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Benchmark Development for TREAT Minimum Critical Mass Core Loading to Support Validation of TREAT Operations

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BENCHMARK DEVELOPMENT FOR TREAT MINIMUM CRITICAL MASS CORE LOADING TO SUPPORT VALIDATION OF TREAT OPERATIONS

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ABSTRACT

Benchmark experiment data is necessary to validate modeling and simulation activities to support Transient Reactor Test (TREAT) Facility restart and operations. Key measurements of interest include criticality, control rod worth, excess reactivity, and shutdown margin for varying core loading sizes. Benchmark evaluations are being developed according to the guidelines provided in the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* (IRPhEP Handbook) that can also support advanced modeling and simulation activities, new experiment design for advanced reactors and accident tolerant fuel, and potential low-enriched uranium conversion of the TREAT reactor. This summary discusses development activities supporting a benchmark evaluation of the TREAT minimum critical mass core loading, which will be submitted for peer-review and publication in the IRPhEP Handbook with the identifier TREAT-FUND-RESR-001. Detailed models of TREAT are being developed and evaluated to prepare benchmark models of the minimum critical mass configuration using MCNP6.1 with ENDF/B-VII.1 nuclear data libraries.

Key Words: **Benchmark, Minimum Critical Mass, TREAT, Validation.**

1. INTRODUCTION

The Transient Reactor Test Facility (TREAT) is an air-cooled, thermal-spectrum test facility designed to evaluate reactor fuels and structural materials under simulated nuclear excursions and transient power/cooling mismatch situations in a nuclear reactor [1]. The TREAT facility was utilized from 1959 to 1994 (when it was placed on standby) to conduct more than 2,800 transient tests supporting TREAT operations and nuclear fuel testing. Upgrades to the TREAT facility were performed in the 1980s and completed in 1989. The U.S. Department of Energy has authorized resumption of transient testing and the restart of the TREAT facility [2]. The data that can be obtained from a transient testing program can support advanced reactor and fuel designs, and validate computational predictions of fuel and core behavior. Testing activities can fill in data gaps remaining from previous transient testing campaigns [3], support Accident Tolerant Fuels (ATF) research in evaluating the performance of fuel/cladding concepts under transient nuclear heating and accident environment [4], and facilitate the development and validation of multi-physics methods [5].

The development of validated benchmark models of TREAT are needed to support reactor restart and operations. Key interest is in evaluating experimental data, criticality, control rod worth, excess reactivity, and shutdown margin for loaded cores of varying sizes. The smallest critical core configuration of TREAT was the minimum critical mass core loading [6]; one of the largest core loadings was one of the M8CAL critical core configurations [7]. Efforts are in progress to identify a mid-sized core loading suitable for benchmark evaluation.

This paper discusses the progress toward development of a benchmark evaluation report for the TREAT minimum critical mass core loading. The benchmark evaluation is prepared following the guidelines of the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* (IRPhEP Handbook) [8]. Submission of a benchmark evaluation through the IRPhEP provides for extensive, qualitative, international peer review within an extensively utilized handbook for validation of nuclear codes and data. Benchmark models are then available for use to support reactor restart and operations needs, as well as, advanced modeling and simulation, TREAT experimentation design [9,10], and low-enriched-uranium (LEU) core conversion [11].

2. DESCRIPTION OF TREAT CORE CONFIGURATION

The general design of the TREAT reactor consists of a 19 by 19 square fuel lattice composing the core region. The core is fully reflected by graphite (~2 ft/~61 cm) on all sides. In its normal operation as a pulsed engineering test reactor, typically a vertical central hole is formed in the fuel lattice to contain the test sample, with one or more large channels, or slots, running horizontally from the core center out through the reflector to accommodate measurement of experiment parameters. The size of the core is adjusted to provide the necessary core excess reactivity to run the various transients required for the test operations [12]. The reactor cavity is designed to accommodate a total of 361 assemblies arranged in a 4-in-(10.16-cm)-square lattice up to a maximum active core size of 6 ft 4 in (~1.93 m) square by 4 ft (~1.22 cm) high [13].

There are a significant quantity of drawings, memos, and reports being recovered regarding the design and experimental history of the TREAT reactor. A modern baseline report has been prepared that provides a summary of the various assemblies, materials, and components utilized in the TREAT facility [14] that currently serves as a single reference source until official benchmark models have been developed and comprehensively evaluated.

