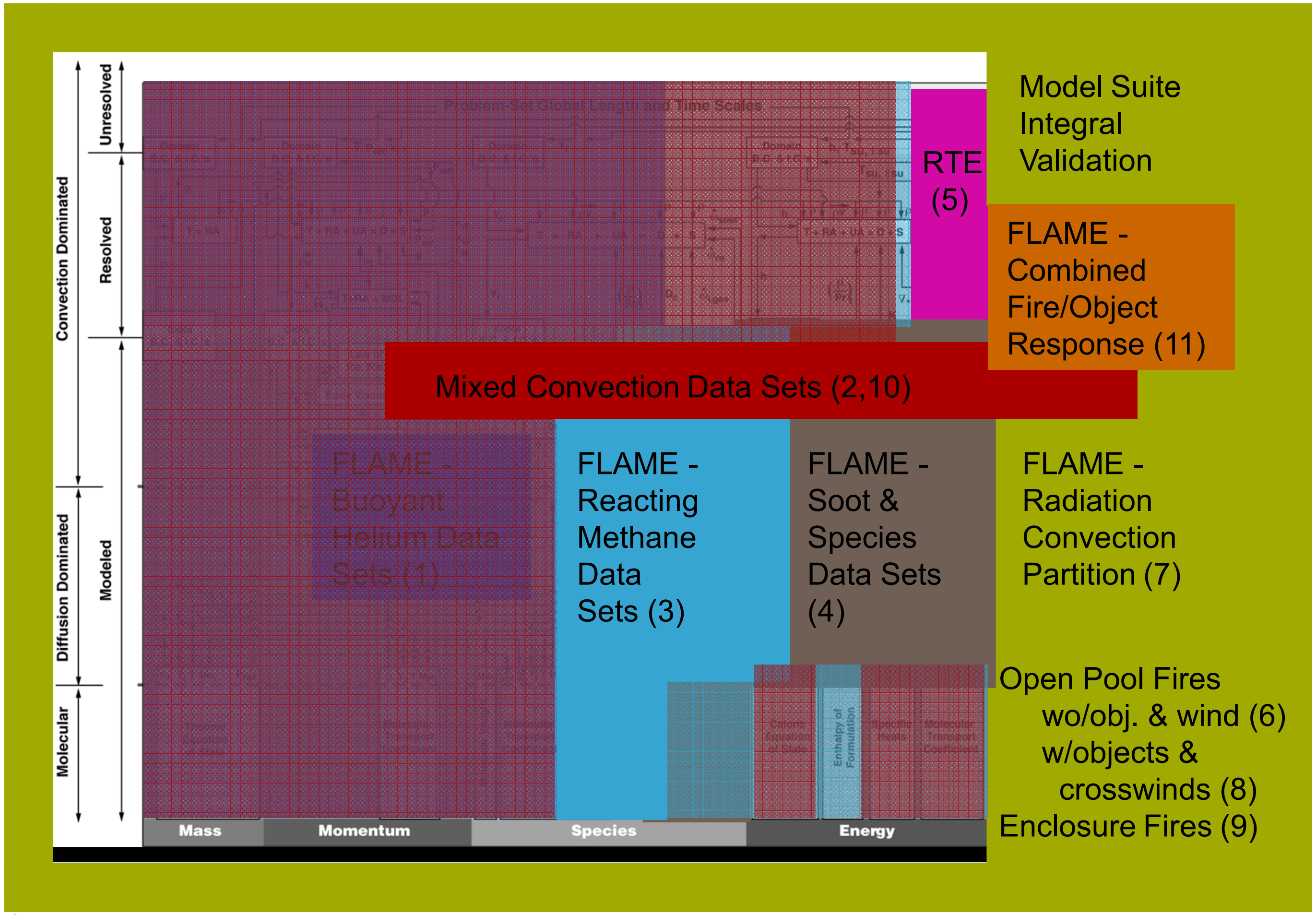


- **South End of Sled Track**
  - Open space for a variety of burn conditions
  - Detonation and large pool environments

Historical Experimental Work

- V&V programmatic driver
- Laser diagnostics applied to fire tests
- Battery Fires (in John Hewson's presentation)
- Propellants
- Composite Materials
- Particle transport (in Dan Guildenbecher's presentation)

Fuego Validation Test Plan



Validation plan

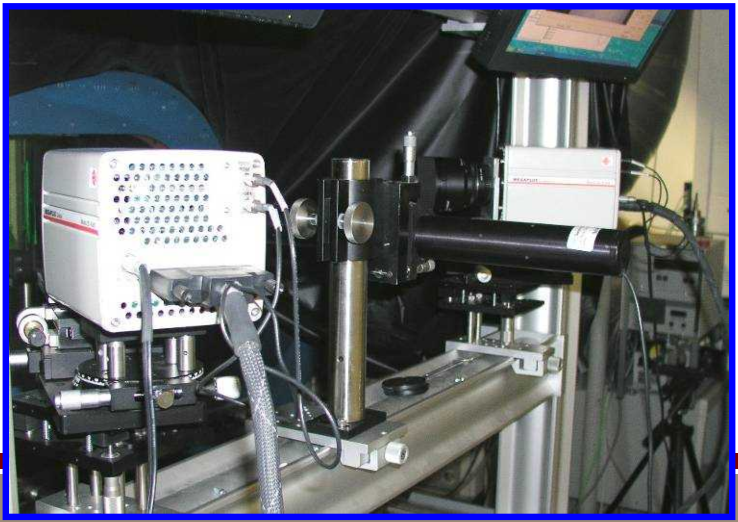
- Verification completed before validation
- Builds from simple to full physics coupling
- Tailored to application space

Some Fundamental Validation Data

- Helium Plume –
  - O'Hern, T. J., Weckman, E. J., Gerhart, A. L., Tieszen, S. R., Schefer, R. W., 2005, "Experimental Study of a Turbulent Buoyant Helium Plume," Journal of Fluid Mechanics, 544:143-171.
- Hydrogen and Methane Fires –
  - Tieszen, S. R., O'Hern, T. J., Weckman, E. J, and Schefer, R. W., 2004, "Experimental Study of the Effect of Fuel Mass Flux on a One Meter Diameter Methane Fire and Comparison with a Hydrogen Fire," *Combustion and Flame* 139:126-141
  - Tieszen, S. R., O'Hern, T. J., Schefer, R. O., Weckman, E. J., and Blanchat, T. K., 2002, "Experimental Study of the Flow Field In and Around A One Meter Diameter Methane Fire," *Combustion and Flame*, 129:378-391
- Soot –
  - Murphy, J.J., and Shaddix, C.R., 2006, "Soot Property Measurements in a Two-Meter Diameter JP-8 Pool Fire," *Combustion Science and Technology* 178:865-894.
  - Murphy, J. J. and Shaddix, C. R., 2004, "Soot Properties and Species Measurements in a Two-Meter Diameter JP-8 Pool Fire: 2003 Test Series," Sandia National Laboratories, Albuquerque, NM, SAND2004-8085
  - Murphy, J.J., and Shaddix, C.R., "Soot Property Measurements in a Two-Meter Diameter JP-8 Pool Fire," in press, Combustion Science and Technology.
- Mixed Convection –
  - Siebers, D. L., Schwind, R. G. and Moffat, R. F. 1982. Experimental Mixed Convection From a Large, Vertical Plate in a Horizontal Flow. paper MC13, 3, Proc. 7th Int. Heat Transfer Conf., Munich, 1982
  - Siebers, D. L. 1983, Experimental Mixed Convection Heat Transfer From a Large, Vertical Surface in a Horizontal Flow. PhD thesis, Stanford University
  - Siebers, D. L., Moffat, R. F. and Schwind, R. G. 1985. Experimental, Variable Properties Natural Convection From a Large, Vertical, Flat Surface. *J. Heat Transfer*, 107, February, 124-132
- Turbulent Mixed Convection –
  - Kearney, S. P., Grasser, T. W., Liter, S. G., Evans, G. H., Greif, R., "Experimental Investigation of a Cylinder in Turbulent Thermal Convection with an Imposed Shear Flow, AIAA-2005-1124, 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, 10-13 Jan., 2005.

