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Idaho National Laboratory

TREAT program and potential use for multiphysics validation

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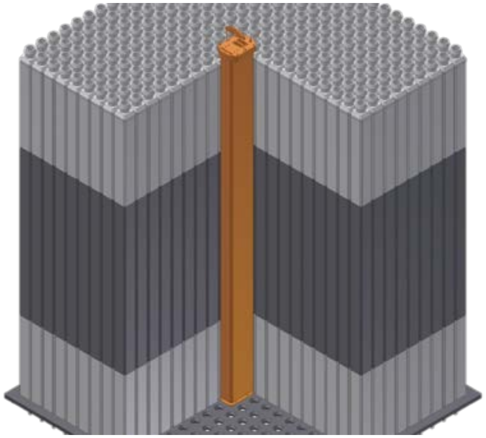
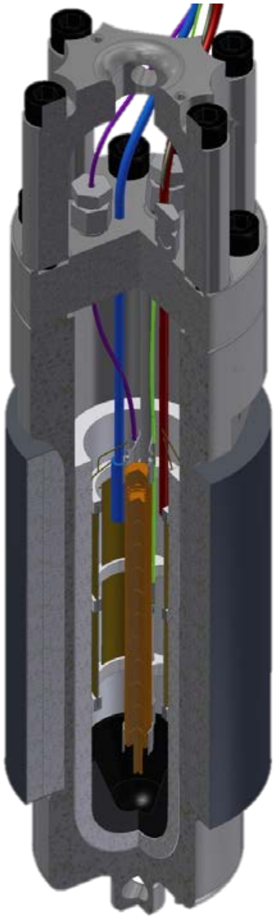




Obligatory Outline

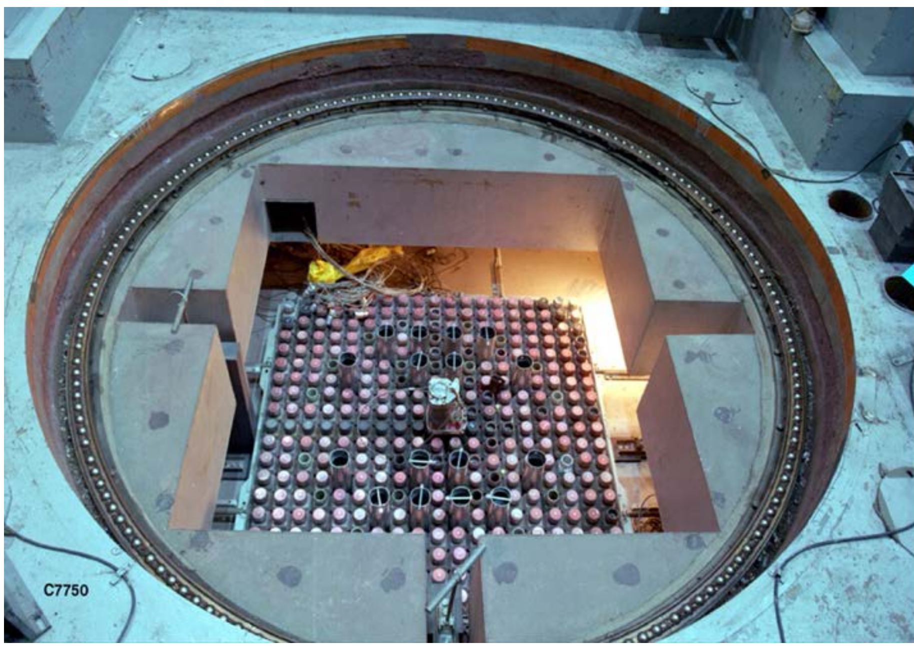
- Description of the Transient Test Reactor (TREAT)
- The challenges of TREAT measurement data and simulation
- Modeling efforts
- MAMMOTH
- M8CAL calibration measurements – 1990-1993
- Limitations (biases) in M8CAL data
- SPOILER – Existing data is inadequate for validation
- Plans for startup measurements/Timeline
- Multi-SERTTA/Multi-SERTTA-CAL experiments and modeling
- Draw your own conclusions.

TREAT (noun) \ˈtrēt

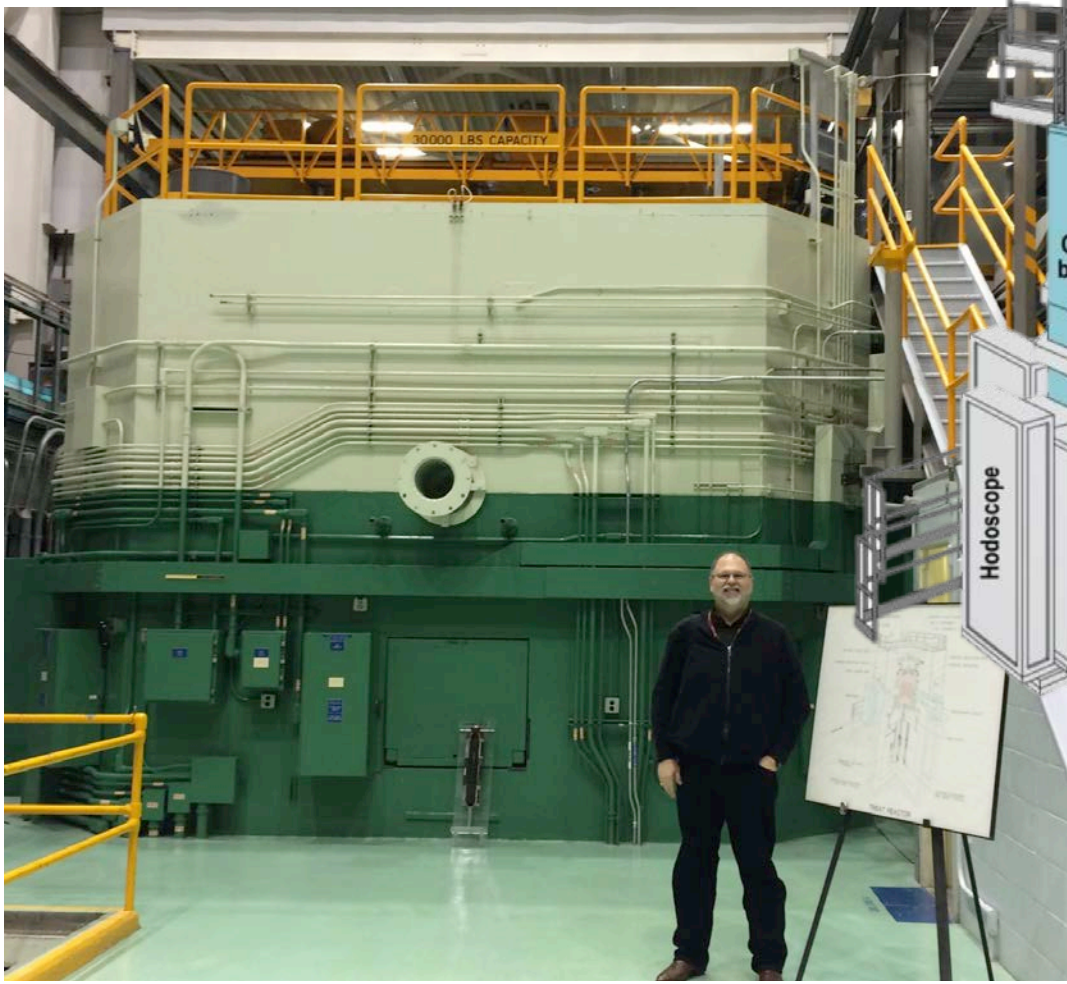
1. The Transient Test Reactor at Idaho National Laboratory
2. Anything that affords particular pleasure or enjoyment.

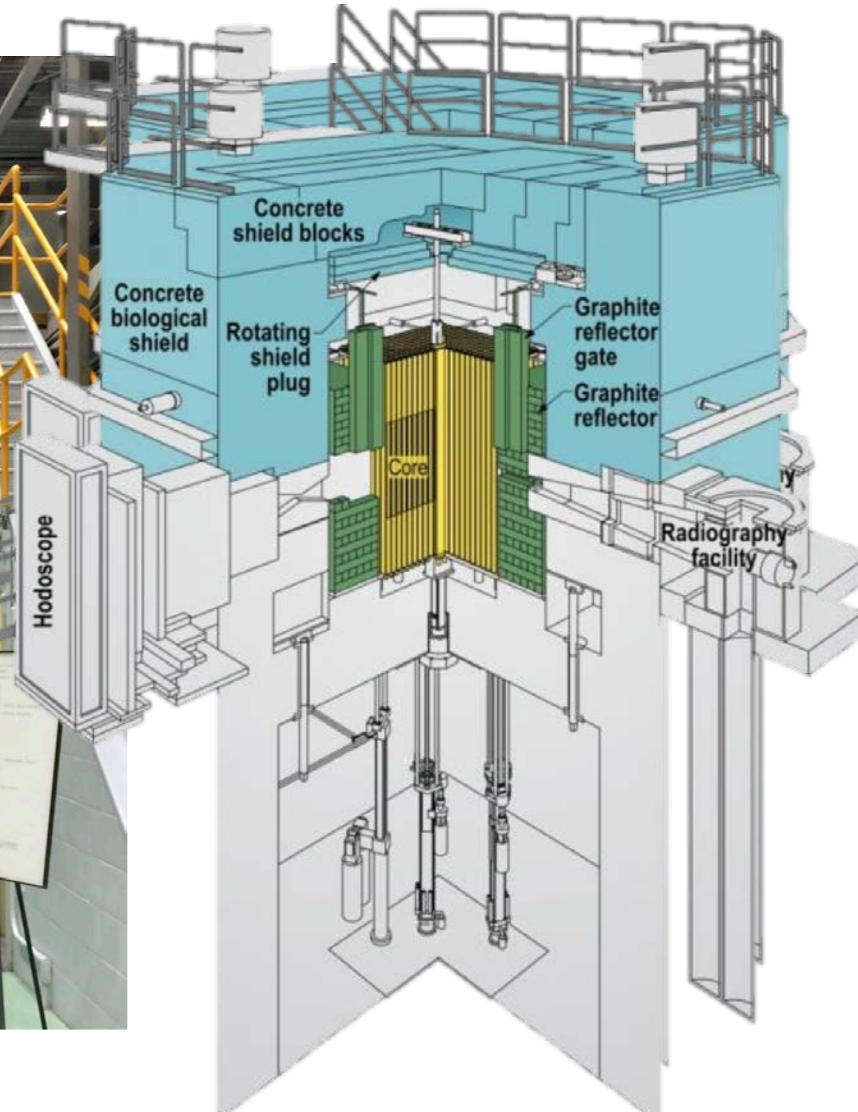
Example:

Working in methods development and validation in support of TREAT restart has been a real treat.



TREAT – The Transient Test Reactor Facility





TREAT's mission is to deliver transient energy deposition to a target or targets inside experiment rigs.

