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# Thermal-Hydraulic Response of the TREAT Multi-Vessel Static Environment Test Vehicle

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## ABSTRACT

As part of the resumption of transient testing in the United States, multiple test vehicles are currently under design, which are ideally suited for achieving various test environments. Of these, the multi- static environment rodlet transient test apparatus (SERTTA) is the most mature design. The test vehicle is designed for testing up to four isolated specimens under a variety of conditions ranging from gas, steam, water, and liquid sodium. During proposed transient events such as reactivity initiated accidents (RIA) and loss of coolant accidents (LOCA) in reactors, prototypic environments dictate a wide range of thermal hydraulic boundary conditions. The purpose of the this work is to provide the thermal hydraulic response of the multi-SERTTA test vehicle subjected to fuel specimen energy depositions representative of PWR accident conditions. The results show the influence of the vehicle geometric and safety constraints and provide indication of the expected thermal-hydraulic conditions relative to prototypic RIA events. For the example case shown in this preliminary abstract, a RIA-type power pulse of 837 J/g energy deposition in a 10 cm long UO2-zircaloy rodlet results in a vessel pressure exceeding the critical point of water. –More to come-

*Key Words*: **TREAT, transient irradiation testing, thermal.**

## 1. INTRODUCTION

The Transient Reactor Test Facility (TREAT) will provide the renewal of transient testing capabilities in the United States. Transient testing plays a crucial role in several aspects of the fuel qualification process providing analysis of fuel performance during design-basis accidents. Additionally, such testing can be used for separate effects studies of irradiation effects during relatively short duration events. Historically, the TREAT facility provided experimental data for hundreds of experiments for a wide variety of reactor development programs and fuel types [1].

The TREAT experimental vehicle design strategy is to create desired test environments within a primary containment vessel that is placed into the experiment position within the TREAT core. The entirety of the experimental vehicles will be inside the reactor's shielding. This provides great flexibility in experiment installation and great benefits to reactor operation safety, but also some geometric limitations for vehicle design.

Several test vehicle designs are currently in development. The most advanced concept at this stage is termed the multi- static environment rodlet transient test apparatus (SERTTA). It consists of a stacked, multi-vessel assembly allowing for simultaneous testing of four independent environments with a suite of instrumentation options. The design is ideal for quantity testing for small specimens, parameter studies, screening applications, etc. Due to the geometric restraints of a four vessel configuration, the total internal free environment volume is constrained to be ~ 300 $cm^3$.

Much of the initial and future transient testing will be done to support reactor design-basis accidents such as reactivity initiated accident (RIA) and loss of coolant accident (LOCA) events for a variety of fuel systems and system environments. Additionally, separate effects studies may require specific environment variable to achieve targeted phenomena. In any case, the TREAT experimental vehicles require prototype testing and analysis to provide the environment performance characteristics for specific conditions. The purpose of this work is to provide the thermal-hydraulic characterization of the multi-SERTTA test vessel under a RIA-type power pulse.

## 2. MODEL DESCRIPTION

### 2.1. RELAP5 Model

The Multi-SERTTA experimental environment has been modeled using RELAP5 thermal-hydraulics code [2]. Figure 1 shows a schematic of the RELAP5 nodalization diagram representing the model. The model consists of UO2/zircaloy rodlet suspended in water. Above the water volumes, a volume is filled with argon. Model heat structures include a multilayer wall made of an inner vessel crucible composed of a low thermal conductivity ZrO2 and the outer inconel-718 vessel wall. The heat structure representing the fueled rodlet consists of a single fuel pellet comprised of ten 1.016 cm UO2 pellets with a diameter of 8.26 mm. Exterior to the fuel is a 0.025 mm gas gap separating the fuel from an outer cladding layer composed of zircaloy with a 0.597 mm thickness.

