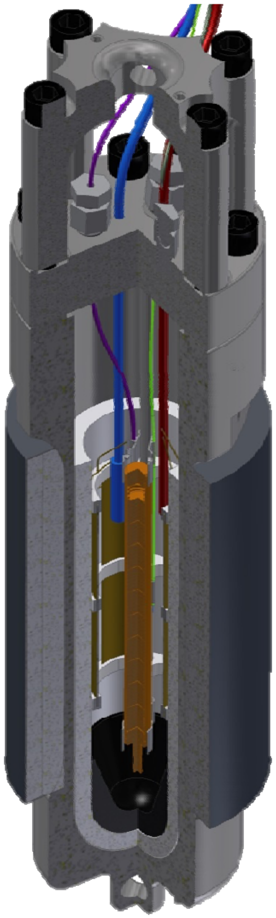
INL/MIS-17-41427

Validation of Rattlesnake, BISON and RELAP-7 with TREAT

Expert Group on Multi-physics Experimental Data, Benchmarks and Validation (EGMPEBV)



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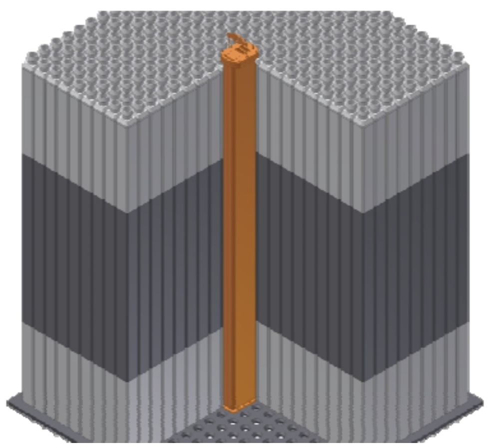
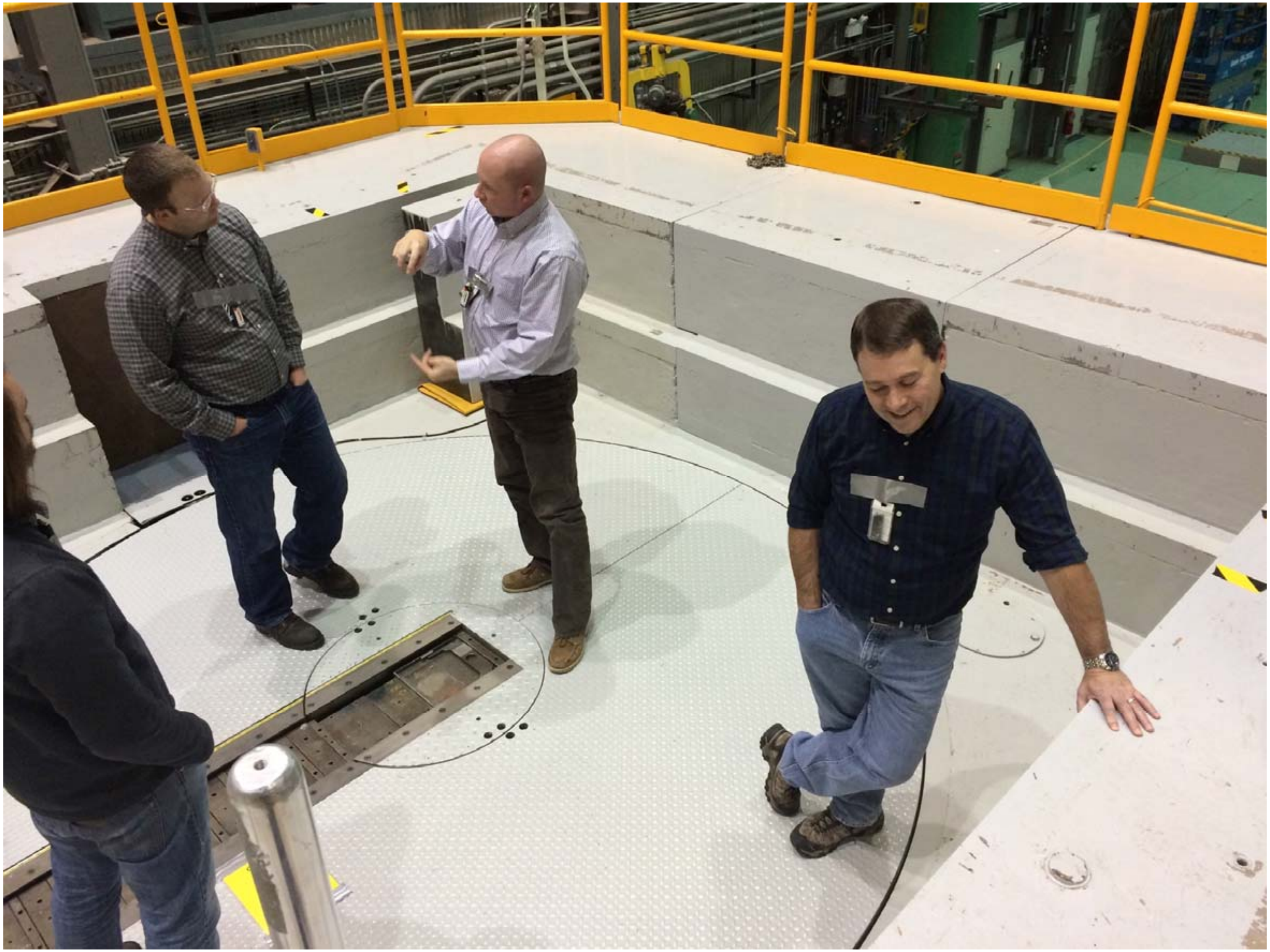
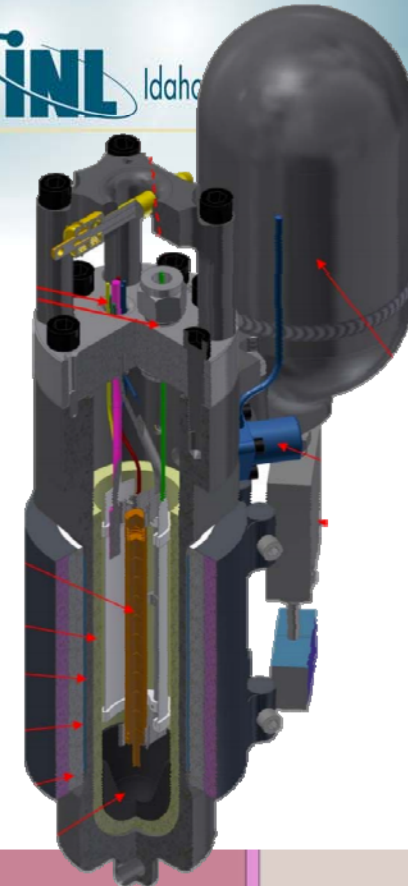


