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# Analyses Supporting Design Review of TREAT Multi-SERTTA Experiment Test Vehicle

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**Abstract** – *Analyses were performed supporting the design review of the Multi-SERTTA experiment test vehicle for intended use in the Transient Test Reactor (TREAT) Facility. The TREAT Facility was designed to evaluate nuclear fuels and materials under simulated accident conditions. Resumption of transient testing in TREAT requires development of new test experiment designs. The analyses performed are necessary as part of a formal design review to address the various practical, implementation, and safety aspects of the new test vehicle. A high-level summary of the neutronics and thermal analysis are provided in this paper. Neutronics calculations include evaluation of the power coupling factor (PCF), which represents the effective quantity of fission-generated energy per mass of fuel specimen per total core energy. Estimates were prepared for three cases of different control rod positionings, representing a start-up critical core, a reactivity step insertion pre-transient critical core, and peak of transient core. Stainless steel shaping collars containing varied concentrations of natural boron were simulated to optimize uniform PCF values in the latter case across test rodlets in the four test vehicle positions. Additional neutronic calculations include estimation of control rod worths, core shutdown margin, core excess reactivity, test vehicle worth, reactivity worth of experiment vertical displacement, heat generation rates in test vehicle components, and local to average ratio core power distribution. Thermal response in the experiment test vehicle is crucial for ensuring safe experiment operation. Several analyses were performed to conservatively define safety limits and provide input to design of instrumentation and thermal control for optimized performance of the Multi-SERTTA experiments. Deposition energy calculations from MCNP and RELAP5 point-kinetics modeling provided the power profiles needed as input parameters for these transient analyses. Results from the thermal analyses have demonstrated safe and desired operability of the Multi-SERTTA experiment test vehicle with desired heat transfer conditions under currently targeted test conditions. Physics testing is planned upon restart of the TREAT Facility to demonstrate safe operability of the core and reproduction of some measurements performed during the historic M8CAL measurement series. Similarity in design and expected core performance will support initial computational assessment of Multi-SERTTA. Further calibration testing efforts will provide additional validation experiment data supporting design and implementation of fueled Multi-SERTTA experiments within TREAT.*

## I. INTRODUCTION

The Transient Test Reactor (TREAT) Facility was designed to evaluate nuclear fuels and structural materials under simulated nuclear excursion and transient power/cooling mismatch situations that could be encountered in nuclear reactors [1]. It was historically operated from 1959 through 1994; ongoing activities at Idaho National Laboratory (INL) include resumption of transient testing capabilities to generate experimental data suitable to validate advanced modeling and simulation of these transient conditions, supporting current and next generation power reactor design and nuclear safety [2].

The resumption of transient testing requires new experiment vehicle designs to satisfy testing needs. The most developed experiment test vehicle candidate in TREAT's arsenal will be the Multi-SERTTA (Static Environment Rodlet Transient Test Apparatuses) [3], which accommodates up to four concurrent rodlets under separate environmental conditions. An overview of the Multi-SERTTA, which would be placed at the center of the TREAT core during use, is shown in Fig. 1. In the current design, all four rodlet test vessels are identical except for flux shaping collar material content to meet design needs.

As the date rapidly approaches for TREAT restart, there is a need to have the Multi-SERTTA design approved and tested. Test experiments are an integral component of TREAT operations, and will be integrated among initial restart testing and supporting core reactor physics measurements. An integral step in finalization of any test vehicle design for TREAT is the hosting and resolution of a formal design review.

## II. DESCRIPTION OF THE ACTUAL WORK

A formal design review is imperative to address the various practical, implementation, and safety aspects in test vehicle design and utility. Two of the key analyses include those supporting neutronics and thermal design as the results from these studies feed into the other components of test vehicle design and safety. A summary of the comprehensive studies of the neutronics and thermal design aspects of the Multi-SERTTA test vehicle are presented in this paper. Final resolution of the design, with subsequent prototype testing, will result in the availability of a robust test vehicle for fuel rodlet transient testing.

The Multi-SERTTA assembly consists of four stacked capsules each containing a small rodlet specimen immersed in water at Pressurized Water Reactor (PWR) conditions. (Other coolants may be envisioned in the future.) Each vessel is charged with water and inert gas at room temperature and a heater surrounds the outer vessel to provide pre-test temperature and pressure conditions of 15.5 MPa and 280 ºC. A $ZrO_2$ crucible protects the vessel walls from hot particulate or melted fuel. A graphite liner (melt catcher) sits within the bottom of the crucible to catch dispersed material and serves to distribute the energy over a greater surface area of the crucible. Under most currently envisioned test objectives, the fuel rodlet material would not relocate. However, fuel melting and dispersal is a possibility for testing and, depending on prescribed reactor transient conditions, is a likely event under the conditions assumed for safety analysis of experiments. An inert-gas-filled expansion tank is connected to the side of the specimen-bearing vessel to provide ample gas plenum volume to damp pressurization during boiling events generating significant water vapor. The Multi-SERTTA assembly coolant volumes have been designed to prevent over-pressurization to supercritical water conditions that would result in non-prototypical heat transfer phenomena. The Multi-SERTTA device allows for several instruments to be employed to control and monitor environmental conditions as well as to measure test specimen response.

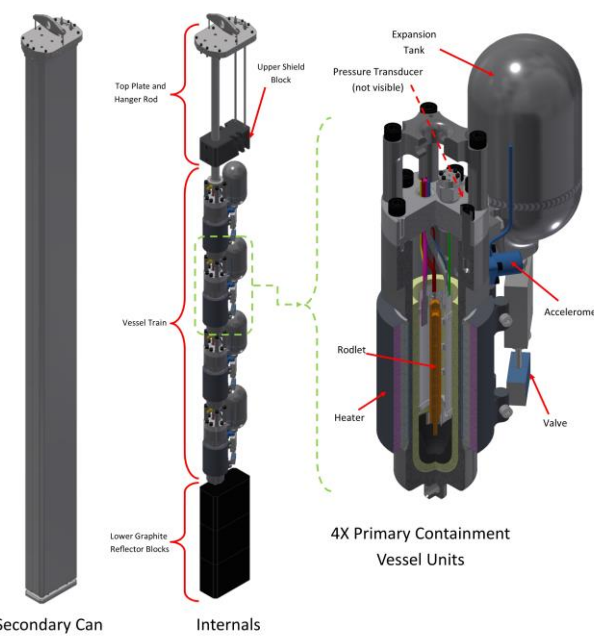


Fig. 1. Basic Overview of the TREAT Multi-SERTTA Experiment Test Vehicle.

