Test on Similarity between the Flooded and Optimum Moderation Conditions of the Spent Fuel Storage Pool

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1. Introduction

In the criticality safety analysis, uncertainty and bias should be considered. The final multiplication factor including uncertainty and bias in addition to calculated k-eff should be below the administrative limit[1]. The administrative limit of spent fuel pool is 0.95 with flooded condition (filled with unborated water), and 0.98 with optimum moderation condition (filled with foggy unborated water, usually occurs near 0.1g/cc water density) for new fuel storage. The bias is determined by comparing the calculation results of the critical experiments[2] ever performed. It is important to choose "good" experiments which have "similar" condition with application. To obtain realistic bias, many experiments with similar conditions should be chosen and considered. In previous approach, same critical experiment set are used to determine bias of the flooded and optimum moderation conditions. It would be correct way if two conditions are similar.

The similarity test on this paper was performed by TSUNAMI code included in SCALE5.1 package[3]. TSUNAMI code produces sensitivity data for each nuclear reaction by using first order perturbation theory. TSUNAMI code performs forward and adjoint multigroup Monte Carlo calculation. Sensitivity data are obtained by forward and adjoint results. TSUNAMI also produces uncertainty data with sensitivity data and cross section covariance data. In this paper, similarity is determined by comparing energy of average lethargy of fission (EALF), uncertainty data, sensitivity data, and correlation coefficient which is also output of the TSUNAMI code.

2. TSUNAMI uncertainty calculation

TSUNAMI code produces uncertainty data by using sensitivity data and cross section covariance data.

$$u^2 = \sum_{i=1}^{N}\sum_{j=1}^{N} S_i C_{ij} S_j,$$

$$S_i = \frac{dk/k}{d\Sigma_i/\Sigma_i}, \qquad (1)$$

$$C_{ij} = \frac{d\Sigma_i}{\Sigma_i}\frac{d\Sigma_j}{\Sigma_j} r(\Sigma_i, \Sigma_j).$$

In Eq.(1), r is 1.0 when two variables are identical, and 0.0 when two variables are independent. The correlation coefficient used in determining similarity is defined as following :

$$c_k = \frac{u_{12}^2}{\sqrt{u_{11}^2}\sqrt{u_{22}^2}},$$

$$u_{AB}^2 = \sum_{i=1}^{N}\sum_{j=1}^{N} S_{A,i} C_{ij} S_{B,j}, \qquad (2)$$

where S_A and S_B are sensitivity data for system A and B, respectively. In Eq.(2), correlation coefficient becomes near 1.0 when two systems have similar sensitivity profile. Usually, it is considered that two systems are similar when c_k >0.9.

3. Numerical results

Simple test problem which has a 16x16 fuel assembly with 5.0wt% enrichment and thick water wall is chosen. Configuration is shown in Fig. 1. Two water densities are used(1.0g/cc for flooded, 0.1g/cc for optimum moderation). The test problem has an infinite array in radial and axial directions.

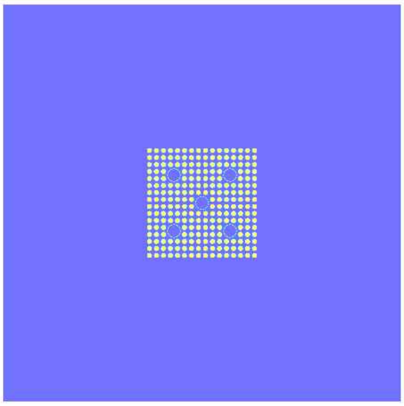

Fig.1 : Configuration of the test problem

In TSUNAMI calculation, 238 energy group library based on ENDF/B-V was used, and 44 energy group covariance data were used in uncertainty calculation. Table 1 shows multiplication factors for forward and adjoint calculation and EALF.

Table 1 : Effective multiplication factor and EALF

	forward	adjoint	EALF(eV)
Flooded	0.91408 ± 0.00016	0.9111 ± 0.0018	0.204329 ± 9.53094E-5
Optimum Moderation	0.95105 ± 0.00012	0.9467 ± 0.0052	0.334141 ± 1.86946E-4

The forward results are obtained with 5000 particles per generation and 5550 generations including 50 inactive generations (51 for optimum moderation), adjoint results are obtained with 10000 particles per generation and 15500 generations including 250 inactive generations (214 for flooded). The comparison between forward and adjoint results which are identical if fully converged should be required to check the effectiveness of the adjoint calculation which has very slow convergence. Table 1 shows the solutions are effective and two conditions have similar EALF (flooded condition has a bit lower EALF.). Tables 2 and 3 show uncertainty data. Five nuclide reactions are selected which largely contribute to uncertainty in k-eff.

Table 2 : Uncertainty data for flooded condition

Covariance Matrix		Contributions to Uncertainty in k_{eff} (% Δk/k)
Nuclide-Reaction	Nuclide-Reaction	Due to this Matrix
^{235}U nubar	^{235}U nubar	6.4134E-01 ± 2.7343E-05
^{235}U chi	^{235}U chi	3.2765E-01 ± 1.8171E-04
^{235}U n,gamma	^{235}U n,gamma	2.8031E-01 ± 5.6889E-05
^{238}U n,gamma	^{238}U n,gamma	2.4989E-01 ± 5.2692E-05
^{1}H elastic	^{1}H elastic	1.8427E-01 ± 4.3422E-03
total		0.8640 ± 0.0016 % Δk/k

Table 3 : Uncertainty data for optimum moderation condition

Covariance Matrix		Contributions to Uncertainty in k_{eff} (% Δk/k)
Nuclide-Reaction	Nuclide-Reaction	Due to this Matrix
^{235}U nubar	^{235}U nubar	6.2513E-01 ± 3.5986E-05
^{1}H n,gamma	^{1}H n,gamma	2.4475E-01 ± 3.3832E-04
^{235}U n,gamma	^{235}U n,gamma	1.8525E-01 ± 4.6293E-05
^{238}U n,gamma	^{238}U n,gamma	1.5432E-01 ± 4.7483E-05
^{235}U fission	^{235}U fission	1.3841E-01 ± 5.0578E-05
total		0.7510 ± 0.0062 % Δk/k

From the uncertainty results, H(n,gamma) reaction contribution is very large in optimum moderation condition, which are relatively small(5.9276E-02 ± 3.2598E-05) in flooded condition. The sensitivity data also show optimum moderation condition is more sensitive in H(n,gamma) reaction. The sensitivity results are shown in Table 4.

Table 4 : H(n,gamma) sensitivity

Flooded	-0.098741 ± 0.00010314
Optimum moderation	-0.40786 ± 0.0010593

The resulting correlation coefficient c_k is 0.7349 ± 0.0082, and it is considered that two systems do not have similar sensitivity profiles.

4. Conclusion

The similarity test between flooded and was performed by using TSUNAMI code. Flooded and optimum moderation conditions have similar energy of average lethargy of fission, but it seems that they do not have similar sensitivity profiles. Because this test problem is so simple and this study is a preliminary approach, it is hard to conclude that use of same critical experiment set leads to bad bias for optimum moderation condition. To ascertain that the bias of optimum moderation condition with critical experiments similar to flooded condition is effective, it is required to show that flooded and optimum moderation conditions are similar each other with more studies. If two conditions are turned out not similar, use of critical experiments similar to each condition would be necessary.

REFERENCES

[1] “Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," Laurence I. Kopp, USNRC, 1998

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