Application of RELAP5-3D to High Energy Deposition Transients within TREAT

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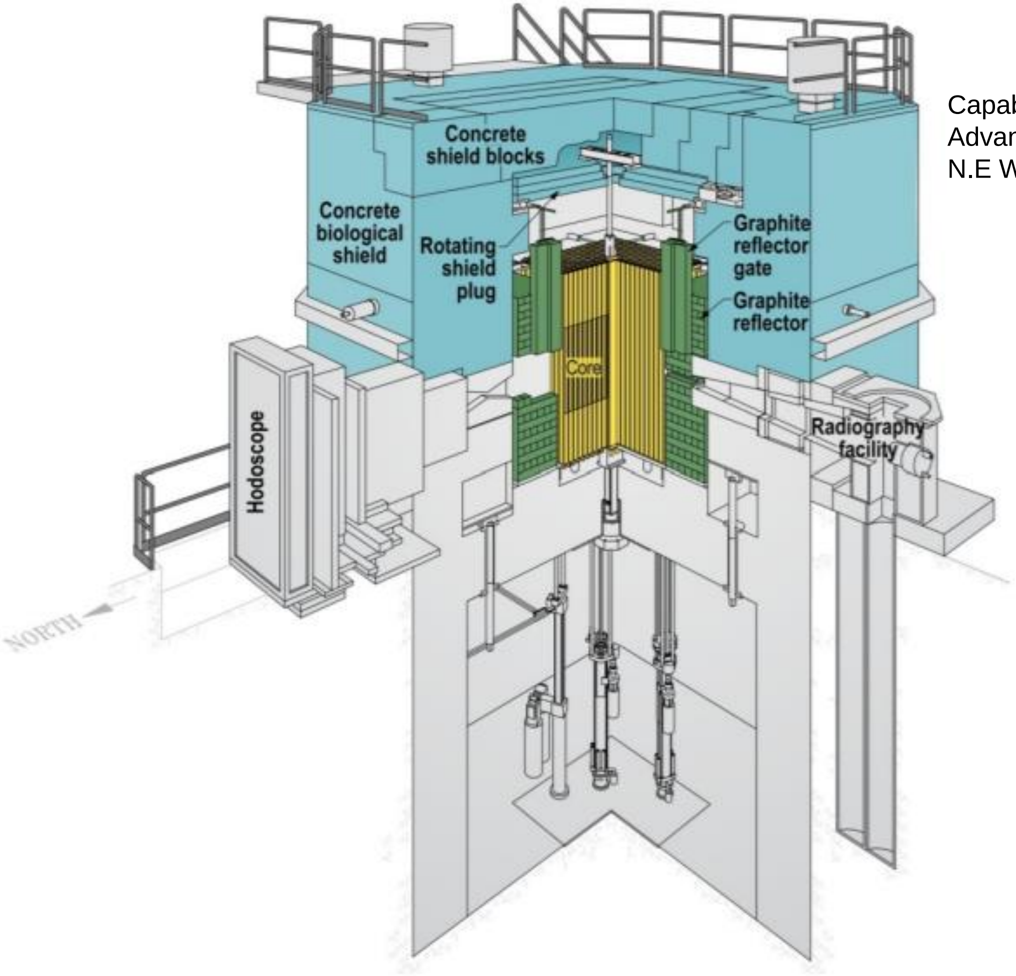
Outline

- TREAT and THOR Overview
- MURA Problem Statement
- RELAP5-3D Model Solution
- Results

