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Benchmark Progress towards TREAT M8CAL Core Loading to Support Validation of TREAT Operations

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John D. Bess, Benjamin M. Chase,
James R. Parry

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BENCHMARK PROGRESS TOWARDS TREAT M8CAL CORE LOADING TO SUPPORT VALIDATION OF TREAT OPERATIONS

John D. Bess, Benjamin M. Chase, James R. Parry
Idaho National Laboratory, USA
John.Bess@inl.gov
Benjamin.Chase@inl.gov
James.Parry@inl.gov

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 ongoing activities supporting plans for a benchmark evaluation of the TREAT M8CAL core loading, which will be submitted for peer-review and publication in the IRPhEP Handbook. Preparation of detailed models with subsequent bias and uncertainty analyses to support benchmark model development includes acquisition of drawings, material data, and experimental measurements from which benchmark experiment data can be derived and evaluated. Supplemental information from prior M-series calibration experiments such as M2CAL, M3CAL, and M7CAL provide additional insight into some of the materials, their respective properties, dimensions, and experiment design later implemented in M8CAL. Further investigation is necessary to fully comprehend, as much as practical, the M8CAL measurement series and evaluate them as integral benchmark experiments.

Key Words: **Benchmark, M8CAL, 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 nuclear fuel transient tests. 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 summary discusses ongoing activities supporting plans for a benchmark evaluation report for the M8CAL core loading, which is almost identical to the current core loading that will be first utilized for core restart. The benchmark evaluation will be 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

A general description of the reactor is that it consists of a right cylindrical core 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 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 practices. 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 M8CAL Core Loading

The M8 Power Calibration Experiment (M8CAL) [7] was one of the few experiments performed using the upgraded core and most accurately reflects the current core loading for TREAT restart. The M8 calibration series included 23 irradiations to determine the relationship between the fission power generated in the TREAT core and the fission power generated in the experiment fuel, which was located at the center of the core in an experiment vessel. The experiment was planned to provide the experiment calibration information necessary for the planning and analysis of a planned M8 test.

Both full- and half-slotted cores were established for this series. An example of a half-slotted core loading for M8CAL is shown in Figure 1, which represents one of the largest core configurations operated in TREAT. The half-slotted core allowed for a maximization of core power while still allowing for sufficient imaging capabilities via the north fast-neutron hodoscope. Of the available 361 assembly positions, there were 20 control rod fuel assemblies, 15 thermocouple fuel assemblies, and 303 standard fuel assemblies. Additional non-fueled, or dummy fuel, assemblies include one source assembly, 11 Zircaloy-clad assemblies, eight slotted assemblies (i.e. containing no graphite or fuel between the experiment and hodoscope), one slotted half-assembly, and one Zircaloy-clad half-assembly. The center of the core held the MK-III test vehicle.

	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	R	S	T	U
1	Z	Z	F	F	F	F	F	F	F	X	F	F	F	F	F	F	F	Z	S
2	Z	F	F	F	F	F	F	F	F	X	F	F	F	F	F	F	F	F	Z
3	T3	F	F	F	F	F	F	CS	F	X	F	CS	F	F	F	F	F	F	F
4	F	F	F	F	F	CS	F	F	F	X	F	F	F	CS	F	F	F	F	F
5	F	F	F	F	F	F	F	F	F	X	F	F	F	F	F	F	F	F	F
6	F	F	F	CT	F	F	F	F	F	X	F	F	F	F	F	CT	F	F	F
7	F	F	F	F	F	F	F	F	F	X	F	F	F	F	F	F	F	F	F
8	F	F	CT	F	F	CC	F	F	F	X	F	F	F	CC	F	F	CT	F	F
9	F	F	F	F	F	F	F	F	F	X2	F	F	F	F	F	F	F	F	F
10	F	F	F	F	F	F	F	T3	F	MK	F	T3	T3	T3	F	F	F	F	F
11	F	F	F	F	F	F	F	T1	F	Z2	F	T1	F	F	F	F	F	F	F
12	F	F	CT	F	F	CC	F	T3	F	F	F	T3	F	CC	F	F	CT	F	F
13	F	F	F	F	F	F	F	T3	F	T3	F	T1	F	F	F	F	F	F	F
14	F	F	F	CT	F	F	F	F	T1	T3	F	F	F	F	F	CT	F	F	F
15	F	F	F	F	F	F	F	F	F	T3	F	F	F	F	F	F	F	F	F
16	F	F	F	F	F	CS	F	F	F	F	F	F	F	CS	F	F	F	F	F
17	F	F	F	F	F	F	F	CS	F	F	F	CS	F	F	F	F	F	F	F
18	Z	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	Z
19	Z	Z	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	Z	Z

