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Experimental Characterization of Foams in Fire Environments

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Foams provide thermal, mechanical, and electrical isolation in engineered systems

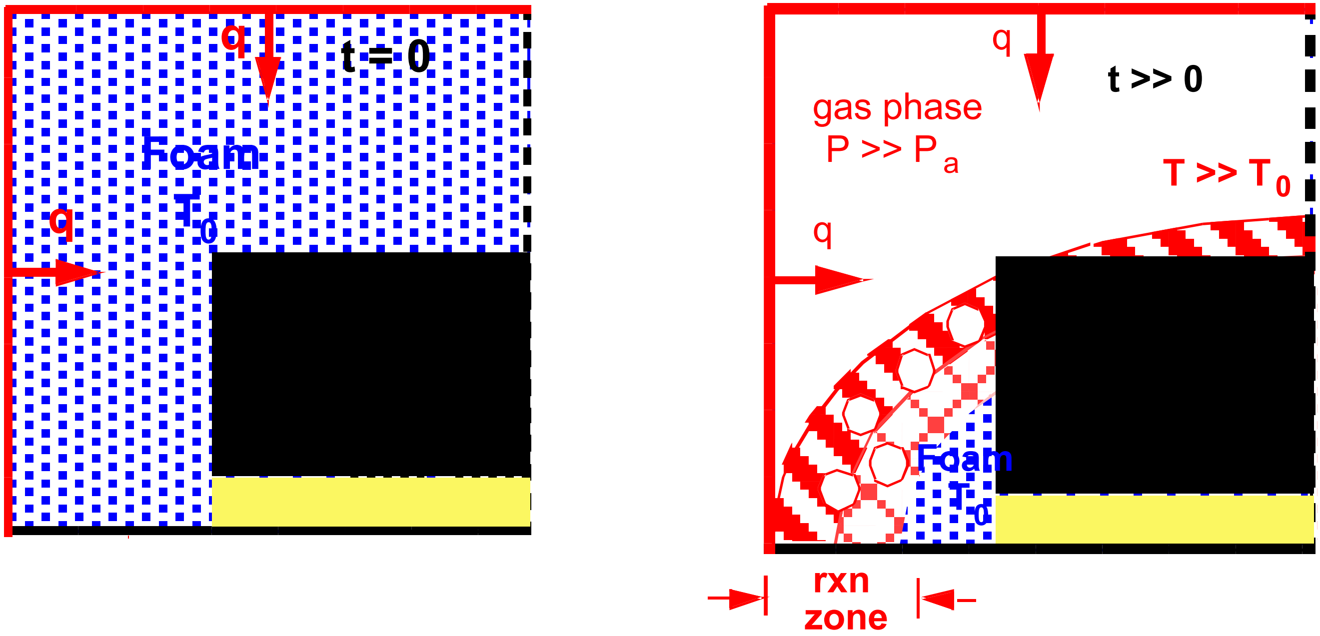
System safety analyses use numerical models to predict system responses in fire environments:

- Heat transfer to sub-systems that are encapsulated in foams and are usually in inert environments.
- Pressurization and failure of sealed containers as a result of gas generation from foam decomposition caused by the incident heat flux from a fire.

Reliable analyses require coordinated experiments and model development/evaluation

- This paper address experimental work
- Roy Hogan's paper addresses modeling work

Hazard analyses can involve coupled thermal, chemical and mechanical phenomena



- Heat transfer: conduction, convection, and radiation
- Foam decomposition chemistry and gas/vapor generation
- Thermal-mechanical failure of sealed containers

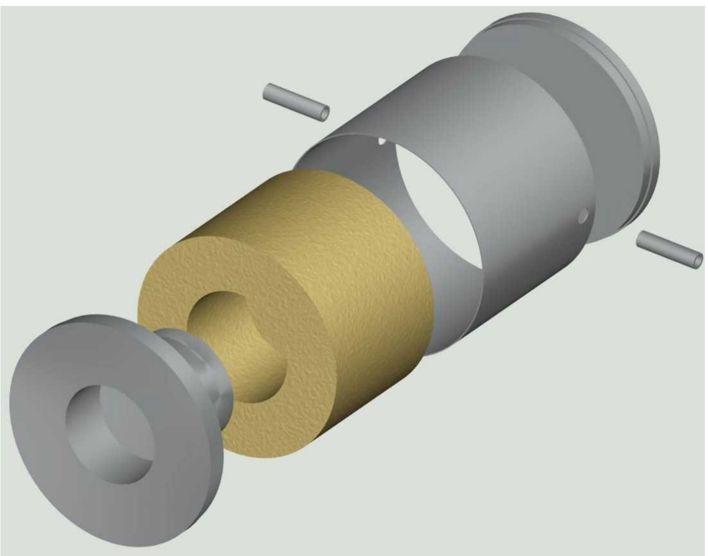
Numerical models requires input from multiple experimental techniques:

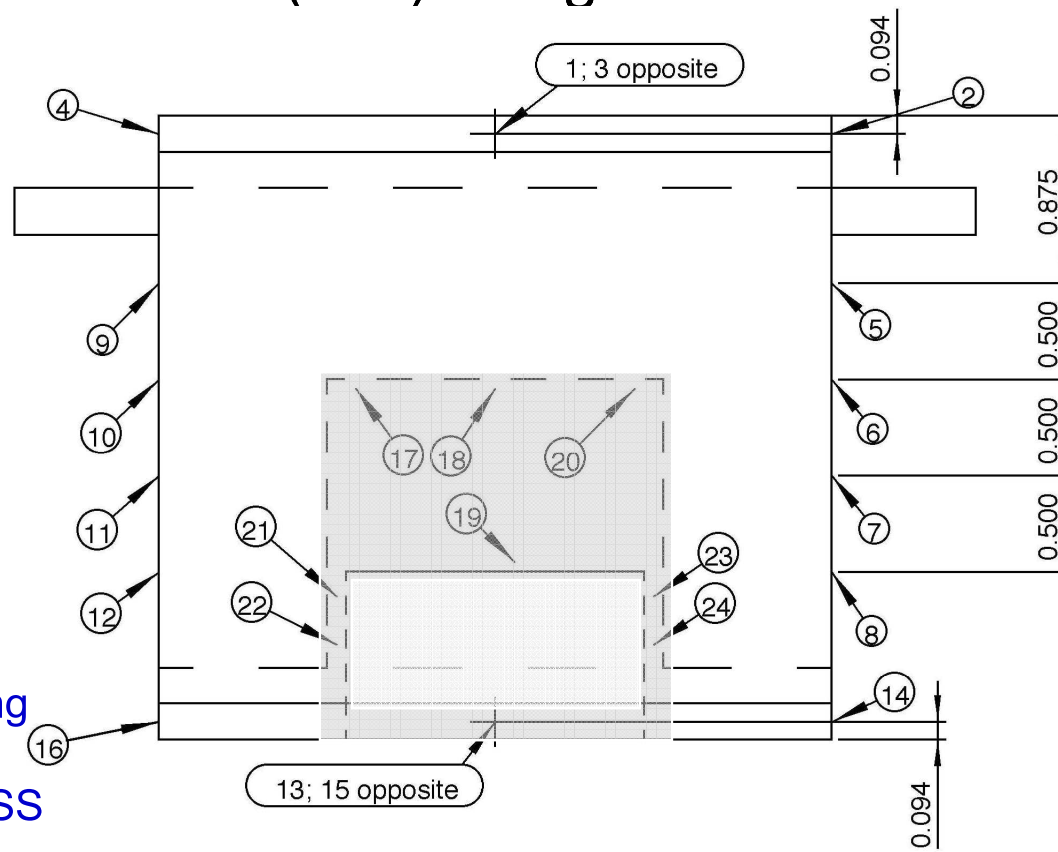
Laboratory experiments (DSC, TGA-FTIR, pyrolysis-GC-FTIR, and other) provide material properties:

- Thermal properties
- Decomposition chemistry: rate data, evolved gases (infer reaction mechanisms and kinetics)
  - Joint work: SNL & VNIIA (colleagues at mendeleev Institute and VNIIPO) - Joint journal article
  - Detailed examination of polymer (epoxy and polyurethane) decomposition mechanisms and evolved gas products: rate data, initial and secondary decomposition products, rate expressions
    - Examined effect of heating on relative rates of reaction in TGA experiments.

Larger-scale experiments are necessary for model development and evaluation

Thermal transport and container pressurization experiments were done using a “foam-in-can” (FIC) design



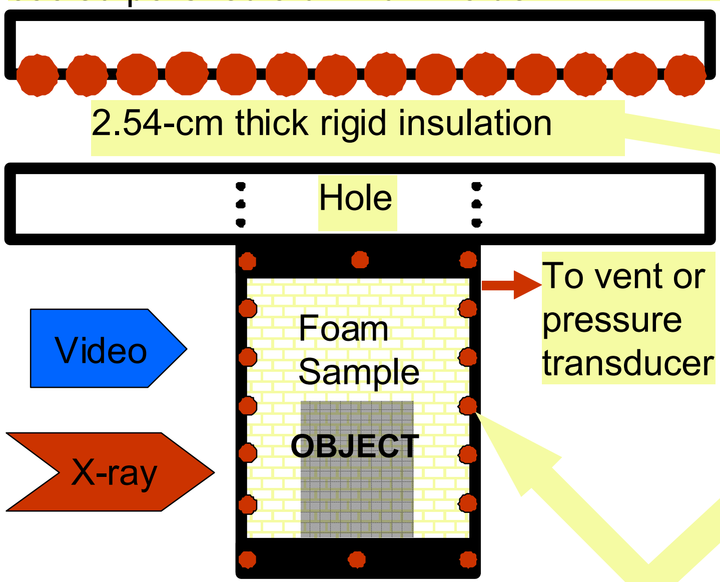


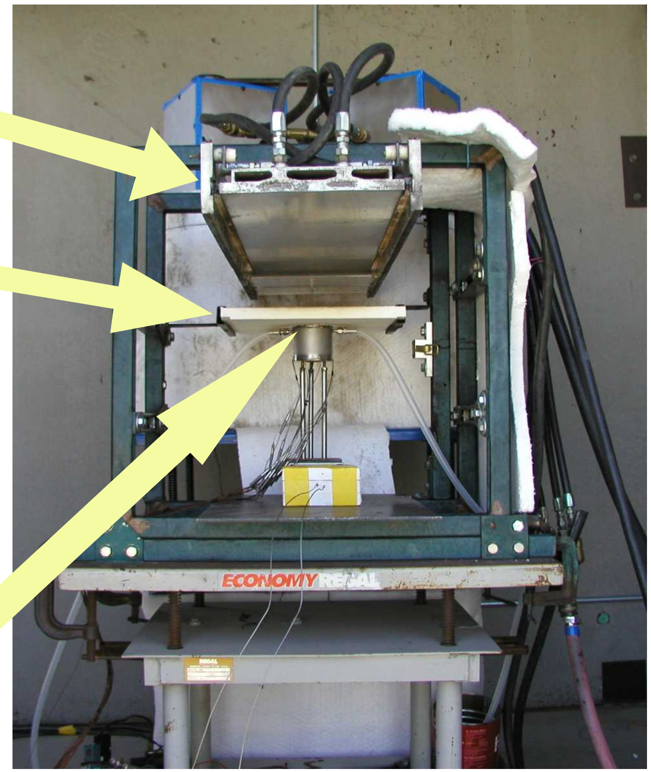
Sample container

- Sleeve 321 SS tubing
  - 8.89 cm OD, 5 to 15 cm long
  - 0.508-mm wall thickness
- End plates: 0.635-cm thick 304 SS
  - E-beam welded to Sleeve

