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Sandia National Laboratories

Fire Science & Technology

MaCFP Working Group on Condensed Phase Phenomena

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Ignition from the Condensed Phase

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

1. Overview of current work by the Sandia fire group
2. Historical ignition for High Heat Flux
3. Active testing at Sandia (facility overview)
4. Recent test results overview
5. Modeling introduction
6. Summary and path forward

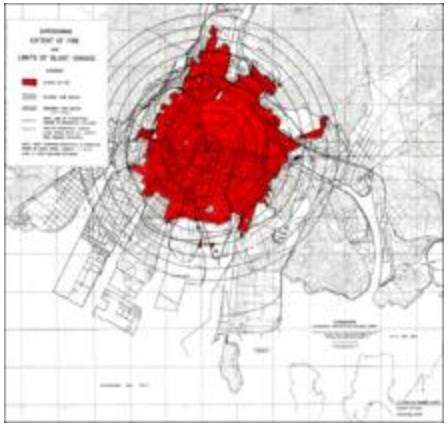
Current SNL Activities

- Ongoing experimental work at Sandia
  - Solid reacting material validation work (Kate Hoffmeister)
    - Using thermophosphors to probe surface temperatures
    - Create detailed validation datasets for solid reacting material model validation
  - High heat flux ignition testing in three facilities:
    - Solar furnace
    - Solar tower
    - Large Blast Thermal Simulator
  - Aircraft damage assessments to high heat flux (Rachel Colbert)
- Simulation campaigns relating to solar furnace datasets
  - SIERRA/Aria
  - SIERRA/Fuego
  - Gpyro
- Rubble fire (mixed solid and liquid fuels)

High Heat Flux Ignition

Sandia National Laboratories

- Why we care?-we seek to be able to adequately plan, predict and respond to NW events
- Bombs dropped on Japan provide some data
  - Hiroshima-Major fire damage, firestorm developed
  - Nagasaki-Fires generally not considered significant source of damage
- US and other countries' test programs provide data
  - Our current sense is these data are not as significant and usable as they could have been (lack of details, weak environment information)
  - Limited to test locations (no forested or similar areas)
- 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
  - Almost nothing intentionally for NW since
- Many modeling efforts



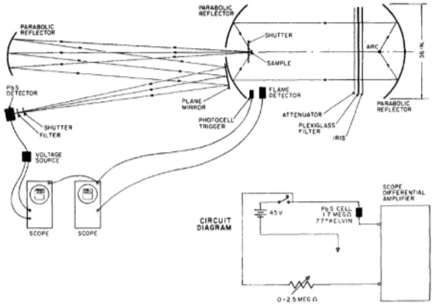
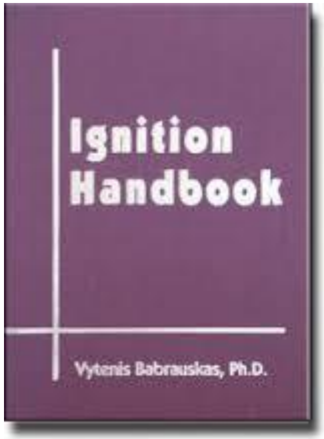
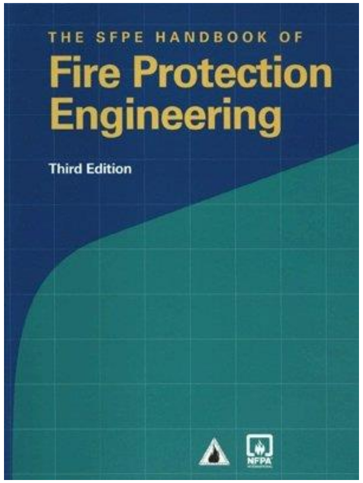


Fig. 4. Apparatus for the measurement of temperatures of the irradiated surface of cellulose.

