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Development of a Fast-Cookoff Test Bed at Sandia National Laboratories

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TTCP “Sub-Scale Hazards Testing and Link to IM Test Results” Workshop

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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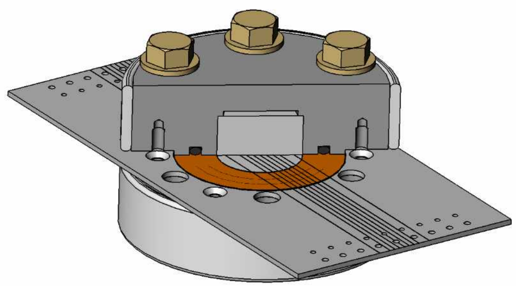
Motivation and Approach

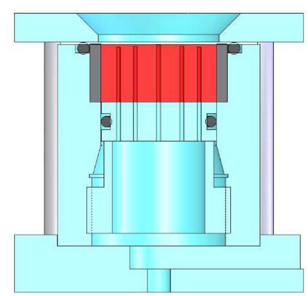
- Seek an understanding of the physical and chemical pre-ignition processes under realistic hazard scenarios.
- Seek an understanding of the post-ignition behavior for effective application of mitigation strategies.

Achieving these goals require:

- Development of sub-scale experiments that allow accurate prediction of full scale behavior
  - Boundary conditions are appropriate, material properties known
  - EM response and EM-confinement interaction are representative of large scale
  - Geometry and operation are suitable for model development



Slow Cookoff Test Apparatus (SITI)



Fast Cookoff Confinement Vessel

- Development of novel diagnostics that can interrogate EM at/near ignition locus
- Collaboration between experiment design and model development

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A closer look--
Update on FCO Experiments and Modeling

- **FCO requires sudden application of high heat fluxes into EM**
  - Specify either temperature or heat flux boundary condition at one surface
  - Strive to achieve insulated boundary conditions on unheated surfaces
  - Diagnostic placement is a challenge (ignition locus varies with thermal penetration)
  - With modeling involvement, explore chemistry at high and low heating rates.

Can slow cookoff models be extrapolated to fast cookoff?

- **Experimental Results**
  - Heated-plunger test bed – plunger with initial temperature directly contacts EM
  - Non-contact radiant heat test bed – utilize IM test standards as guide

STANAG 4240 “Liquid Fuel Fire, Tests for Munitions” (ref. MIL-STD-2105C “Hazard Assessment Test for Non-Nuclear Munitions“)

Measured heat fluxes from crosswind pool fires range from 40-400 kW/m^2

Heat Fluxes in Crosswind Fire

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FCO Test Bed Development

Concept: Sudden application of high heat fluxes between HE and heat source. Initial conditions are well defined. Temperature or Heat Flux boundary condition along one surface. “Insulated” boundary condition on remaining surfaces.

- Approach
  - Unconfined (Pneumatic plunger; Drop tower)
  - Confined with heated plunger (not discussed here)
  - Non-contact radiative heating with confinement

- Diagnostics
  - Internal explosive temperature
  - Time-dependant boundary temperature
  - Internal pressure of confinement
  - Time-independent surface heat flux
  - Planned: Strain/surface velocity of confinement prior to rupture

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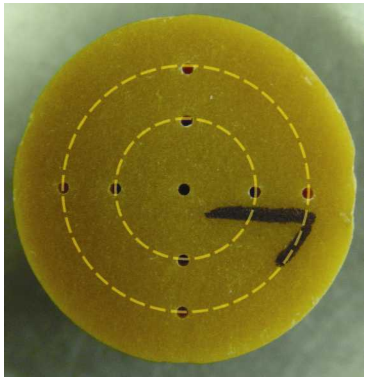
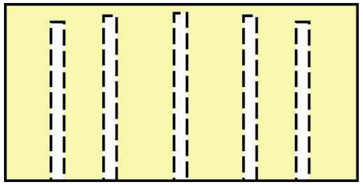
Heated-Plunger Test Bed (Pneumatic)

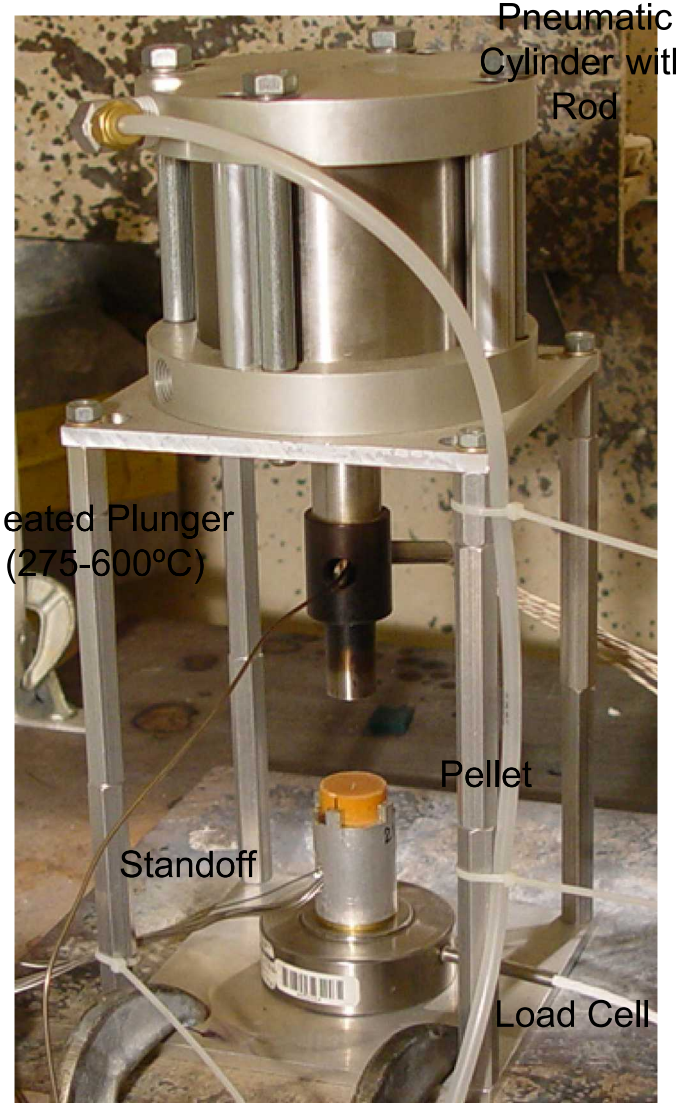
- 1-D heating of HE
- Internal HE temperature measured
- Observed material responses:
  - gas generation; flame; melting
- Experimental Details:
  - PBXN-109, PBX-9501, CompB
  - Plunger temperatures up to 600°C
  - Plunger-HE impact velocity ~3 cm/s
  - Pellet specifics



