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Parameter Study for Optimal PWR Spent Fuel Shipping Cask

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Abstract

The burnup effects and design parameters for optimal design of PWR spent fuel shipping cask were analyzed for various cases of PWR spent fuel shipping casks by using the HELIOS, MCNP-4/B, and CAPSIZE computer codes. The investigated parameters were burnup, cooling time, combinations of nuclides in the PWR spent fuel and shielding materials of shipping casks. The fuel compositions for burnup effects and design parameters of shipping casks were evaluated by HELIOS, MCNP-4/B and CAPSIZE codes, respectively. The results of the analysis show that the largest saving effect of the neutron multiplication factor due to burnup credit is 30 %. This is mainly due to the consideration of actinides and fission products in the criticality analysis. On the other hand, the evaluated maximum SLC(Specific Loading Capacity) of Fe-cask, Lead-cask and DU-cask were 0.2, 0.24 and 0.3, respectively.

I. Introduction

The use of the burnup credit in the design of criticality control systems enables more spent fuel to be loaded in a shipping cask. Increased loading capacity result in a reduced number of storage, shipping and disposal containers for a given number of spent fuel assemblies.

The burnup credit methodology consists of five major steps:

i) Validate a computer code system to calculate isotopic concentrations in spent fuel created during burnup in the reactor core and subsequent decay;

ii) Validate a computer code system to predict the subcritical neutron multiplication factor of a spent fuel cask;

iii) Establish bounding conditions for the isotopic concentration and criticality calculations;

iv) Use the validated codes and bounding conditions to generate loading criteria (burnup credit loading curve). Burnup credit loading curves show the minimum burnup required for a given initial enrichment;

v) Verify the spent fuel assemblies meet the loading criteria and confirm proper assembly selection prior to loading.

Given the burnup of the spent fuel, its cooling time, the thickness of the internal basket walls, the desired external dose rate, and the nominal weight limit of the loaded cask, someone should determine the maximum number of PWR spent fuel assemblies that may be shipped in some cask meeting those criteria.

In order to investigate the maximum loading capacity of PWR spent fuel shipping cask, we used the concept of the SLC(Specific Loading Capacity) as follows:

SLC(Specific Loading Capacity) = Number of Fuel Assembly / Total Weight of Cask(ton)

II. Computational Methods

1. Computer codes

We used the HELIOS, MCNP-4/B and CAPSIZE computer codes for the calculation of neutron multiplication factors and cask design parameters, respectively.

The HELIOS computer code is a multi-group (ENDF/B-VI) two-dimensional transport theory program for fuel burnup and gamma-flux calculations[1].

The MCNP-4/B[2] computer code is a general-purpose, continuous-energy (ENDF/B-VI), generalized geometry, coupled neutron-photon-electron Monte Carlo transport calculation, including the capability to calculate eigenvalues for critical systems. Also, this code has ten statistical checks that provide a meaningful measure of false convergence. The MCNP-4/B allows one to calculate the effect of a small perturbation in a problem. This feature estimates the tally differences due to changes in nuclear cross-section data, material density, and material composition[3].

Given the burnup of the spent fuel, its cooling time, the thickness of the internal basket walls, the desired external dose rate, and the nominal weight limit of the loaded cask, the CAPSIZE[4] computer code determine the maximum number of PWR spent fuel that may be shipped in a lead, steel, or uranium shielded cask meeting those objectives. The necessary neutron and gamma shield thickness are determined by the program in such a way as to meet the specified external dose rate while simultaneously minimizing the overall weight of the loaded cask. Neutron and gamma source terms, as well as the decay heat terms, are based on ORIGEN-S analyses of PWR spent fuel assemblies having exposures of 10,000 ~ 60,000(MWD/MTU).

2. Compositions and Geometry Data

2-1. Multiplication factors

The spent fuel rod data and fuel assembly data are shown in Table.1. Also, the PWR spent fuel in a modelled cask for HELIOS and MCNP-4/B are shown in Fig.1. The selected nuclides for the calculations of burnup credit are shown in the following table. In the context of this analyses, the terms "major actinides", "all actinides", and "fission products" are considered as follows :

	Nuclides
Major Actinides (15)	· U-234, 235, 236, 237, 238, Pu-238, 239, 240, 241, 242 · Np-237, 238, 239 Am-241, 243
All Actinides (19)	· Major Actinides + (Cm-242, 243, 244, 245)
Fission Products (24)	· Mo-95, Tc-99, Ru-101, Rh-103, Ag-109, Cs-133 · Nd-143, 145, Sm-147, 149, 150, 151, 152 · Eu-153, 154, 155 Gd-155, 156, 157, 158, Br-81 · Kr-81, 83 Zr-93