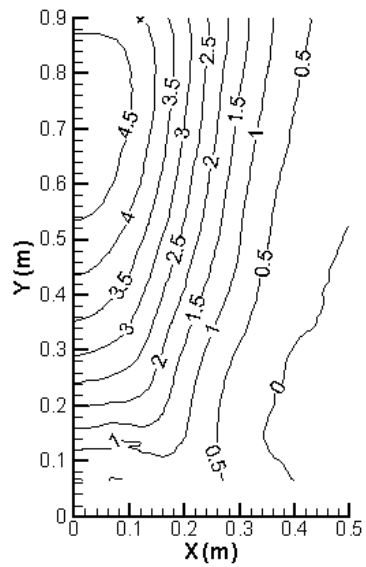
PIV Diagnostics in FLAME

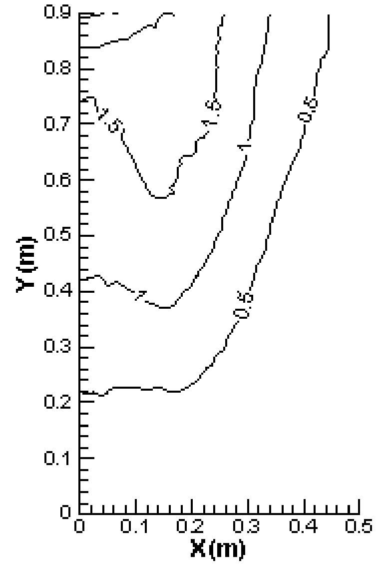
- Illumination sources
  - Two Nd:YAG lasers
    - 300 mJ per sheet at 532 nm
    - Variable laser pulse separation 1 µs to > 1ms
  - Two UV excimer lasers
    - 200 mJ per pulse at 308, 240 nm
    - Laser pulse repetition rate 200 Hz
- Use frame-straddling CCD cameras
  - Photometrics CoolSnap Diff HQ:
    - 1024 × 1024 pixels, 8 bit
  - Redlake Megaplus 4.0/E: 2048 × 2048 pixels, 8 bit
  - Extensive analog film cameras
- Data processing
  - IDT ProVision 2.02
  - ImagePro
  - PIV Sleuth (UIUC)
- Particle seeding
  - Plume/fire particles 4-60 µm diameter
  - Wind tunnel/jet particles 0.2-0.3 µm diameter



1 meter CH_4 Fire at 0.040 kg/m^2s

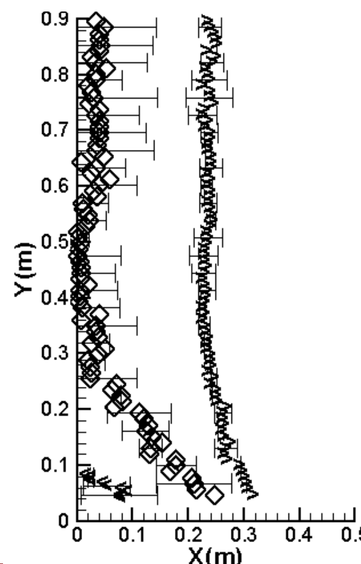
Vertical Velocity (m/s)

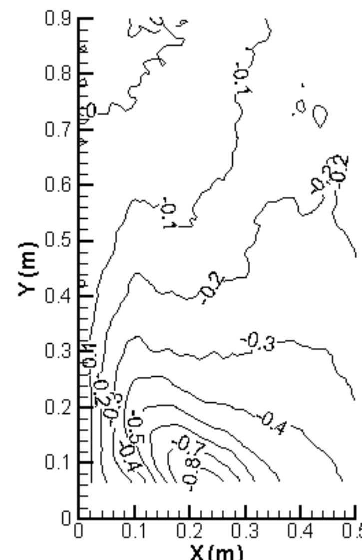




Turbulent Kinetic Energy (m^2/s^2)

Radial Position of Maximum Reaction Rate (m)

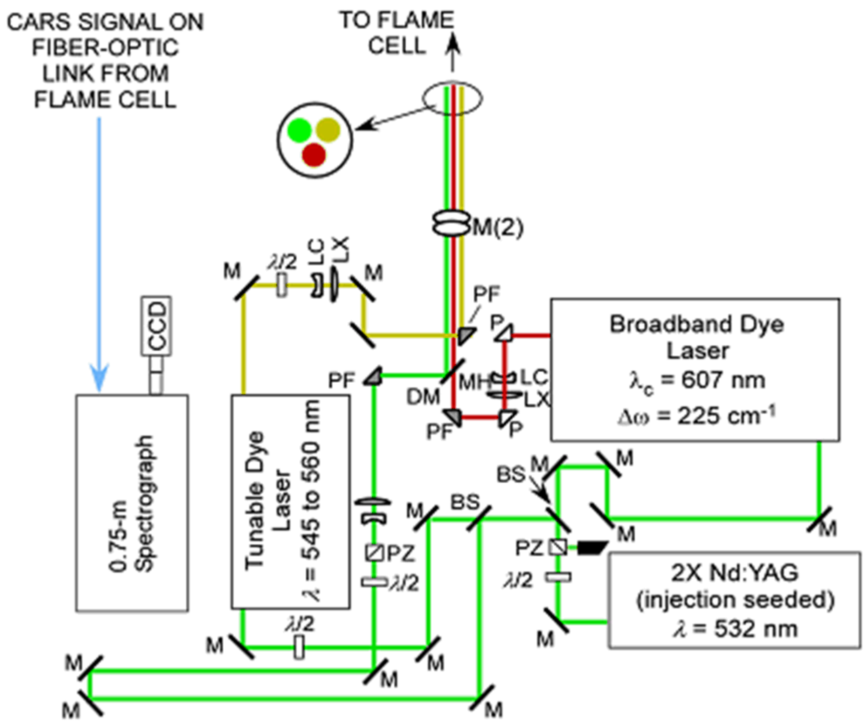


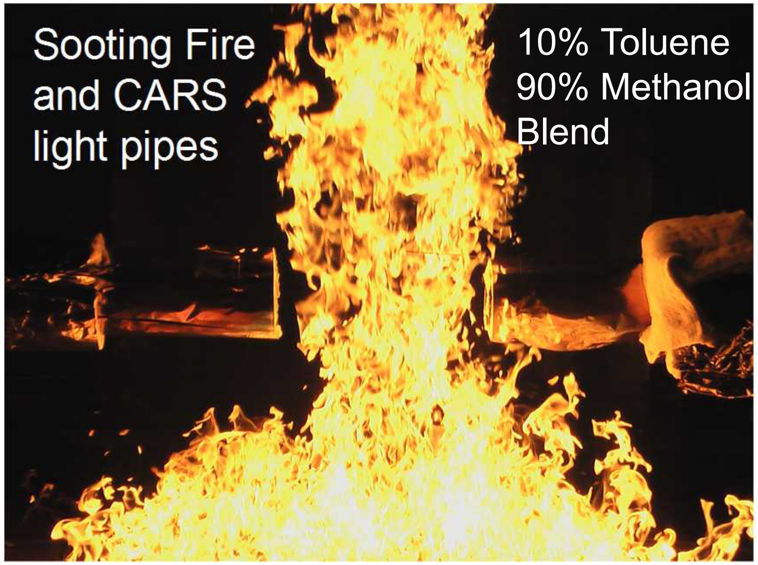


Horizontal Velocity (m/s)

Dual-Pump CARS Instrument at FLAME

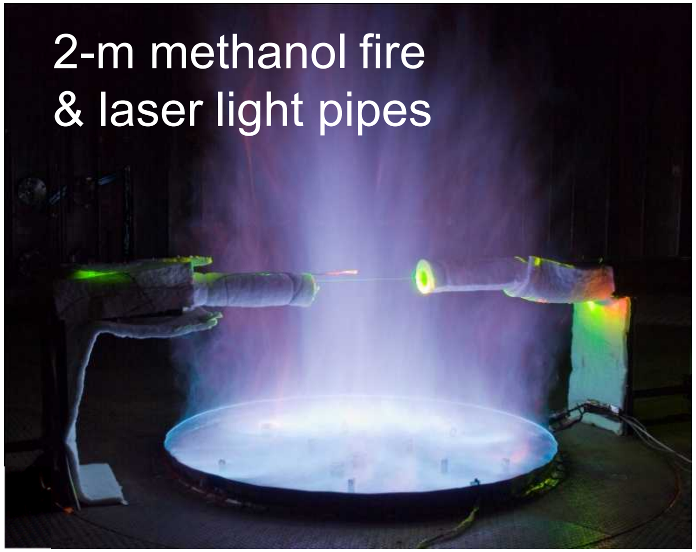
- First-ever implementation of CARS for large-scale fire testing
- Methanol and sooting methanol/toluene blends have been tested to date
- Simultaneous mole-fraction measurements have been added to thermometry capabilities