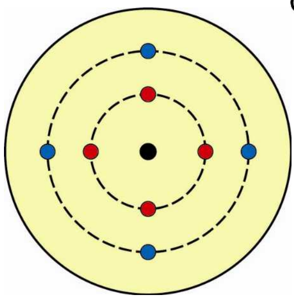
Bottom view

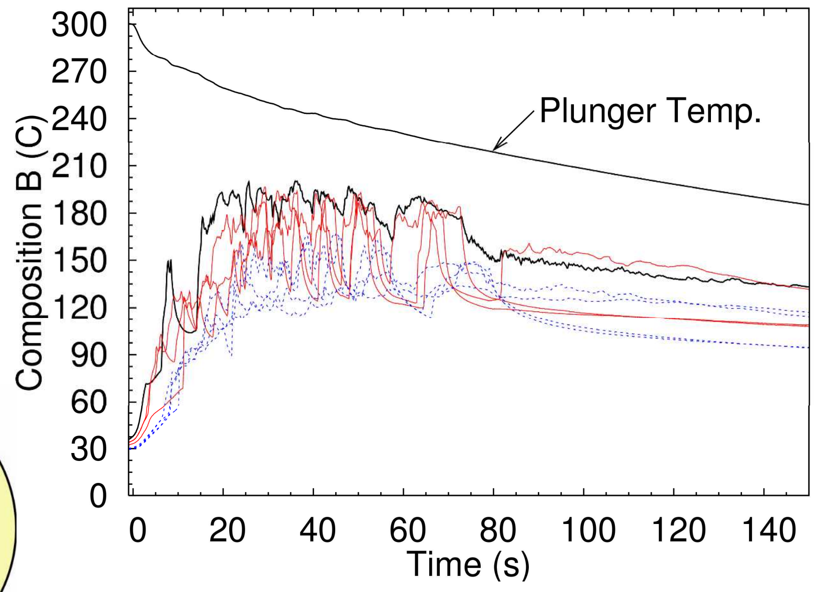


Side view



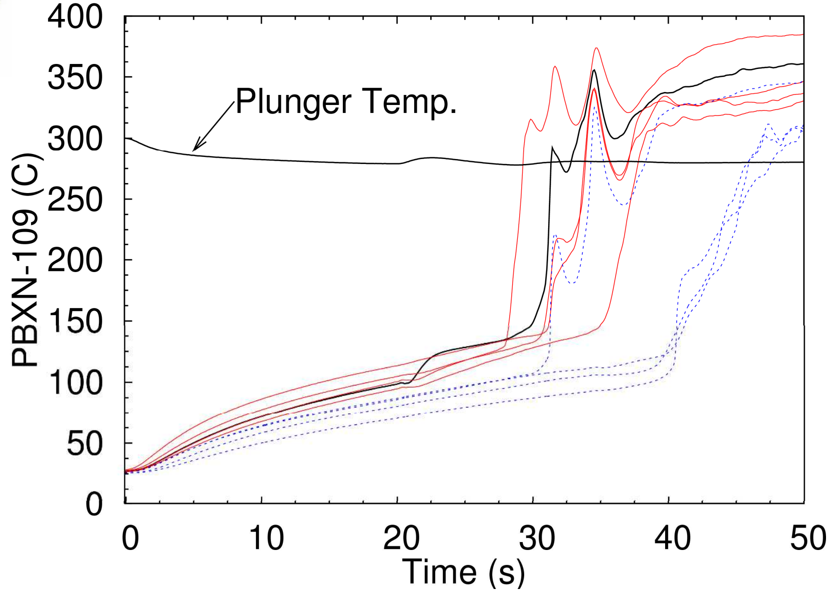
Temperature Histories
300ºC Initial Plunger Temperature





CompB

- TNT melt
- Temperatures do not exceed plunger T
- No ignition



PBXN-109

- Gas generation ~22s
- TCs exceed plunger T ~30s
- Ignition

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Time-to-Event Data

Plunger (C)	PBXN-109	PBX-9501		Comp B
	Δt (gas)	Δt (gas)	Δt (flame)	
600	0	0	0.25	---
450	0	0	14.2	---
400	---	0	21	---
350	10	1.5 (3/3)	42 (1/3)	---
300	22	30.5 (1/3)	128.7 (1/3)	TNT Melt only
275	38.5 (2/3)	---	---	TNT Melt only

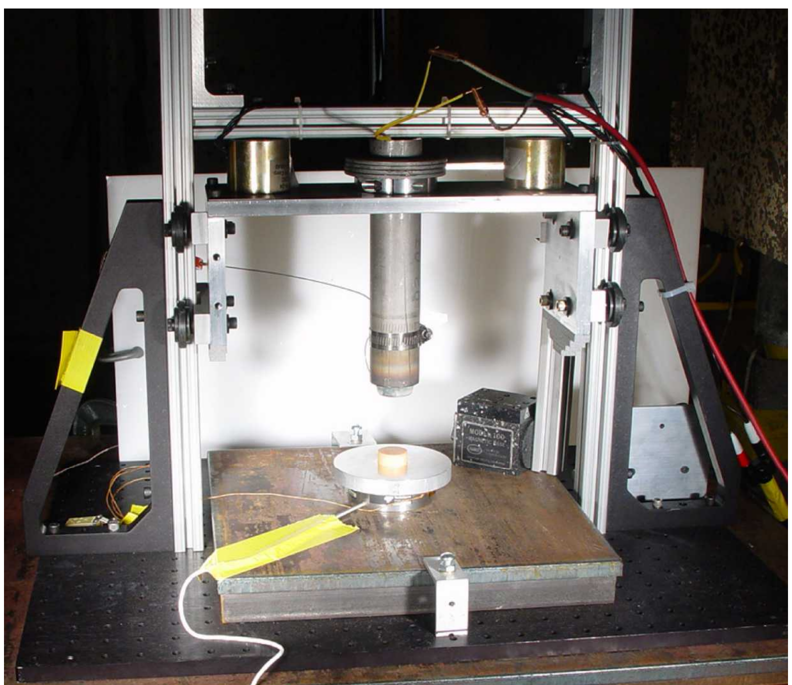
PBXN-109 (350 C)

