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VALIDATION OF KENO-VI: A COMPARISON WITH HEXAGONAL LATTICE LIGHT-WATER-REACTOR CRITICAL EXPERIMENTS

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DISCLAIMER

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I. INTRODUCTION

The KENO-VI Monte Carlo code, released with Version 4.3 of the SCALE Code System[1], provides the capability to model more complex geometries than previously allowed by KENO-V.a. One significant improvement is the simplistic specification of hexprism unit cells and hexagonal arrays, an arduous task to complete in KENO-V.a.

This report documents the validation of KENO-VI against 30 critical experiments consisting of low-enriched uranium, light-water-reactor (LWR) fuel rods in hexagonal lattices with no poisons. The reference, enrichment, pitch, cladding, and core identification of the experiments are given in Table 1. The results indicate that KENO-VI accurately calculates these critical experiments, with a bias of -0.51% for the 238-group cross-section library and -0.24% for the 44-group cross-section library. If these biases are properly taken into account, the KENO-VI code can be used with confidence for the design and safety analysis of storage and transportation systems of similar LWR-type fuels.

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II. CALCULATIONS

The calculations were performed with the CSAS26 control module of the SCALE-4.3 Code System. CSAS26 invokes BONAMI and NITAWL for cross-section processing, and the Monte Carlo code KENO-VI for neutron multiplication factor determination. KENO-VI was run with the 238-fine-group and 44-broad-group cross-section libraries (ENDF/B-V), a cosine starting neutron distribution, 425 generations, skipping the initial 25, and 600 neutrons per generation for a total of 240,000 active histories. The *USLSTATS*[5] computer program was used to calculate upper subcritical limit (USL) correlations based on calculated k_{eff} values and corresponding values of a single associated parameter.

III. RESULTS

Figure 1 presents a scatter plot of k_{eff} as a function of the energy (eV) of the average lethargy causing fission (EALCF) for the 238-group calculations. A similar scatter plot was obtained for the 44-group library and, therefore, is not presented here. EALCF, a neutron spectral index, can be used as a single global parameter for correlating calculational biases to and for defining range of validation applicability (for systems of similar fissile species, pitch, enrichments, etc.). The EALCF is defined as

$$\mathrm{EXP}\left\{\frac{\sum_i F_i \dfrac{(lnE_i^U + lnE_i^L)}{2}}{\sum_i F_i}\right\} \qquad (1)$$

where E_i^U and E_i^L are the upper and lower energy boundaries of group *i* and F_i is the number of fissions in group *i*. In Figure 1, the average EALCF is 0.2438 eV, minimum is 0.0717 eV, and maximum is 0.8895 eV.

Presented in the figure is a linear-least-squares fit to the k_{eff} values, $k_c(x)$, and upper subcritical limits USL_1 and USL_2. The bias is defined as the difference between $k_c(x)$ and one. W represents a confidence band that accounts for uncertainties in experiments, the calculational approach, and in calculational data. W is determined at a 95% confidence level; therefore, for a **critical** system similar to those validated, one would expect to calculate above $k_c(x)$-W for a single future estimate of k_{eff} at 95% confidence. USL_1 is defined as $k_c(x)$-W minus an additional, arbitrary (in this case 5%) administrative margin and is given by

$$USL_1 = 0.9342 - EALCF*9.9719E\text{-}04. \quad (2)$$

Again, for a **critical** system similar to those validated, one would expect to calculate above USL_1 for a single future estimate of k_{eff} at 95% confidence. USL_2 represents $k_c(x)$ minus a statistically determined multiplier. The difference between the multiplier and W represents the statistically determined margin (in this case 1.48%). The multiplier was calculated so as to produce a USL_2 for which there is a 95% confidence that 995 out of 1000 future calculations of **critical** systems will yield a k_{eff} above USL_2, where USL_2 is given by

$$USL_2 = 0.9695 - EALCF*9.9719E\text{-}04. \quad (3)$$

Any calculated k_{eff} below USL_2 is considered subcritical.

