A STUDY ON THE CORE CHARACTERISTICS FOR A CANDU 6 REACTOR FUELLED WITH RECOVERED-URANIUM CANFLEX BUNDLES

BYUNG-JOO MIN, CHANG-JOON JEONG AND HO-CHUN SUK

Korea Atomic Energy Research Institute
P.O. Box 105, Yusong, Taejon 305-600, Korea

ABSTRACT

A study on the core characteristics for CANDU 6 reactor fuelled with reference (CANFLEX-RU) and low-void (version 1, CANFLEX-ST) fuels was performed. The time-average calculations with a 4-bundle shift fuelling scheme, the maximum bundle and channel powers of two fuel models have sufficient values to satisfy the design criteria of CANDU 6 reactor. The average exit burnups of two fuel models are over 50 % higher than that of CANFLEX-NU fuel. From the xenon transient calculations, the xenon load of two fuel models are lower than that of CANFLEX-NU fuel.

1. INTRODUCTION

The use of recovered uranium(RU) fuel in CANDU reactors potentially offers economic, environmental and public acceptance benefits. The RU can be used to flatten the channel power across the core to increase reactor power in new reactor designs or in existing designs where sufficient heat removal capacity exists. The RU fuel will have burnup of about 13,000 MWD/MTU and then reduce the annual spent fuel volume. It will also reduce the annual fuelling cost, depending on the RU price.

A study on the core characteristics for CANFLEX-RU has been performed to introduce recovered uranium in the CANDU 6 reactor. To analyze the core characteristics for the CANFLEX-RU(reference) fuel, time-average calculations have been carried out and the xenon load has been calculated for various reactor conditions. The static reactivity worths are also calculated for adjuster rods, light water zone control system and mechanical control absorbers.

The low-void (version 1, CANFLEX-ST) fuel bundle [1] is also considered. In this paper, the results of these calculations for reference fuel and low-void fuel bundles are described .

2. CALCULATION PROCEDURE

The lattice parameters were generated using WIMS-AECL code[2], and the incremental cross-sections of the reactivity devices and structural materials were calculated by MULTICELL code[3] for the reference (CANFLEX-RU) and low-void (version 1) fuel bundles.

In the time-averaged calculations, RFSP code[4] using the three-dimension realistic core model has been used with a 4-bundle shift fuelling scheme. In setting up the time-average model, the core was divided into 5 irradiation zones, over which the average fuel discharge irradiation is constant. These irradiation zones were chosen to make the reactor critical. The water levels in the zone control compartments were set to 50 % full, representative of the normal operating condition. The static reactivity worths for adjuster rods, light water zone control system and mechanical control absorbers are also calculated at time-average core.

Xenon load in a CANDU 6 reactor with reference and low-void fuel bundles has been calculated. The xenon properties were validated by WIMS-AECL code. After confirming the validity of the WIMS-AECL code, xenon loads were calculated for the case of various reactor power level changes and reactor shutdown from various power levels.

3. RESULTS

3.1. Time-Average Calculations

The results of the time-average calculation are shown in Table 1. Time-average calculations for 37-element NU fuel (CANDU 6) were calculated by WIMS-AECL/RFSP code and the results were compared to those of CANDU 6 design codes, POWDERPUF-S(PPV)[5]/RFSP.

In the case of reference fuel (CANFLEX-RU), the maximum time-average channel power is 6570 kW at the location of channel P-08. The maximum time-average bundle power is 774.7 kW at the location of bundle 4 in the channel N-08. In the case of low-void fuel (CANFLEX-ST, version 1), the maximum time-average channel power is 6499 kW at the location of channel N-17. The maximum time-average bundle power is 756.5 kW at the location of bundle 5 in the channel

M-19. The maximum bundle and channel powers are sufficient to satisfy the design criteria of CANDU 6 reactor.

The average exit burnup of reference fuel is 321 MWh/kgU, which is 17% higher than that (267 MWh/kgU) of low-void fuel. But this average exit burnup of version 1 bundle is 53% higher than that of CANFLEX-NU bundle. The other results of time-average calculations are shown in Table 2.

The reactivity worths of control devices for two fuel models are listed in Table 3. The reactivity worths of adjuster rod at reference and low-void fuels are 14.7 and 15.0 mk, respectively. These values are sufficient to override xenon at 30 minutes after shutdown because 30-minute xenon loads are less than ~ 12 mk, which is described in the next section. The functions of ZCU and MCA might be proper to control the CANDU 6 reactor with two fuels.

