The Use of Gadolinia Credit for Criticality Evaluation of a Spent-Fuel Cask

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INTRODUCTION

There has been a tendency recently toward a high initial enrichment grade for light water reactor (LWR) fuels and, in the future, even higher grades are anticipated. If we make a subcriticality evaluation of a cask design based on the initial enrichment of the fuel, the resulting cask will have an increased basket price and a decreased transport efficiency. This is because the cask basket will require the enriched boron or an increase of the basket thickness in order to increase the neutron absorbing performance.

In order to prevent this disadvantage, an introduction of burnup credit can be very effective. But with regard to boiling water reactor (BWR) fuels, it is possible to apply the simple method by taking into consideration the negative reactivity of gadolinia contained in the fuel pellets. With this method the evaluation work will be more simplified and easily put into practice through elimination of the work to specify the burnup.

In this report we have established an applicable method for using gadolinia credit for the criticality evaluation of spent fuel shipping casks.

JAPANESE BWR FUEL CHARACTERISTICS

An example of the enrichment split design of the Japanese BWR fuel assembly is shown in Figure 1. This fuel assembly, with its large central water rod, is the newest type in Japan. Its bundle maximum burnup reaches up to 50 GWD/T. This high-enrichment and high-burnup fuel is called STEP-II fuel in Japan.

In BWR the inside of a channel box is a boiling region, and the outside of the box is a nonboiling region. Therefore, generally the enrichment of the peripheral rods adjacent to the nonboiling region is low, and contrarily, the enrichment of the inner rods is high in order to flatten the power distribution of a bundle.

Also, fuel rods containing gadolinia, which is a burnable poison, are located in an assembly in order to control the excess reactivity at the beginning of the life (BOL).

As a result, the bundle reactivity performance with burnup is shown in Figure 2. In the nuclear design of BWR reload fuels, all gadolinia in pellets is essentially burned out at the end of the cycle (EOC). Therefore, the peak reactivity of the bundles appears near the burnup of 10 GWD/T. The maximum reactivity of the BWR fuel bundles used in Japan at the present time never exceeds the value of 1.3 Kinf of the bundle in any axial position when it is under the cold state in a reactor core.

APPLICATION OF GADOLINIA CREDIT

In this paper, "Gadolinia Credit" means taking the negative reactivity of gadolinia in fuels into account during the criticality analysis. In the analysis, the characteristic that the bundle Kinf in the core never exceeds 1.3 is utilized. A hypothetical "model bundle" whose Kinf is 1.3 under the cold core state is specifically used instead of initial enrichment fuels, which neglect gadolinia in the criticality analysis model.

PREPARATION OF THE MODEL BUNDLE

Though any model bundle is applicable if it has an adequate safety margin, it needs to have the considerations shown below.

- The model bundle needs an inclusive safety margin for many varieties of fuel, enrichment distributions, and exposed histories.

- The model bundlc must be able to evaluate criticality conservatively, considering the spectrum difference between the model bundle and actual spent fuels containing various nuclides. This means that the model bundle must be able to evaluate criticality conservatively, considering differences of geometry between a reactor core and a cask.

One method used to make the model bundle established in this study is described below.

Concerning the first consideration above, it is not reasonable to make one common model bundle for the use of different fuel types such as 7×7 fuel and 8×8 fuel because there are considerable differences in nuclear characteristics. Also, because fuels used in Japan have rather low enrichment before the STEP-II type fuel, it is not a problem to load them into the cask which is designed to load STEP-II fuels.

Therefore, the gadolinia credit has been adopted to the STEP-II fuel in this study. It has been confirmed by the fuel lattice cell analysis code system used for the BWR core design, that the Kinf of all STEP-II fuels in Japan is enough below 1.3 under the cold core state.

This code system generates cross-sections by GAM and THERMOS type calculation, and calculates fuel rod power distribution and Keff by the two-dimensional multigroup diffusion calculation equivalent to the PDQ code, and it is possible to calculate nuclide compositions with burn-up.

The second consideration means that even if the reactivities of the model bundle and actual spent fuel bundles are the same in the case of the cold core state, the reactivities of them would be different in other states because of the difference of their spectra.

If the actual spent fuel bundle (which has a harder spectrum, because of the existing fission products and actinides, compared with the model bundle that is made with fresh enriched fuel rods) is inserted into a basket channel surrounded by neutron absorbers, the reactivity becomes higher than in the case of using the model bundle, even if both reactivities are the same in the case of the cold core state.

Therefore, the model bundle must have a safety margin in criticality evaluation taking into consideration the spectrum effect mentioned above.

