Experiment Completion: Thermal Epithermal eXperiments (TEX) with Iron Diluents for Hanford Tank Safety Basis

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INTRODUCTION

The Hanford Site in Washington state was established during the Manhattan Project to produce plutonium. During operation over the project and through the Cold War large quantities of radioactive chemical waste where generated which remain stored in underground tanks through today. The tank farms now contain approximately 56 million gallons of waste distributed across 177 tanks in a variety of physical and chemical forms, including sludge, salt-cake, and supernatant liquid [1]. Figure 1 shows the inside of one such tank and a top layer of waste. Because these wastes were produced over decades of changing process conditions and subsequently redistributed through transfers, evaporation, and interim storage operations, the resulting tank inventories are heterogeneous.

Safety basis from applicable critical fissile experiments is required validate predictive models in fissionable systems (ANSI/ANS 8) [2]. When modeling the Hanford tanks with only currently validated material properties, inadequate criticality safety margin is present. Particularly, crediting absorbers is needed to establish an adequate margin of subcriticality. Existing benchmark evaluations in the International Handbook of Evaluated Criticality Safety Benchmark Experiments do not provide sufficient similarity and iron sensitivity for several limiting Hanford waste models, which constrains the extent to which iron specifically can be credited in safety basis calculations. The Hanford tanks are unusual because they combine plutonium-bearing waste with large masses of moderating and absorbing materials in compositions that are not common in standard industrial applications in such large geometries. Additional critical experiments are required to validate the iron absorption and capture cross sections to allow for the crediting of the significant iron concentration in the Hanford tanks.

The Thermal/Epithermal eXperiments (TEX) program was developed as a flexible benchmark platform for generating plutonium and highly enriched uranium critical experiment data across a range of neutron spectra. The plutonium series of TEX experiments use layered assemblies of Plutonium-Aluminum No-Nickel (PANN) Zero Power Physics Reactor (ZPPR) fuel, polyethylene moderator, and selected diluent materials [4, 5]. Earlier TEX benchmarks established the underlying experimental approach for bare and moderated plutonium systems and for systems containing additional interstitial materials, providing a framework for benchmarking thermal, intermediate, and fast spectrum plutonium configurations on National Criticality Experiments Research Center (NCERC) vertical-lift machines [4]. TEX-Fe builds directly on that earlier baseline by retaining the same basic fuel, tray, moderator, and machine design while introducing iron absorber plates as the material of interest [6].


Fig. 1. Image of the inside a tank at Hanford showing sludgy waste of the tank. Current models give insufficient subcriticality margin without iron absorption. TEX-Fe is intended to provide validation for Fe absorption and capture cross sections so adequate margine of subcriticality in calculations can be achieved. Image provided from WA State Dept of Ecology [3].

Three critical configurations, Fe-14, Fe-11, and Fe-16, were completed across fifteen critical measurements at NCERC using the the Planet vertical-lift assembly machine [7]. In this paper we will describe the experimental methods, including assembly operations, approach to critical, dimensional metrology, and the detailed unstacking and restacking process used for reproducibility measurements. We then summarize the completed critical configurations and the associated measurements, with an overview provided in Table I. Finally we discuss the significance of the results and the path forward toward a benchmark evaluation and validation of the iron absorption cross section.

METHODS

The TEX-Fe campaign was executed at the National Criticality Experiments Research Center (NCERC) by Los Alamos National Laboratory experimenters using the Planet general-purpose vertical-lift assembly machine [1, 6, 7]. Initial handstacking, mass, and dimensional measurements were performed in July 2025, and the critical experiment campaign was completed over three weeks from December 2025 through January 2026. The campaign implemented three iron-bearing TEX configurations, Fe-14, Fe-11, and Fe-16, selected to span distinct combinations of moderator thickness, iron thickness, and fuel layering developed to support Hanford validation needs. In all three configurations, plutonium ZPPR plates were loaded into polyethylene fuel trays and separated by polyethylene moderator and iron absorber

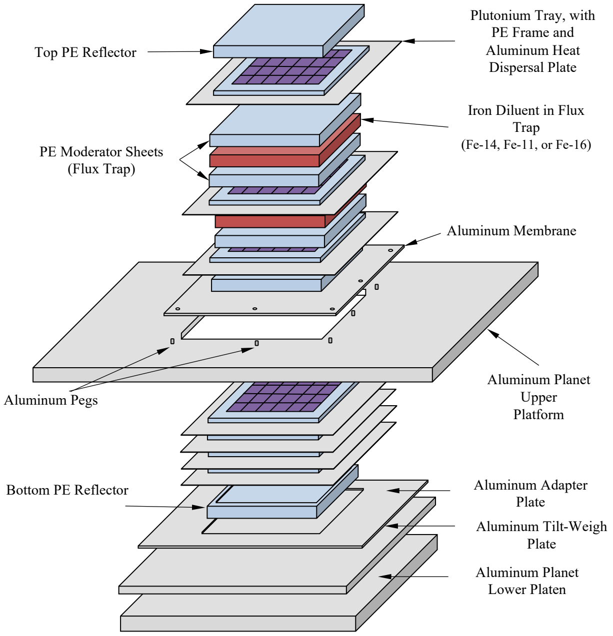

Fig. 2. Notional diagram showing the TEX-Fe stack with Fe-14, Fe-11, Fe-16 diluents in a flux trap between moderators and PANN ZPPR plates on heat dissipating fuel trays.

layers arranged to form a thermal flux trap around the absorber material. Figure 2 notionally shows the overall layout of the TEX-Fe experiments including the dilliuant-moderator flux traps, top reflector, and various components of Planet.

