Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Multi-Cycle Fuel Loading Patterns of an LWR Core for a Nuclear Desalination Plant

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1. Introduction

Various nuclear systems for the desalination of sea water have been studied. As one of the options, for the exclusive use of desalination we propose a light water reactor (LWR), of which the operating pressure and temperature are lower than those of conventional pressurized water reactors (PWRs) in electricity generation,. This approach can improve the safety and economics of desalination plants owing to the milder requirements with the materials and dimensions of the major components. This study provides the related fuel loading patterns and the major core nuclear design parameters from initial to equilibrium cycles. The nuclear design system DeCART2D/MASTER[1,2] developed by the Korea Atomic Energy Research Institute is used for the analyses.

2. Design of Core Loading Patterns

In this section the design basis, core details, and the fuel management plan with fuel loading patterns are described.

2.1 Design Bases

The following design basis is adopted considering the status of the current technology development and the required system parameters described in Table 1.

a. Fuel Assembly: 17x17 array with UO_2 fuel rods used in typical PWRs
b. Active Core Height: 200 cm
c. Number of Fuel Assemblies in the Core: 69
d. Core Reactivity Control: soluble boron in the coolant, control rods using Ag-In-Cd neutron absorbers and burnable poisons in the fuel
e. Cycle Length: 3 years
f. Moderator Temperature Coefficient: negative at hot zero power (HZP)

Table 1: System parameters

Core Thermal Power	400 MW
Primary System Pressure	15 bar
Core Inlet Coolant Temperature	150.2 ℃
Core Outlet Coolant Temperature	180.2 ℃

A fuel assembly with a 200 cm active height and the same dimensions as the SMART core[3], is selected. The core average linear power density is 90.5% of that of the SMART core, consisting of 57 fuel assemblies to obtain 365 MW core thermal power. Because the lower operating temperature requires the higher excess reactivity control capability, more burnable poison rods should be used in the core where the resulting higher power peaking factor is compensated by the lower core average power density.

UO_2 fuel mixed with Gd_2O_3 is used for the burnable poison rods. The typical concentration of Gd_2O_3 in the fuel pellets is less than 10 w/o to suppress the centerline temperature increase due to the lower thermal conductivity from higher concentrations. In this study, however, a concentration of 12 w/o is applied to improve the performance of the excess reactivity control as the core burnup goes on, by the judgment that the lower operating temperature allows less thermal conduction in the fuel pellets. Axial cutback to remove Gd_2O_3 in the burnable poison rods is applied to both the top and the bottom 10 cm.

2.2 Fuel Management and Fuel Loading Patterns

A cycle length of 36 months with a 95% capacity factor corresponding to 1041 EFPD(effective full power days) can be achieved by a partial two-batch fuel management scheme using 40 feed fuel assemblies for each reload core. This means that 29 fuel assemblies are used for two cycles and 11 fuel assemblies are used for a single cycle. Table 2 shows the fuel management plan.

Table 2: Fuel management plan

Cycle	Batch[1)]	235U Enrichment	# of FAs	# of Feed FAs
Cy-1	A3	2.68	17	69
	B4	3.40	20	
	C3	4.40	12	
	C4		12	
	C6		8	
Cy-2	D4	4.72	16	40
	D6		8	
	D7		16	
Cy-3	E3	4.78	4	40
	E4		12	
	E6		8	
	E7		16	
Cy-4 & after	F3	4.74	4	40
	F4		12	
	F6		8	
	F7		16	

1) The number in the batch name means the number of burnable poison rods per FA divided by 4.

Fig. 1 shows the fuel loading patterns of the initial and reload cores. Blank boxes represent once-burned fuel assemblies, and batch F means the feed fuel assembly. One difference between cycle 2 and other reload cycles is the use of D4 batch that substitutes for F3. The fuel shuffling of each reload cycle maintains quarter-core rotational symmetry.

