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Dr. Lambros Lois
U.S. Nuclear Regulatory Commission
7920 Norfolk Avenue
Bethesda, Maryland 20014

Subject: Calculations for Indian Point-2
Storage Racks

Dear Lambros:

The calculations requested by the Division of Systems Integration[1] (DSI) in support of the USNRC review of the Indian Point-2 (IP-2) Fuel Storage Rack Submittal[2] have been completed.

Essentially, BNL had been asked to perform two calculations:

1. The determination of k_{eff} for an experimental critical configuration "similar to the arrangements used in fuel storage pools," in order to "qualify the BNL computational tools for their capability to compute k_{eff} for fuel storage pools."

2. A "confirmatory" calculation of k_{eff} for the fuel storage rack arrangement proposed for IP-2 (see Figure 1).

Our major results are summarized in the following.

Summary

Detailed calculations of two critical experimental benchmarks, and the proposed IP-2 fuel storage rack design have been performed using the continuous energy Monte Carlo program SAM-F[3] with ENDF/B-V cross section data. The k_{eff} from the simulations of the experimental configurations is 0.998 + 0.003 at the 1σ confidence level which is in excellent agreement with the critical k_{eff} = 1.0.

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The results from these calculations served to qualify the SAM-F (ENDF/B-V data) procedure for the determination of k_{eff} for configurations of low enrichment UO_2 lattices with and without borated stainless steel absorbers, at room temperature.

The calculation for the reference IP-2 fuel storage rack configuration yielded an eigenvalue of 0.938 + 0.007 at the 1σ confidence level. This compares favorably with the value quoted in Reference 2 of 0.933 + 0.006 at the 95% confidence level. The latter value was obtained using the KENO-IV Monte Carlo program with a 123 energy group cross section set obtained from the XSDRN library (based on ENDF/B-II).

Analysis

The SAM-F program (the Monte Carlo component of the SAM-CE code system used for forward neutron transport problems) was used to simulate two critical configurations from a series of experiments that had been performed at Battelle Pacific Northwest Laboratories (PNL)[4]. The experiments involved the determination of the critical separation between 3 clusters of 4.31 w/o enriched UO_2 rods, with and without various poison materials between the clusters.

The critical configurations that have been simulated are as follows:

1. Three 15 x 8 clusters

2. Three 15 x 8 clusters with 1.1 w/o borated 304-L stainless steel plates between the clusters.

The calculations with SAM-F used neutron cross sections based on ENDF/B-V at a temperature of 300K. These nuclear data were generated by the National Nuclear Data Center at BNL.

Following the processing of 20,000 neutron histories, good agreement was obtained for both experimental configurations: k_{eff} = 1.005 + 0.007 and 0.996 + 0.004 respectively. The results (and all results quoted for SAM-F) were obtained using the Maximum Likelihood Estimator (MLE) available in SAM-F. The MLE combines the four separate estimates of eigenvalue computed by SAM-F (two estimators are based on collisions, two on track-length) in such a way that the result has close to minimum variance.

The simulation of the reference IP-2 fuel storage rack configuration represented an infinite array of fuel storage cells with centrally located Westinghouse 15 x 15 fuel assemblies (cf. Figure 1). The fuel was assumed to be 3.5 w/o enriched UO_2. One-eighth of the cell was represented with a 100cm axial dimension, and reflecting boundary conditions on all exterior surfaces. The fuel pellet, gap and cladding, as well as the guide tubes, were explicitly modelled. Number densities for the fuel assembly were calculated from data presented in References 2 and 5. Number densities for the water,

the type 304 stainless steel can, and the borated stainless steel sheets were essentially identical to those used in the simulations of the PNL experiments.

The eigenvalue for this configuration (20,000 neutron histories, 500/batch) was 0.938 + 0.007 at the 1σ confidence level with the Maximum Likelihood Estimator used in SAM-F. This result is in substantial agreement with the result presented in Reference 2 which was obtained with a totally different calculational procedure.

Discussion

The result from the SAM-F calculation for the reference IP-2 fuel storage rack configuration essentially confirms the k_{eff} of 0.933 + 0.006 reported in the IP-2 submittal. The submittal, however, sheds little or no light on a number of areas relating to whether or not the IP-2 design can be expected to satisfy the NRC criteria for fuel storage racks.

