Proceedings of Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1998

ASSESSMENT OF REACTIVITY DEVICES FOR CANDU-6 WITH DUPIC FUEL

Chang-Joon Jeong and Hangbok Choi
Korea Atomic Energy Research Institute

ABSTRACT

Reactivity device characteristics for a CANDU-6 reactor loaded with DUPIC fuel have been assessed. A transport code WIMS-AECL and a three-dimensional diffusion code RFSP were used for the lattice parameter generation and the core calculation, respectively. Three major reactivity devices have been assessed for their inherent functions. For the zone controller system, damping capability for spatial oscillation was investigated. The restart capability of the adjuster system was investigated. The shim operation and power stepback calculation were also performed to confirm the compatibility of the current adjuster rod system. The mechanical control absorber was assessed for the capability to compensate the temperature reactivity feedback following a power reduction. This study has shown that the current reactivity device systems retain their functions when used in a DUPIC fuel CANDU reactor.

1. INTRODUCTION

The direct use of spent pressurized water reactor in CANDU(DUPIC[1]) fuel cycle aims to utilize the existing CANDU reactor system which was originally designed to a natural uranium fuel. The reactor system includes not only the fuel and fuel channels but also all the reactivity devices and structural material in the system. Because the characteristics of the DUPIC fuel is different from those natural uranium fuel especially in the fissile content, the core characteristics and the reactivity device performance of the DUPIC fuel core will be different from those of natural uranium fuel core.

Preliminary studies[2,3] have shown that the DUPIC core performance represented by the maximum channel bundle powers can be well maintained when an appropriate refueling scheme and a burnup distribution are determined. However, such a change in a power distribution different from the natural uranium core, which causes change in the neutronic importance of reactivity devices spatially distributed in the core. In addition higher fissile content of DUPIC fuel shifts the neutron spectrum and the reactivity of the devices will change accordingly.

There are three major reactivity devices in a CANDU reactor; the zone controller unit(ZCU), the adjuster (ADJ) rod system and the mechanical control absorber (MCA). In this study, static reactivity worth of the reactivity device and insertion characteristics of some devices will be assessed through comparative analyses with those of the 37-element natural uranium core. In this calculation, cross-sections are generated by WIMS-AECL[4] code and core calculation is performed by RFSP[5] code.

2. LIGHT WATER ZONE CONTROLLERS

The zone control system provides means of short term reactivity control to maintain reactor power at a demanded level during normal operation. The zone control system maintains the desired global power distribution by counteracting any power distortion or oscillation brought on by a reactivity perturbation. The static reactivity worth of the zone controllers has been calculated as a function of the average zone level. The static reactivity worths of the zone control system at 100 % full and 50 % full are to be 5.76 and 3.22 mk, respectively, for the DUPIC fuel core. For 37-element natural uranium fuel core, the static reactivity at 100% full and 50% full are 6.50 mk and 3.65 mk, respectively.

The effectiveness of the zone control system in suppressing xenon-induced spatial oscillations was studied. A typical RFSP simulation for xenon transient was carried out by refueling channel J-14 at an equilibrium condition. The effectiveness of the zone control system is shown in Fig.1 for the top-to-bottom and side-to-side tilts at various times during the first 13 hours of the transient, where the tilts are defined as,

$$\text{top-to-bottom tilt (\%)} = \frac{(P_1+P_3+P_6)-(P_2+P_5+P_7)}{P_1+P_2+\ldots+P_7}\times 100$$

$$\text{side-to-side tilt (\%)} = \frac{(P_1+P_2)-(P_6+P_7)}{P_1+P_2+\ldots+P_7}\times 100$$

where P_i is the rate of neutron production in zone i (i = 1, 2, ..., 7).

It can be seen from Fig.1 that both the top-to-bottom and side-to-side tilts reach their first extreme values around 4 hours. The rates of change of tilts after 4 hours become smaller than the corresponding rates before 3 hours, indicating that spatial oscillations are damped.

3. ADJUSTER ROD SYSTEM

Twenty one graded adjusters (stainless steel absorbers) are provided in the CANDU-6. The adjuster rods are used for xenon-override capability needed to restart the reactor after a short shutdown, and for power maneuvering during startup or power derating, and for reactivity shim when fueling is temporarily interrupted.