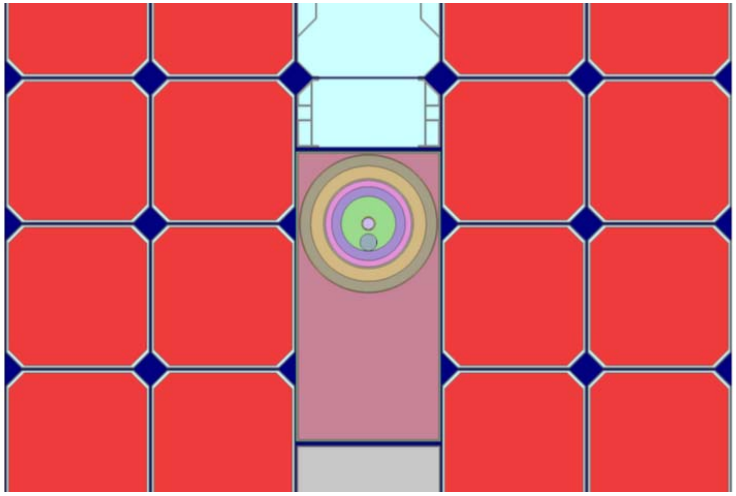
TREAT – The Transient Test Reactor Facility

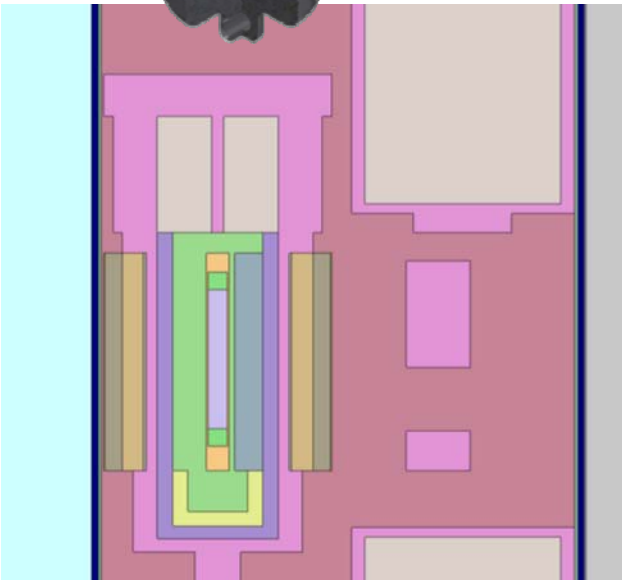


TREAT Advanced Multi-Physics Simulation

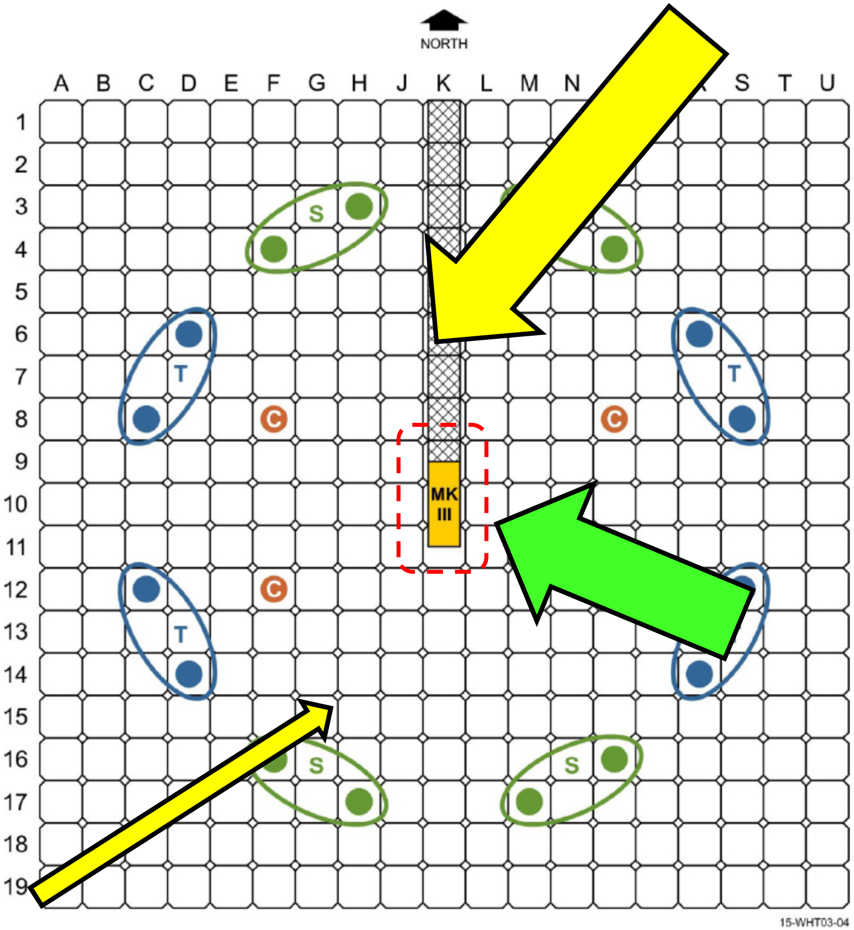


- Current benchmark efforts are based on data available from M8CAL calibration measurements from early 1990s
- Parallel work in progress to model Multi-SERTTA, which is being designed as the first test capsule.