## III. RESULTS

### 1. Neutronics Analyses

*A. Power Coupling Factor*

Historic methodologies applied in TREAT utilized very approximate models and kinetics to establish predicted transient power shapes. Extensive calibration test experiments were essential and required prior to the actual transient test to more accurately estimate the power to be deposited into the experiment during a transient pulse [4].

Two key parameters are needed when designing and characterizing the performance of a transient fuel irradiation experiment in TREAT: power coupling factor (PCF) and transient correction factor (TCF). The PCF represents the effective quantity of fission-generated energy per mass of fuel specimen per total core energy [4]. The TCF is necessary to account for time-dependent effects [5], and traditionally is obtained as part of the comprehensive calibration procedure [4]. The product of PCF and TCF is used to estimate the total quantity of energy delivered into the test specimen in a single experiment. The quantity of energy deposited into a suite of test fuel rodlets under varying test environment conditions can then be utilized to evaluate overall fuel performance, including failure mechanisms and thresholds.

Whereas PCF can be estimated computationally with some degree of accuracy and full-core transient simulation of TREAT is still an integral need of advanced modeling and simulation, the historic approach of computing PCF to support design review analysis was followed. It is expected that TCF will be experimentally obtained as part of the calibration campaign until sufficient testing and benchmark validation is available to prove modern three-dimensional transient testing analysis.

Neutronic calculations were performed using detailed models of TREAT with the Multi-SERTTA test vehicle in Monte Carlo N-Particle (MCNP) version 6.1 [6] with ENDF/B-VII.1 nuclear data libraries [7]. MCNP is a general-purpose, continuous-energy, generalized-geometry, time-dependent, coupled n-particle Monte Carlo transport code. The baseline test rodlet design includes eight standard PWR fuel pellets, with a natural uranium dioxide pellet placed on each end, within Zircaloy cladding. Further information on modeling of the test rodlet environment was previously provided [8]. The PCF values are estimated by calculating the total energy deposited in the fuel rodlet pellets divided by the total energy deposited in the TREAT fuel and graphite reflector, which accounts for about 98.9 % of the total core power.

Control rod positions were estimated for three core loadings: Case 1) reactor startup criticality based solely upon control/shutdown rods positioned within the core, Case 2) pre-transient critical core condition with both transient and control/shutdown rods inserted, such that a step insertion of 2.6 %Δk/k can be achieved by removing the transient rods from the core, and Case 3) peak transient configuration with control/shutdown rods remaining in the Case 2 position and transient rods completely withdrawn. A diagram of the core loading showing non-fuel assembly positions is provide in Fig. 2, with a schematic showing control rod positions of the three cases in Fig. 3.

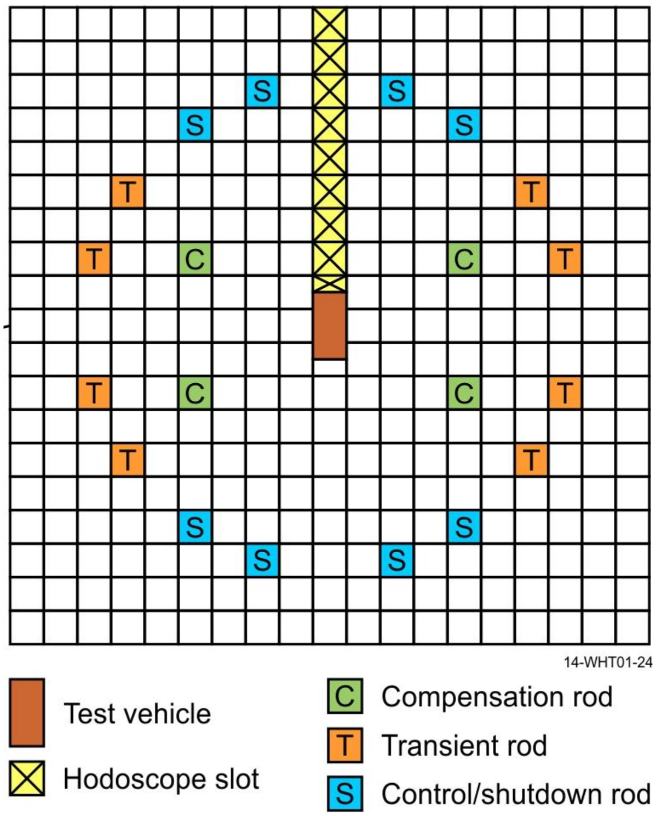


Fig. 2. TREAT Core Loading for Multi-SERTTA Analysis.

Because the axial neutron flux distribution across the active region of the TREAT core is not uniform, flux shaping collars are necessary in an attempt to achieve uniform PCF values in each of the four test vehicle positions. Stainless steel shaping collars, with a fixed maximum thickness of 50 mil (0.127 cm) containing various concentrations of natural boron, were simulated around the primary pressure vessel of each unit. The topmost test vehicle, Unit 1, has the lowest flux; therefore the steel collars contain no boron and that position represents the reference PCF position to which the other three units must equate. Units 2 through 4, respectively, have steel collars containing 0.70, 0.82, and 0.22 wt.% natural boron, and were optimized to provide equivalent PCF values for all four units during Case 3.

The rodlet-average PCF for Cases 1 through 3 are provided in Table I. The average PCF is within approximately 1 % for Case 3, 2 % in Case 1, and almost 10 % in Case 2. The redistribution of the neutron flux within the core due to control rod positioning can have a significant impact upon the core centerline flux within the Multi-SERTTA experiment test vehicle environment. Additional calculations were performed for Case 3 investigating the effect of fuel relocation on PCF (also shown in Table I). Severe accident scenarios require the investigation of fuel relocation whether as the formation of a molten fuel mass at the bottom of each vessel, or complete homogenized vaporization of the fuel with the primary vessel test environment. For the molten fuel case, there is a significant drop in PCF because the fuel drops into a less favorable geometry as a conical mass surrounded by graphite instead of cylindrical pellets surrounded by water. The decrease in PCF for the dispersed fuel case does not drop as significantly, but is attributed to redistribution of fuel mass within a larger volume and the reduction in water density, which is less favorable for neutron moderation and reflection.