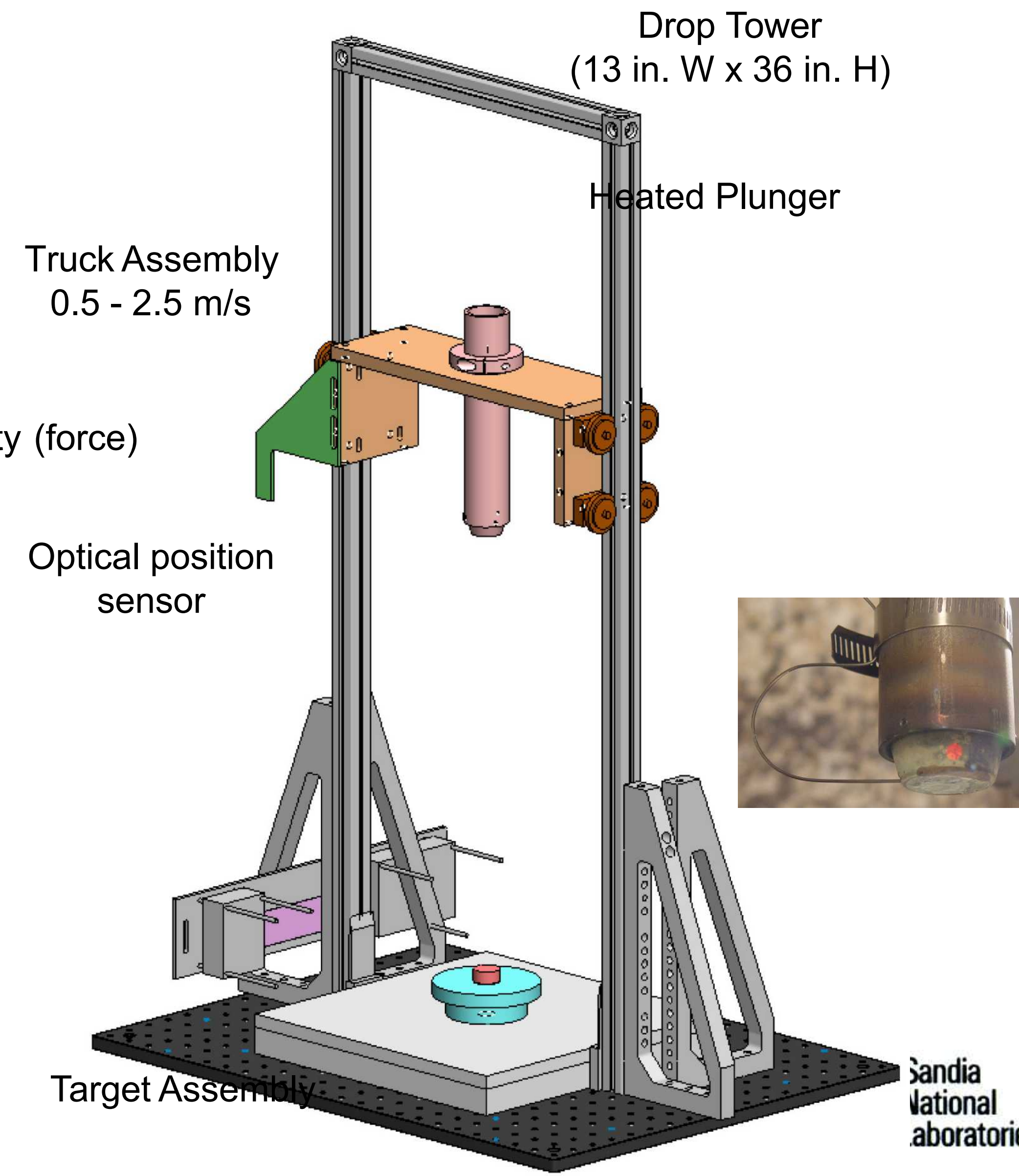
PBX-9501 (400 C)

Comp B (275 C)

Heated-Plunger (Drop Tower)

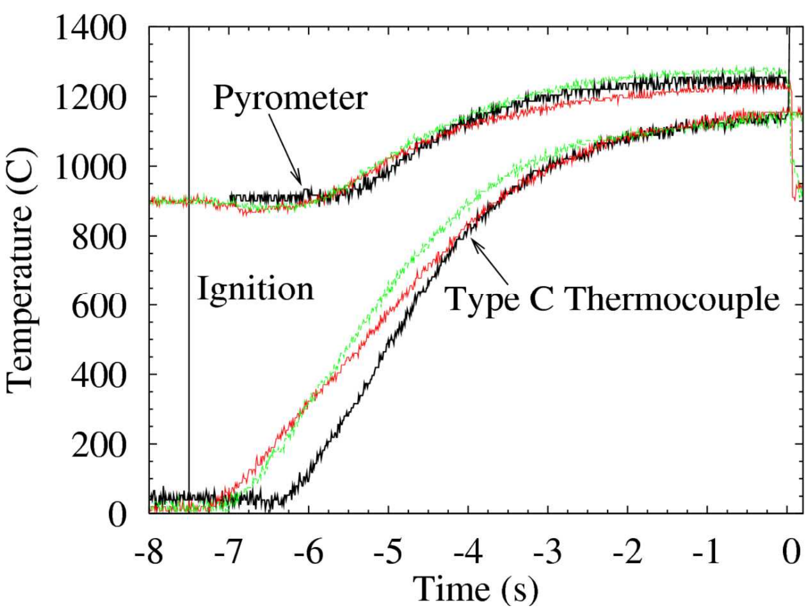
- Target Assembly
  - 1-in dia. x 0.5-in thick HE pellet
  - Load cell under pellet
  - 1.5-in Steel base plate
- Heated Plunger
  - Stainless steel collar
  - Pure Tungsten 15-cc crucible
  - Al + Iron(III) Oxide thermite
- Available test parameters
  - temperature (<1400°C), impact velocity (force)

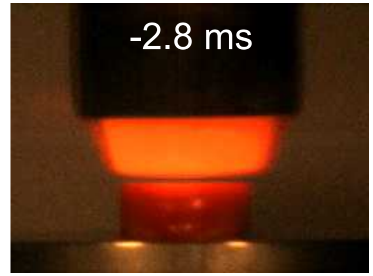


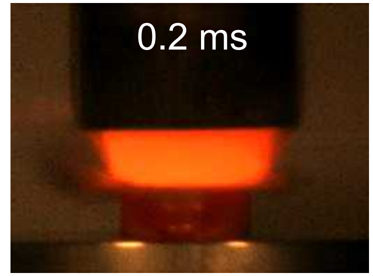


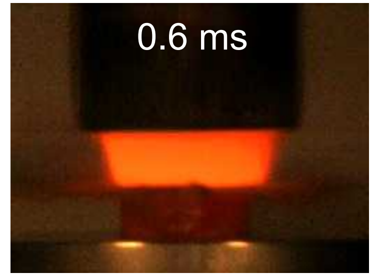
High-T, Heated Plunger Test Results

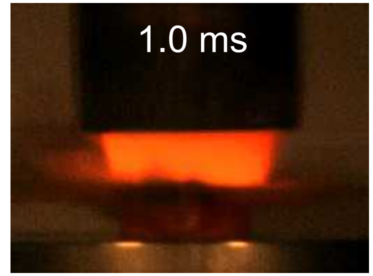
- Time-to-event determined from video
- CompB – spray of melted material upon impact, no ignition of bulk material
- PBX9501 – ignition of bulk material
- PBXN-109 – significant gas generation observed followed by ignition of bulk material.