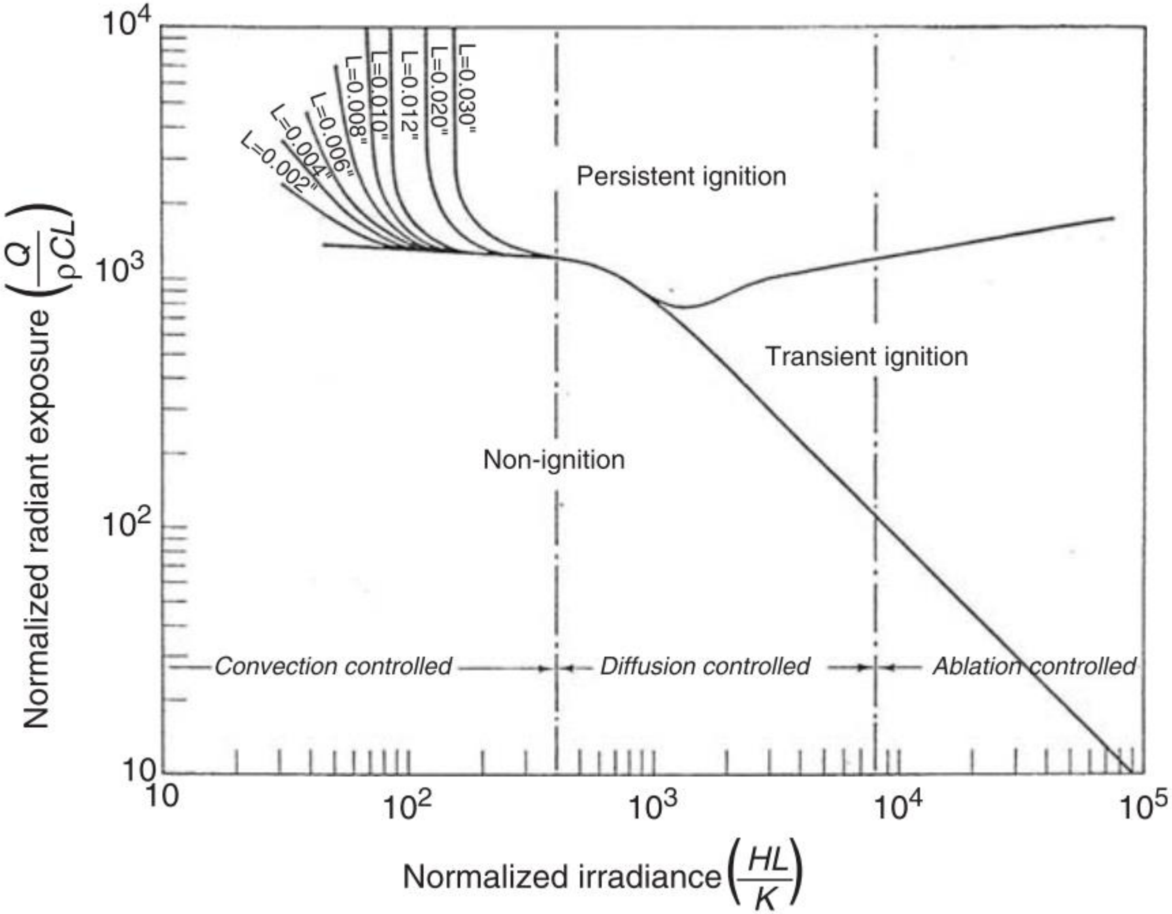
Current Ignition Literature

- Ignition Handbook (Babruskas, 2003)
  - Cites Glasstone and Dolan (1977) as main source
  - We believe their ignition data are based on the historical data from the 50's-60's.
- SFPE Handbook (Sec. 2-11)
  - Ignition section written by Kanury, heavily references Martin's work
  - "Martin and his collaborators had honed the technique of ignition measurement to such a fine art that their measured ignition thresholds of drapes, typing paper, dry rotted wood and leaves were included in the newer printing of Glasstone's Effects of Nuclear Weapons"—Kanury, A. M. (2009). SFPE Classic Paper Review: Diffusion-Controlled Ignition of Cellulosic Materials by Intense Radiant Energy by Stanley B. Martin. Journal of Fire Protection Engineering, 19(2), 125-131.
- Most current recommendations for high flux ignition go back to the same dated sources





Martin's Regimes of Ignition



- Maps ignition regimes for cellulose
- Has units of temperature (K)
- Based on black α-cellulose paper using square flux waves
- Recommended in the SFPE handbook
- Diagonal lines (45º) are constant Fourier numbers
- Massive testing contributed to the map

Martin S.B., Diffusion-controlled ignition of cellulosic materials by intense radiant energy. In Symposium (International) on Combustion 1965 Jan 1 (Vol. 10, No. 1, pp. 877-896). Elsevier.