A	Al-Clad Dummy Assembly
CC	Compensation Rod Fuel Assembly
CS	Control/Shutdown Rod Fuel Assembly
CT	Transient Rod Fuel Assembly
F	Standard Fuel Assembly
MK	MK III Test Vehicle (M8CAL)
S	Zr-Clad Source Assembly
T1	4-Fuel Thermocouple Assembly
T2	Reflector-Fuel Gradient Thermocouple Assembly
T3	Midfuel, Reflector & Skin Thermocouple Assembly
T4	Transient Thermocouple Assembly
X	48" Access Hole Dummy Assembly
X2	48" Access Hole Dummy Half-Assembly
Z	Zr-Clad Dummy Assembly
Z2	Zr-Clad Dummy Half-Assembly

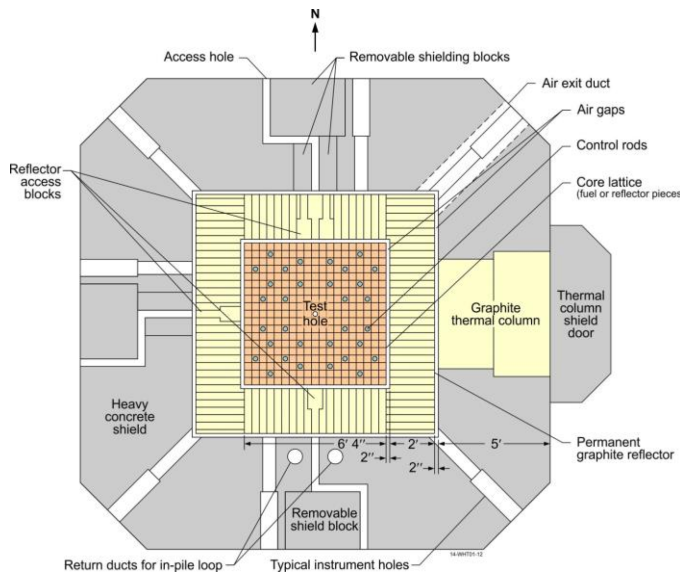

Figure 1. Example TREAT M8CAL Core Loading (Left) and TREAT Core Overview (Right).

The standard control rods consisted of 60-in-(152.4-cm)-long steel tubes filled with boron carbide [6]. Control rods were designated as four single pneumatic compensation rods, typically completely withdrawn "up" from the core, four pairs of pneumatic control/shutdown rods used for primary reactivity control, and four pairs of hydraulic transient rods utilized for rapid insertion of reactivity to initiate transient responses within the core [7]. It should be noted that the pneumatic drives are screw drives with pneumatic scram assist.

The total worths of the transient and control/shutdown rods in the full-slotted core were measured at

9.02 and 7.77 %, respectively. The half-slotted core worths were 8.46 and 8.83 %, respectively. The maximum reactivity for experimental use was 5.8 %Δk/k. Worth curves and excess reactivity measurements were assessed for some of the core measurements performed during the M8CAL experimental series and recorded in their respective operational logbooks and reports.