Table I. Average Calculated PCF (W/g-MW) Values.

| | Case 1 | | |
|---|---|---|---|
| Unit # | PCF | ±1σ | % of Ref. |
| 1 | 1.207 | 0.007 | Ref. |
| 2 | 1.201 | 0.007 | 99.5 |
| 3 | 1.192 | 0.007 | 98.7 |
| 4 | 1.183 | 0.007 | 97.7 |
| | Case 2 | | |
| Unit # | PCF | ±1σ | % of Ref. |
| 1 | 1.138 | 0.006 | Ref. |
| 2 | 1.167 | 0.007 | 102.6 |
| 3 | 1.232 | 0.007 | 108.3 |
| 4 | 1.250 | 0.007 | 109.8 |
| | Case 3 | | |
| Unit # | PCF | ±1σ | % of Ref. |
| 1 | 1.150 | 0.006 | Ref. |
| 2 | 1.152 | 0.007 | 100.1 |
| 3 | 1.156 | 0.007 | 100.5 |
| 4 | 1.149 | 0.007 | 99.9 |
| | Case 3 – Molten Fuel | | |
| Unit # | PCF | ±1σ | % of Case 3 |
| 1 | 0.715 | 0.006 | -37.9 |
| 2 | 0.866 | 0.006 | -24.8 |
| 3 | 0.853 | 0.006 | -26.2 |
| 4 | 0.822 | 0.006 | -28.5 |
| | Case 3 – Dispersed Fuel | | |
| Unit # | PCF | ±1σ | % of Case 3 |
| 1 | 0.902 | 0.002 | -21.6 |
| 2 | 1.065 | 0.002 | -7.5 |
| 3 | 1.164 | 0.002 | 0.7 |
| 4 | 1.095 | 0.002 | -4.7 |

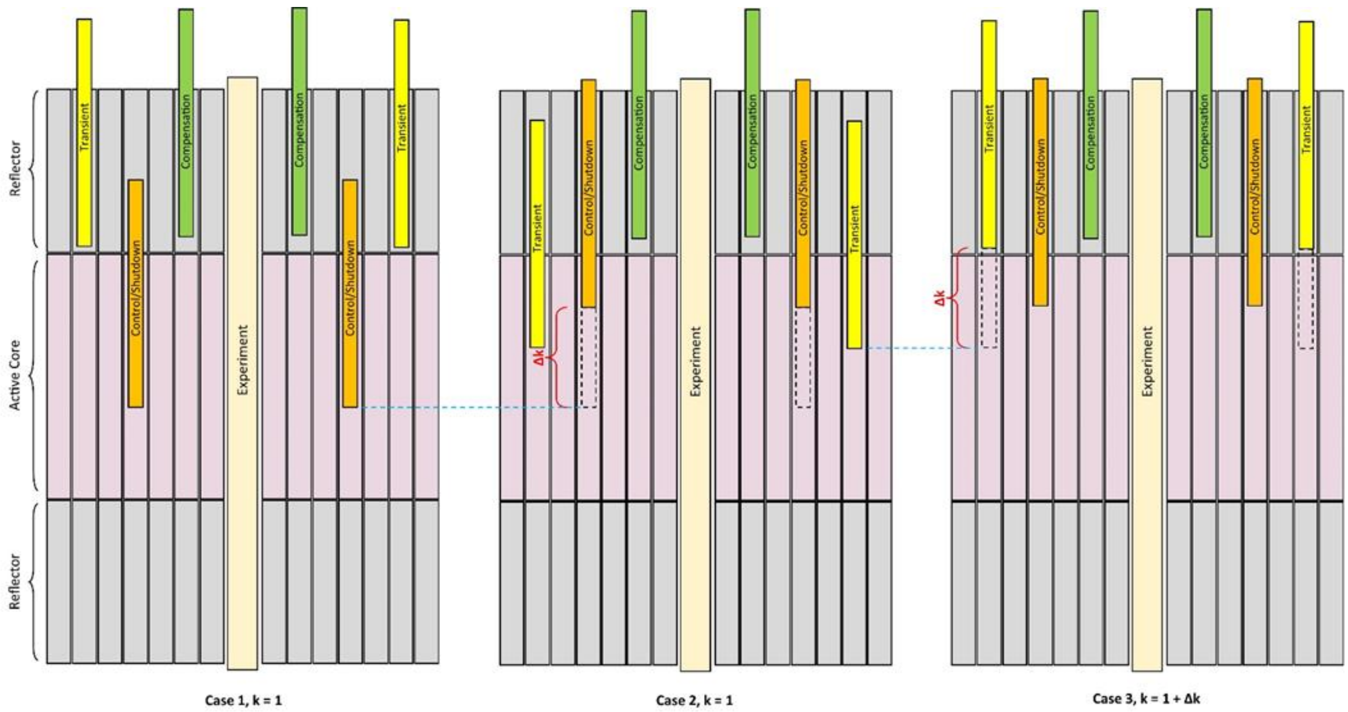


Fig. 3. Sketch of Control Rod Positions for Each Evaluated Case.

*B. Reactivity Worth Values*

Additional neutronics calculations were performed to support design and safety analysis for a baseline PWR experiment in the Multi-SERTTA test vehicle [9]; results were gathered supplying the following simulated information:

- Control Rod Worths,
- Core Shutdown Margin,
- Core Excess Reactivity,
- Test Vehicle Worth,
- Reactivity Worth of Experiment Vertical Displacement,
- Heat Generation Rates in Test Vehicle Components, and
- Local to Average Ratio (L2AR) Core Power Distributions.

The Multi-SERTTA experiment test vehicle reactivity worth is approximately -3.34 %Δk/k during a planned reactivity step insertion transient of 2.6 %Δk/k. The compensation rods have sufficient negative reactivity to maintain reactor subcriticality during experiment change-out activities (i.e. the compensation rod inserted bank worth of -8.30 %Δk/k is greater in magnitude than the effective worth of removing the Multi-SERTTA experiment test vehicle from the core).

Control rod worth curves for TREAT control/shutdown rods and transient rods were estimated and are provided in the complete evaluation report [9]. Fig. 4 provides a visual representation of the control/shutdown and transient rod bank worths relative to criticality.

From All Rods Out (ARO) core configuration, the total worth of the control rod banks are -8.30 % Δ k/k for the compensation rods, -9.76 % Δ k/k for the control/shutdown rods, and -9.20 % Δ k/k for the transient rods for a total rod worth of -27.25 % Δ k/k. The core excess reactivity at criticality is estimated to be +6.98 % Δ k/k and is ≤ 8 % Δ k/k; the shutdown margin is ≥ 0.5 % Δ k/k. The excess reactivity, or maximum reactivity available above criticality, which is the difference between total rod worth and the rod worth at criticality (i.e. the worth, or partial worth, of control rods remaining within the core), must be ≤ 8 % Δ k/k. The minimum shutdown margin for TREAT is defined to be at ≥ 0.5 % Δ k/k when the most reactive rod or rod pair attached to a single drive is in its most reactive position (i.e. stuck full withdrawn from the core). These limits need to be accounted for when performing control rod reactivity calculations.

