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Void Reactivity of DUPIC Fuel Bundle

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Abstract

The coolant void reactivity is positive for CANDU reactor loaded with DUPIC fuel which has more fissile content compared to natural uranium. A parametric study was done to reduce the void reactivity of the fuel bundle and loss in discharge burnup was estimated. It is observed that the burnable absorbers like gadolinium, boron, europium are not able to keep the reduction in void reactivity uniform throughout fuel burnup. Dysprosium and erbium can keep the void reactivity reduction uniform throughout fuel burnup but loss in discharge burnup for erbium case is more compared to that of dysprosium case.

1. Introduction

The feasibility studies done so far have shown that the spent PWR fuel can be reused in CANDU reactor in the form of DUPIC fuel[1]. The fissile content and the isotopic composition of fuel are the key features distinguishing DUPIC fuel from natural uranium. The fissile content of the reference DUPIC fuel is 1.56 wt% which is more than twice that of natural uranium fuel.

Coolant void reactivity refers to the change in the core reactivity when coolant is lost. Coolant void reactivity is generally positive in CANDU reactors throughout its life. In CANDU reactors loaded with DUPIC fuel which has more fissile content, it is expected that the reactivity worth of existing shutdown systems will be reduced. Therefore it will be desirable to reduce the coolant void reactivity even at the cost of discharge burnup. In this paper, the results of the parametric study to reduce the void reactivity of the fuel bundle are discussed and loss in discharge burnup is estimated.

2. Behaviour of Void Reactivity

The neutron transport theory code WIMS-AECL[2] is used to calculate the void reactivity for 43-element fuel bundle of DUPIC fuel. The nuclide data used for lattice calculation is

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89-group cross-section library developed by AECL based on ENDF/B-V.

The coolant voiding introduces neutron spectrum shift both in fast and thermal energy region. This is considered to be due to the role of coolant scattering effect. When the coolant is present, it reduces the energy of fast neutrons coming out of the fuel while it increaces the energy of thermal neutrons which are coming from the moderator to the bundle centre region. When the coolant is lost upon voiding, these two effects will be missing and, therefore, the spectrum shift both in fast and thermal energy region is expected. To understand the behaviour of void reactivity, the reaction rates calculated by WIMS-AECL are studied through four factors which are defined as follows :

$$k = \eta' \, f \, p' \, \varepsilon'$$

$$\eta' = \left(\frac{\nu \Sigma_{f2} \phi_2}{\Sigma_{a2} \phi_2} \right)_{fuel}$$

$$f = \frac{(\Sigma_{a2} \phi_2)_{fuel}}{(\Sigma_{a2} \phi_2)_{cell}}$$

$$p' = \frac{(\Sigma_{a2} \phi_2)_{cell}}{(\Sigma_{a1} \phi_1 + \Sigma_{a2} \phi_2)_{cell}}$$

$$\varepsilon' = \left(\frac{\nu \Sigma_{f1} \phi_1 + \nu \Sigma_{f2} \phi_2}{\nu \Sigma_{f2} \phi_2} \right)_{fuel}$$

Table 1 shows the changes that occur in these four factors upon coolant voiding for DUPIC fuel with and without absorber at 0 and 7453 MWD/T fuel burnup. The change in η' is negative while change in all other factors are positive upon voiding for 0 and 7453 MWD/T for both with and without dysprosium in the centre fuel rod of the bundle. It is observed from the reaction rates that increase in thermal production rate is less compared to increase in thermal absorption rate in fuel upon voiding. Therefore η' decreases upon voiding. It is observed from Table 1 that changes in all these four factors are slightly more at 7453 MWD/T compared to that of 0 MWD/T for both with and without dysprosium in the centre fuel rod. By putting the absorber in the centre fuel rod, change in η' becomes more negative while the change in other factors is not much significant. Therefore void reactivity is reduced when the absorber is put in the centre fuel rod.

3.0 Reduction of Void Reactivity by Absorbers

The coolant void reactivity can be reduced by adding the absorber materials to the fuel bundle. Various absorbers like dysprosium, boron, gadolinium, erbium and europium are considered to be put in the inner rings of the 43-element bundle of DUPIC fuel to reduce the void reactivity. The amount of absorber is varied to see the change of coolant void reactivity as a function of burnup.