The material properties for the rodlet constituents are taken directly from the built-in properties supplied by the RELAP5 code [2] including 95% theoretical density UO2, unoxidized zircaloy, and gas gap properties corresponding to a PWR fuel rod at the end of an equilibrium cycle (pressure of 4.1 MPa). Material properties for ZrO2 and Inconel 718 were taken from [3-5]. The fuel behavior is not the focus of this analysis but some detail provides representative heat transfer delay for power into the fuel rod to the coolant. Thermal expansion effects are not accounted for in the model.

The model boundary conditions are illustrated in Figure 1. The hydrodynamic volumes are connected to the heat structures using RELAP5 boundary option “101”. The outer vessel surface is insulated so the entire system is adiabatic. An adiabatic condition is a reasonable approximation for the time scales of interest for the transient, especially due to the vessel being wrapped in insulation and immersed in a nearly static gas environment.

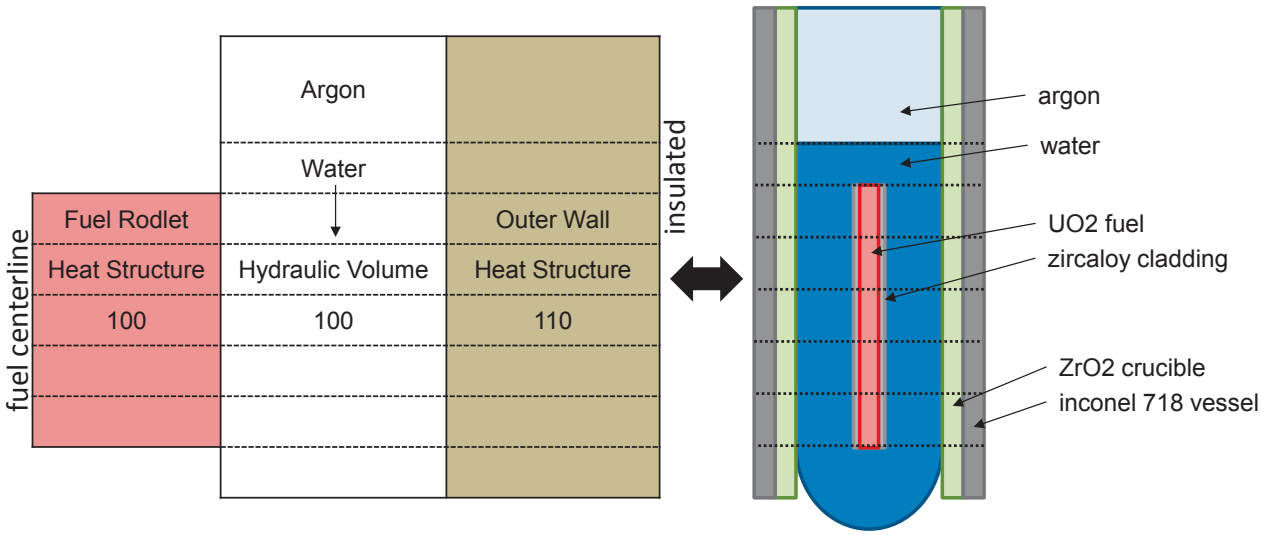


**Figure 1.** RELAP5 model description - Left: RELAP5 nodalization diagram, Right: schematic representation of modeled components.

Initial conditions for the model correspond to hot zero power (HZP) conditions. All components are initially at 300°C. The vessel interior is set to 15.8 MPa. (Additional cases of various initial conditions will be included as part of the final paper.)

### 2.1. Power Profile Input

The power profiles used as input to the model were generated assuming a Gaussian shape for the power versus time function. The shape of PWR RIA pulses differ somewhat from the Gaussian shape because of delayed neutrons/delayed fissions and the time of reactor scram. Typical PWR RIA power pulses have a low power runout period following the pulse so the overall event energy deposition occurs over relatively long periods of time (seconds) versus the relatively short initial power pulse (several tens of milliseconds). More details of RIA pulse characteristics are described in [6]. A Gaussian shape is a good representation of expected RIA power pulses generated by TREAT [7]. The pulse width for a given TREAT reactor power has yet to be determined.

