Proceedings of the Korean Nuclear Society Spring Meeting
Suwon, Korea, May 1998

Analysis of the Nuclear Subcriticality for the High Density Spent Fuel Storage at PWR Plants

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Abstract

The marginal nuclear criticality analysis for the high density spent fuel storage at a PWR plant was carried out by using the HELIOS and CASMO-3 codes.

More than 20 % of the calculated reactivity saving effect is observed in this analysis. This mainly comes from the adoption of some important fission products and B-10 in the criticality analysis.

By taking burnup and boron credits, the high capacity of the spent fuel storage rack can be more fully utilized, reducing the space of storage. Larger storage for a given inventory of spent fuel should result in remarkable cost savings and more importantly reduce the risks to the public and occupational workers.

I. Introduction

For a long time, storage rack of the spent fuel has been designed on the fresh fuel assumption, although the spent fuel has lost a large part of its reactivity. The loss of reactivity, caused by the burning of the fissile nuclides and by FPs (fission products) accumulation, provides an important safety margin, called burnup credit.

Many FPs are produced and induced in spent fuel but only 11 FPs contribute roughly at least to the half of the total absorption (excepting gases or volatile species such as Xe, I, Br, Kr)$^{1)}$. These 11 selected FPs, U and Pu isotopes are shown in Table 1.

In Korea, the safety authorities agree on the methodology for calculating the neutron multiplication factor of spent fuel storage racks in which a partial use of burnup credit and no soluble boron credit are taken except in accident conditions. Recently, burnup and boron credits are being taken into account in the nuclear subcriticality safety assessment of the spent fuel storage racks.

This analysis pointed out that a load increase in spent fuel storage pool is possible when FPs and boron are accounted for in nuclear subcriticality analysis.

The spent fuel assemblies are centrally located in each storage cell on a nominal lattice spacing of 10.4" in the east-west direction and 10.2" in the north-south direction. Stainless steel gap channels connect one storage cell box to another in a rigid structure and define an outer water space between boxes. This outer water space constitutes a flux-trap between the two neutron absorber panels that are essentially opaque (black) to thermal neutrons. The absorber has a thickness of 0.075 ± 0.007 " and a nominal B-10 areal density of 0.0238 g/cm^3. B-10 plays an important role in nuclear subcriticality of the spent fuel storage rack and its important physical properties of B-10 are shown in Table 2.

Actually, more than 2,000 ppm boric acid coolant is located in spent fuel storage pool for decay heat removal and nuclear subcriticality.

II. Method of Criticality Analysis

The criterion establishing acceptability of the spent fuel storage racks requires the inclusion of uncertainties to assure that the maximum k_∞ is less than 0.95 with a 95% probability at the 95% confidence level. These uncertainties may be statistically combined and the calculation for the maximum k_∞ may therefore be described as follows:

$$k_\infty^{max} = k_{calc} + \Delta k_{bias} + \Delta k_{axi} + \Delta k_{uncer}, \qquad (1)$$

where k_∞^{max} is the maximum reactivity with an infinite radial array of storage cells:

1) k_{calc} is the calculated reactivity
2) Δk_{bias} is the bias from the benchmark calculations
3) Δk_{axi} is the effect of the axial burnup distribution
4) Δk_{uncer} is the combined effect of all uncertainties.

The major contributor to criticality of spent fuel storage due to burnup is the long-lived fission products which have high neutron capture cross sections. A proper criticality analysis of high-level radioactive wastes such as PWR spent fuel requires knowledge of the concentration of the neutron absorbers. Although being minor contributors, several fission products absorb neutrons.

The CASMO-3 code$^{2)}$ is a multigroup (70 group) transport theory code utilizing transmission probabilities to accomplish two-dimensional calculations of reactivity and depletion for BWR and PWR fuel assemblies. Also, we used the HELIOS code for the calculations of depletion. The HELIOS code is a multigroup (190 group) two-dimensional transport theory program for fuel burnup and gamma-flux calculations$^{3)}$.