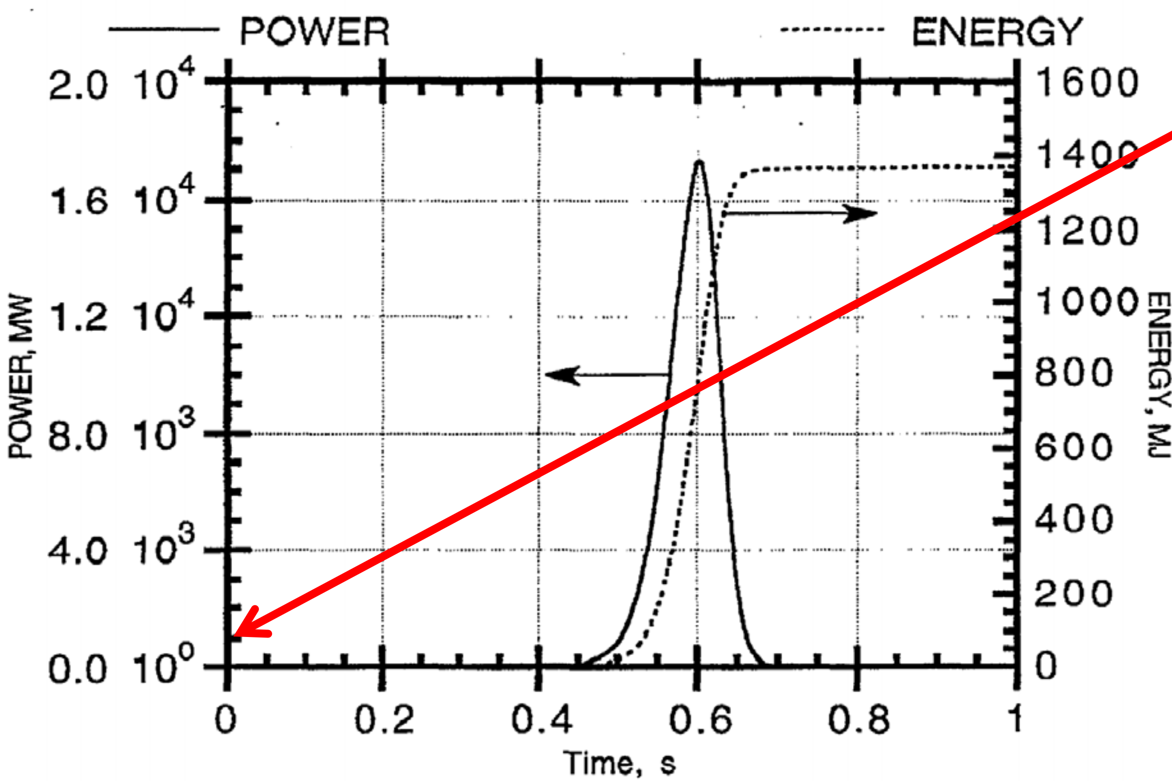
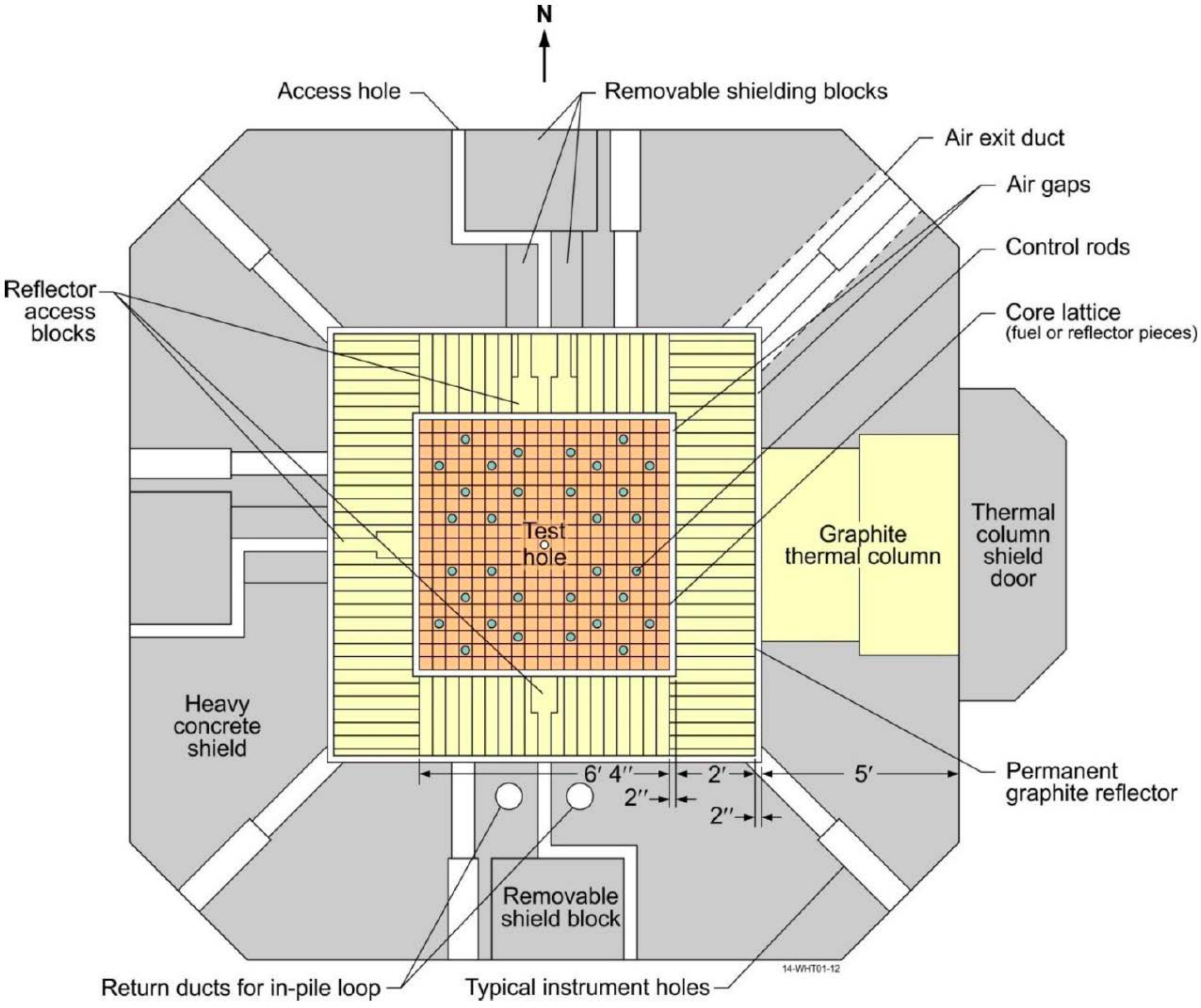
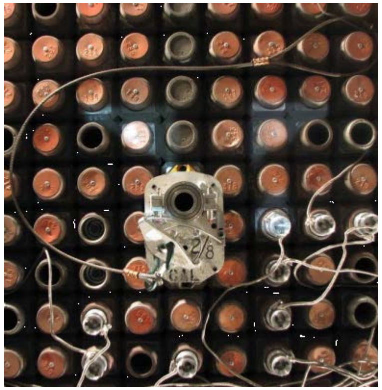


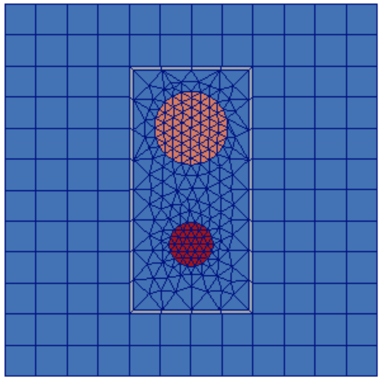
FIG. 5. Plot of TREAT reactor power and energy for hypothetical RIA-type transient resulting in 1400-MJ pulse with a 72-msec FWHM capable of depositing 1200 kJ of energy per kg of fuel (290 cal/g).