Figure 2 shows an example of a power profile and total energy deposition as a function of time for an assumed (not calculated) 100 ms full-width, half-max (FWHM) power pulse with a total energy deposition of 837 J/g (200 cal/g). The energy is applied uniformly to the fuel volume.

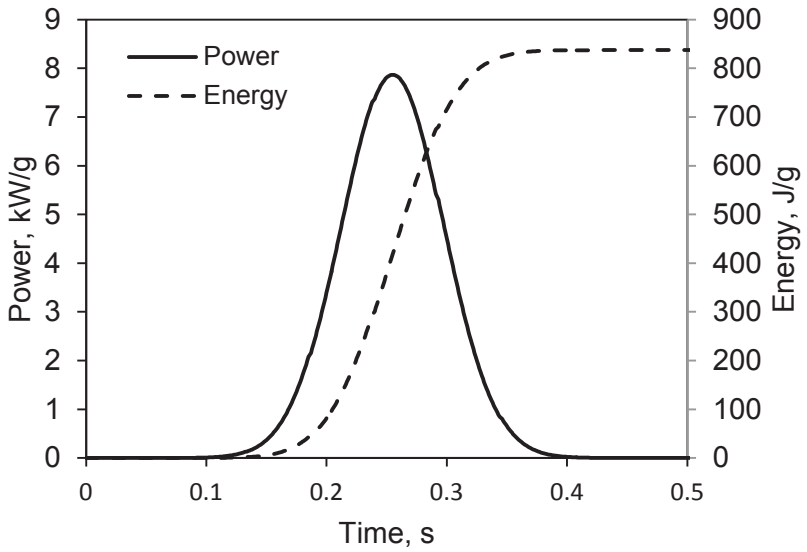


**Figure 2.** Example power and total deposited energy for an assumed 100 ms FWHM RIA power resulting in 837 J/g (200 cal/g) energy deposition.

## 3. RESULTS AND DISCUSSION

Using the previously described RELAP5 multi-SERTTA vessel model, the thermal-hydraulic response to a 100 ms FWHM 200 cal/g energy pulse (see Figure 2) has been calculated. Figure 3 shows the resulting pressure response of test vehicle. The result of a rather small vessel volume capacity and poor heat transfer from the fluid to the vessel walls (crucible insulator) is a steady rise in pressure while the heat is removed from the rodlet. For the 837 J/g (200 cal/g) pulse, the critical point of water (~22.064 MPa) is reached at time = 6.2 seconds. Beyond this time, the entire system is in a supercritical thermodynamic state. A maximum vessel pressure of 33.6 MPa is reached at time ~ 88 seconds.

