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TREAT Modeling and Simulation Development with Validation Requirements

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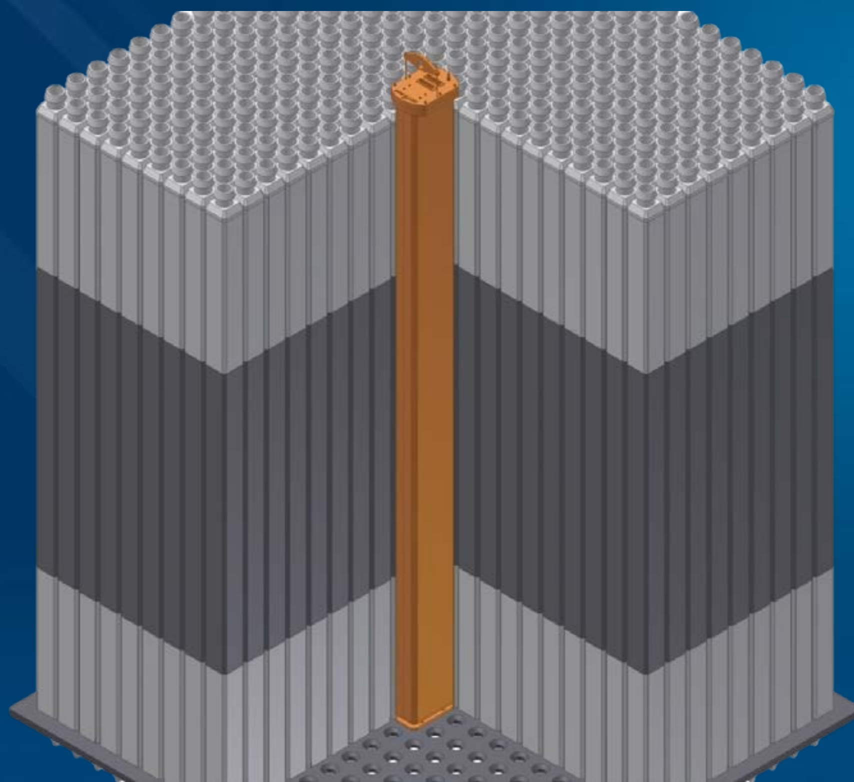
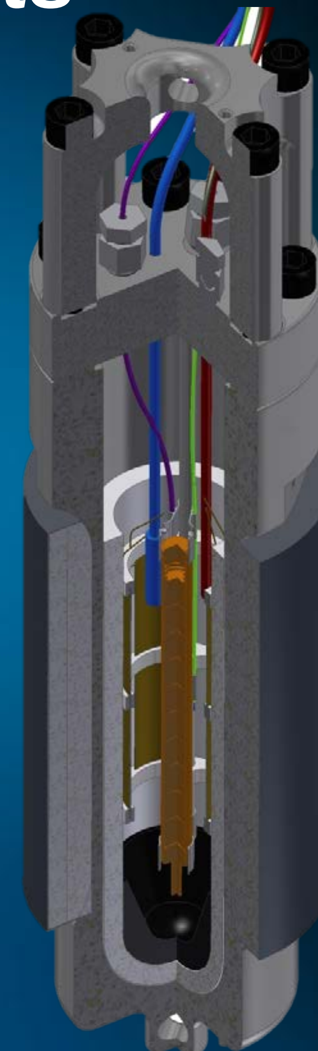




Idaho National Laboratory

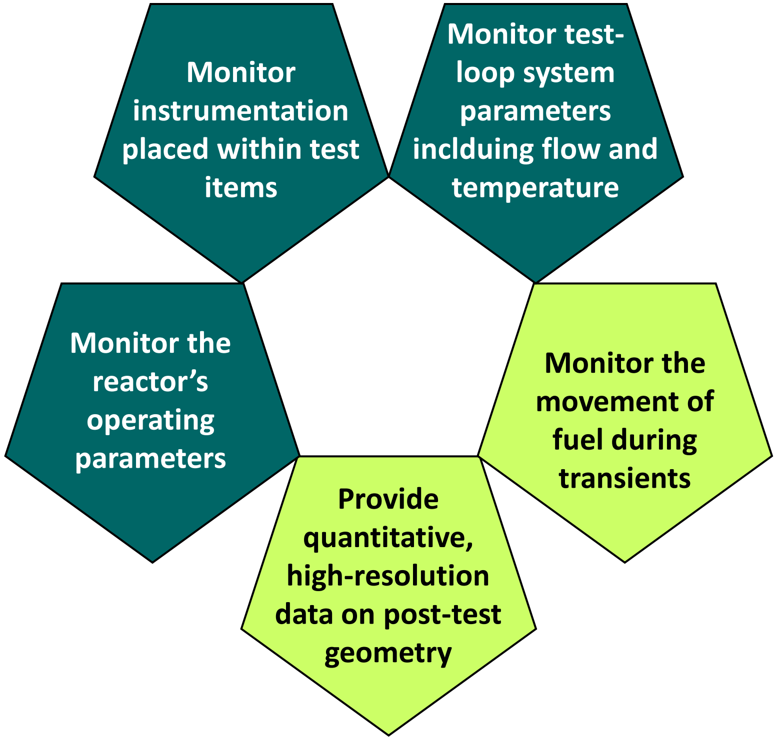
Obligatory Outline

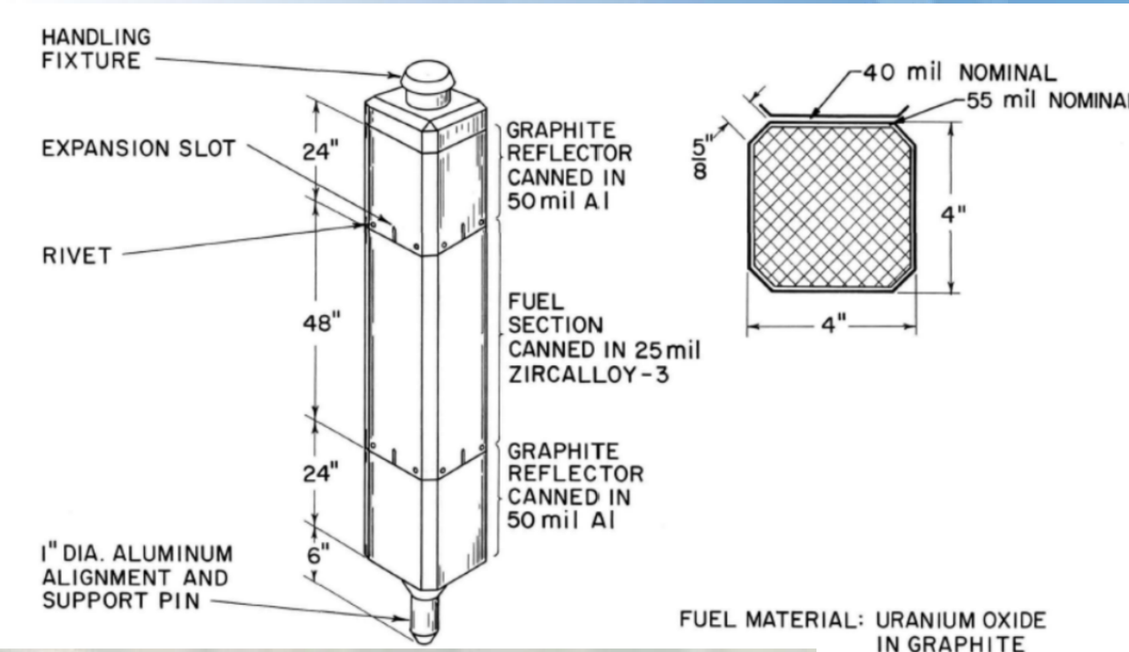
- Need for TREAT and Fuel Experiments
- Overview of TREAT Configuration
- Experiment Design
- TREAT Modeling and Simulation
- Validation of Multi-Physics Calculations
- The TREAT Hodoscope