3. BENCHMARK PREPARATION PROGRESS

Much of the data provided in the baseline report [14] is 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]. With a detailed model of the core established, simplifications to the model can be effected, biases with bias uncertainties computed, and the benchmark model of the critical configuration can be developed. Subsequent uncertainty evaluation of specific measurements can further be evaluated such that the complete benchmark evaluation report can be submitted to the IRPhEP for international peer review and subsequent publication in the IRPhEP Handbook.

Prior to comprehensive evaluation of M8CAL measurements, additional efforts are necessary to identify, quantify, and characterize the available experimental data from which benchmark models can be established. While the baseline report [14] contains much of the core assembly data utilized in the M8CAL core, details regarding experimental measurements are limited. The M8CAL summary report [7] provides a summary of the experiment campaign but not the comprehensive details regarding each individual experiment and the detailed experiment design and loading.

Ongoing efforts at Idaho National Laboratory (INL) include recovery and digitization of numerous reports, logbooks, memorandums, and printouts from the original TREAT library. Logbooks indicate startup of the upgraded core begins with loading 1449 completed on August 7, 1989, which supported the initial test program. The upgraded core was last operated with loading 1469 on April 28, 1994. Transients performed during this operational period run from 2782 to 2885. Not all experimental measurements performed during this operational time period directly supported M8CAL; however, they are relevant to modern operations using the upgraded core design. Core loading maps, rod worth data, core heat balance data, and transient measurement data include some of the information being identified and gathered.

Details regarding the calibration test train configuration for M8CAL are not very detailed in the M8CAL report [7], providing basic material and dimensional information. Better details regarding the test fuel pins themselves can be obtained from the previous calibration report for M7CAL [16]. Design drawings providing detailed dimensions and component assembly for the M8CAL vehicle containing fuel pins or flux wires have yet to be located. The calibration vehicle used for M2CAL [17], M3CAL, and M7CAL was modified for use in M8CAL. As such, many of the components are identical and drawings from the earlier calibration campaigns can facilitate understanding of the calibration design for M8CAL. The center section of the calibration vehicle drawing for the earlier calibration vehicles is shown in Figure 2. The pin profile found in M8CAL is redrawn in Figure 3, and is very similar to that shown for M7CAL in Figure 2. Vertical placement of components of the M2+3CAL test train is depicted in Figure 4.