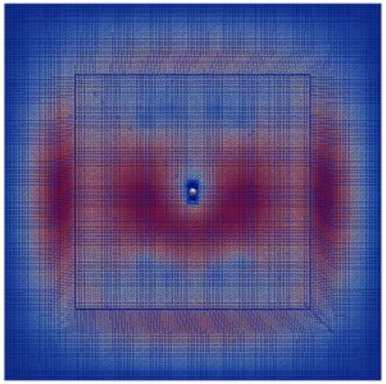
1.21 Gigawatts

TREAT – The Transient Test Reactor Facility





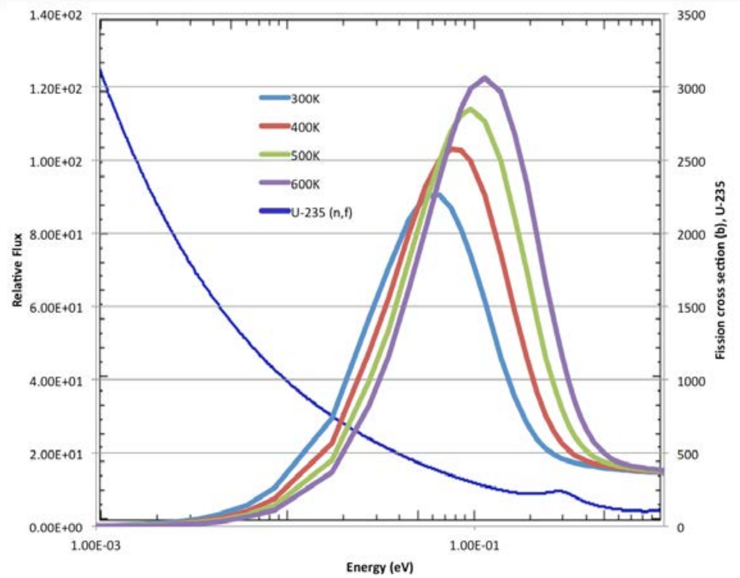




High-Speed Videos of Historic Transient Tests

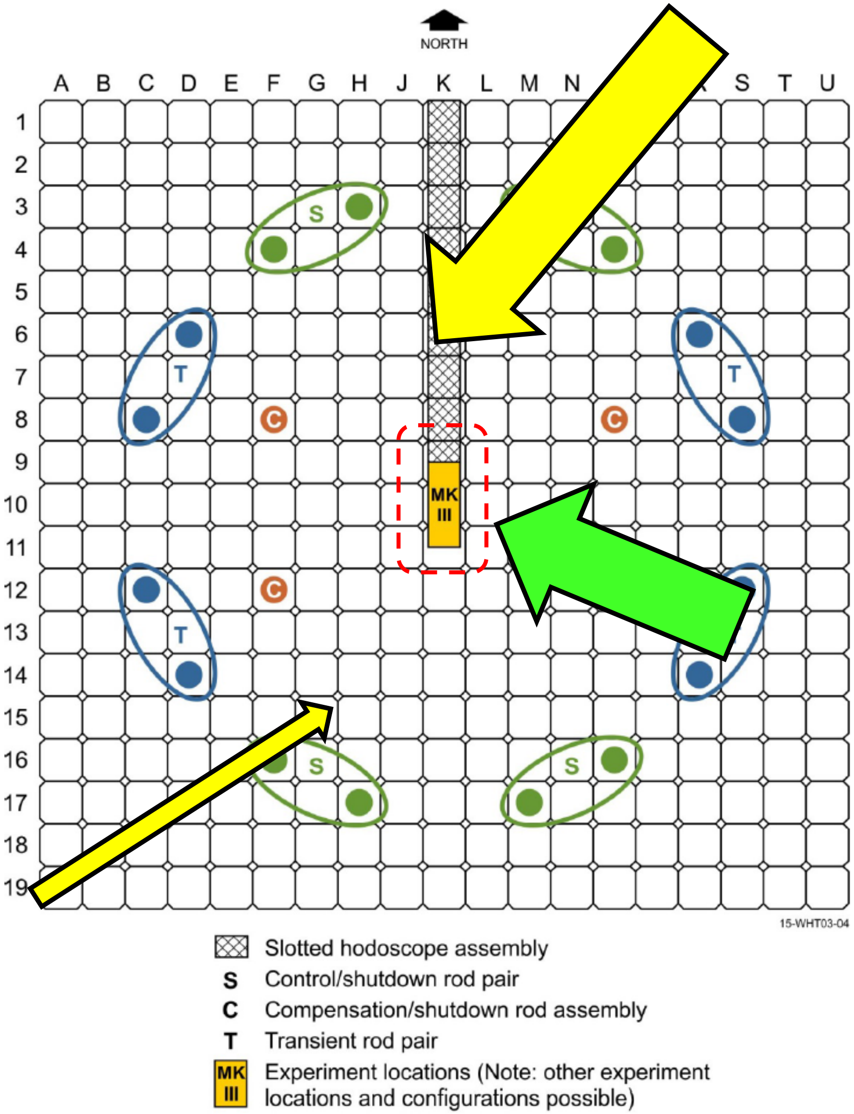
TREAT Multiphysics

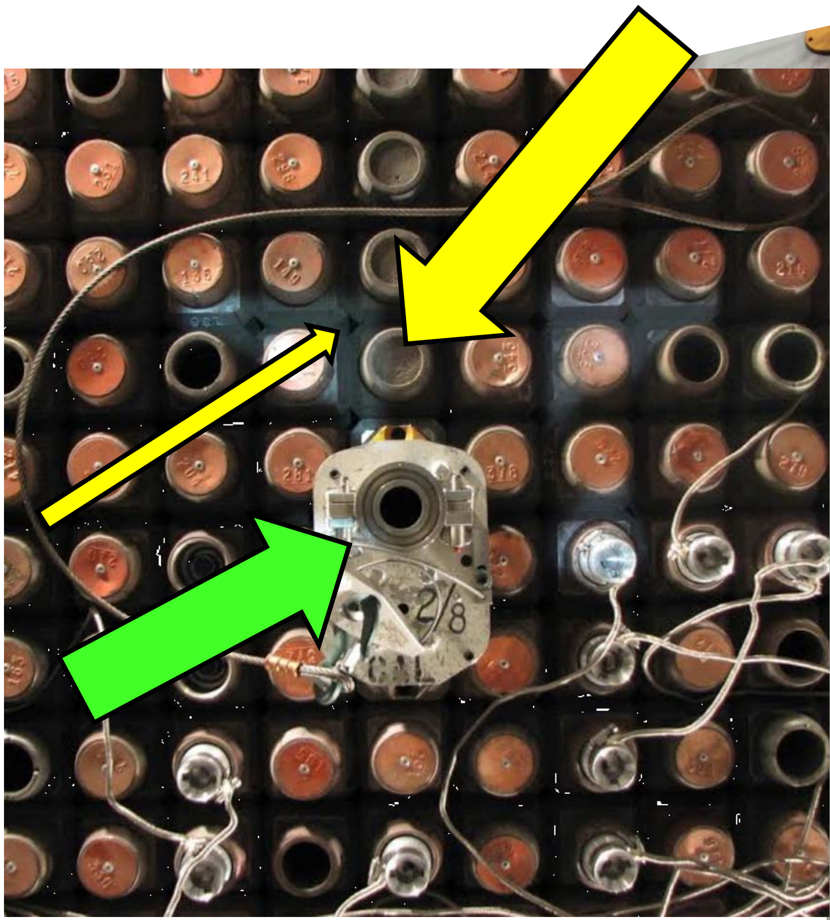
- TREAT was placed in cold standby mode in 1994 – scheduled to restart Nov 2017.
- Three sets of control rods:
  - Safety – fully out for transient
  - Compensation – partially inserted to set critical state pre-transient
  - Transient – partially inserted for desired delta-k, then rapidly fully withdrawn
- Core is 100 ppm highly enriched uranium – very little resonance absorption.
- As core heats, a shift in the thermal Maxwellian neutron spectrum reduces the fission rate in the core.



- Eventually rods are driven in to terminate the transient
- Temperature distributions (and thus feedback) are spatially distributed.
  - Simple (20th century) methods were never able to capture these effects
  - Primitive methods were used to estimate energy deposition in the experiments
    - Power coupling factor (PCF)
    - Transient coupling factor (TCF)
    - Both estimated from experimental calibration measurements
  - Full core power distributions and time-dependent energy production in experiment were never actually known

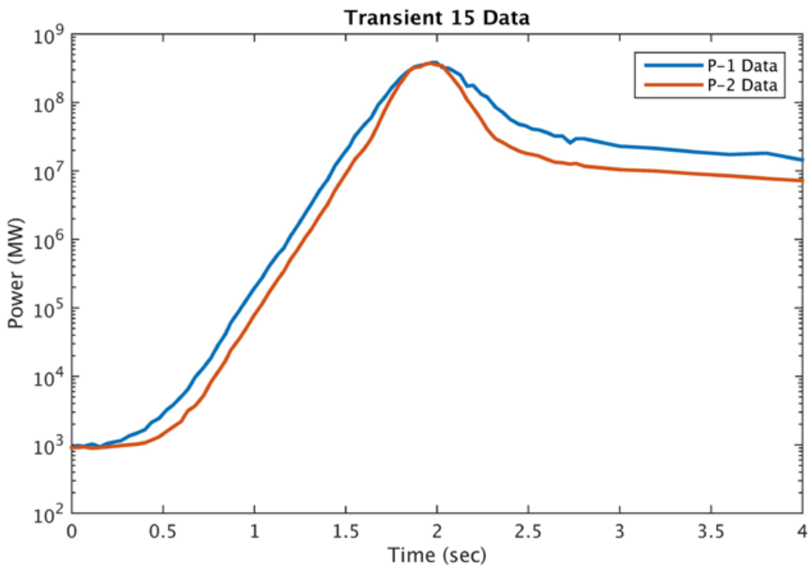
Modeling and Simulation Challenges





Neutron Kinetics – “Real” data

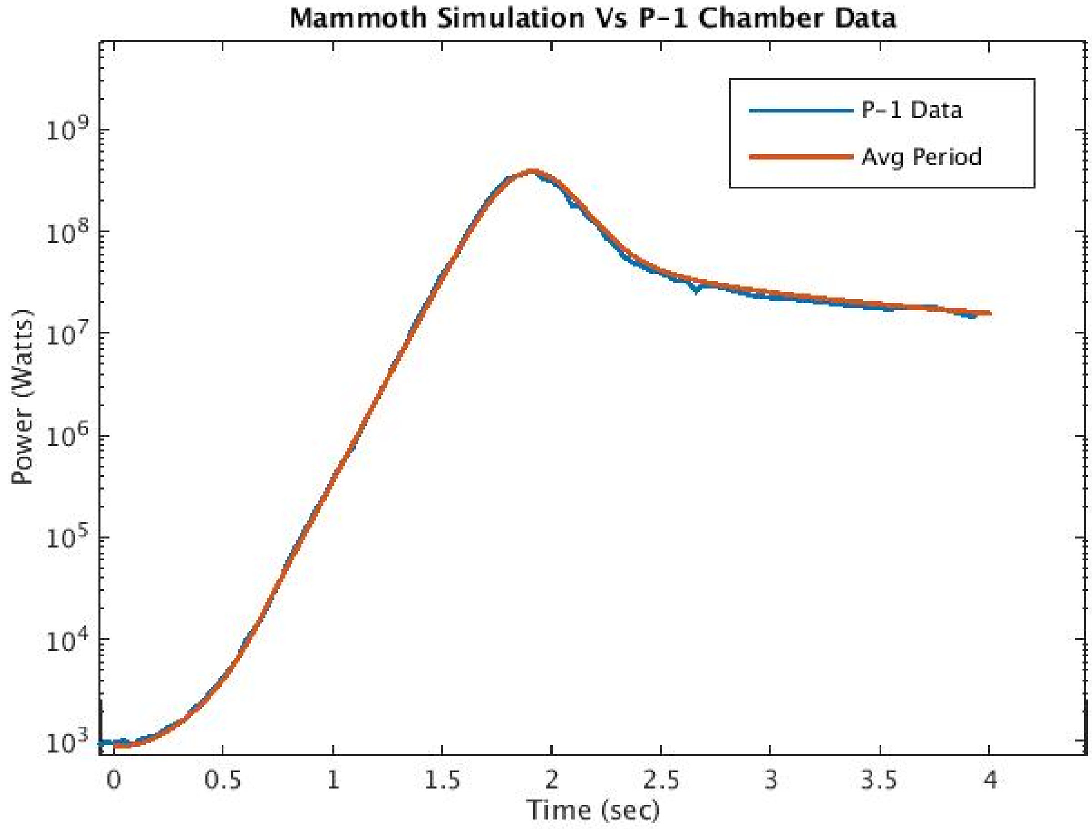
- Real Data
  - Transient 15: ANL-6173 Listed period = 0.105 sec and reactivity = 1.55%Δk/k
  - Original chamber current data was re-evaluated to determine appropriate bounds to place on these measurements
    - Period is the measured quantity, not reactivity
    - Chamber P-1 tented towards longer periods while P-2 tended toward shorter periods
    - Two detectors, same transient, different solutions



Period	Reactivities
0.103 sec (min)	0.01552
0.1075 sec (most probable)	0.01515
0.112 sec (max)	0.01481

Combine Kinetics and Feedback in Mammoth

- MAMMOTH P1 Data vs Average Period
- True multiphysics, but not good validation
- Agreement is almost "too good"



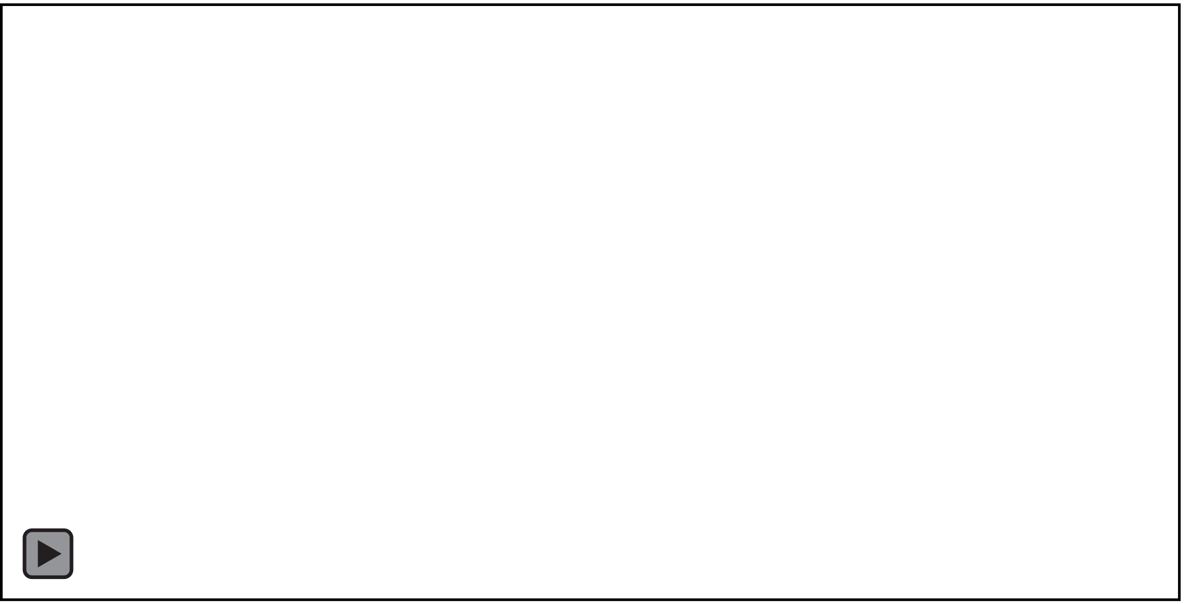
Combine Kinetics and Feedback in Mammoth