- Development of methods to handle cross section challenges
  - 3-D effects – base cross sections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





Modeling and Simulation Challenges



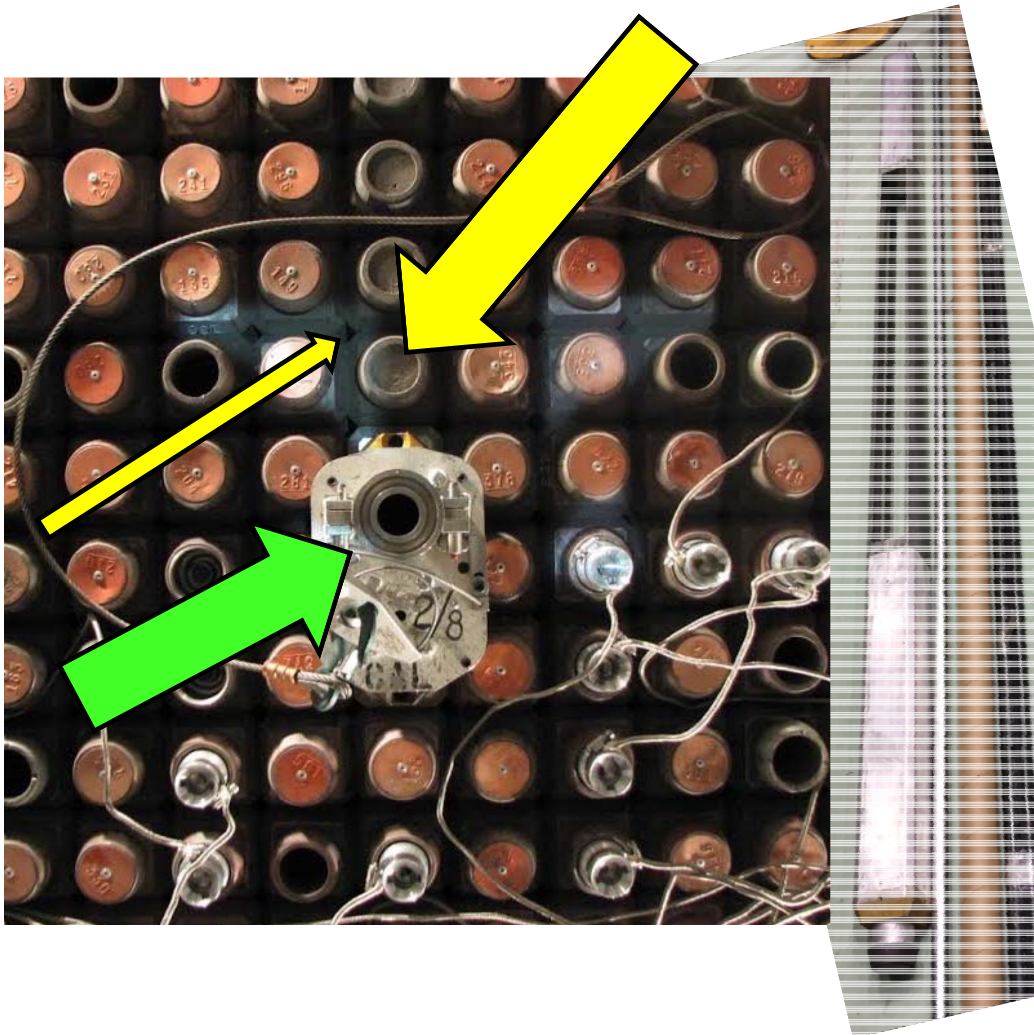
Slotted hodoscope assembly

S Control/shutdown rod pair

C Compensation/shutdown rod assembly

T Transient rod pair

MK III Experiment locations (Note: other experiment locations and configurations possible)