Relevance to RELAP5-3D User Base

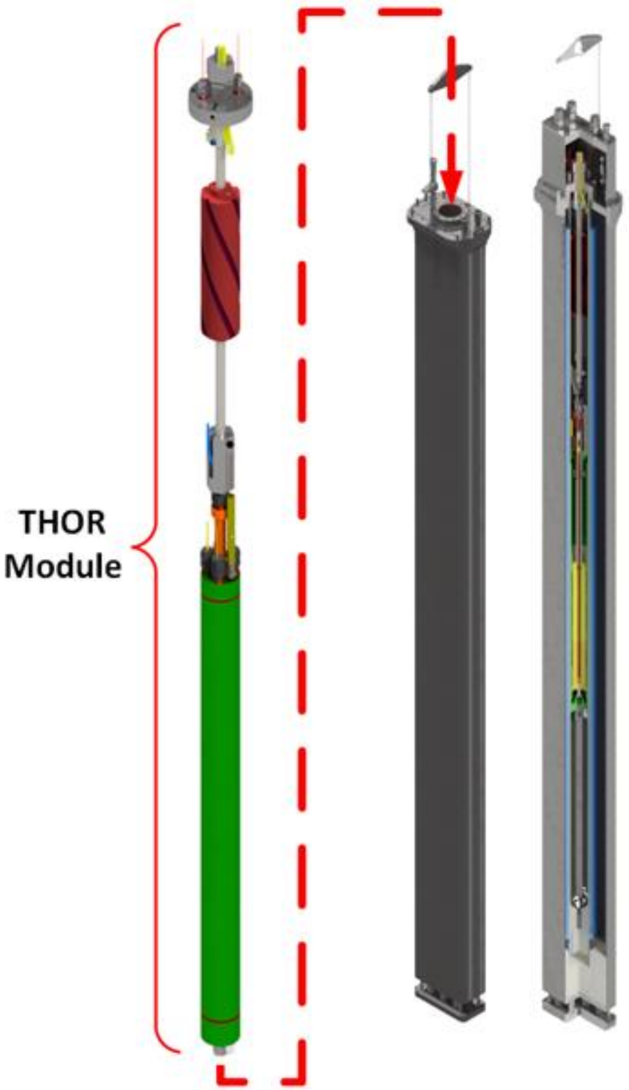
- Demonstrate RELAP5-3D extreme robustness as a mathematical tool
- Showcase ability to remove and add heat structures during restart
- Highlight radiative + gas gap conductance enclosure

TREAT



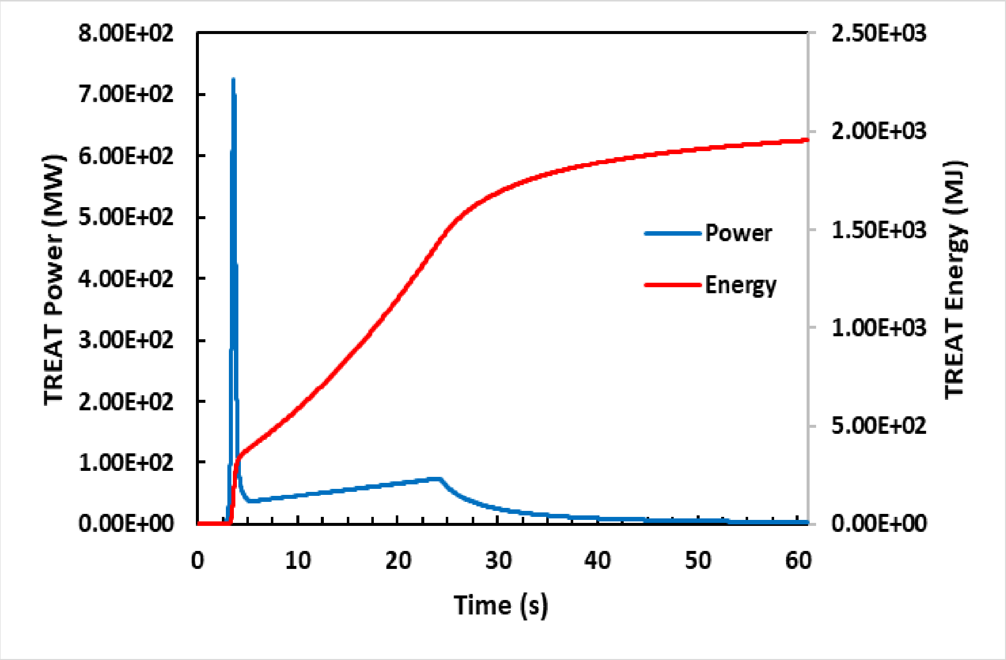
Capabilities Development for Transient Testing of Advanced Nuclear Fuels at TREAT, Top Fuel 2016, N.E Woolstenhulme et al.