Earlier study[3] has shown that the prompt inverse period of DUPIC bundle will be the same as that of natural uranium fuel at equilibrium burnup when 5.27 at% of natural dysprosium is put in the centre rod of 43-element DUPIC fuel bundle. The amount in atom percent is determined for various absorbers to be used in the centre rod of DUPIC fuel bundle such that the same void reactivity can be obtained as that of reference DUPIC fuel which has 5.27 at% of natural dysprosium.

Table 2 shows the corresponding amount of absorbers, void reactivity at equilibrium, discharge burnup and peak linear power ratio. It can be observed from this Table that peak linear power ratio is deteriorated because radial power profile shifted to outer fuel ring of a bundle compared to the case without poison. The differences of peak linear power ratio among burnable poisons are relatively small. Fig.1 shows the variation of void reactivity with burnup. It can be observed from this Figure that void reactivity changes very rapidly with fuel burnup when gadolinium is put in the centre fuel rod. For the cases of boron and europium, the same amount of reduction in void reactivity is not maintained either throughout the fuel burnup. The dysprosium and erbium keep the reduction in the void reactivity more or less constant throughout the fuel burnup. Table 2 shows that discharge burnup for erbium case is lower than that of dysprosium case.

The amount of absorber is varied to see the reduction in void reactivity and loss in exit burnup. The dysprosium with 5.27 at% case is taken to be the reference case. The effect of putting the dysprosium in the second ring is also studied. Two cases are analyzed namely when 0.5 and 1.0 at% dysprosium is put in the second ring while keeping 5.27 at% dysprosium in the first ring. It is observed that in these two cases the coolant void reactivity decreases compared to the reference case. The increase in the coolant void reactivity with burnup in these two cases is more rapid compared to the case when dysprosium is put only in the centre rod. The result are summarized in Table 3. It can be seen from this Table that loss in discharge burnup increases as the void reactivity is decreased.

4. Other Attempts to Reduce Void Reactivity

4.1 Pin Size

Some other ways to reduce the coolant void reactivity are studied. In the first case, the centre rod of 43-element bundle was made thicker. And same atomic fraction of dysprosium, i.e. 5.27 at%, is put in the centre rod as in the reference case. In this case, the void reactivity at equilibrium is 10.9 mk compared to reference case where it is 11.8 mk. The loss in discharge burnup is 650 MWD/T.

4.2 Scattering Material

In the next two cases, the DUPIC fuel in the centre rod of 43-element bundle is replaced by thorium and graphite. The amount of dysprosium in the centre rod is kept same, i.e. 5.27 at%. The void reactivity in the two cases are 10.7 and 10.8 mk. The losses in discharge burnup in the two cases are 1310 and 410 MWD/T, respectively. The results are summarized in Table 4.

5. Conclusions

The presence of absorber in the fuel bundle can reduce the void reactivity but also reduces the discharge burnup. Gadolinium, boron and europium are not able to keep the reduction in void reactivity same throughout fuel burnup. Dysprosium and erbium keep the void reactivity control uniform throughout fuel burnup. For the same void reactivity at equilibrium burnup, erbium reduces dischage burnup more compared to dysprosium.

References

(1) J.S. Lee et al., "Research and Development Programme of KAERI for DUPIC (Direct use of spent PWR fuel in CANDU Reactors)", Proceedings of International Conference and Technical Exhibition on Future Nuclear System: Emerging Fuel Cycles and Waste Disposal Options, Global '93, Seattle, USA 1993.

(2) J.V. Donnelly, "WIMS-CRNL: A User's Manual for the Chalk River Version of WIMS", AECL-8955, Chalk River, Canada (1986).

(3) B.W. Rhee et al., "A Comparative Analysis on Low Void Reactivity DUPIC Fuel Bundle" Proceedings of International Conferences on Mathematics and Computations, Reactor Physics, and Environmental Analyses, Portland, USA (1995).