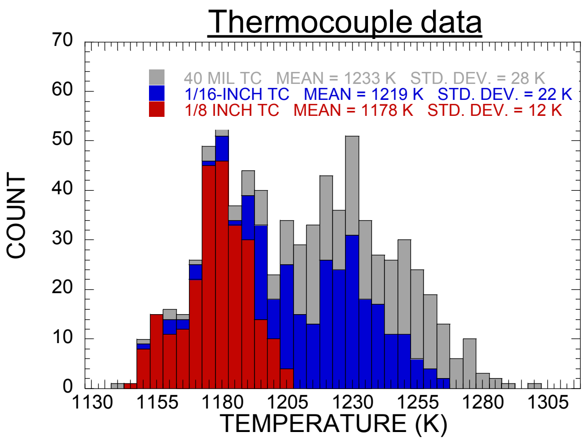


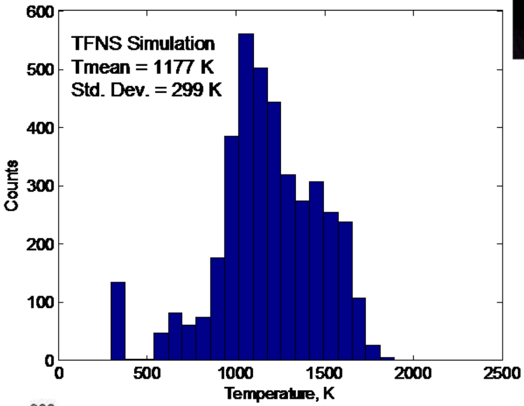


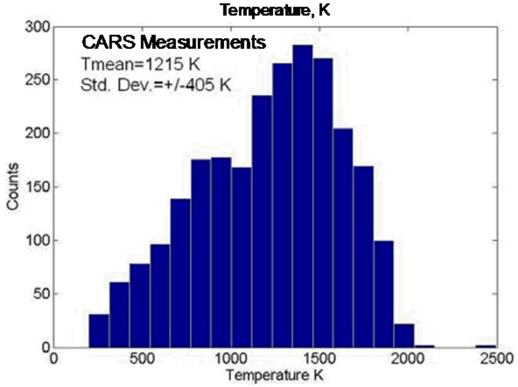
Results – Temperature and O_2 Data from a Methanol Pool Fire

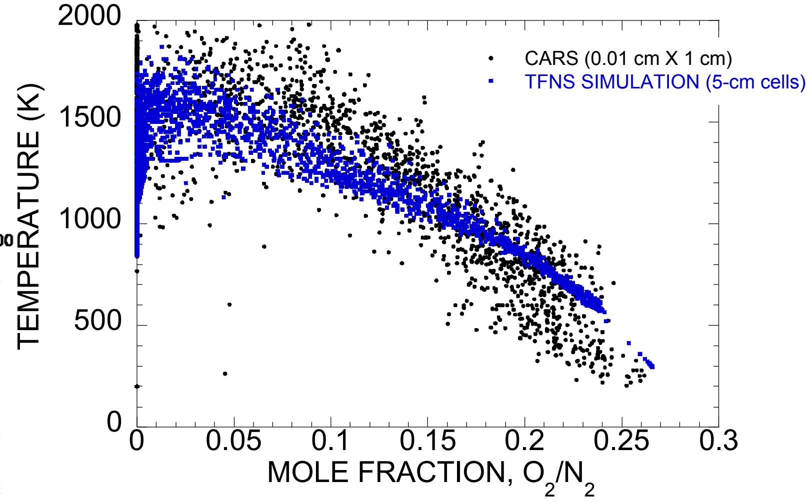
- First experiments conducted in methanol fire
- Nonsooting fuel is simpler starting point for diagnostic development
- Temperature and simultaneous O_2 data extracted
- Nearby thermocouples cannot follow turbulent fluctuations