Experiments examined physical phenomena and provided data for model development & evaluation

Tungsten lamp (0.95-cm diameter, 25-cm length, 6 kW max. power) array in water cooled polished aluminum holder

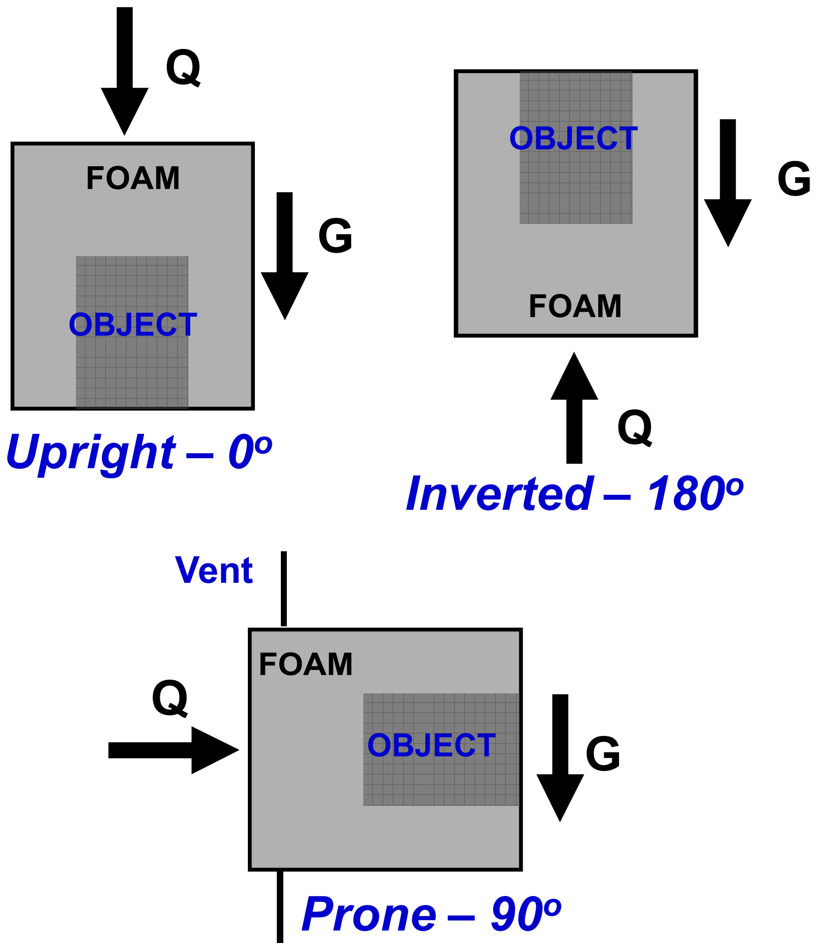


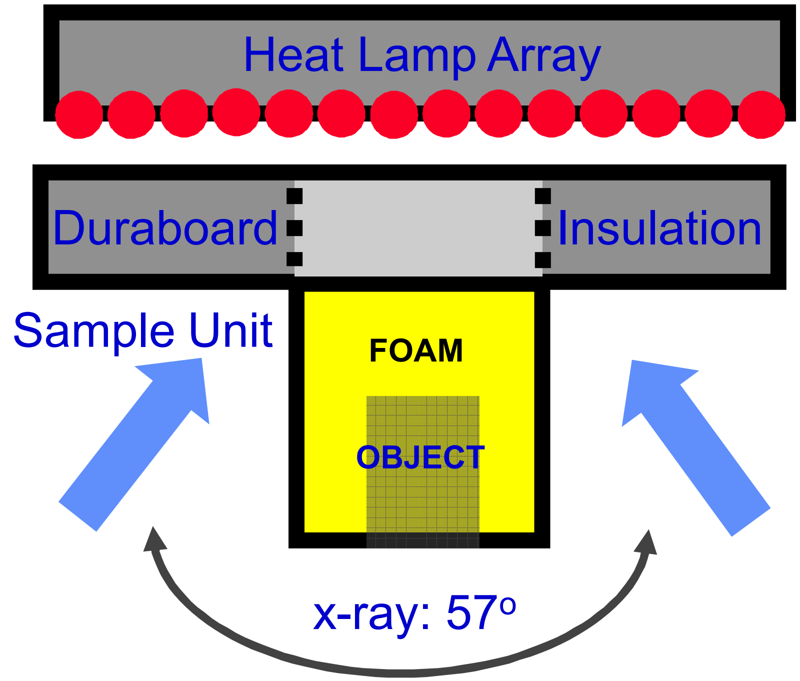


Cylindrical sample container
- Sleeve 321 SS tubing
- 8.89-cm OD, 5- to 15-cm length
- 0.508-mm wall thickness
- End plates
    - 0.635-cm thick 304 SS
    - E-beam welded to Sleeve

6 to 30 K-type thermocouples
- 0.81-mm OD, Inconel™-sheathed
- Controlling temperature of heated plate
- Monitoring temperature of container surface

Experiments were done with samples in three orientations





- Plate temperatures: 873 K to 1173 K
- Vented samples
- Sealed samples for pressurization

Liquefaction and flow were observed in several experiments

Several foams have been studied using a variety of conditions

Removable epoxy foam (REF) – SNL

Vented and sealed

TDI-polyester based rigid polyurethane foam (TDI-RPU)

