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Graphite and Beryllium Reflected Critical Assemblies of UO_2 (Benchmark Experiments 2 and 3)

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INTRODUCTION

A series of experiments was carried out in 1962-65 at the Oak Ridge National Laboratory Critical Experiments Facility (ORCEF) for use in space reactor research programs. A core containing 93.2 wt% enriched UO_2 fuel rods was used in these experiments. The first part of the experimental series consisted of 252 tightly-packed fuel rods (1.27-cm triangular pitch) with graphite reflectors [1], the second part used 252 graphite-reflected fuel rods organized in a 1.506-cm triangular-pitch array [2], and the final part of the experimental series consisted of 253 beryllium-reflected fuel rods in a 1.506-cm-triangular-pitch configuration and in a configuration comprised of fuel-tube clusters [3]. Fission rate distribution and cadmium ratio measurements were taken for all three parts of the experimental series. Reactivity coefficient measurements were taken for various materials placed in the beryllium reflected core.

All three experiments in the series have been evaluated for inclusion in the International Reactor Physics Experiment Evaluation Project (IRPhEP) [4] and the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbooks [5]. The evaluation of the first experiment in the series was discussed at the 2011 ANS Winter meeting [6]. The evaluations of the second and third experiments are discussed below. These experiments are of interest as benchmarks because they support the validation of current compact reactor designs with similar characteristics to the design parameters for a space nuclear fission surface power systems [7].

DESCRIPTION OF THE ACTUAL WORK

The experiments were assembled in the east cell of the ORCEF on a vertical assembly machine. All experiments used the same fuel tubes. Each fuel tube was 30.48-cm-long with a 0.051-cm-thick stainless steel 347 clad (1.27 OD). The fuel region of each rod contained 26 1.141-cm-diameter UO_2 pellets with a total length of 29.88 cm. The second part of the experimental series used graphite reflectors while the third used beryllium reflectors.

Experiment Two

The second experiment in the series had only one critical configuration that had an array of 252 fuel tubes in a 1.506-cm triangular pitch; the center fuel tube was removed in the critical configuration. The graphite reflector size was varied to achieve a critical configuration. The core was positioned on top of a 22.86-cm-thick, 25.42-cm-diameter bottom axial reflector and was lifted up into the cavity formed by the radial and top axial reflectors, which each had an upper and lower section. The critical configuration was examined and is summarized in Table I and shown in Fig. 1.

Table I. Experiment Two Reflector Dimensions

Configuration	Lower Section	Upper Section
Side Reflector		
Thickness (cm)	27.9	25.53
Inside Diameter (cm)	26.135	26.135
Height (cm)	46.63	7.63
Top Reflector		
Height (cm)	15.25	8.36
Diameter (cm)	76.2	50.8

Experiment Three

The third experiment in the series had two configurations. The first configuration had 253 fuel tubes arranged in a 1.506-cm-triangular-pitch array. The second configuration arranged the 253 fuel tubes in seven-tube clusters. The beryllium reflector was the same for both configurations. The bottom and top beryllium reflectors were made of 7.303- and 3.647-cm-square blocks arranged in a nearly cylindrical shape. The side reflector was an annulus. The dimensions of the reflectors, with the nominal diameter given for the top and bottom reflectors, are given in Table II and shown in Fig. 2.

Table II. Experiment Three Reflector Dimensions

Side Reflector	
Thickness (cm)	11.37
Inside Diameter (cm)	26.16
Height (cm)	30.63
Bottom Reflector	
Height (cm)	7.62
Nominal Diameter (cm)	41.3
Top Reflector	
Height (cm)	6.985
Nominal Diameter (cm)	41.3

Benchmark Evaluation

For the benchmark evaluation of the critical configurations, detailed and simple benchmark models were created. A bias analysis was completed to determine the benchmark k_{eff} due to model simplifications. Simplifications include the removal of the surroundings (i.e. room-return effects); modeling simplifications; homogenization of the bottom, side, and top reflectors; homogenization of fuel with the void region within rods; and removal of impurities.