Status of MAMMOTH R&D

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

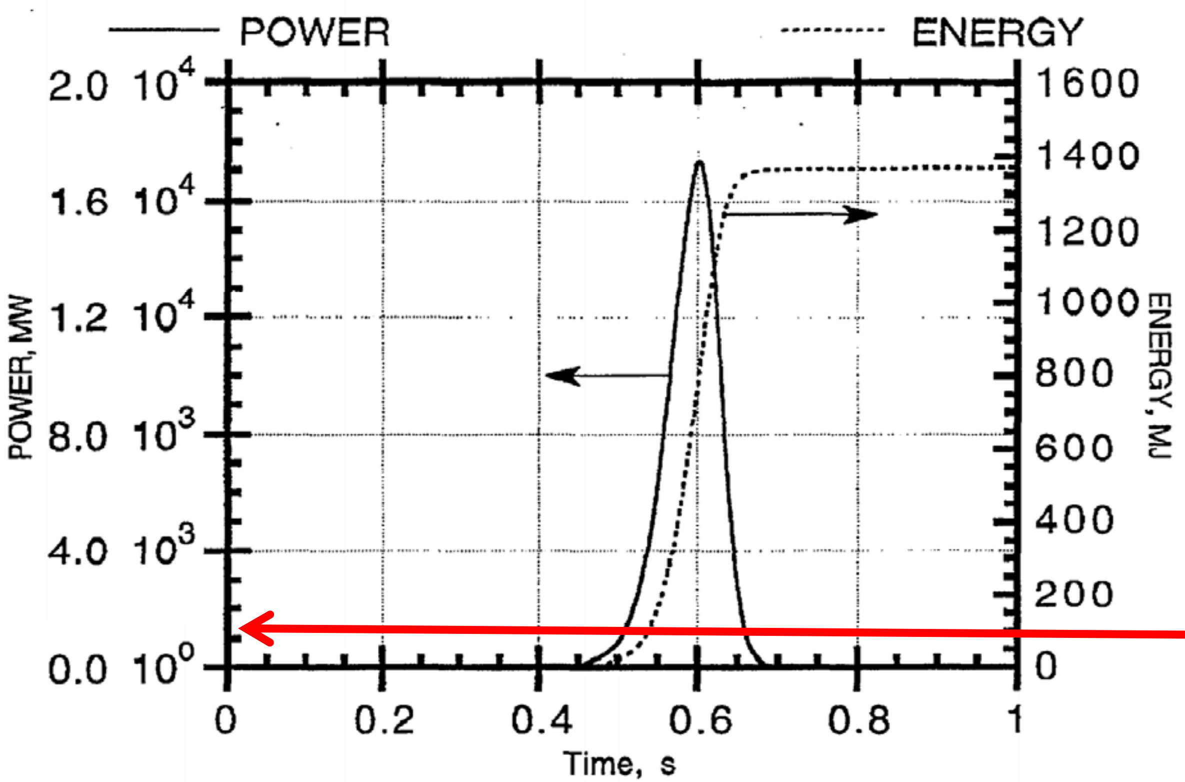
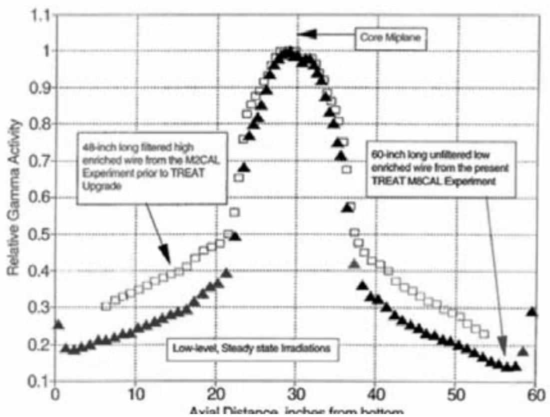


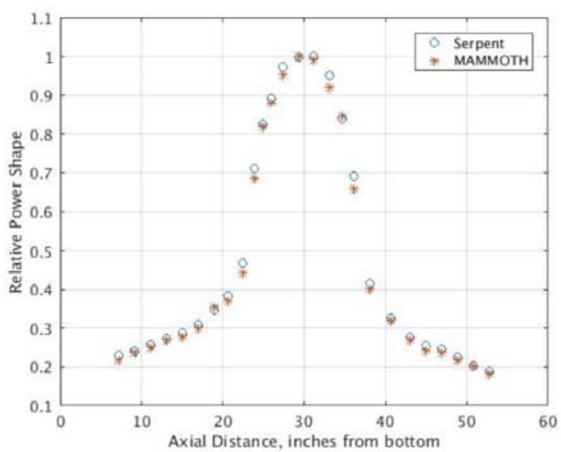
FIG. 5. Plot of TREAT reactor power and energy for hypothetical RIA-type transient resulting in 1400-MJ pulse with a 72-msec FWHM capable of depositing 1200 kJ of energy per kg of fuel (290 cal/g).