- ANL – 6173 (Trans 15)
- Peak Power = 380MW
- Integral Power = 315 MW-sec or (MJ)
- ΔT at core center = 176 ° C (K)
- Note: We have no uncertainties from the data on these values

Period	Peak Power (MW)	Peak Power (% Diff)	Integral Power (MJ)	Integral Power (% Diff)	ΔT max (Kelvin)	ΔT max (% Diff)
Min (0.1033 sec)	425	11.7	291	7.6	180	2.2
Avg (0.1082 sec)	384	1.1	281	10.7	174	1.3
Max (0.1126 sec)	355	6.5	268	14.9	166	5.8

MAMMOTH Reactor Multiphysics App

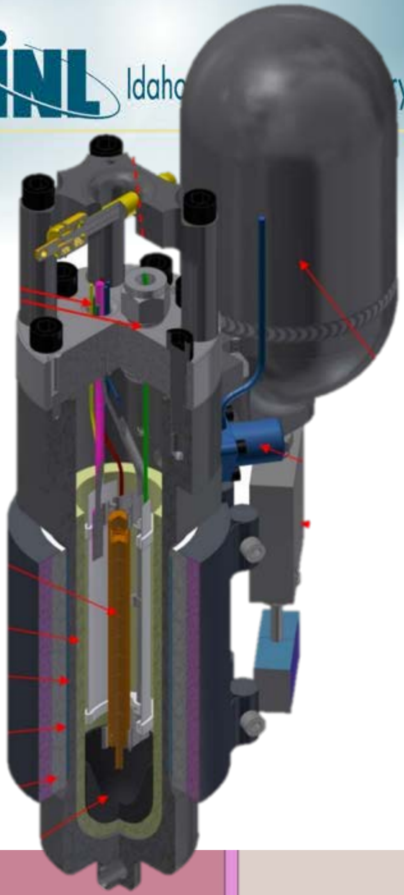
- MAMMOTH has successfully been used to simulate M8CAL transient simulations based on power data.
- Cross section methods have been developed to overcome difficulties with TREAT streaming paths.
- Current efforts are focused on calculation of PCF and TCF terms that were measured in the M8 calibration series (from steady state and time-dependent energy deposition simulations).

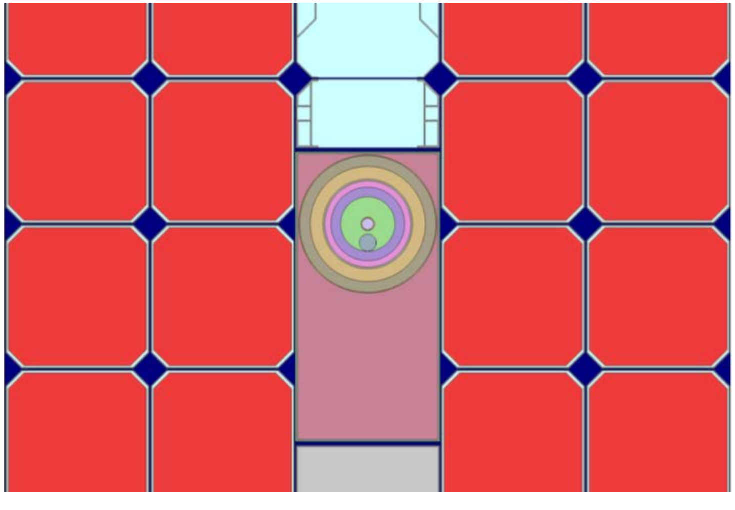


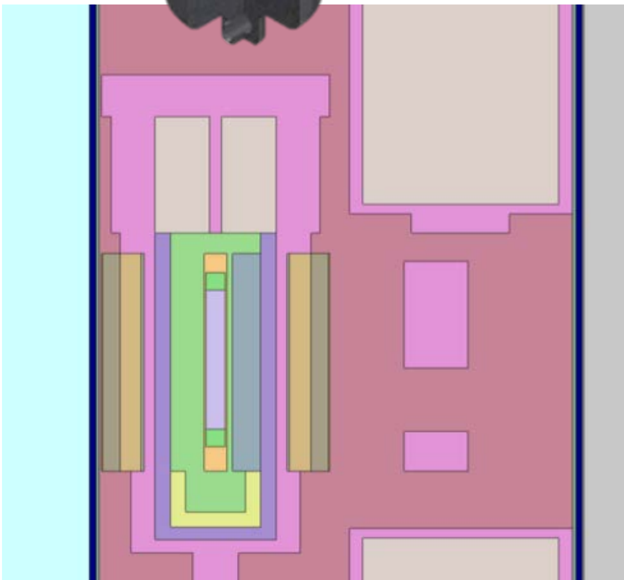
- These results will lead to confidence in ongoing Multi-SERTTA simulations being performed to allow understanding of transient response of system.
- Improved hodoscope streaming calculations
- Sensitivity/uncertainty work supporting M8CAL validation
- These are coupled fuel/transport calculations – multi-physics experiment simulations

TREAT Advanced Multi-Physics Simulation

- Current benchmark efforts are based on data available from M8CAL calibration measurements from early 1990s
- Parallel work in progress to model Multi-SERTTA, which is being designed as the first test capsule.
- Development of methods to handle cross section challenges
  - 3-D effects – base cross sections generated using *Serpent 2*
  - Strong neutron streaming in hodoscope slot and air channels
  - Strong absorption near control rods
  - Complex models

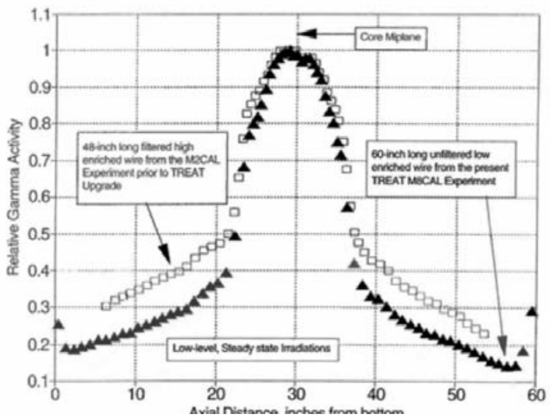


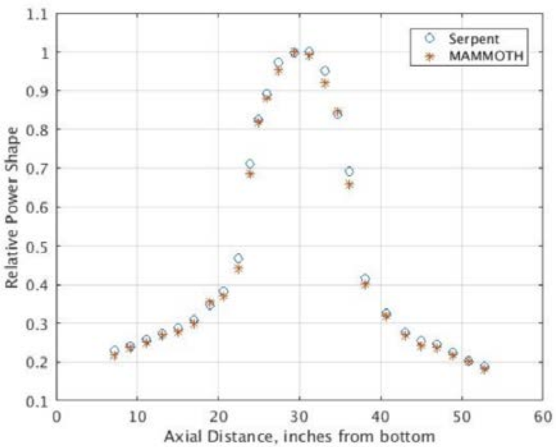


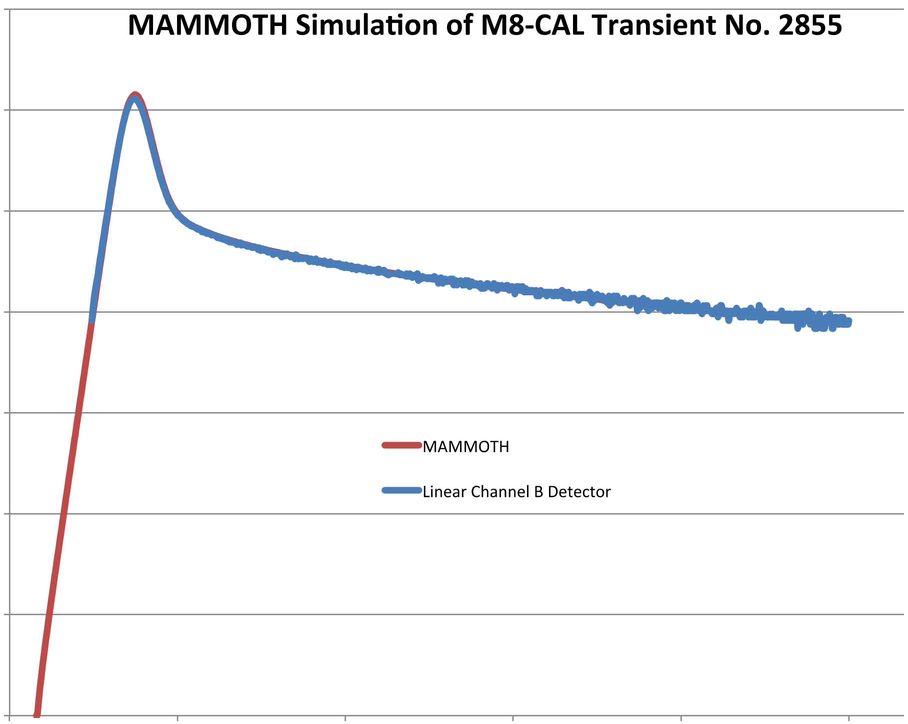


M8CAL Simulation with MAMMOTH

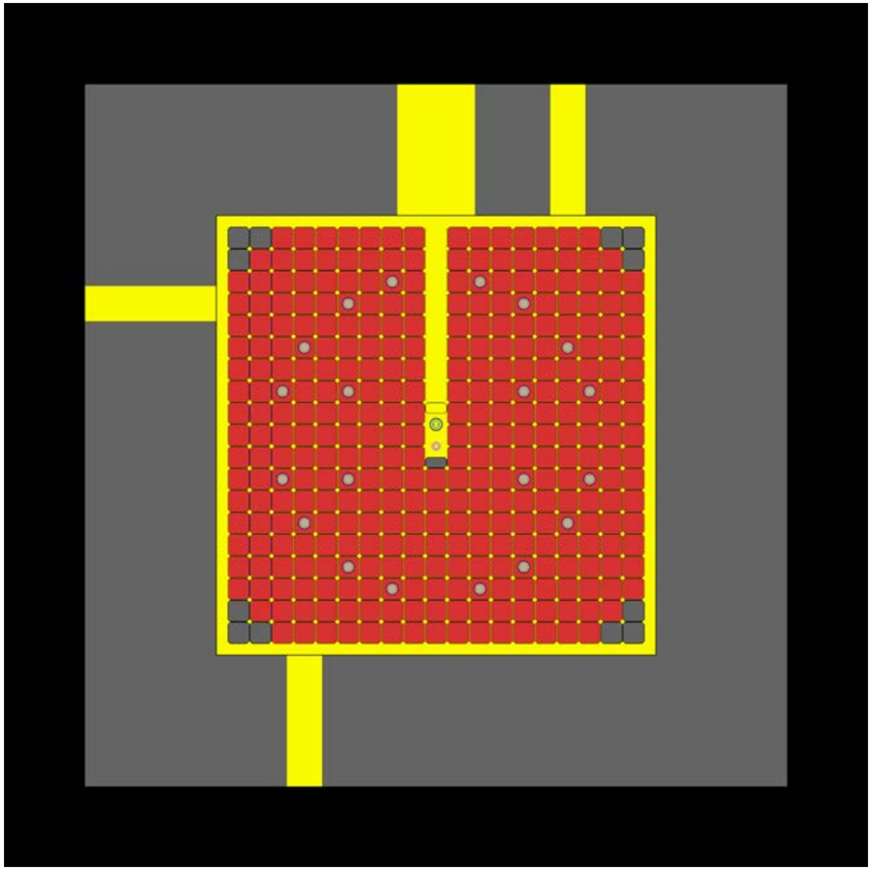
- Successful modeling of historical transients from M8CAL measurements with slotted core and in-core calibration vehicle.
  - transient power measurements
  - fission wires

