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LLNL-CONF-670702

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May 14, 2015

International Confernece on Nuclear Criticality
Charlotte, NC, United States
September 13, 2015 through September 17, 2015

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Preliminary Design for Thermal/Epithermal eXperiments with Jemima Plates with Polyethylene and Hafnium

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INTRODUCTION

The need for epithermal and intermediate energy range critical benchmarks is an established international criticality safety data need. Addressing these needs is the goal of the U.S. Nuclear Criticality Safety Program's (NCSP) TEX Project by executing experiments. These experiments will use NCSP fissile assets that can be used to create critical assemblies that span a wide range of fission energies, from thermal (below 0.625 eV), through the intermediate energy range (0.625 eV to 100 keV), to fast (above 100 keV). An additional goal is to design critical assemblies that can be easily modified to include various high priority materials (diluents), like hafnium, identified by the international criticality safety and nuclear data communities.

Preliminary design for the TEX experiments, completed in 2012 [1], focused on NCSP assets and facilities that could be used to execute critical experiments that meet the TEX goals, including Los Alamos National Laboratory's highly enriched uranium (HEU) Jemima plates. The Jemima plates are NCSP assets that comprise a large HEU mass that is uniformly discretized and amenable to neutron spectrum tuning, through the arrangement of interspersed moderation. Previous calculations confirmed the feasibility of using the idealized Jemima plates, moderated with varying thicknesses of interspersed polyethylene and various diluents, to create thermal, intermediate, and fast fissioning systems. This report documents calculations for configurations using the real HEU Jemima plate fuel moderated by polyethylene (PE) and diluted with hafnium (Hf). Optimization of Hf thickness was performed previously [2], and the focus of this report is to show feasibility with current limited Jemima plate inventory.

DESCRIPTION OF ACTUAL WORK

Description of Jemima Plates

Los Alamos National Laboratory (LANL) has used thin (3 mm thickness) solid and annular disks of U(93+), collectively known as the Jemima plates, in many critical experiments. As seen in Figure 1, the type HEU1 disks (15" (38.1 cm) in diameter with no internal holes) along with similar HEU2 plates with a 2.5-inch-diameter (3.81 cm) central hole were manufactured at LANL in the mid-1950s and used in the Jemima experiments (IEU-MET-FAST-001) [3]. Some of the original 15" plates were modified with 6" central holes and 10" central holes for the series of Big Ten experiments at LANL [4]. For this experiment only the 15" diameter plates will be used.

The Jemima plates have also been used to create intermediate spectra benchmarks. HEU-MET-INTER-006, *The Initial Set of Zeus Experiments: Intermediate-Spectrum Critical Assemblies with a Graphite-HEU Core Surrounded by a Copper Reflector* [5], details four critical intermediate-energy spectrum configurations with the 21" Jemima plates interspersed with varying amounts of graphite and reflected by a large copper reflector. The percentage of intermediate energy neutrons causing fission for the four experiments varied from 50% to 79%.

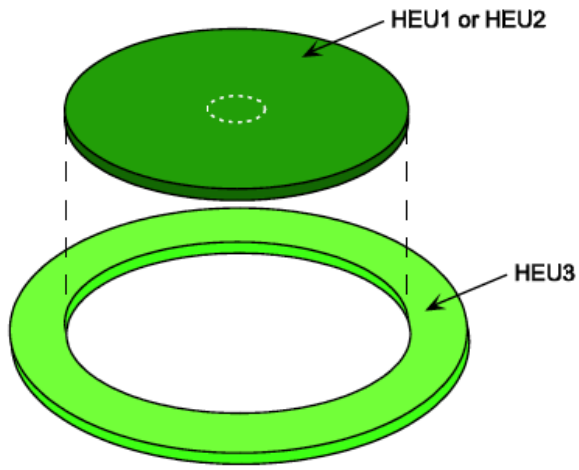

Fig. 1. Jemima Plate Configuration., taken from HEU-MET-INTER-006 [5].

Table I: Current HEU Jemima Plate Inventory

Name	Outer radius (cm)	Inner radius (cm)	Thickness (cm)	Available	HEU Mass (kg)
Solid Disk	19.05	-	.2997	5	5.46
6 wedges[1]	19.05	-	.2997	1	5.46
2.5 in hole	19.05	3.1877	.2997	7	5.28
6 in hole	19.05	7.62	.2997	7	4.43
6 in piece[2]	7.62	-	.2997	1	1.03
10 in hole	19.05	12.7	.2997	8	2.60
Total					118.3

[1]Six 60° wedges, 15-inch OD providing HEU equivalent to one solid 15-inch OD disk.
[2]One 6-inch OD piece plus one 15-inch OD, 6-inch ID disk providing HEU equivalent to one solid 15-inch OD disk.

The number of available Jemima plates will be a limiting factor in design of the TEX-Hf experiments. The inventory for the 15" plates can be seen in Table I. The total HEU mass available in the 15-inch OD Jemima plates is 118.3 kg. Experimental configurations requiring more this will not be practical unless additional Jemima plates or pieces are fabricated.

Methodology

Using an optimized Hf thickness of 0.10 cm and real HEU Jemima plate inventory, feasibility calculations using KENO V.a in the SCALE 6.1 package confirmed that even with the holes in plates, critical configurations could be achieved. Continuous energy ENDF/B-VII cross sections (ce_v7_endf) were used in all KENO V.a calculations. To confirm KENO V.a calculations, MCNP5 Version 1.60 was used, with continuous energy ENDF7.1 cross sections.