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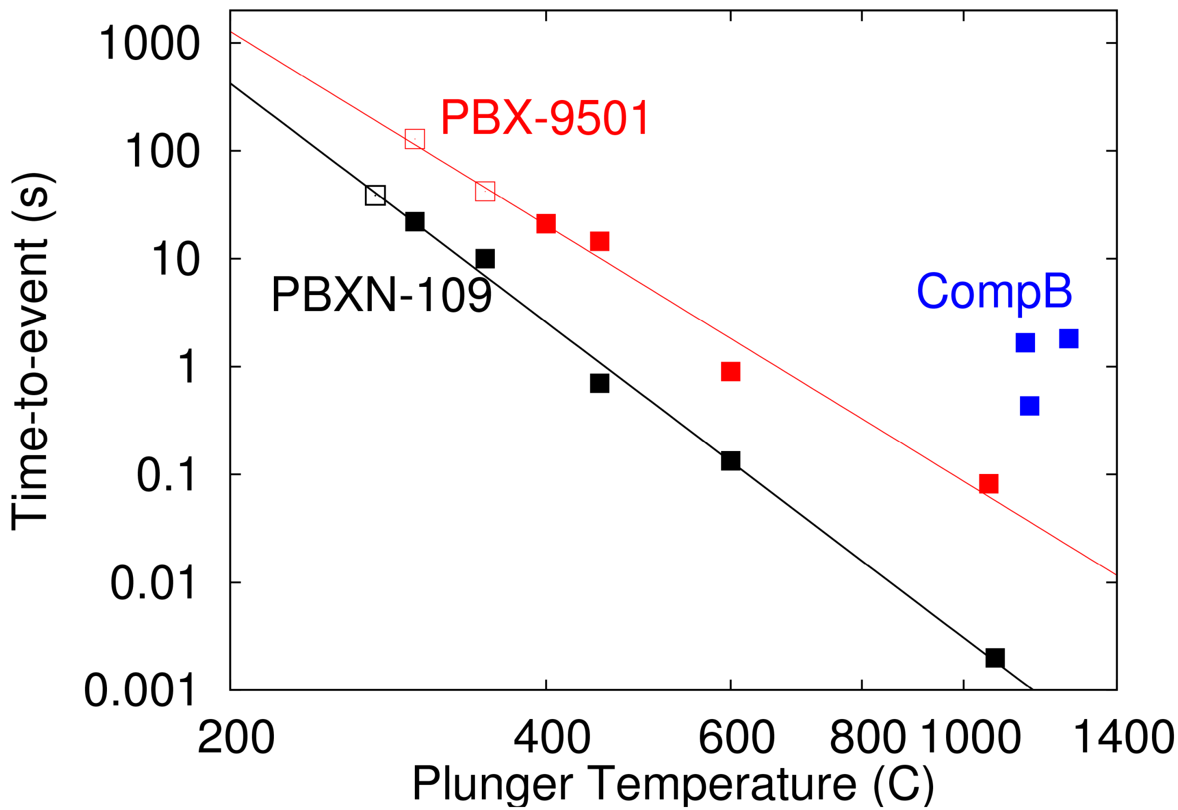
Time-to-Event Summary



- Unconfined FCO event times measured – thermite-heated plunger increases temperature range.
- Ignition observed for 1057C plunger temperature and PBXN-109. Previously, only gas generation observed.
- Variation of observed "event" at low plunger temperatures likely affected by material variations, contact between plunger and HE, etc.
- Significant gas generation observed for both materials means that confinement is important.
- Data represented by power function (R^2>0.98): $\Delta t = A * T^B$

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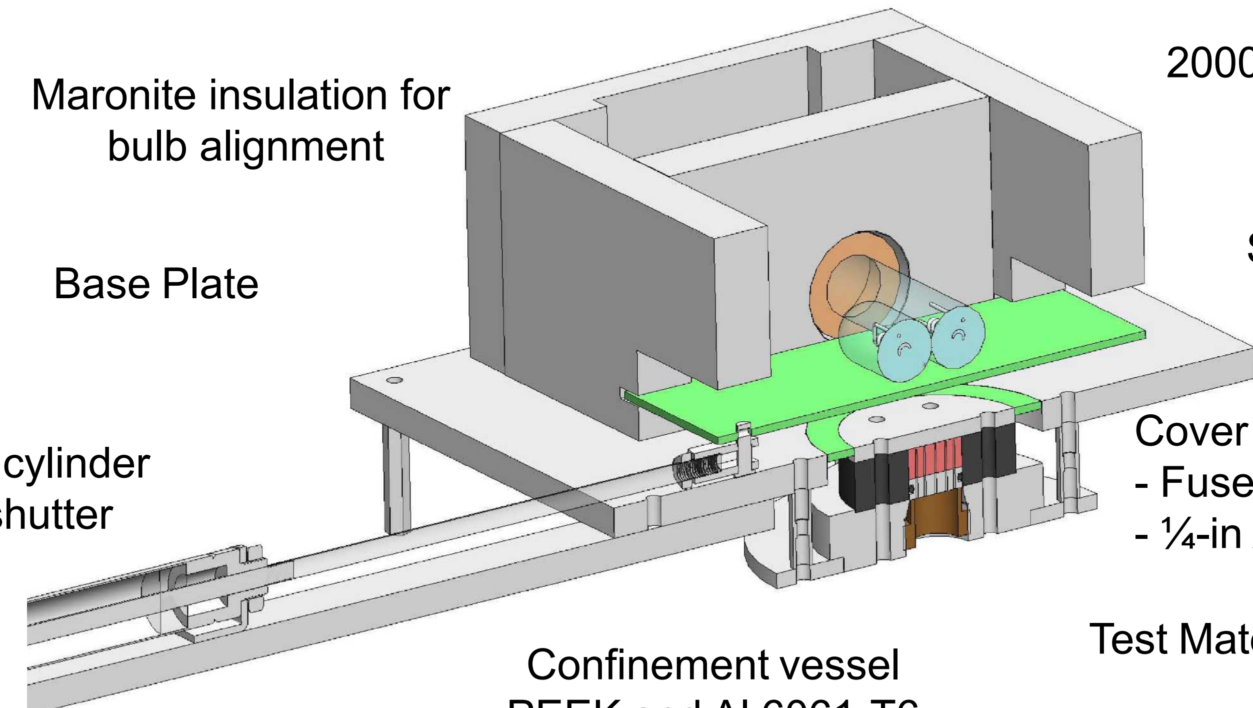
Radiant-Heat Test Bed

- Radiant-heat test bed developed to address experimental challenges associated with contact heating
- 2000-W quartz lamps
  - fast time response
  - high wattage; high filament temperature
- Confinement vessel – aluminum shim with pyromark and fused silica cover
- Non-contact heating enables access to confinement surfaces for additional diagnostics (strain, surface velocity, etc).