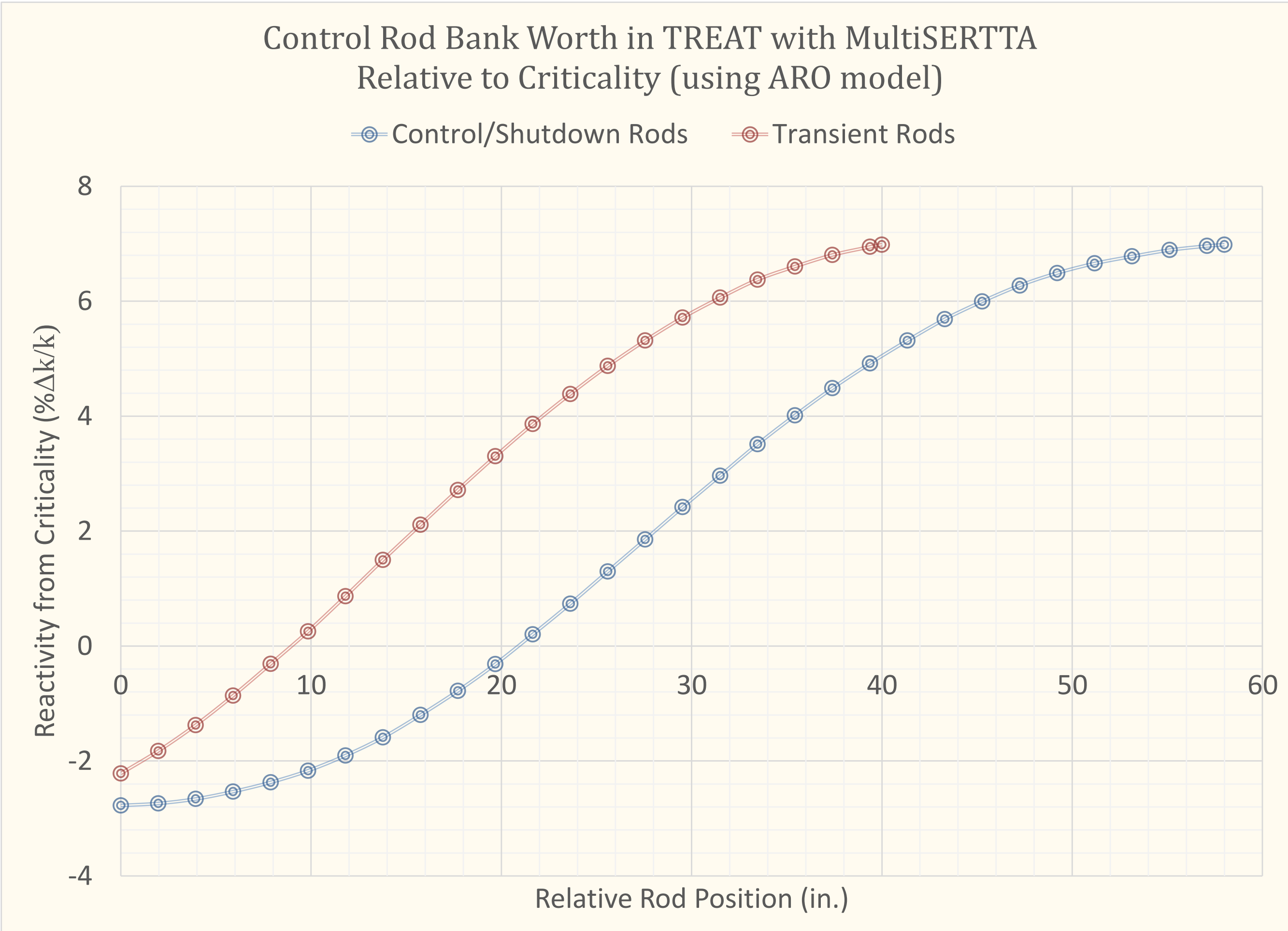


Fig. 4. TREAT Rod Worth Curves, Relative to Criticality, with Multi-SERTTA Experiment Test Vehicle Inserted.

As a comparison, a "best-guess" calculation of the worth of the M8CAL experiment and test vehicle was previously performed and a value of 3.48 %Δk/k (4.83 ρ$) was calculated. This compares well with the reported M8CAL reactivity worth of 3.44 %Δk/k. Unfortunately, the exact composition and dimensions of all M8CAL components are not completely known, and cancelling errors in the model may not be adequately reflected in the apparently well-calculated results. This value appears comparable to the 3.34 %Δk/k (4.64 ρ$) worth calculated for Multi-SERTTA. Whereas M8CAL contains a significant quantity of dysprosium filter, Multi-SERTTA contains a significant quantity of Inconel components. The impact of the control rod positions on flux redistributions within the core would similarly be expected to impact worth calculations for M8CAL.

Calculated rod worths were compared against historically measured values during the M8CAL campaign [4]. Historic values for the control/shutdown, compensation, and transient rod banks were -8.83, -6.91, and -8.46 %Δk/k, respectively, for a total absorber rod worth of -24.20 %Δk/k. The current MCNP models overpredict the total worth of the rod banks by 10.5, 20.1, and 8.8 %, respectively, and the total rod worth by 12.6 %. The calculated core excess reactivity overpredicts the measured value of +6.5 %Δk/k by 7.4 %. These results indicate that the simulated balance between positive core reactivity and negative control rod worth is not perfectly accurate. The current calculations are sufficient for experiment scoping exercises because the calculated worth of M8CAL and Multi-SERTTA are similar and the calculated M8CAL worth matches well the experimentally reported value. While shutdown margins and excess reactivity calculations do not match experimental values exactly, the expected core performance should fall within the calculated and historically measured values, which both comply with current excess reactivity and shutdown margin requirements while providing sufficient excess reactivity to perform the desired experiment.