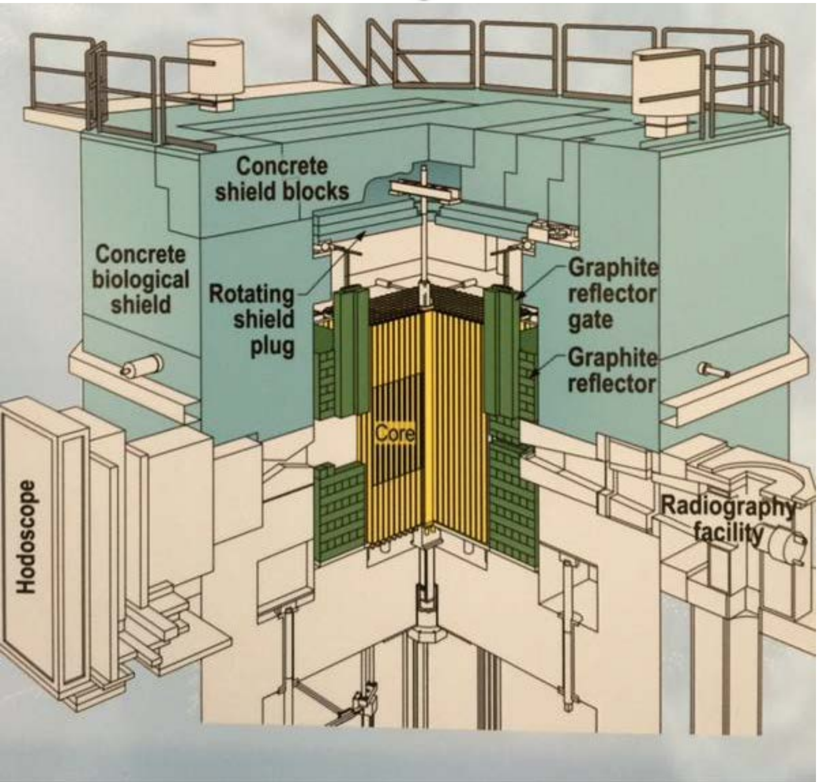
TREAT and Fuel Measurements

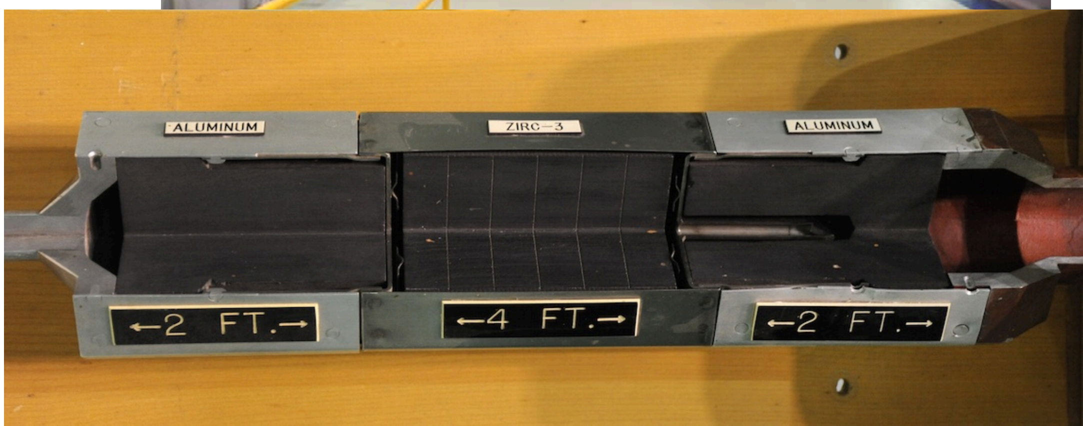
The **Transient Reactor Test Facility (TREAT)** is a tool to study fuel behavior and support reactor safety research and development.

1. Provide basic data for predicting the safety margin of fuel designs and the severity of potential accidents
2. Serve as a proving ground for fuel concepts designed to reduce or preclude the hazards associated with potential accidents.
3. Provide non-destructive test data through neutron radiography of fuel samples.



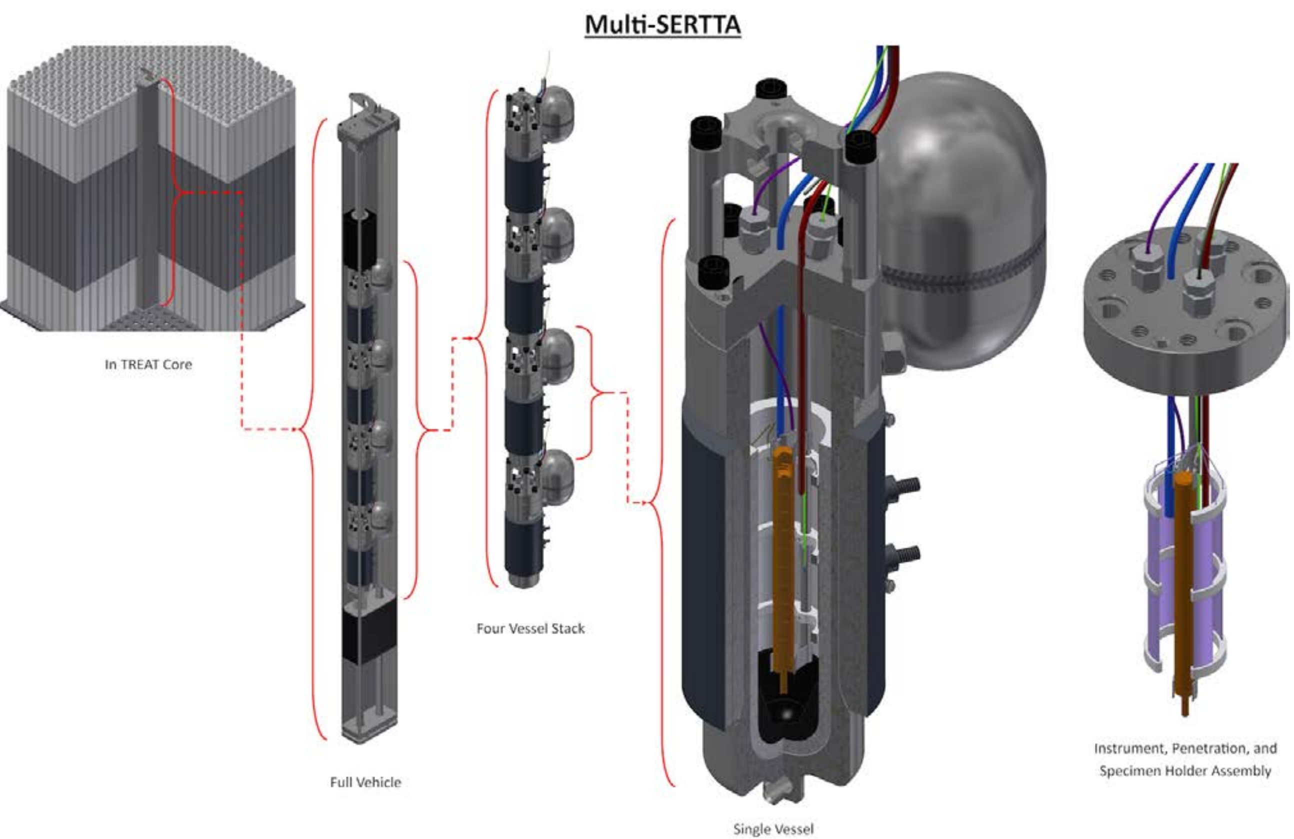

HANDLING FIXTURE
EXPANSION SLOT
RIVET
24"
48"
24"
6"
GRAPHITE REFLECTOR CANNED IN 50 mil Al
FUEL SECTION CANNED IN 25 mil ZIRCALLOY-3
GRAPHITE REFLECTOR CANNED IN 50 mil Al
1" DIA. ALUMINUM ALIGNMENT AND SUPPORT PIN
40 mil NOMINAL
55 mil NOMINAL
5"/8
4"
4"
FUEL MATERIAL: URANIUM OXIDE IN GRAPHITE


Concrete shield blocks
Concrete biological shield
Rotating shield plug
Graphite reflector gate
Graphite reflector
Core
Radiography facility
Hodoscope