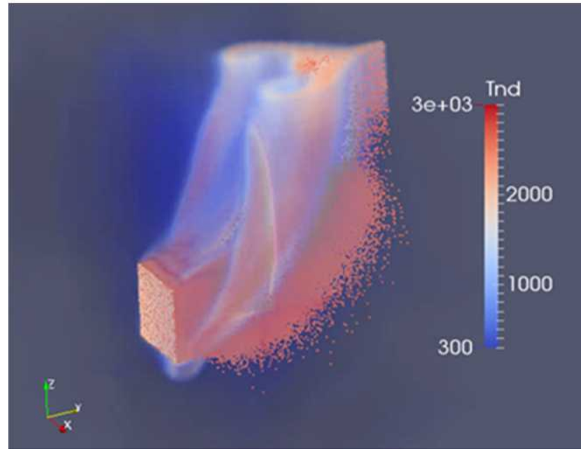


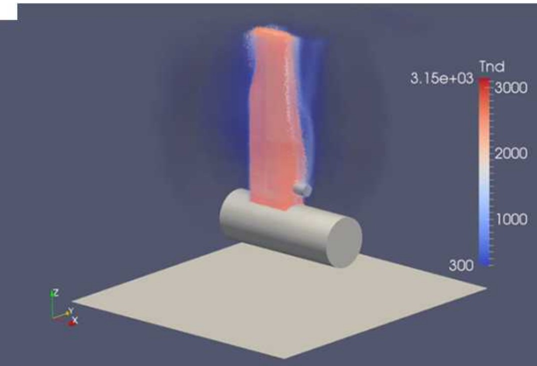


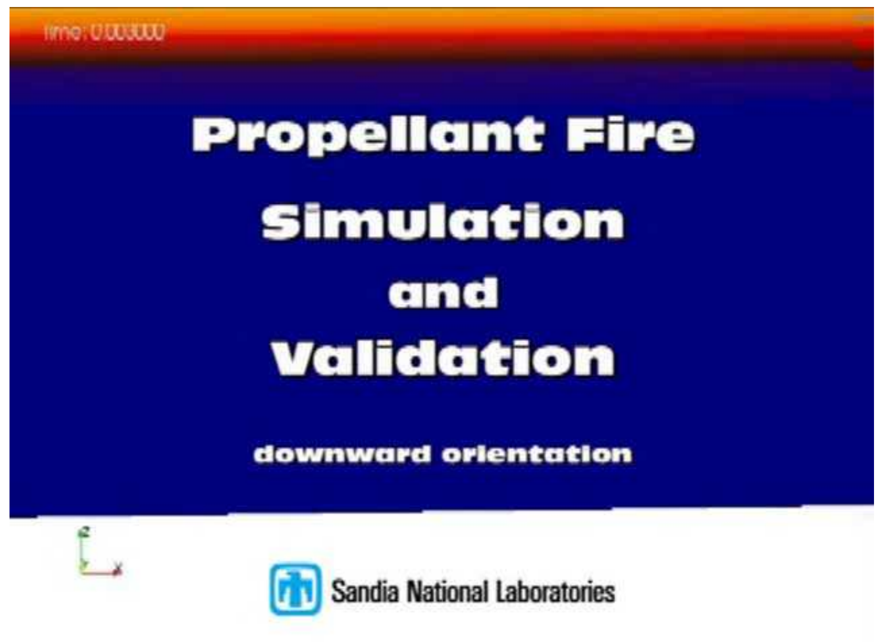




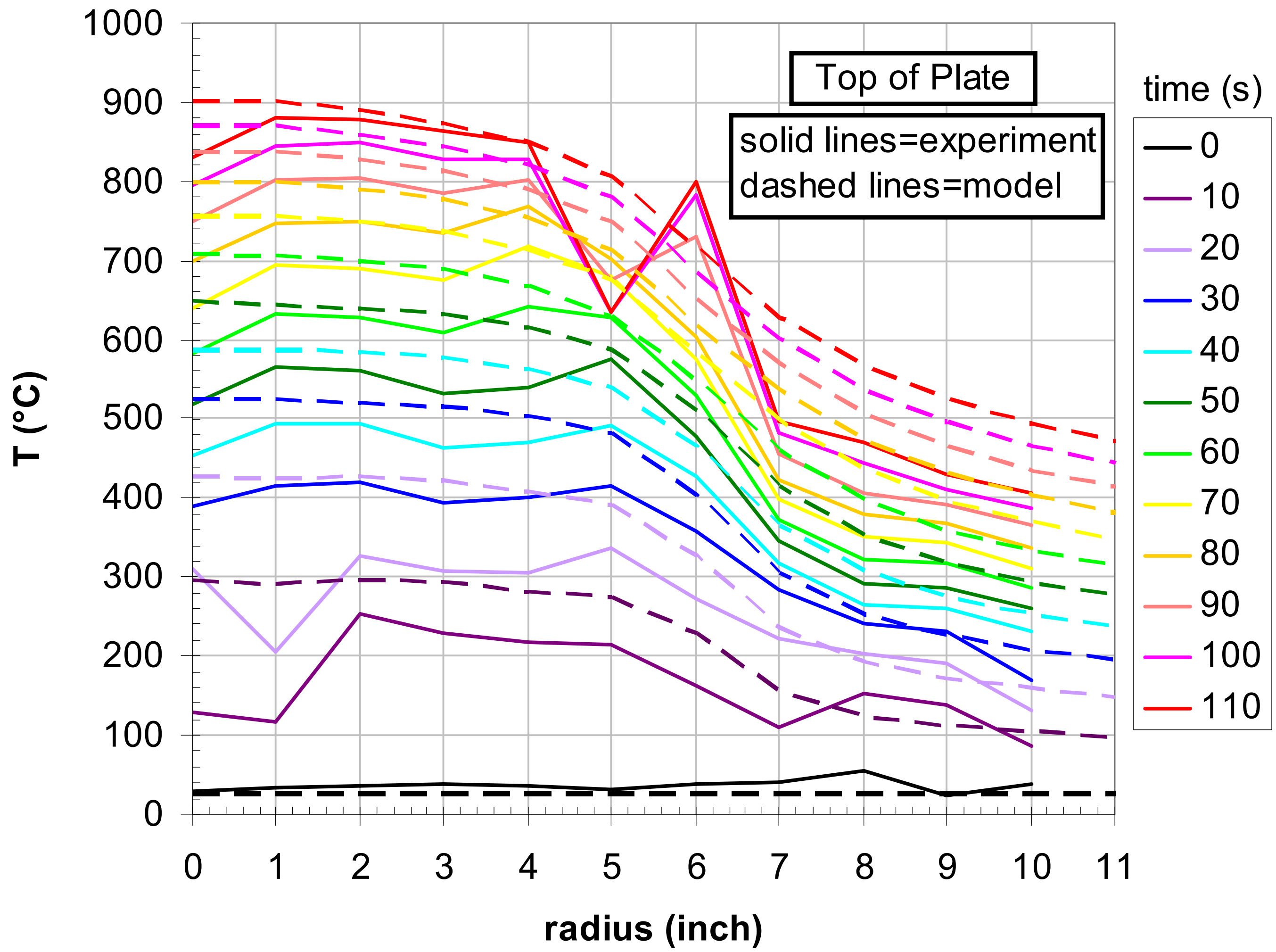
Propellant Tests and Models







Temperatures Beneath a Propellant



Composite Material Fires

- Increasingly used in aviation applications, carbon fiber epoxy materials exhibit complex behavior in fires
- Experimental program focused on the thermal environment with tests ranging from micrograms to hundreds of kilograms

Back-side of a heated panel

Rubble fire involving 900 lbs. of composite material and 320 gal. of jet fuel

End of burn for a test involving 40 kg of crib-arranged composite material in an insulated enclosure (with AFRL-Tyndall)

Modeling at Sandia

Enabled by world class computing resources, dedicated programs to support tools designed to take advantage of resource.

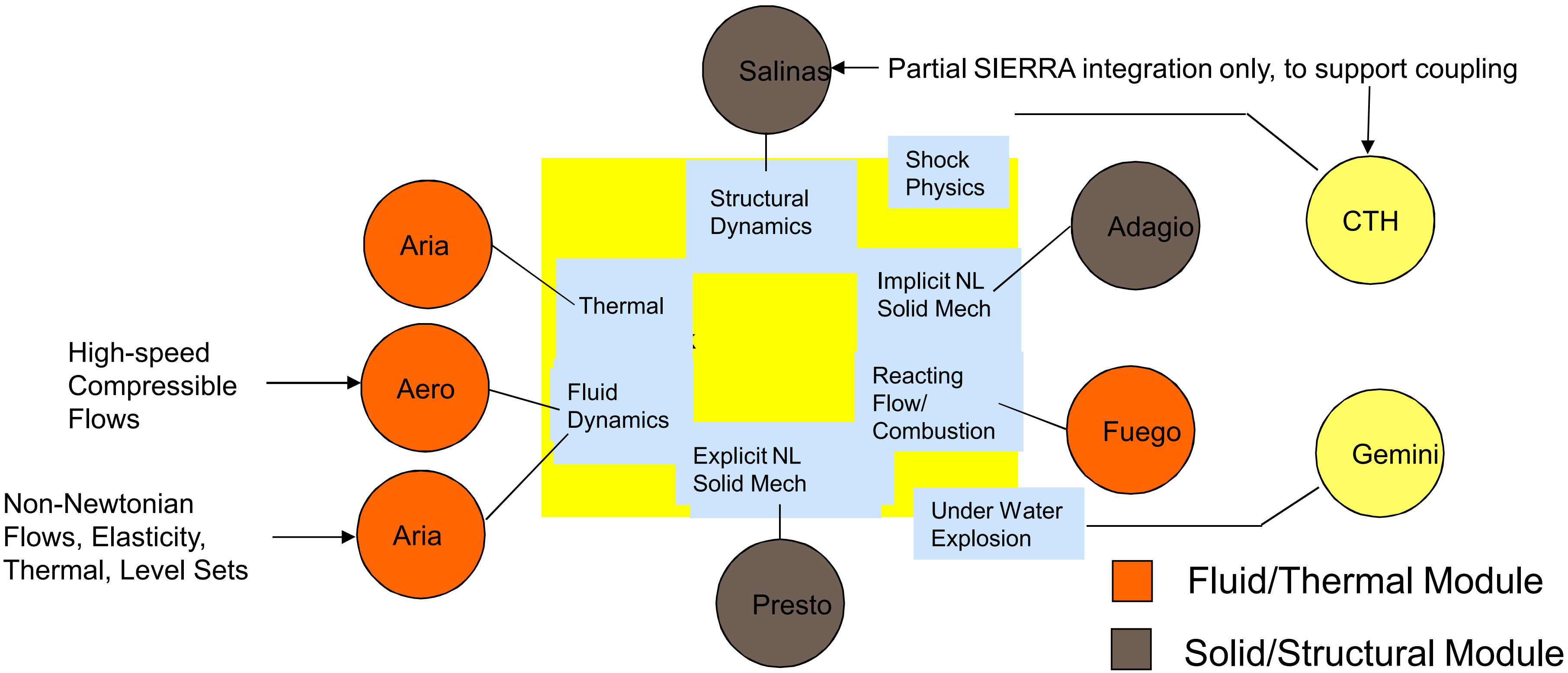
Outline:

- Introduction to SIERRA
- Vulcan/SIERRA-Fuego history
- Code coupling
- Propellants/Particle Combustion Models
- Solid reacting materials
- Spray and chemical suppression