Approach to Criticality

Each TEX-Fe configuration was assembled in two halves on Planet, with the lower stack resting on the movable platen and the upper stack supported on a removable membrane on the stationary platform. Initial hand stacking proceeded by adding fuel trays and moderator-absorber units incrementally while monitoring multiplication. After reaching the multiplication limit for handstacking, remote operations were performed with an approach to critical. Figure 3 shows a TEX-Fe configuration during these operations.

Each fuel layer consisted of a thin polyethylene tray riveted to a thin aluminum heat dispersal plate and holding up to 24 plutonium ZPPR plates in a 6 by 4 array. Between fuel layers, the iron-bearing diluent units were assembled from an iron absorber plate sandwiched between two polyethylene moderator plates and secured with aluminum binding posts. Fine reactivity control near delayed critical was achieved by adjustment of polyethylene top reflector thickness and, where necessary, by controlling the plutonium loading in the uppermost fuel tray replacing ZPPR plates with aluminum surrogate plates to preserve geometry while varying fissile mass.

Dimensional Measurements & Reproducibility

Because prior TEX benchmark evaluations identified stack height and gap distribution as major contributors to benchmark uncertainty, dimensional measurements were emphasized throughout the campaign. After benchmark-critical configurations were established, stack heights and levelness were measured on Planet before any restacking operations were performed. These measurements were completed primarily by hand with an articulated-arm coordinate measuring machine (CMM), with height-gage checks used during the Fe-14 critical experiment to verify CMM measurements. Measurements were made for both the upper and lower stacks relative to their local support surfaces, namely the lower platen for the bottom half and the upper platform or membrane-supported assembly for the top half as close to the stack as possible.

Fig. 3. TEX-Fe-11 on the Planet vertical lift machine between closures. The vertical-lift machine will close taking the experiment slightly supercritical. A period measurement is taken using three compensated ion chamber detectors. Excess reactivity and the criticality coefficient are computed using the Inhour equation. Image provided by LANL.

Levelness measurements were taken using a digital level on both the machine support surfaces and the assembled stacks. This provided information on the relative tilt of the top surfaces with respect to the support planes and supported later interpretation of stack height variation and possible gap redistribution. These dimensional measurements were repeated after restacking so that the effect of disassembly and reassembly on the critical configuration could be quantified.

After CMM measurements on Planet each half stack would was disassembled and reconstructed on a granite surface plate for an additional confirmation CMM measurement. The restacking process was carried out by unloading the upper and lower halves and reverse stacking onto a movable cart keeping an inverse material order. Components of each half were then stacked in their original order on a granite surface plate, so the lower and upper stacks were rebuilt from the same identified trays, moderator plates, absorber plates, and reflector components used in the benchmark configuration. Stack heights and levelness were measured again on the granite surface plate to quantify changes introduced by disassembly, handling, and reconstruction.

After off-machine metrology was completed, the two halves were returned to Planet and reassembled for a reproducibility critical measurement. Once a stack had been removed from the machine, exact alignment between layers and between the upper and lower halves could no longer be guaranteed; accordingly, the reproducibility measurements quantify the reactivity impact of realistic reassembly variation using the same materials rather than an idealized exact reconstruction. This is the relevant quantity for later benchmark uncertainty assessment because it captures the combined effects of handling, reseating, local gap redistribution, and practical restacking tolerances.

Additional Measurements

In addition to benchmark and reproducibility measurements, the campaign included several targeted perturbation measurements intended to characterize the reactivity importance of selected configuration details [6]. These measurements included top reflector thickness adjustments, elevated-temperature or thermal-equilibrium repeat measurements, a resistance temperature detectors (RTD) related worth measurement in Fe-11, and localized perturbation measurements in Fe-16 associated with replacing a diluent layer and swapping fuel tray positions. These supporting data strengthen the defensibility of the experimental dataset by documenting the sensitivity of the assemblies to realistic variations that may inform the benchmark evaluation. The complete set of critical measurements obtained during the campaign is summarized in Table I. Note that Inhour permeates used by NCERC to calculate excess reactivity are for a generic Plutonium system. Future work will use Inhour parameters specific to the benchmark model, and recalculating the excess.

CRITICAL CONFIGURATIONS

Three TEX-Fe critical configurations were completed during the campaign: Fe-14, Fe-11, and Fe-16. Together, these configurations span different levels of moderation and iron loading and were selected to improve benchmark representativity for Hanford tank farm applications [1]. The execution and measurement history are summarized in Table I. Table II shows the predicted fission fraction for each configuration.