ALUMINUM
ZIRC-3
ALUMINUM
←2 FT.→
←4 FT.→
←2 FT.→

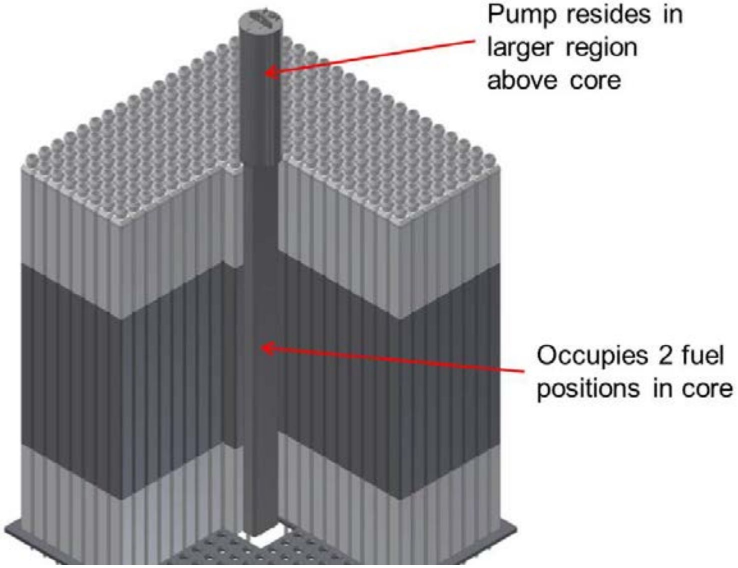
TREAT Experiments

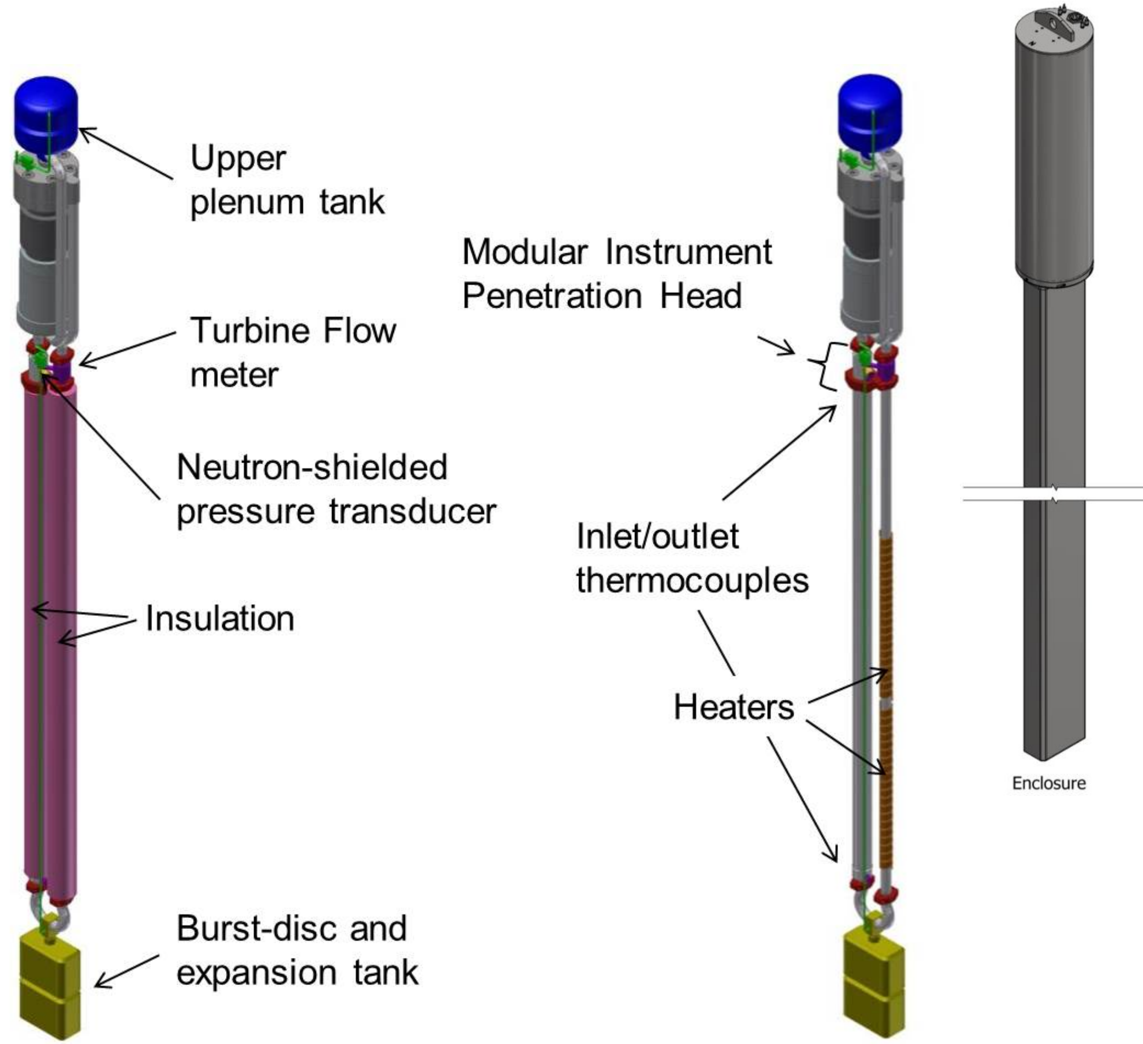
- TREAT's mission is to deliver transient energy deposition to a target or targets inside experiment rigs.
- Historically, failure conditions were determined by a number of transient experiments.
- In these experiments, very little predictive capability for experiment performance existed.



- The current modeling and simulation effort seeks to assist in the design of fuel experiments, and eventually use experimental data to improve fuel modeling on the fuel grain level and smaller.