3.2. Xenon Dynamics

Xe-135 is an important fission product in reactor physics because it has a very large absorption cross-section and is therefore regarded as a poison material.

The xenon load refers to the reactivity holdup due to Xe-135. The xenon load affects reactor power control, spatial oscillation and restart of the reactor. If the reference and low-void fuels are loaded in a CANDU 6 reactor, the power distributions are different from those of a natural uranium fuel core, which cause reactivity worth changes of all the devices in the system. It is also expected that the xenon load of CANFLEX-RU fuel in CANDU reactor core will be smaller than that of a natural uranium fuel core, because the effective thermal flux is lower due to higer fissile content. Therefore it is necessary to assess the xenon load accurately for CANFLEX-RU in a CANDU 6 core in order to confirm the function of reactivity device used to control the xenon reactivity.

The following xenon transients were simulated for CANDU 6 core with the reference and low-void fuels.

3.2.1. Shutdown and Startup

Xenon reactivity transients after shutdown from various power levels are shown in Fig. 1. Power levels of 20%, 40%, 60%, 80% and 100% of full power were considered. Calculations were performed for two cases; the adjusters were fully in and fully out from the core. The magnitude of the peak xenon load is seen to increase with the power (flux) of the reactor before shutdown. When the adjusters are fully out, the peak xenon load is higher than that with the adjusters fully in. The reactor startup was simulated from zero power without xenon to various power levels including 20 %, 40 %, 60 %, 80 % and 100 % of full power. The variation in xenon load during the first 70 hours of startup is shown in Fig. 2. Note that the adjusters were fully in for these cases. The simulation has shown that xenon loads are back to their equilibrium value after 40 hours.

3.2.2. Power Step Backs From Full Power

Xenon reactivity transients after power set back from full power to 80 %, 60 %, 40 %, 20 % and 0 % are shown in Fig. 3. The transients were followed for 70 hours. The adjusters were fully in for all cases. It was found that the xenon loads are back to their equilibrium value within 30 hours ~ 40 hours, which is 5 hours shorter than that of the natural uranium fuel core.

3.2.3. Thirty-Minute Xenon Load

A thirty-minute xenon override capability of the adjusters is specified for the CANDU 6 reactor. Fig. 4 shows the xenon transient for 30 minutes after a reactor shutdown from an equilibrium core. It can be seen that the xenon buildups of the cores with reference and low-void fuels at 30 minutes after shutdown are 11.1 mk and 11.6 mk, respectively. These values are about 3 mk lower than that of the natural uranium fuel(CNAFLEX-NU) core. Therefore the adjuster rod worth should be greater than ~12 mk for the cores with two fuels in order to maintain the 30-minute xenon override capability.

4. SUMMARY

A study on the core characteristics for CANDU6 reactor fuelled with reference(CANFLEX-RU) and version 1(Low-void model, CANFLEX-ST) fuels was carried out. The results of time-average calculations and xenon load calculations for two fuel models are summarized as follows:

- From the results of time-averaged calculations, maximum channel and bundle powers of reference and low-void fuels are compatible with those of natural uranium fuel. In addition, the average exit burnups of the two fuel models are larger than that of natural uranium fuel core. (over 50 % for low-void and 80 % for reference fuels)

- From the results of static reactivity worths, the functions of control devices with above two RU fuels may maintain their requirements in the CANDU 6 reactor.
- From the results of xenon load calculations, it is shown that the xenon loads of two RU fuel models are lower than that of the natural uranium fuel core. However, the impact of the lower xenon load on the core characteristics of two RU fuels should be studied extensively.
- To know more detailed information of core characteristics, the fuelling simulations for the equilibrium core and transition core from the CANFLEX-NU to CANFLEX-RU are recommended.

ACKNOWLEDGEMENT

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Table 1.Results Of Time-Average Calculations