An uncertainty analysis was completed for all measured dimensions and parameters. The investigated uncertainties include composition, mass measurement, and dimensional uncertainties. Each parameter studied was perturbed above and below the base value. The uncertainty effect on k_{eff} was half the difference between the upper and lower perturbed eigenvalues.

The benchmark models were then used to compute worth measurements and fission-rate and cadmium ratio distributions; the results were then compared to those that were experimentally measured.

RESULTS AND CONCLUSIONS

Calculations were performed using Monte Carlo n-Particle version 5-1.60 (MCNP5) [8]. The simplification bias for Experiment 2 was -42 and -216 pcm for the detailed and simple benchmark models, respectively. For Experiment 3, Configuration 1 the detailed and simple model simplification biases were -21 and -171 pcm, and -82 and -197 pcm for Configuration 2, respectively.

For Experiment 2 the total experimental uncertainty was 59 pcm. The largest contributor to the total uncertainty was due to the uncertainty in the reflector dimensions. For Experiment 3 the total uncertainty was 66 and 60 pcm for Configuration 1 and 2, respectively. The largest contributor to the total uncertainty was due to the uncertainty in the composition of the top and bottom reflectors.

Sample calculations for the simple benchmark models using ENDF/B-VII.0 cross-section libraries [9] are given in Table III along with the benchmark k_{eff} and uncertainty.

Table III. Simple Benchmark Model Calculation Results

Experiment 2		
Benchmark k_{eff} Benchmark uncertainty	0.9978 [(b)] ± 0.0007	
Sample Calculation[(a)] (MCNP5 ENDF/B-VII.0)	1.0008 ± 0.00002	
Experiment 3		
Configuration	1	2
Benchmark k_{eff} Benchmark uncertainty	0.9989[(b)] ±0.0009	0.9998[(b)] ±0.0008
Sample Calculation[(a)] (MCNP5 ENDF/B-VII.0)	0.9930 ±0.00006	0.9947 ±0.00006

(a) Results obtained using 1,000,000 histories for 2150 cycles, skipping the first 150 cycles.
(b) Benchmark k_{eff} derived using as built model and simplified model to determine simplification bias. Bias was applied to experimental k_{eff}.

It was determined that these experiments are acceptable for use as criticality safety benchmark experiments. Detailed results of these evaluations will be included in the IRPhEP and ICSBEP Handbooks.

REFERENCES

1. J. T. MIHALCZO, "A Small Graphite-Reflected UO_2 Critical Assembly," ORNL-TM-450, Oak Ridge National Laboratory (1962).

2. J. T. MIHALCZO, "A Small Graphite-Reflected UO_2 Critical Assembly, Part II," ORNL-TM-561, Oak Ridge National Laboratory (1963).

3. J. T. MIHALCZO, "A Small Beryllium-Reflected UO_2 Assembly," ORNL-TM-655, Oak Ridge National Laboratory (1963).

4. *International Handbook of Evaluated Reactor Physics Benchmark Experiments*, NEA/NSC/DOC(2006)1, OECD-NEA, Paris (2012).

5. *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2012).

6. M.A. MARSHALL, J.D. BESS, "Benchmarking of Graphite Reflected Critical Assemblies of UO_2," *Trans. Am. Nucl. Soc.*, **105**, 881-882.

7. J. R. PARRY, J. D. BESS, B. T. REARDEN, G. A. HARMS, "Assessment of Zero Power Critical Experiments and Needs for a Fission Surface Power System," INL/EXT-08-14678, Idaho National Laboratory (2008).

8. F. B. BROWN, et al., "MCNP Version 5," LA-UR-02-3935, Los Alamos National Laboratory (2002).

9. M. B. CHADWICK, et al., "ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology," *Nucl. Data Sheets*, **107**, 2931 (2006).