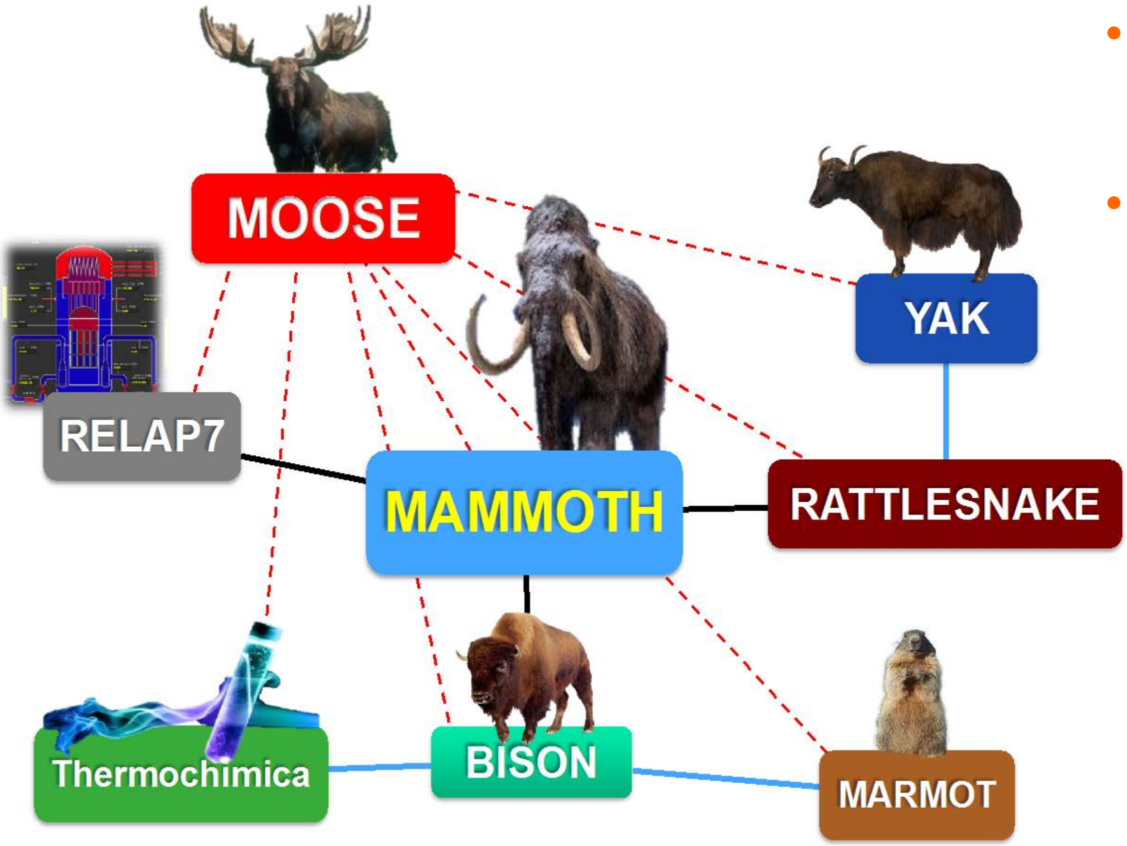
Flowing-Water Loop





Funding Support for TREAT M&S

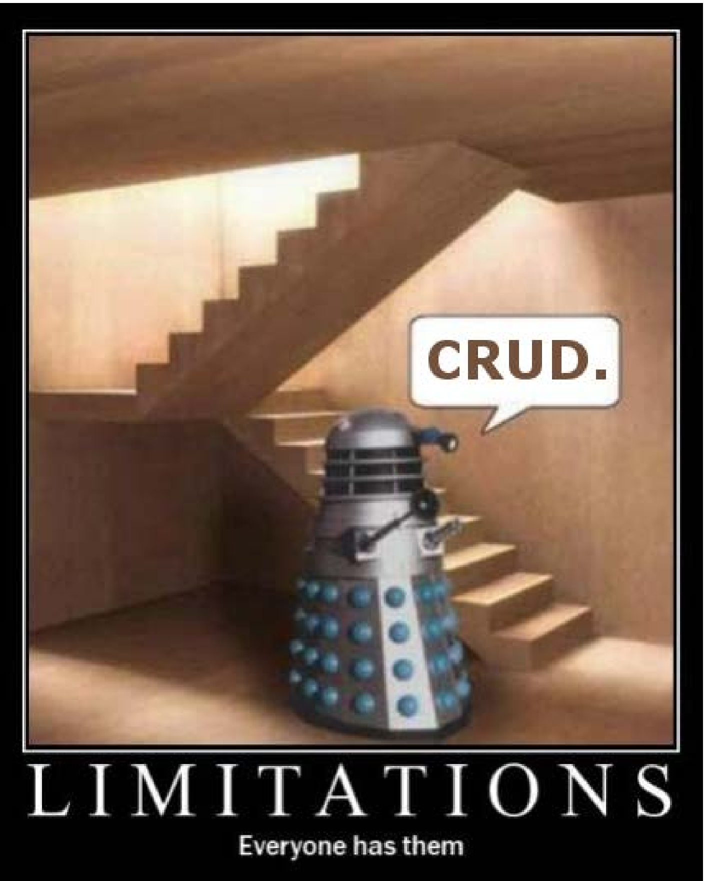
- Prior to FY15, MAMMOTH development and TREAT simulation (non-MAMMOTH) was funded by LDRD and NNSA programs, and limited Restart funding.
- Beginning in FY15, INL has been funded under US DOE Nuclear Engineering Advanced Modeling and Simulation (NEAMS) program to develop and apply tools for TREAT experiment simulation.



- Existing NEAMS tools unable to meet project objectives and timelines
- INL is focusing on the MAMMOTH reactor physics package for TREAT simulation.

TREAT Modeling and Simulation (M&S)

- Unfortunately, advanced modeling and simulation isn't.
- Based on an advanced concept, the process to adapt that concept to a complex real-world problem requires time in terms of effort and testing.



- The desired outcome of MAMMOTH M&S will be to simulate the complex interactions occurring in a TREAT experiment, driven by the coupled physics of a temperature-limited or controlled transient.
- The first phase of this approach will be to develop the core transient simulation capability that couples RATTLESNAKE, BISON, and cross section generation.
- Fortunately, no burnup is involved, and cross section processing approaches are somewhat simplified.

TREAT Core Transient Modeling and Simulation

$$\nabla\cdot\boldsymbol{\Omega}\Phi(\mathbf{r},E,\boldsymbol{\Omega},t)+\Sigma_t(\mathbf{r},E,T)\Phi(\mathbf{r},E,\boldsymbol{\Omega},t)$$

$$-\iint\Sigma_s(\mathbf{r},E'\to E,\boldsymbol{\Omega}'\to\boldsymbol{\Omega},T)\Phi(\mathbf{r},E',\boldsymbol{\Omega}',t)dE'd\boldsymbol{\Omega}'$$

$$-\chi_p(\mathbf{r},E)(1-\beta)\iint\nu(\mathbf{r},E')\Sigma_f(\mathbf{r},E',T)\Phi(\mathbf{r},E',\boldsymbol{\Omega}',t)\,dE'\,d\boldsymbol{\Omega}'$$

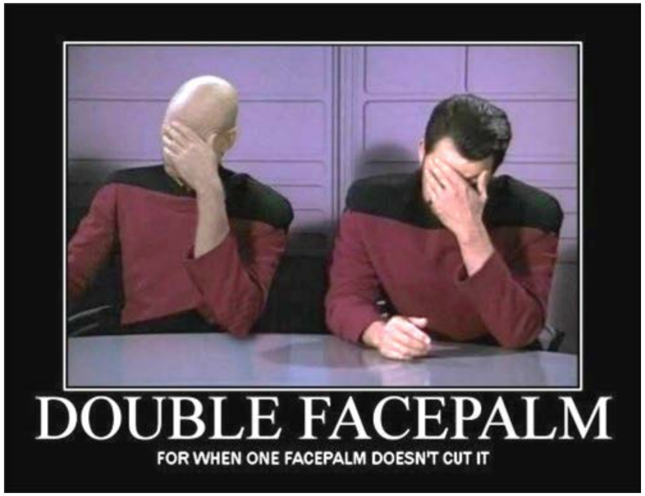
$$-S(\mathbf{r},E,\boldsymbol{\Omega},t)-\sum_i\lambda_i C_i(\mathbf{r},t)\chi_i(\mathbf{r},E)=-\frac{1}{\upsilon(E)}\frac{\partial}{\partial t}\Phi(\mathbf{r},E,\boldsymbol{\Omega},t)$$

$$\frac{\partial}{\partial t}C_i(\mathbf{r},t)=\iint\nu(\mathbf{r},E')\beta_i\Sigma_f(\mathbf{r},E',T)\Phi(\mathbf{r},E',\boldsymbol{\Omega}',t)\,dE'\,d\boldsymbol{\Omega}'$$

$$-\lambda_i C_i(\mathbf{r},t)\qquad i=1,N$$

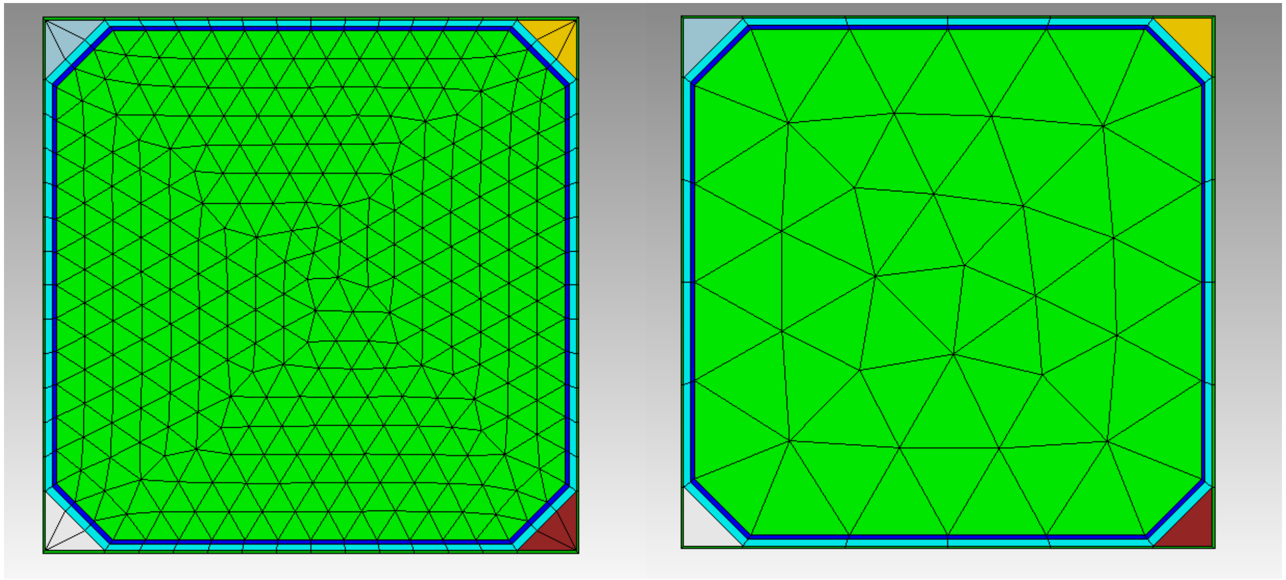
$$\rho(\boldsymbol{r},T)c_p(\boldsymbol{r},T)\frac{\partial T}{\partial t}=\nabla\cdot(k(\boldsymbol{r},T)\nabla T)$$