The level of vertical test vehicle displacement at which a change in reactivity results in 0.05 %Δk/k during the transient is approximately 1.85 in. (4.71 cm); limiting the vertical displacement to ≤ 1.57 in. (4 cm) is suggested when accounting for the 1 σ statistical uncertainty in the computed values. This axial displacement allows for the determination of the hold-down distance needed to limit reactivity insertion below 0.05 %Δk/k. Hold-down on the test vehicle is necessary to counteract any forces generated during the test that could lift the test vehicle enough to cause significant reactivity addition. Historically, a reactivity addition of ≤ 0.05 % Δ k/k was considered insignificant because the reactivity of TREAT could not be controlled to a precision better than ~0.05 % Δ k/k.

### *C. Heat Generation*

Heat generation rates within all components of the Multi-SERTTA test vehicle were determined in detail and tabulated at length elsewhere [9]. Identification of heating rates for the various components is essential in addressing heat transport and changes in mechanical properties throughout the course of the transient experiment. Photon and neutron energy depositions in units of MeV/g were tallied using MCNP for each part and then converted to W/g-MW, similar to the calculations performed for PCF. Gamma heating accounts for much of the component heating throughout the test vehicle except for materials containing significant quantities of fissionable isotopes (such as $^{235}U$), strong neutron absorbers (such as boron), or very low-Z elements (such as hydrogen and helium).

The local to average ratio (L2AR) core power distribution was similarly tallied in MCNP but on an MeV per TREAT assembly basis. The total energy deposition was therefore obtained for each of the individual 361 positions in the TREAT core. A distribution map was then generated. While currently there are no specified requirements for calculation of the core power distribution in upcoming TREAT experiments, the capability will become more relevant in future analyses as additional advanced modeling and simulation computational tools are implemented.

The L2AR for Case 3 is shown in Fig. 5. Exact magnitudes of the power peaking values are not as important as to demonstrate the typical power profile for the half-slotted loading of the TREAT core. Because of the hodoscope slot running from the experiment to the north edge of the core, the power distribution is symmetric east to west but not north to south. The power profiles have the peak assembly power regions located around the compensation rod positions and create a "smile" around the south end of the experiment test region. It is important to note that this type of power distribution represents steady-state conditions calculated for a transient event. The actual power distributions will evolve with time and temperature feedback through the course of a transient simulation analysis. The highest L2AR positions are between 1.50 and 1.60. While not shown in the figures, the 1σ statistical uncertainty propagated into the L2AR ratio calculations is approximately between ±0.045 and ±0.075 for the fueled assemblies. The uncertainty in the dummy assemblies is approximately between ±0.085 and ±0.175. This ratio is deceptively large because it includes the uncertainty contribution from each and every assembly when computing the average assembly power in the core. For a given individual assembly power calculation, the 1σ uncertainty is much smaller at ≤ 0.13 %, with the uncertainty in fueled assemblies between 0.05 to 0.07 %.

| | A | B | C | D | E | F | G | H | J | K | L | M | N | O | P | R | S | T | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.014 | 0.023 | 0.689 | 0.686 | 0.687 | 0.682 | 0.671 | 0.656 | 0.644 | 0.007 | 0.643 | 0.652 | 0.664 | 0.673 | 0.670 | 0.665 | 0.678 | 0.023 | 0.014 |
| 2 | 0.024 | 0.717 | 0.709 | 0.714 | 0.713 | 0.699 | 0.674 | 0.650 | 0.666 | 0.009 | 0.664 | 0.647 | 0.671 | 0.694 | 0.706 | 0.710 | 0.711 | 0.729 | 0.024 |
| 3 | 0.756 | 0.749 | 0.770 | 0.784 | 0.769 | 0.731 | 0.708 | 0.530 | 0.711 | 0.010 | 0.711 | 0.529 | 0.706 | 0.730 | 0.769 | 0.789 | 0.781 | 0.769 | 0.789 |
| 4 | 0.799 | 0.813 | 0.853 | 0.878 | 0.848 | 0.620 | 0.812 | 0.817 | 0.817 | 0.011 | 0.817 | 0.817 | 0.814 | 0.622 | 0.856 | 0.889 | 0.871 | 0.841 | 0.844 |
| 5 | 0.868 | 0.891 | 0.946 | 0.987 | 0.992 | 0.973 | 0.982 | 0.974 | 0.927 | 0.013 | 0.928 | 0.976 | 0.987 | 0.979 | 1.001 | 1.002 | 0.967 | 0.921 | 0.914 |
| 6 | 0.944 | 0.973 | 1.036 | 0.811 | 1.133 | 1.147 | 1.136 | 1.095 | 1.011 | 0.014 | 1.013 | 1.098 | 1.142 | 1.155 | 1.143 | 0.823 | 1.058 | 1.002 | 0.983 |
| 7 | 1.012 | 1.045 | 1.118 | 1.192 | 1.248 | 1.265 | 1.246 | 1.183 | 1.061 | 0.015 | 1.061 | 1.186 | 1.253 | 1.276 | 1.260 | 1.210 | 1.140 | 1.071 | 1.046 |
| 8 | 1.067 | 1.104 | 0.881 | 1.275 | 1.336 | 1.000 | 1.324 | 1.233 | 1.062 | 0.017 | 1.065 | 1.239 | 1.333 | 1.010 | 1.352 | 1.294 | 0.897 | 1.129 | 1.097 |
| 9 | 1.109 | 1.152 | 1.245 | 1.341 | 1.406 | 1.424 | 1.387 | 1.264 | 1.008 | 0.012 | 1.010 | 1.271 | 1.397 | 1.439 | 1.424 | 1.361 | 1.266 | 1.176 | 1.136 |
| 10 | 1.133 | 1.182 | 1.282 | 1.383 | 1.453 | 1.478 | 1.440 | 1.310 | 0.998 | mS | 1.001 | 1.317 | 1.452 | 1.493 | 1.471 | 1.402 | 1.304 | 1.205 | 1.160 |
| 11 | 1.139 | 1.186 | 1.285 | 1.391 | 1.468 | 1.502 | 1.485 | 1.394 | 1.171 | 0.058 | 1.173 | 1.401 | 1.498 | 1.518 | 1.486 | 1.411 | 1.308 | 1.209 | 1.163 |
| 12 | 1.126 | 1.169 | 0.938 | 1.371 | 1.454 | 1.107 | 1.511 | 1.476 | 1.395 | 1.343 | 1.398 | 1.483 | 1.522 | 1.120 | 1.471 | 1.390 | 0.955 | 1.193 | 1.151 |
| 13 | 1.097 | 1.138 | 1.227 | 1.323 | 1.406 | 1.463 | 1.496 | 1.503 | 1.489 | 1.482 | 1.495 | 1.512 | 1.509 | 1.478 | 1.426 | 1.345 | 1.250 | 1.162 | 1.122 |
| 14 | 1.054 | 1.087 | 1.170 | 0.926 | 1.318 | 1.373 | 1.421 | 1.456 | 1.474 | 1.480 | 1.479 | 1.463 | 1.433 | 1.390 | 1.339 | 0.943 | 1.192 | 1.111 | 1.078 |
| 15 | 1.000 | 1.024 | 1.094 | 1.155 | 1.185 | 1.199 | 1.268 | 1.332 | 1.375 | 1.393 | 1.380 | 1.341 | 1.280 | 1.216 | 1.207 | 1.178 | 1.117 | 1.048 | 1.025 |
| 16 | 0.942 | 0.954 | 1.007 | 1.050 | 1.037 | 0.782 | 1.073 | 1.140 | 1.213 | 1.250 | 1.218 | 1.148 | 1.086 | 0.794 | 1.060 | 1.075 | 1.032 | 0.978 | 0.967 |
| 17 | 0.897 | 0.891 | 0.920 | 0.952 | 0.956 | 0.940 | 0.949 | 0.742 | 1.048 | 1.103 | 1.053 | 0.749 | 0.963 | 0.960 | 0.981 | 0.981 | 0.949 | 0.918 | 0.925 |
| 18 | 0.028 | 0.859 | 0.855 | 0.874 | 0.894 | 0.908 | 0.911 | 0.917 | 0.972 | 1.004 | 0.979 | 0.930 | 0.929 | 0.933 | 0.927 | 0.910 | 0.890 | 0.891 | 0.029 |
| 19 | 0.017 | 0.027 | 0.832 | 0.838 | 0.865 | 0.896 | 0.918 | 0.938 | 0.962 | 0.976 | 0.970 | 0.955 | 0.942 | 0.930 | 0.911 | 0.890 | 0.878 | 0.028 | 0.017 |