2.1. TREAT Minimum Critical Mass Core Loading

Soon after initial criticality, the TREAT core was rearranged to determine the minimum critical size, with the loading shown in Figure 1. The TREAT core contained 122 standard fuel assemblies, 11 thermocouple fuel assemblies, and 8 control rod fuel assemblies. Zircaloy-clad dummy fuel assemblies would have been placed surrounding the fueled portion of the core with additional aluminum-clad dummy fuel assemblies filling the remaining positions within the core. Dummy fuel assemblies contained graphite instead of the graphite-urania fuel found in standard TREAT fuel assemblies. A single start-up source assembly was also located within the core [6].

Two sets of control rods were designed for the initial TREAT startup. The regular set consisted of 60-in-(152.4-cm)-long steel tubes filled with boron carbide in the poison section. The second set contained graphite in the bottom 18 in (45.72 cm) of the control rod poison section, replacing the boron carbide, to effectively shorten the length of the poison section. In the fully withdrawn, or "up", position of these rods, the poison section would thus be completely removed from the upper reflector of the core. The purpose of the shortened rods was to provide as clean of a reactor core as possible for the initial physics measurements. The shorter rods were not as effective for reactor control and hence not used for subsequent measurements and operation [6].

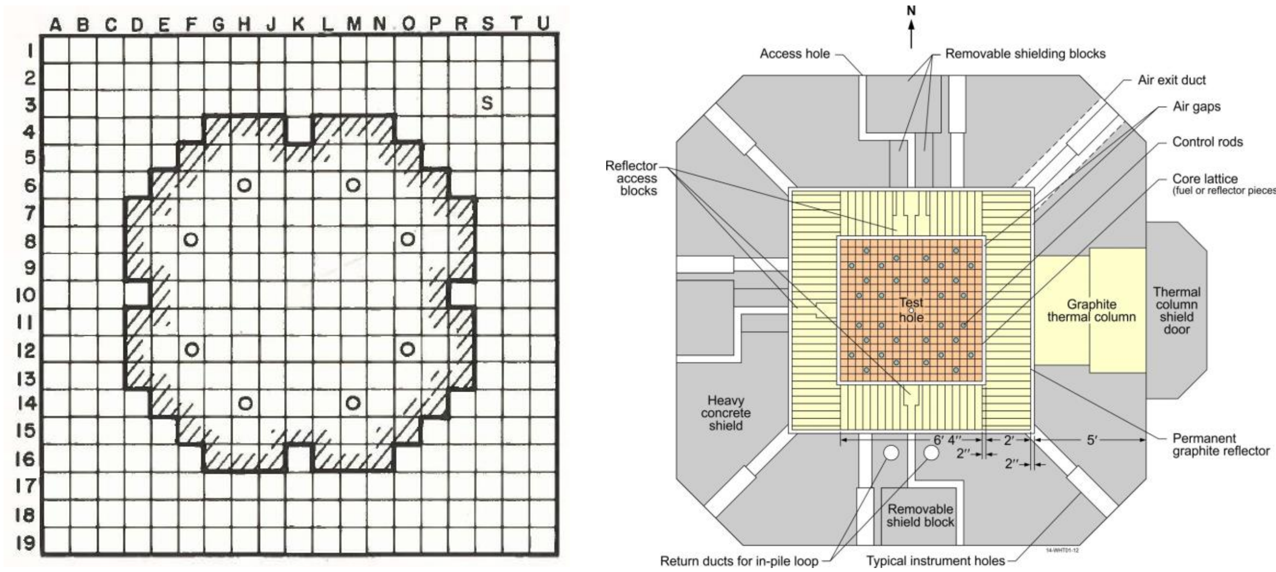

Figure 1. TREAT Minimum Critical Mass Core Loading (Left) and TREAT Core Overview (Right).

The standard control rods were calibrated using reactor period measurements corresponding to incremental changes in control rod position. Additional fuel assemblies were added stepwise to the core to allow for rod calibration over nearly half of its range. While simple and straightforward in implementation, the increase in core size and addition of elements near the control rods tended to impact the worth of the control rods during the calibration process. A similar calibration technique was used for the shorter control rods over the first 0.5 %Δk of reactivity; subcritical multiplication methods were implemented to obtain the remaining worth of these rods. Rod calibration was dependent upon which counter was utilized to measure the subcritical counting rates because of rod-shadowing effects [6].