Depletion, burnup and boron credit calculations were performed with the CASMO-3 and HELIOS codes using the restart option to describe spent fuel in the spent fuel storage rack at a PWR plant. These criticality analyses used isotopes for zero cooling time.

In the geometric model used in this analysis, each fuel rod and its cladding were described explicitly and reflecting boundary conditions (zero neutron current) were used at the centerline between storage racks. These boundary conditions have the effect of creating an infinite array of storage racks in all directions.

In order to quantify the burnup and boron credit effect of the spent fuel storage rack, the spent fuel storage rack (region-2) at a PWR plant is modeled with a square cross section.

III. Results and Conclusions

Three kinds of Westinghouse 17 x 17 fuel assemblies were used as the reference fuel type for this criticality analyses. Initial enrichments of the spent fuel considered were 3.6 wt%, 4.2 wt% and 5.0 wt%, respectively. The calculation results obtained by the CASMO-3 and HELIOS codes are shown in Figures 1, 2, 3 and 4. As shown in the figures, one can observe the variations of k_∞ of the spent fuel assemblies in a spent fuel storage rack.

The first spent fuel assembly was divided in four cases based on the initial enrichment and burnup. The four cases considered are slightly enriched (3.6 and 4.2 wt%) with burnup equal to 40,000 and 45,000 (MWd/MTU), respectively. For burnup credit, we considered 8 fission products. By CASMO-3 analysis as shown in Fig. 1, the k_∞ of this spent fuel in a storage rack is evaluated approximately 5% less compared to the licensing upper limit ($k<0.95$).

The second spent fuel assembly considered is slightly enriched (3.6 wt%) with burnup equal to 40,000 (MWd/MTU). In this case, we did not consider fission products. By CASMO-3 and HELIOS analysis as shown in Fig. 2, the k_∞ of this spent fuel in a storage rack is evaluated approximately 5% less compared to the licensing upper limit ($k<0.95$).

The third spent fuel assembly considered is slightly enriched (4.2 wt%) with burnup equal to 45,000 (MWd/MTU). By HELIOS analysis, the k_∞ of this spent fuel in a storage rack is evaluated approximately 26% less compared to the licensing upper limit ($k<0.95$) as shown in Fig. 3.

The fourth spent fuel assembly considered is highly enriched (5.0 wt%) with burnup equal to 45,000 (MWd/MTU). By HELIOS analysis, the k_∞ of this spent fuel assembly in a storage rack is evaluated approximately 21% less compared to the licensing upper limit ($k<0.95$). These results are shown in Fig. 4.

Note that more than 20% of the k_∞ saving effect is observed in this analysis. This mainly comes from the adoption of fission products and B-10 in the criticality analysis by using burnup and boron credits.

In the future with more reliable benchmark data and more refined analysis, these biases and uncertainties will likely be reduced, allowing the minimum required burnup to be reduced.

By taking burnup and boron credits into consideration, the high capacity of the storage can be more fully utilized, reducing the space of storage. Thus, larger storage for a given inventory of spent fuel should result in remarkable cost savings and more importantly reduce the risks to the public and occupational workers.

References

1. Duck Joon Koh, Chang Keun Jo, et. al., "The Use of Burnup Credit in Criticality Control for the Korean Spent Fuel Management Program", *Proceedings of the Korean Nuclear Society Autumn Meeting,* Taegu, October 1997.
2. M. Edenius and A. Ahlin, "CASMO-3: New Feature, Benchmarking, and Advanced Applications", *Nuclear Science and Engineering*, **100**, 342-351 (1988).
3. *HELIOS Methods*, SCANDPOWER, 5 December 1994.