The first area relates to how closely the KENO-IV (XSDRN library) procedure models reality. This is important because if the calculational model has a tendency to underpredict the eigenvalue for a critical configuration, this would represent a non-conservative bias in the calculational procedure. Note that the claim is made in the IP-2 submittal that the KENO-IV (123-groups) calculational model systematically overpredicts k_{eff}, however, no penalty is taken for the calculational errors from the benchmarking in their final uncertainty analysis.

The submittal states that the KENO-IV (123 groups) calculational procedure was benchmarked against "several critical experiments," including some from the PNL series of Reference 4. However, there is no information concerning the exact experiments simulated, or what results were obtained. All that is stated is that "calculated k_{eff} values greater than the experimental values" were obtained, and hence the calculational model "provides conservative results."

In this context it should be noted that Oak Ridge National Laboratory (ORNL) has reported results of extensive benchmark testing of the SCALE system[6,7] against a large number of critical experiments, including all of the PNL experiments of Reference 4. The calculations were performed using KENO-IV and three cross section libraries: 1) a 27-group library based on ENDF/B-IV, 2) a 123-group GAM-THERMOS library based on early versions of ENDF/B, and 3) the 16-group Hansen-Roach library. For the PNL experiments of Reference 4, the averages of the multiplication factors calculated by ORNL were 0.988, 0.989, and 0.993 for the three libraries, respectively.[7] These results seem to indicate a general tendency by KENO-IV with multigroup libraries to underpredict the results of some critical experiments, which is non-conservative. If the ORNL results were to be accepted as indicative of the performance of KENO-IV (with various multigroup libraries) relative to "truth," the calculated eigenvalue quoted for the reference IP-2 storage rack

configuration in the submittal would have to be increased by 0.7 - 1.2%Δ k in order to provide assurance that the "true" multiplication factor is conservative. Alternatively, an uncertainty would have to be included in the uncertainty analysis in order to account for the possibility that the KENO procedure may, in fact, not always be conservative.

Note that there is insufficient data at this point to determine whether the SAM-F (ENDF/B-V) model is conservative or non-conservative relative to "truth."

The procedure employed in the IP-2 submittal in order to account for expected deviations from the reference configuration also raises some questions. The deviations considered include variations in the borated poison sheet thickness, poison concentration, storage cell pitch, etc. The Δk_{eff}'s resulting from possible deviations from the reference configuration were determined using a standard multigroup diffusion theory program. (It should be noted, however, that diffusion theory might be inadequate for an accurate assessment of the effects of some of the perturbations considered.) The resultant Δk_{eff}'s then appear to have been treated as standard deviations, and combined in a root-mean-square fashion with the uncertainty from the KENO-IV Monte Carlo calculation in order to yield an overall uncertainty for what is called the "worst case normal configuration."

It is not intuitively clear to these authors that root-mean-square formality quantifies the philosophical statement of "worst case" analysis. All the individual perturbations considered, when viewed in the context of reactor physics, tend to categorize themselves into two distinct partitions - a) changes in the effective amount of moderation and b) changes in the ratio of fission to poison. One should, thus, separately ask the question about true event independence within three contexts - two simultaneously occurring reactivity producing events that are i) both essentially changes in moderation, ii) both essentially changes in the fission to poison ratio, and iii) a change in moderation coupled with a change in the fission to poison ratio. If the events are truly independent then the root mean square formalism has some statistical merit. If, however, the Δk_{eff} are not truly independent then a more detailed investigation of the combining of the uncertainties is probably required.

Additionally, those reactivities grossly estimated by few group diffusion theory should not be considered without error in the estimates of the reactivity perturbations used in "worst case" analysis, regardless of the combining formalism contained in Reference 2.

Sincerely,

Laurance D. Eisenhart

Michael Todosow

MT/JL

cc: J. F. Carew
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4. S. R. Bierman, et al., "Critical Separation Between Subcritical Clusters of 4.29wt% U-235 Enriched UO_2 Rods in Water with Fixed Neutron Poisons", NUREG/CR-0073/RC, U. S. Nuclear Regulatory Commission (May 1978).