2-2. Cask design parameters

The structures of a typical PWR spent fuel shipping cask are shown in Fig.2. Nine different cases were chosen to investigate the burnup effect and design parameters for optimal design of PWR spent fuel shipping cask as follows;

Case	Burnup (MWD/MTU)	Cooling Time (Years)	Dose Limit (mrem/hr)	Weight limit (ton)
Case-1	35,000	8	10.0	30
Case-2	45,000	8	10.0	30
Case-3	60,000	8	10.0	30
Case-4	35,000	8	10.0	50
Case-5	45,000	8	10.0	50
Case-6	60,000	8	10.0	50
Case-7	35,000	8	10.0	86
Case-8	45,000	8	10.0	86
Case-9	60,000	8	10.0	86

III. Results of Numerical Analysis

1. Results of MCNP and HELIOS

The infinite neutron multiplication factors of single assembly by HELIOS(34 groups) are shown in Table 2. Also, the infinite neutron multiplication factors of spent fuel shipping cask by HELIOS(34 groups) are shown in Table 3. The burnup credit saving effect (%) calculated by MCNP, HELIOS are given in Table 2 and Table 3, respectively.

More than 30 % of the calculated reactivity(due to burnup credit) saving effect is observed in this analysis by considering both actinides(17) and fission products(24). From this, we can get the reduced separator(borated stainless steel) thickness of PWR spent fuel shipping cask up to 1 cm.

2. Results of CAPSIZE

Fig.3 and Fig.4 show calculational results of increased loading capacities and specific loading capacities of spent fuel shipping casks, respectively. In Fig.3, the calculated values of increased loading capacity of spent fuel shipping casks are varies with cask materials(Fe, Lead and Depleted Uranium), burnup and weight limit. Realistic values of the increased loading capacity of spent fuel shipping casks are located in the ranges of 20 % ~ 40 %.

In Fig.4, the calculated minimum and maximum values of SLC of Fe-cask were 0.03(Case-2) and 0.2(Case-8), respectively. Also, the calculated minimum and maximum values of SLC of DU-cask were 0.07(Case-2) and 0.3(Case-8), respectively.

IV. Conclusion

In this paper, the burnup effects of PWR fuel pincell reactivity for fresh and irradiated MOX fuels were analyzed by using the HELIOS, MCNP-4/B, CRX and CDP computer codes.

The investigated parameters were burnup, cooling time and combinations of nuclides in the fuel region. Overall, the most interesting result in this analysis is that the largest saving effect of neutron multiplication factor due to burnup credit is 30%. This is mainly due to the consideration of actinides and fission products in the criticality analysis.

On the other hand, the evaluated maximum SLC of Fe-cask, Lead-cask and DU-cask were 0.2, 0.24 and 0.3, respectively.

References

1. *HELIOS Methods*, SCANDPOWER, 5 December 1994.
2. J.F. Briesmeister, *MCNP-A General Monte Carlo N-Particle Transport Code,* Version 4B, LA-12625-M(March 1997).
3. H.E. McLaughlin, J.S. Hendricks, "Performance of Scientific Computing Platforms with MCNP-4/B", *Nuclear Science and Engineering*, **129**, pp.311-319, 1998.
4. J.A. Bucholzho, *CAPSIZE A Personal Computer Program and Cross-Section Library for Determining The Shielding Requirements, Size, and Capacity of Shipping Casks Subject to Various Proposed Objectives*, ORNL/CSD/TM-248(May 1987).