THOR Module



MURA Safety Analysis

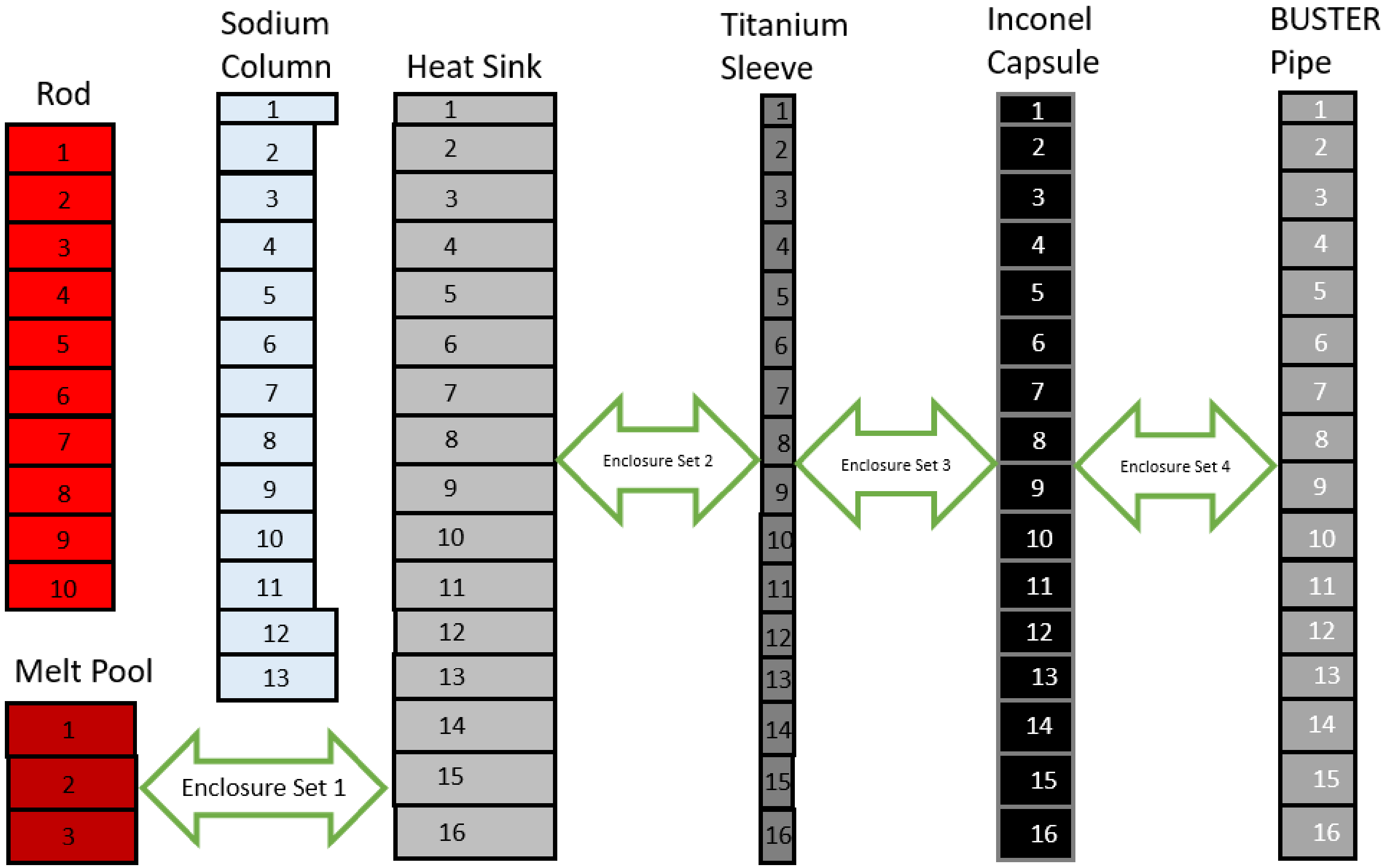
- Maximum Unplanned Reactivity Accident
  - Conservative analysis to determine capsule integrity under RIA like accidents
- MURA results in specific energies >14,000 j/g
  - Sufficient energy to vaporize fuel four times over
  - Adiabatic analysis would result in super heated plasma of extreme pressure