SIERRA Mechanics: The Big Picture

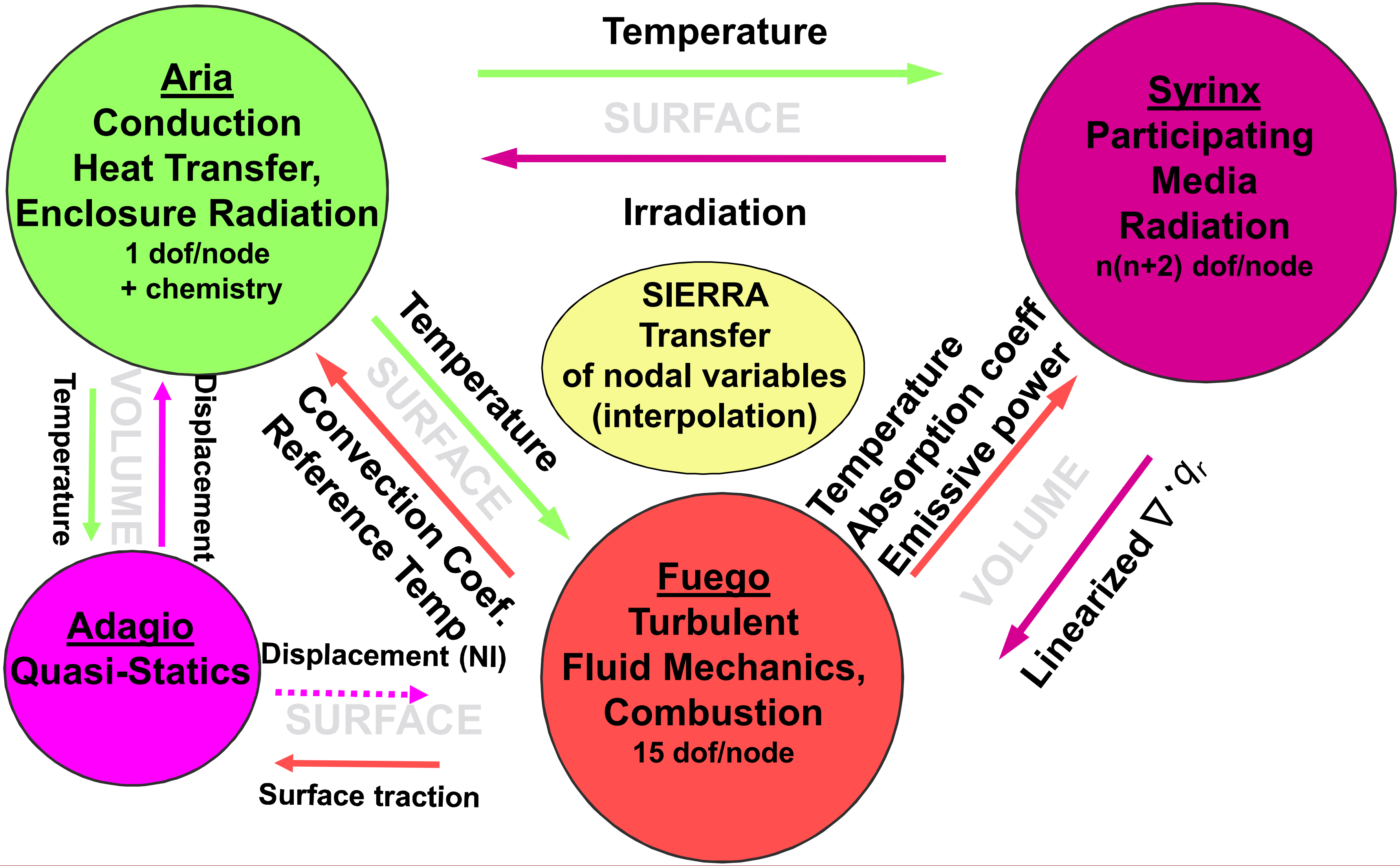
Sandia National Laboratories

- *SIERRA Mechanics* consists of the following modules:



- Modules can readily be coupled for multi-physics applications
- Strategic activities underway to combine modules
- SIERRA open source capabilities enable non-open source codes

Coupled-Mechanics Example
Object-in-Fire with Structural Response

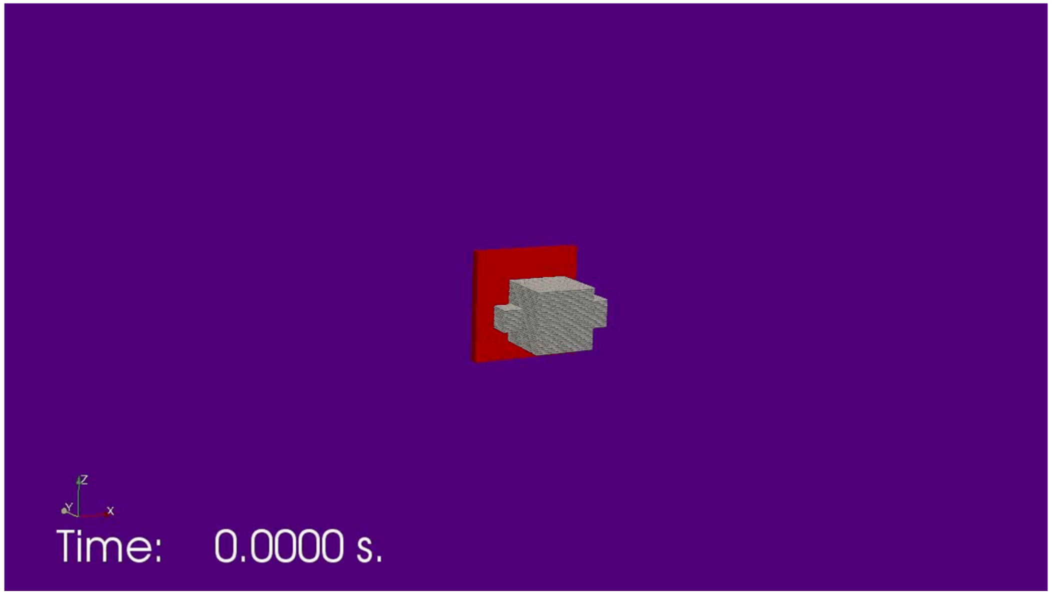


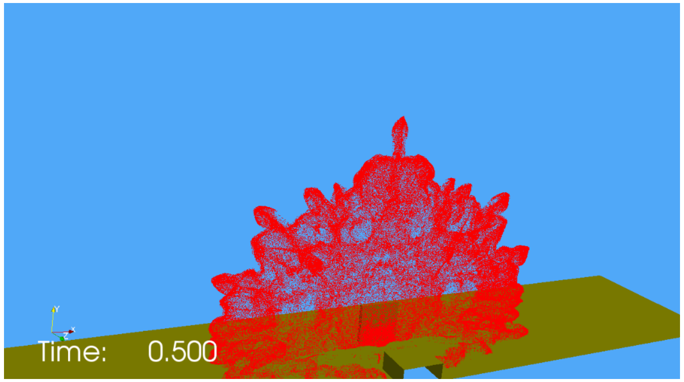
Vulcan/Fuego History

- In the early 1990s, Sandia began fire simulation work with a reacting CFD code, Vulcan, based on ComputIT Kameleon
  - Structured elements, limited solver capabilities
  - Currently a ‘legacy’ code, not heavily used
  - Was a platform for some suppression work, initial particle model development
- A few years later, the DOE ASC program began funding SIERRA/Fuego, which is currently our standard tool
  - Unstructured mesh support, rich solver capabilities
  - Massively parallel, designed to run on high performance computers
  - Currently the active model development platform
  - Enables more complex analyses

SIERRA-Presto/Fuego Coupling

- Methods are being developed to couple structural mechanics and fluid mechanics calculations in SIERRA
  - Data are limited in this regime
  - Limited validation of model methods –
  - Brown, A.L., G.J. Wagner, and K.E. Metzinger, "Impact, Fire and Fluid Spread Code Coupling for Complex Transportation Accident Environment Simulation," *Journal of Thermal Science and Engineering Applications*, Vol. 4, No. 2, pp. 021004-1 to 021004-10, June 2012.
- Capability represents a unique modeling and simulation capability
- Detonation and impulse initiated dispersal events have been simulated



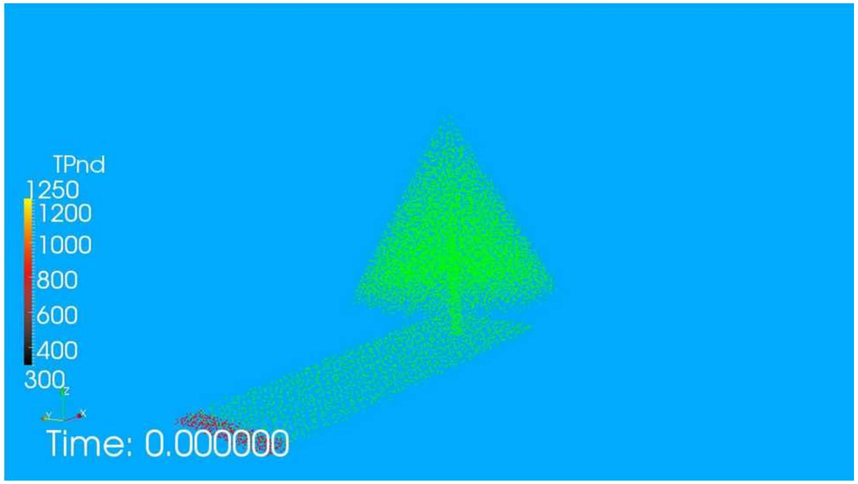


Model liquid dispersion from a liquid tank impact

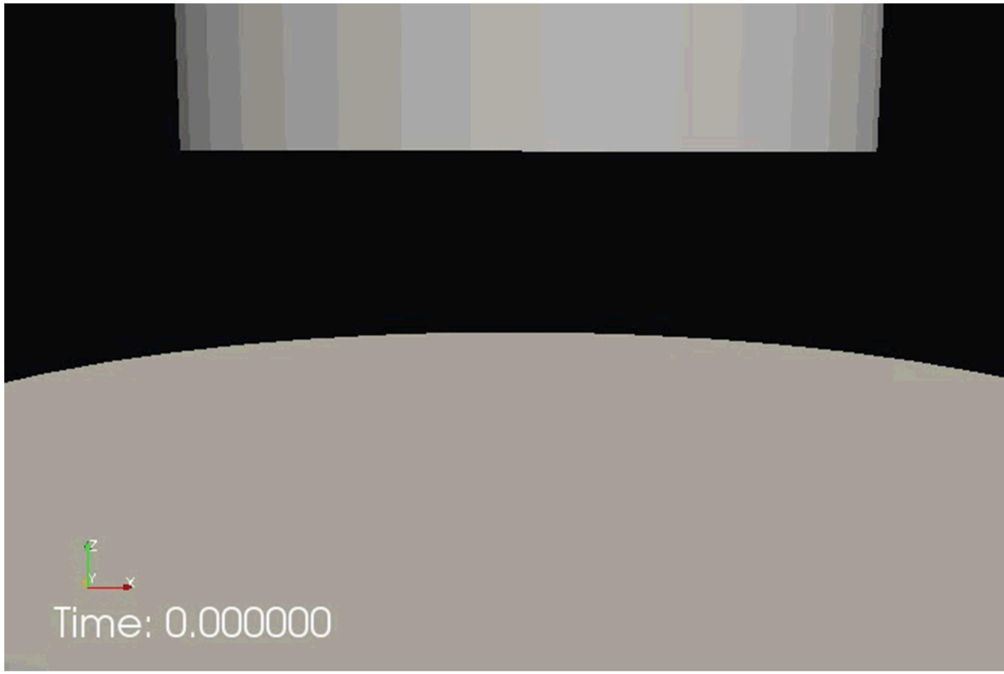
Corresponding experimental dispersion

Particle Combustion Model

- Primarily used in the past for two projects:
  - Wildland fire predictions for idealized trees
  - Aluminized propellant reactions
  - Has more general applicability