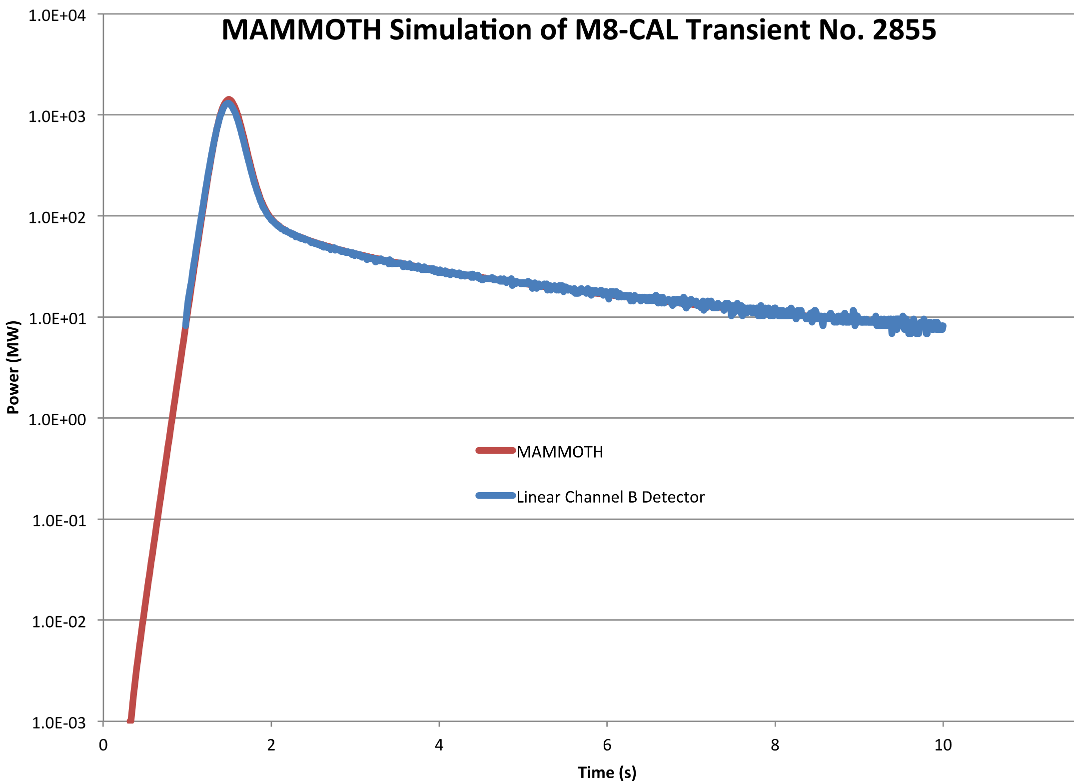
1.21 Gigawatts

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





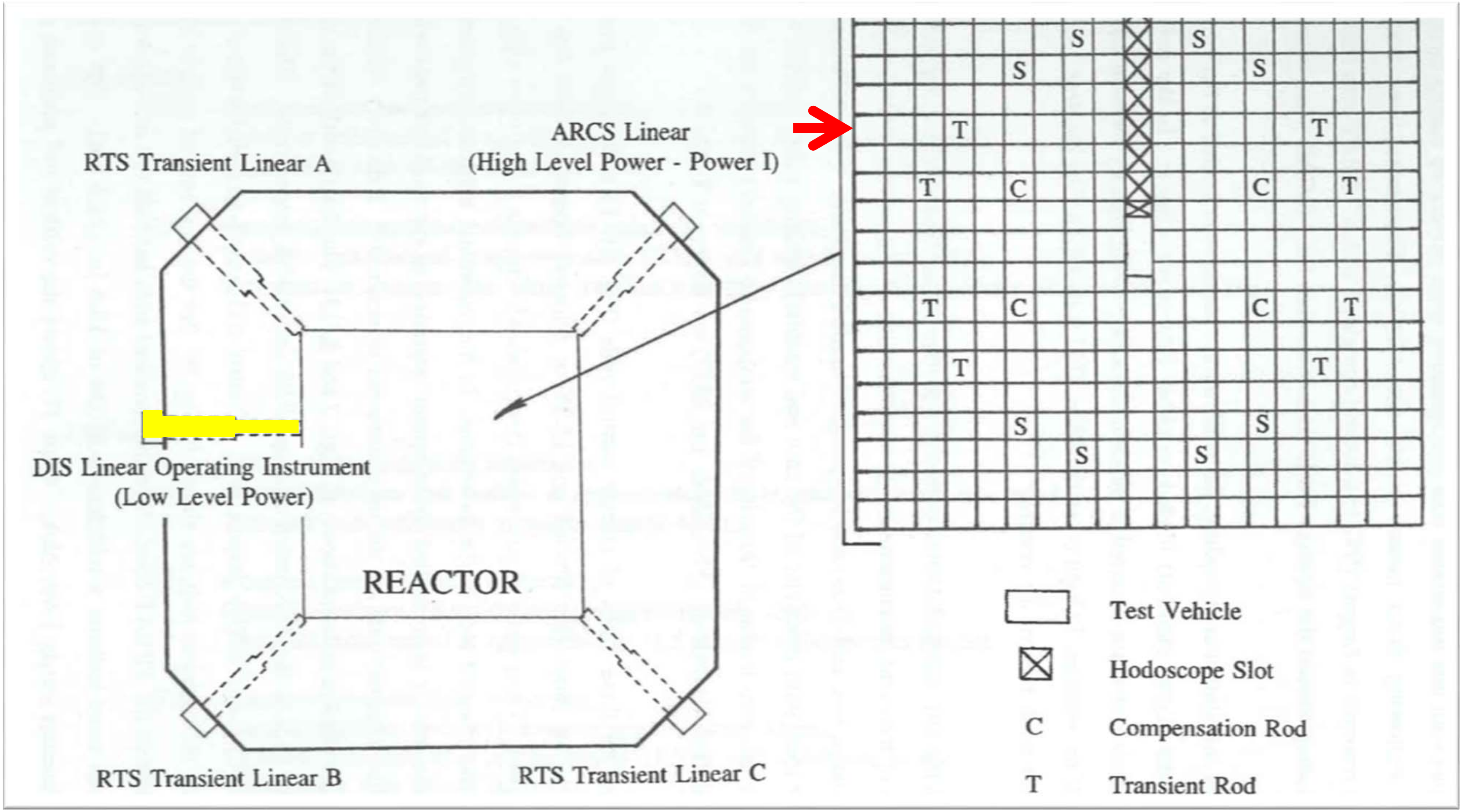


M8CAL Fission wires

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	C/R Config.	Wire ID	Measured PCF	Predicted PCF	Error (%)
1	B	L91-8-10	1.79	1.204	-32.7
2	A	L91-60-1	1.40	1.190	-15.0
5	A	L91-7-1	0.503	0.439	-12.7
6	B	L91-8-6	1.84	1.24	-32.6

TREAT Detector Locations



Coupling Factors

- Historical operations lacked detailed 3D kinetics capabilities for experiment design and execution.
- Those operations relied on a “Power Coupling Factor” and “Transient Correction Factor” (TCF)
- Measurements were performed using both fission wires and fuel pin(s) representative of the fuel to be tested in a transient.
- PCFs were determined for both wires and fuel pin(s)
- PCF = power per gram of test sample, per unit of TREAT power
  - PCFs were expressed in different units – the form of the expression was irrelevant as long as used consistently:

$$\frac{fissions/g_{U_{235}}}{MJ_{core}}, \frac{J/g_{U_{235}}}{MJ_{core}}, \frac{fissions/g_{fuel}}{MJ_{core}}, \frac{J/g_{fuel}}{MJ_{core}}$$

  - Typically PCFs were measured at a low-level steady-state (LLSS) power, 80-100 kW.

Coupling Factors