Vented and sealed

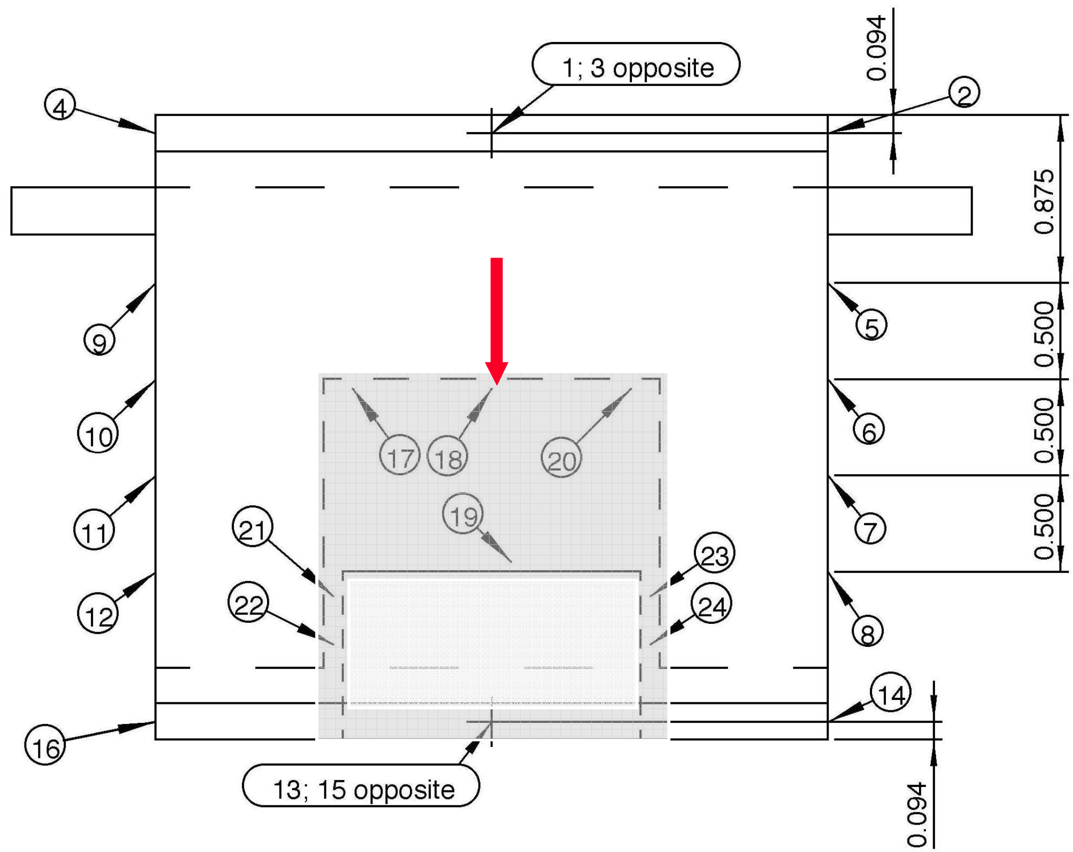
PMDI-polyether based rigid polyurethane foam (PMDI-RPU)

Sealed

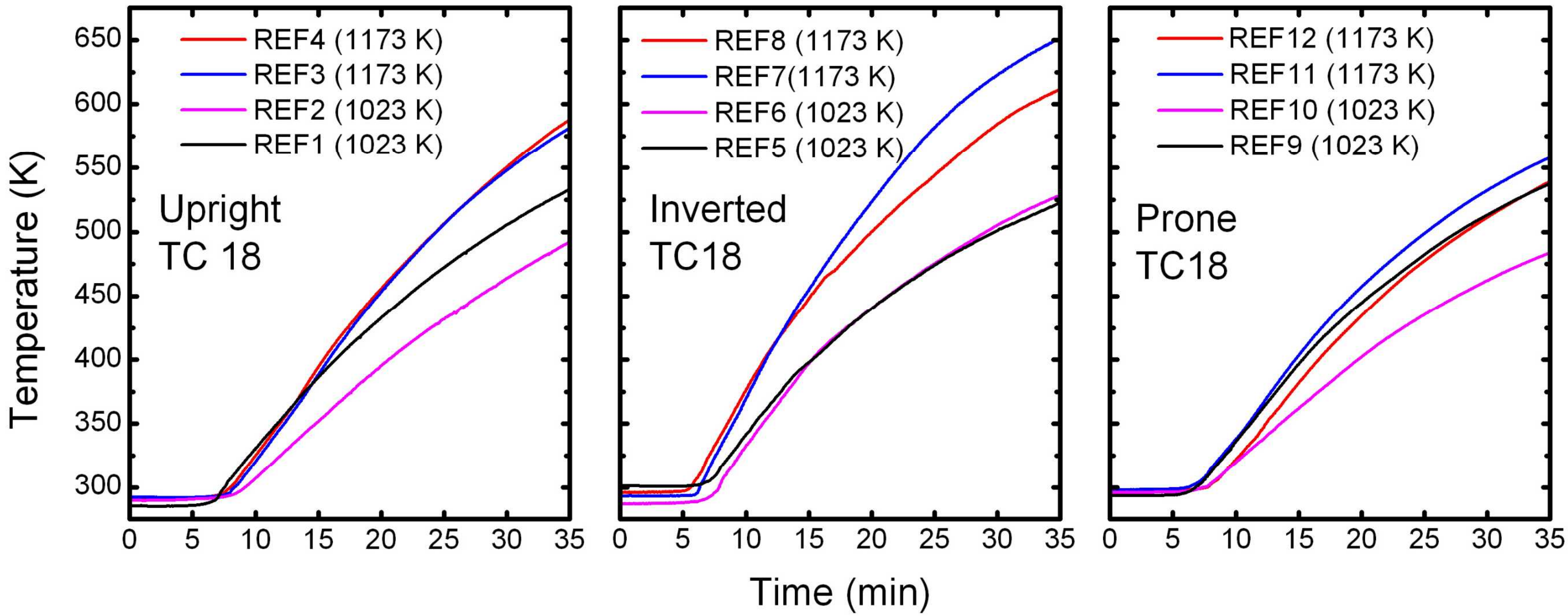
Hybrid epoxy-polyurethane-cyanate-ester foam rigid foam (HC foam)