In order to get a conservative Kinf in a basket channel using fresh fuel rods, a model bundle having an enrichment distribution has been prepared in this study.

The two types of model bundles, one consisting of uniform enrichment and the other consisting of two enrichment splits, are shown in Table 1. These enrichment distributions of the model bundles have been adjusted by using the core design code system as each Kinf of the model bundles becomes just 1.3 under the cold core state. Because the reactivity of Case 1 in Table 1 does not become higher, the bundle average enrichment has become higher than Case 2. This is because in Case 1 the low enrichment rods are located adjacent to the water gap. How do the reactivities change when each model bundle is placed in a cask basket ? It is evident that in Case 1 when many low enrichment rods are located at the peripheral of the bundle, there is a higher reactivity than in Case 2. This is because the neutron absorber's worth in the basket channels becomes less in Case 1. It has been confirmed by the core design code system that the reactivity of Case 1 is higher than Case 2 with a cask basket channel, as shown in Table 2.

In addition, it has been confirmed by comparing with Case 3 in Table 2 that the reactivity of Case 1 is higher than in the case of using the actual nuclide composition of the spent fuel which shows maximum reactivity among Japanese STEP-II fuels. This means that the conservative setup of the model bundle compensates for the disadvantage caused by the difference of the spectra between the model bundle and the actual spent fuel bundle mentioned before.

Here, general codes such as the WIMS can be used to create the model bundle instead of the core design code. The reactivities calculated by the core design code and the WIMS code are almost the same as shown in Table 1.

ADVANTAGE OF USING GADOLINIA CREDIT

The maximum bundle average initial enrichment of the Japanese STEP-II fuel is 3.67%. The comparison of Keff, with or without using the gadolinia credit, is listed in Table 3. These Keff were calculated by the KENO code of the NFT-38B cask, which is now being constructed for the transportation of the STEP-II spent fuels to the Rokkasho Reprocessing Plant. The advantage of gadolinia credit was found to be about 5-6% ΔK in the effective neutron multiplication factor using the cask geometry with the specific fuel used in this study.

It is anticipated that the initial enrichment of BWR fuels will become higher as the burnup increases in the future. Therefore, the amount of gadolinia contained will be increased in order to control the core excess reactivity. As a result, in the future the advantage of gadolinia credit will become greater than when using the STEP-II fuels. However, it will not always be that the maximum Kinf of a new fuel type will be below 1.3. Also, because the new fuel type will be different from the present fuel, geometrically, it is necessary to prepare a new model bundle with an adequate safety margin for the new fuel type.

CONCLUSION

An applicable method for using gadolinia credit for the criticality evaluation of spent fuel shipping casks has been established with regard to BWR fuels. The advantage of the gadolinia credit is less when compared with the burnup credit for a cask design. But the gadolinia credit is still much more easily used through elimination of the work to specify the burnup.

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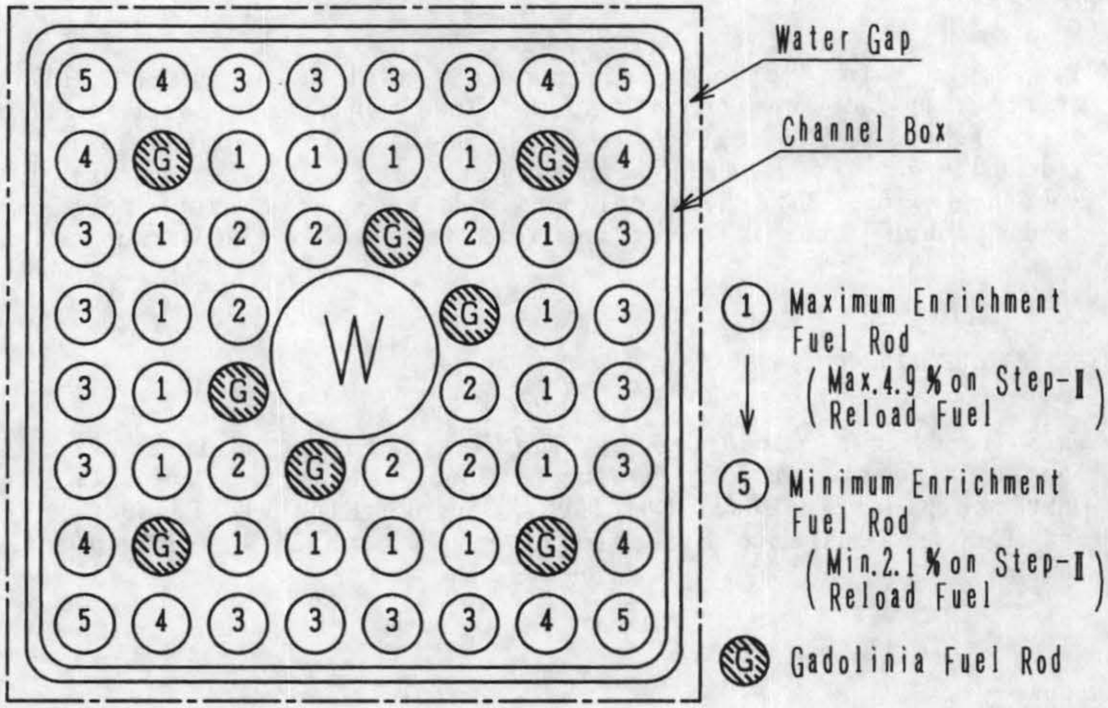