Proposed Solution

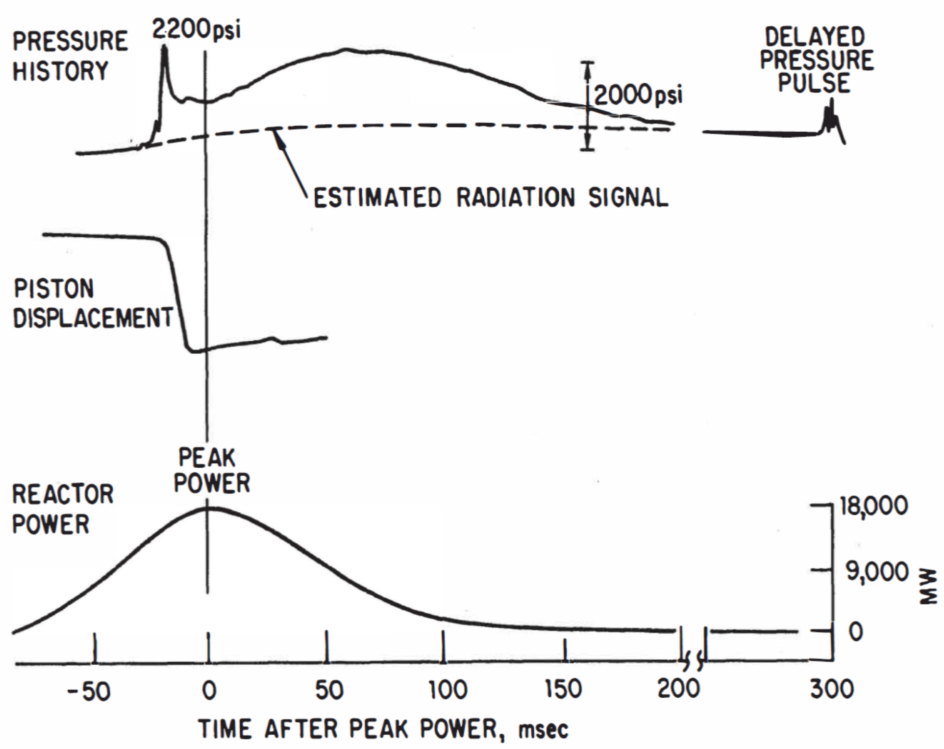
- Two separate models employed
  - High pressure model
  - High temperature model
- High pressure model includes an intact fuel rod which takes credit for heat transfer to the heat sink
- High temperature model includes a melt pool formation in order to analysis the most thermally limited configuration

