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Abstract. A series of small, compact critical assembly (SCCA) experiments were performed in 1962-1965 at the Oak Ridge National Laboratory Critical Experiments Facility (ORCEF) for the Medium-Power Reactor Experiment (MPRE) program. The MPRE was a stainless-steel clad, highly enriched uranium (HEU)-O_2 fuelled, BeO reflected reactor design to provide electrical power to space vehicles. Cooling and heat transfer were to be achieved by boiling potassium in the reactor core and passing vapor directly through a turbine. Graphite- and beryllium-reflected assemblies were constructed at ORCEF to verify the critical mass, power distribution, and other reactor physics measurements needed to validate reactor calculations and reactor physics methods. The experimental series was broken into three parts, with the third portion of the experiments using a beryllium-reflected system. The latter experiments are of interest for validating current reactor design efforts for a fission surface power reactor. The graphite experiments have been evaluated as acceptable benchmark experiments and submitted for publication in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* and in the *International Handbook of Evaluated Reactor Physics Benchmark Experiments*. Evaluation of the beryllium-reflected experimental data is currently in progress.

Keywords: Benchmark, critical experiment, MPRE, reactor, SCCA.

INTRODUCTION

A series of critical experiments was performed at the Oak Ridge Critical Experiments Facility (ORCEF) in 1962-1965 to support the Medium Power Reactor Experiment (MPRE) space reactor design.[1] These small, compact critical assembly (SCCA) experiments were graphite- or beryllium-reflected assemblies of stainless-steel-clad, highly enriched uranium (HEU)-O_2 fuel on a vertical lift machine.[2-4] The delayed critical experiments were a mockup of a small, potassium-cooled space power reactor designed to provide electrical power for space vehicles. Cooling and heat transfer for the 1 MWt (140 kWe) MPRE was to be achieved via boiling potassium in the reactor core passed as vapor directly through a turbine to generate electricity. The critical assemblies were designed to verify the critical mass, power distribution, and other reactor physics measurements necessary to validate reactor calculations and reactor physics methods. A three-part experimental series, yielding five unique critical configurations, was performed, with the third portion comprised of beryllium-reflected measurements. The latter configurations are of interest for validating current reactor design efforts for a fission surface power (FSP) reactor.[5-6] All five configurations were evaluated as benchmarks for inclusion in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* (ICSBEP Handbook)[7] and the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* (IRPhEP Handbook).[8]

DESCRIPTION OF EXPERIMENTS

The core of the experiments contained either 252 or 253 SS-clad UO_2 fuel rods (26 fuel pellets apiece) enriched to 93.15 wt.% ^{235}U. The first part of the three-part experimental series included two graphite-reflected tightly-packed arrays (1.27-cm triangular pitch).[2] The second part of the series consisted of a single graphite-reflected critical assembly with a 1.506-cm triangular-pitch array.[3] The third set of experiments consisted of two beryllium-reflected arrays, one with a triangular pitch of 1.506 cm, and the other comprised of multiple seven-rod fuel clusters.[4] Additional measurements such as fission-rate distributions, cadmium-ratio distributions, and material worths were also performed on the various assemblies. Figure 1 shows both a graphite and a beryllium reflected configuration with the vertical assembly machine in a lowered position.