3. BENCHMARK EVALUATION PROCESS

Much of the data provided in the baseline report [14] was instrumental in developing detailed models of the minimum critical mass core loading of the TREAT reactor [6]. The benchmark evaluation process defined in the IRPhEP Handbook is characteristically demonstrated in a previous study focused on the evaluation of standard TREAT fuel assemblies within an infinite lattice [15]. Current efforts are focused on development of a detailed model of the TREAT reactor. The model is being developed using Monte Carlo N-Particle (MCNP) version 6.1 [16] and ENDF/B-VII.1 nuclear data libraries [17].

The minimum critical core was chosen as the first configuration to model for the benchmark effort due to its simplicity and the data available from original documents. Reference 6 specifies the details of the minimum critical core configuration and provides measurement data from the minimum critical configuration. Table 1 lists the fuel assembly types and quantities that were used in the minimum critical configuration. Data regarding the critical mass of the minimum critical core configuration are available. Control rod worth measurements were also performed and those data are also available for comparison with the benchmark model being developed. Excess reactivity and shutdown margin measurements are also provided and those values can be compared with the results of the benchmark model as well.

Table 1. TREAT Core Assembly Loading for Minimum Critical Core.

Element Type	Quantity	Fuel Mass per Assembly (g/assembly)	Total Mass of Fuel (g)
Standard	122	37.5	4570
Thermocouple	11	37.0	407
Control Rod	8	26	208
Total	141	N/A	5185

As shown in Table 1, the U-235 content of the fuel loaded in the minimum critical configuration is 5185 g. Due to the fixed quantity of fuel in each assembly, the incremental addition of fuel mass in this process results in the reactor being in a supercritical state. The minimum critical mass is stated as 5171 g after correcting for the supercritical state of the reactor.

The initial efforts towards developing a benchmark model have focused on detailed models of the fuel assemblies and the core lattice. Models of the standard fuel assemblies, zirconium dummy fuel assemblies, aluminum dummy fuel assemblies, and control rod fuel assemblies have been completed. The control rods are designed to fit with the control rod fuel assemblies; however, they are actually separate components. Detailed models of the control rods have also been completed. Figure 2 presents a drawing of the standard fuel assembly with the MCNP model of the assembly. Figure 3 illustrates the model of the control rod fuel assembly with a control rod along with a drawing of the assembly and a control rod. Figure 4 illustrates a model of the minimum critical configuration in MCNP along with an illustration of the minimum critical configuration. The MCNP model in Figure 4 replaced the thermocouple fuel assemblies with the standard fuel assemblies as the thermocouple fuel assemblies are not yet modeled in full detail.