Table 1. Relative Changes (x1000) in Four Factors for DUPIC Fuel

	DUPIC without Absorber		DUPIC with Dy	
	0 MWD/T	7453 MWD/T	0 MWD/T	7453 MWD/T
η'	-2.0	-2.3	-6.6	-6.4
f'	2.7	3.0	2.8	3.1
p'	9.7	10.2	9.1	9.5
ε'	5.2	5.8	5.8	6.3
k'	13.0	15.8	9.4	11.8

Table 2. Comparision of Burnable Poisons for DUPIC Fuel

Burnable Poison	Amount of Poison (at%)	Coolant Void Reactivity*(mk)	Discharge Burnup (MWD/T)	Peak Relative Linear Power Ratio*
None	0.00	15.85	18839.5	1.139
B	2.85	11.78	15258.3	1.174
Gd	4.77	11.73	16023.0	1.164
Eu	4.80	11.74	15228.0	1.172
Dy	5.27	11.75	15041.0	1.174
Er	22.90	11.72	14172.3	1.185

* Values at Equilibrium Burnup

Table 3. Comparison of Burnable Poisons

Absorber	Amount (at%)		Discharge Burnup (MWD/T)	Loss in Burnup (MWD/T)	Void Reactivity* (mk)
	Ring-1	Ring-2			
Natural Dy	5.27	-	15041.0	-	11.8
	10.0	-	13170.0	1870.0	9.8
	15.0	-	12300.0	2740.0	8.9
	5.27	0.5	11200.0	3840.0	8.9
	5.27	1.0	7570.0	7470.0	5.8
Natural B	5.0	-	13343.0	1700.0	9.9
	10.0	-	11880.0	3160.0	8.8
	15.0	-	11360.0	3680.0	8.3
Natural Er	30.0	-	13415.0	1625.0	10.9
	50.0	-	12120.0	2920.0	9.4
Natural Eu	10.0	-	12710.0	2330.0	9.2
	20.0	-	11200.0	3840.0	8.2

* Values at Equilibrium Burnup

Table 4. Effect of Scattering Material In Centre Rod Position

Centre Rod	Discharge Burnup (MWD/T)	Loss in Burnup (MWD/T)	Void Reactivity* (mk)
DUPIC Fuel + 5.27 at% Dy	15040.0	-	11.8
Thicker Rod + 5.27 at% Dy	14390.0	650.0	10.9
Thorium + 5.27 at% Dy	13730.0	1310.0	10.7
Graphite + 5.27 at% Dy	14630.0	410.0	10.8

* Values at Equilibrium Burnup

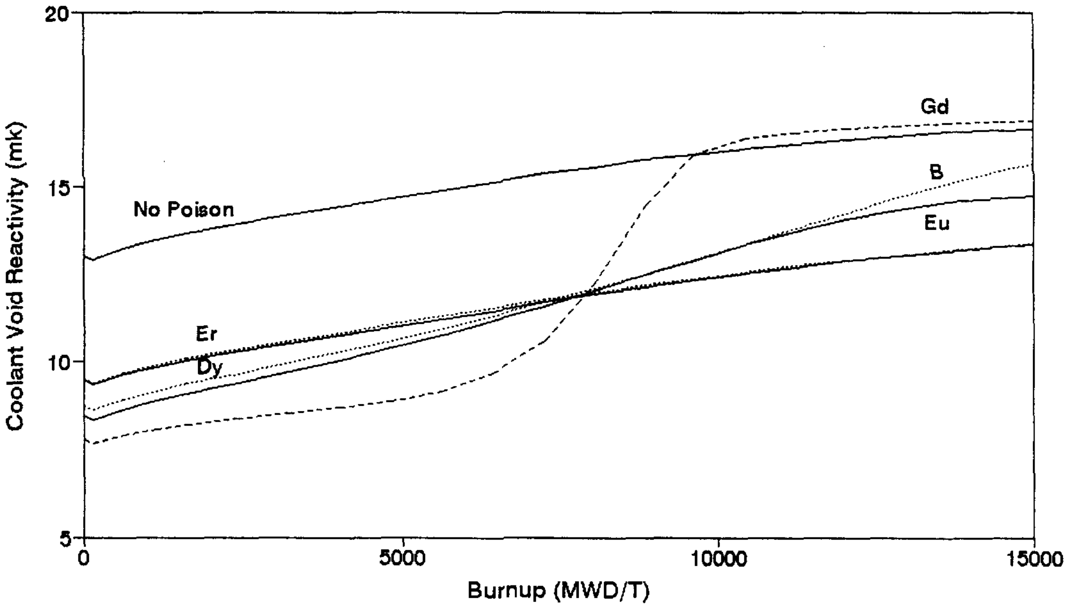

Figure 1. Void Reactivity for Each Burnable Poison Option