The standard model, as seen in Figure 2, has a repeating structure of PE, Hf, and Jemima plates. The solid disk Jemima plates are to be concentrated in the center of the stack in order to concentrate as much of the fissile mass in the center of the stack.

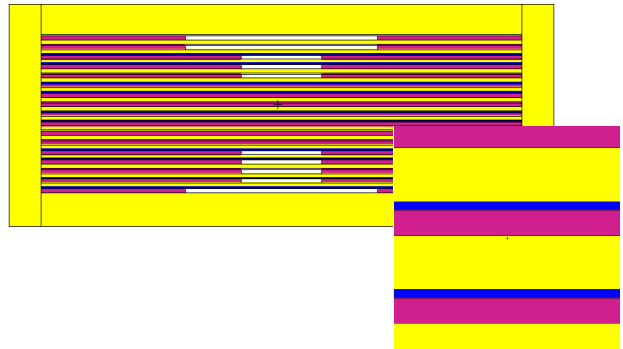

Fig. 2: Example of standard Stacking Model (left) using real Jemima plates (pink), Hf (blue) as a diluent and PE (yellow) as moderator and reflector.

The sandwich model, as seen in Figure 3, utilizes PE of half thickness with a repeating structure of PE, Hf, PE, and Jemima plate.

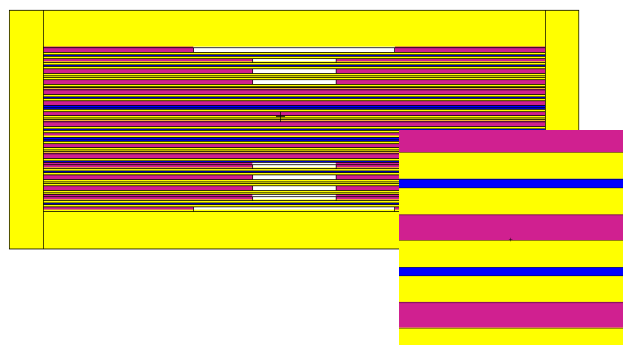

Fig. 3: Example of standard Sandwich Model using real Jemima plates (pink), Hf (blue) as a diluent and PE (yellow) as moderator and reflector

The polyethylene thickness of stacks varied from 0" to 1 ¼" (3.175 cm). Both stacking models were modeled with a one inch reflector around the stack as well as a one inch reflector above and below the stack.

RESULTS

Feasibility Results

In order to ensure experiments span a large range of energies fission fractions are recorded in Tables II and III. The percentage of fissions for each of the 3 energy groups was tallied: thermal (10^{-5} eV - 0.625 eV), intermediate (0.625 eV-100 keV), and fast (100 keV-10 MeV) energies. Thermal, intermediate, and fast fission fractions are defined as the fractions of fissions attributed to thermal, intermediate and fast neutron energy groups respectively and the sum of these fractions equals 1.0 for each configuration.

Both the standard and the sandwich stacking configurations have similar trends, with a lot of fast fissions occurring with little to no PE moderation, intermediate fissions dominating with small amounts of moderation. While trends are similar for the fast and intermediate fissions, different trends are seen in the more moderated cases.

Table III: Fission Fractions for 0.10 cm Hf and Real Jemima Plates over Various PE Thicknesses (Standard Stacking)

PE (in)	Fast	Inter	Therm
0	**0.7919**	0.1629	0.045
1/16	**0.5399**	0.4041	0.0554
1/8	0.4285	**0.5008**	0.0709
1/4	0.3134	**0.5467**	0.1395
1/2	0.2169	0.4872	0.2954
3/4	0.1753	0.4097	0.4142
1	0.152	0.3525	0.4952
1 1/8	0.1453	0.3314	**0.5231**
1 1/4	0.1403	0.3129	**0.5472**

Important to note here is the fact that thermal fission fraction for both 1 1/8" and 1 ¼" PE plates both reach over the 50% threshold for a thermal experiment. Also, only the standard case includes the fastest case with no PE because the configurations were identical without PE for the Hf to sandwich.

Table IV: Fission Fractions for 0.10 cm Hf and Real Jemima Plates over Various PE Thicknesses (Sandwich Stacking)

	Fast	Inter	Therm
1/16	**0.5296**	0.4037	0.0666
1/8	0.4204	**0.5018**	0.0784
1/4	0.3118	**0.5647**	0.124
1/2	0.2191	**0.5386**	0.2427
3/4	0.1787	0.4764	0.3442
1	0.1573	0.4209	0.4213
1 1/4	0.1434	0.3782	0.4788

At the highest amounts of PE in the standard case, thermal cases with at least 50% fission occur at thicknesses above 1 inch. It is notable that even at 1 ¼" PE, the sandwich configuration will not make a thermal case, with less than 50% of fissions occurring in the thermal range. Further study on a case with 1 5/8" PE in the sandwich stacking case does not go critical with current HEU material inventory, therefore a thermal case with sandwich stacking cannot be attained with current limited HEU material inventory.

Conclusions

These calculations focused on the feasibility of the TEX-Hf configurations using the real inventory. The KENO V.a calculations presented in this preliminary design demonstrate that it is feasible to meet the TEX goal of creating critical assemblies with the Jemima plates, polyethylene, and hafnium that spans all three fission energy ranges. This experiment will help us acquire greater data information on both HEU and Hf throughout a range of energies.

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Prepared by LLNL under Contract DE-AC52-07NA27344.