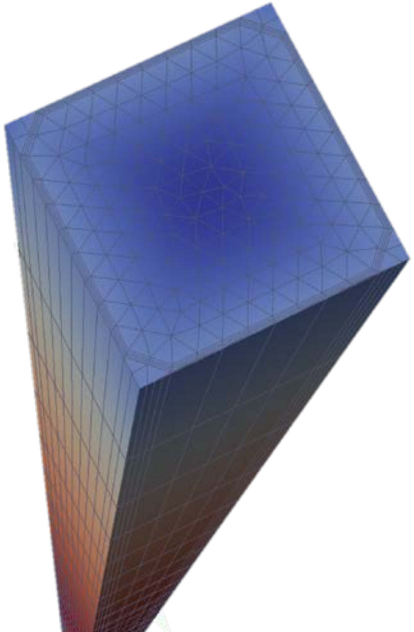
$$+E_f\iint\nu(\mathbf{r},E')\Sigma_f(\mathbf{r},E',T)\Phi(\mathbf{r},E',\boldsymbol{\Omega}',t)\,dE'\,d\boldsymbol{\Omega}'$$



Current Status of TREAT M&S

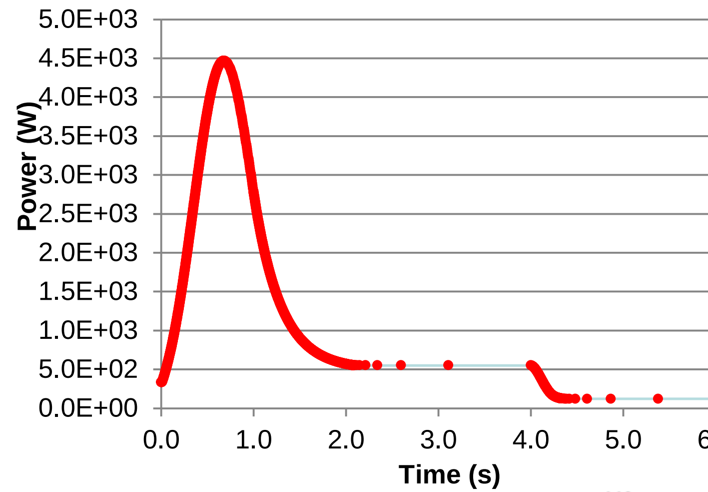
- Completed development and testing of steady state (criticality) calculations with Rattlesnake (MOOSE-based neutron transport solver)
  - Simple but representative model (single fuel element)
  - Materials and Cross sections
  - Meshing
  - Evaluate different transport solution modes
  - Comparison to independent solutions (Monte Carlo simulations)

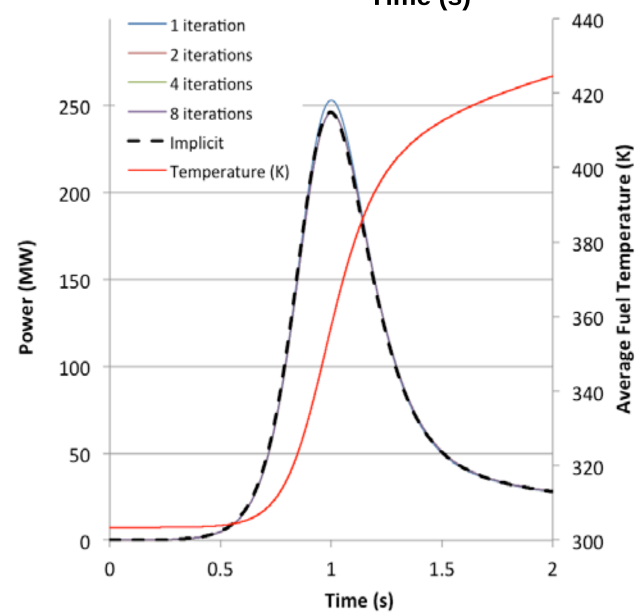




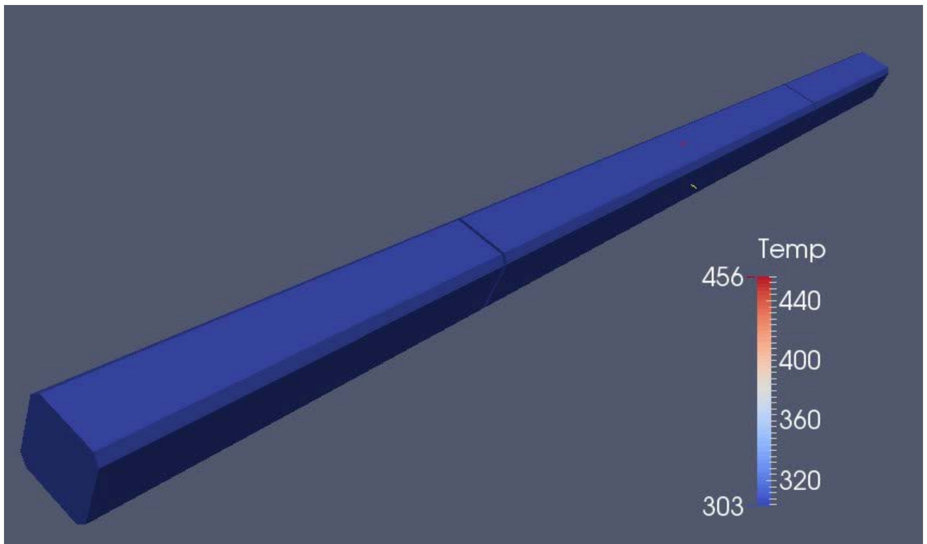
Current Status of TREAT M&S

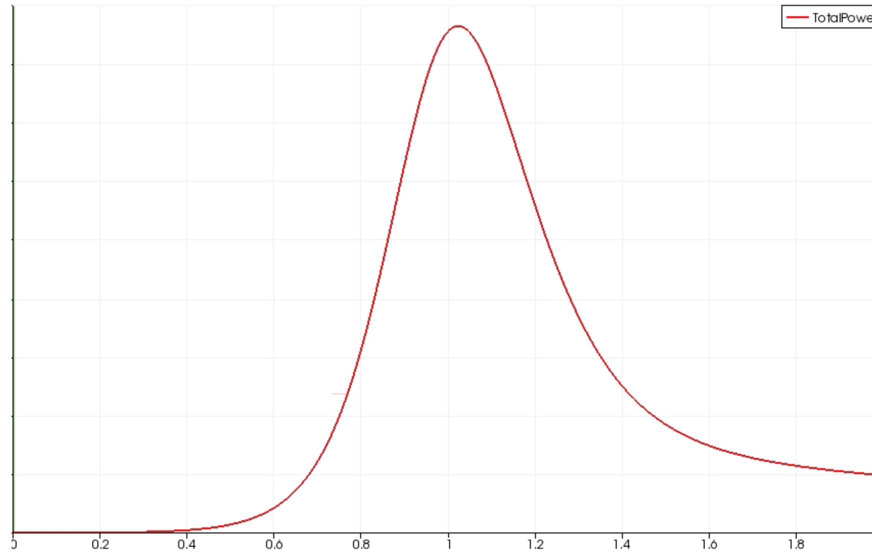
- Coupled Rattlesnake to BISON within MAMMOTH
  - Rattlesnake calculates spatial power distributions
  - BISON solves heat equation and calculates spatial temperatures
  - MAMMOTH updates cross sections
  - Study implicit vs explicit coupling
  - Study time differencing and adaptive time stepping