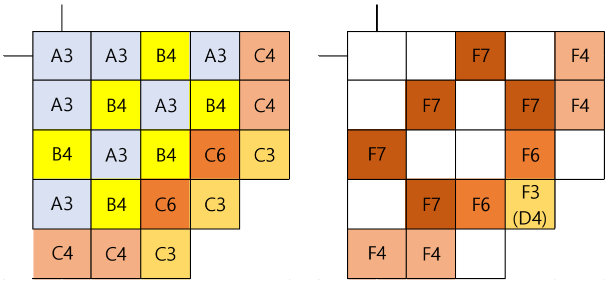

Fig. 1. Fuel loading patterns

3. Estimated Nuclear Parameters

In this section, the multi-cycle analysis results including critical boron concentration, moderator temperature coefficient (MTC) and peaking factors are described. The analyses were performed for cycles 1 through 6. The same fuel shuffling pattern is used after cycle 4. Because the analysis results of cycles 3-6 are similar, they are described as equilibrium cycle results.

3.1 Critical Boron Concentration and MTC

Fig. 2 shows the critical boron concentrations of cycles 1, 2, and equilibrium. The maximum value is low enough to provide a negative MTC at HZP, as shown in Table 3.

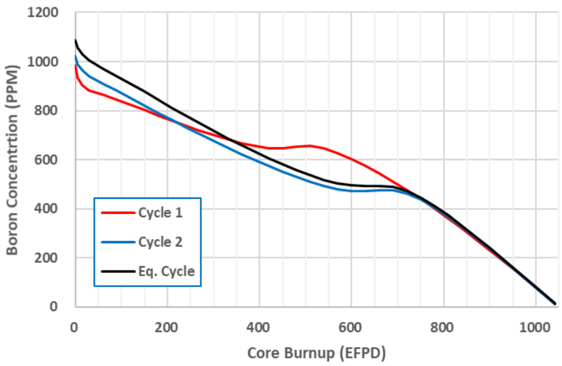

Fig. 2. Critical boron concentration.

Table 3: MTC at HZP condition

Cycle	Cy-1	Cy-2	Max.
MTC (pcm/ºC)	-6.4	-4.3	-3.6

3.2 Peaking Factors and Axial Power Distribution

The maximum radial, axial and three-dimensional power peaking factors at the hot full power (HFP) all rod out (ARO) condition through all cycles are 1.50, 1.33, and 1.89, respectively. Considering that the core average power density is lower than that in the PWR operating at higher temperature, the peaking factors are low enough to satisfy safety and design margin concerns. Fig. 3 shows the BOC and EOC axial power distributions for the initial and equilibrium cycles.

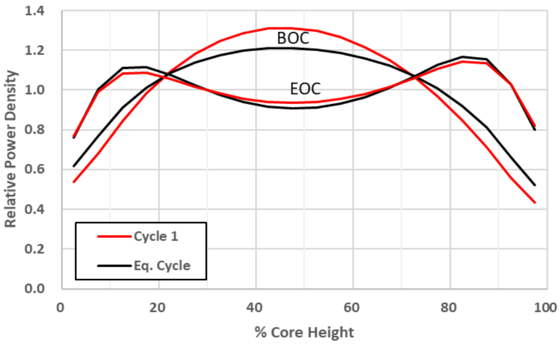

Fig. 3. Axial power distributions

4. Conclusions

Multi-cycle fuel loading patterns were designed for nuclear desalination plants with a core thermal power of 400 MW and a primary system pressure of 15 bar. A partial two-batch fuel management plan was established to load 40 feed fuel assemblies per reload cycle for a 36 month operational period. The critical boron concentration was founded to be low enough to maintain a negative MTC at HZP. The resulting power peaks and distributions are comparable to commercial PWRs.

ACKNOWLEGEMENTS

This study was supported by Korea Atomic Energy Research Institute (KAERI) and King Abdullah City for Atomic and Renewable Energy (K.A.CARE), Kingdom of Saudi Arabia, within the Joint Research and Development Center.

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