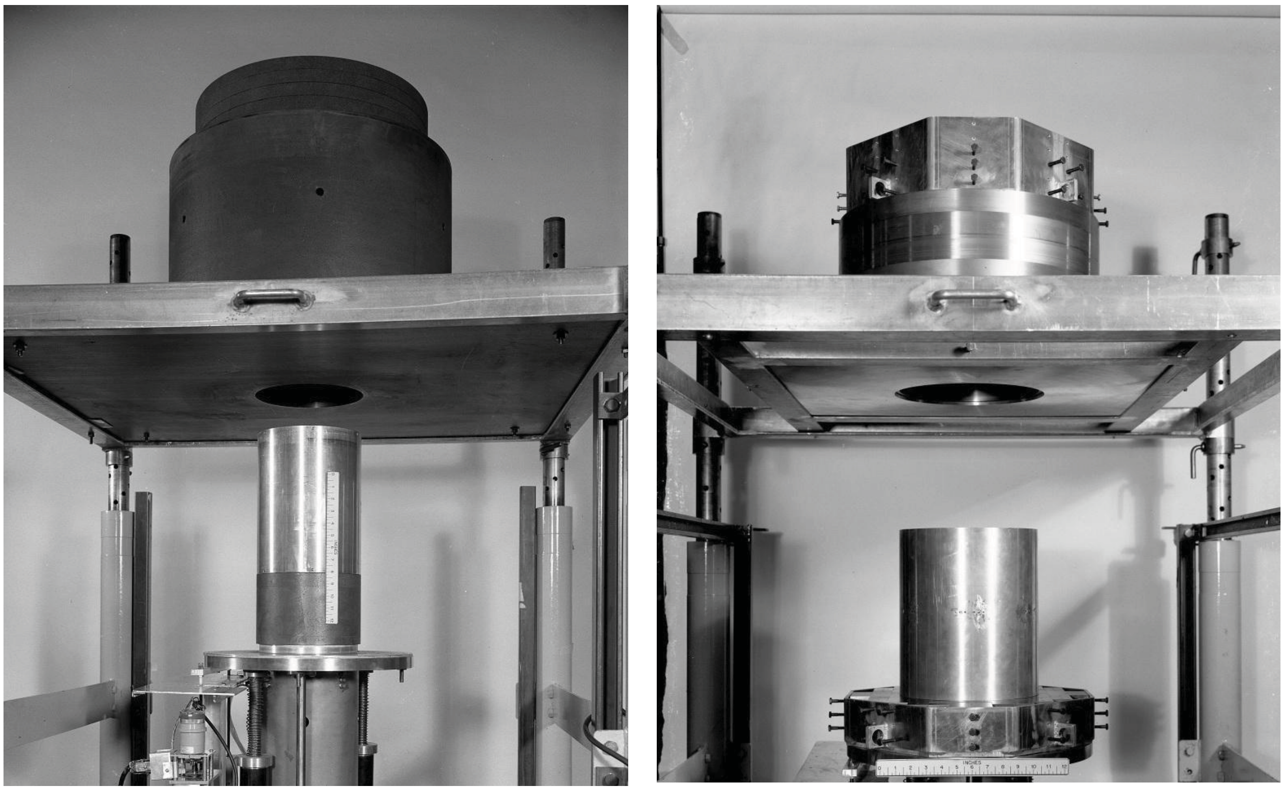

FIGURE 1. Graphite- (left) and Beryllium- (right) Reflected SCCA Experiments.

BENCHMARK EVALUATION

Detailed analyses and discussions of the benchmark evaluation of these experiments are contained elsewhere with the identifiers of HEU-COMP-FAST-001, -002, and -004 for the critical configurations in the ICSBEP Handbook,[7] and the identifiers of SCCA-SPACE-EXP-001, -002, and -003 in the IRPhEP Handbook.[8]

Benchmark Model Development

Both detailed and simple benchmark models were developed to evaluate the uncertainty and measurements in the SCCA experiments. Biases, with associated uncertainties, were explicitly quantified for both models compared against the as-built experimental configuration. The simple benchmark model for the third graphite-reflected experiment is shown in Figure 2; the detailed benchmark models for the two beryllium-reflected experiments are shown in Figure 3. The detailed benchmark models were used to evaluate the reactor physics measurements performed on each critical assembly. The graphite-reflected assemblies include radial and axial fission-rate distributions, radial cadium-ratio distributions, the worth of plugs removed from the radial reflector, and the worth of the center fuel rod. The beryllium-reflected assemblies include radial and axial fission-rate distributions, radial cadmium-ratio distributions, the reactivity worth of removing a single fuel rod from various radial positions within the core, reactivity coefficients for the introduction of various neutron moderator or absorber materials, and the impact on reactivity for the addition of potassium to a calandria-type core vessel.