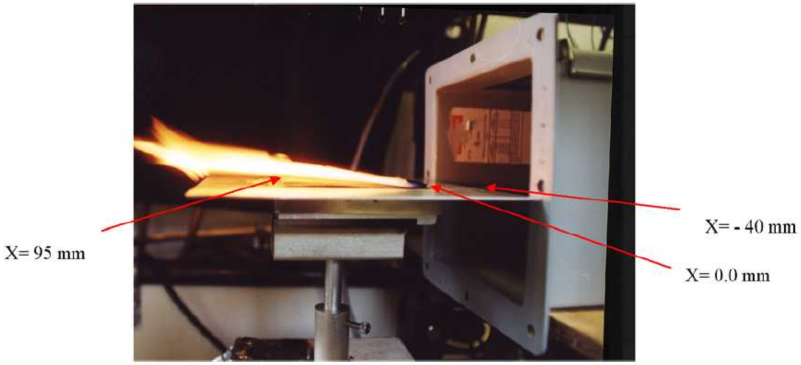
Particles arranged to represent wildland plants

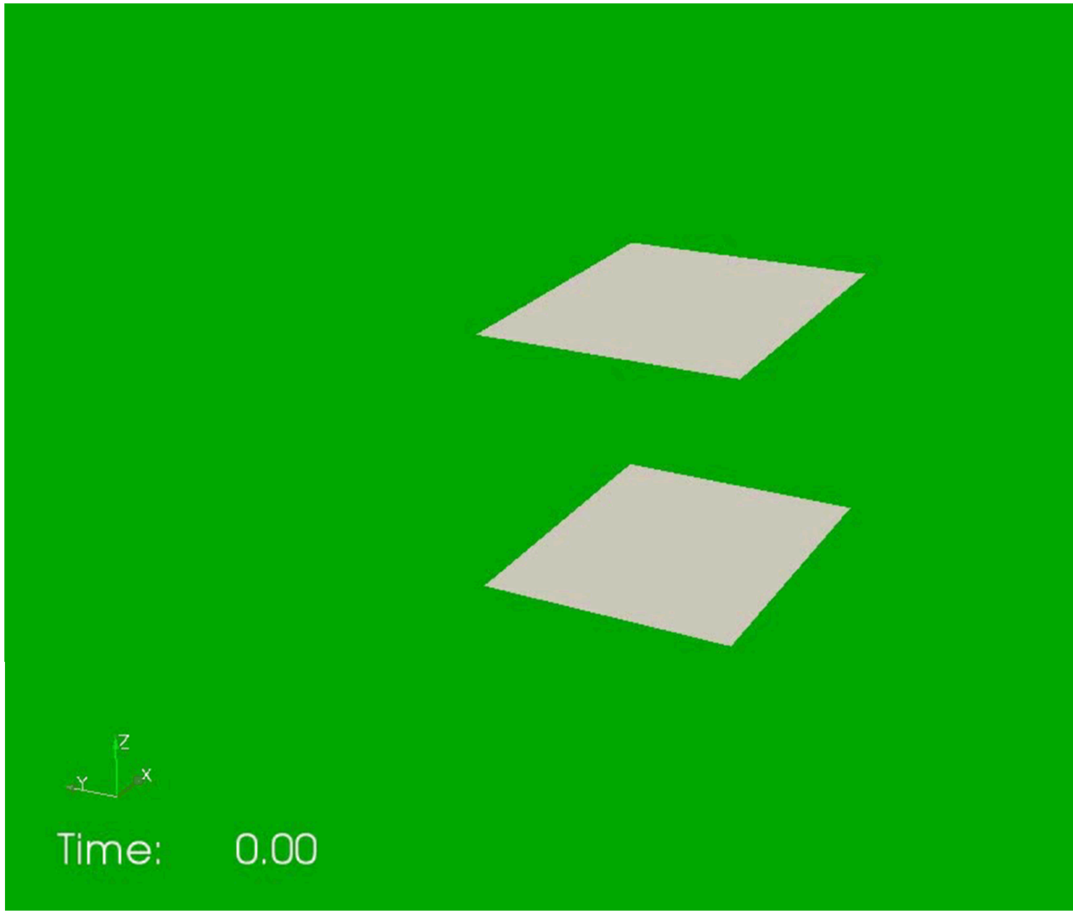


Particles emerging from aluminized propellants

1-D Solid Reacting Boundary Condition

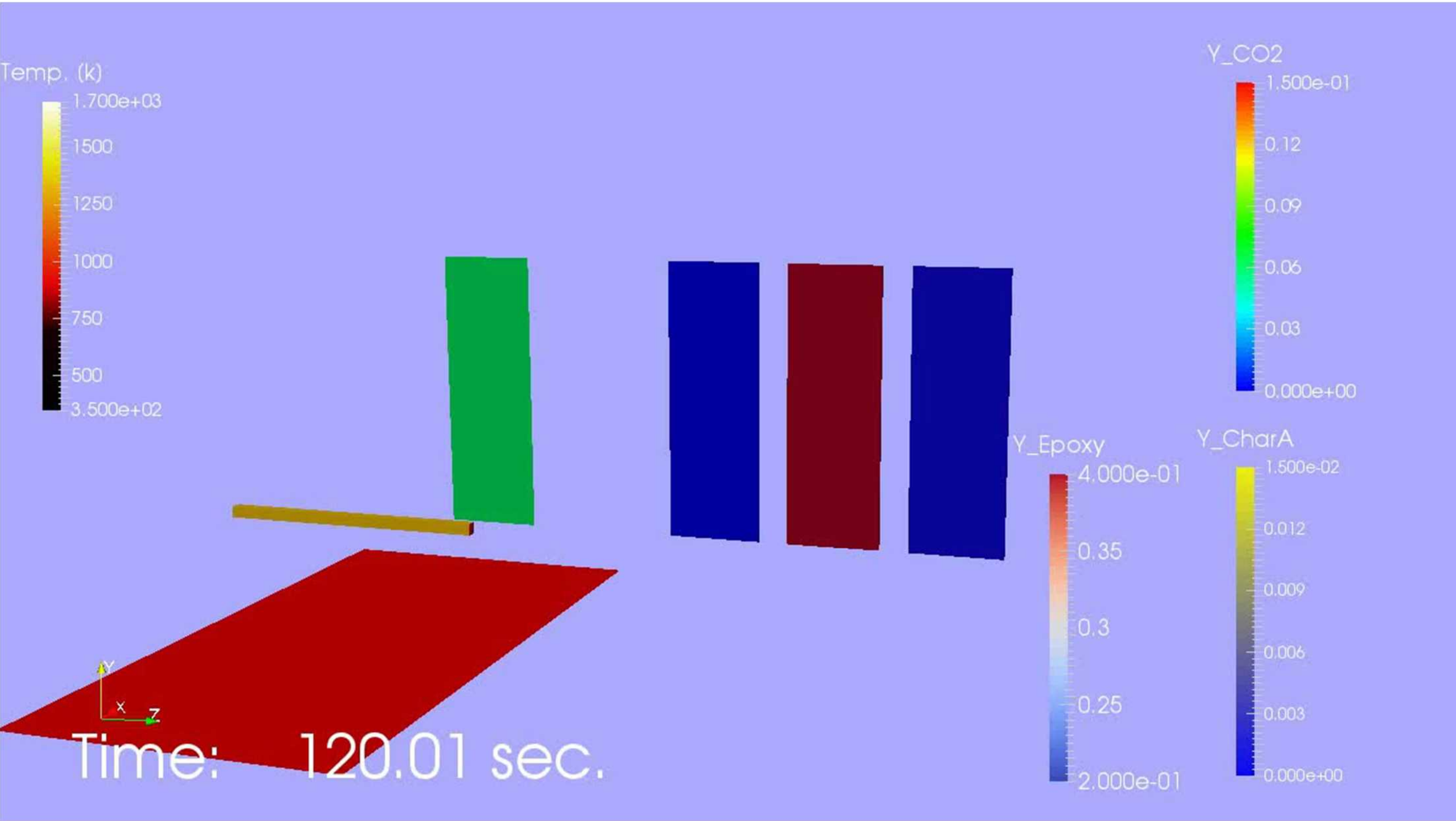
- Recent work demonstrates the verification of the methods and compares to data in the context of a sensitivity analysis.
  - Brown, A.L., D. Glaze, F. Pierce, “Sensitivity Analysis and Verification of a 1-D Surface Solid Combustion Model for a Fire CFD Boundary Condition,” The 2014 ASME/AIAA Summer Conference, Atlanta, Georgia, June 16-20, 2014.
- Data source:
  - Ndubizu, C.C., R. Ananth, P.A. Tatem, “Transient burning rate of a noncharring plate under a forced flow boundary layer flame,” Combustion and Flame, 141, 131-148, 2005.