Table 1. Nuclides Included in Criticality Analysis of Spent Fuel

Nuclides	Half-Life(yr)	Neutron Capture Cross Section (2200 m/s, barn)(ENDF-B/VI)
Mo-95	Stable	13.99
Tc-99	2.111E05	19.64
Ru-101	Stable	3.36
Ag-109	"	90.54
Cs-133	"	29.00
Nd-143	"	325.00
Nd-145	"	43.84
Sm-147	1.06E11	58.01
Sm-150	Stable	108.60
Sm-152	"	206.20
Eu-155	4.7611	3758.00
U-235	7.038E08	98.81 (fiss : 584.4)
U-238	4.468E09	2.717(fiss : 1.177E-07)
Pu-239	2.411E04	270.30 (fiss : 747.4)
Pu-240	6.564E03	289.40 (fiss : 5.877E-02)
Pu-241	1.435E01	361.50 (fiss : 1.012E03)

Table 2. Important Physical Properties of B-10 (abundance : 19.9 %).

Reaction	2,200(m/sec) (barns)	14(MeV) (barns)	Fiss. Avg (barns)
Total	3.840E03	1.467	2.638
Elastic Scattering	2.144	9.425E-01	2.062
Capture	5.0E-03	2.126E-05	7.603E-05
(n, p)	3.0E-03	3.751E-02	1.525E-02
(n, α)	3.837E03	4.895E-02	4.355E-01

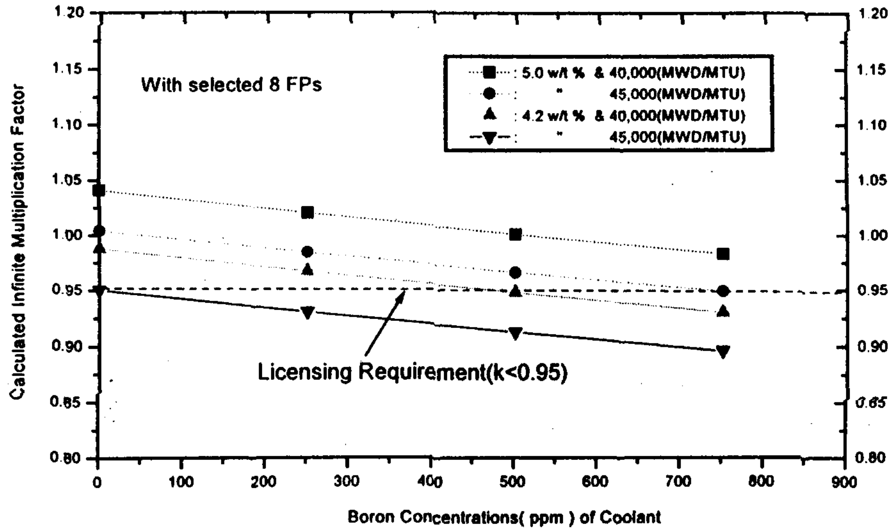

Fig.1 Calculated Infinite Multiplication Factors of the 17 x17 Spent Fuel with Boron Concentrations(ppm) by Using CASMO-3.

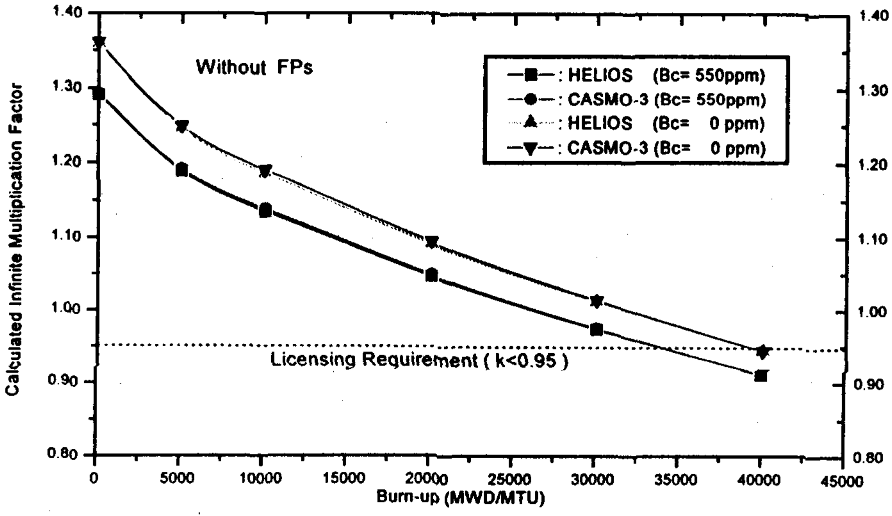

Fig. 2 Calculated Infinite Multiplication Factors of the 17 x 17 (3.6 w/t %) Spent Fuel with Burnup by Using CASMO-3 & HELIOS Codes.