| | |
|---|---|
| **0** | **Minimum** |
| **0.152** | **10%** |
| **0.304** | **20%** |
| **0.457** | **30%** |
| **0.609** | **40%** |
| **0.761** | **50%** |
| **0.913** | **60%** |
| **1.065** | **70%** |
| **1.217** | **80%** |
| **1.370** | **90%** |
| **1.522** | **Maximum** |

Fig. 5. Local to Average Ratio Power Peaking for Case 3.

## 2. Experiment Thermal Analyses

Defining the thermal response of the experimental vehicle is crucial for ensuring safe experiment operation under unplanned events in the test reactor as well as for ensuring the experiment vehicle will provide the desired experimental boundary conditions to the test specimen. Therefore, several types of analyses have been performed to conservatively define safety limits of the experimental vehicle, provide input to design of instrumentation and thermal control, and to make best-estimate predictions of the vehicle performance during transients. For the Multi-SERTTA experiment vehicle, finite element analysis (FEA) provides the predicted temperature distributions of the vehicle hardware prior to and post-transient initialization using the commercial code, ABAQUS [10]. The thermal-hydraulic conditions within the test environment, which define the experimental boundary conditions for the test specimen, are modeling using RELAP5 [11]. A description and results of RELAP5 predictions may be found in [12]. The initial testing in Multi-SERTTA will be focused on Reactivity Initiated Accident (RIA) events in water at PWR conditions [13]. Though the Accident Tolerant Fuels (ATF) program will test a variety of fuel systems in Multi-SERTTA, the current analysis only considers test specimens with 4 in. (10.16 cm) fueled lengths having eight 4.95 wt.% $^{235}U/U$ enriched $UO_2$ pellets and two end insulator pellets of natural $UO_2$ within Zircaloy cladding.

Within the TREAT reactor, the experimental vessel sits in the TREAT core with two graphite dummy half-assemblies next to the short sides, displacing a total of three TREAT fuel elements. The TREAT fuel elements and Multi-SERTTA containment have 0.625 in. (1.5875 cm) chamfers at each corner that runs the axial length of the assemblies. These chamfers form the main air coolant channels in the core. Nominal gaps between each TREAT fuel element is 0.040 in. (0.1016 cm), however, because each fuel element has been evacuated to vacuum, the sides of the elements may have some concavity. Therefore, some airflow exists between adjacent parallel faces. The coolant channels and the gaps around the fuel are modeled using a film condition with temperature-dependent heat transfer coefficients calculated with the Dittus-Boelter correlation.

Material deposition energies come from the prediction of reactor-to-specimen PCF values provided by neutronics calculations. A RELAP5 point-kinetics model of the TREAT core generates reactor power profiles used as input to the transient analyses. Depending on the characteristic time of a given analysis, a variety of sub-models of the experimental vehicle (i.e. full assembly, single capsule assembly, fuel and coolant, etc.) may be considered with associated boundary conditions. The exterior of the secondary enclosure has several air channels providing forced convection cooling during pre-test heat up conditions. During the short period of an RIA transient, the exterior of the can may be considered adiabatic. Between the secondary and primary enclosures, both radiation and natural convection heat transfer modes are modeled in the gaps. The FEA model of a single Multi-SERTTA vessel unit is shown in Fig. 6.

An example of pretest-heated conditions for a capsule with a specimen heated to 300 ºC (572 ºF) is given in Fig. 7. To support safety analyses of the thermomechanical response of the system, a transient analysis was performed for step insertion of $\Delta k/k = 2.634\,\%$. Fig. 8 shows the results of this analysis at various times following the initiation of the transient, demonstrating the evolution of temperature distribution across the various components in the system.

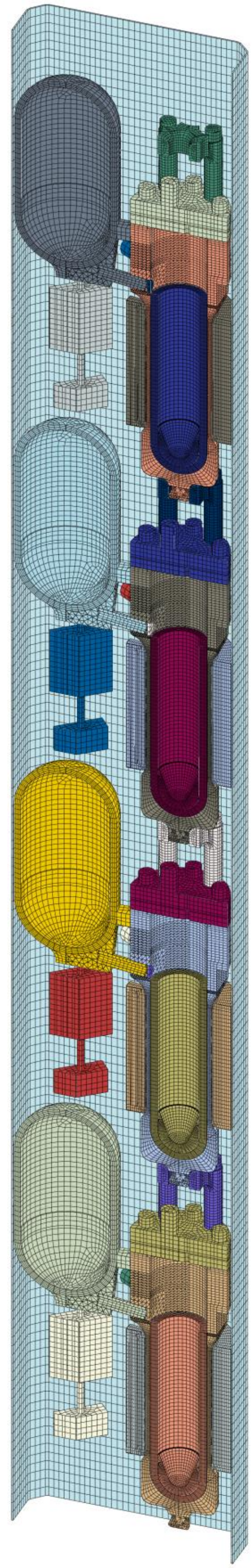

Fig. 6. Finite Element Mesh of the Multi-SERTTA Vehicle.