5. L. Lois, (USNRC), personal communication.

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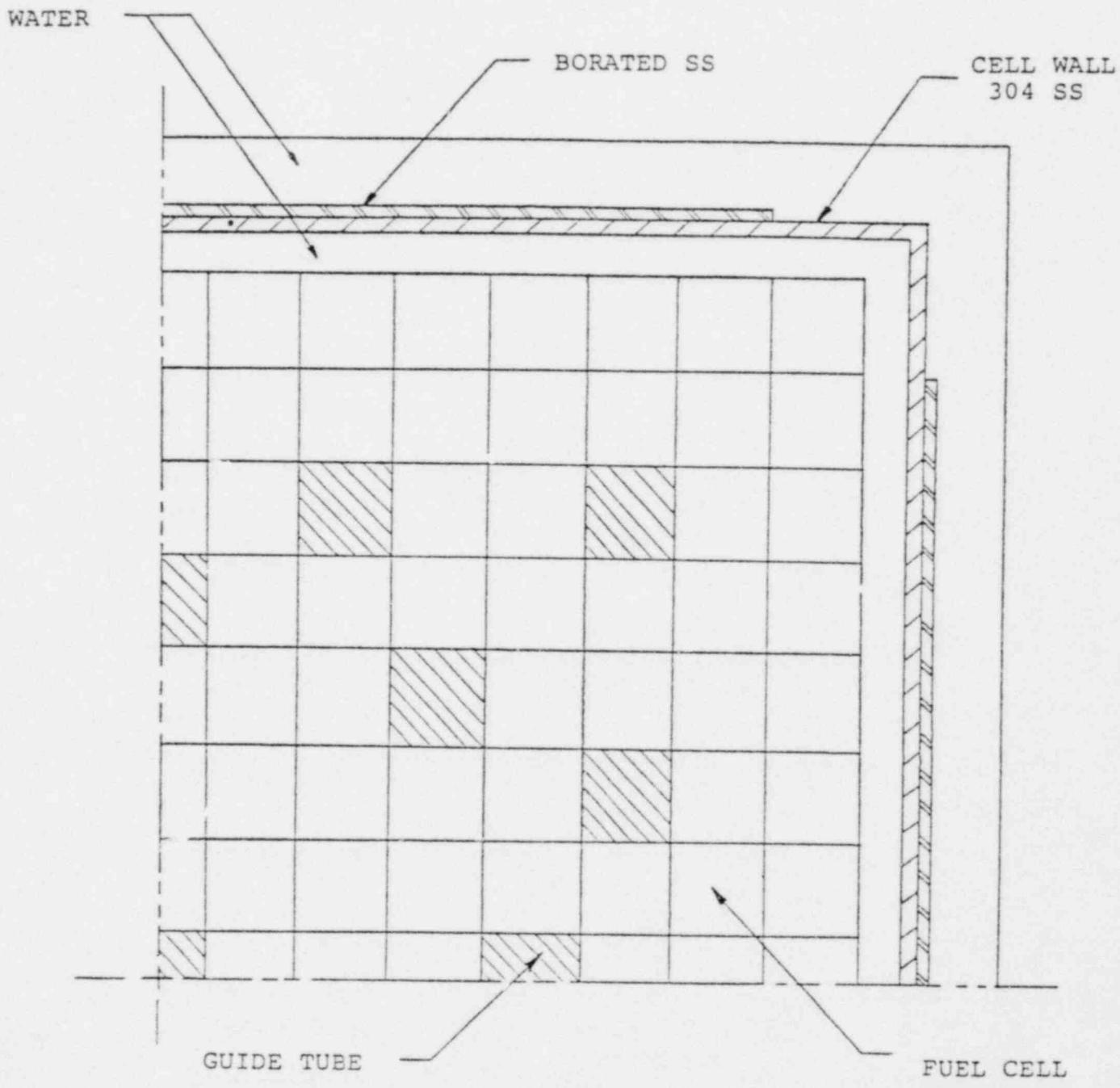

FIG. 1 REFERENCE IP-2 FUEL STORAGE RACK CONFIGURATION