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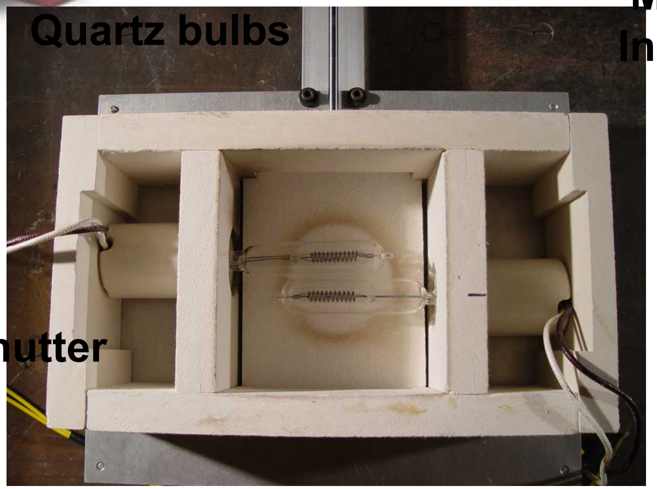
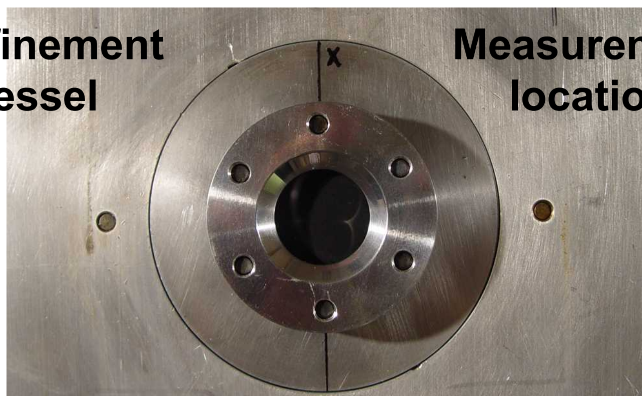
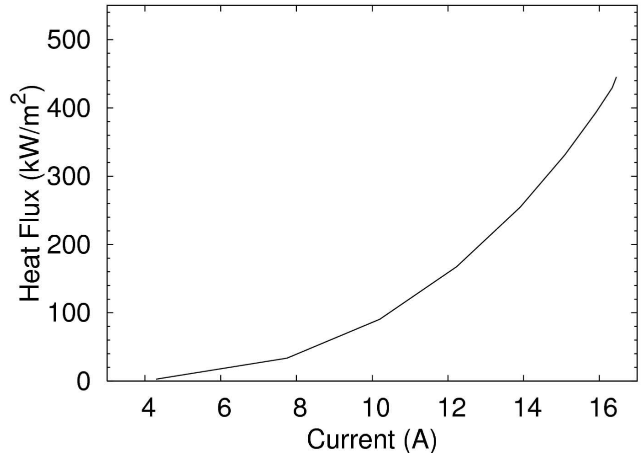
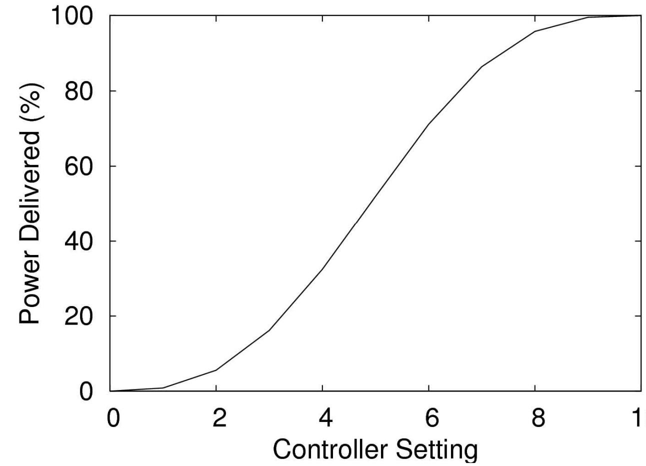
Heat Flux Measurements









- Measured incident heat flux as function of current delivered to each bulb. Power to bulbs varied with Omega “Phase Angle Fired” SCR Power Controller.
- Incident heat flux measurements obtained with Vatell Thermogage Circular Foil Heat Flux Transducer, surface emissivity 0.94
- 2 bulbs needed to achieve desired heat flux range

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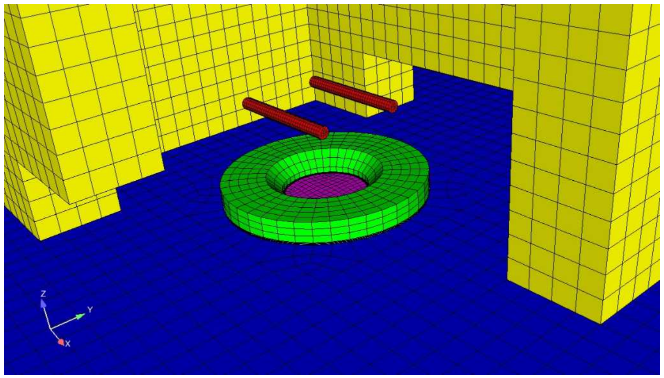
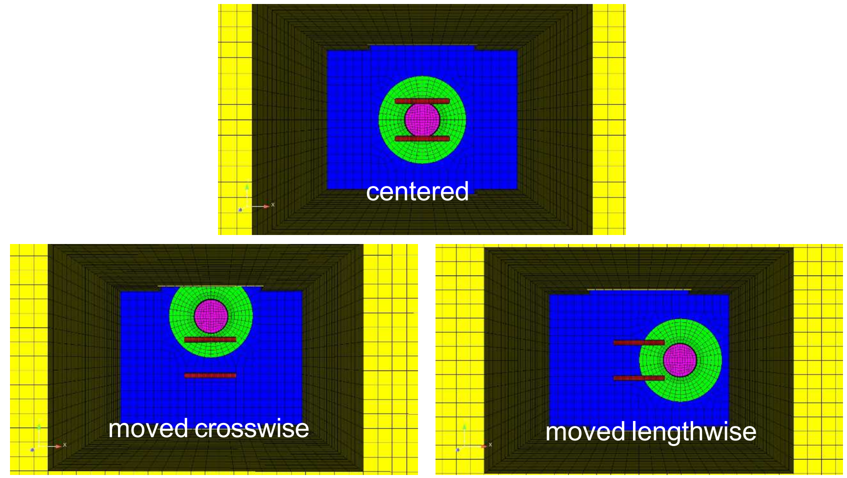
Full 3-D Models for Representing Radiant Heat Flux Boundary Condition

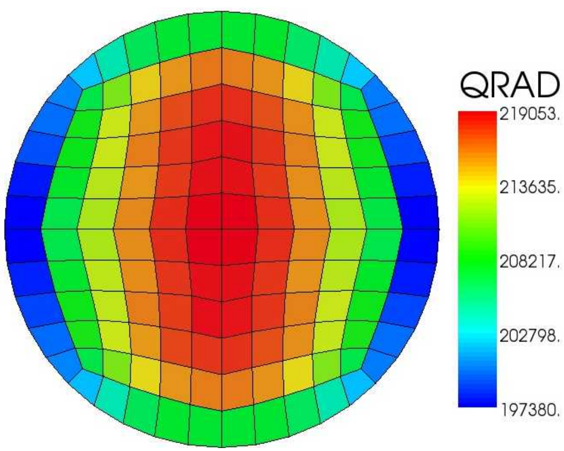
Model of radiant heating apparatus with two lamps



Radiant heating distribution within box was "mapped out" by moving the heat flux gauge.