A 30-minute xenon-override capability was specified for the CANDU-6. The xenon load at 30 minutes after shutdown is 6.8 mk for the DUPIC CORE. Because the static reactivity worth of the adjusters is -10.2 mk, the adjuster rods can surely override the 30-minute xenon load.

A detailed simulation is required to confirm that the present adjuster rod system and banking scheme is adequate for the 30-minute xenon override time. This has been done with the code RFSP. The results of RFSP simulations are shown in Fig.2, where it can be seen that the xenon override time (about 45 min) is longer than 30 minutes. The simulation also shown that it takes 440 minutes to return to full power, which is 200 minutes longer than that of the natural uranium fuel core. At one hour after return to full power, the average zone controller water level exceeds 90%, however the channel and bundle powers within operational limits. Therefore, it would be necessary to do moderator poisoning or MCA insertion in order to maintain reactor criticality.

If the reactor is not restarted within 30 minutes after shutdown, the reactor must be kept at shutdown state until poison(xenon) decays out. The startup transient after a poison-out was simulated to estimate the time required for the reactor to reach full power level. The simulation has shown that it takes 29.1 hours to restart the core if the reactor is not restarted within 30 minutes after shutdown. This is shorter than the time required for natural uranium fuel core(36.4 hrs) . The time required to reach full power level is 39.6 minutes for DUPIC fuel core, which is a little longer than that of the 37-element natural uranium fuel core(28.8 min.). However, it is expected that the adjuster rods perform well their function for restart after poisonout shutdown.

In the shim operation, some adjusters may be withdrawn to provide the needed reactivity in the event of a loss of refueling capability. The reactivity decay rate in a CANDU-6 with the DUPIC fuel is about 0.4 mk/FPD. Results of detailed simulation using RFSP code are shown in Fig.3. After withdrawing the first shim bank (bank #1), the power may be maintained at 94% without exceeding the bundle power constraint. The worth of bank #1 in shim operation is 1.11 mk and, therefore, the reactor can be operated with one bank out for about 2.8 full power days without refueling. When the second shim bank is out, the restraint on reactor power would be 87%. The worth of bank #2(bank #1 already withdrawn) is 1.59 mk and the withdrawal of the second shim bank provides additional 4 full power days of operation without refueling. This simulation has shown that successive withdrawal of adjusters would permit operation for about 31 days without refueling, which is about 10 days shorter than that of the natural uranium fuel. However, the shim operation is also available for the DUPIC fuel core without exceeding the maximum bundle and channel power limits.

4. MECHANICAL CONTROL ABSORBERS

Four identical mechanical control absorbers are provided in a CANDU-6 for rapid power reduction and to override the reactivity increase following a power reduction (due to the negative fuel temperature coefficient). Since the reactivity increase is significant and usually rapid, the zone controller system is incapable of counteracting the increase in all cases. In particular, the reactivity increase is the highest following a hot shutdown. The calculated total static reactivity of four control absorbers in an equilibrium core is -8.36 mk, which is 2.99 mk smaller in magnitude than that for the natural uranium fuel core. The reactivity increase following a hot shutdown in an equilibrium core is 3.0 mk and, therefore, the mechanical control absorber can compensate for the reactivity increase following a reactor hot shutdown.

The static reactivity worth of the control absorbers depends sensitively on the insertion depth and location. The static reactivity insertion characteristics when all four absorbers are inserted simultaneously was studied, and the results are shown in Fig.4. It can be seen that the difference of reactivity between DUPIC and natural uranium fuel core increases as mechanical control absorbers inserted deeply.

5. CONCLUSIONS

The reactivity device system assessments have been performed for a CANDU-6 with the DUPIC fuel. From the assessment, the following conclusions are obtained:

The zone controller system can suppress spatial oscillation following a reactor power level change or refueling of a channel. The MCA can compensate for the temperature reactivity feedback of the equilibrium core. The adjuster rod system has enough reactivity to override the xenon load 30 minutes after reactor shutdown. With current adjuster system, DUPIC core can be restarted without exceeding the bundle and the channel power limits following a short shutdown or poisonout shutdown. Moreover, the shim operation is available for 30 days without exceeding the maximum bundle and channel powers limits. The adjuster system can also be successfully used for power step back to 60% full power.