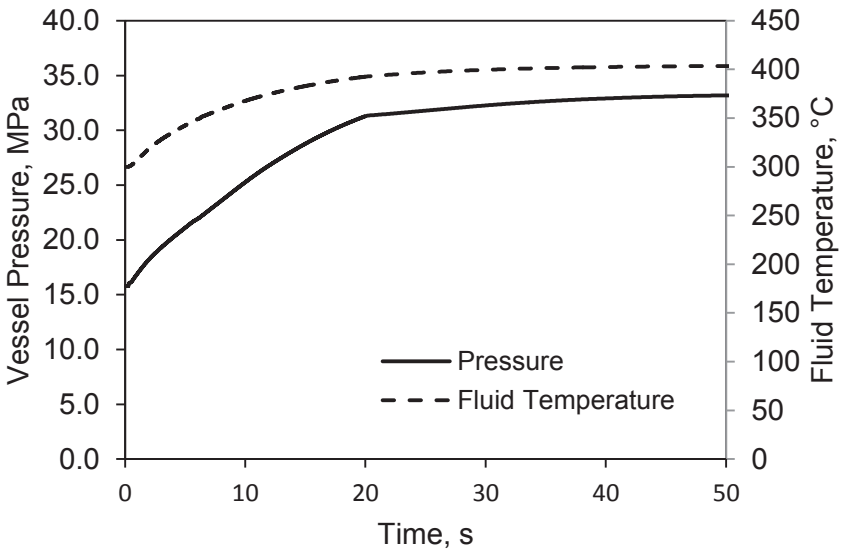


**Figure 3.** Vessel pressure and coolant temperature next to the fuel rodlet during a 100 ms FWHM 837 J/g RIA pulse.

The temperature response of the vehicle is also shown in Figure 3. Based on the results, the temperature reaches a plateau at ~ 20 seconds into the transient, where the rodlet surface temperature and the liquid temperature approach an equilibrium point. The maximum coolant temperature is ~404°C. In the calculation, the coolant above and below the rodlet do not heat up to the same extent as the volumes connected to the rodlet. The amount of fluid mixing between the different regions is expected to be underestimated by the RELAP5 model.

Figure 4 shows calculated temperature responses at various radial locations in the rodlet. These results do not include the effects of thermal expansion on heat transfer through the gas gap, which plays an important role in the dynamic process. For this reason the peak outer fuel surface temperatures are overpredicted. The maximum surface temperature of 858 °C is reached at ~1.12 seconds or ~0.865 seconds after the peak power of the power transient.

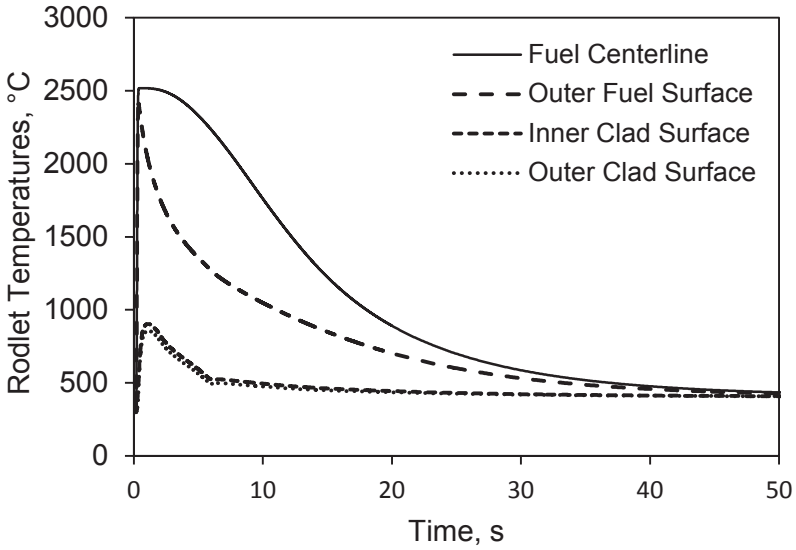


**Figure 4.** Rodlet temperatures at the mid-length location during a 100 ms FWHM 837 J/g RIA pulse. Thermal expansion effects are not included in the model.

Surface heat transfer coefficient (HTC) is shown in Figure 5. At the initiation of the transient, HTC rises quickly to a peak value of ~159 $kW \cdot m^{-2}$. After critical heat flux (CHF) is reached, it drops off to the film boiling regime and after several seconds enters into a supercritical heat transfer condition, throughout which, the HTC maintains a value of ~5-7 $kW \cdot m^{-2}$ until equilibrium conditions are reached.