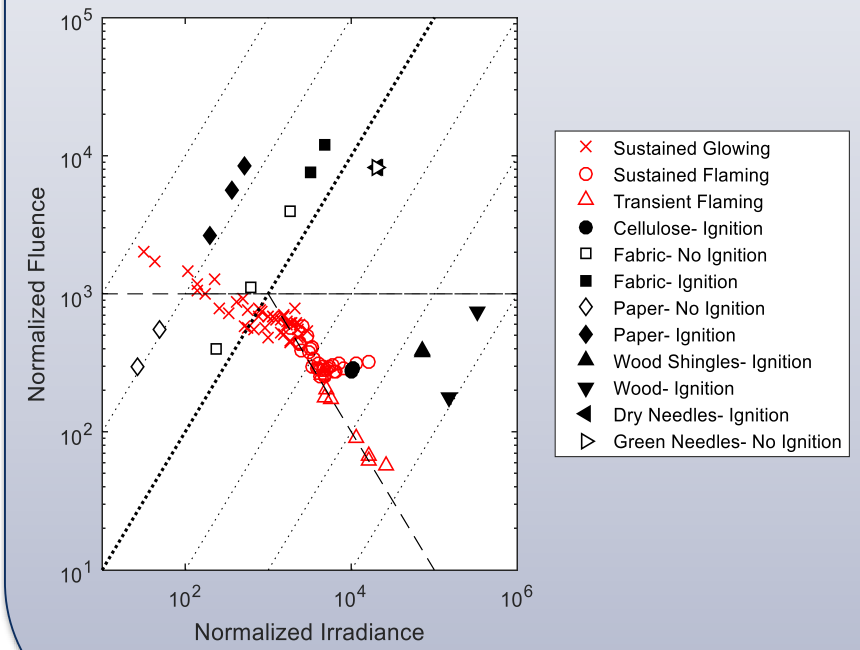
Fire Test Facilities

- SNL Solar Furnace
  - Relevant fluxes at 10 cm-scale spot
  - Relatively agile for testing
- Solar Tower
  - Relevant fluxes at meter-scale spot
  - Field of heliostat mirrors
  - Moderately agile for testing
- LBTS
  - Combines blast and fire
  - Commissioning underway
  - Need to design fire initiation methods, a topic of current effort

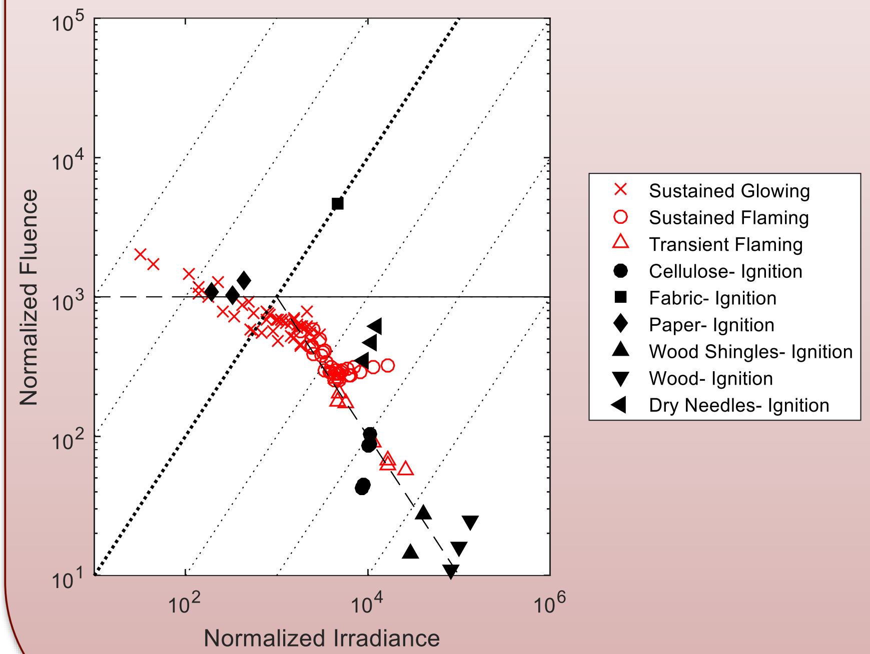
Solar Furnace Test Results

Comparison to Martin: Organics

Total Quantities
-Preliminary-



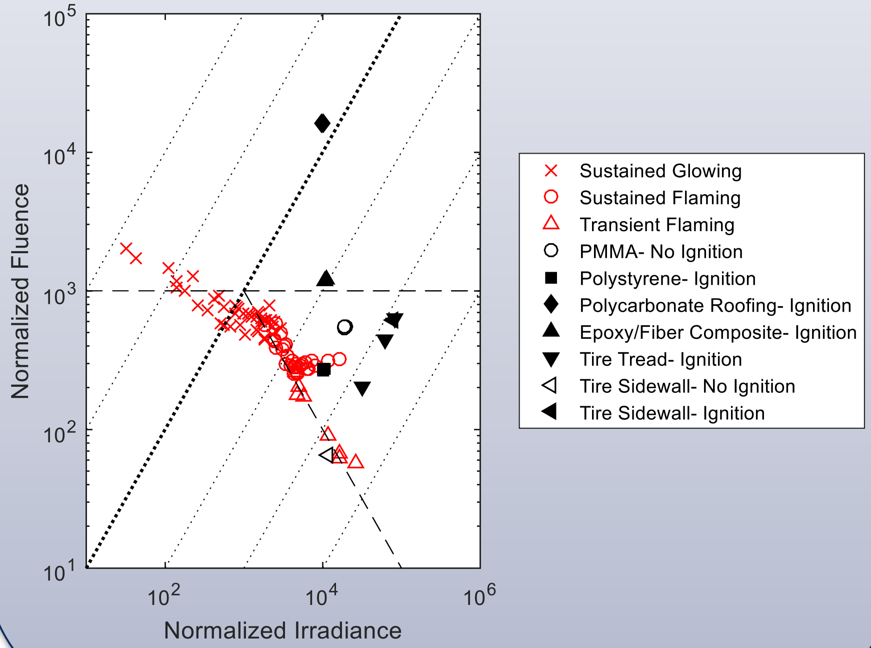
Time-of-Ignition Quantities
-Preliminary-