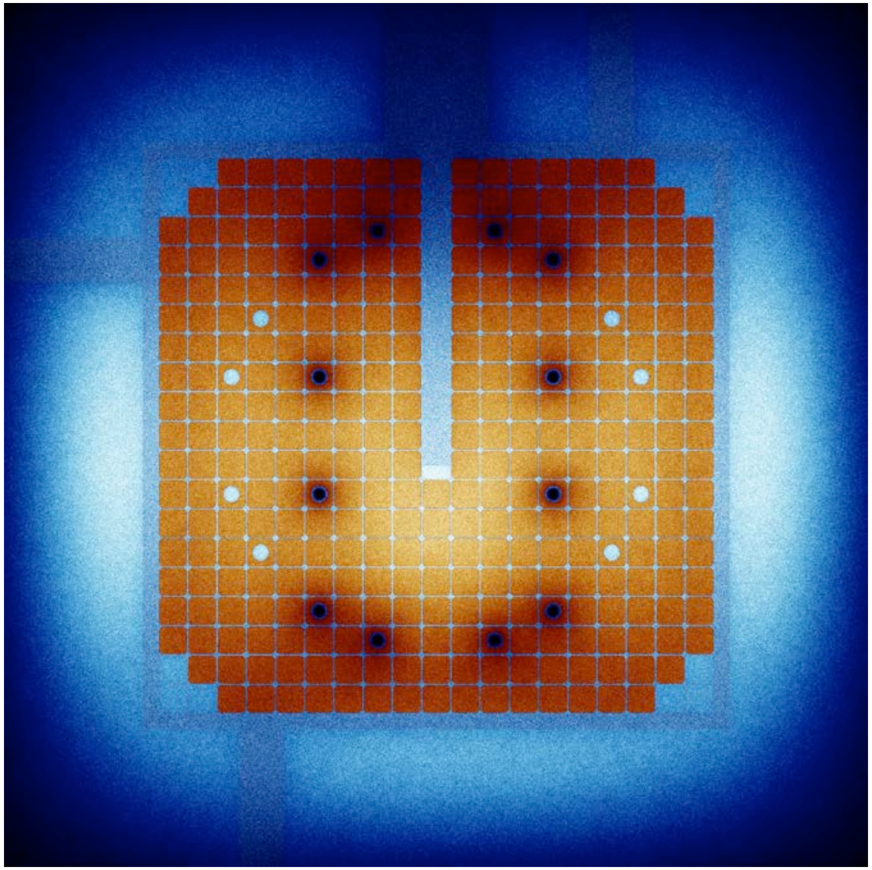




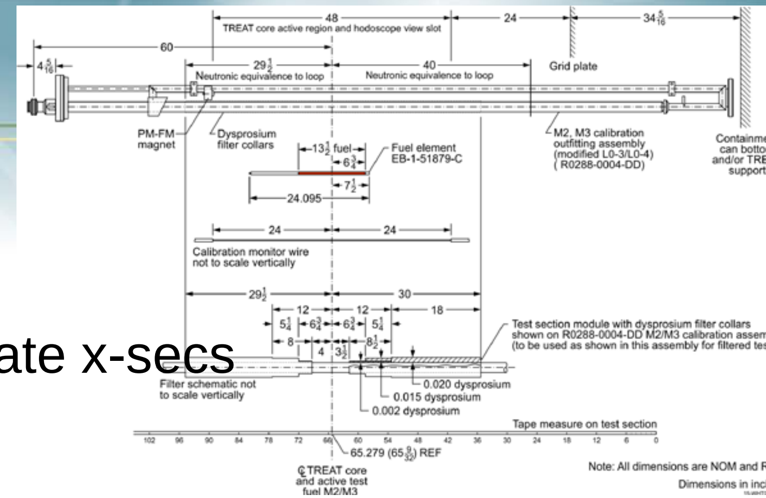


M8 Calibration Series (M8CAL)

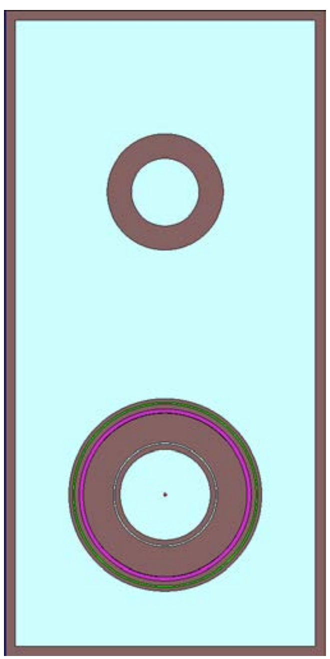


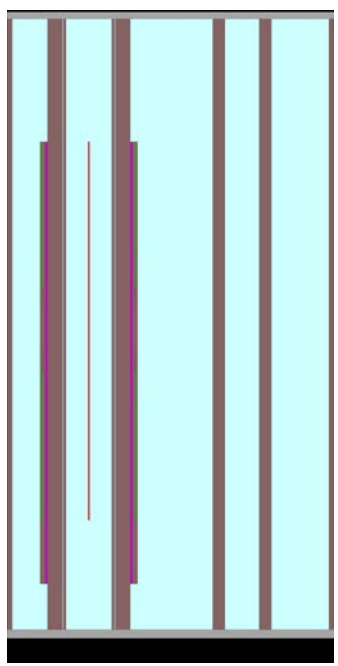


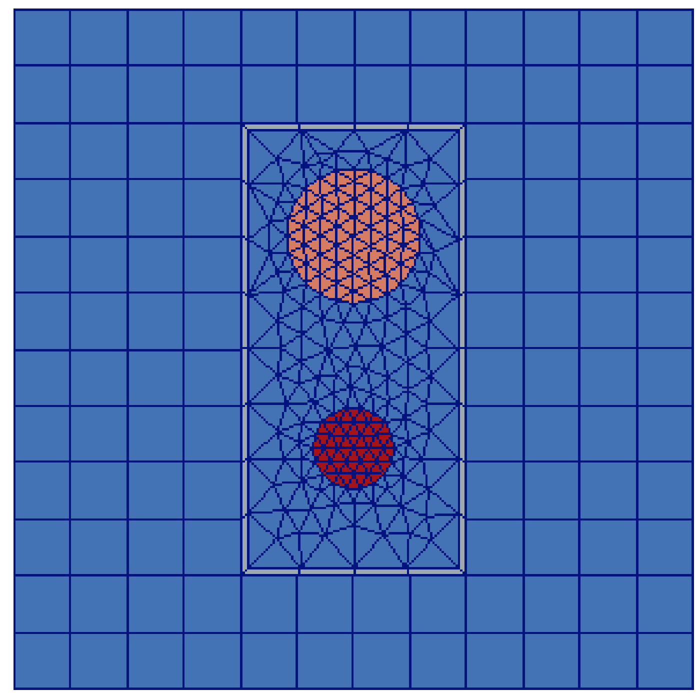
M8CAL



- Started with Serpent calculations to generate x-secs
- Designed M8-Calibration core
- Dy collar – Equivalent to a control rod
  - ~1.0468 with only air inside M8-Cal vehicle region
  - ~0.9964 – 0.999989 (Depending on critical CR positions) with M8CAL vehicle modeled





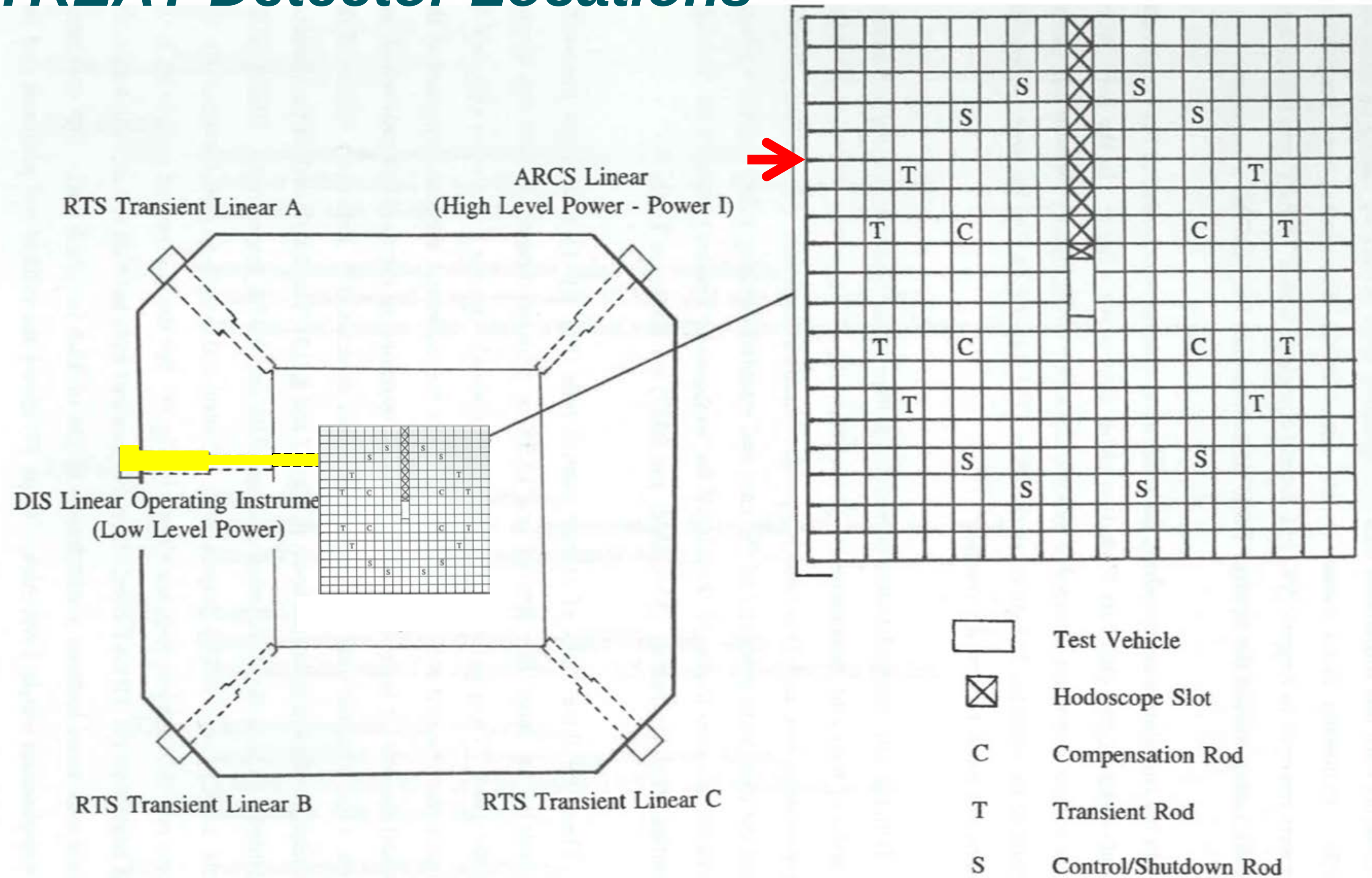


M8CAL Fission wires

Item	Date	Wire Identification	Core Slot	Axial Peak: Absolute (f/g) (x10E13)	Total Energy in Irradiation, MJ	Measured Coupling Factor (f/g U-235-MJ) (x10E12)	Control Rod Configuration	Appropximate Initial (Critical) Rod Position, in.		Wire Holder
								Control/Shutdown	Transient	
1	10/19/90	L91-8-10	Full	1.42	667	1.79	B	Fully Withdrawn	18.5	Unfiltered
2	8/24/92	L91-60-1	Half	0.958	576	1.40	A	22	Fully Withdrawn	Unfiltered
3	11/20/92	L91-8-1	Half	0.968	576	1.41	A	22	Fully Withdrawn	Unfiltered
4	2/ 8/93	L91-8-6	Half	0.819	480	1.44	A	22	Fully Withdrawn	Unfiltered
5	2/12/93	H91-8-1	Half	0.972	576	0.503	A	22	Fully Withdrawn	Filtered
6	3/ 2/93	L91-8-16	Half	1.26	576	1.84	B	48	11.5	Unfiltered

