Proceedings of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 1996

Assessment of CANDU Adjuster System for DUPIC Fuel

Hari P. Gupta*, Hangbok Choi, Bo W. Rhee, Hyunsoo Park
Korea Atomic Energy Research Institute

Abstract

The characteristics of adjuster rods have been studied for the application to DUPIC core in two aspects: the half an hour xenon override capability and power flattening. The transient analysis has shown that the adjusters used for CANDU 6 have the reactivity worths more than required to override xenon load for DUPIC core. Parametric study has shown that removing 7 adjuster rods in the middle row and adjusting the strength of the rest of adjuster rods can provide the performances no worse than those of natural uranium core.

1. Introduction

The Direct Use of Spent PWR Fuel in CANDU (DUPIC) fuel cycle is aiming to reduce the spent fuel arising and increase the resources utilization by reusing the spent Pressurized Water Reactor (PWR) fuel in Canadian Deuterium Uranium (CANDU) reactor which was originally designed for natural uranium fuel. If the spent PWR fuel, of which the fissile content is 1.56 wt%, is loaded in the existing CANDU reactor, the characteristics of the reactor core and performance of reactivity devices will change accordingly. Previous study[1] has shown that the reactivity worths of various reactivity devices are degraded because flux distribution is more flattened and neutron spectrum is hardened in DUPIC core compared to natural uranium core.

The adjuster rods are the reactivity devices which are deployed in CANDU reactors during normal operation in order to establish a flattened power shape and to restart the reactor in half an hour after shutdown by overriding the negative xenon reactivity[2]. In CANDU 6 reactor, there are 21 adjuster rods (Figure 1) which are made of stainless steel in rod-in-tube form. In this study, the half an hour restarting capability of adjuster rods in DUPIC core was assessed and the parametric study was performed to minimize the burnup penalty caused by the adjuster rods without losing the half an hour restarting capability and power flattening.

---

* Visiting Scientist from Bhabha Atomic Research Center, India

2. Xenon Transient Analysis

The xenon reactivity load was calculated by WIMS-AECL[3] for equilibrium burnup fuel. For DUPIC core, the equilibrium xenon concentration is higher because of lower thermal flux level (the flux levels are 1.40×10^{14} and 1.86×10^{14} n/cm^{2}sec for DUPIC and natural uranium core, respectively) caused by higher fissile content. The equilibrium xenon concentration is the starting condition of xenon buildup after shutdown. Since more xenon is decayed at the earlier stage, the xenon reactivity load is smaller for DUPIC core as shown in Figure 2.

The spatial effect of xenon reactivity was also considered in WIMS-AECL depletion calculation by incoperating the flux-square weighting. The form factor of DUPIC core is 0.61 at equilibrium burnup while that of natural uranium core is 0.55. The higher form factor (more flattening) enhances a slightly less weighting factor for xenon load in the finite medium. Therefore the spatial effect also introduces less xenon reactivity load in DUPIC core.

The xenon reactivity load at half an hour after shutdown is -5.7 mk and -12.4 mk for DUPIC and natural uranium core, respectively. The reactivity worth of adjuster rods for CANDU reactor loaded with DUPIC fuel at equilibrium state is 8.7 mk for 2-bundle shift refueling scheme. Therefore the reactivity worth of adjuster rods in CANDU reactors loaded with DUPIC fuel is more than needed for half an hour xenon override capability and will decrease discharge burnup during normal operation.

3. Options to Reduce Burnup Penalty

The optimum configuration and position of adjuster rods in DUPIC core will be different from those of natural uranium CANDU core. Because the DUPIC fuel cycle is aiming to use the existing CANDU reactor with minimum hardware changes, the repositioning[4] of adjuster rods is not considered as an option for reducing burnup penalty. Instead, selective use and dimensional change have been studied. These calculations were performed by CANDU core analysis code RFSP[5].

3.1 Selection of Adjuster Rods

In DUPIC core, the thermal flux level is lower in the middle (in axial direction) and centre (in radial direction) region because two fresh fuels are loaded at the front end of a fuel channel per each refueling operation for 2-bundle shift refueling scheme and adjuster rods are located in the middle region. Therefore the adjuster rods in the middle region have less importances and the contribution to total reactivity worth is relatively small compared to those in natural uranium CANDU core in which the thermal flux is peaked in the middle region. In order to reduce the reactivity worth, seven adjuster rods in the middle row were removed from the core maintaing the symmetry. The reactivity worth, peak channel and bundle power and exit burnup were calculated and the results are presented in Table 1.

The first case in Table 1 is the normal case where all the 21 adjuster rods are present. The worth of adjuster rods for 2-bundle shift refueling scheme is 8.7 mk. In the next three cases, removal of various adjuster rods is considered. For example, the middle row of adjuster rods, i.e. rod numbers 8 to 14, have been removed in the second case. The reactivity worth of remaining 14 adjuster rods reduces to 6.1 mk. The peak channel and bundle power increase compared to normal case by 0.77% and 2.8%, respectively, and the exit burnup increases by 348 MWD/T.