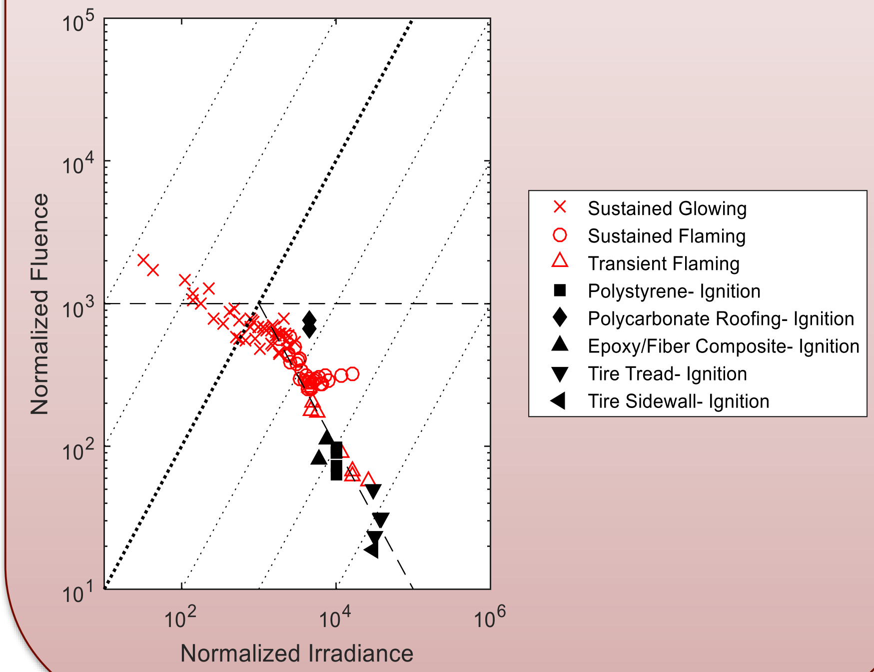
- Fabric and green needles do not ignite
- Wood, fabric ignite later than Martin's cellulose
- All data points are for transient flaming (other than Dry Needles)

Comparison to Martin: Polymers

Total Quantities
-Preliminary-



Time-of-Ignition Quantities
-Preliminary-



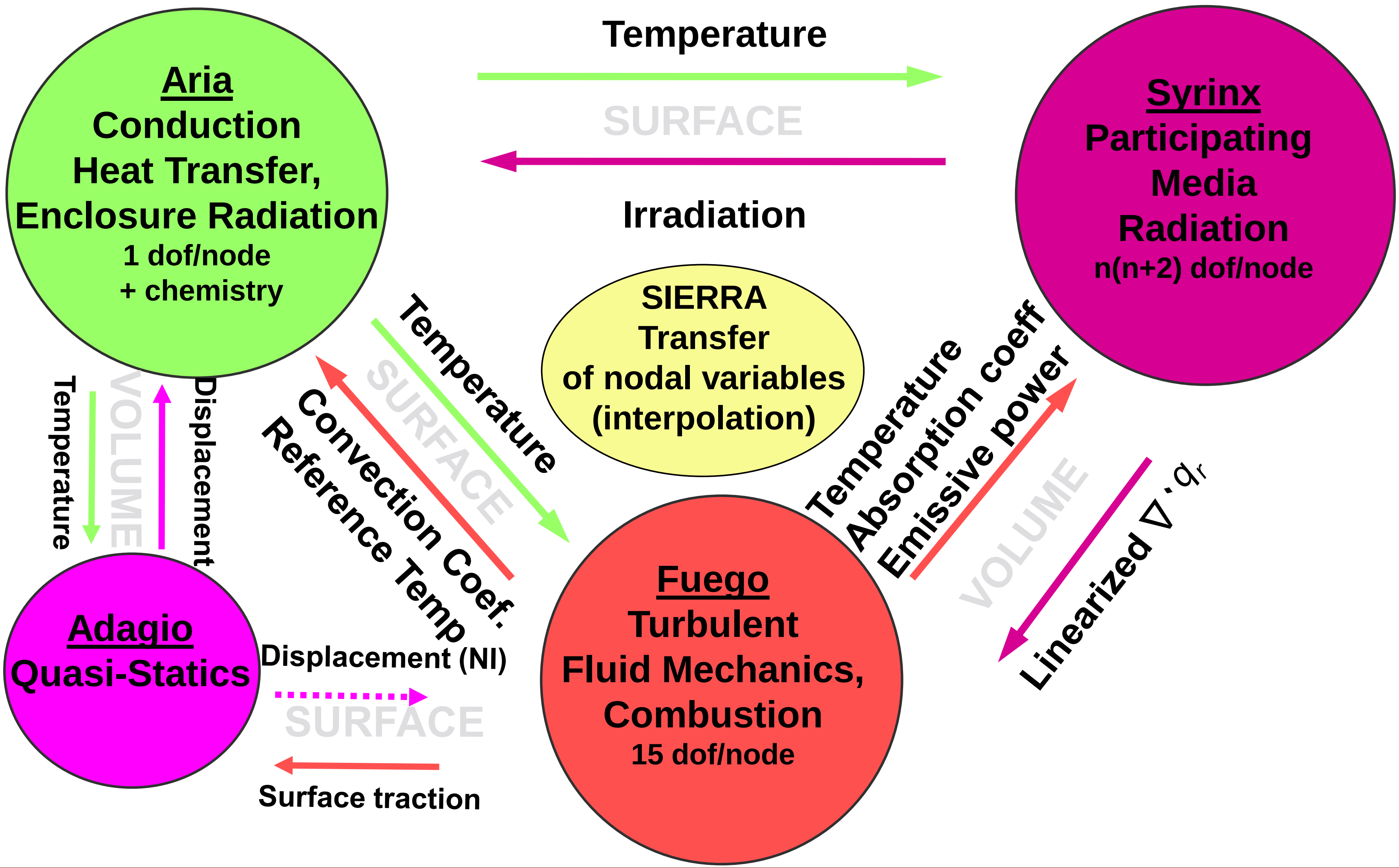
- PMMA is more difficult to ignite
- Many ignite similar to cellulose
- All data points are for transient flaming