THOR RELAP5-3D Nodalization



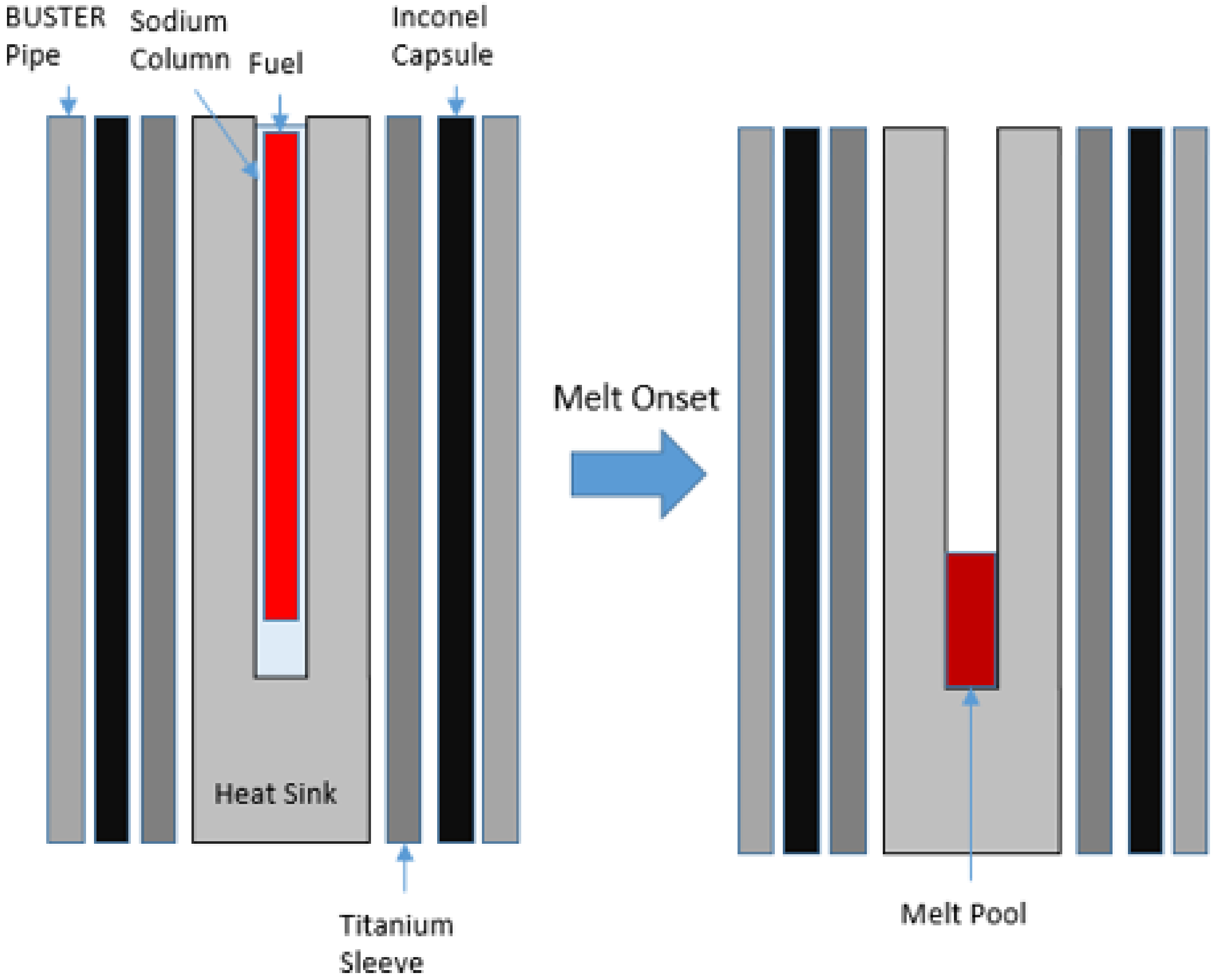
Maximum Pressure Calculations

- In order to avoid prohibitive adiabatic assumptions, the pressure calculations take credit for heat transfer through the sodium to the heat sink
- Post processors integrate over the structure to determine the maximum mean specific energy deposition that occurs during the transient



Wright, R., Barghusen, J., Zivi, S., Epstein, M., Ivins, R., & Mouring, R. (1974). Summary of autoclave TREAT tests on molten-fuel-coolant interactions. Retrieved from Argonne National Laboratory:

Two Phase Hybrid Melt Pool Transient



Gamma Heating

- Model includes gamma heating of heat structures from MCNP power coupling factors
- This is achieved by referencing the power curve of the fuel and entering in the appropriate scaling factors in the 700 cards
- This accounts for 100 to 200 K increase in surrounding heat structures

Enclosures Account for Radiative and Gas Conductance

- Total heat flux given as the combination of radiative and gas conductance
- RELAP5-3D prohibits a heat structure surface from being in multiple heat structures
- If radiative and gas conductance can be joined, both effects can be captured in single enclosure

Kreith F. 1964. *Principles of Heat Transfer*, 8th Edition, Scranton: International Book Company.