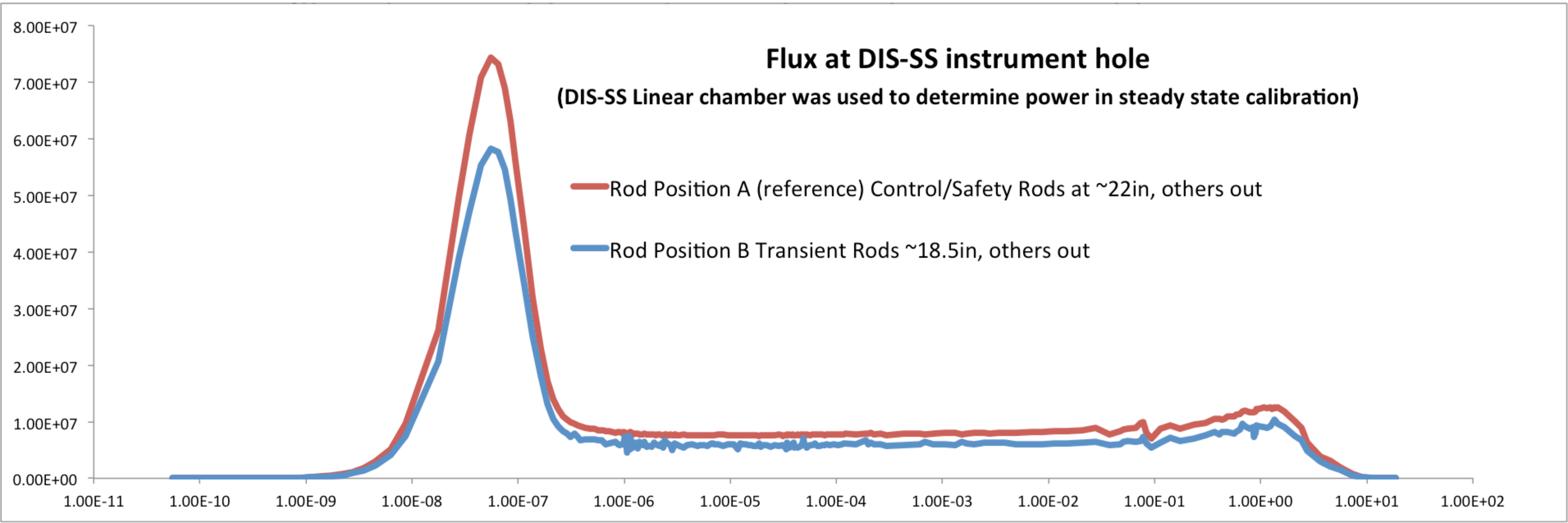
Item	Wire ID	Measured PCF	Predicted PCF	Error (%)
1	L91-8-10	1.79	1.204	-32.7
2	L91-60-1	1.40	1.190	-15.0
5	H91-8-1	0.503	0.439	-12.7
6	L91-8-6	1.84	1.24	-32.6

TREAT Detector Locations



M8CAL Fission wires

- Modeling problems
  - PCF defined as fissions/(g-U235 MJ-Reactor).
  - We used wrong Q value (202.27 MeV/fission) – *contributes to the denominator of the PCF*
  - MCNP calculations indicate Q = 171-175 MeV/fission
  - Add ~9 MeV/fission from decay heat, Q ≈ 182
  - Also found 1982 ANL document that indicates that temperature and control rods can influence the detector response and samples
  - For control rod position B, a significant flux change is seen relative



M8CAL Fission wires

- Modeling problems
  - Data for the H91-8-1 irradiation gives a max temperature of 115 C and critical 23 C. If calibration was performed at 23 C, the detector is biased ~5.7% (without CR effects)
  - $^{10}B(n,\alpha)$ reaction which is measured by the DIS-SS chamber should have changed by ~24% (flux ratio of ~76% relative to that at 23 C) for Rod position B measurements - consistent with ANL estimates.
  - Two simulations were performed based on different locations of the detector to obtain a range of possible flux ratios.
    - Assuming the detector was in its closest position to the core, a flux ratio of 0.752 was calculated
    - Assuming the detector was situated farther out in the instrument hole in the biological shield, a flux ratio of 0.77 was calculated.
  - L91-8-10 → **1.204***(202.27 MeV/182 MeV)/(0.752 or 0.77)

    = 1.74 or 1.78.
  - Measured value was 1.79

M8CAL Fission wires

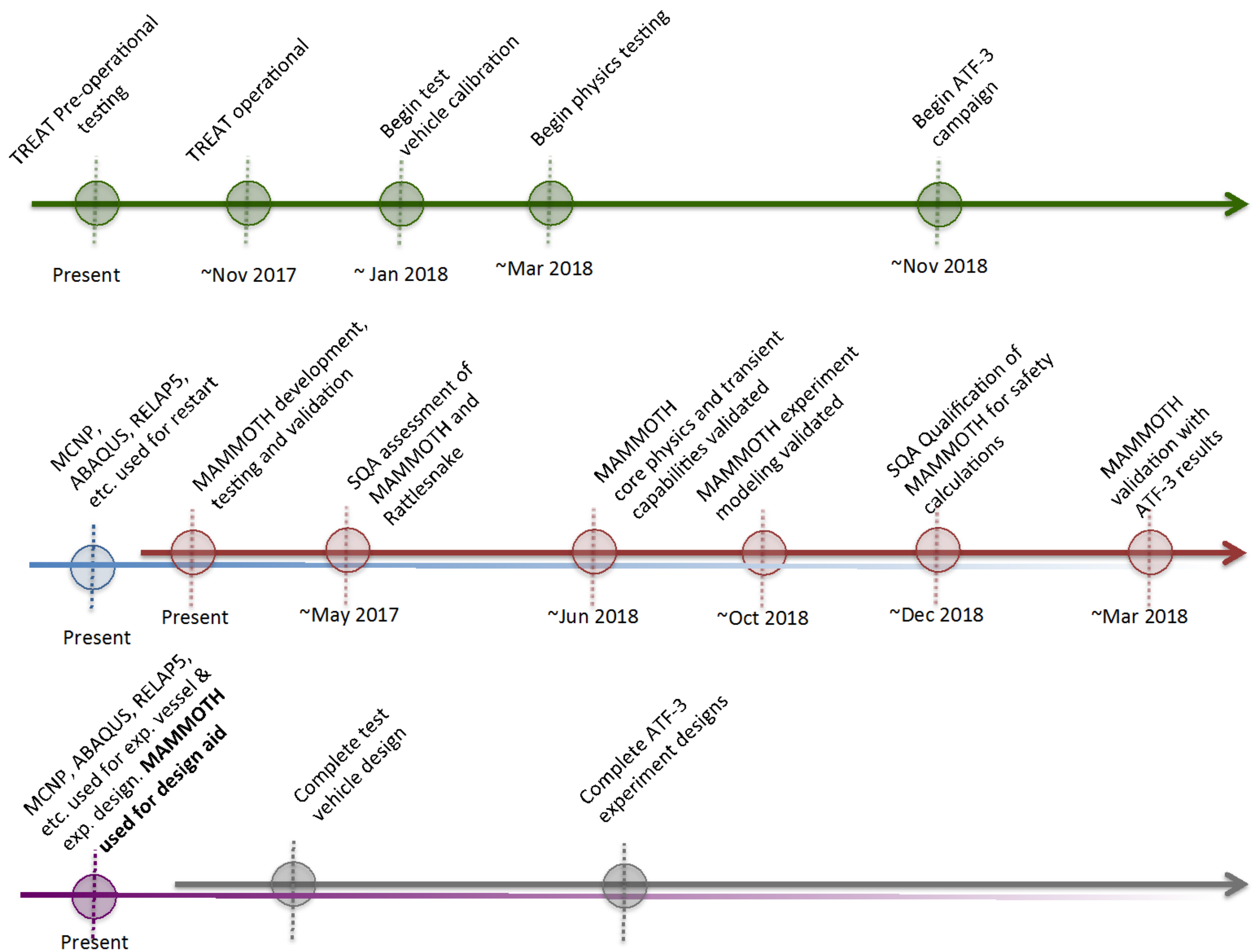
- Correcting for Q value, rod position and temperature effects, as appropriate

Item	Wire ID	Measured PCF	Correction Type	Revised Prediction of PCF	Error (%)
1	L91-8-10	1.79	Q value, Rod position B + full slot core, Temperature	1.74	-2.79
				1.78	-0.56
2	L91-60-1	1.40	Q value, Temperature	1.39	-0.71
				1.44	+2.86
5	H91-8-1	0.503	Q value, Temperature	0.487	-3.02
				0.499	-0.80
6	L91-8-6	1.84	Q value, Rod position B, Temperature	1.88	+2.17
				1.94	+5.40

Conclusions from M8CAL Measurements

- The quality of data is not appropriate for full validation.
  - Critical information is not available (e.g., detector positions)
  - TREAT measurements and data acquisition were never designed for multi-physics validation nor for 3D simulations.
  - How would you factor in uncertainties for original measurements given the complexity of the responses.
- Nevertheless we have learned how to characterize some of the calibration issues and have developed <u>confidence</u> in our methods.
- Confidence and validation are unfortunately not the same thing.
- We need better data to be able to do true validation.
- TREAT will start providing that opportunity within a year.