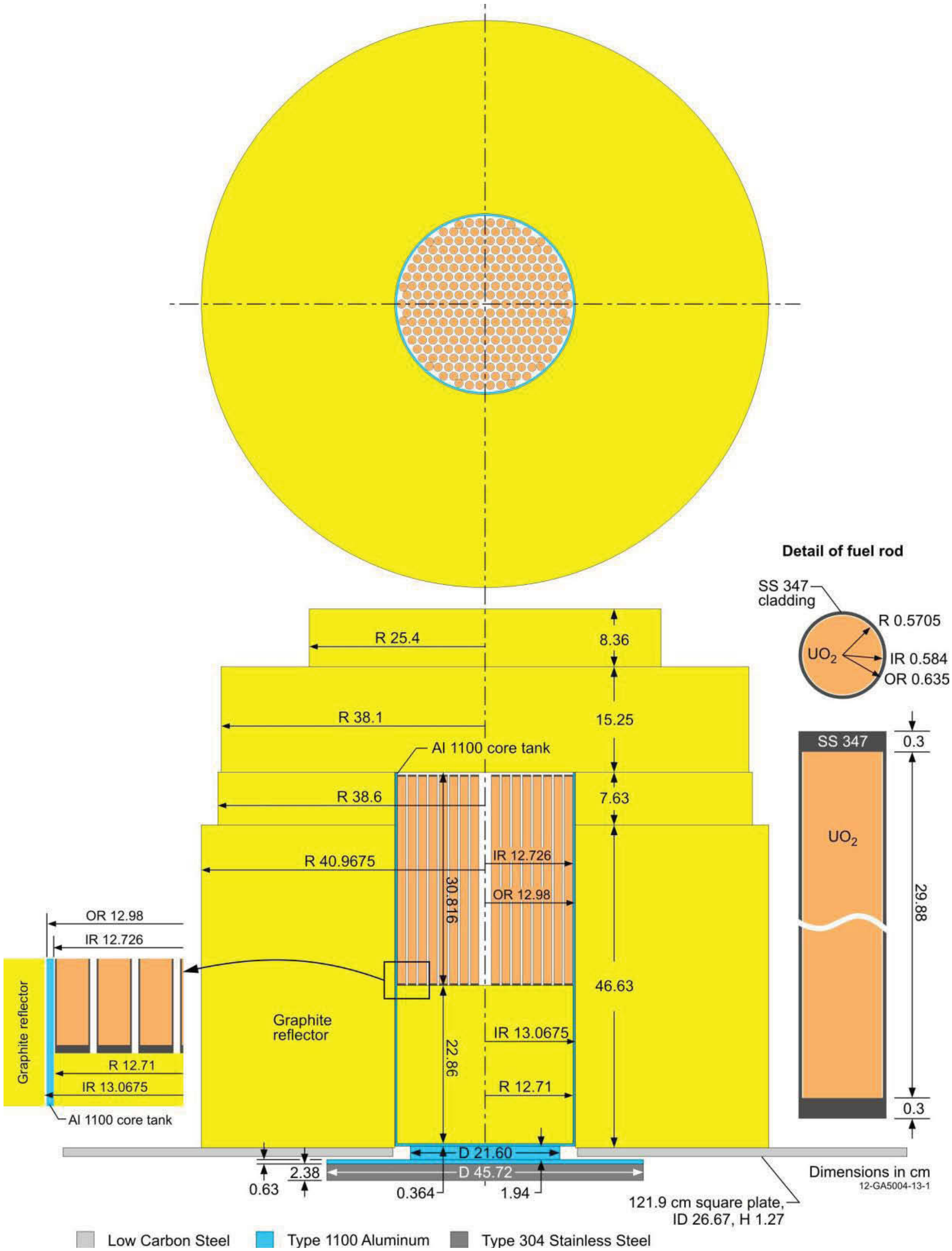

FIGURE 2. Simple Benchmark Model for the Third Graphite-Reflected SCCA Experiment.