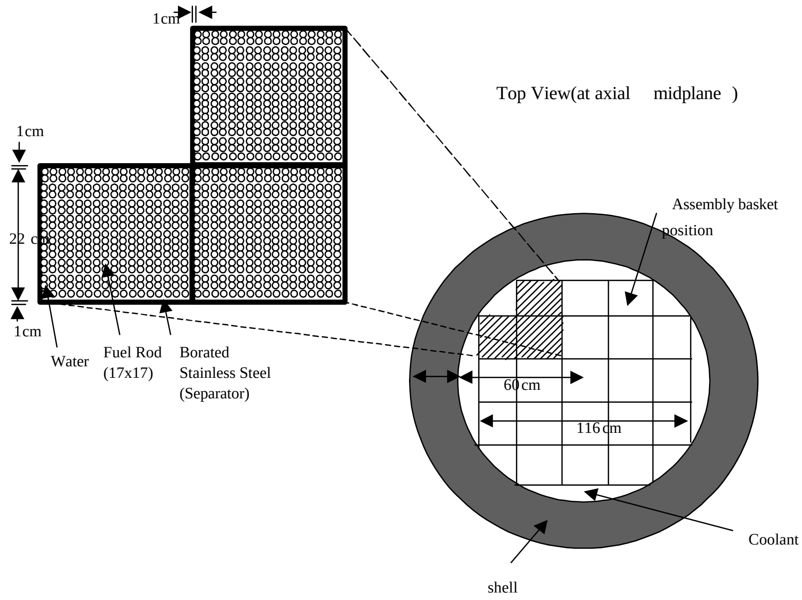

Fig.1 PWR Spent Fuel in A Modelled Cask for HELIOS and MCNP-4/B.