Solar Tower Test Video

Recent Experimental Findings

- Ignition thresholds are different at different scale
  - Solar tower and solar furnace ignition flux/fluences vary significantly (at least a factor of 3)
- Organics tend to form char towards the end of the test
  - Early char formation is less significant
- Martin's map reasonably predicts ignition for many materials
  - Some exceptions

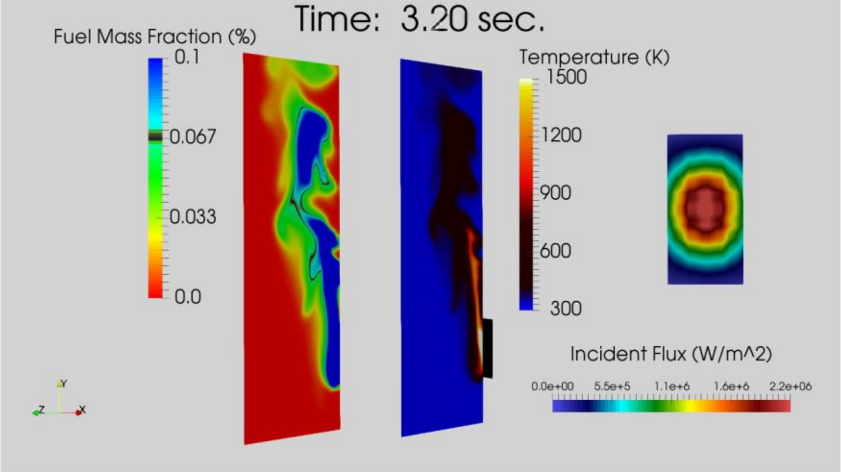
SIERRA Coupled-Mechanics Example
Object-in-Fire with Structural Response



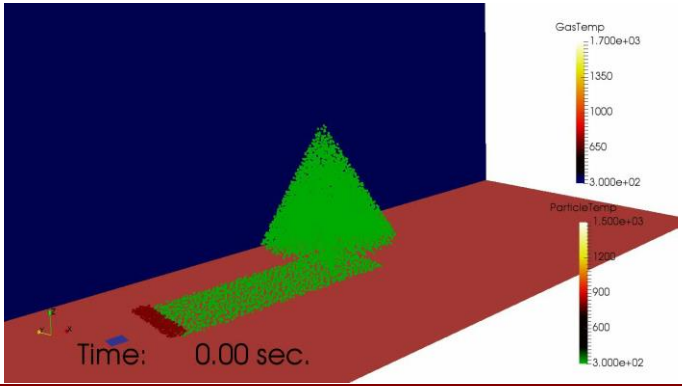
Current Modeling Activities

- SIERRA/Fuego (1-D surface and particle reaction models) used to model solar furnace and solar tower material response
- SIERRA/Aria is being explored for modeling tests (3D capability)
- Gpyro is being used to simulate tests

Predicted response of a PMMA sample to the solar furnace test conditions



Wildland fire with firebrands predicted with SIERRA/Fuego



Summary

- Sandia is actively evaluating material response to high heat flux for fire events
- Modeling and simulation efforts are in progress
- We are trying to determine the need for reaction kinetics at the high heat flux conditions
- Char formation, kinetics, and material properties are topics of interest

We are interested in contributing to a community effort to validate this type of models