Startup Testing Timeline and MAMMOTH

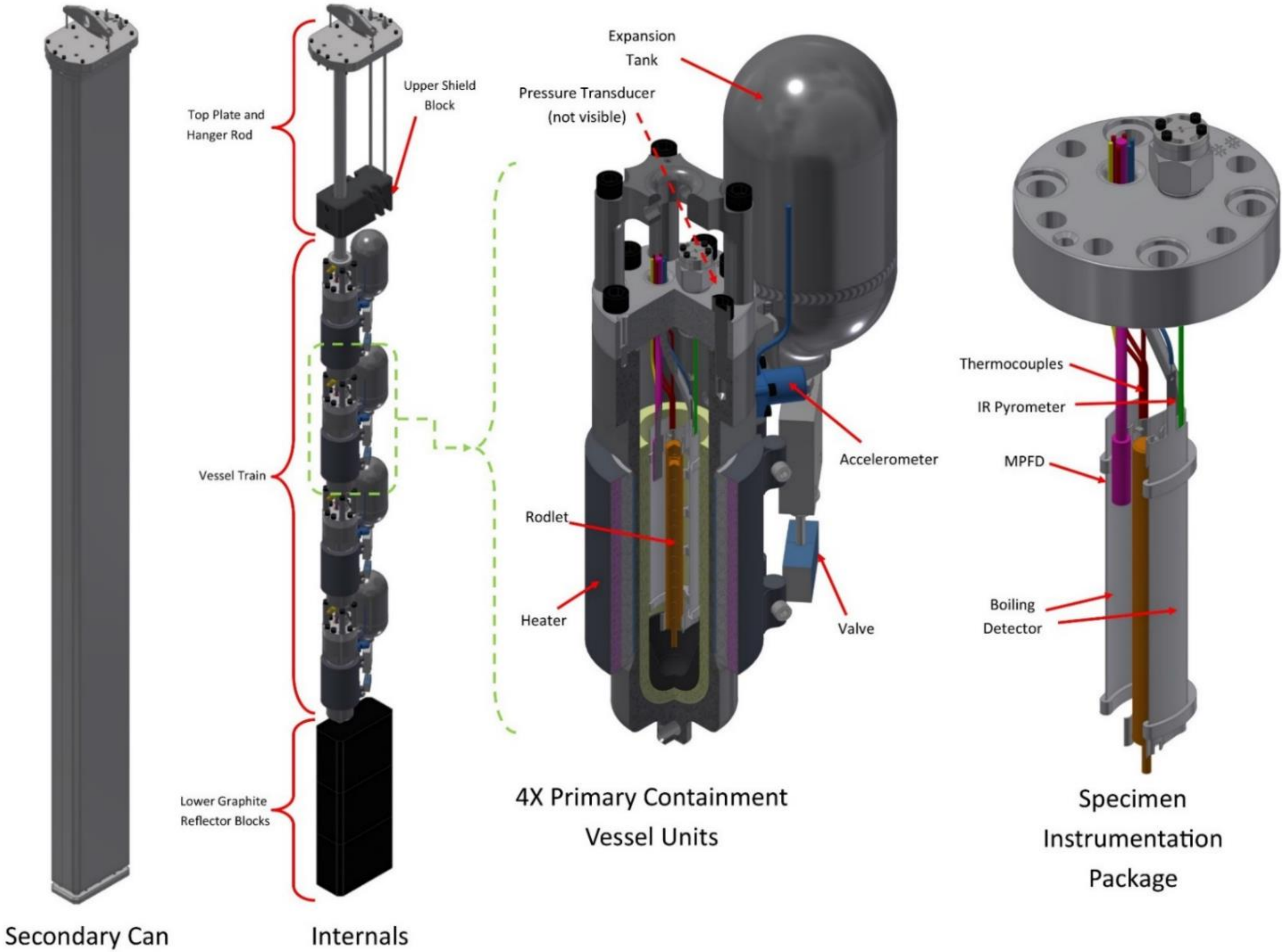


Support core characterization work and reactor physics experiments

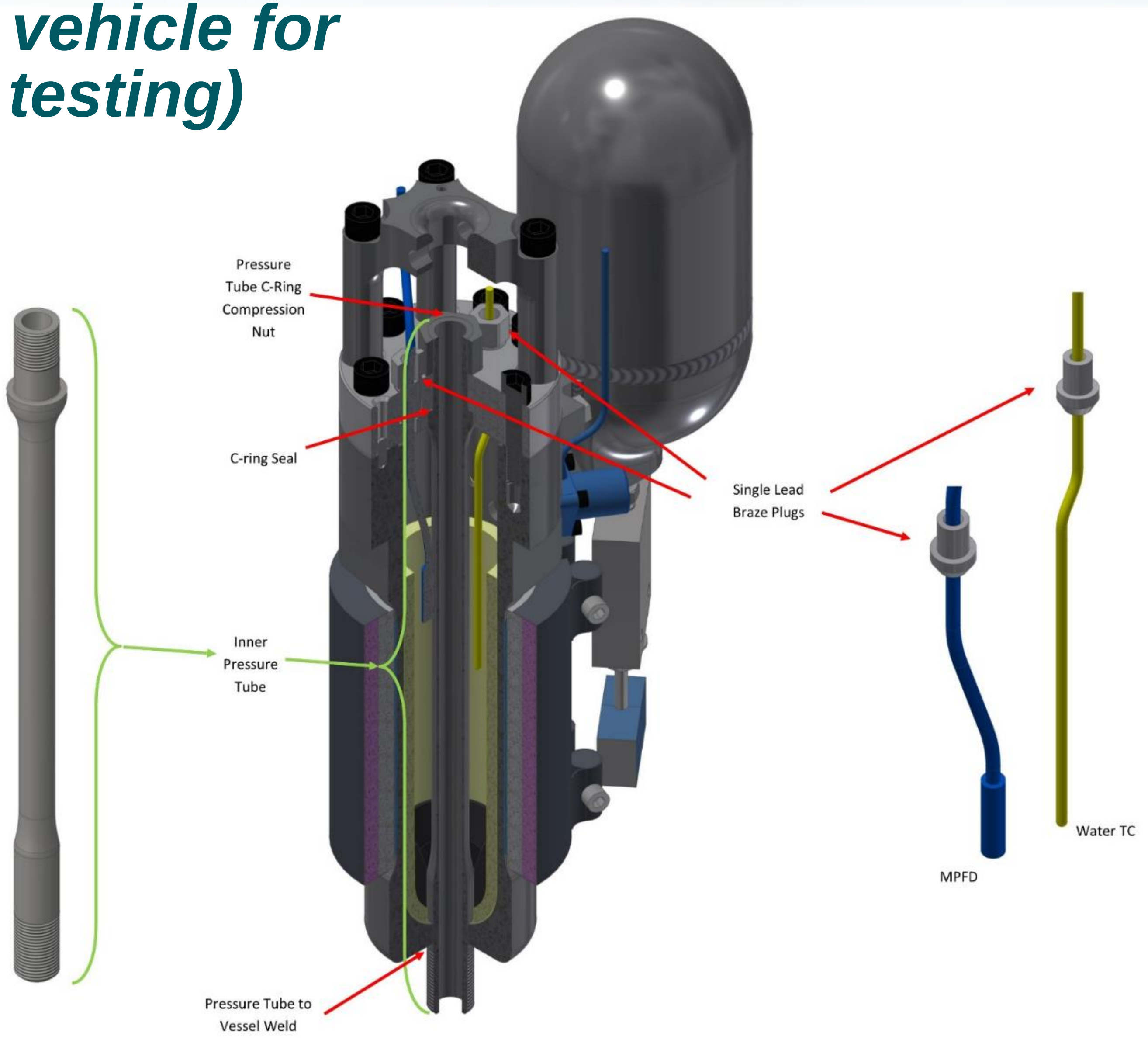
- Specify and procure gamma spectrometer, gross beta counter, fission and flux wires, fabricate wands
- Rod worth measurements
- Support planned ATF calibration experiments
- Develop power coupling and transient correction factors
- Develop neutron flux, power, and temperature profile throughout the experiment calibration vehicle
- Map neutron flux profile throughout the core, varying temperature
- Map the reactor power profile throughout the core, varying temperature
- Map the temperature profile throughout the core, , varying power
- Measure beta and neutron lifetime
- Measure negative temperature coefficient
- Measure neutron spectrum as a function of temperature in core center (spectroscopy)

Multi-SERTTA

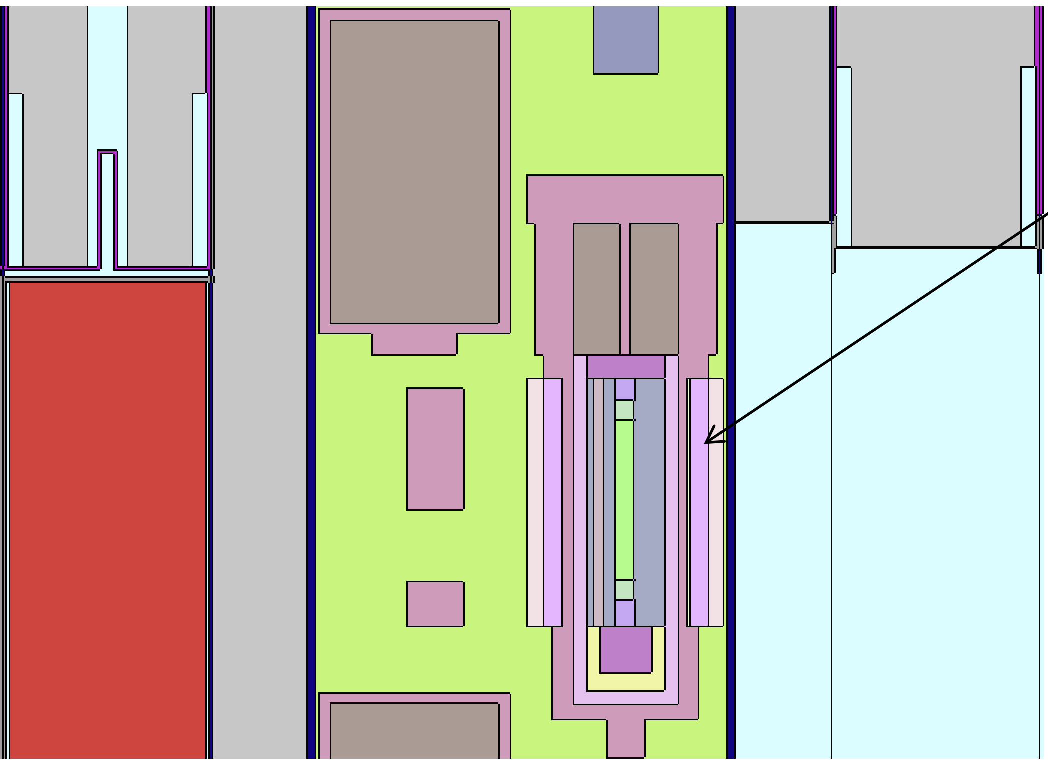
SERTTA: Static Environment Rodlet Transient Test Apparatus