$$q = \sigma F \left({T_f}^2 + {T_c}^2 \right) \left(T_f + T_c \right) \left(T_f - T_c \right) + \frac{k_g}{d_g} \left(T_f - T_c \right)$$

$$F = \frac{1}{\varepsilon_f + \frac{r_f}{r_c} \left(\frac{1}{\varepsilon_c} - 1 \right)}$$

$$q = \left(h_r + h_g \right) \left(T_f - T_c \right)$$

Radiative Gap Conductance Assumption

- Radiative flux can be altered via polynomial expansion

$$q_r = \frac{\sigma}{\varepsilon_f + \frac{r_f}{r_c}\left(\frac{1}{\varepsilon_c} - 1\right)}\left({T_f}^4 - {T_c}^4\right)$$

$$q_r = \frac{\sigma}{\varepsilon_f + \frac{r_f}{r_c}\left(\frac{1}{\varepsilon_c} - 1\right)}\left({T_f}^2 + {T_c}^2\right)\left(T_f + T_c\right)\left(T_f - T_c\right)$$

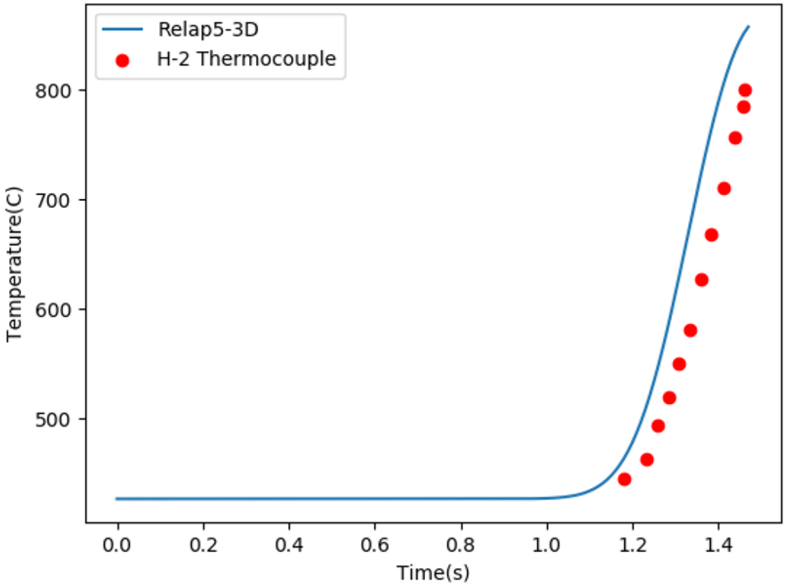
- For application at hand, T_c may reasonably be treated as a constant
  - h_r tends with T_c
  - T_f is dominant variable