- Because of core changes during a transient (principally rod motion and changes in the neutron spectrum due to non-uniform temperature increases), the PCF changes with time.
- A TCF was used to correct for those changes to obtain an effective PCF for a fuel experiment.
- To determine a TCF, it was assumed that there is a proportionality of fissions in both test fuel pins and fission wires:

$$\frac{PCF_{pin,transient}}{PCF_{pin,LLSS}} = \frac{PCF_{wire,transient}}{PCF_{wire,LLSS}}$$

- Rearranging:

$$PCF_{pin,transient} = PCF_{pin,LLSS} \cdot \frac{PCF_{wire,transient}}{PCF_{wire,LLSS}}$$

- Or,

$$PCF_{pin,transient} = PCF_{pin,LLSS} \cdot TCF.$$

Coupling Factors

- For the actual transient, a relationship between core energy and energy in the experiment was assumed as:

$$E_{pin} = E_{core} \cdot PCF_{pin,LLSS} \cdot TCF,$$

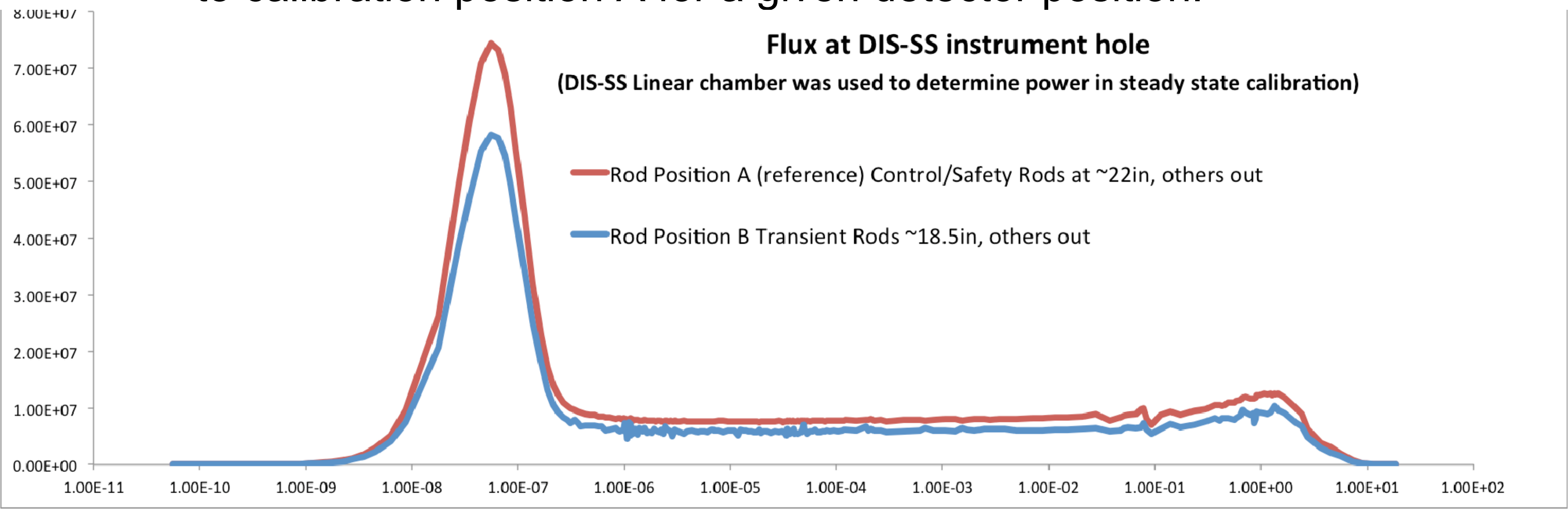
- Note that fuel pins were never subjected to a transient – only fission wires
- To measure $PCF_{wire,transient}$, for high power transients without wires melting:
  - Fission wires (usually a zirconium-uranium alloy) were typically LEU
  - HEU wires could be used but had to be enclosed in a filter
- Hence, measurements were performed for
  - $PCF_{pin,LLSS}$
  - $PCF_{wire,LLSS}$
  - $PCF_{wire,transient}$
- And TCF was calculated as $PCF_{wire,transient}/PCF_{wire,LLSS}$