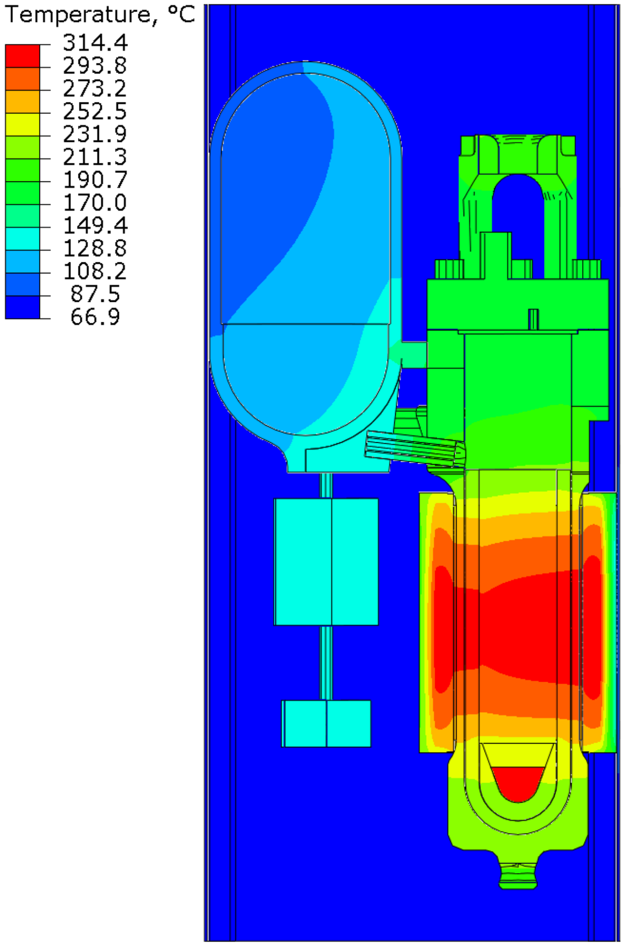


Fig. 7. Steady-State Temperature Prediction for Pretest Conditions for a Single Multi-SERTTA Unit Assembly.

The results of the thermal analyses have demonstrated the safe and desired operability of the Multi-SERTTA experiment vehicle and its capability to provide desired experiment boundary conditions. Both safety and best-estimate experiment analyses have been performed to support the design of RIA experiments in pool water at PWR thermal conditions. Peak temperature gradients in containment components have been predicted as input to structural analyses with results showing adequate safety margin for containment under accident conditions. Thermal-hydraulic predictions of experiment heat transfer and pressure vessel response show desired heat transfer conditions of complete evolution of the boiling curve during a given experiment. The cladding surface of test specimen will pass through critical heat flux to film boiling and back to saturated state. The vehicle will undergo some pressurization in the process on the order of 2 to 3 MPa under currently targeted test conditions [12].

## 3. Validation Experiment Design and Development

Upon restart of the TREAT Facility, various activities are planned that can enable validation of reactor physics and thermal analyses. Initial restart activities will include reactor operations to verify operability of the reactor within safety guidelines and capabilities. Reactor physics testing is planned to enable validation of worth measurements taken during the M8CAL campaign [4]. Whereas the worths of the M8CAL test vehicle and Multi-SERTTA test vehicle are similar, these tests will provide initial validation of absorber rod worth calculations until the actual Multi-SERTTA vehicle is loaded into the core. Actual worth measurements performed upon TREAT restart to confirm M8CAL test vehicle worth, and later Multi-SERTTA test vehicle worth, can be utilized to further validate computational analyses.

Additional components of the restart physics testing include utility of thermocoupled fuel assemblies to measure the temperature at various individual locations throughout the core. Discussions to implement additional thermocouples, as well as flux/fission wire arrays, will likely be effected to more fully characterize the core and support validation of computational analyses and tools

Prior to experimentation efforts in Multi-SERTTA, a supporting calibration measurement campaign similar to earlier TREAT experiments such as the M-series [4] will be conducted. A Multi-SERTTA-CAL vehicle is in development that is neutronically similar to the Multi-SERTTA vehicle and allows for preliminary measurement of worth values, heating effects, PCF, and TCF without subjection of fueled rodlets to transient test conditions. Many of the measurements will be performed using fission wires, as was performed historically, to obtain and calibrate the system prior to subjecting test specimens to the planned transient. Similarly, these calibration measurements will serve to validate and calibrate our computational models and tools.

A key component of historic and future test vehicles is to include multiple forms of instrumentation to characterize the experiment throughout the course of the transient test. Multi-SERTTA will similarly be outfitted with instrumentation to experimentally validate test conditions, and to also serve as a means to validate computational analyses. Currently some of the instrumentation planned for use in Multi-SERTTA includes boiling detector, micro-pocket fission detector, thermocouples, optical-fiber-based IR pyrometer, pressure transducer, and accelerometer. Some of the intended internal instrumentation planned for Multi-SERTTA is shown in Fig. 9.