Fe-14

Among the three TEX-Fe configurations, Fe-14 most directly corresponds to the principal iron-validation objective identified in the design study for Hanford tank applications. Initial analysis showed that a configuration of this type provides strong similarity to several limiting Hanford waste models while maintaining practical assembly, moderation, and structural constraints [1].

Fe-14 was the first TEX-Fe configuration executed and used 16 fuel layers with 0.500-in. iron absorber plates and 0.3125-in. polyethylene moderator plates between fuel layers. The benchmark measurement (1E) achieved an average reactor period of 134.98 s with an estimated excess reactivity of 8.691 cents. Additional Fe-14 measurements included repeated criticality, top reflector worth, an elevated-temperature repeat measurement, and a restacking reproducibility measurement, as shown in Table I.

Fe-11

Fe-11 employed a more highly moderated configuration than Fe-14, using 0.375-in. iron absorber plates and 0.4375-in. polyethylene moderator plates. The benchmark measurement for Fe-11 was 2A, which used 13 fuel layers total, including a partial upper layer with 8 plutonium plates and aluminum surrogate plates occupying the remaining tray positions. For this benchmark measurement, the reported average reactor period was 143.07 s and the estimated excess reactivity was 8.289 cents. The Fe-11 campaign included a reproducibility measurement, a top reflector worth measurement, a repeat critical measurement after thermal equilibration, and an RTD-related worth measurement, as summarized in Table I.

Fe-16

Fe-16 was the most weakly moderated and most heavily loaded of the three configurations, using 20 fuel layers with 0.500-in. iron absorber plates and 0.125-in. polyethylene moderator plates. The benchmark measurement for this configuration was 3B, with a reported average reactor period of 86.45 s and estimated excess reactivity of 12.318 cents. The Fe-16 series also included an initial criticality measurement, a restacking reproducibility measurement, a diluent-layer perturbation measurement, and a fuel-tray perturbation measurement, as listed in Table I.

DISCUSSIONS, CONCLUSIONS, & FUTURE WORK

The TEX-Fe campaign successfully completed three critical configurations, Fe-14, Fe-11, and Fe-16, and a total of fifteen critical measurements at NCERC using PANN ZPPR plates, polyethylene moderator and reflector, and iron absorber plates. These experiments were designed specifically to address the lack of highly relevant iron-sensitive benchmark data for Hanford tank farm criticality safety validation.

Beyond the immediate Hanford application, these experiments should have broader value to the criticality safety community. Iron is a common structural and process material, yet high-quality plutonium benchmarks with strong sensitivity to iron absorption in thermal and epithermal spectra remain limited. The TEX-Fe configurations therefore have the potential to support both application-specific validation and broader assessment of iron nuclear data performance in criticality calculations and beyond [8].

TABLE I. Overview of TEX-Fe Critical Measurements showing period and excess reactivity and briefly describing experiment intention. Time of “full close” as recorded in logbook in YYYY-MM-DD and HH:MM (Pacific daylight time). Average of estimated linear channel data from all three compensated ion chamber detectors, as reported by NCERC experimenters.

Configuration	Date and Time	ID	Period (s)	Excess (¢)	Notes
Fe-14	2025-12-09 10:51	1A	315.8	4.1	Initial criticality
	2025-12-09 11:14	1B	304.7	4.3	Second criticality
	2025-12-09 12:50	1C	164.37	7.3	1/32” Top reflector added for additional excess
	2025-12-09 13:35	1D	140.0	8.4	Criticality at elevated center stack temperatures
	2025-12-10 08:24	1E	135.0	8.6	Benchmark
	2025-12-11 09:34	1F	39.4	21.0	Restacking reproducibility
Fe-11	2026-01-07 12:54	2A	143.1	8.2	Benchmark
	2026-01-08 14:10	2B	112.9	10.0	Restacking reproducibility
	2026-01-08 15:22	2C	70.5	14.3	1/32” Top reflector added for additional excess
	2026-01-12 09:52	2D	103.1	10.8	Reproducibility at thermal equilibrium (2B config)
	2026-01-12 10:35	2E	32.4	23.7	RTD stack height worth (2B config)
Fe-16	2026-01-13 16:02	3A	86.5	12.5	Initial criticality
	2026-01-14 08:46	3B	86.5	12.3	Benchmark
	2026-01-15 08:57	3C	28.2	25.7	Reproducibility after restacking
	2026-01-15 09:41	3D	25.5	27.2	Diluent layer swap
	2026-01-15 11:08	3E	30.6	24.5	Fuel layer swap

TABLE II. Predicted fission fractions for configurations from Monte Carlo analysis [1]. Energy ranges are: thermal: < 0.625 eV, intermediate: 0.625 eV to 100 keV and fast < 100 keV.

Config	Thermal (%)	Intermediate (%)	Fast (%)
Fe-14	52.9	32.1	15.0
Fe-11	60.3	26.3	13.4
Fe-16	33.3	45.1	21.6

We will be evaluating the three experimental configurations for submission to the International Criticality Safety Evaluation Benchmark Project.

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