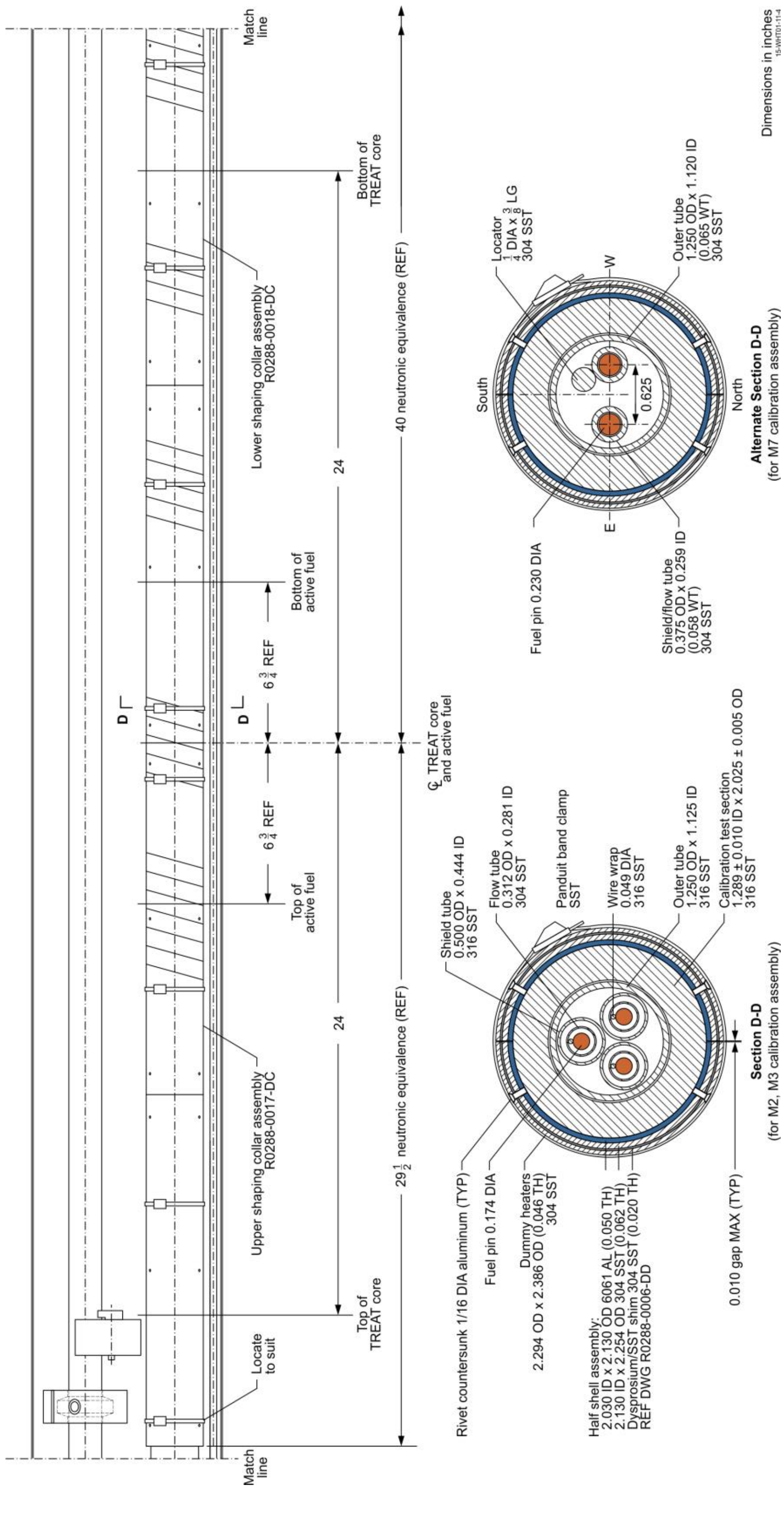

Figure 2. Middle Section of M2, M3, and M7CAL Vehicle Assembly.