Acknowledgements

- The Sandia experimental team, Ryan Anderson, Michael Bejarano, Josh Christian, Deshawn Coombs, Alvaro Cruz-Cabrera, Byron Demosthenous, Jeff Engerer, Bill Kolb, Doug Robb, Richard Simpson, Leland Sharp, Anthony Tanbakuchi, Dan Worley
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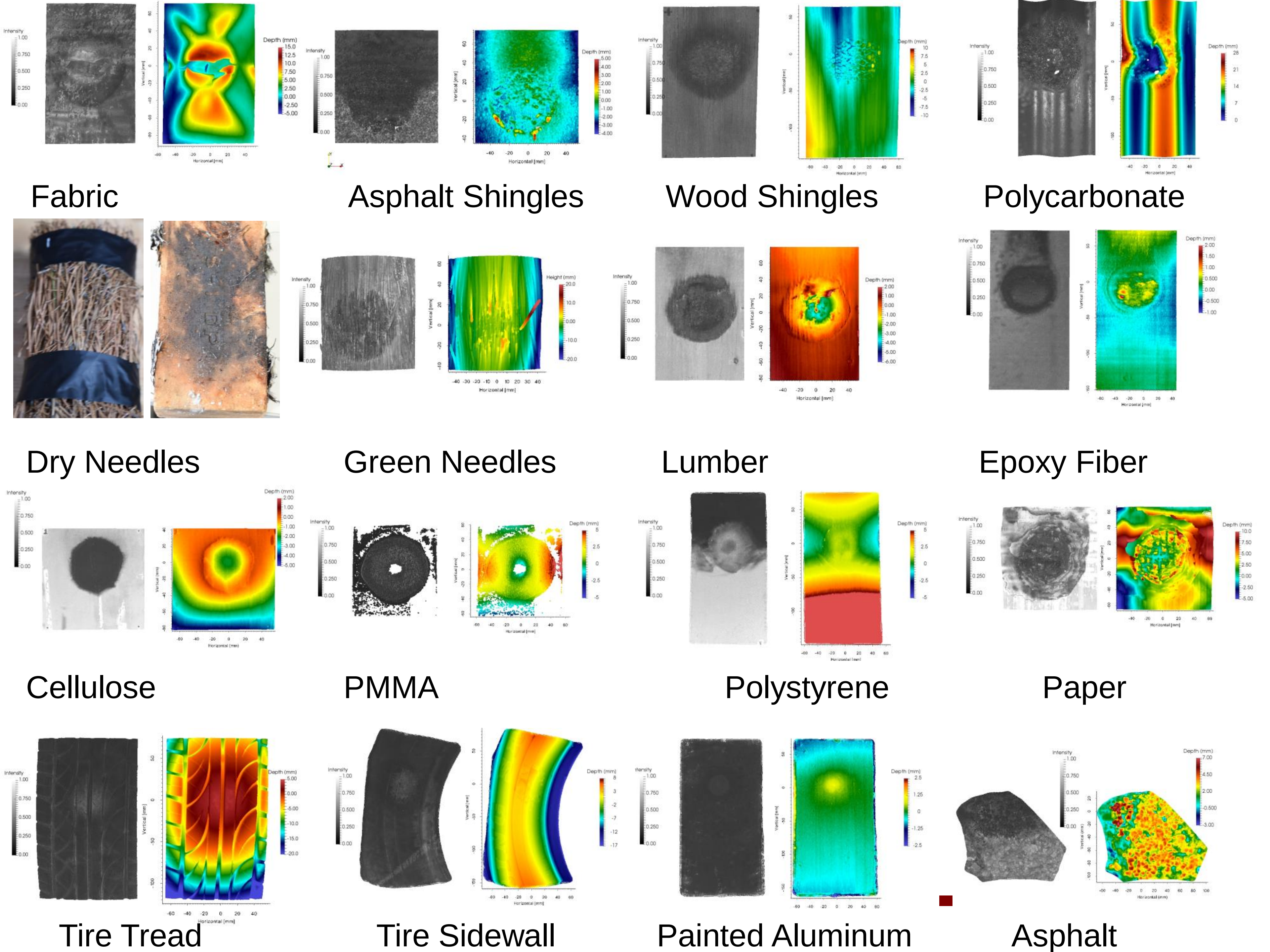
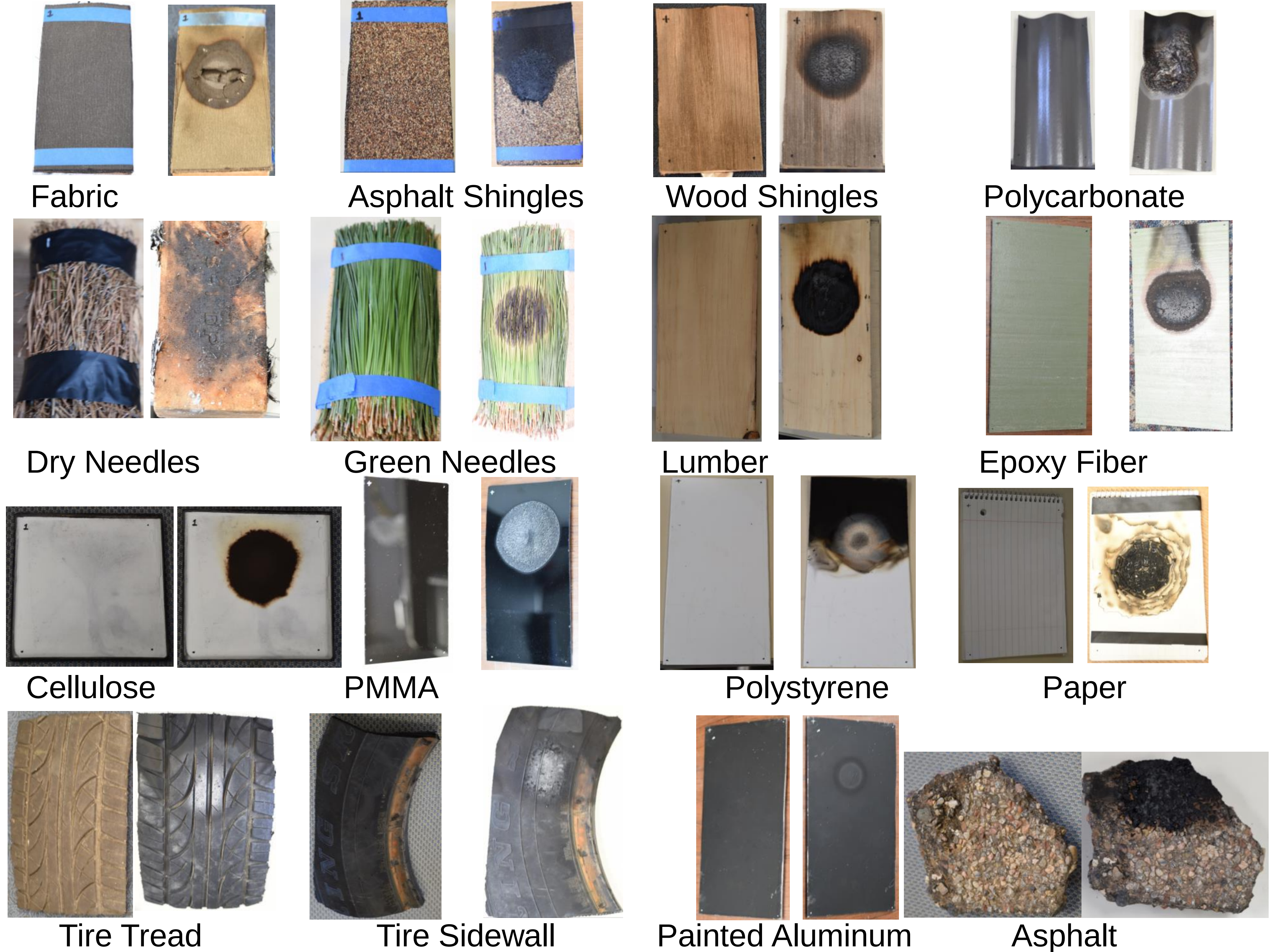
Additional Content