For the 238-group cross-section library, the mean k_{eff} is 0.9949 ± 0.0046 (standard deviation of means), the resulting bias is -0.51%, and the minimum and maximum k_{eff} values are 0.9860 ± 0.0018 and 1.0038 ± 0016. For the 44-group cross-section library, the mean k_{eff} is 0.9976 ± 0.0045 (standard deviation of means), the resulting bias is -0.24%, and the minimum and maximum k_{eff} values are 0.9894 ± 0.0020 and 1.0067 ± 0.0016.

IV. CONCLUSIONS

Overall, the experimentally measured and calculated KENO-VI k_{eff} values are in good agreement. No trend in k_{eff} with EALCF, correlation coefficient of -0.033, was observed for the 238-group (or 44-group) library over the range of the validation. Thus, if biases are properly account for, KENO-VI can be used with confidence in the criticality analysis of systems of similar LWR-type fuels.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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Table 1. Critical parameters[2,3,4]

Document	Clad Material	Enrichment	Pitch (cm)	Core Size[b] (No. of rods)
NS&E Vol. 71, 154-163 (1979)	Al alloy (AG5)	4.742 wt.%	1.35	519, 505, 495,484
			1.72	277
			2.26	225
PNL-4976	Al alloy (6011)	2.350 wt.%	1.598	1029
			1.878	431
		4.306 wt.%	1.801	378
			2.398	132
LEU-COMP-THERM-007[a]	Al alloy (AG5)	4.742 wt. %	1.35	547
			1.72	271
			2.26	217
LEU-COMP-THERM-015[a]	Zr alloy	3.6 at. %	1.50	212, 213, 219
			1.905	208, 199
		1.6 & 3.6 at. %	1.27	80, 160
			1.50	231
		4.4 at. %	1.27	110, 164
		3.6 & 4.4 at. %	1.27	166
LEU-COMP-THERM-031[a]	Zr alloy	5.12 at. %	0.8	3717, 3710, 3011, 2903, 2877, 2649

[a]International Handbook of Evaluated Criticality Safety Benchmark Experiments
[b]For LEU-COMP-THERM-015, values are core identification numbers

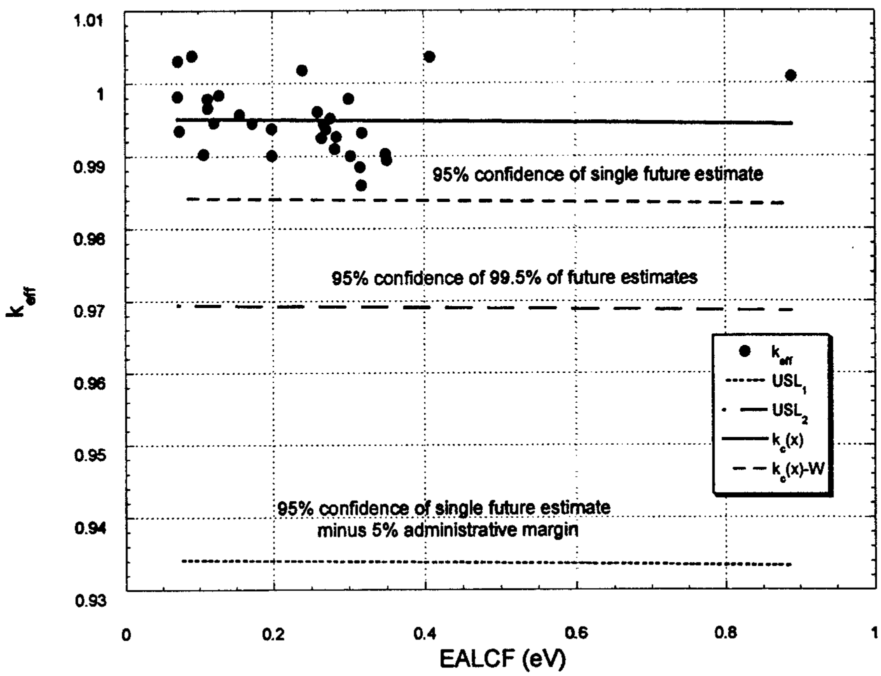

Figure 1. Scatter plot k_{eff} vs. EALCF for 238-group ENDF/B-V library.

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