Historical Approach for TREAT Calibration

1. Heat balance measurements (calorimetry) were used to determine steady state power at one or more flux levels – prescribed CR positions, core at thermal equilibrium (after ~6-7 hours) at a prescribed power.
2. A sample fuel rod(s) was placed within TREAT, and a steady-state test was performed for a set amount of time. The test rig was then removed and the number of fissions/sec/gm determined by destructive analytical chemistry techniques or gamma scan => $PCF_{pin,LLSS}$. <u>Core not at thermal equilibrium.</u>
3. Fission wires of uranium alloy were irradiated at steady state and also assayed to obtain burnup data => $PCF_{wire,LLSS}$
4. TREAT would be operated in transient mode with a second set of fission wires with the planned transient => $PCF_{wire,transient}$
5. Power deposition in the experiment estimated from pin PCF and wire TCF
6. If power did not meet experiment requirements, the transient was modified as appropriate then return to step 4.
7. Finally the test rig was placed in the test volume within TREAT and the prescribed transient test was performed.

M8CAL Fission wires

- Modeling problems
  - PCF defined as fissions/(g-U235 MJ-Reactor).
  - Wrong Q value (202.27 MeV/fission) – *denominator of PCF*
  - Calculations indicate Q = 171-175 MeV/fission prompt local energy deposition
  - Add ~9 MeV/fission in-core from decay heat @ 10 sec, 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 to calibration position A for a given detector position.



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)
  - B(n,α) 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

    = 1.74
  - Measured value was 1.79

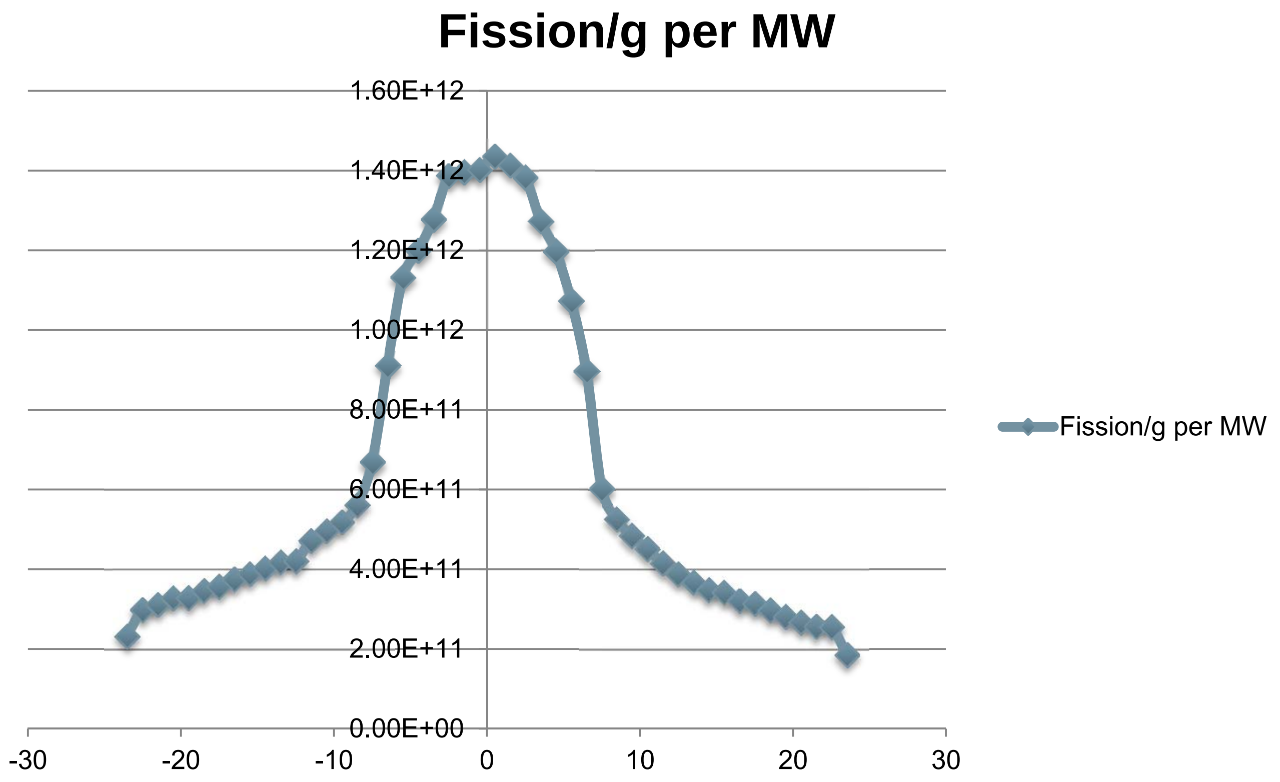
M8CAL Fission wires

- 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, Temperature	1.74	-2.79
2	L91-60-1	1.40	Q value, Temperature	1.39	-0.71
5	H91-7-1	0.503	Q value, Temperature	0.487	-3.02
6	L91-8-6	1.84	Q value, Rod position B, Temperature	1.88	+2.17