Fabric
Asphalt Shingles
Wood Shingles
Polycarbonate
Dry Needles
Green Needles
Lumber
Epoxy Fiber
Cellulose
PMMA
Polystyrene
Paper
Tire Tread
Tire Sidewall
Painted Aluminum
Asphalt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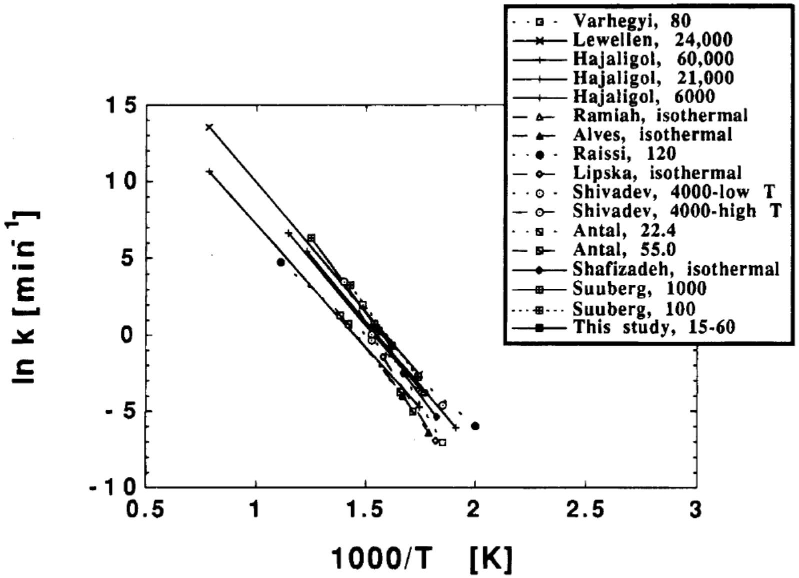
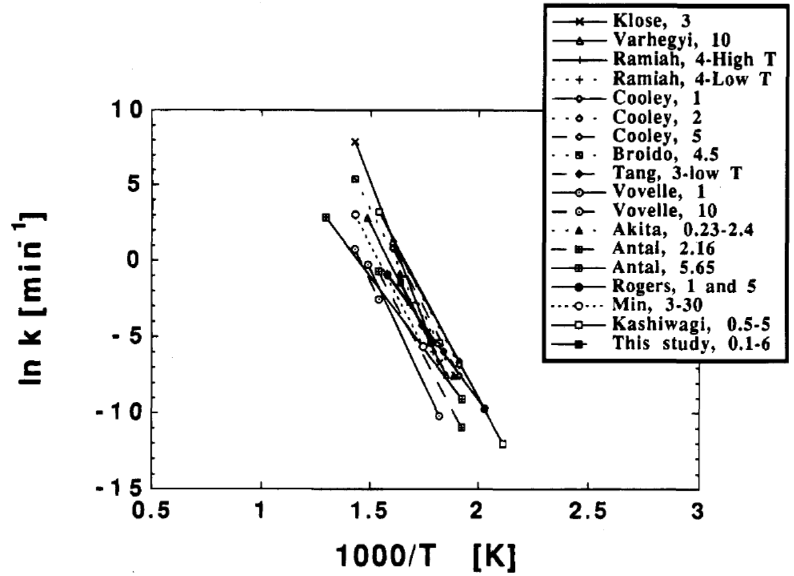
Cellulose
PMMA
Polystyrene
Paper
Tire Tread
Tire Sidewall
Painted Aluminum
Asphalt