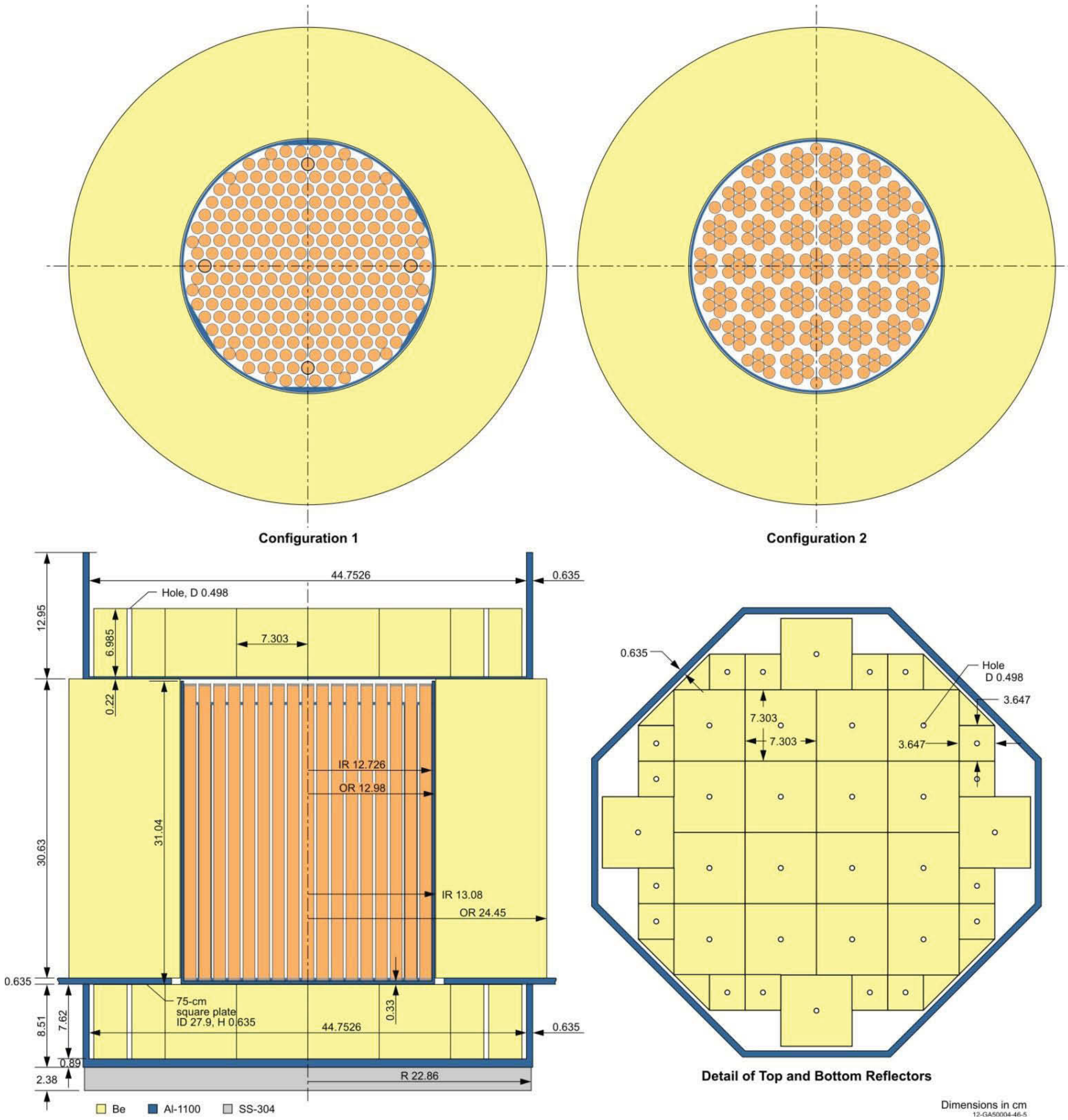

FIGURE 3. Detailed Benchmark Configurations of the Two Beryllium-Reflected SCCA Experiments.