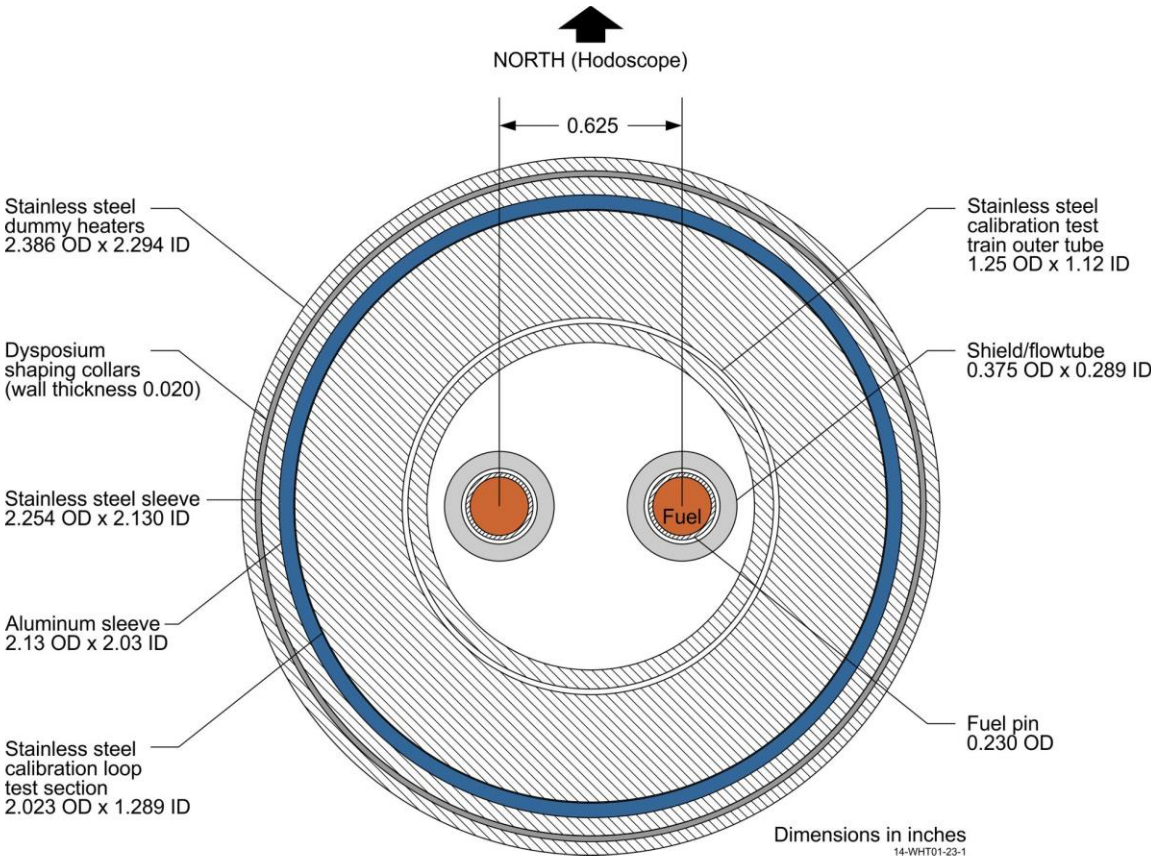

Figure 3. M8CAL Fuel Pin Loading Cross Section.

Efforts continue to locate and digitize additional drawings of experiment vehicles used in TREAT. Material data, such as impurity content, for the fuel pins and flux monitor wires are also not available in the M8CAL report. However, data from the X425 Casting Campaign in the appendices of another Integral Fast Reactor (IFR) report [18] provides information to further evaluate uncertainties and impurities in the T-433 and T-462 fuel rods. Other reports from the IFR series might also provide additional insight and understanding into details necessary to evaluate fuel pins used in the M-series TREAT experiment campaign. Additional effort is necessary to identify in more detail properties, with their respective uncertainties, of the flux monitor wires used in TREAT.

Both fueled and unfueled thermocouple assemblies were used in TREAT to monitor temperature at various points of interest during core operations. Five types of thermocouple assembly design strategies incorporated three types of thermocouple installations. Type A thermocouples were chromel-alumel couple sheathed in stainless steel type 304 with MgO insulation. Type B thermocouples were chromel-alumel couple using 28-gauge wire in asbestos-glass insulation (i.e. asbestos overbraid with fiberglass). Type C thermocouples were fast-response chromel-alumel couple with 28-gauge wire attached individually to the fuel blocks by means of small conical wedges [13]. Additional investigation into the material properties of the thermocouple components are addressed in the baseline report [14]. Additional calculations based on standards for thermocouple manufacturing [19,20] are necessary to assess the proper volume and mass of thermocouple material present within the TREAT thermocouple assemblies. Typical manufacturing tolerances found in this manual further to support uncertainty analyses regarding the estimated worth of these components and their impact on integral benchmark measurement data.