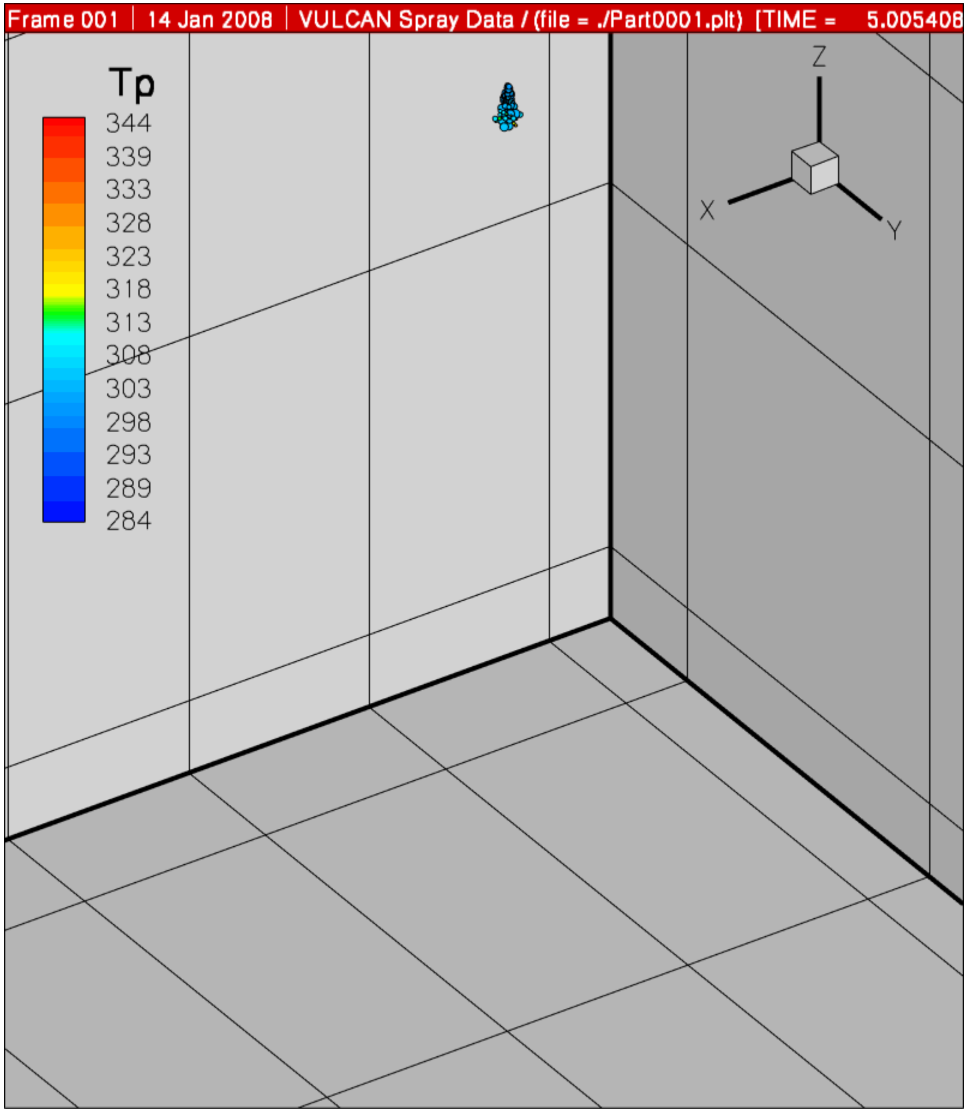


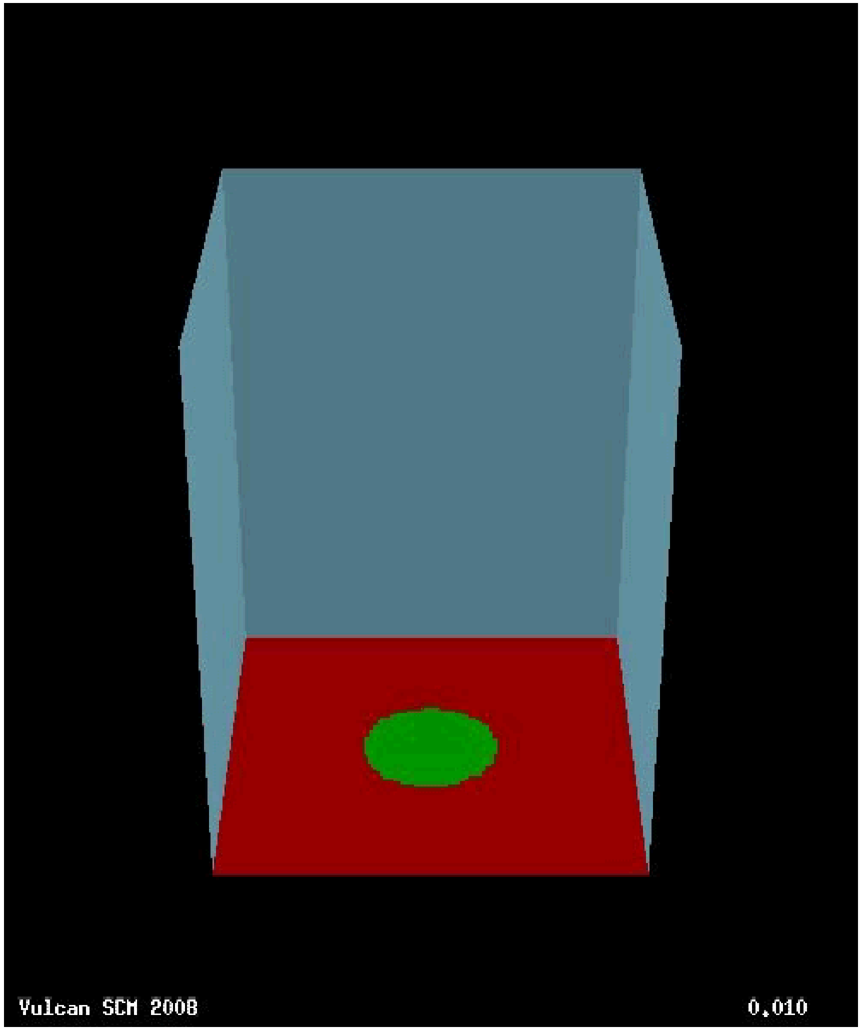
3-D Solid Reacting Material Model

- New model includes porous transport, charring reactions, oxidative reactions.
  - Hubbard, J.A., A.L. Brown, A.B. Dodd, S. Gomez-Vasquez, and C.J. Ramirez, “Aircraft carbon fiber composite characterization in adverse thermal environments: radiant heat and piloted ignition flame spread,” Sandia Report SAND2011-2833.