Uncertainty Analysis

It should be noted that there were very precise measurements of the dimensions and physical properties of the materials used in these experiments, such that the uncertainties in many of the experimental components had a negligible effect, and the uncertainty is the reactivity worth measurement was of merit when computing the total uncertainty in the experiment. This is typical of many ORCEF experiments performed by John T. Mihalczo, especially for HEU metal critical experiments using the same vertical assembly machine.[9]

The majority of the uncertainty in the third graphite-reflected experiment and the two beryllium-reflected experiments comes from uncertainties in properties of the radial reflectors. Fuel rod parameters such as fuel tube diameter and fuel mass are important in the first two graphite-reflected experiments due to the close-packed condition of the core. As seen in Table 1, the total uncertainty in the benchmark models is quite small (less than 100 pcm or 0.1% δk_{eff}. Low-uncertainty benchmark experiments are useful for refining neutron cross section data.

TABLE 1. Summary of Calculations and Benchmark Analysis of the SCCA Experiments.

Benchmark Configuration	Model	Analysis Code	Neutron Cross Section Library	Calculated k_{eff}	±	1σ	Benchmark Experiment k_{eff}	±	1σ	$\frac{C-E}{E}$(%)
Graphite 1	Detailed	MCNP5	ENDF/B-VII.0	1.00551	±	0.00006	1.0005	±	0.0005	0.50
	Simple	MCNP5	ENDF/B-VII.0	1.00329	±	0.00002	0.9980	±	0.0007	0.53
		KENO-VI	ENDF/B-VII.0	1.00312	±	0.00006				0.51
Graphite 2	Detailed	MCNP5	ENDF/B-VII.0	1.00484	±	0.00006	1.0003	±	0.0005	0.46
	Simple	MCNP5	ENDF/B-VII.0	1.00465	±	0.00002	0.9997	±	0.0006	0.49
		KENO-VI	ENDF/B-VII.0	1.00442	±	0.00006				0.47
Graphite 3	Detailed	MCNP5	ENDF/B-VII.0	1.00180	±	0.00002	0.9996	±	0.0006	0.22
	Simple	MCNP5	ENDF/B-VII.0	1.00077	±	0.00002	0.9978	±	0.0006	0.22
		KENO-VI	ENDF/B-VII.0	1.00061	±	0.00009				0.28
Beryllium 1	Detailed	MCNP5	ENDF/B-VII.0	0.99435	±	0.00006	1.0003	±	0.0008	-0.60
	Simple	MCNP5	ENDF/B-VII.0	0.99293	±	0.00006	0.9989	±	0.0008	-0.60
		KENO-VI	ENDF/B-VII.0	0.99211	±	0.00009				-0.68
Beryllium 2	Detailed	MCNP5	ENDF/B-VII.0	0.99615	±	0.00006	1.0011	±	0.0008	-0.50
	Simple	MCNP5	ENDF/B-VII.0	0.99474	±	0.00006	0.9998	±	0.0008	-0.50
		KENO-VI	ENDF/B-VII.0	0.99422	±	0.00009				-0.56

CALCULATION RESULTS

A summary of the calculated results for these five benchmark configurations, compared against the benchmark eigenvalues, is shown in Table 1. Calculations were performed using Monte Carlo N-Particle (MCNP) version 5-1.60[10] with ENDF/B-VII.0 neutron cross section data.[11] Additional calculations using KENO-VI[12] and ENDF/B-VII.0 were also performed using the simple benchmark models, in preparation for sensitivity analysis calculations. Results from both Monte Carlo codes underpredict the benchmark eigenvalues for the beryllium-reflected configurations and overpredict for the graphite-reflected configurations using the same continuous-energy cross section library.