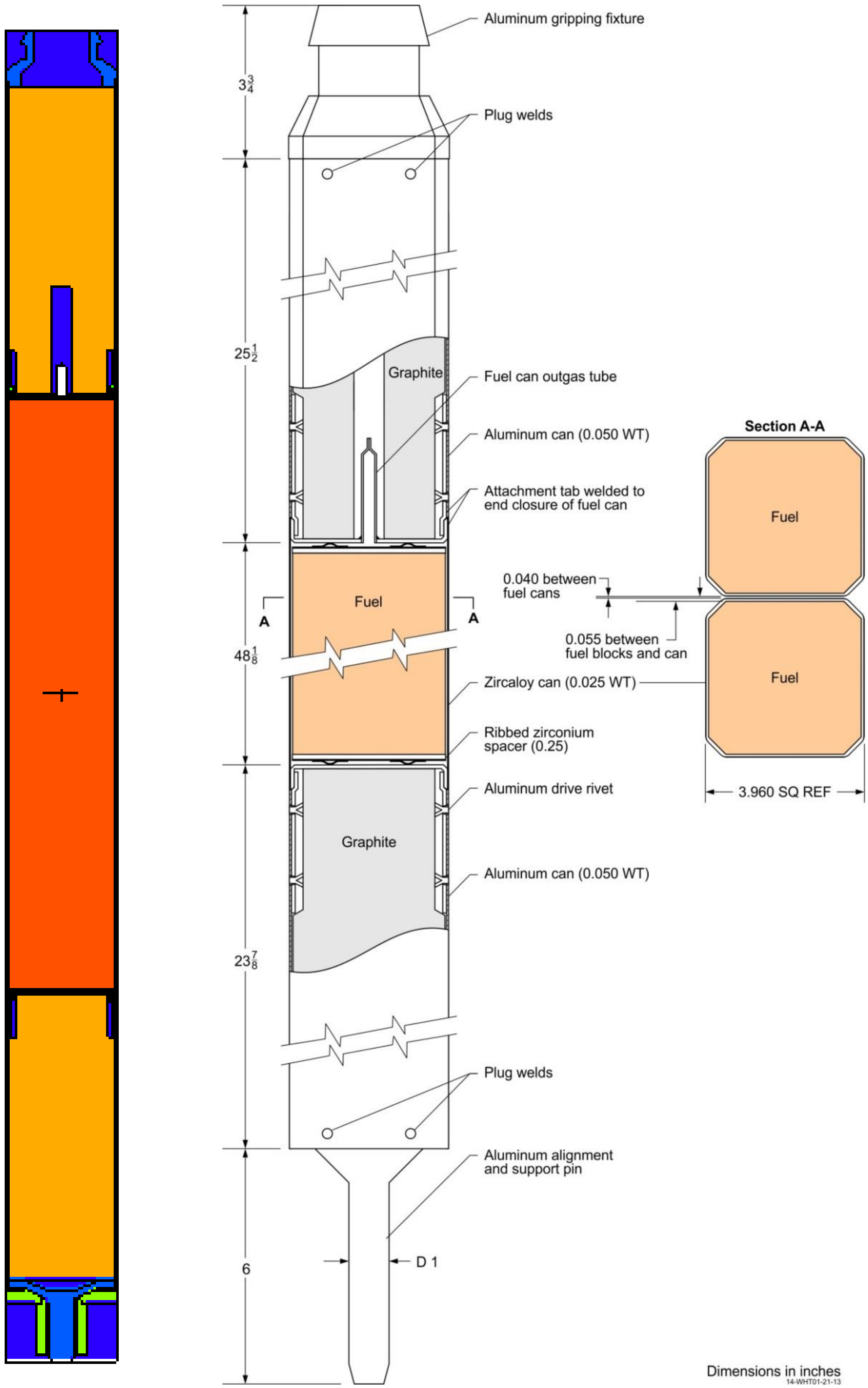

Figure 2. Standard Fuel Assembly: Model (left) and Drawing (Right).