Coupled Physics in MAMMOTH

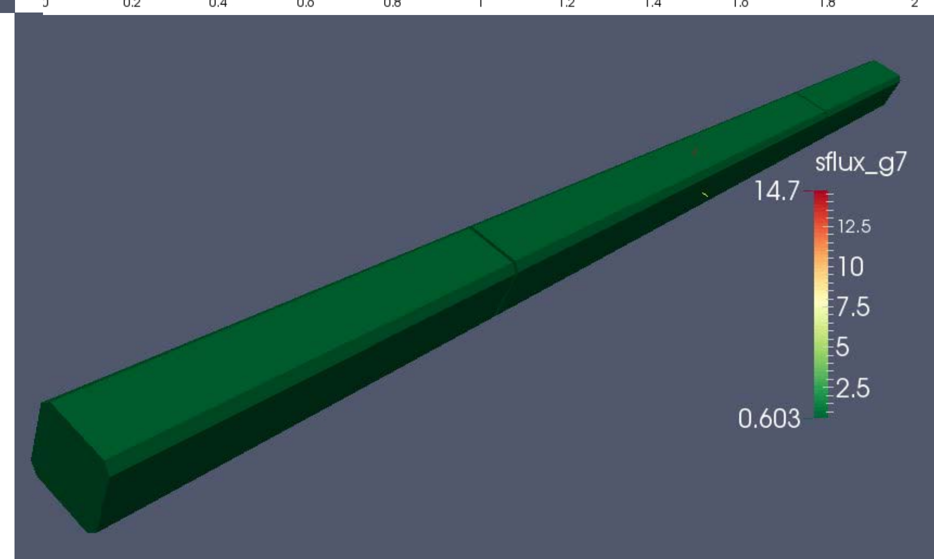




Temperature (K) 🡅

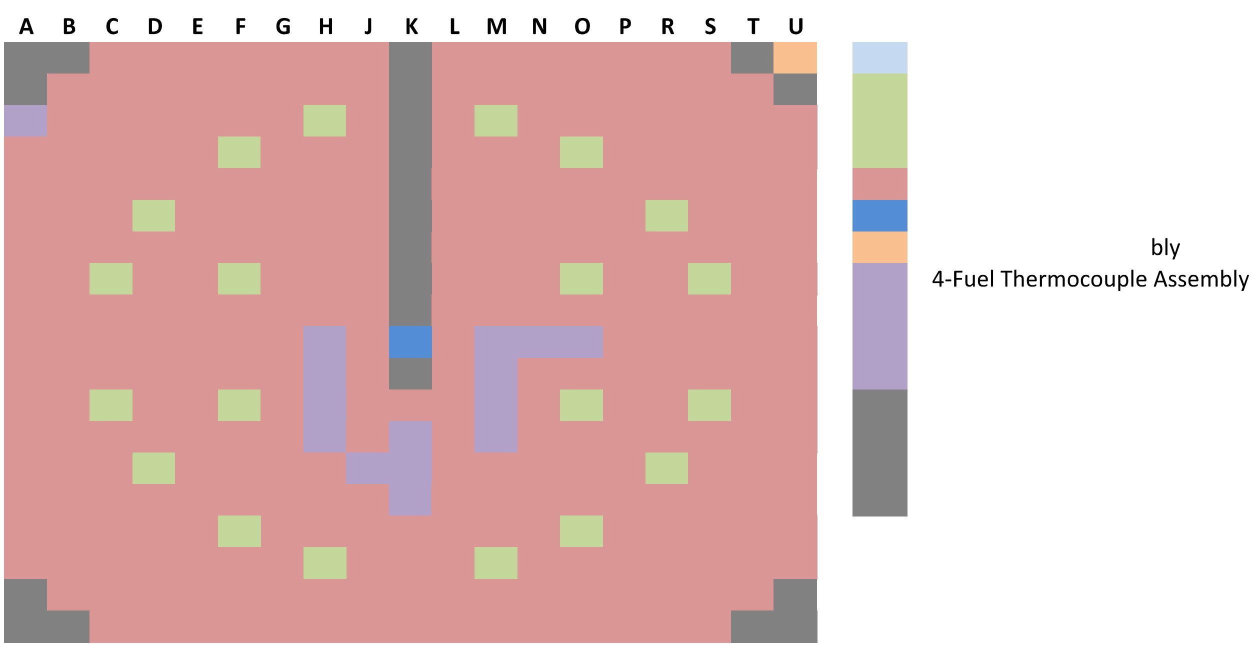
- Reactivity increase (boron removal) between 0.01 and 0.1s
- Reactivity decrease is due to temperature feedback

Thermal Flux 🡆



Ongoing Efforts

- Extend single assembly model to full TREAT core.
  - Continue transient testing
  - Study cross section generation approaches
  - Compare to historical measured data
  - OSU is nearing completion of a fully meshed core
  - Will begin with simulation of minimum critical configuration



Validation and Testing

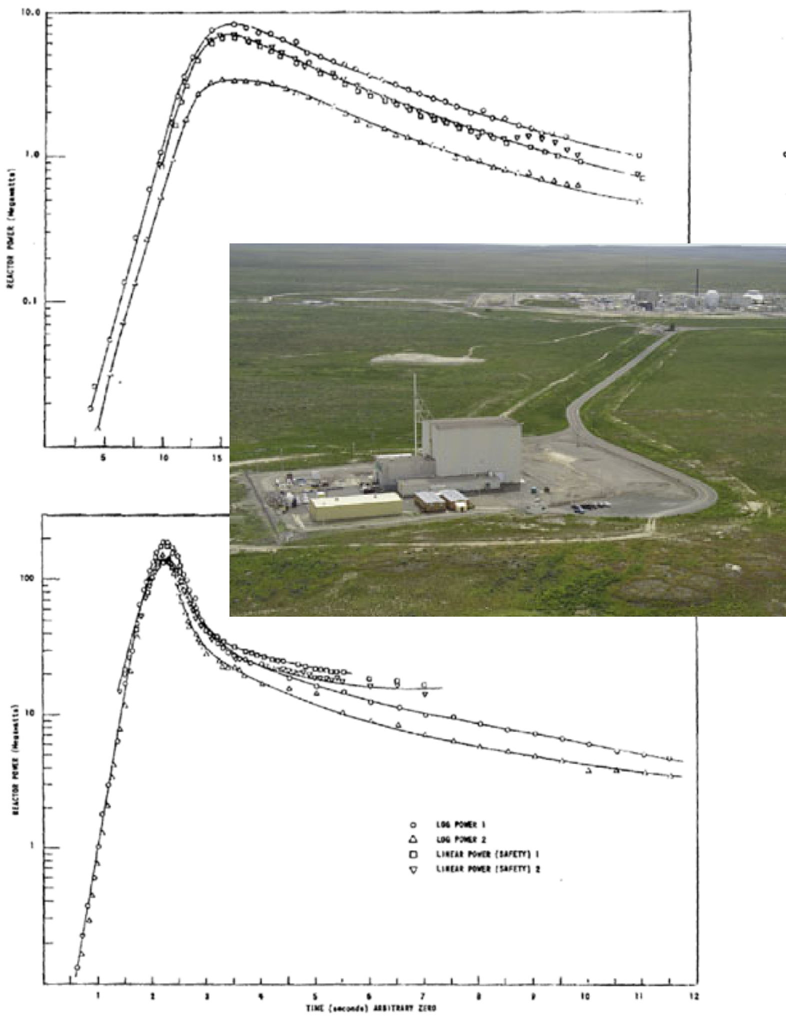
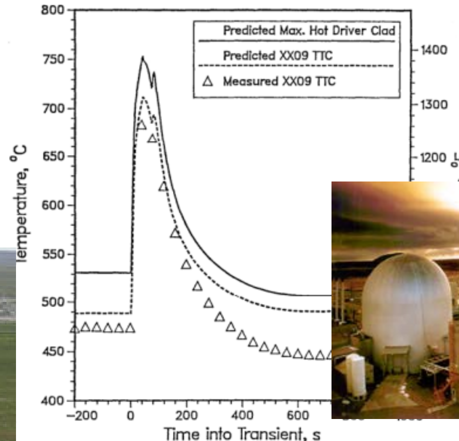
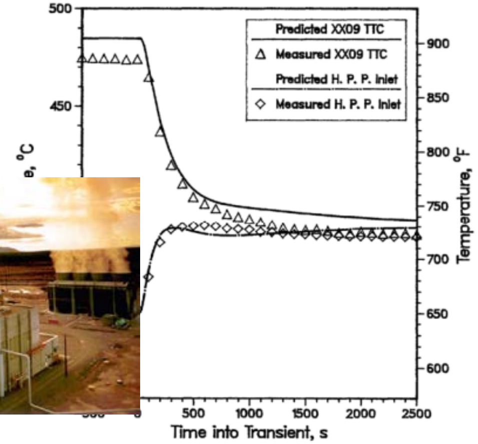