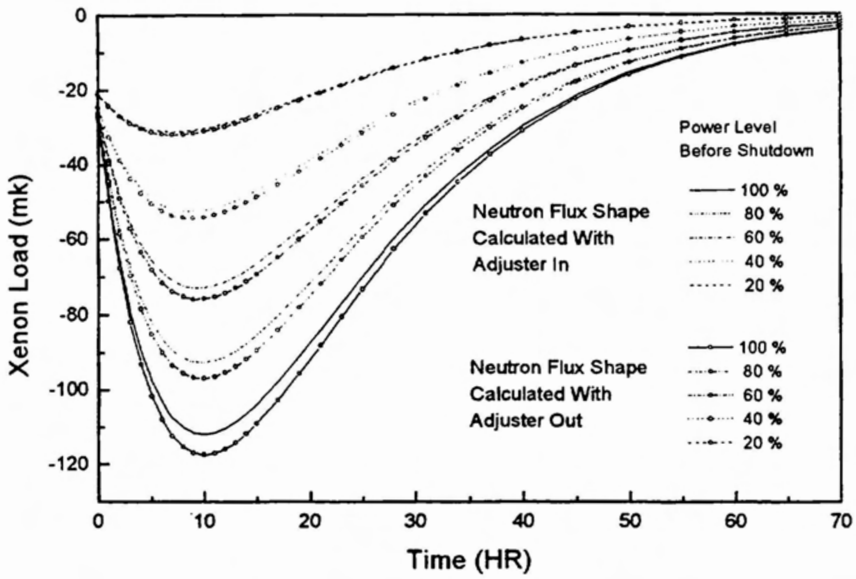
	CANDU 6 (PPV)	CANDU 6 (WIMS-AECL)	CANFLEX-NU	CANFLEX-RU (Reference)	Low-Void Fuel (Version 1)
Maximum Channel Power (kW)	6582	6583	6583	6570	6499
Location	N-17	P-08	P-08	P-08	N-17
Average Channel Power (kW)	5425	5425	5425	5425	5425
Maximum Bundle Power (kW)	801.8	791.5	790.6	774.7	756.5
Location	P-11 (bundle 6)	P-06 (bundle 6)	P-06 (bundle 6)	N-08 (bundle 4)	M-19 (bundle 5)
Radial Form Factor	0.824	0.824	0.824	0.826	0.835
Axial form factor	0.684	0.693	0.694	0.707	0.716
Overall Form factor	0.564	0.571	0.572	0.584	0.598
K_{eff}	1.001182	0.996500	0.996500	0.996500	0.996500
Average Exit burnup (MWh/kgU)	175.1	177.7	174.3	321.2	266.7

Table 2. Results Of Time-Average Calculations
Based On A Four Bundle Shift Fuelling Scheme

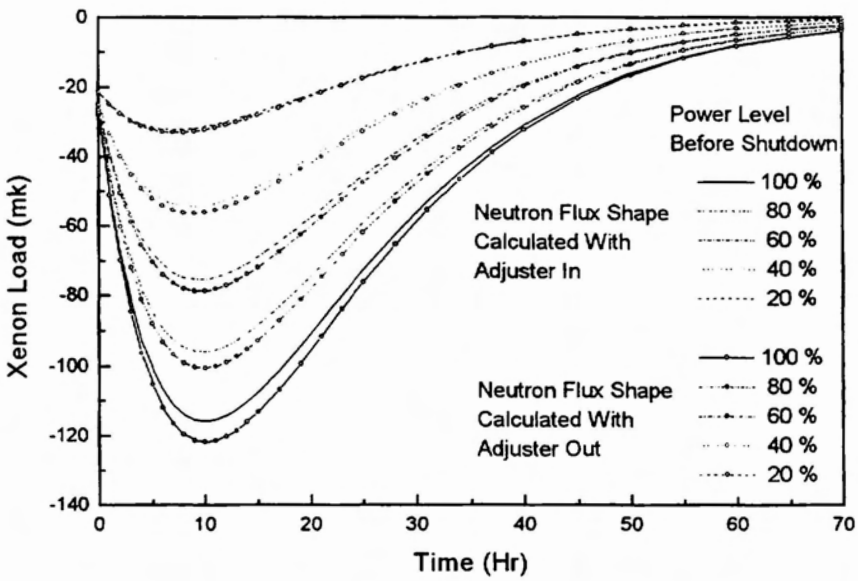
			CANFLEX-RU fuel (reference)	Low-void fuel (version 1)
Exit Burnup, (MWh/kgU)		Average	321.2	266.7
		Inner Zone	330.7	278.0
		Outer Zone	315.0	259.7
Reactivity decay Rate (mk/day)			- 0.609	- 0.645
Channel Dwell Time (FPD)	Inner Core	Maximum	157	136
		Average	151	129
		Minimum	148	125
	Outer Core	Maximum	312	253
		Average	189	152
		Minimum	145	120

Table 3. The Reactivity Worths Of Control Devices

	Adjuster Rod (mk)	ZCU (mk)	MCA (mk)
CANDU 6	16.6	6.5	-11.3
CANFLEX-RU	14.7	7.3	- 8.5
Version 1	15.0	7.1	- 9.0