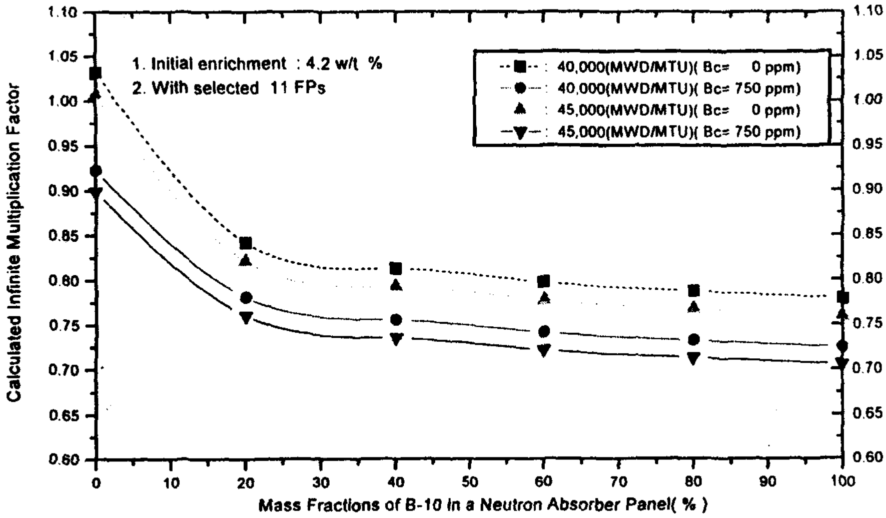

Fig. 3 Calculated Infinite Miltiplication Factors with Mass Fractions(%) of B-10 in a Neutron Absorber Panel of the Spent Fuel Storage Racks by Using the HELIOS Code.

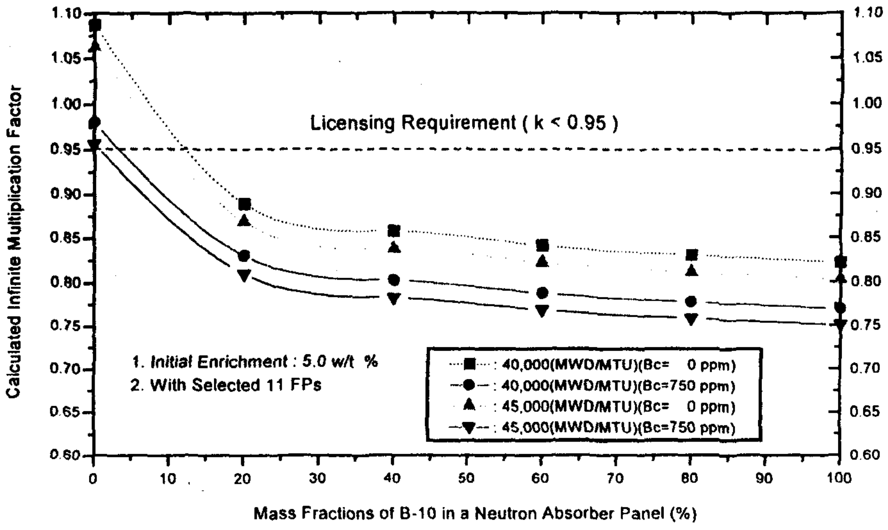

Fig. 4 Calculated Infinite Multiplication Factors with Mass Fractions (%) of B-10 in a Neutron Absorbe Panel of the Spent Fuel Storage Racks by Using the HELIOS Code.