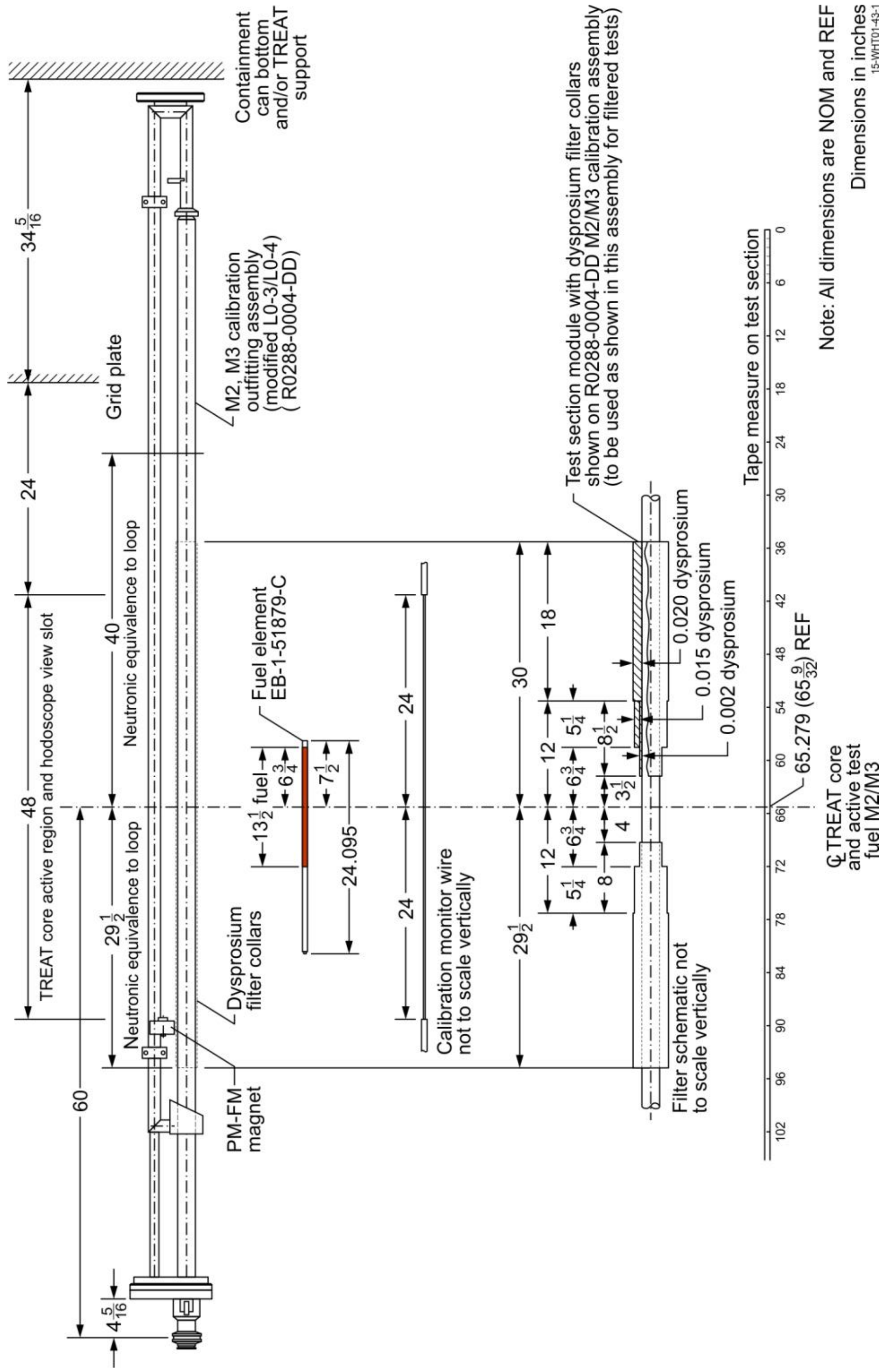

Figure 4. M2+3CAL Test Train Vertical Reference Diagram.

4. CONCLUSIONS

Results discussing current progress are summarized in this paper regarding activities to support benchmark evaluation of the TREAT M8CAL experiments. Some success has been achieved in locating documented data supporting what is relayed in the M8CAL report. Supplemental information from prior M-series calibration experiments such as M2CAL, M3CAL, and M7CAL are instrumental in evaluating M8CAL experiments as a comprehensive summary of all drawings, material data, and experimental measurements from M8CAL has yet to be assembled to support benchmarking efforts. Additional evaluation of the IFR program documentations and standards for typical reactor components, such as thermocouples, may further clarify gaps in available information that need to be filled to support a more comprehensive benchmark analysis. The complete benchmark evaluation report will be submitted to the IRPhEP for peer-review and subsequent publication.

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