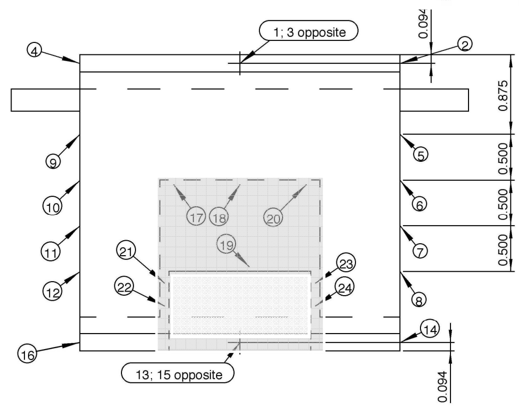
Vented and sealed

Experiments with vented samples examined heat transfer to foam encapsulated objects



Sample-to-sample temperatures varied more than desired with vented REF samples





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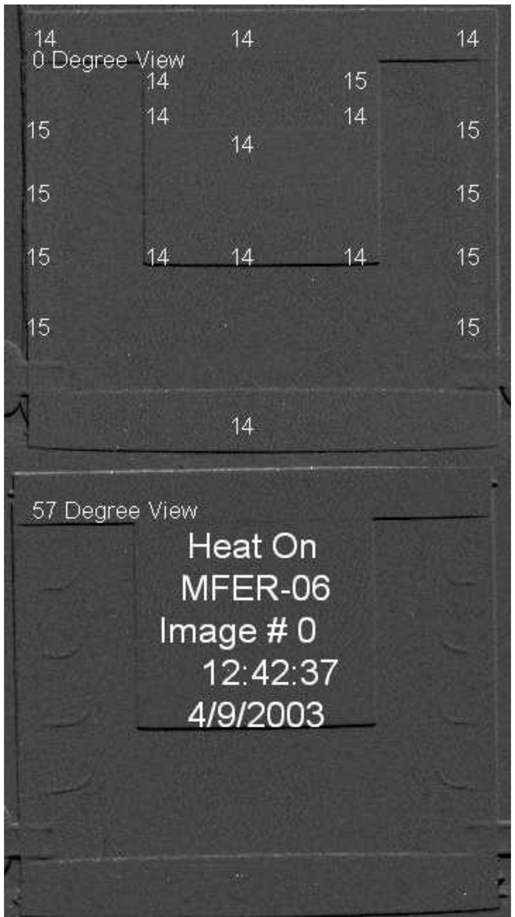
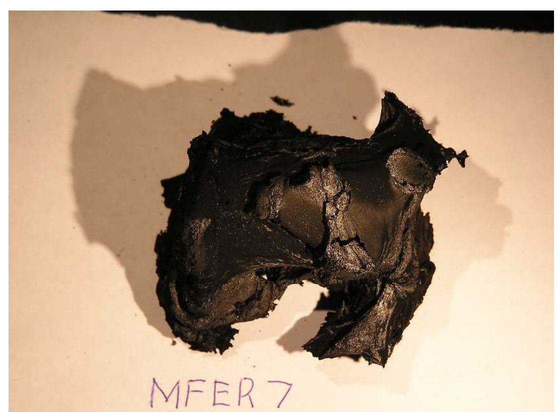
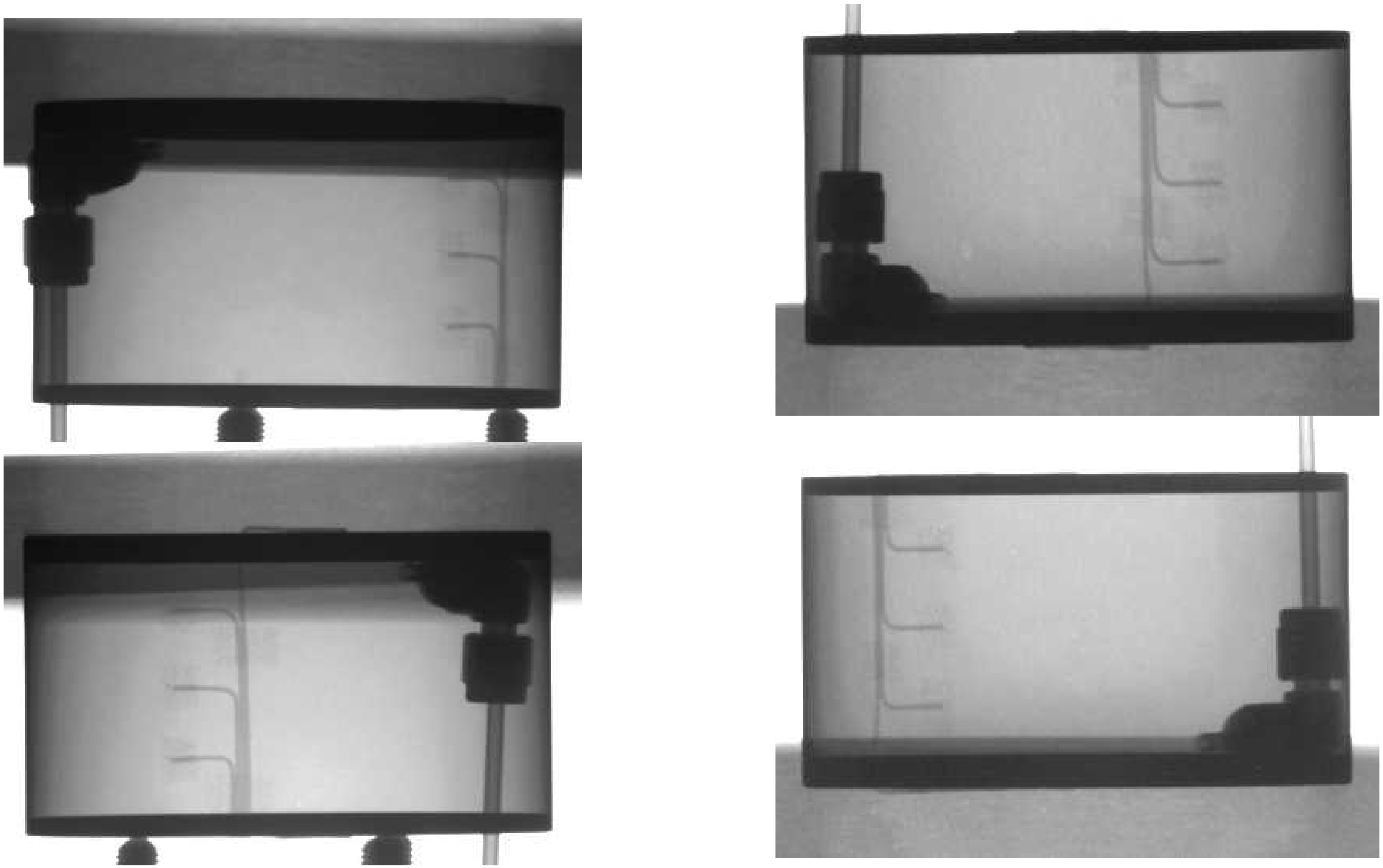
Irregular bubble-like char formed during experiments with vented REF samples