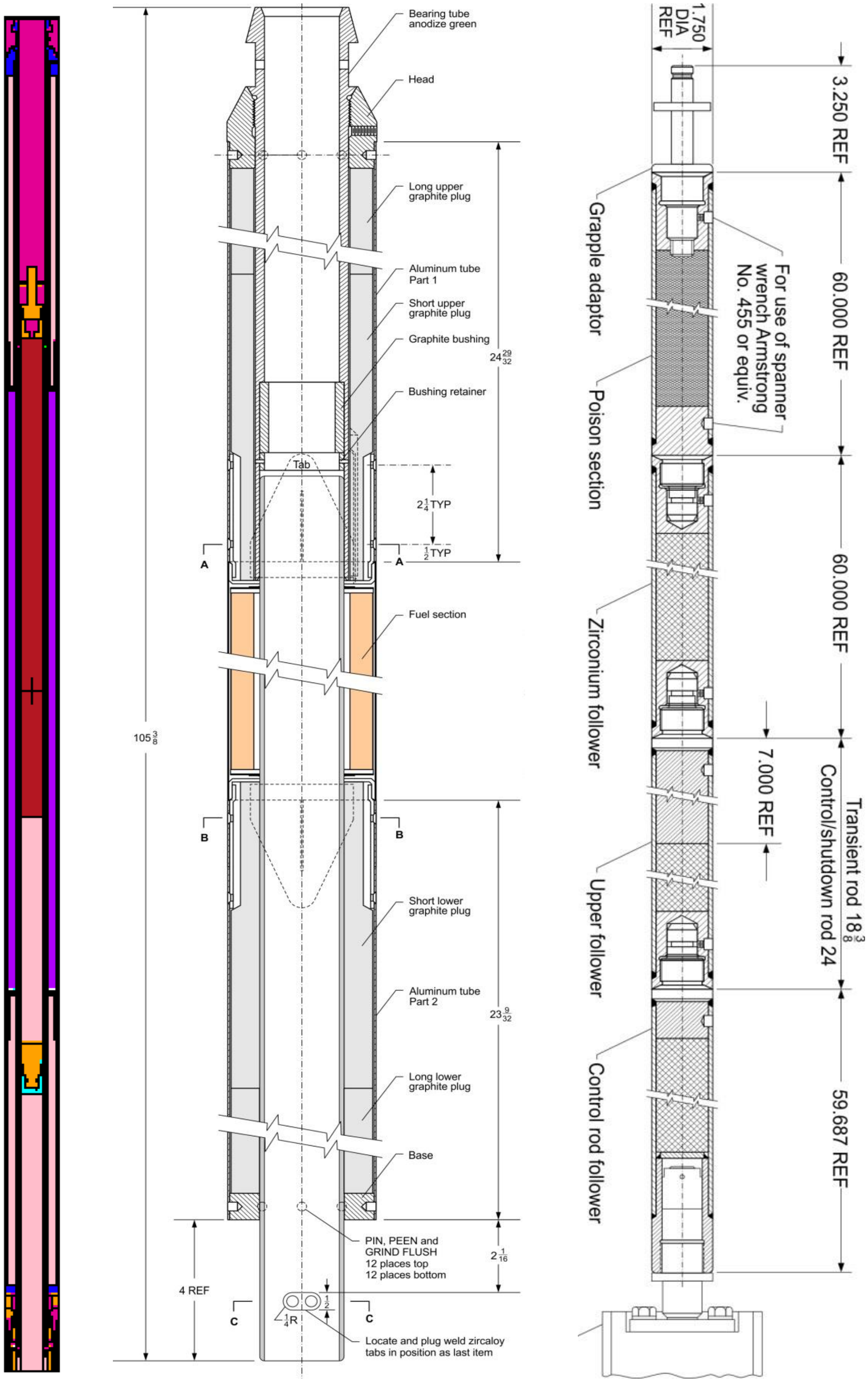

Figure 3. Control Rod Fuel Assembly with Control Rod: Model (Left) and Drawings (Right).

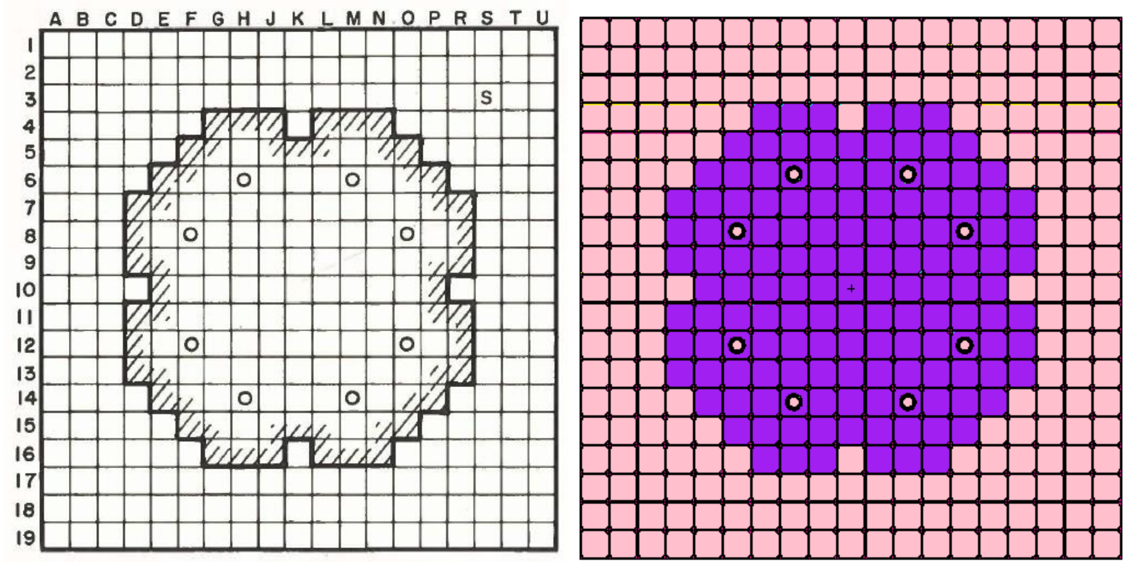

Figure 4. MCNP Model (Right) of Minimum Critical Core Configuration (Left).

4. CONCLUSIONS

Experimental data from the TREAT minimum critical mass core configuration were evaluated to determine applicability for an IRPhEP Benchmark. The TREAT minimum critical configuration was selected to be a candidate for development of an IRPhEP Benchmark. Development of the benchmark model has been initiated. Several fuel assembly models have been completed as well as models of the control rods. Future work includes development of thermocouple fuel assemblies, the source fuel assembly, permanent reflector, and core structure and shielding. After a detailed model is complete, benchmark model applied bias simplifications will be analyzed and the respective worths and uncertainties will be evaluated according to the guidelines provided in the IRPhEP Handbook. Further evaluation of the uncertainties will be performed using perturbation analysis and those results will be reported in the benchmark. The complete benchmark evaluation report will be submitted to the IRPhEP for international peer-review and subsequent publication in the IRPhEP Handbook under the identifier TREAT-FUND-RESR-001.

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