The analysis and calculation of the reactor physics measurements for these experiments are also discussed in more detail in the benchmark reports. Some examples are provided herein. The relative axial distribution of induced fissions within a uranium fission counter for the first graphite-reflected experiment is provided in Figure 4. There is good agreement between calculated (MCNP5 with ENDF/B-VII.0) and benchmark experiment values. The greatest deviation occurs at the bottom of the core region, where the deviation is less than 14%. The comparison of calculated and benchmark experiment values for the relative activation of ^{235}U foils in the radial reflector for the first graphite-reflected experiment is shown in Figure 5. Data points in Figure 5 are normalized to the peak value in Figure 4. The greatest difference between calculated and benchmark values is less than 11%. A comparison of cadmium-ratio measurements, distributed through the radial reflector of the third graphite-reflected experiment is shown in Figure 6. The difference between the calculated and benchmark values increases through the thickness of the radial reflector to a maximum difference of almost 16%.

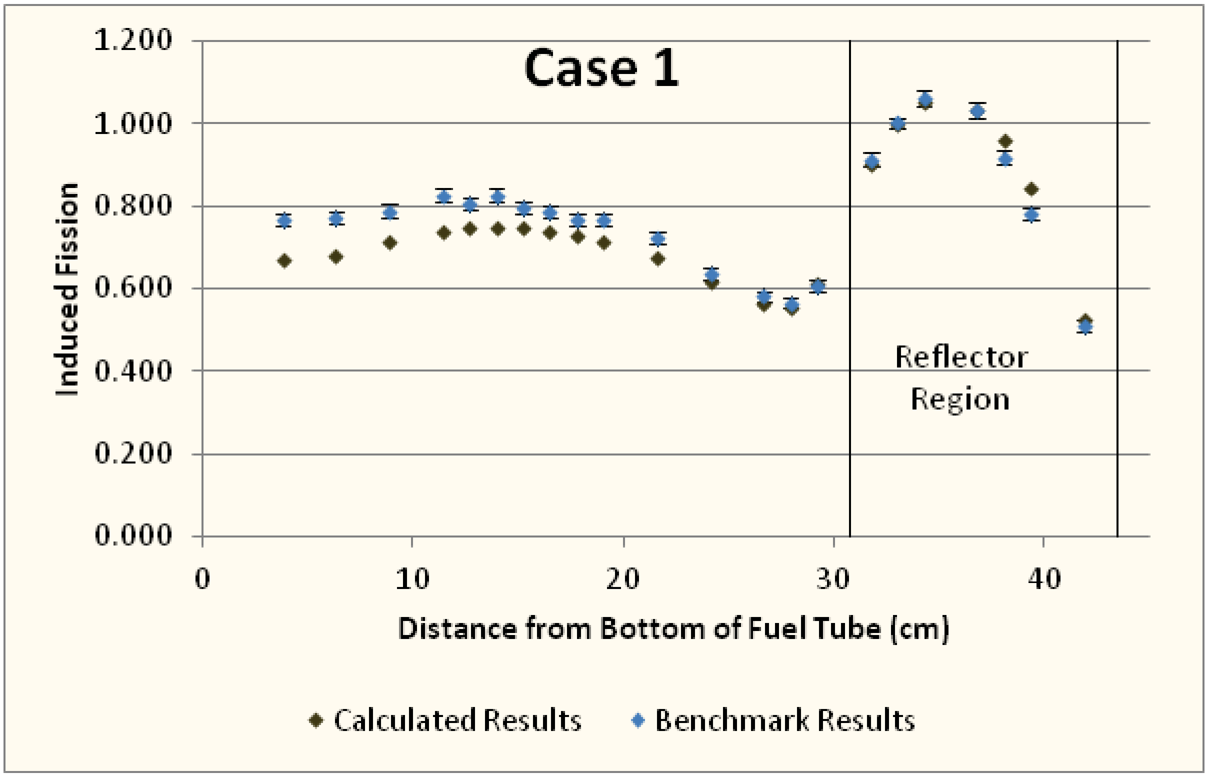

FIGURE 4. Relative Axial Uranium Fission Counter Count-Rate Distribution for First Graphite-Reflected SCCA Experiment.