Char layers formed inconsistently and impacted radiant heat transfer to encapsulated objects.

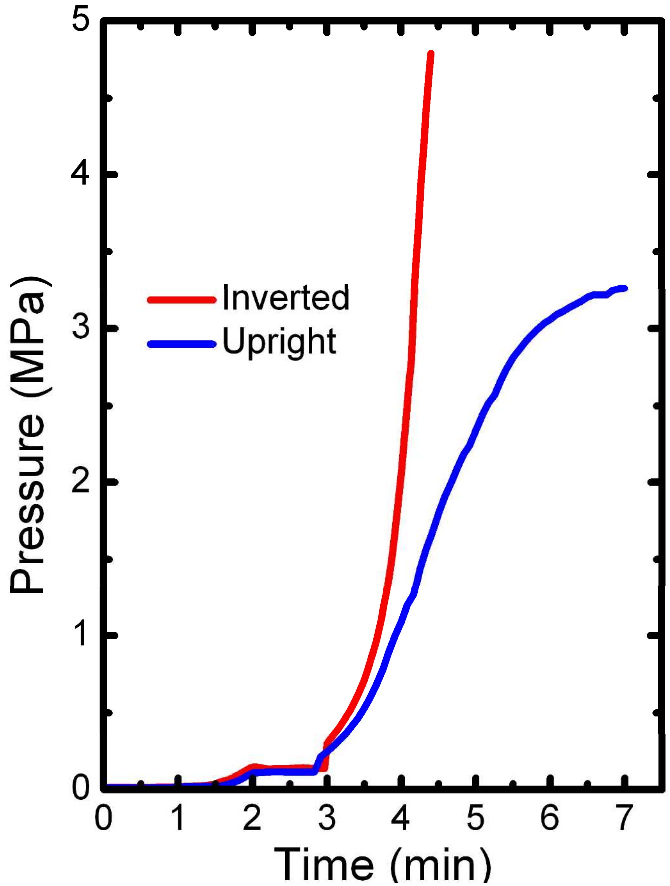




Erosive channeling and flow occurred during pressurization of sealed REF samples

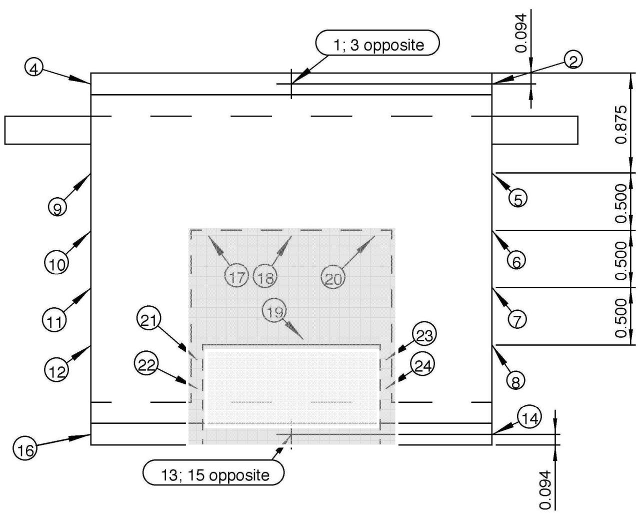


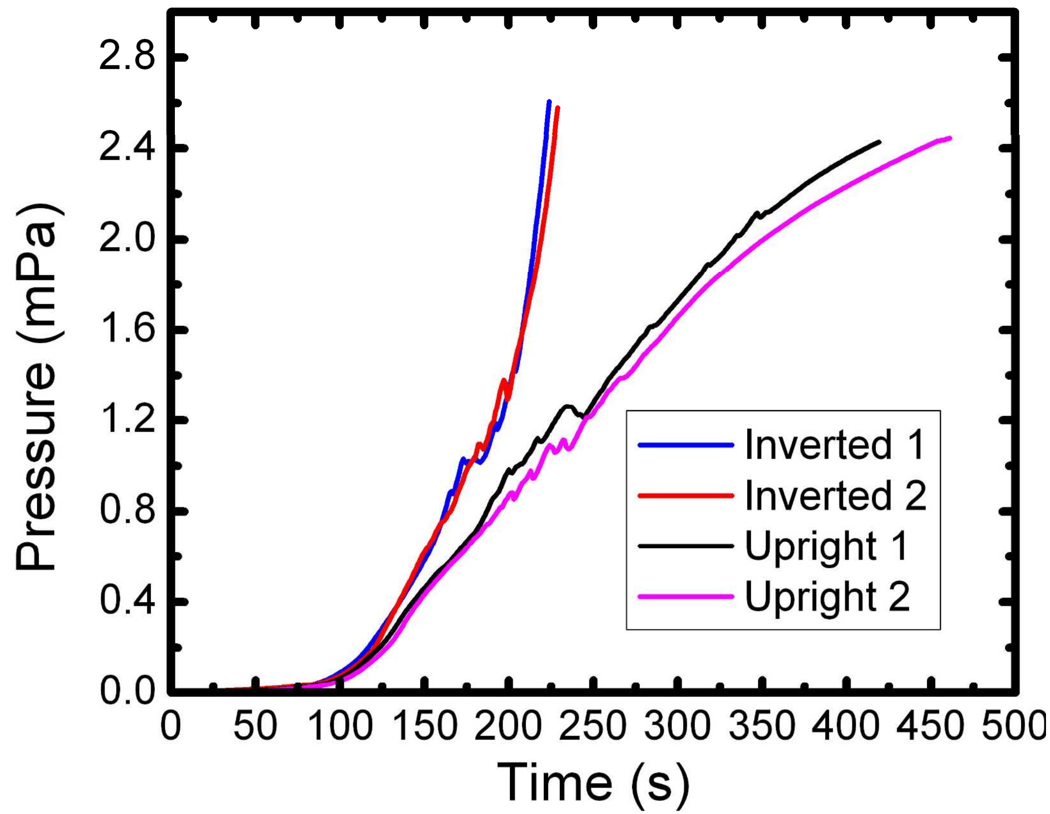
Rate of pressurization depended on sample orientation (direction of liquid flow)



Results from recent experiments with TDI-RPU produced similar results