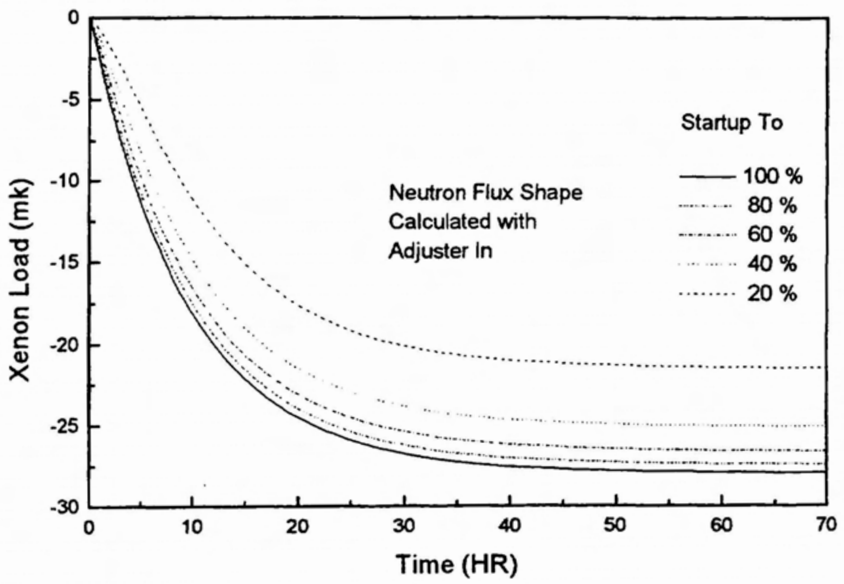


(a) CANFLEX-RU Fuel(Reference)

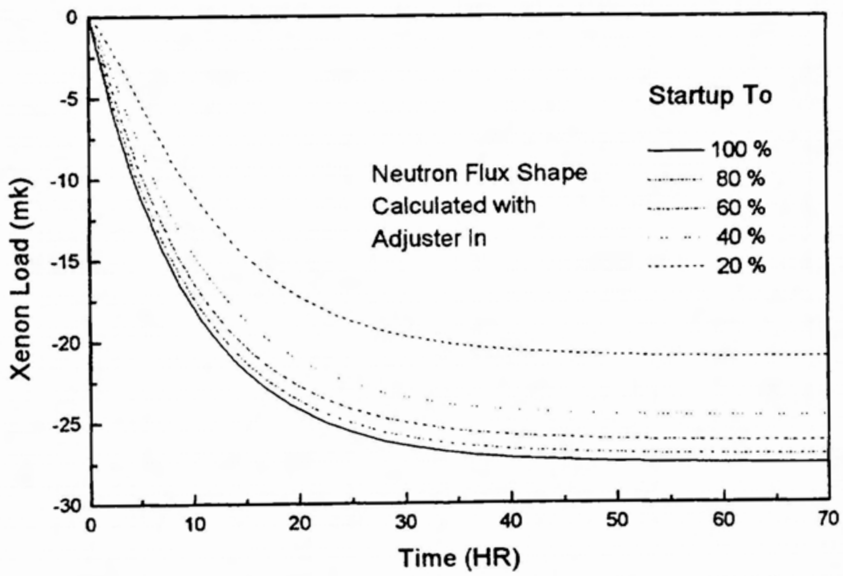


(b) Low-Void Fuel(Version 1)

Figure 1. Xenon Transient After Shut Down From Various Initial Steady State Power Levels

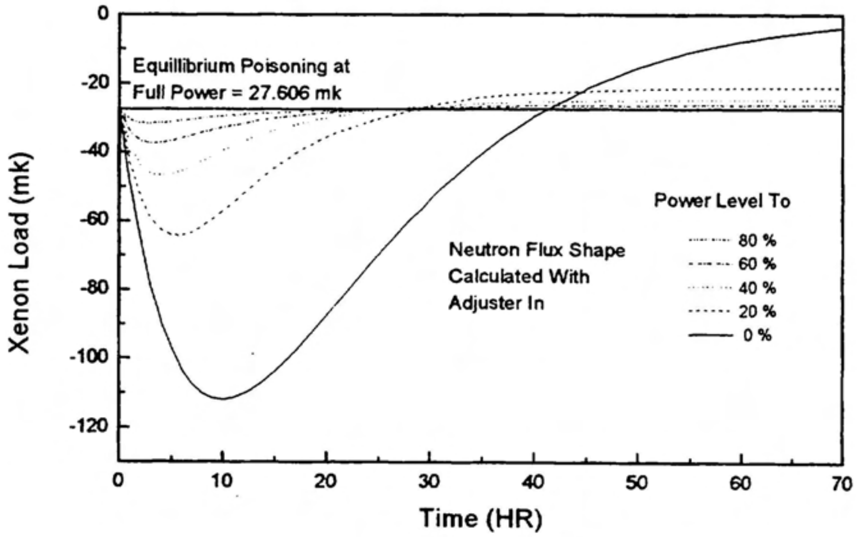


(a) CANFLEX-RU Fuel(Reference)