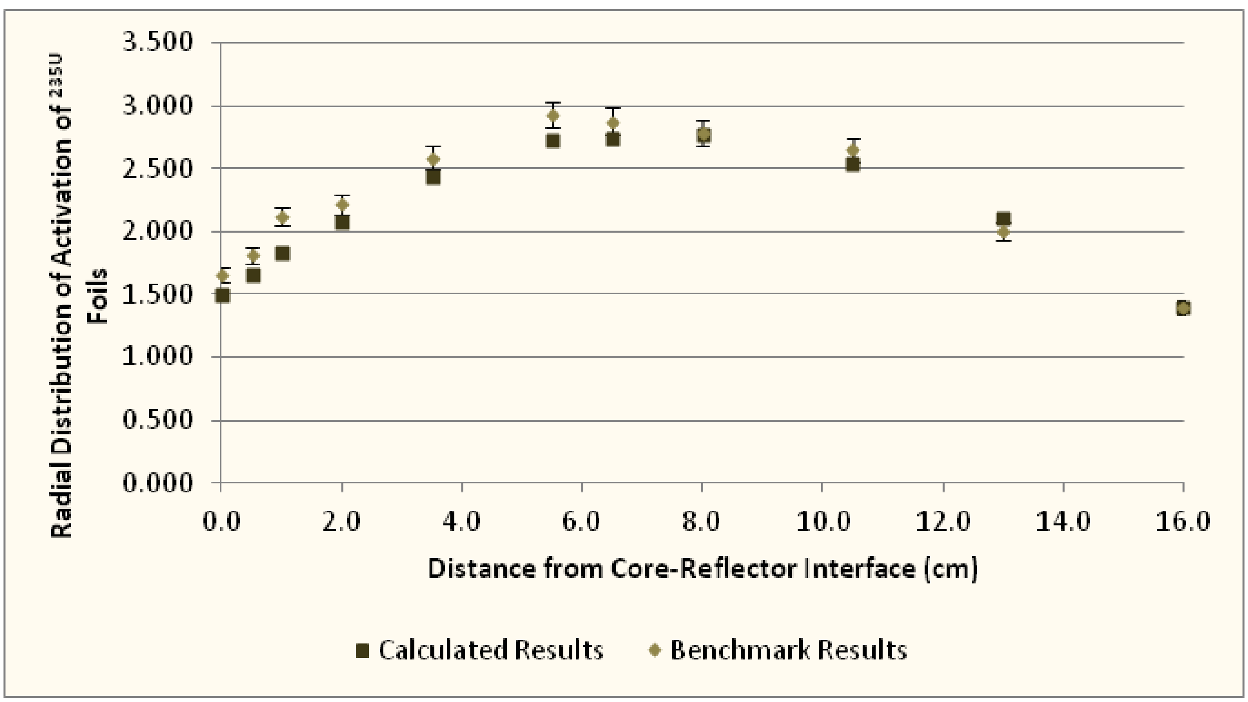

FIGURE 5. Relative Radial Distribution for Activation of ^{235}U Fission Foils for First Graphite-Reflected SCCA Experiment.