Heated plate: dT/dt = 200 K/min --- set point temperature = 900 K





X-ray images indicated channeling, liquefaction, and flow

Developing models for coupled decomposition, liquefaction, and flow is challenging

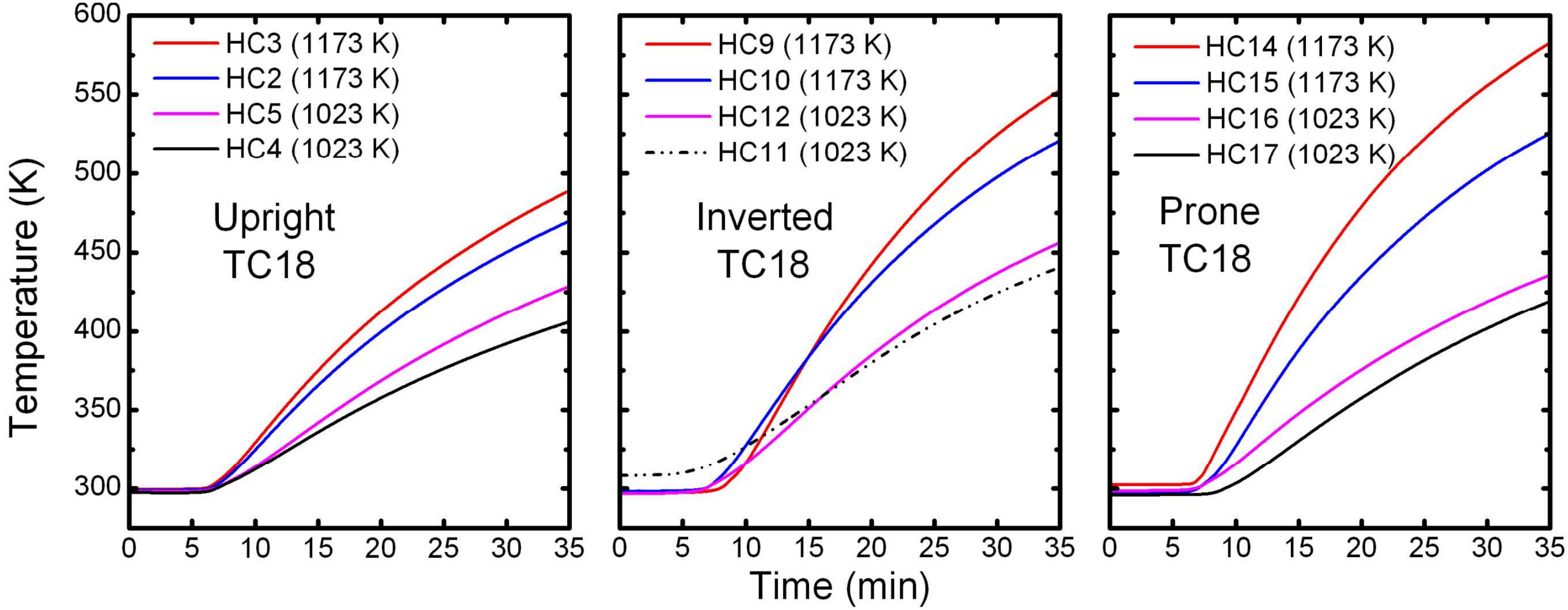
Particularly when

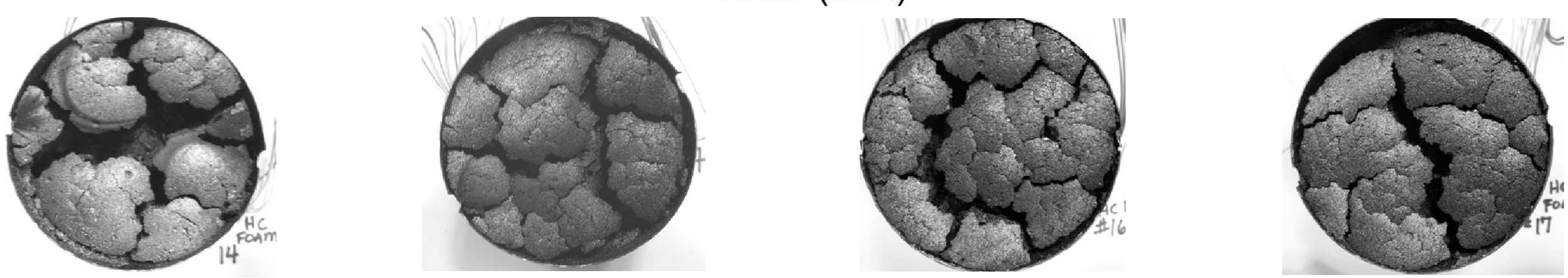
- Erosive channeling and/or pressurization occurs in sealed containers
- Irregular bubble like char evolves inconsistently and unpredictably