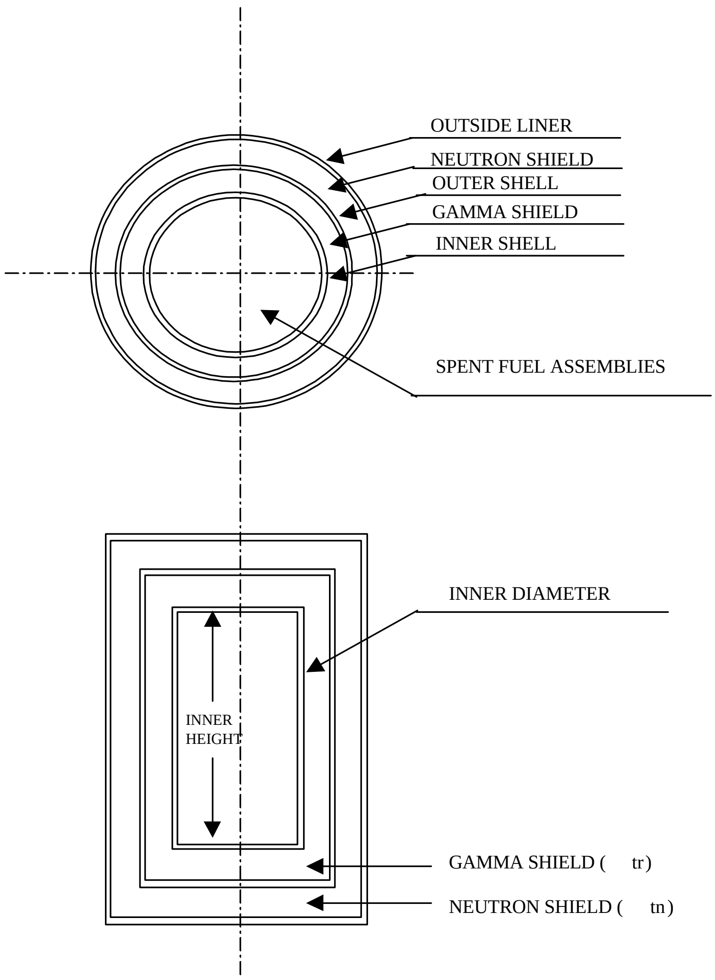

Fig. 2 Overview of a Typical Spent Fuel Shipping Cask

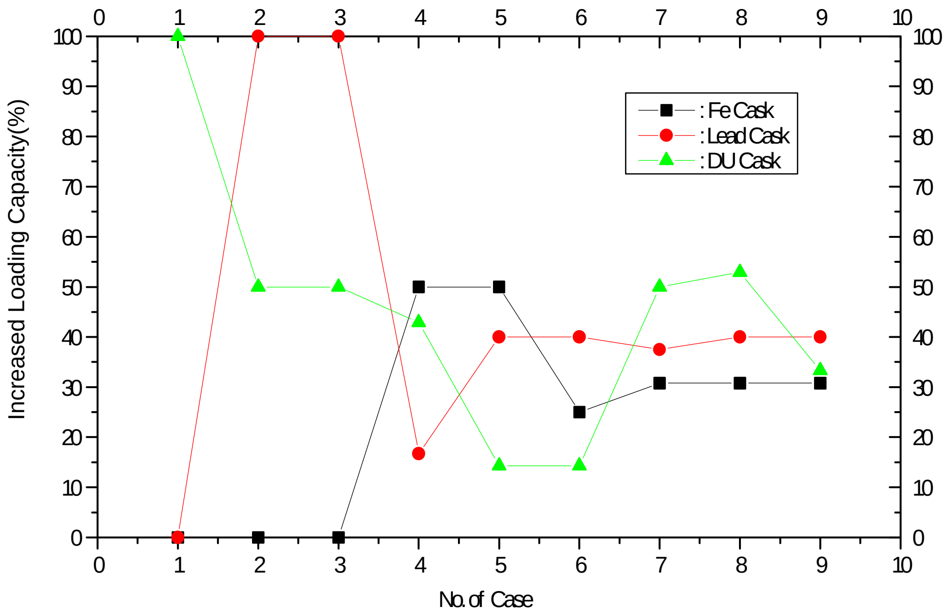

Fig. 3 Increased Loading Capacity of Shipping Casks by The Reduction of Separator Thickness Due to Burnup Credit(6.35 cm- 1.27 cm).

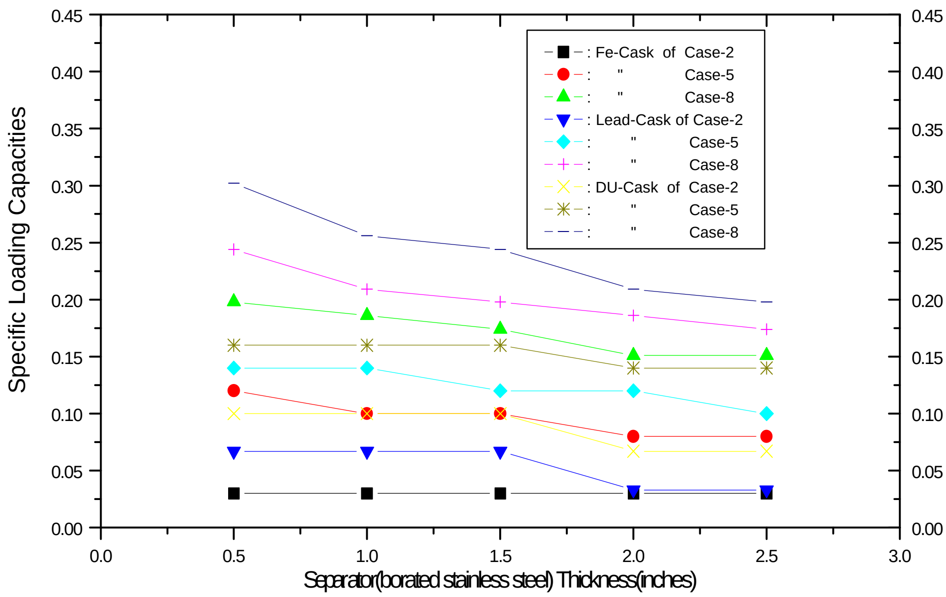

Fig. 4 Calculational results of Specific Loading Capacities by Using CAPSIZE Code.

Table.1 Fuel Rod and Assembly Data

Fuel Rod Data		Fuel Assembly Data	
-Fuel Diameter	0.8192 cm		
-Rod I.D	0.8357 cm	-Lattice	17x17
-Rod O.D	0.9500 cm	-Dimensions	21.41728x21.41728x409.2 cm^3
-Fuel Length	365.7 cm	-Pitch	1.25984 cm
-Fuel Material	UO_2(5.0 w/o)	-Moderator	Water
-Clad Material	Zircaloy		

Table.2 Infinite Neutron Multiplication Factors(k_{inf}) of Single Assembly Calculation of HELIOS Code.

Burnup(MWD/MTU)	k_{inf} (Without Borated Stainless Steel)	k_{inf} (With Borated Stainless Steel)
0	1.38153	1.03153
60,000	0.91261	0.69447 (MCNP-4/B : 0.68460)
Burnup Credit Saving Effect	33.94 %	32.68 %

Table.3 Infinite Neutron Multiplication Factors of Spent Fuel Shipping Cask Calculation of MCNP-4/B Code(500 cycle, 3000 history/cycle).

Burnup(MWD/MTU)	Coolant Material		
	Water	Nitrogen	Helium
0	0.55283 (0.00029)	0.49159 (0.00026)	0.49100 (0.00026)
60,000	0.35981 (0.00020)	0.33877 (0.00019)	0.33838 (0.00022)
Burnup Credit Saving Effect	34.91 %	31.09 %	31.08 %

※( ) : Standard Deviation of Infinite Neutron Multiplication Factor Calculation by MCNP-4/B Code.