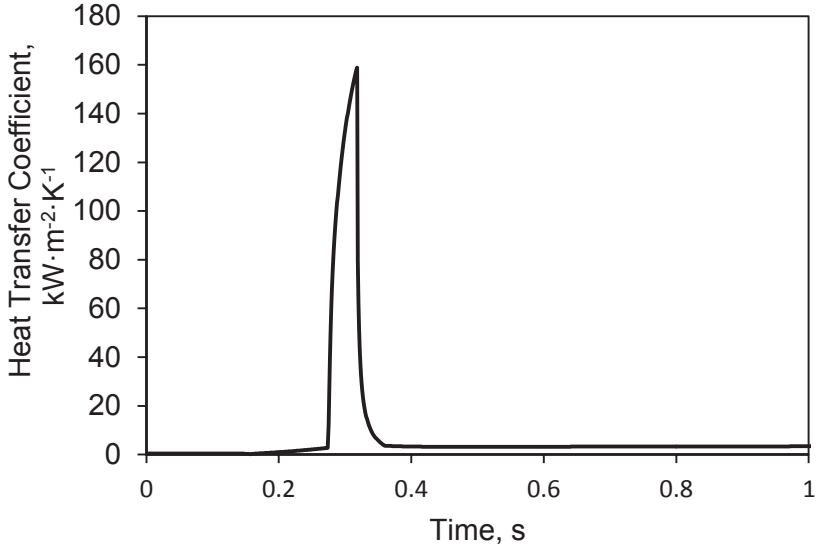


**Figure 5.** Heat transfer coefficient at the mid-length location during a 100 ms FWHM 837 J/g RIA pulse.

Heat flux from the rodlet surface and CHF are shown in Figure 6. A critical heat flux value of 2.25 MW·m-2 is reached at ~ 0.318 seconds or ~ 0.063 seconds after the peak power. After boiling crisis, the heat flux again increases significantly, driven primarily by the temperature difference between cladding and coolant.

Transient boiling studies have shown that CHF is a strong function of temperature ramp rate. In some cases, transient CHF for static coolant conditions has been shown to be ~ 5 times that of standard CHF values. It is expected that the RELAP5 code will underpredict CHF for rapid transient heating.

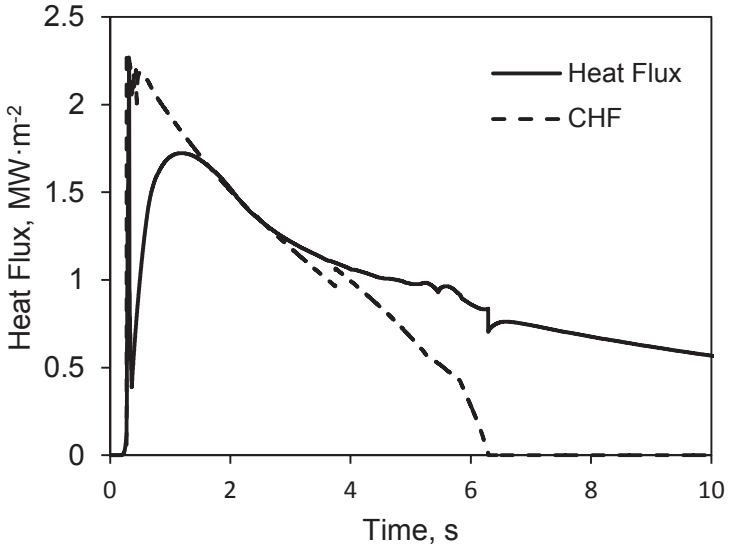


**Figure 6.** Surface heat flux and critical heat flux at the mid-length location during a 100 ms FWHM 837 J/g RIA pulse.

In addition to these results, the full paper will include a more detailed comparison and discussion of the relationship to prototypic PWR conditions and RIA-type fuel failure phenomena. The intent is also to include some parametric studies of gas volume, total energy deposition, fuel rodlet size, system heat losses, CHF, etc.

## 4. CONCLUSIONS

With the restart of the TREAT reactor, experiment design efforts are underway to create versatile transient test vehicles. As part of these efforts, this study presented the thermal-hydraulic response of a multi-SERTTA test vehicle containing a 10 cm fuel rodlet immersed in PWR-prototypic water conditions subjected to a RIA-type power pulse. For an 837 J/g (200 cal/g) pulse, the vessel volume reaches supercritical conditions due to a steady increase of vessel pressure. Low heat transfer rates out of the vehicle and the small vessel volume contribute to the non-prototypic pressure increase. Additionally, the results of the analysis provide an estimate of the expected heat transfer conditions within the vehicle, which will provide guidance for the specific experiment design.

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