Variable Cellulose Decomposition Rate

- From Milosavljevic and Suuberg, Ind. Eng. Chem. Res., 34, 1081-1091, 1995:



Kinetics for heating rates >10 K/min



Kinetics for heating rates <10 K/min

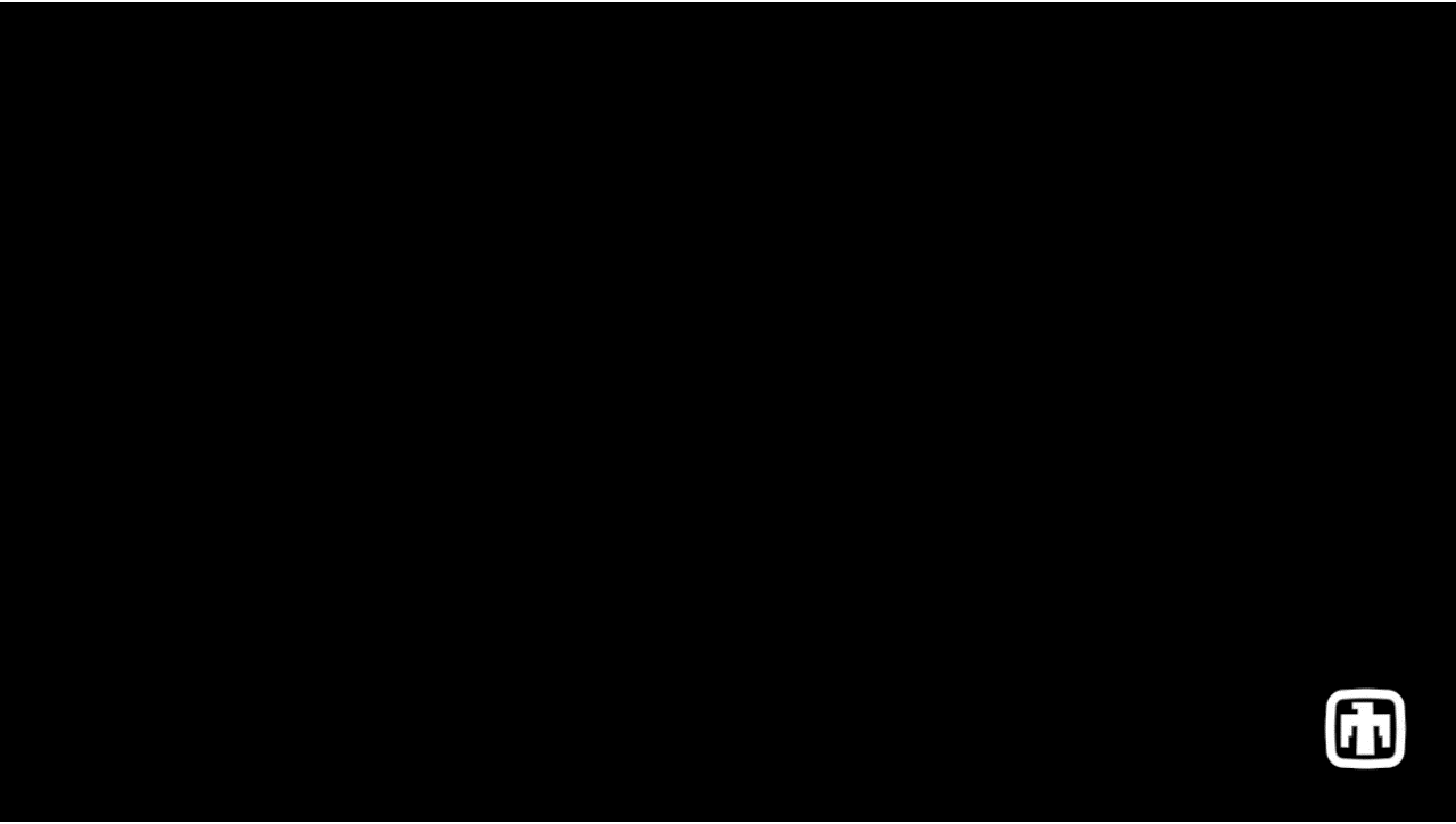
<u>Kinetics depend on rates of heating!</u>

Solar Tower Test Results

- Similar flux and fluence as at the solar furnace, except larger scale
- Green needles and PMMA ignited at the tower, did not in the furnace

TP1 Results

TP2 Results



TP3 Results