FIG. 17
POWER TRACES FOR 1.165 k_{ex} TRANSIENT

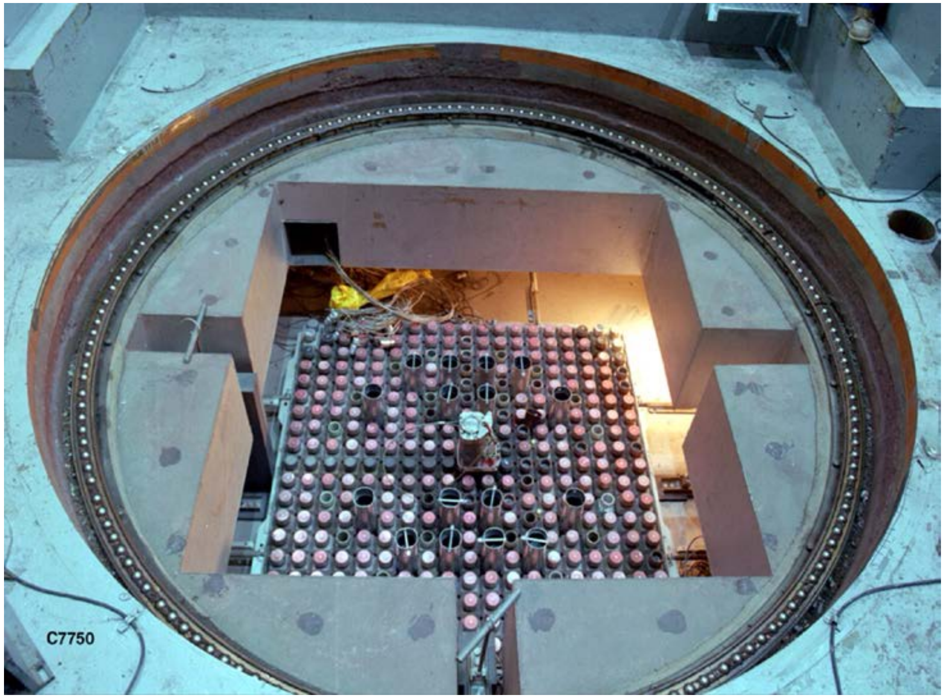


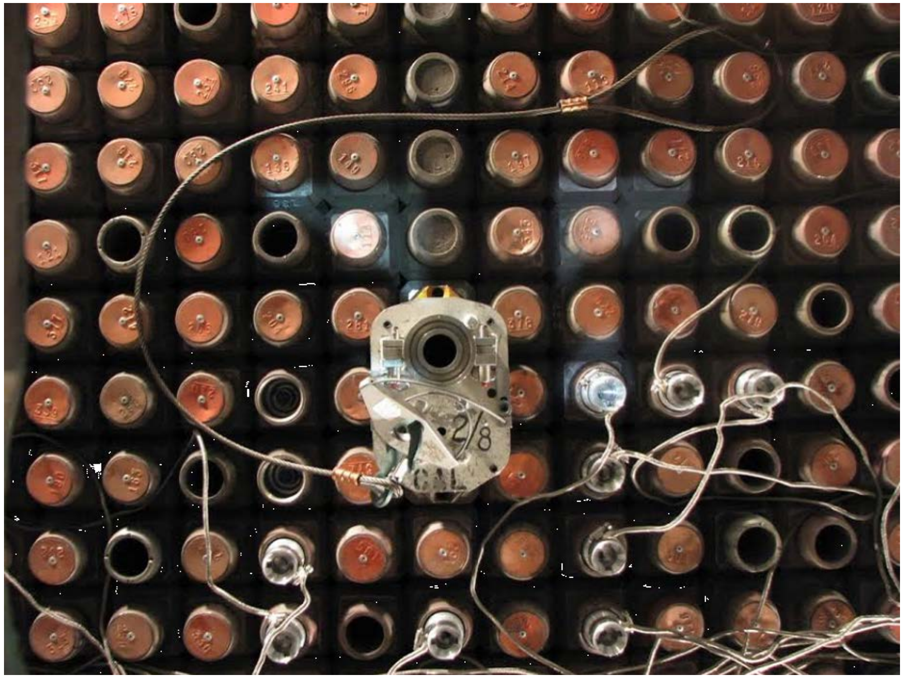


- TREAT temperature limited and controlled transient tests (basic multi-physics)
- EBR-II Loss of Flow and Loss of Heat Sink measurements (more detailed multi-physics
- Simulation of TREAT experiments (complex multi-physics)
- Simple computational benchmarks and code-to-code comparisons

Next Steps – after FY15.

- Initiate complete multi-physics modeling of experiments placed in center of the core using MAMMOTH
  - Neutronics
  - Fuels/materials performance
  - Fluids flow
  - Structural
  - Ongoing validation