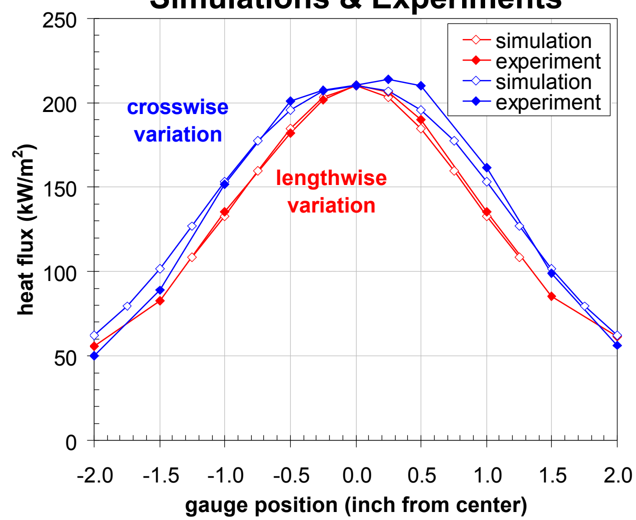


Flux distribution on the 1 inch diameter gauge face produced by two lamps.



(max to min varies by ± 11%)

Flux Mapping within Box: Simulations & Experiments



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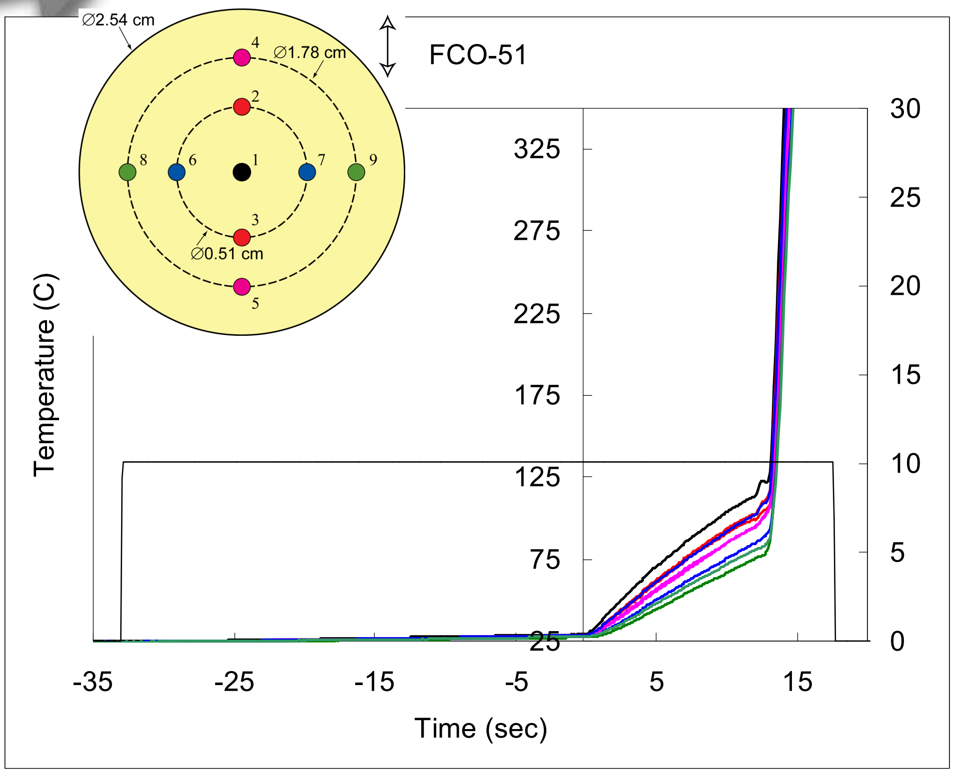
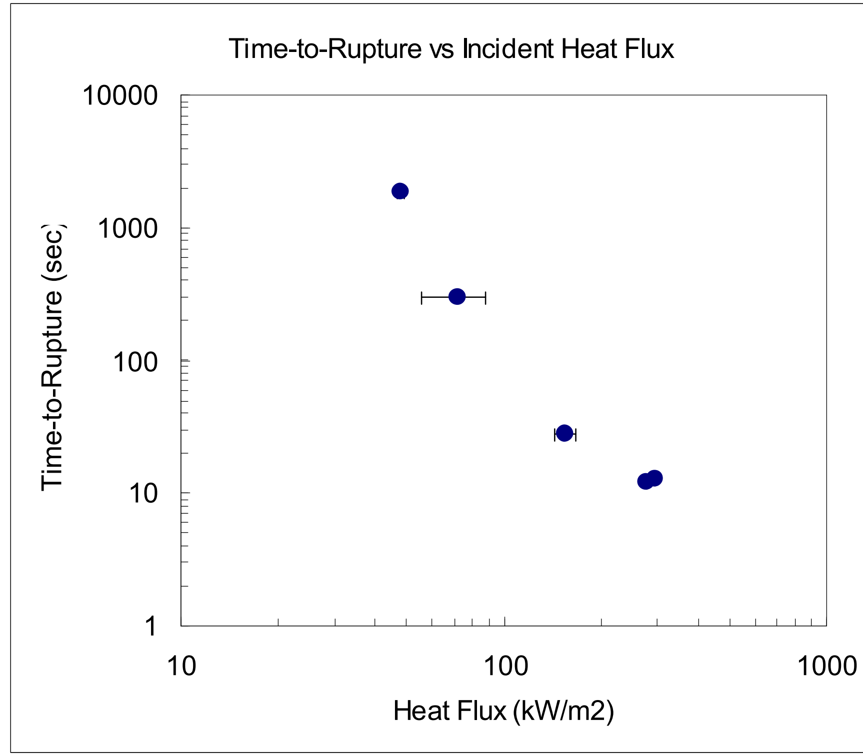
PBXN-109 Results





- 294 ± 2 kW/m^2 incident heat flux.
- Power on at t = -33 sec.
- Shutter open at t = 0 sec.
- Confinement ruptured at t = 13 sec.
- Temperature at rupture = 122°C

- Tests conducted varying incident heat flux
- Trend of time-to-rupture observed
- Final event varied from unreacted material to material ignition