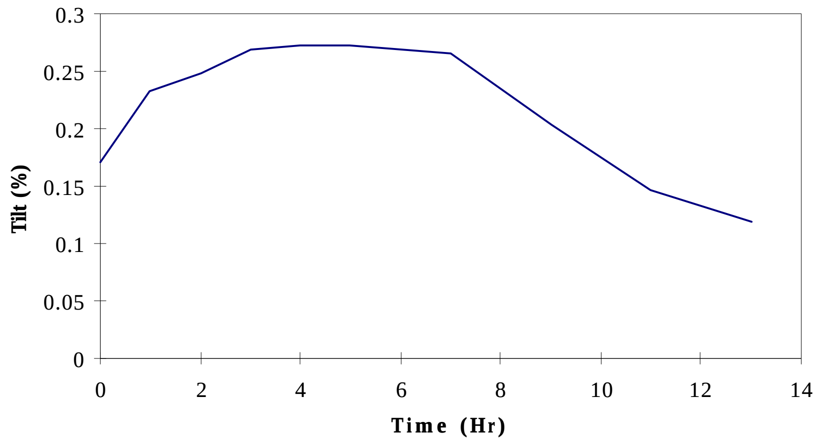
Consequently, it can be concluded that the current reactivity device system satisfies its design requirement even for the DUPIC core.

ACKNOWLEDGEMENT

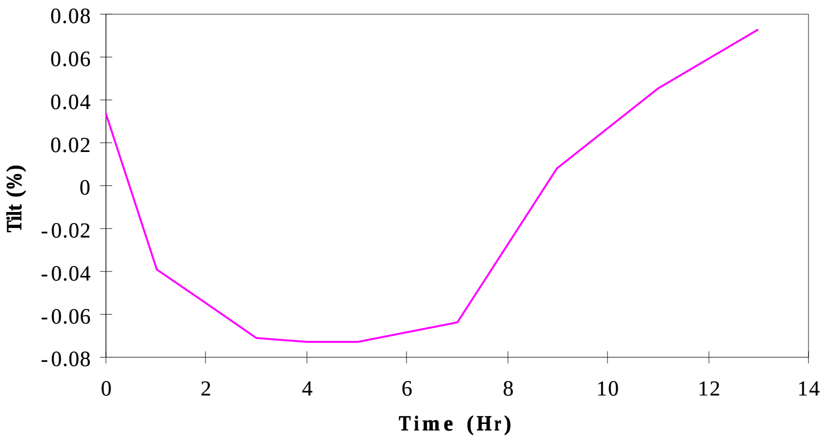
This project has been carried out under the Nuclear R&D Program by MOST.

REFERENCES

1. J.S. Lee et al., "Research and Development Program of KAERI for DUPIC (Direct Use of Spent PWR Fuel in CANDU Reactors)", Proc. of Int. Conf. and Tech. Exh. on Future Nuclear System, GLOBAL'93, Seattle, USA, 1993.
2. H.B. Choi et al., "Physics Study on Direct Use of Spent Pressurized Water Reactor Fuel in CANDU(DUPIC)", *Nucl. Sci. Eng.,* **Vol 126**, 80-93, 1997.
3. H.B. Choi et al., "Fuel Management and DUPIC Fuel Performance", *Trans. Am. Nucl. Soc.,* **Vol 73**, Oct. 29 - Nov. 2, 1995.
4. J.V. Donnelly, "WIMS-CRNL, A User's Manual for the Chalk River Version of WIMS", AECL-8955, 1986.
5. D.A. Jenkins and B. Rouben, "Reactor Fuelling Simulation Program - RFSP: User's Manual for Microcomputer Version", TTR-321, AECL 1991.