Figure 1. An example of the enrichment split design of the Japanese BWR fuel assembly.

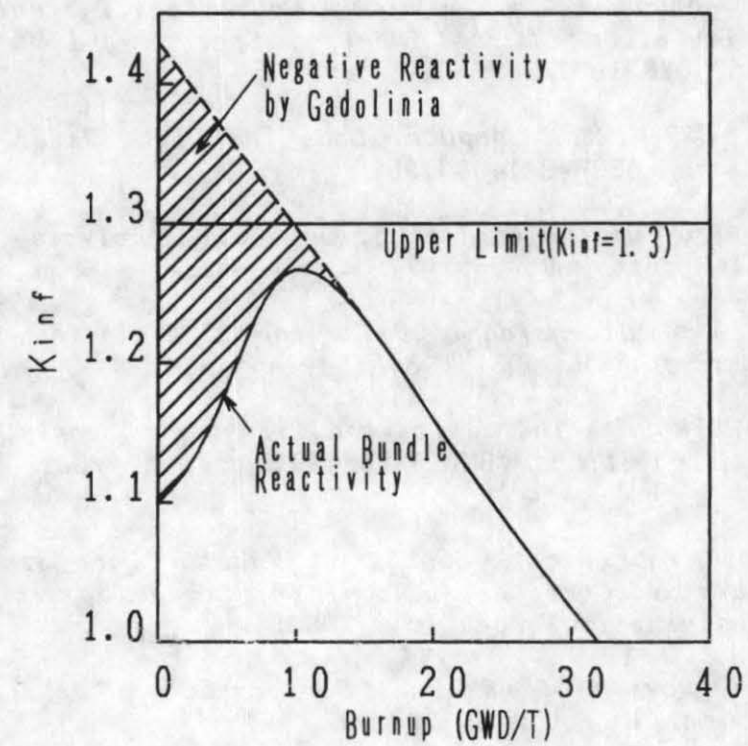


Figure 2. Bundle reactivity performance with burnup.

Table 1. Examples of Model Bundle

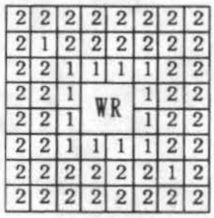
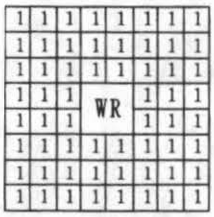
	Enrichment Distribution		Kinf under Cold Core State
Case 1		1 : 4.90% (Maximum Pellet Enrichment of STEP-II Reload Fuel) 2 : 2.10% (Minimum Pellet Enrichment of STEP-II Reload Fuel) Avg : 2.75%	1.301 (1.300 by WIMS)
Case 2		1 : 2.54%	1.301

Table 2. Comparison of Kinf in Cask Basket Cell

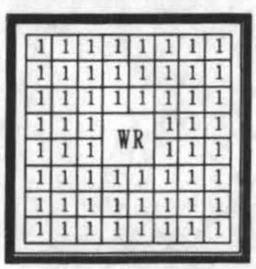
	Enrichment Distribution		Kinf in Cask Basket Cell
Case 1	Basket channel (Boron-Stainless-Steel) 	1 : 4.90% 2 : 2.10% Avg : 2.75%	0.83294
Case 2		1 : 2.54%	0.82791
Case 3		For STEP-II Fuel at Maximum Reactivity Time Period	0.82674

Table 3. Advantage of Gadolinia Credit

	Keff ± σ *	Advantage
Conventional Method (Using Bundle Average Initial Enrichment)	0.89892 ± 0.00566 (Keff+3σ = 0.91590)	0
Application of Gadolinia Credit (Using Model Bundle)	0.84273 ± 0.00564 (Keff+3σ = 0.85966)	5～6% △K

* The calculational model is shown below.