As seen in Table 1, the peak channel and bundle powers increase much when the adjuster rods in the first and third rows are removed while the gain in discharge burnup increases monotonically as the total reactivity worth of remaining adjuster rods decreases. The adjuster rods are located at bundle positions 5, 6-7 and 8 for rows 1, 2 and 3, respectively, while the bundle power is peaked around bundle positions 3 and 4. Therefore removal of any adjusters in rows 1 and 3 deteriorates the axial power peaking while excellent radial (x-direction) power distribution is achievable for a certain case (e.g., removal of adjuster type A which is in the middle of x-direction). If the adjuster type B or C is removed with 7 adjuster rods in the middle row, the total reactivity worth of remaining adjuster rods is less than 5 mk, which will reduce the xenon override time considerably (less than 27 min).

3.2 Resizing of Adjuster Rods

The adjuster rods are represented typically by their thermal absorption cross-sections. Thus the change of rod size can be simulated by changing thermal absorption cross-section. When the thermal absorption cross-section of all 21 adjuster rods is increased, the burnup reduces and the peak channel and bundle power increases. Because of increased strength of adjuster in the middle region, the axial peaking was reduced slightly but the power suppression in the center region causes a slight channle power increase in the peripheral region where the channel power is peaked. The reduction of thermal absorption cross-section increases the peak channel and bundle powers and exit burnup by 1.1%, 1.4% and 389 MWD/T, respectively. In this case, the axial and radial flattening is reversed compared to the case of increasing strength. The results are summarized in Table 2.

3.3 Selection and Resizing of Remaining Adjuster Rods

For the option of removing 7 adjuster rods in the middle row, a parametric study was done for the further reduction of peak channel and bundle powers. In this case, the strength of remaining adjuster rods were changed by modifying the thermal absorption cross-section of adjuster rods. Table 3 summarises the results of changing sizes for two data points which were selected such that the total reactivity worth is the same as that of normal core (21 adjuster rods) for one case and the total reactivity worth is the minimum (5.7 mk) for the other case.

When the centre row of adjuster rods is removed and the thermal absorption cross-section of the remaining 14 adjuster rods is increased such that the reactivity worth of adjuster rods becomes nearly the same as that of normal 21 adjuster rod case, there is no appreciable change in burnup, peak channel and bundle power. If the central row of adjuster rods is removed and the thermal absorption cross-section is reduced such that the reactivity worth of adjuster rods is slightly more that 5.7 mk, the increases in peak channel and bundle powers and exit burnup are 1.0%, 3.0% and 380 MWD/T, respectively.

4. Conclusions

The xenon transient analysis has shown that the xenon reactivity load is -5.7 mk for DUPIC core at half an hour after shutdown. Considering that the reactivity worth of adjuster rods is 8.7 mk, it can be concluded that the existing adjuster rods in CANDU is having the half an hour restarting capability in DUPIC core. As an option for reducing excess reactivity worth of adjusters, the case where centre row of adjuster rods is removed has shown the potential of being adopted for DUPIC core. In this case, the increase in peak channel and bundle power is less than 3% while the increase in exit burnup is about 350 MWD/T.

References

1. H.B. Choi et al., "Comparison of Refueling Schemes for DUPIC Core", 4th Int. Conf. on CANDU Fuel, Pembroke, Canada, 1995.

2. "Design Manual : CANDU 6 Generating station Physics Design Mannual", 86-03310-DM000, Rev. 1, Atomic Energy of Canada Limited, 1995.

3. J.V. Donnelly, "WIMS-CRNL: A User's Manual for the Chalk River Version of WIMS", AECL-8955, Atomic Energy of Canada Limited, 1986.

4. P.G. Boczar and M.T. VanDyk, "Improved Location of Reactivity Devices in Future CANDU Reactors Fuelled with Natural Uranium or Enriched Fuels", AECL-9194, Atomic Energy of Canada Limited, 1987.

5. D.A. Jenkins and B. Rouben, "Reactor Fuelling Simulation Program - RFSP: User's Manual for Microcomputer Version", TTR-321, Atomic Energy of Canada Limited, 1993.

Table 1. Summary of Removing Adjuster Rods in Middle Row

Adjusters removed (Position)	Reactivity Worth (mk)	Peak Channel Power (kW) & Location	Peak Bundle Power (kW) & Location	Exit Burnup (MWD/T)	Xenon Override Time (min)
None	8.69	6490.8 (M-4)	738.8 (M-4-4)	15050.9	47
⑧⑨⑩⑪⑫⑬⑭	6.08	6541.2 (F-8)	758.6 (E-12-7)	15398.8	32
①⑦ ⑧⑨⑩⑪⑫⑬⑭ ⑮㉑	5.55	6794.6 (M-5)	788.4 (L-5-6)	15452.9	29
④ ⑧⑨⑩⑪⑫⑬⑭ ⑱	5.32	6650.9 (H-11)	780.9 (E-12-7)	15486.3	28