$$q_r = h_r\left(T_f - T_c\right)$$

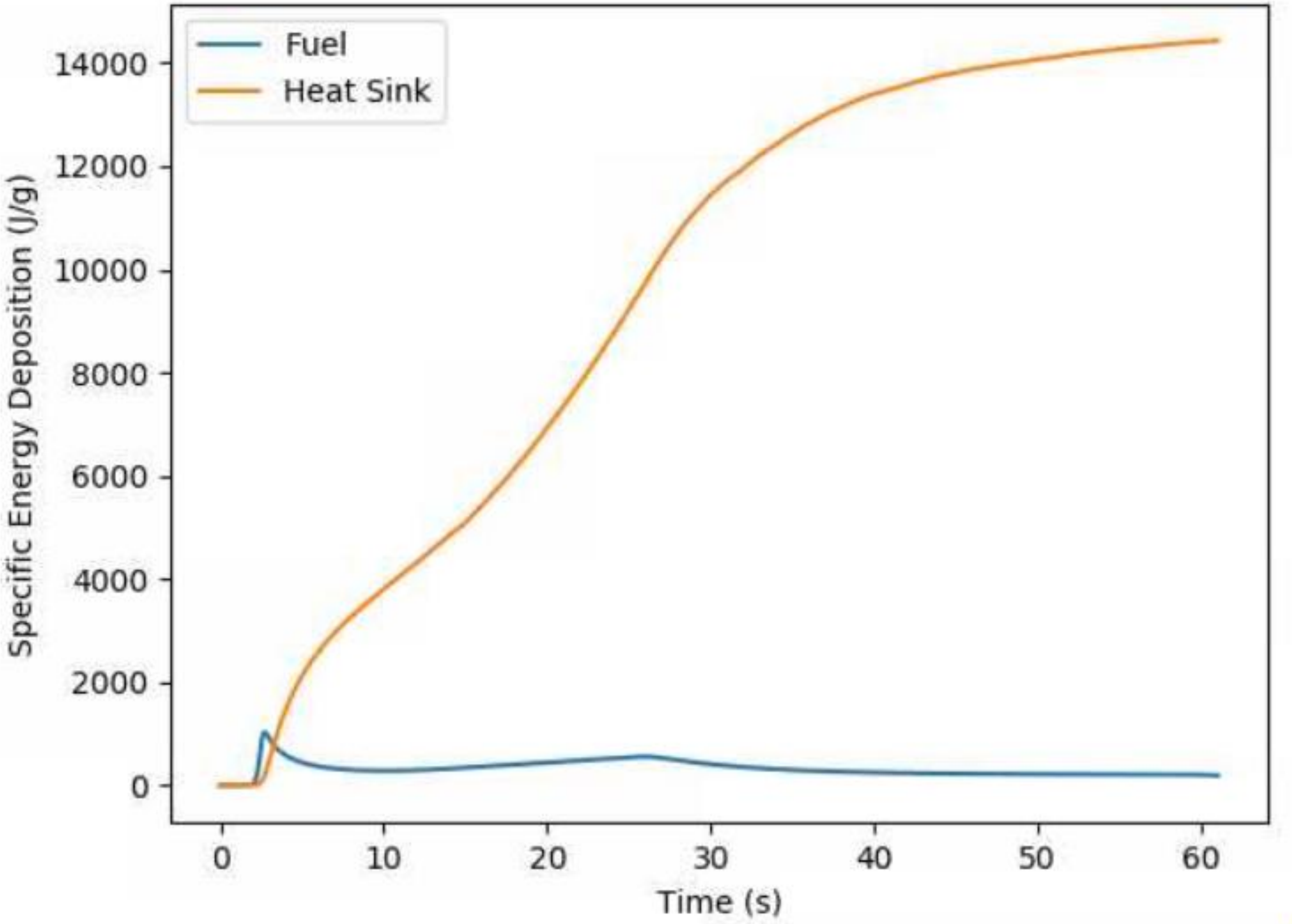
$$h_r = \frac{\sigma}{\varepsilon_f + \frac{r_f}{r_c}\left(\frac{1}{\varepsilon_c} - 1\right)}\left({T_f}^2 + {T_c}^2\right)\left(T_f + T_c\right)$$

Model Weaknesses

- Dynamic gap conductance
  - Due to the extreme thermal expansion and melting, the gap was ignored.
  - This assumption was validated experimentally for the lower energy H-2 experiment
- Sodium voiding not modeled
  - Clad fails within ~0.01s of rapid sodium voiding occurring
  - Dispersion of fuel aids in heat dispersal, hence ignoring projectile boiling is conservative



Specific Energy Deposition



Energy Deposition Results

	aLEU-THOR		MOXTOP-THOR			THOR-C					
Value	A	B	1-A & 2-A	1-B	2-B	1	2 & 5	3-A	3-B	4	6
TREAT Reactor Energy (MJ)	581	1555	378	1216	1322	377	1420	1552	1082	1082	1954
Input Deposited Energy (J/g)	2627	2197	1945	7425	8072	10593	12443	13606	9489	9489	17125
Maximum Stored Thermal Energy (J/g)	1319	1933	1676	3156	3156	1276	2183	809	2031	2183	1021

Maximum Temperature Results

	aLEU-THOR		MOXTOP			THOR-C					
Value	A	B	1-A & 2-A	1-B	2-B	1	2 & 5	3-A	3-B	4	6
Capsule Temperature (K)	740.0	766.4	858.1	868.0	902.4	932.8	1023.2	1116.8	902.8	900.0	1235.2
BUSTER Main Pipe Temperature (K)	733.8	762.9	842.2	852.2	886.8	856.0	927.6	1005.4	832.5	830.5	1107.4
BUSTER Thermal Equilibrium Temperature (K)	738.6	714.7	641.8	646.7	661.4	667.1	690.2	715.4	658.0	657.6	744.9