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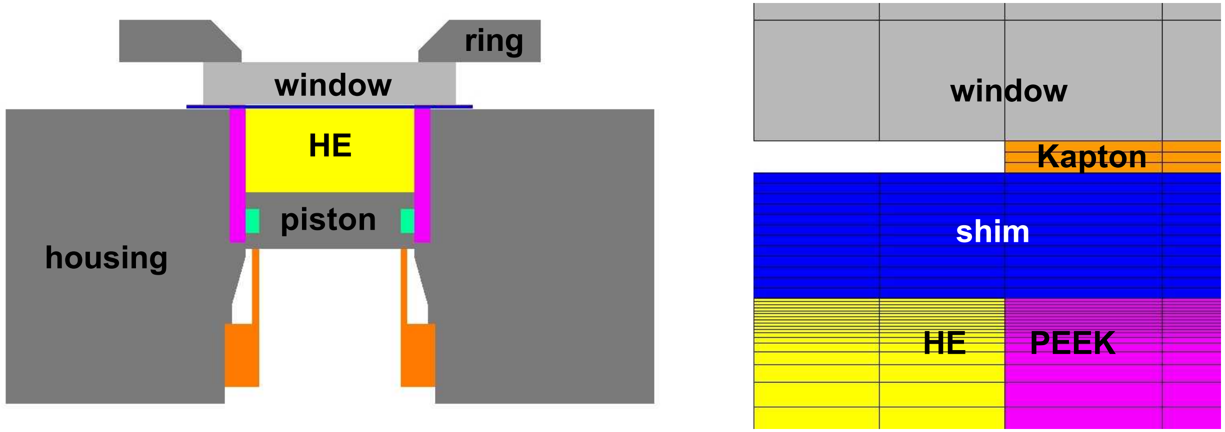
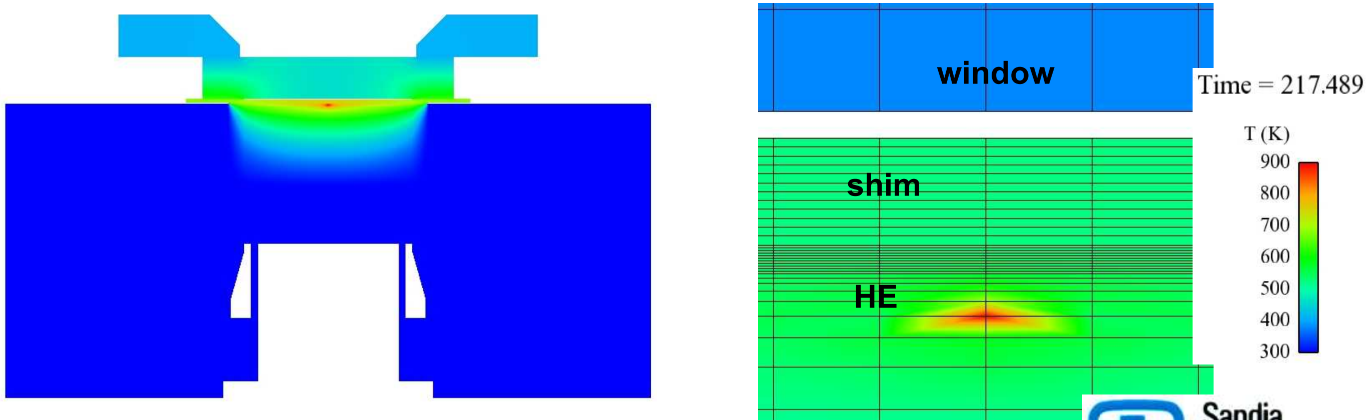
Simplified Models for HE ignition

- simplified models were built of apparatus. The full model (including lamps, etc.) became exceedingly large and complex given the fine mesh required to capture HE ignition.
- a fine mesh was used in upper portion of HE (12.7 µm spacing, then graduated)
- constant flux boundary condition applied on shim (not on window, ring, or housing)
- a 1-D model was also developed (not shown) which included only the shim and HE; this was meshed very finely (1 µm spacing on upper portion of HE)

Slice of 2-D Axisymmetric Model



Results for 75 kW/m^2 Imposed Heat Flux



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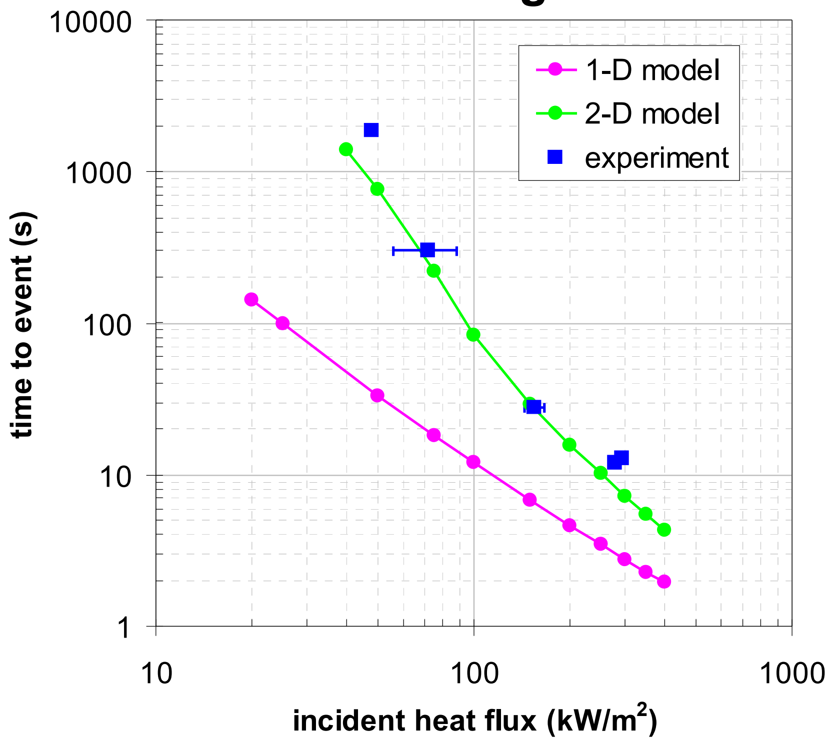
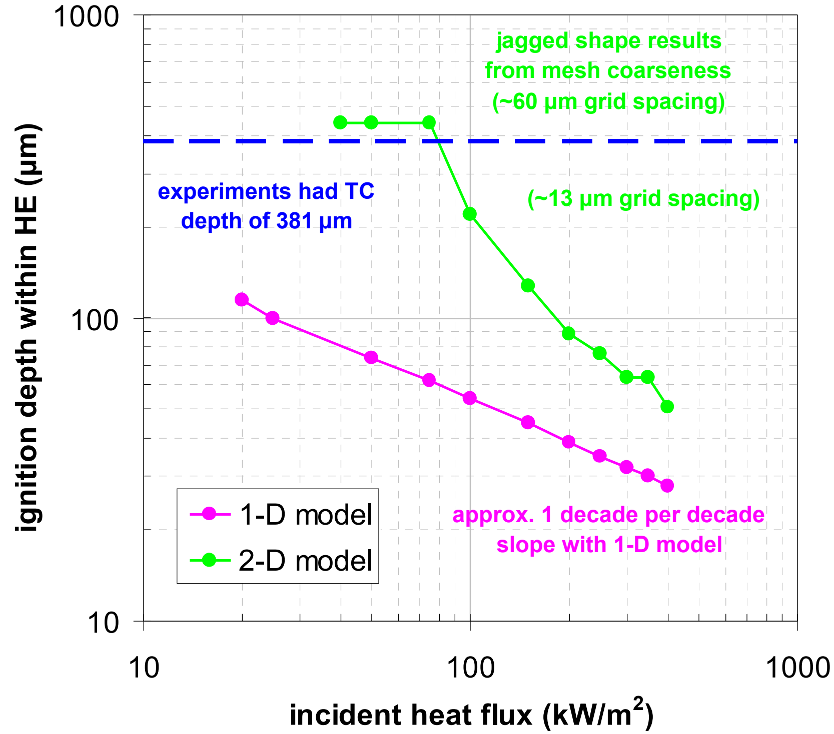
Simplified Models for HE ignition