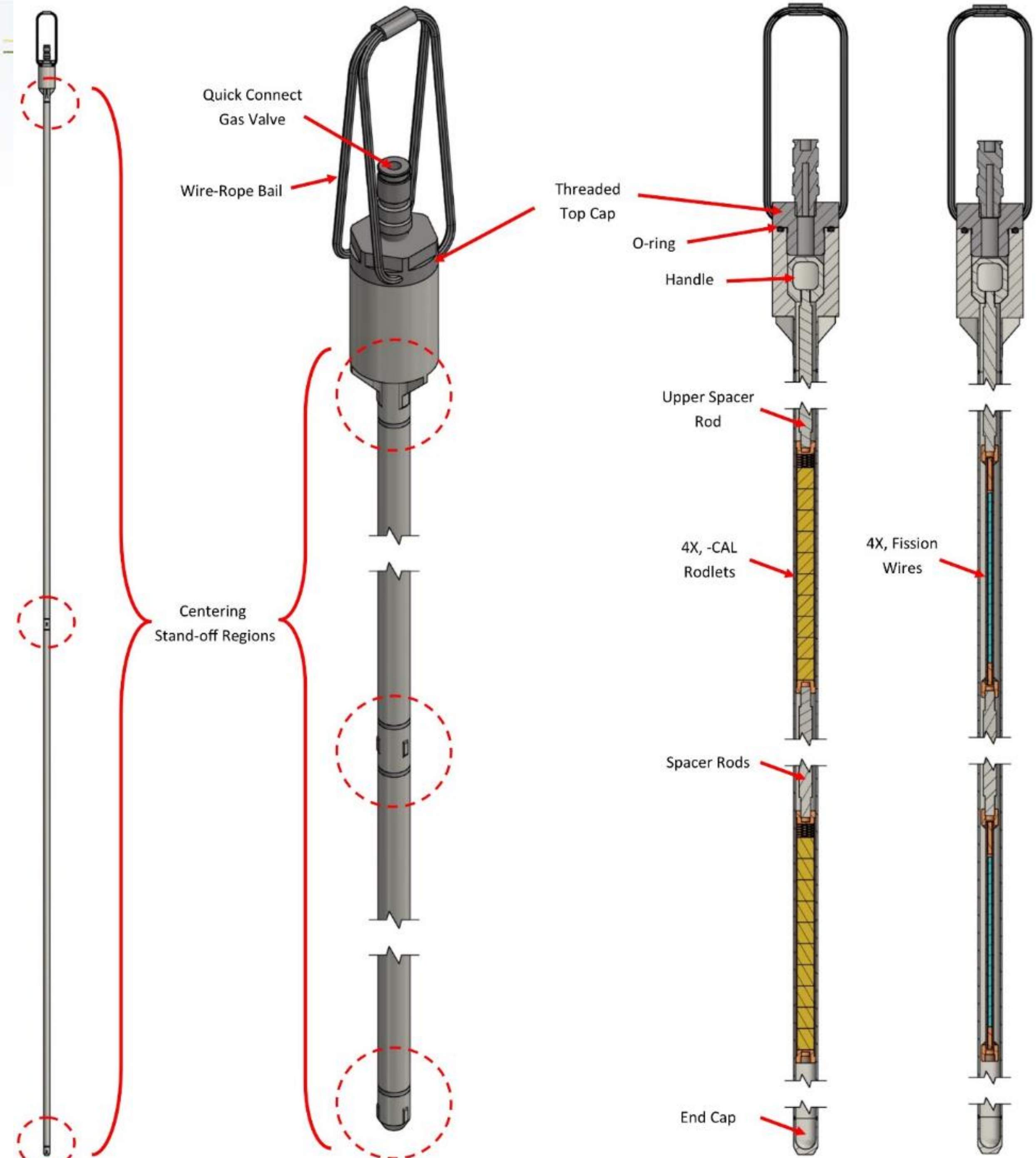
Multi-SERTTA-CAL (Simplified vehicle for calibration testing)



Multi-SERTTA-CAL Modeling



- Steady state calculations
  - MCNP and Serpent
  - Estimate initial PCFs
  - Design flux filters to create axially uniform PCFs
  - MAMMOTH calculations in progress
- Transient calculations
  - Serpent used to generate cross sections
  - MAMMOTH ultimately used to



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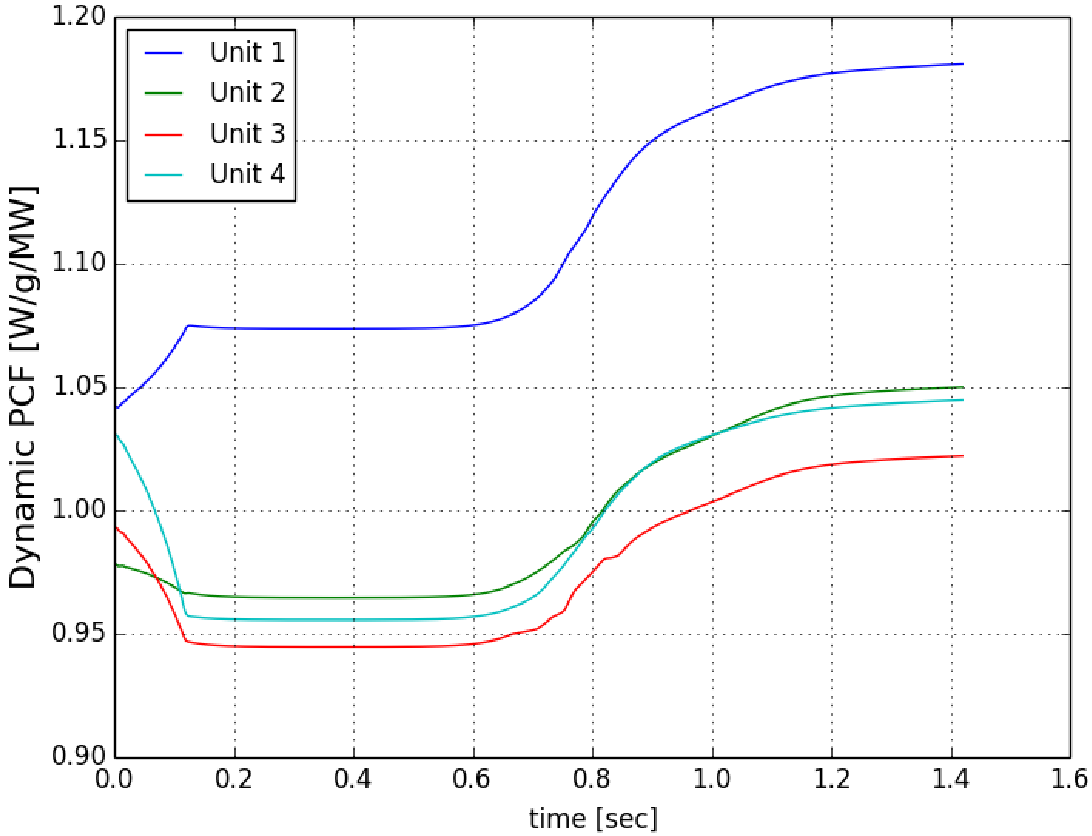
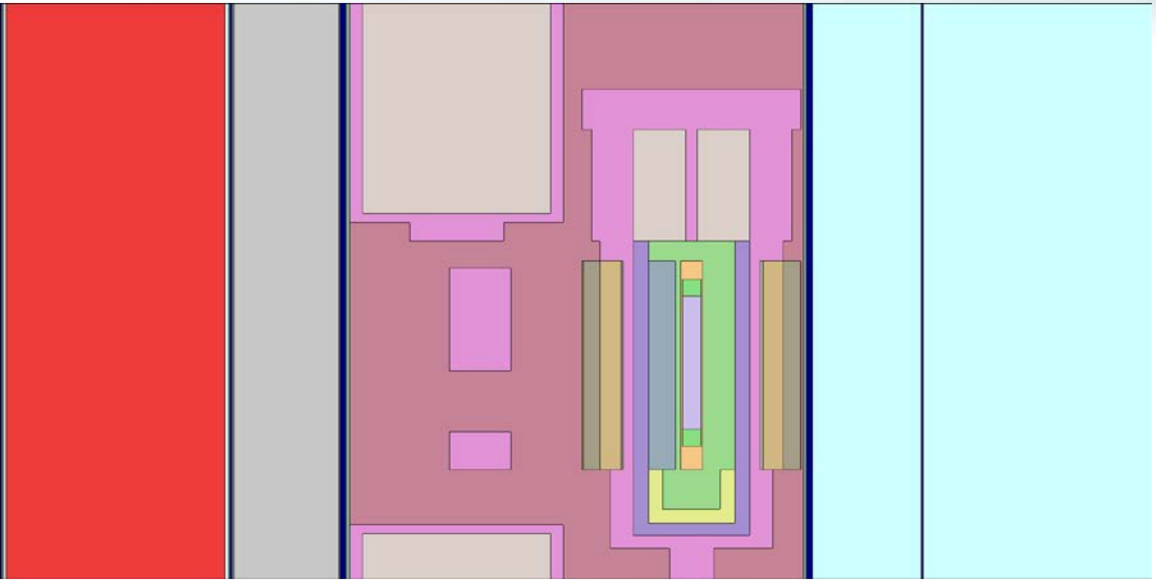
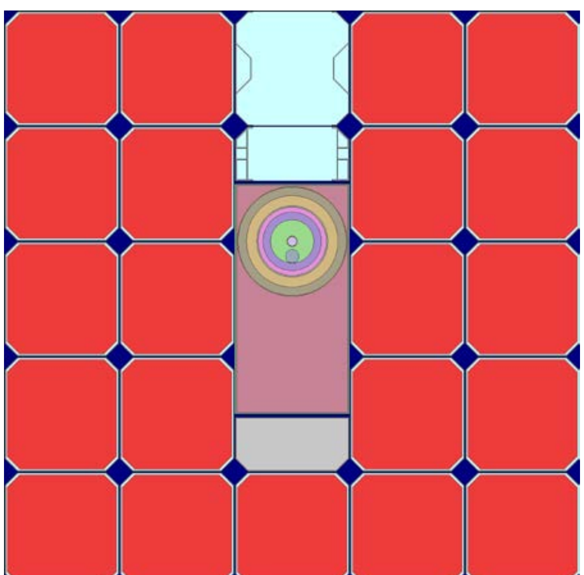
Transient Calculations using MAMMOTH

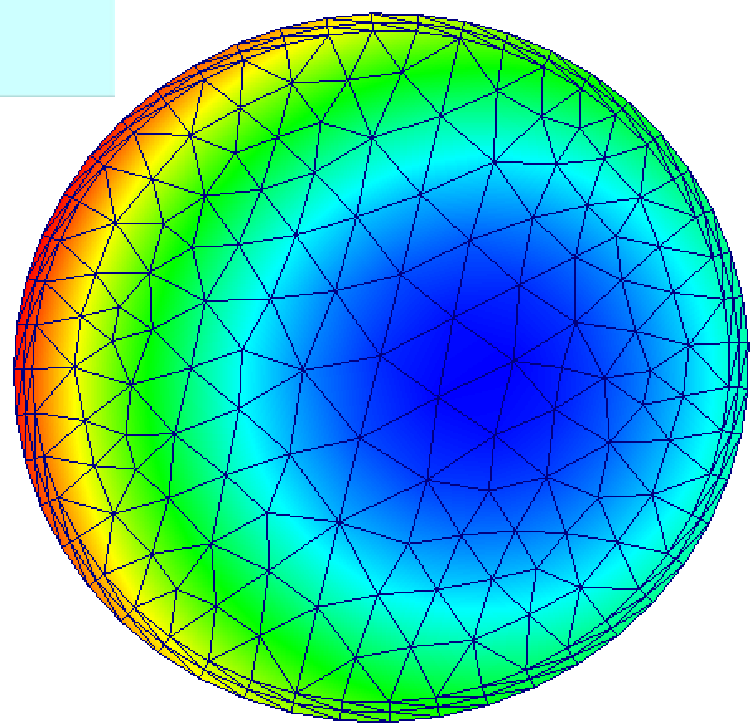
- Currently trying to calculate instantaneous coupling factors for each SERTTA unit
  - spatial effects due to rod motion (0 ➔ 0.115s)
  - temperature effects beginning around 0.7s



- This experiment series should provide validation of MAMMOTH for transient simulations
- The data will be published and become available of other multi-physics validation efforts.







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