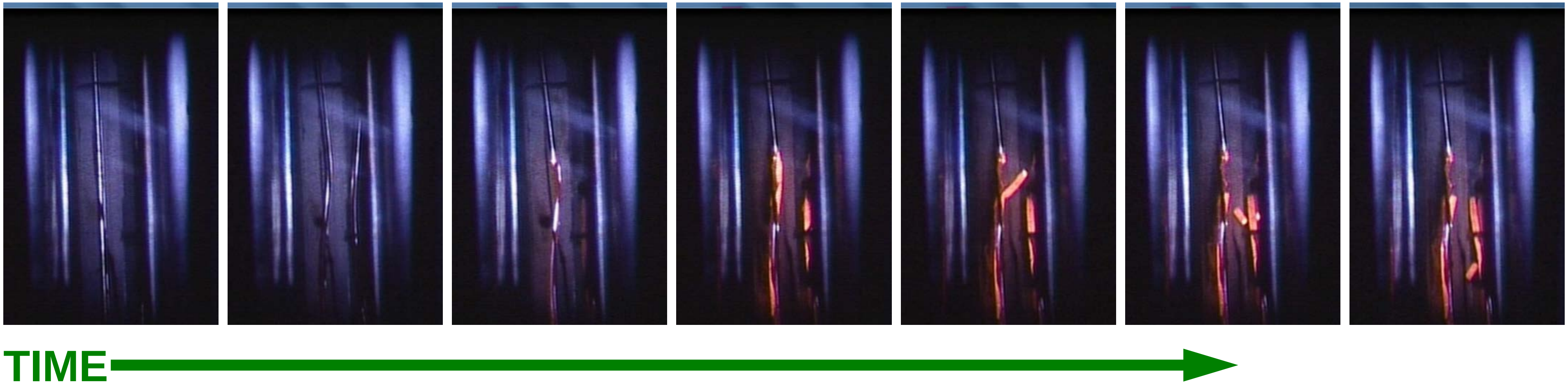




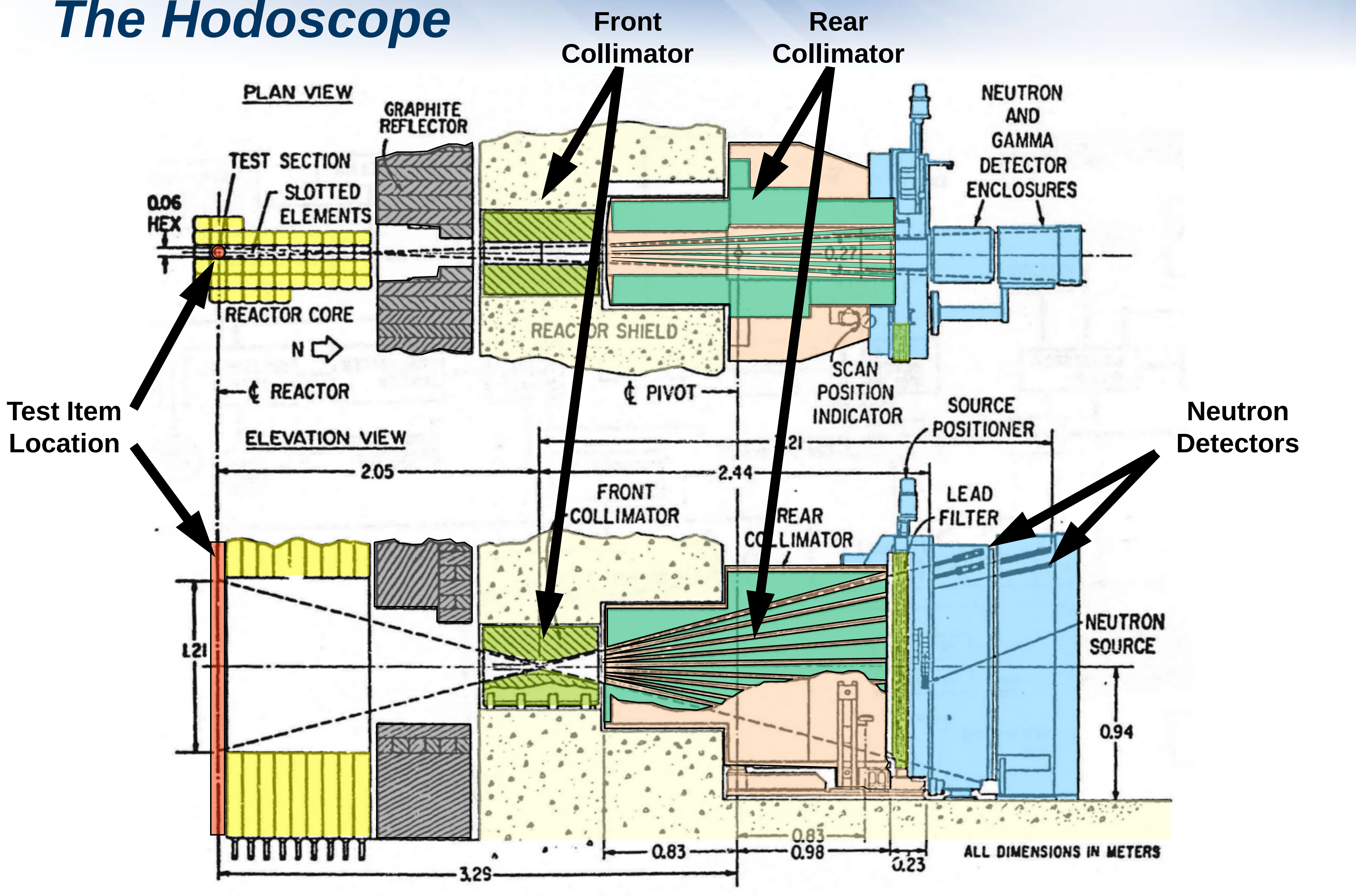
TREAT End Game – Fuel Performance Modeling

- Fuel motion monitoring is a critical diagnostic tool used in support of advanced fuel research and development
- The TREAT hodoscope is a unique tool used for real-time fuel motion monitoring; it provides a highly-sensitive measure of <u>when</u> and <u>where</u> initial fuel system failures occur during transient nuclear events
- The TREAT hodoscope is being refurbished to support DOE's next generation of advanced fuel research, it will be ready for operation for the first round of fuel testing

TREAT Transient #1022



The Hodoscope



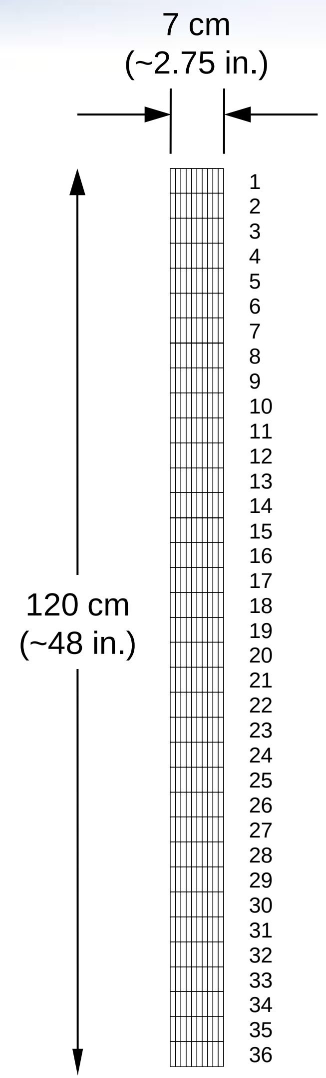
Photographs of the Hodoscope

View of the Hodoscope system from the side

View of the Hodoscope system from the rear, with the detector panel open

The Hodoscope Rear Collimator

- At the test-item location (the center of the TREAT reactor), the system has a field of view 120-cm tall by 6.7-cm wide area
- The collimator has 360 pixels
  - 36 vertical pixels
  - 10 horizontal pixels.
- Channel spacing:
  - Vertical = 34 mm
  - Horizontal = 7 mm
- Detectable motion
  - Horizontal = 0.2 mm
  - Vertical = 6 mm
- For typical experiment fuel loadings, each pixel has a sensitivity of ~0.1 g of fuel
- Reactor power
  - Minimum = 10 kW
  - Maximum = 20,000 kW

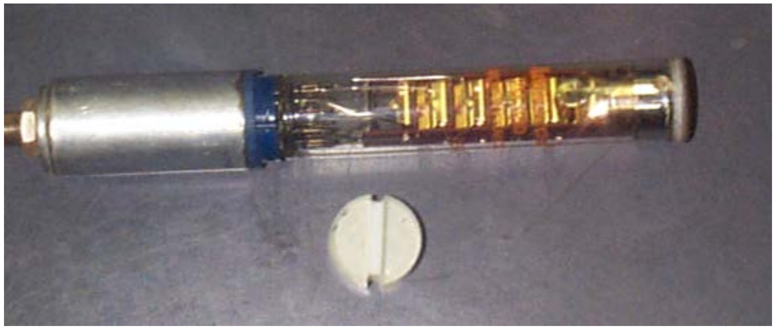


Hodoscope field of view at the test item location

ANL--82-72 (1982) "Fuel-Motion Diagnostics and Cineradiography"

Idaho National Laboratory

Hodoscope Detectors



Recoil Scintillator

Recoil Gas Proportional Counter

- Experiments at TREAT are one-of-a-kind events, very-high reliability is required for measurements.
- There are 360 detector slots in the Hodoscope collimator.
- The Hodoscope employed multiple, redundant detector systems to ensure reliability.
  - Recoil scintillators – neutrons scatter in a small plastic scintillator; a feint burst of light is emitted for each event.
  - Recoil gas counters – neutrons scatter in a small, gas-filled tube; a very small electrical charge is generated for each event.
- During a test, data was recorded from >720 detectors every 0.001 seconds.

Questions?

"My presentation lacks power and it has no point. I assumed the software would take care of that!"