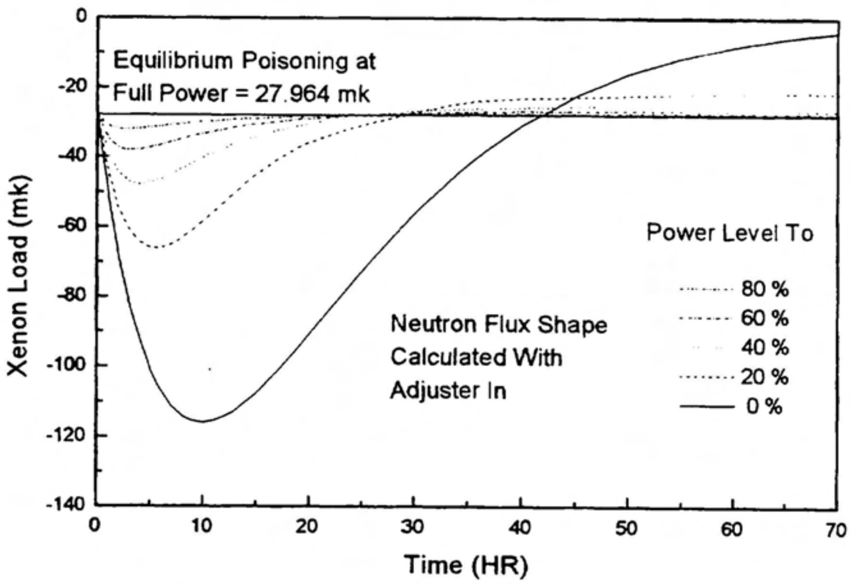


(b) Low-Void Fuel(Version 1)

Figure 2. Xenon Reactivity Transients After Startup From Long Shutdown
To Various Local Power Levels



(a) CANFLEX-RU Fuel(Reference)



(b) Low-Void Fuel(Version 1)

Figure 3. Variation Of Xenon Load Following Step Power Reduction From Equilibrium Full Power Condition

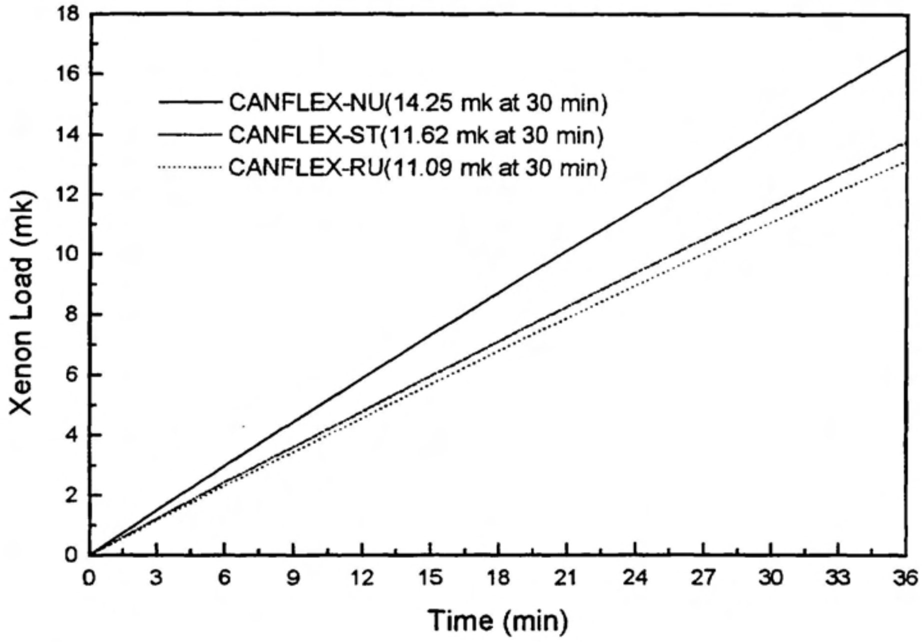


Figure 4. Xenon Transient For 30 Minutes After Reactor Shutdown