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KENO V.a VALIDATION OF FUEL PIN EXPERIMENTS*

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This paper describes the results of computations performed on a set of critical experiments designed to simulate high-density storage of reactor fuel pins. The purpose of these computations is to validate the Monte Carlo criticality code KENO V.a[1] with the four cross-section libraries provided with the SCALE[2] modular code system. This work was sponsored by the DOE Office of Civilian Radioactive Waste Management.

A series of 21 critical experiments,[3] performed by the Babcock & Wilcox Company to simulate close-packed fuel-pin storage, were modeled. The CSAS4 control module within SCALE was used to calculate the effective neutron multiplication factor (k_{eff}) via the KENO V.a criticality code. The experiments consisted of 5 x 5 arrays of fuel-pin modules each about 19 cm square. Three different module types were utilized in the experiments such that the pin packing density ranged from slightly more dense than typical PWR fuel assemblies, to the most compact configuration possible. In order of decreasing packing density, the fuel-pins in each module were arranged as follows:

(a) T-type: 243 pins in triangular pitch with pins touching (forming an approximate 15 x 17 array of pins), spacing between modules ranged from about 1.86 cm to 3.39 cm;

(b) S-type: 221 pins in square pitch with pins touching (forming a 15 x 15 array of pins), spacing between modules at 1.778 cm; and

(c) SO-type: 165 pins in square pitch with pins on a 1.4097 cm pitch (forming a 13 x 13 array of pins), spacing between modules at 1.792 cm.

The four corner pin positions of each type module was an aluminum rod, to connect the top and bottom plates.

All experiments were conducted in a 274 cm (9 ft) diameter tank. Boric acid (H_3BO_3) was dissolved in the water moderator as a reactivity shim, such that each core configuration would initially be critical at a water height of about 145 cm, as measured from the bottom of the fuel. For each module configuration, the boric acid content was progressively reduced until the critical height of the moderator was about 100 cm. Table 1 gives the basic critical parameters (from ref. 3).

In addition to the normal detailed geometry description permitted by KENO V.a, each fuel pin was explicitly modeled, and identified such that Dancoff factors could be input for each unique pin position within each type module. The Dancoff factors are applied as part of the resonance data processing. They characterize the neutron transmission probabilities between the fuel pins in a heterogeneous lattice.

Table 2 presents the calculated k_{eff} of the 21 critical configurations of Table 1, using the four cross-section libraries available in SCALE: the Hansen-Roach 16 energy group, the ENDF/B-IV 27 energy group, the GAM-THERMOS 123 energy group, and the ENDF/B-IV 218 energy group libraries.

Earlier computations of these experiments[3] using KENO IV[4] with cell homogenized GAM-THERMOS cross sections, compare very well with these results, except for Experiment Nos. 2464 and 2472 (called Core II and Core III in ref. 3). The KENO IV results produced a trend, which progressively underpredicts k_{eff} as the module spacing increases; this trend has been observed in other similar experimental/calculational studies.[5] This trend is not observed in the present KENO V.a results for any of the four cross-section libraries. There are numerous explanations for the improved performance, including code improvements and cross-section processing improvements. However, no attempt has been made in this study to qualify or quantify these improvements, or lack of improvement for the ENDFB-IV based libraries. Other similar experimental programs have been identified to be modeled and calculated, as part of this validation effort. Only then can the improvements be truly assessed.

The principal conclusion drawn from this study is the satisfactory performance of the SCALE cross-section libraries in the analysis of systems containing consolidated light-water reactor fuel. As observed in previous studies, the ENDF/B-IV-based libraries undercalculate k_{eff} by 1 to 2% k, depending on the degree of neutron moderation.

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TABLE 1

EXPERIMENTS FROM B&W-1645-4

2.459% ENRICHED UO2 FUEL PINS IN TRIANGULAR (T-TYPE), SQUARE (S-TYPE), AND SQUARE OPEN (SO-TYPE) PIN LATTICES FORMING FUEL MODULES. THE FUEL MODULES ARE IN 5X5 ARRAYS, VARYING MODULE SPACING, BORON CONTENT OF WATER MODERATOR, AND WATER HEIGHT.