M8CAL Fission wires

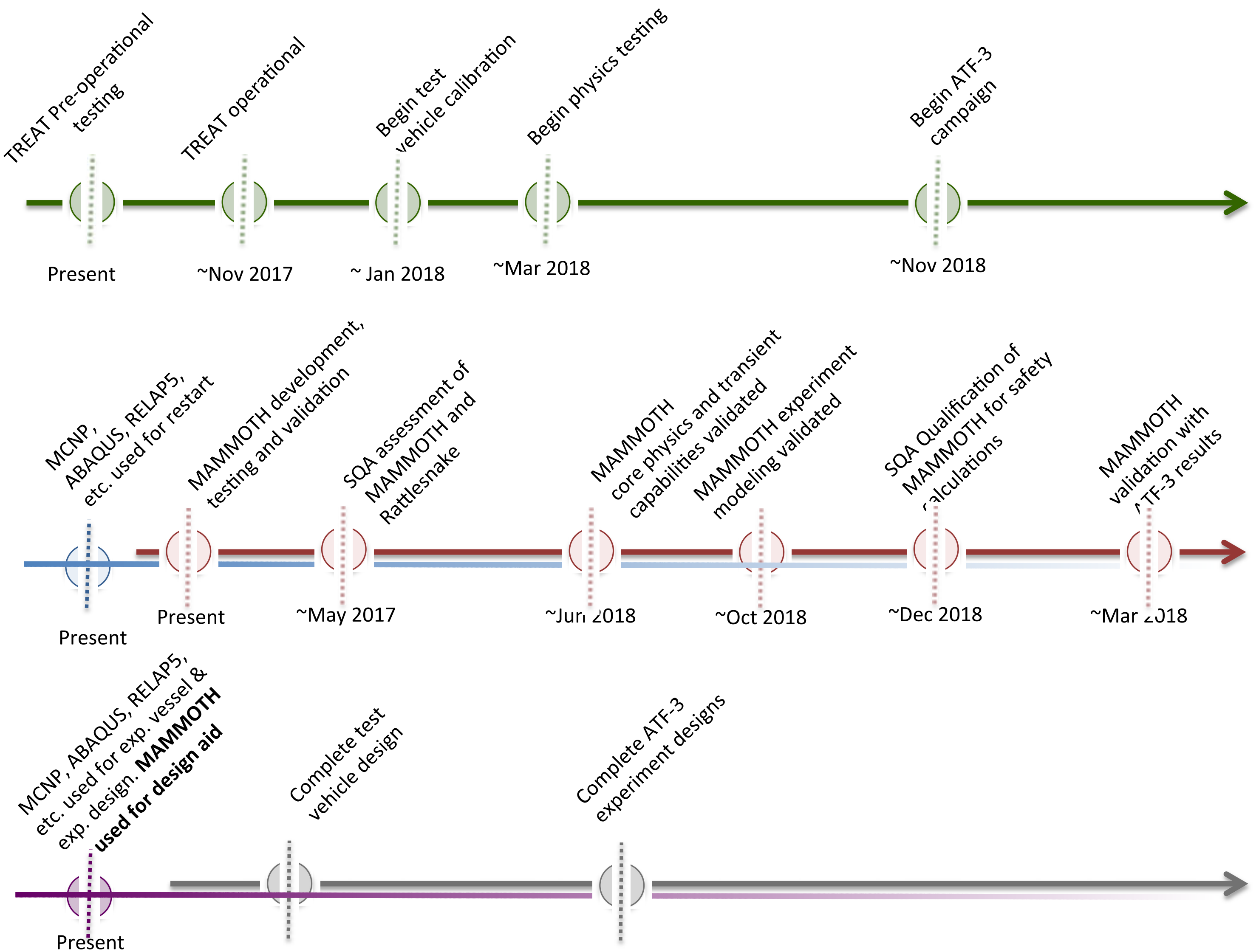
- Fission distribution in 122 cm (48”) wires
  - Where was the fission measured to calculated PCF?
  - M8CAL report indicates they looked at the “Peak” PCF.
  - There are a few points that are near the peak.
  - Possible that a data fit was performed and used to estimate the peak?



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 doyou factor in uncertainties for original measurements given the complexity of the responses.
- "We have learned how to characterize some of the calibration issues and have developed confidence in our methods. This consistency of the measured data with bias-adjusted calculations gives us confidence in our ability to calculate PCFs. However, confidence and validation are not the same thing, and it is difficult to call this a validation of the method, because of the need to introduce bias factors that were calculated, not measured. Instead, validation calculations must be performed in a manner similar to the actual measurements, by performing simulation of detector responses for heat balance, LLSS and transient runs. We need better data to be able to do true validation."
  - M. D. DeHart, B. A. Baker and J. Ortensi, "Interpretation of Energy Deposition Data from Historical Operation of the Transient Test Facility (TREAT)," INL/JOU-17-41863, submitted to Nucl. Engr. Design May 2017
- 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)

Experiment Schedule to Support Validation

TREAT Experi

Idaho National Laboratory