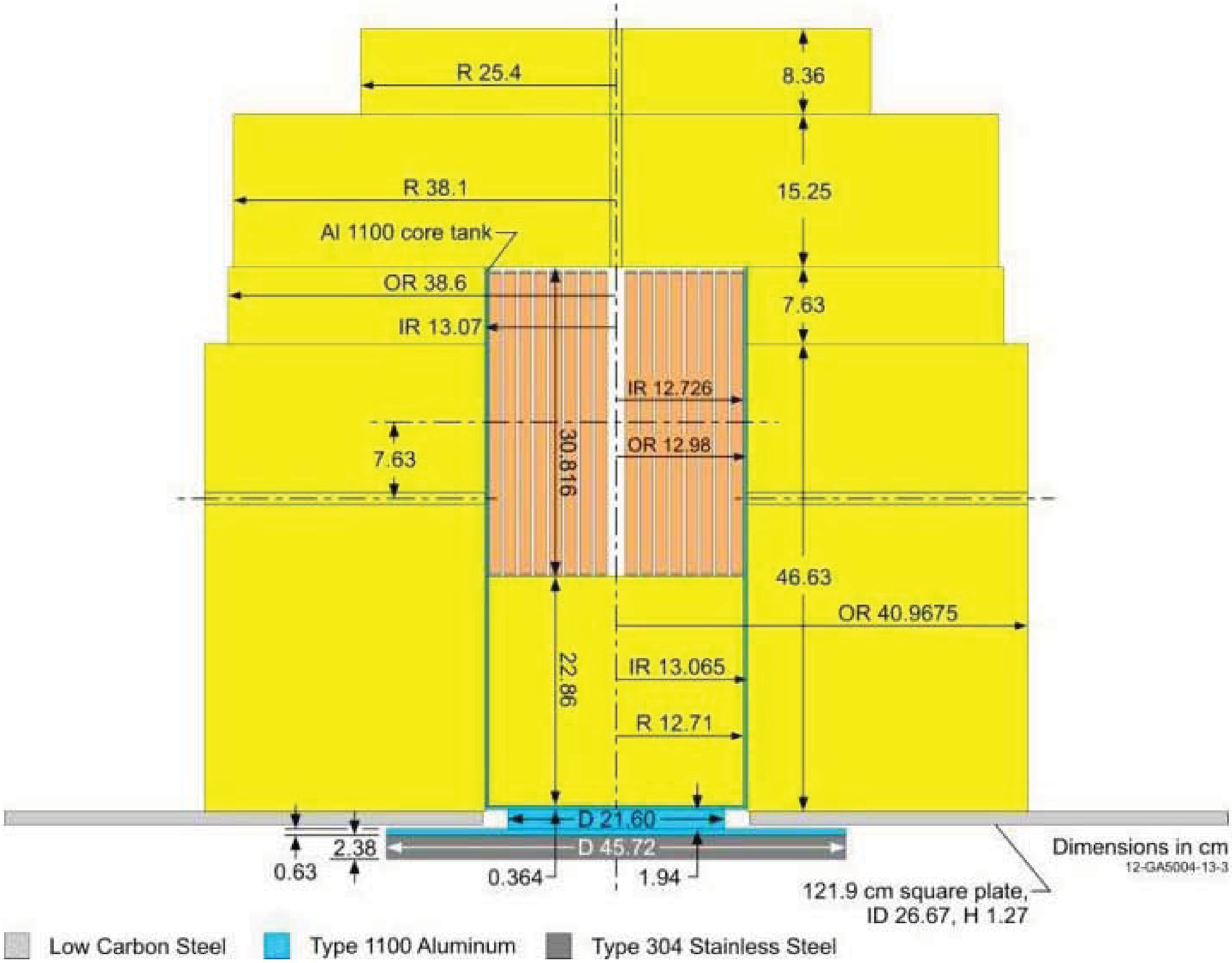

Fig. 1. Experiment 2, Detailed Benchmark Model.

