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Fuel Composition Heterogeneity Effect for DUPIC Core

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Abstract

A preliminary study of the heterogeneity effect of spent PWR fuel in CANDU was made using a reduced spent PWR fuel data base. The instantaneous core simulation has shown that the refueling ripple in the CANDU reactor is large if the spent PWR fuel is directly used. But the fuel heterogeneity effect can be reduced appreciably by blending spent PWR fuel with a small amount of fresh UO_2. The refueling simulation has shown that the operating margins of 6.0% and 8.7% are achievable for the peak channel and bundle powers, respectively, with the blended fuel.

I. Introduction

As an alternative to the disposal of spent PWR fuel, the recycling of spent PWR fuel in CANDU reactors (DUPIC) has been studied. In DUPIC fuel cycle, the spent PWR fuel is refabricated by the dry process (OREOX) and reused in the CANDU reactor, resulting in a higher discharge burnup than the natural uranium fuel which is currently being used in CANDU reactors. Because of various spent PWR fuel conditions such as initial enrichment, discharge burnup, and assembly type, the composition of refabricated fuel is not always the same.

The PWR to CANDU synergistic fuel cycle assumes no hardware change in CANDU reactor. Thus it is required to adjust the fuel composition such that the reactor performance is within the capacity of the reactor control system. In this study, we have estimated, in a preliminary fashion, the effect of the fuel composition heterogeneity effect using a reduced spent PWR fuel data base. As a way of reducing fuel heterogeneity, a blending method was proposed, which utilizes fresh UO_2 material.

II. Spent PWR Fuel Data Base

By the end of 1993, there were 2906 spent PWR fuel assemblies in Korea. The composition of each fuel assembly depends on its initial enrichment, discharge burnup, burnup history, and assembly type. There are nine different assembly types such as 14x14OFA, 16x16KOFA, 17x17KOFA, etc. The initial enrichment varies from 1.6 to 3.6 w/o and the discharge burnup is distributed between 7000 and 45000 MWD/T.

Modeling 2906 fuel types in core simulation is impractical because i) the purpose of this study is to estimate the effect of different fuel compositions which is obtainable using a fewer number of fuel types and ii) the spent PWR fuel composition strongly depends on the initial enrichment and the discharge burnup. Therefore it was decided to reduce the number of fuel types based on the initial enrichment and the discharge burnup only. The whole spent PWR fuel assemblies were grouped into 33 fuel types of which the distribution is shown in Figure 1.

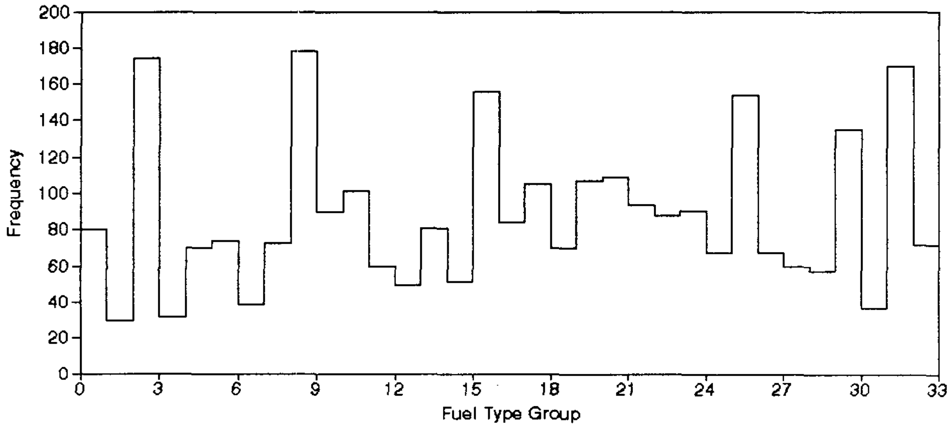

Figure 1. Distribution of 33 Fuel Types

III. Heterogeneity Effect

The neutronics properties of the 33 fuel types in CANDU reactor are calculated by WIMS-AECL[1] using ENDF/B-V nuclear data. The k_∞'s of 33 fuel types and of the nominal fuel are plotted in Figure 2. The nominal fuel is made of spent PWR fuel of which the initial enrichment and discharge burnup are 3.5 w/o and 35000 MWD/T, respectively.