Alternative: Develop highly charring foam(s) that

- Char uniformly/predictably & do not liquefy/flow
- Have physical and chemical properties amenable to modeling with available radiation-conduction heat transfer codes

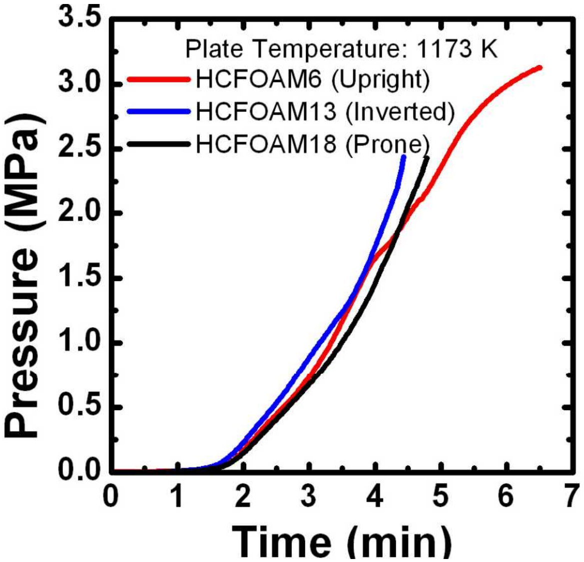
Sample-to-sample temperatures varied more than desired with vented REF samples

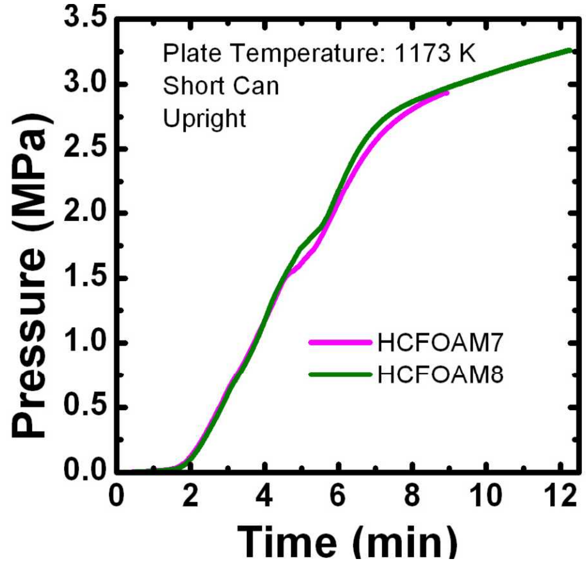


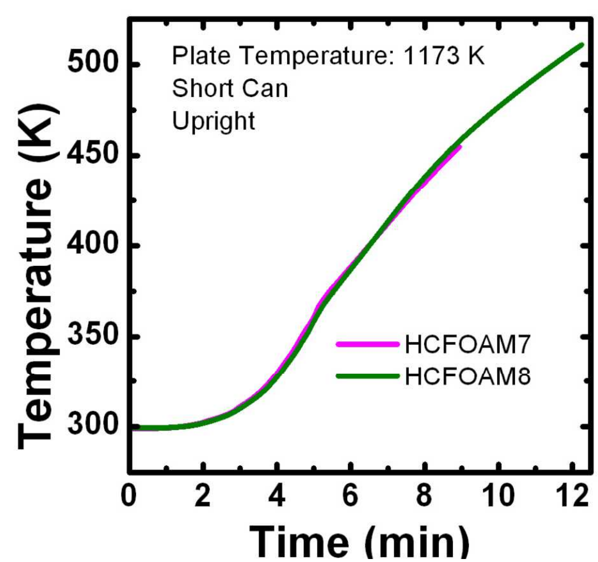


HC Foam 14 HC Foam 15 HC Foam 16 HC Foam 17

Results from limited *FIC* experiments with sealed samples were also encouraging

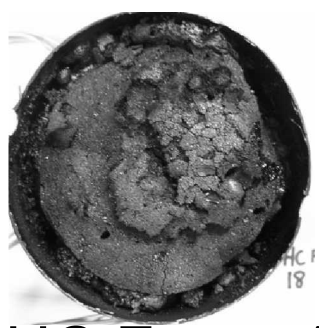






HC Foam 6
(Upright)

HC Foam13
(Inverted)



HC Foam 18
(Prone)

HC Foam 7
(Upright)

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Results of FIC experiments have implications for model development and evaluation

- **Examined heat transfer to foam encapsulated objects and pressure growth in sealed containers during decomposition in inert environments**
- **Physical behavior of foam depended on thermal and physical boundary conditions. Observed:**
  - Liquefaction and flow due to gravity
  - Two-phase (vapor-liquid) flow due to pressure gradients
  - Erosive channeling producing complicated 3-D decomposition zones
  - Formation of a large volume of relatively stable char.
- **Physical behavior significantly impacted:**
  - Radiant heat transfer to encapsulated objects (impact on modeling discussed by Hogan)
  - Heat transfer to foam and rate of pressure growth in sealed containers.
- **Need to understand chemical and physical behavior during decomposition**

Current and future work will examine pressure generation in sealed systems

- TDI- and PMDI- based polyurethane foams, both of which liquefy and flow during decomposition.
- That work involves
  - Additional radiant heat transfer experiments
  - Potential for further collaborative work with VNIIA involving multiple experimental techniques to provide results from variety of physical and thermal boundary conditions and sample geometries.