Vulcan Suppression Modeling

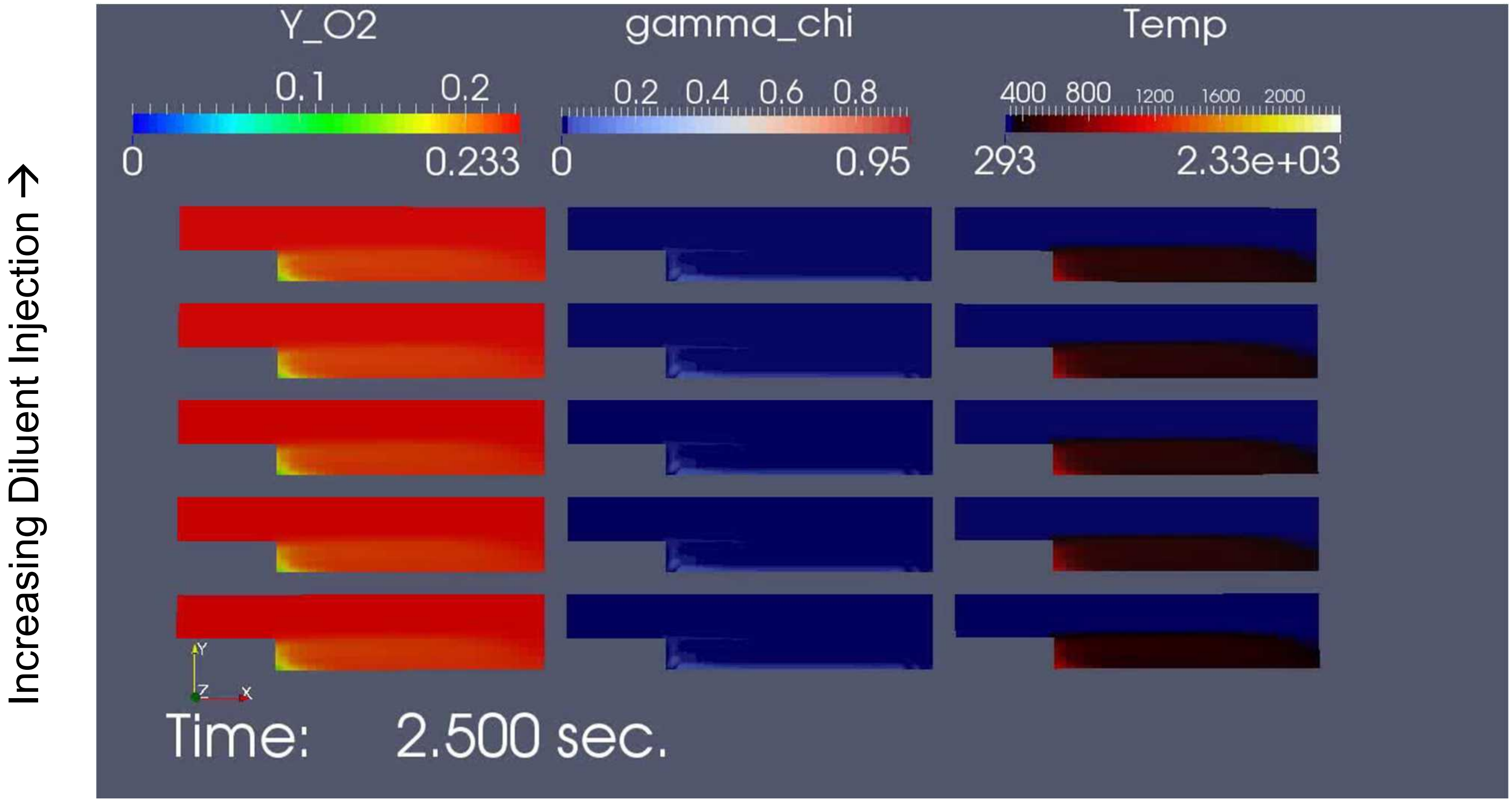




Extinguishment was achieved within 2 seconds, from the point of water spray injection (5 sec) to about 7.0 sec.

Fuego EDC Suppression Modeling

- A fire stabilized behind a backward facing step
  - Takahashi, F., W.J. Schmoll, E.A. Strader, V.M. Belovich, "Suppression of a Nonpremixed Flame Stabilized by a Backward-Facing Step," Combustion and Flame, 122, 105-116, 2000.



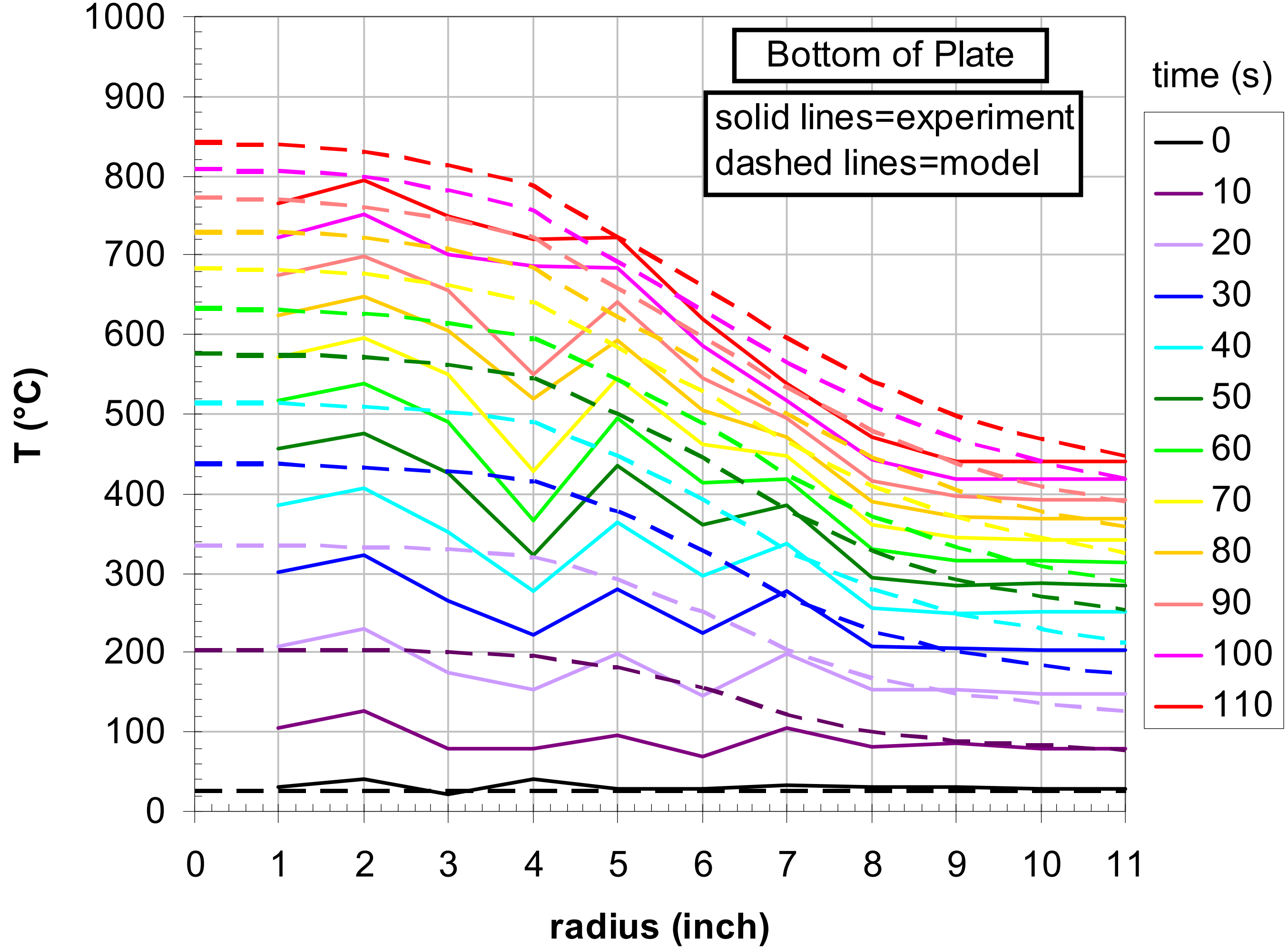
Extinguishment was approximate in time to the experiments, and close in terms of diluent concentrations

Summary

- The Sandia Fire Science and Technology department is a DOE facility that solves high consequence fire problems
  - Unique experimental facilities
  - World class diagnostics
  - High-performance scientific computing capabilities
  - Unique engineering modeling capabilities to solve multi-physics problems
  - People with quality characteristics to match the hardware and software
- Many of our capabilities align well with the objectives of the this exchange meeting
  - Presentation material selected to align with the statement of interest
- We collaborate with the DOD on problems of mutual interest

Acknowledgements

- A large number of Sandia staff colleagues contributed to the material in this presentation, including major R&D contributions from Sheldon Tieszen, Sean Kearney, Joe Jung, Stefan Domino, Tom Blanchat, Walt Gill, Jim Nakos, John Hewson, Greg Wagner, Flint Pierce, David Glaze, Vern Nicolette.



Bottom of Plate
solid lines=experiment
dashed lines=model
T (°C)
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
radius (inch)
time (s)
0
10
20
30
40
50
60
70
80
90
100
110