TOTAL NUMBER OF FUEL PINS IN T-TYPE MODULE EXPERIMENTS IS 6075
TOTAL NUMBER OF FUEL PINS IN S-TYPE MODULE EXPERIMENTS IS 5525
TOTAL NUMBER OF FUEL PINS IN SO-TYPE MODULE EXPERIMENTS IS 4125

B&W EXPERIMENT NO.	PIN PITCH TYPE	AVERAGE MODULE SPAC'NG (CM)	BORON CONC. (PPM)	CRIT HEIGHT (CM)	MODERATOR TEMP. (C)
2452	T	1.86	435	143.96	22.5
2453	T	1.86	426	137.85	23.5
2454	T	1.86	406	128.34	24.0
2455	T	1.86	383	119.57	22.5
2456	T	1.86	354	110.20	23.0
2457	T	1.86	335	104.82	23.0
2464	T	2.62	361	142.54	20.0
2472	T	3.39	121	145.64	18.5
2485	S	1.778	886	145.00	21.0
2486	S	1.778	871	137.79	21.0
2487	S	1.778	852	128.56	22.0
2488	S	1.778	834	122.95	21.0
2489	S	1.778	815	116.21	21.0
2490	S	1.778	781	108.20	22.0
2491	S	1.778	746	100.24	22.0
2500	SO	1.792	1156	144.85	22.5
2501	SO	1.792	1141	133.49	22.5
2502	SO	1.792	1123	125.19	23.0
2503	SO	1.792	1107	116.59	23.0
2504	SO	1.792	1093	111.47	23.0
2505	SO	1.792	1068	101.81	23.0

TABLE 2

B&W EXP'MT NO	HANSEN-ROACH (16 GROUP)	ENDF/B-IV (27 GROUP)	GAM-THERMOS (123 GROUP)	ENDF/B-IV (218 GROUP)
	K-EFF +/- SIGMA			
TRIANGULAR (T) PITCHED PIN MODULES				
2452	0.9944 0.0030	0.9763 0.0036	0.9918 0.0034	0.9795 0.0035
2453	0.9979 0.0029	0.9835 0.0033	0.9999 0.0034	0.9810 0.0038
2454	0.9972 0.0035	0.9793 0.0034	0.9969 0.0036	0.9819 0.0041
2455	0.9990 0.0038	0.9816 0.0036	0.9988 0.0035	0.9838 0.0037
2456	0.9986 0.0036	0.9828 0.0029	1.0170 0.0035	0.9760 0.0037
2457	1.0017 0.0034	0.9679 0.0038	1.0033 0.0035	0.9835 0.0035
AVG-T	0.9981	0.9786	1.0013	0.9810
2464	0.9978 0.0033	0.9750 0.0036	0.9915 0.0035	0.9783 0.0039
2472	1.0194 0.0037	0.9928 0.0038	0.9974 0.0035	1.0003 0.0039
SQUARE (S) PITCHED PIN MODULES				
2485	0.9911 0.0033	0.9735 0.0028	0.9953 0.0033	0.9850 0.0038
2486	0.9995 0.0036	0.9820 0.0033	0.9983 0.0030	0.9833 0.0037
2487	0.9991 0.0035	0.9772 0.0034	1.0023 0.0035	0.9773 0.0038
2488	0.9999 0.0035	0.9828 0.0035	0.9890 0.0035	0.9715 0.0038
2489	0.9954 0.0036	0.9837 0.0033	1.0005 0.0030	0.9847 0.0040
2490	1.0044 0.0036	0.9825 0.0033	0.9925 0.0038	0.9791 0.0038
2491	1.0036 0.0037	0.9754 0.0030	1.0020 0.0041	0.9862 0.0037
AVG-S	0.9990	0.9796	0.9971	0.9810
SQUARE-OPEN (SO) PITCHED PIN MODULES				
2500	1.0057 0.0028	0.9924 0.0030	1.0042 0.0030	0.9857 0.0028
2501	0.9975 0.0033	0.9844 0.0034	1.0006 0.0032	0.9930 0.0035
2502	0.9989 0.0039	0.9918 0.0039	0.9999 0.0034	0.9900 0.0039
2503	1.0063 0.0033	0.9831 0.0033	0.9997 0.0033	0.9947 0.0038
2504	1.0002 0.0034	0.9872 0.0028	1.0042 0.0031	0.9815 0.0038
2505	1.0055 0.0026	0.9843 0.0031	0.9920 0.0038	0.9829 0.0034
AVG-SO	1.0021	0.9872	1.0001	0.9880
TOTAL AVG.	1.0006	0.9819	0.9989	0.9837