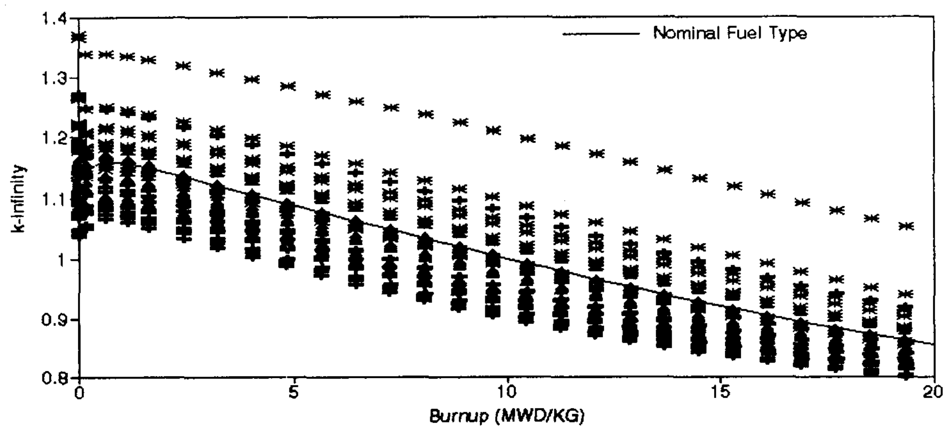

Figure 2. k_∞'s of 33 Fuel Types

III.1 Nominal Core

As a reference for the heterogeneity effect calculation, a nominal core was simulated first. The core is loaded with the nominal fuel type only and the refueling simulation was performed for 600 FPD using a 2-bundle shift refueling scheme. The average property of the nominal equilibrium core is summarized in Table 1.

III.2 Heterogeneous Core

For the heterogeneous core, the core performance is represented by the fuel type and burnup distribution. In order to save computing effort, the heterogeneity effect was first estimated by an instantaneous model of RFSP[2] representing a snapshot of the time-dependent core. The sequence of calculations is summarized as follows :

i) The bundle burnup of axial position k in channel (i,j) is expressed as:

$$w(i,j,k) = w_1(k) + f(i,j) \times (w_2(k)-w_1(k))$$

where $w_2(k)$ and $w_1(k)$ are the burnups before and after refueling, respectively, and are obtained from the refueling scheme which is 2-bundle shift in this study. The f(i,j) is the burnup fraction that channel (i,j) is through its cycle and is generated by patterned random numbers which are distributed uniformly over the interval (0,1). The patterned random number is then assigned to channel (i,j) based on an appropriate radial refueling zoning which is determined by actual refueling experience.

ii) Once the fuel burnup distribution is calculated, the 33 fuel types are assigned to the various bundle positions in the core. The frequency of 33 fuel types in the core is the same as that of Figure 1.

iii) Because one pattern of fuel type distribution is not sufficient to represent the time-dependent core, 30 different patterns were modeled using a random number generator. The results are summarized in column 2 of Table 1.

As shown in Table 1, it is expected that the peak channel and bundle powers of the heterogeneous core are beyond the operating limits. The local power peaking is attributable to the distribution of heterogeneous fuels in the core. The average zone controller level is lower than the time-average value (0.51) of the nominal core because the excess reactivity of the whole spent PWR fuel in the core is lower than that of the nominal fuel.

IV. UO_2 Blending

There could be several ways of reducing the heterogeneity effect such as i) selective use of spent PWR fuel which is mostly close to the nominal fuel type, ii) mixing 2 or 3 spent PWR fuel assemblies such that the average property is close to the nominal fuel type, or iii) blending the spent PWR fuel with fresh UO_2 to reproduce the nominal fuel property. The first option may reduce the spent PWR fuel utilization unless it is combined with the second option for the rest of spent PWR fuel. But both options may require UO_2 blending for the fine adjustment of CANDU fuel property. Therefore UO_2 blending was chosen as an option for reducing the fuel heterogeneity effect in this study.

The fissile enrichment of OREOX-processed CANDU fuel varies from 1.0 to 2.4 w/o, while that of nominal fuel is 1.56 w/o. For the fuel with low fissile content, the slightly enriched uranium (3.5 w/o SEU) is blended during the OREOX process. If the fissile content is high, it is diluted by adding depleted uranium (0.2 w/o DEU) during the OREOX process.