Table 2. Summary of Resizing Adjusters

Variation of Thermal Absorption Cross-Section	Reactivity Worth (mk)	Peak Channel Power (kW) & Location	Peak Bundle Power (kW) & Location	Exit Burnup (MWD/T)	Xenon Override Time (min)
Σ_{a2} increased (by 20%)	10.07	6555.2 (M-4)	745.5 (M-4-4)	14878.2	55
None	8.69	6490.8 (M-4)	738.8 (M-4-4)	15050.9	47
Σ_{a2} decreased (by 35%)	5.75	6559.3 (F-8)	749.3 (F-8-4)	15440.4	30

Table 3. Summary of Removing Adjusters 8-14 and Resizing

Variation of Thermal Absorption Cross-Section	Reactivity Worth (mk)	Peak Channel Power (kW) & Location	Peak Bundle Power (kW) & Location	Exit Burnup (MWD/T)	Xenon Override Time (min)
Σ_{a2} increased (by 56%)	8.77	6489.3 (M-4)	747.2 (L-4-7)	15063.7	47
None	6.08	6541.2 (F-8)	758.6 (E-12-7)	15398.8	32
Σ_{a2} decreased (by 6%)	5.75	6553.0 (F-8)	760.7 (E-12-7)	15431.4	30

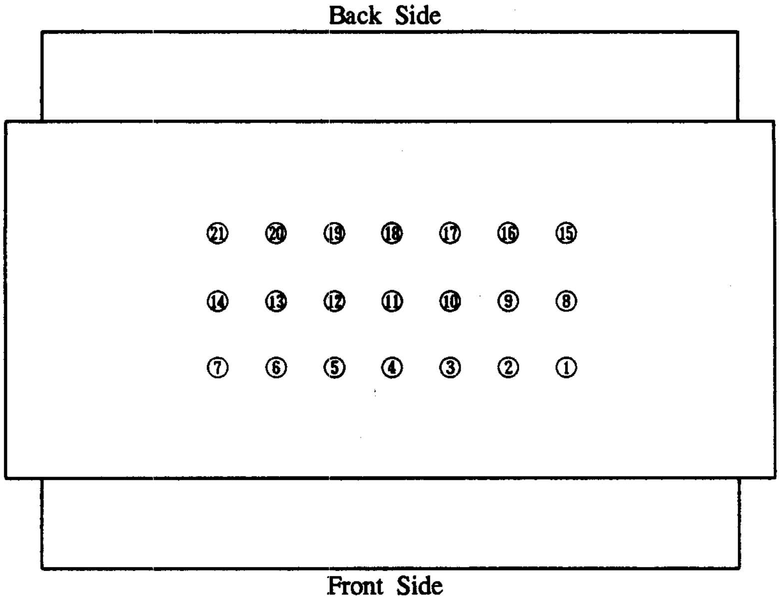

Figure 1. Plan View of Adjuster Positions

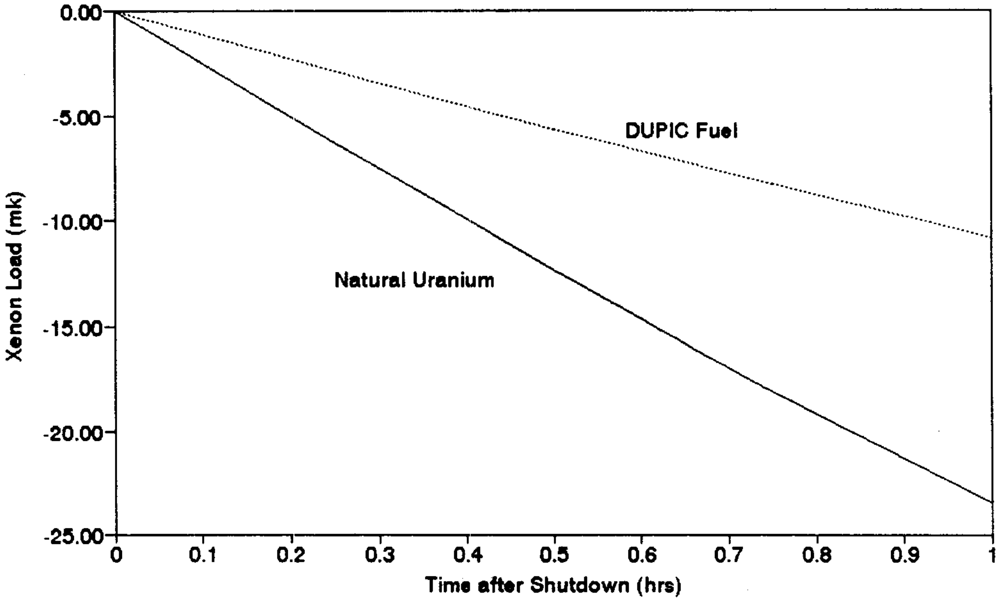

Figure 2. Xenon Reactivity Load for 1 Hour after Shutdown