Time to Ignition



Ignition Point Depth



- The model for PBXN109 chemistry developed during a previous joint project with the Navy was applied to this geometry.
- 1-D does NOT adequately represent time to ignition results—multidimensional heat transfer effects clearly play a role
- 2-D model reproduces measured time to ignition trends reasonably well at moderately high flux levels. At low flux levels, heat losses to un-represented surrounding material become relatively more important; this has not been captured in the current 2-D model.
- We expect the thermal runaway may be difficult to capture experimentally with the 381 µm TC location depth.

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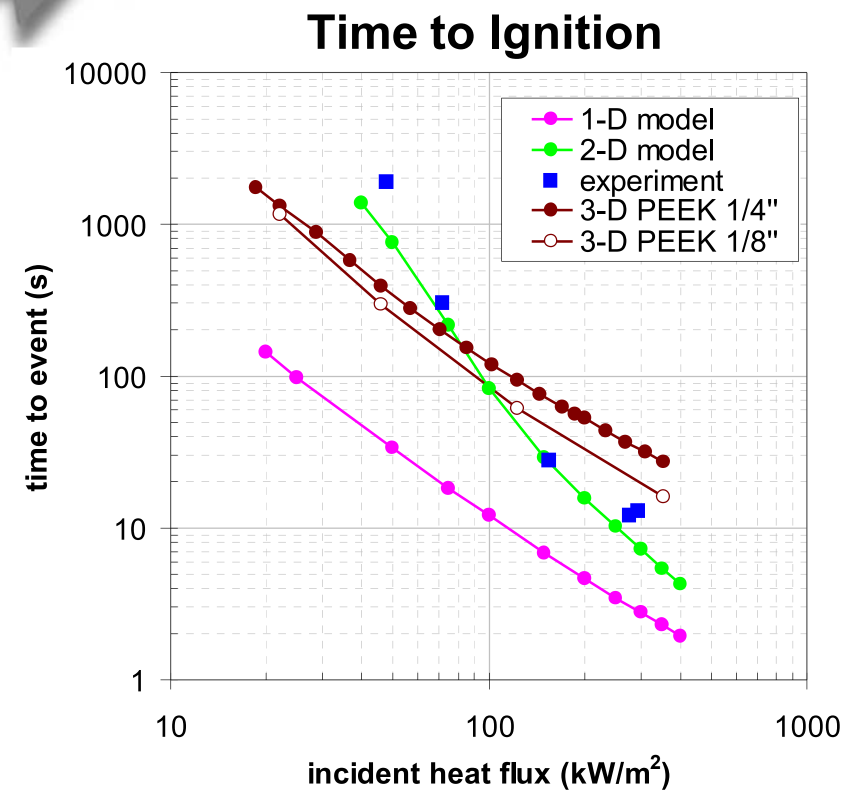
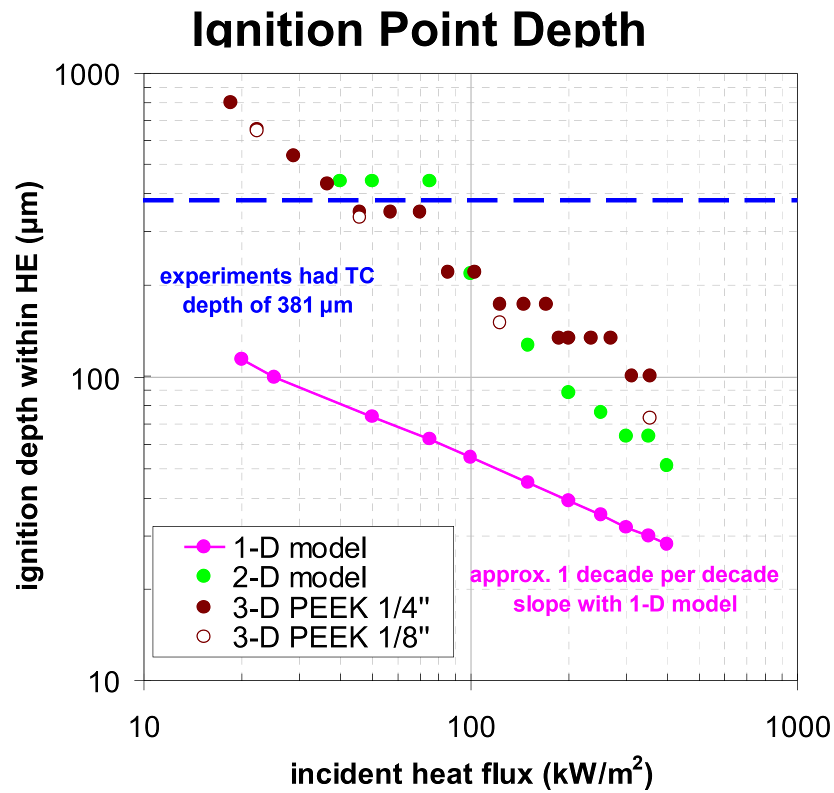
Simplified Models for HE ignition





- Updated model for metal cover plate. 3-D demonstrated 1-d heat flow through explosive pellet.
- Experiments in progress.

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Summary and Future Work

- Recent accomplishments with SCO and FCO experiments investigating pre-ignition behavior
  - Extended temperature range of data for unconfined EM using heated plungers
  - Radiant heat FCO experiment has been designed and capable of representing heat flux conditions of cross-wind pool fires. Ongoing improvements to design for correlation to model development
  - Initial modeling results demonstrated previously with heated plunger experiment and demonstrated with radiant heat experiment.

- Future work
  - testing to continue with explosive pellets in radiant heat experiment (PBXN-9)
  - thermochemical modeling and analysis of radiant heat experiment to continue
  - additional diagnostics to address confinement expansion and control of rupture