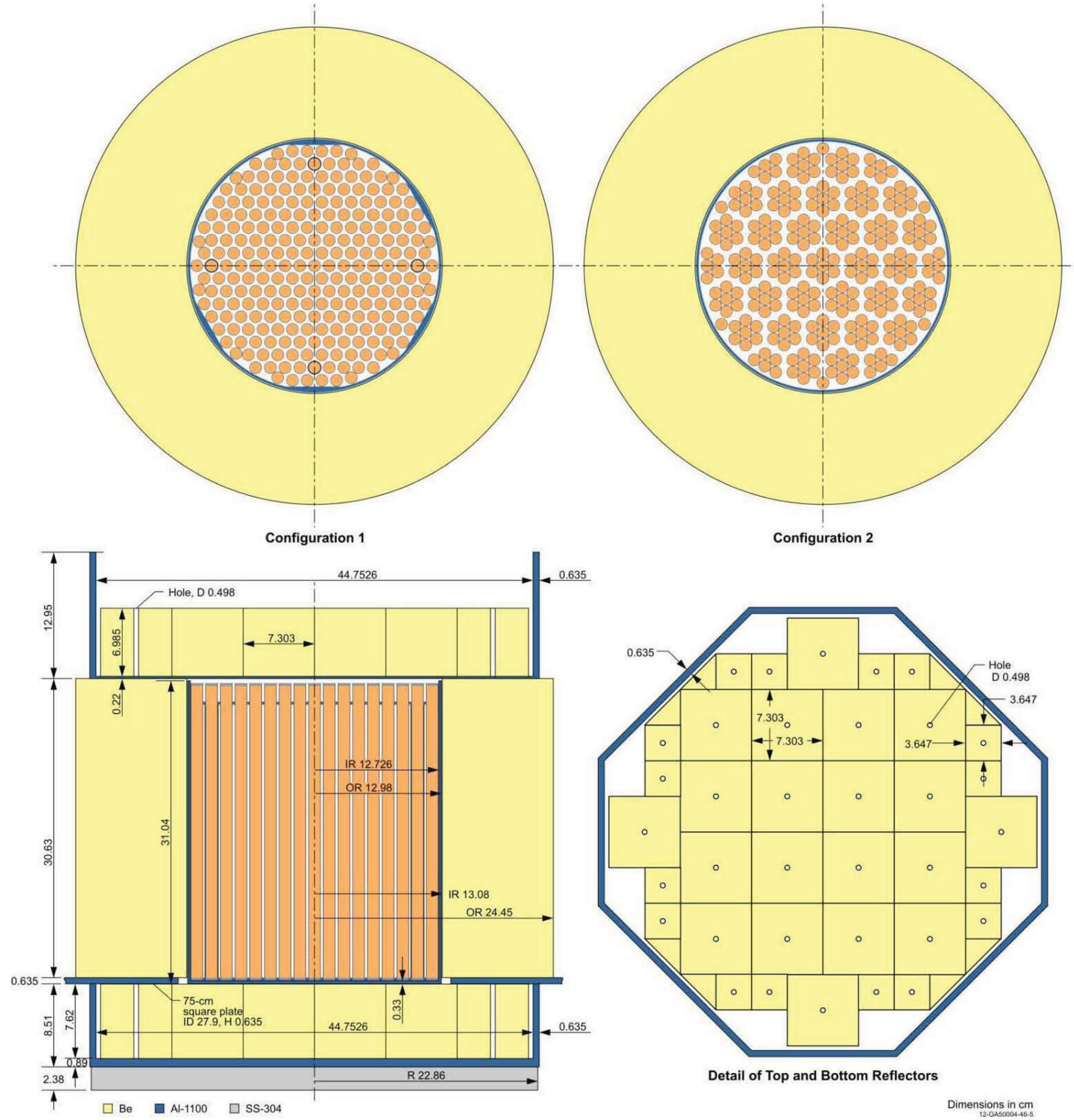

Fig. 2. Experiment 3, Detailed Benchmark Model.