(a) Percent Top To Bottom Tilt



(b) Percent Side To Side Tilt

Fig. 1 Zone Controller System Operation-Transient After Refuelling Perturbation

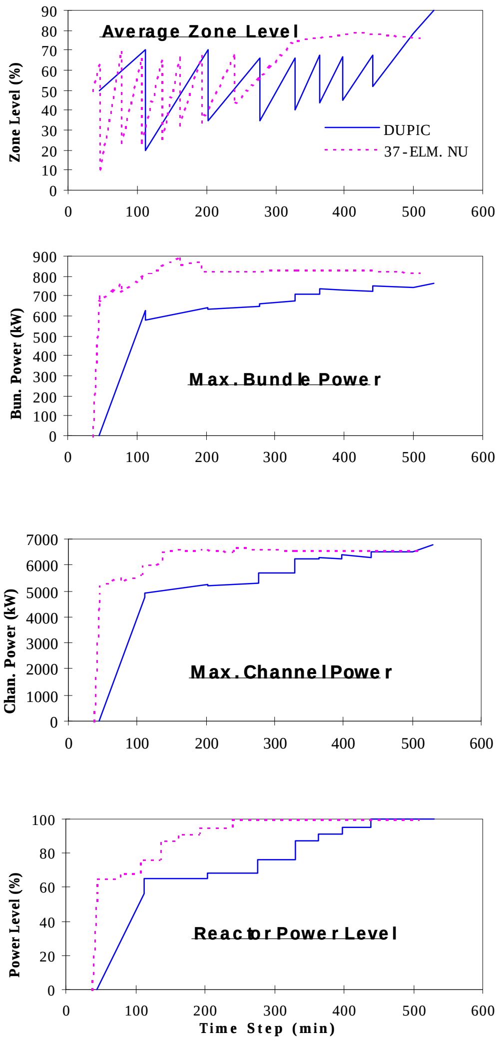


Fig. 2 Startup After Short Shutdown

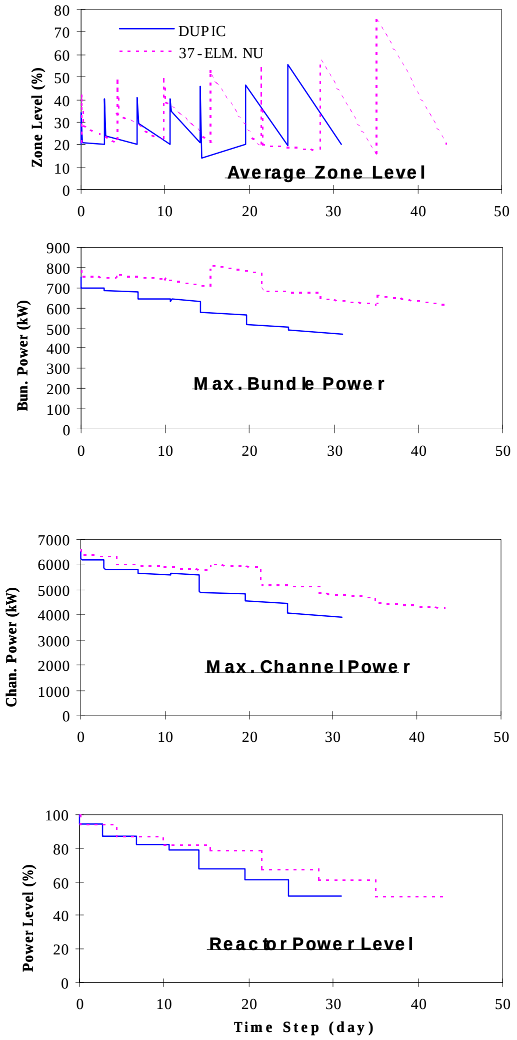


Fig. 3 Shim Operation

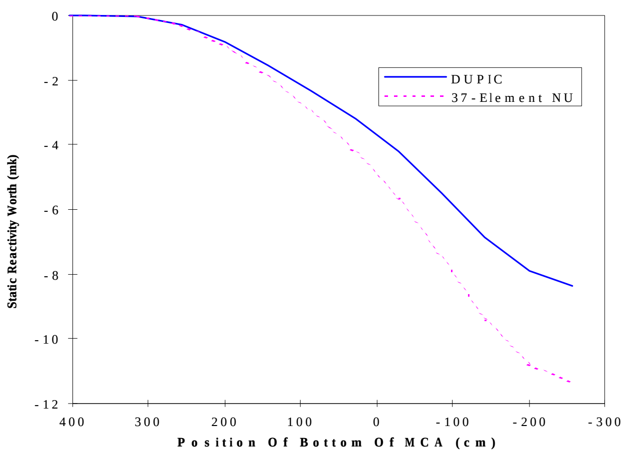


Fig. 4 MCA Insertion Characteristics