The amount of fresh UO_2 was determined such that the initial k_∞ of blended fuel is the same as that of nominal fuel which is 1.1547. The k_∞'s of 33 fuel types after UO_2 blending are shown in Figure 3. Compared to Figure 2, the variation of k_∞ is much smaller throughout the fuel burnup.

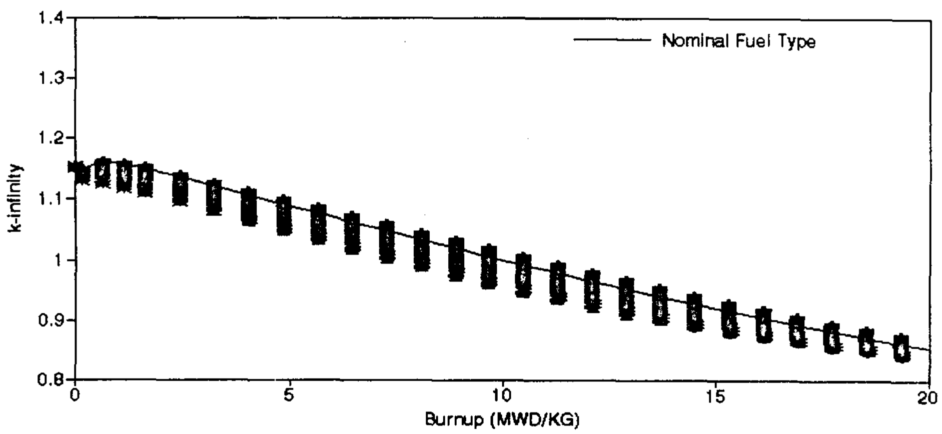

Figure 3. k_∞'s of 33 Fuel Types after Blending

The core simulation was performed for 600 FPD using the 33 fuel types blended with UO_2. The sequence of refueling fuel type is provided by a random number generator. The result of the refueling simulation is given in column 3 of Table 1. It is seen that the blending enables achieving 6.0% and 8.7% operating margins, on the average, for the channel and bundle power, respectively.

The channel power peaking factor(CPPF) is a measure of the channel power deviation from the reference value. Because the reference value used in this calculation is the channel power of the nominal core, the average CPPF of the heterogeneous core is somewhat larger than that of the nominal core. The time-dependent behaviors of the peak channel power and peak bundle power are plotted in Figures 4 and 5, respectively, and compared to those of nominal core.

V. Conclusion and Future Work

Without adjustment, the composition heterogeneity effect of spent PWR fuel on CANDU core performance is expected to be large. In order to allow the spent PWR fuel to be used in CANDU reactor without chemical reprocessing, the heterogeneity should be reduced, for instance, by blending the spent PWR fuel with fresh UO_2 during the OREOX process.

In the future it will be necessary to establish the sequence in which the spent PWR fuel is actually delivered to the OREOX process and CANDU reactor. If the capacity of the OREOX process facility is determined, the option of mixing several spent PWR fuel assemblies will be considered. It is important to note that the results derived here are preliminary and that further improvements are envisioned by the investigation of advanced methods for reducing fuel composition heterogeneity.

Acknowledgement

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References

(1) J.V. Donnelly, "WIMS-AECL: A User's Manual for the Chalk River Version of WIMS", AECL-8955, Chalk River, Canada, 1986.
(2) B. Rouben and D.A. Jenkins, "Calculation of 3-D Flux Distributions in CANDU Reactors Using Lattice Properties Which Include the History of the Lattice", 12th Annual Canadian Nuclear Society Conference, Saskatoon, Canada, 1991.

Table 1. Comparison of Performance Parameters

		Nominal Core(1)	Heterogeneous Core(2)	Heterogeneous Core(3)
Peak Channel Power(kW)	Maximum	7150	9169	7114
	Average	6722	7576	6859
	Minimum	6530	7001	6624
Peak Bundle Power(kW)	Maximum	825	1438	913
	Average	775	1184	854
	Minimum	750	1044	801
Channel Power Peaking Factor	Maximum	1.147	1.450	1.158
	Average	1.072	1.242	1.105
	Minimum	1.048	1.146	1.071
Zone Controller Level	Maximum	0.80	0.79	0.80
	Average	0.51	0.26	0.51
	Minimum	0.20	0.20	0.20

(1) 600 FPD Simulation
(2) 30 Instantaneous Calcultions (no blending)
(3) 600 FPD Simulation (UO_2 blending)

