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Benchmarking of Graphite Reflected Critical Assemblies of UO_2

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INTRODUCTION

A series of experiments was carried out in 1963 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 253 tightly-packed fuel rods (1.27-cm triangular pitch) with graphite reflectors [1], the second part used 253 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 with a 1.506-cm triangular pitch [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.

The first part of this experimental series has 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] and is discussed below. These experiments are of interest as benchmarks because they support the validation of compact reactor designs with similar characteristics to the design parameters for a space nuclear fission surface power systems [6].

DESCRIPTION OF THE ACTUAL WORK

The experiment was assembled in the east cell of the ORCEF on a vertical assembly machine. The core was positioned on top of a 15.24-cm-thick, 22.87-cm-diameter bottom axial reflector and was lifted up into the cavity formed by the radial and top axial reflectors. Two different critical configurations of reflectors were examined and are summarized in Table I.

Table I. Reflector Dimensions

Configuration	1	2
Side Reflector		
Thickness (cm)	19.25	24.34
Inside Diameter (cm)	23.07	23.07
Length (cm)	46.63	46.63
Top Reflector		
Thickness (cm)	12.70	5.08
Diameter (cm)	50.80	50.80

The core consisted of 253 tightly-packed fuel rods in an aluminum 1100 can with an outside diameter of 22.87 cm and a wall thickness of 0.29 cm. Aluminum shims were used around the core tank to keep the fuel rods tightly packed. Each fuel rod 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.

For the benchmark evaluation, a detailed model of each configuration was created. A bias analysis was completed to determine the benchmark k_{eff} value of a simple model. Simplifications include the removal of the surroundings (i.e. room-return effects); homogenization of the graphite mass over 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 one half the difference between the upper and lower k_{eff}. The benchmark models were then used to compute fission-rate and cadmium ratio distributions; the results were then compared to those that were experimentally measured.

RESULTS AND CONCLUSIONS

All models were run using Monte Carlo n-Particle version 5 (MCNP5) [7]. It was found that the benchmark models had a simplification bias of -741 ± 8 pcm for Configuration 1 and -738 ± 8 pcm for Configuration 2. The total uncertainty for Configuration 1 and 2 is 295 pcm and 291 pcm, respectively. The maximum uncertainty was due to uncertainty in the fuel rod outer diameter (~290 pcm), which affected the pitch of the tightly-packed fuel rods. Sample calculation results using ENDF/B-VII.0 cross-section libraries [8] are given in Table II along with the benchmark k_{eff} and uncertainty. The sample calculation results are approximately 0.4% above the benchmark k_{eff}. The reason for this difference is unknown; however, the sample results are within 2σ of the benchmark values.

Table II. Benchmark and Sample Calculation Results

Configuration	1	2
Benchmark k_{eff} Benchmark uncertainty	0.99238 ± 0.00293	0.99250 ± 0.00289
Sample Calculation[(a)] (MCNP5 ENDF/B-VII.0)	0.99690 ± 0.00005	0.99715 ± 0.00006

(a) 2000 cycles with 100,000 histories per cycle were run dropping the first 150 cycles.

It was determined that these experiments are acceptable for use as criticality safety benchmark experiments. The results of this evaluation will be included in the IRPhEP and ICSBEP Handbooks. Future work includes the evaluation of the second and third experiments in the experimental series.

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