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Fissile Sample Worths in the Uranium/Iron Benchmark

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One of the long-standing problems from LMFBR critical experiments is the central worth discrepancy, the consistent overprediction of the reactivity associated with introducing a small material sample near the center of an assembly.[1] Reactivity (sample worth) experiments in ZPR-9, assembly 34, the Uranium/Iron Benchmark (U/Fe), were aimed at investigating this discrepancy.

U/Fe had a large, single-region core whose neutronics was governed almost entirely by ^{235}U and iron.[2,3] The essentially one-dimensional plate unit cell had one 1.6 mm-wide column of 93% enriched uranium (U(93)) near the center, imbedded in about 50 mm of iron and stainless steel. The neutron spectrum was roughly comparable to that of an LMFBR, but the adjoint spectrum was much flatter than an LMFBR's.

The worths of four different fissile materials were measured and the worth of U(93) was measured using several different experimental techniques. The four fissile materials were dominated (90 wt% or more) by ^{239}Pu, ^{241}Pu, ^{233}U and ^{235}U, respectively. They were measured with the radial tube pneumatic oscillator, which uses a steel tube installed through a 29 mm-diameter hole in the core. The U(93) worth was also determined using the axial drawer oscillator with the sample at three in-cell locations: transverse to the plates of the unit cell (cell-spanning), parallel to the plates adjacent to the fuel, and parallel at the cell edge. Unlike the radial tube, the drawer oscillator allows sample insertion with minimal distortion of the normal core environment. In addition to these small sample experiments, there were fuel-thickened zone worth experiments, in which U(93) foils were placed next to fuel throughout a central zone. In this experiment, rather than inferring worth from the reactor response to a small sample that is oscillated in and out of the assembly, the

U(93) worth was determined from the difference in assembly reactivity (measured by positive period) between the fuel-thickened and reference configurations.

The calculations used ENDF/B Version 4 cross section data (except for iron). The MCC2/SDX code system was used to generate 29 group effective cell-averaged cross sections for the assembly materials and detector cross sections for the samples.[4] These were used in RZ diffusion theory calculations. The fuel-thickening worths were determined from the eigenvalue difference between reference and fuel-thickened configurations, where reference and fuel-thickened cell-averaged cross sections were used in the appropriate regions. Small sample worths were calculated by first-order perturbation theory (FOP).

The C/Es presented here are about 5% lower than those obtained when ENDF/B Version 4 iron cross sections were used and processed in the traditional manner. There are three improvements in the adopted iron: 1) Version 5 iron is employed, 2) ^{57}Fe is included, which is missing from ENDF/B iron, and 3) elastic scattering resonance structure above the ENDF/B resonance range cutoff is self shielded.[2]

Initial results are shown in Table 1. The most important feature is that the ratio of calculated to experimental worth (C/E) is much lower for fuel thickening experiment than for all the other experiments. This difference led to recognition of the magnitude of an error in conventional FOP calculations.

Computation of the adjoint flux with homogenized cross sections that are produced by the conventional real flux weighting procedure results in a several percent error in FOP calculations of $(k-k_0)/k$ for ZPR plate-type unit cells.[5] The conversion to inhours is affected as well, which impacts all worth calculations. The prescription of Ref. 5 was used to generate adjoint correction factors.

The adjoint-corrected (final) C/Es are shown in Table 1. There are a number of interesting results.

- The final C/E spread among experiments is 6%, down from the initial spread of 12%.

- The in-cell variation in U(93) worth is well predicted, but only when adjoint corrections are included.

- The radial tube does not appear to introduce unacceptable distortions of fissile worths in this assembly, since the difference between results, both experimental and C/E, from radial tube vs cell-spanning foil, is small.

- The worths of all four fissile material are computed with comparable accuracy.

The fissile worth C/Es from U/Fe are near unity. It was only by accounting for the effect of plate cell heterogeneity on the adjoint flux that the C/Es from the various types of experiments were brought into reasonable agreement. Even with adjoint corrections, the projected fissile worth C/Es from LMFBR-type assemblies are significantly larger than those from the two uranium-fueled diagnostic cores, U/Fe and U9.[6] The remainder of the problem is being pursued by 1) analyzing the remaining data from the diagnostic cores program,[7] 2) refining analysis techniques, 3) re-evaluating LMFBR critical experiment data and calculations, and 4) performing diagnostic-type experiments in the current ZPPR assembly.

References

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