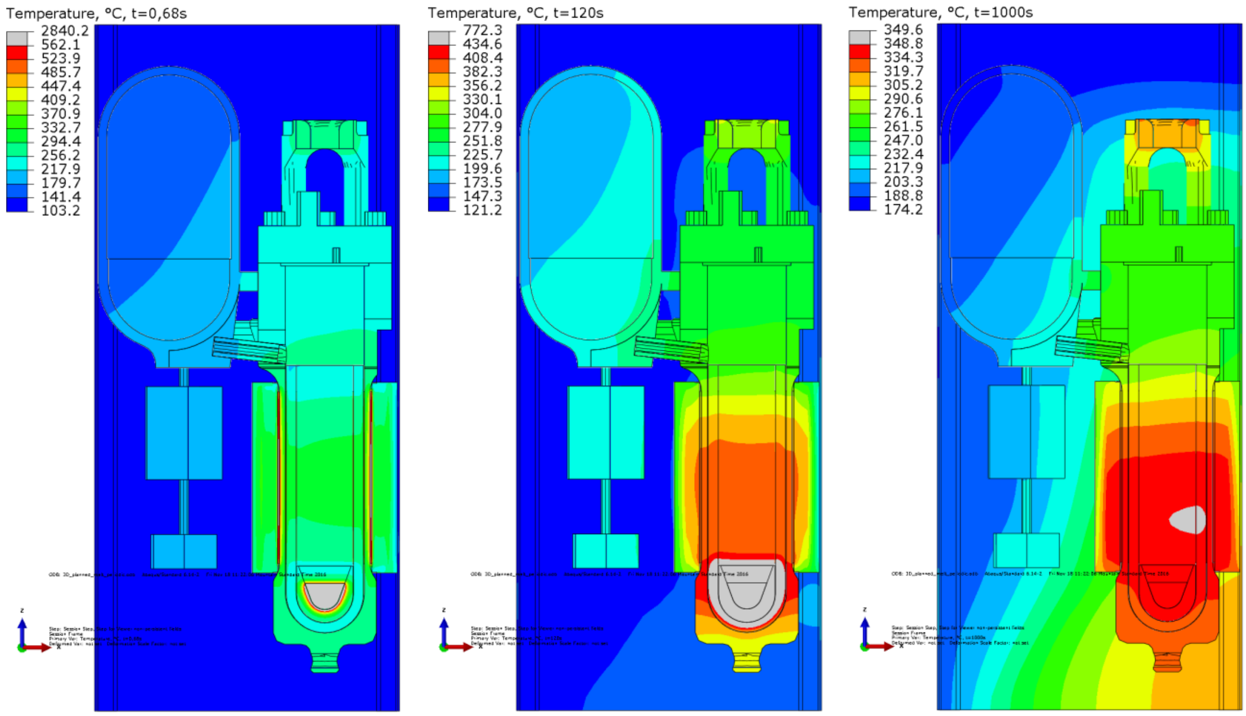


Fig. 8. Example of Temperature Predictions in a Single Multi-SERTTA Unit Assembly.

## IV. CONCLUSIONS

Neutronics and thermal analyses were performed to support the design review of the Multi-SERTTA experiment test vehicle for intended use in the TREAT Facility to evaluate nuclear fuels and materials under simulated accident conditions. Neutronics calculations evaluated the PCF for Multi-SERTTA units with borated steel flux-shaping collars designed to achieve the same core-to-specimen power coupling in each of the four units. Additional supporting calculations included experiment worth, control rod worths, shutdown margin, excess reactivity, worth of experiment displacement, heat generation rates, and L2AR core power distributions. Thermal response in Multi-SERTTA was evaluated to demonstrate safe and desired operability with desired heat transfer conditions under currently targeted test conditions. Physics testing is planned upon TREAT Facility restart to demonstrate operability of the reactor and provide experimental measurements to support computational validation. Additional calibration experiments will be designed and performed to enable fueled Multi-SERTTA experimentation in TREAT.

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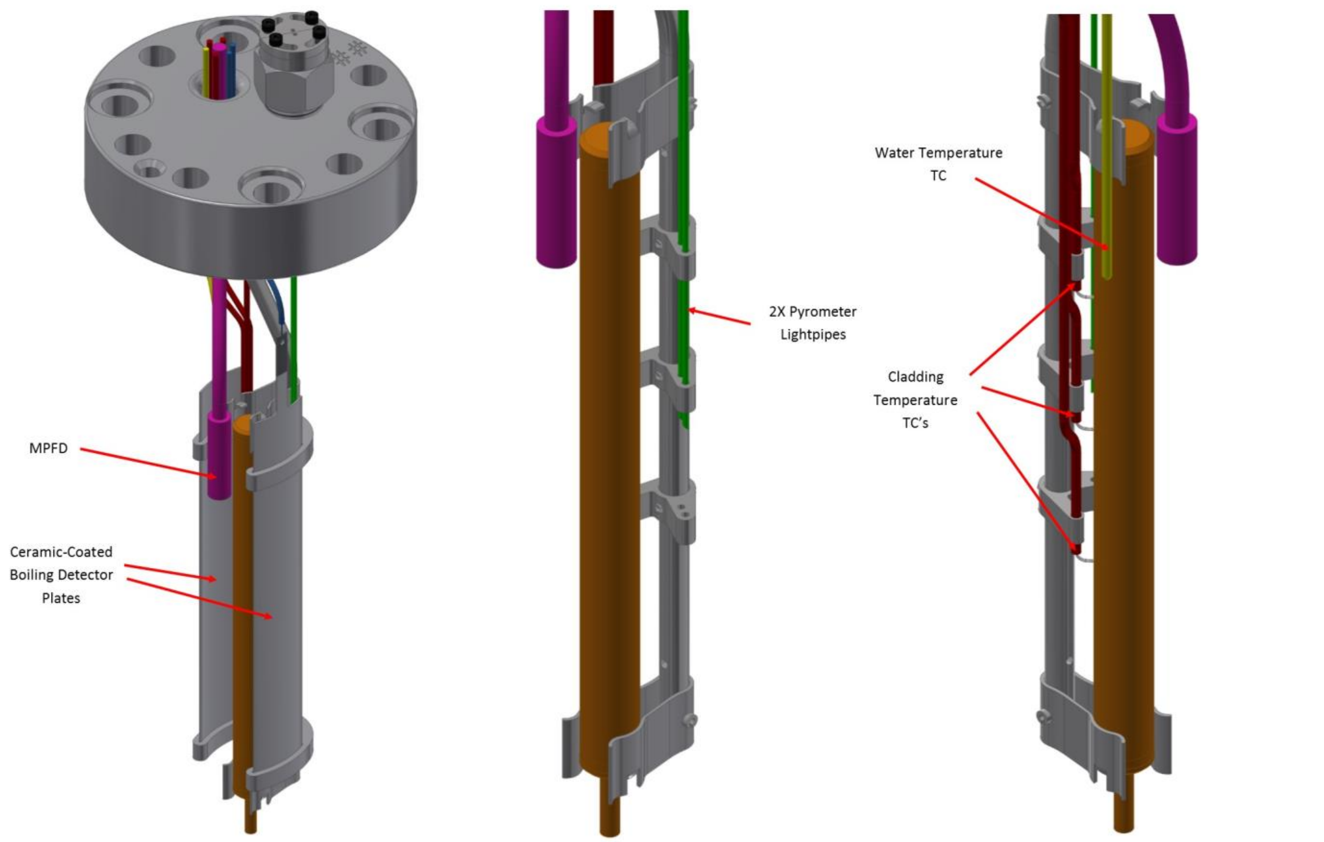


Fig. 9. Various Instrumentation within the Multi-SERTTA Primary Vessels.