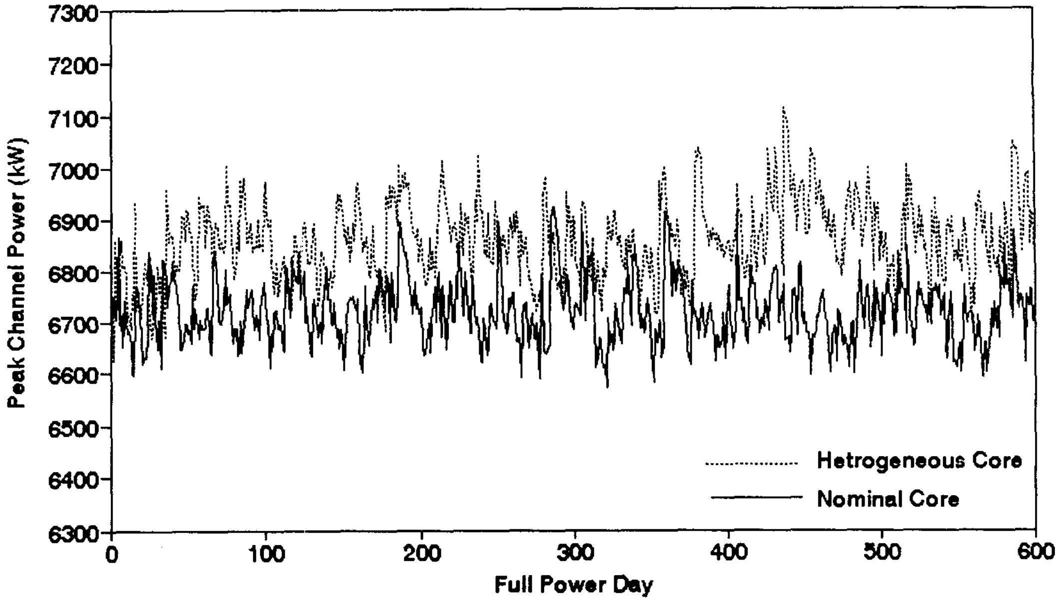

Figure 4. Comparison of Peak Channel Power

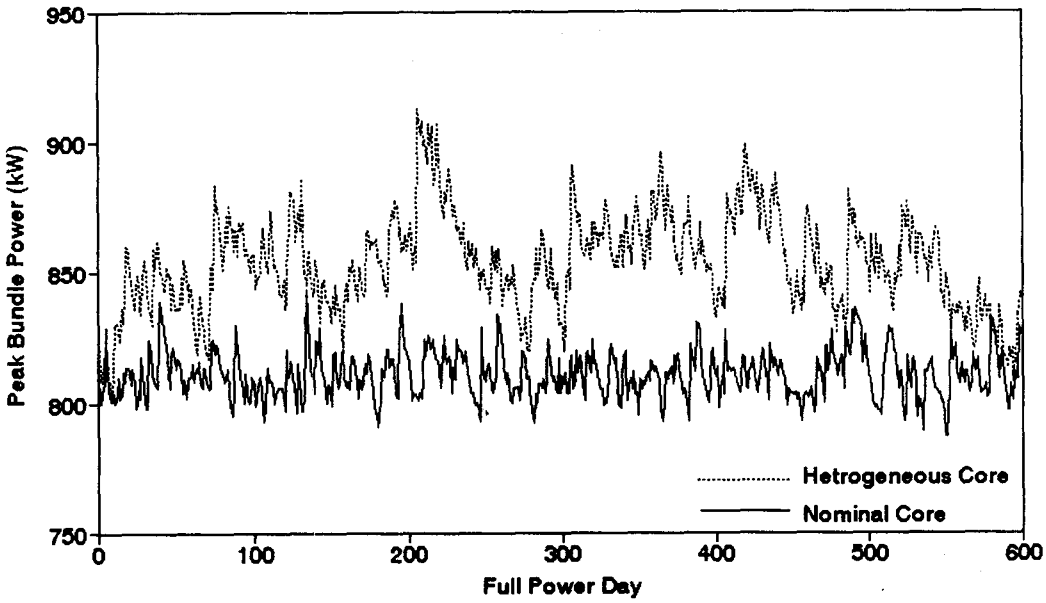

Figure 5. Comparison of Peak Bundle Power