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VALIDATION OF SCALE-4 FOR LWR FUEL IN TRANSPORTATION AND STORAGE CASK CONDITIONS

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Validation of SCALE-4 for LWR Fuel in Transportation and Storage Cask Conditions

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This paper presents the results of criticality calculations performed to validate the recently released SCALE-4 modular code system[1] for light water reactor (LWR) fuel under various conditions typical of transportation and storage casks. The modifications in SCALE-4 include NITAWL-II[2], an updated version of the NITAWL code that performs resonance self-shielding calculations using the Nordheim Integral Treatment. In order to validate SCALE-4 with the new resonance self-shielding treatment, the CSAS4 control module was used to calculate the effective neutron multiplication factor (k_{eff}) via the BONAMI[3], NITAWL-II, and KENO V.a[4] codes. The cross section library used was the 27 group ENDF/B-IV library, which has been updated for use with NITAWL-II.

Sixteen experiments from eight references were modeled in order to examine eight different criticality aspects related to fuel storage in transportation and storage casks:

1) Neutron interaction between fuel assemblies
2) The effectiveness of neutron flux traps between fuel assemblies to reduce reactivity
3) The effect of voiding on the effectiveness of neutron flux traps
4) The effectiveness of neutron absorber plates and rods to reduce interaction between fuel assemblies
5) The reactivity effect of commonly used biological shielding materials
6) Neutron spectra shift or relative neutron moderation caused by dissolved boron
7) Plutonium buildup and uranium depletion
8) Subcritical neutron multiplication in a cask configuration, including neutron poison baskets.

Table I lists the experiments modeled, their distinctive characteristics as related to the eight aspects of criticality listed above, and the calculated k_{eff}'s. All experiments were water moderated and reflected, unless otherwise noted.

The first set of experiments[5] listed in Table I consisted of four fuel assemblies of 4.31 weight percent (wt%) UO_2 rods in a 1.891 cm square lattice pitch arranged in a 2 x 2 array. The assemblies were separated by a 3.73 cm wide neutron flux trap created by 0.673 cm thick Boral™ plates. Voids were created in the flux trap region of experiment # 214V3 by inserting three 0.63 cm thick aluminum plates. This resulted in voiding of 51% and decreased the critical size of the experiment by approximately 9.5%.

The second experimental set[6] consisted of three fuel assemblies of 2 35 wt% UO_2 rods in a 2.032 cm square lattice pitch arranged in a row. Plates of Boral™, aluminum , or stainless steel were inserted between the fuel assemblies (0.645 cm from the center assembly) to determine the effect on the critical separation between the fuel assemblies.

The third set[7,8] consisted of three fuel assemblies of 4.31 wt% UO_2 rods in a 1.892 cm square lattice pitch arranged in a row, similar to the setup of the second set. Reflecting walls of depleted uranium, lead, or steel were positioned on both sides of the fuel assemblies, 1.956 cm from the cell boundary of the assemblies.

The fourth set[9] examined the effects of adding soluble boron to the water moderator. These experiments used a single array of 4.31 wt% UO_2 rods at two different lattice pitches, 1.890 cm and 1.715 cm, in order to study the effect of water-to-fuel volume ratios on highly borated systems. Although the wide pitched assembly required less rods (357) to achieve criticality than the narrow pitched one (509) with no boron in the system, the opposite was true for the borated cases (1237 versus 1192 rods, respectively).

The next experiment[10] consisted of nine fuel assemblies of 2.46 wt% UO_2 in a 1.636 square lattice pitch arranged in a 3 x 3 array. The assemblies were separated by a water gap containing 84 equally spaced B_4C rods.

The experiment from Reference 11 had 583 mixed oxide pins (2 wt% PuO_2, 98 wt% natural UO_2) and 1174 4.31 wt% UO_2 rods distributed uniformly in a close packed triangular pitch of 1.598 cm to obtain a Pu/U^{235} ratio approximating that of 20,000 MWD/MTU burnup. The final experiment[12] consisted of seven assemblies of 4.31 wt% UO_2 rods encased in AlB_2 alloy sleeves arranged in a subcritical shipping cask geometry. The measured k_{eff} of this experiment was 0.92±0.005.

The mean k_{eff} for the fifteen critical experiments is 0.9931. However, more insight may be gained by separating the results into four categories:

1) UO_2 fuel reflected by water
2) UO_2 fuel reflected by metal walls
3) mixed oxide fuel
4) subcritical experiments.

The eleven water reflected UO_2 cases have a mean k_{eff} of 0.9921 for a bias of 0.8% k, while the three UO_2 cases with reflecting walls have a mean k_{eff} of 0.9999, exhibiting no bias. The mixed oxide case has a lower calculated k_{eff} than any of the UO_2 cases and has a bias of 1.6% k. The subcritical case underpredicts the measured k_{eff} by 1.5% k.

Although there were other experiments in the above references which were not modeled, this study covers a large scope of typical transportation and storage cask conditions. SCALE-4 with the 27 group ENDF/B-IV cross section library produces satisfactory results for unirradiated LWR fuel stored in cask conditions. Analysis of additional mixed oxide critical experiments is planned in order to substantiate the bias observed for the mixed oxide case in this study.

TABLE I
EXPERIMENT DESCRIPTIONS AND CALCULATED RESULTS

Reference/Experiment	Characteristics	Results
5 / 214R	Flux traps	0.98935±.00215
5 / 214V3	Flux traps with voids	0.99713±.00222
Mean k_{eff}		0.9932
6 / 005	No plates	0.99498±.00205
6 / 017	Boral™ plates	0.99697±.00221
6 / 024	Aluminum plates	0.99433±.00198
6 / 028	SS304 plates	0.98903±.00285
Mean k_{eff}		0.9938
7 / N/A	Depleted uranium walls	0.99711±.00201
7 / N/A	Lead walls	1.00461±.00236
8 / N/A	Steel walls	0.99787±.00228
Mean k_{eff}		0.9999
9 / 173	No boron, wide pitch	0.99196±.00237
9 / 177	2.55 g/l boron, wide pitch	0.99252±.00156
9 / 178	No boron, narrow pitch	0.99028±.00233
9 / 181	2.55 g/l boron, narrow pitch	0.98695±.00147
Mean k_{eff}		0.9904
10 / 2282	B_4C rods betweens fuel assemblies	0.98929±.00217
11 / 196	Ass'y of mixed oxide and UO_2 rods arranged in an uniform pattern to approximate 20,000 MWD/MTU burnup	0.98396±.00198
12 / TTC-5	7 assemblies encased in AlB_2 alloy sleeves arranged in a subcritical shipping cask geometry (k_{eff}=0.92)	0.90509±.00196

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