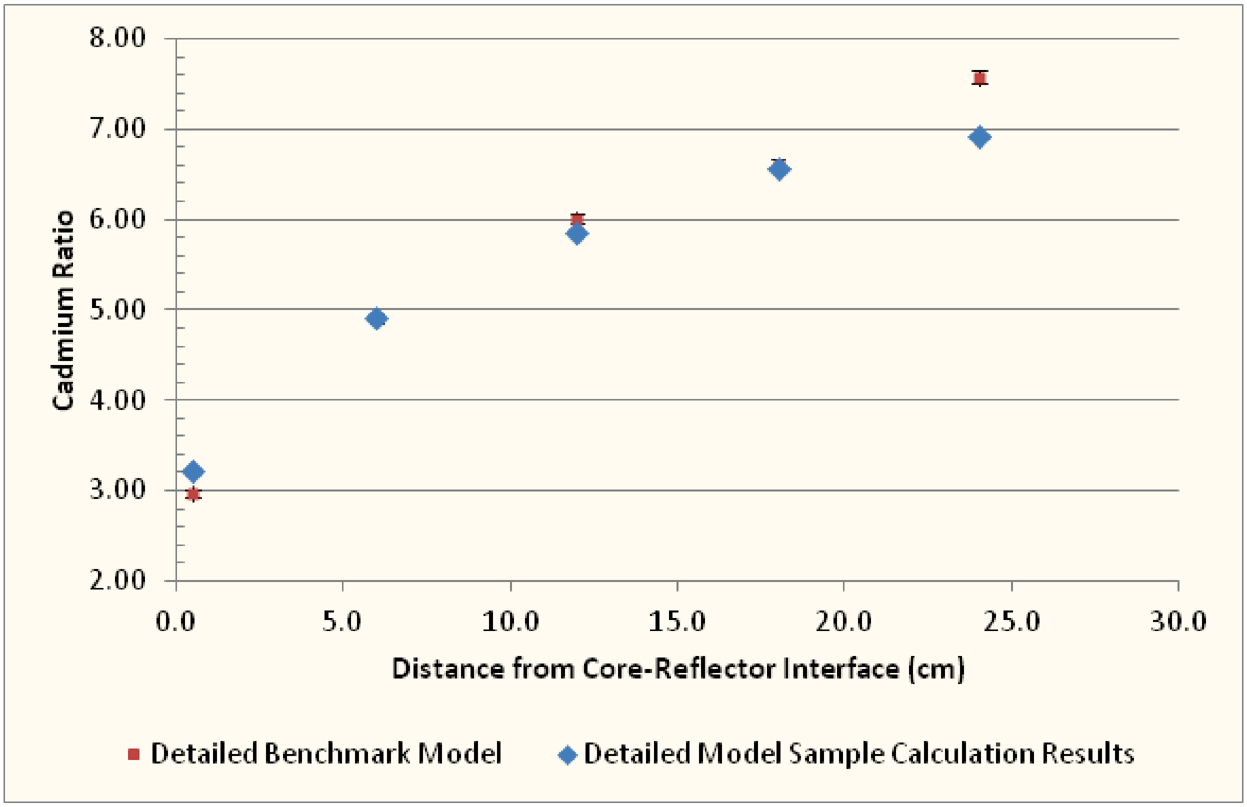

FIGURE 6. Cadmium Ratio Radial Distribution for the Third Graphite-Reflected SCCA Experiment.

Evaluation of the reactor physics measurements for the beryllium-reflected experiments is currently ongoing. They will be included as a revision to the SCCA-SPACE-EXP-003 evaluation in a subsequent release of the IRPhEP Handbook.

CONCLUSION

The series of SCCA experiments performed at ORCEF in the 1962-1965 to validate reactor calculations and reactor physics methods for the MPRE space reactor design have been evaluated as benchmark experiments and are available in the ICSBEP and IRPhEP Handbooks. These experiments, especially the beryllium-reflected SCCA configurations, are of merit today for the validation of current FSP reactor design. The low uncertainty in the experimental measurements is indicative of quality experiments that are useful for refining cross data used to analyze compact, fast-neutron-reflected reactors typically identified for use in space nuclear applications.

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