Study on Initial Core Loading Pattern for 50% MOX and 50% UO_2 in iPOWER reactor

Florencia de los Angeles Renteria del Toro [a*], Hyo-young Ahn [a], Chang Joo Hah [a]

[a]KEPCO International Nuclear Graduate School, 658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan, 45014, Republic of Korea,
florenciaren@gmail.com

Introduction

- The Innovative Passive Optimized Worldwide Economical Reactor (iPOWER) is an advanced pressurized water reactor (PWR) with 1,250 MWe capacity which is under development.
- iPOWER has passive safety features such as the passive emergency cooling system (PECCS) and passive containment cooling system (PCCS).
- The core consists of 193 Fuel Assemblies (FAs) of the Westinghouse type 17 x 17 lattice fuel.
- The objective of this study is to investigate the development of an Initial Core Loading Pattern (ICLP) in iPOWER that uses 50% of FA with Mixed Oxide (MOX) Fuel and the rest of the FAs Uranium Dioxide (UO_2) Fuel.

Model Description

- The core is designed for an operating cycle of 18 months with discharge burnup of 17,707 MWD/tHM (Tones of heavy metal).
- 97 of the total FAs were loaded with UO_2 [content: 2.818 wt% of U-235 average enrichment] and 96 MOX FAs [content: 3.644 wt% of average total fissile content (3.537 wt% Pu, 0.382 wt% U-235)] were used in the core.
- Gadolinia (Gd_2O_3) is used as the burnable absorber material to suppress excess of reactivity and control power distribution.

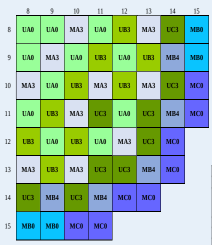


Fig. 1. Quarter core loading pattern reference for MOX and UO_2 fuel assemblies.

Table I: FA design for UO_2 fuel

UO_2 Fuel									
FA		Fuel Rods				[illegible]	BA Rods		
Type	No	wt% High	wt% Low	No. High	No. Low	wt%	wt% (U-235)	wt% (Gd_2O_3)	No.
UA0	33	2.00	-	264	-	-	-	-	-
UB3	32	3.30	2.80	184	64	2.20	2.20	10.0	16
UC3	32	3.80	3.30	184	64	2.20	2.20	10.0	16
Total	97								

Table II: FA design for MOX fuel

MOX Fuel									
FA		Fuel Rods				[illegible]	BA Rods		
Type	No	wt% High	wt% Low	No. High	No. Low	wt%	wt% (U-235)	wt% (Gd_2O_3)	No.
MA3	32	2.20	1.70	200	40	-	2.20	4.00	24
MB0	12	4.40	3.40	200	64	2.20	-	-	-
MB4	20	4.40	3.40	200	32	2.20	2.20	4.00	32
MC0	32	5.40	4.40	200	64	-	-	-	-
Total	96								

Method

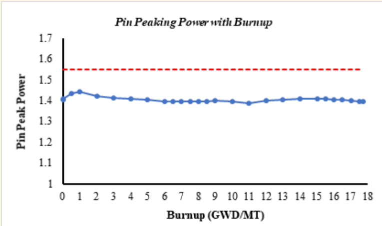
- CASMO-4 and SIMULATE-3 design codes were used to conduct the simulations at FA design and safety evaluation.
- Several comparisons were made with varying the numbers of feed FA, and optimization of the fuel management strategy was performed to reach the following design criteria: **18 months cycle length (17,707 MWD/tHM), Critical Boron Concentration (CBC) less than 1000 ppm and Maximum Pin Peaking Factor ($F_{\Delta H}$) less than 1.55**.
- Fuel Temperature Coefficient **(FTC)**, Moderator Temperature Coefficient **(MTC)**, and Shutdown Margins **(SDM)** parameters were calculated in order to know if the design criteria of the core meets the safety specifications and maintains the level of criticality during operation.

Results

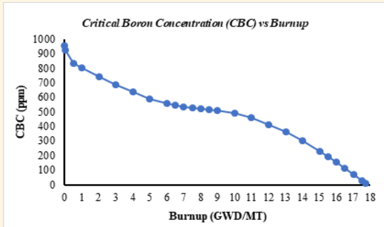
The coming evaluations follow the methodology and approach developed by APR1400 reactor in the Design Control Document (DCD):

Power Distribution

Keeping the power distribution helps to maintain the economical utilization of the fuel and allows operation at high power without reaching Departure from Nuclear Boiling (DNB) in the core. DNB values are still under design stage of iPOWER but this result could provide an input how the fuel will behave during operation.



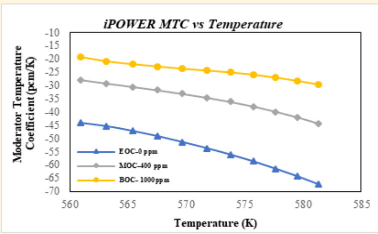
The reduction of soluble-boron, control rod and burnable poison worth are affected by the spectrum hardening effect in maintaining the reactor core criticality.



Reactivity Parameters at 0 (BOC), 9 (MOC) and 17.7 (EOC) GWD/tHM

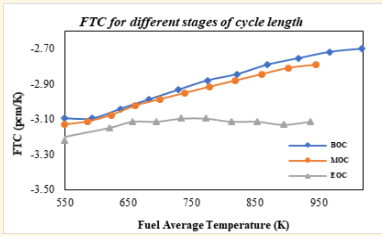
Moderator Temperature Coefficient

In moderator, boron density plays an important role in controlling the reactivity and power distribution. The boric acid concentration is decreased and it is used to compensate for the decrease in reactivity due to burnup of the fuel.



Fuel Temperature Coefficient

The maximum fuel temperature decreases over the time that reactor is operating. It could cause fuel temperature increment is the release of fission product gasses into the air gap that is originally filled with helium. However, fuel swelling is one of the most dominant factors over burnup. FTC decreases over burnup. This could be explained by production of Pu-240 over time operation.



Shutdown Margin

SDM calculation assures that the reactor will be capable of shutdown during an accident scenario and to maintain the subcriticality in the core. It was found that the Shutdown Thermal Margin satisfied the design criteria of SDM value should be ≥ 5500 pcm from APR1400 design .

Requirements	*BOC (pcm)*	*MOC (pcm)*	*EOC (pcm)*
Control Rod Worth			
All Rods In Worth with Most Reactive Rod Stuck Out (a)	9886	10758	11178
Uncertainty (4.65 %) (b)	460	500	520
Most Reactive Stuck Rod Worth	2781	2139	3454
Total Worth (a) – (b) = (c)	9426	10258	10658
Control Rod Requirements			
Total Power Defect (d)	1518	1652	2790
Rod Insertion Allowance (RIA) (e)*	83	130	367
Total Requirements (d) + (e) = (f)	1601	1782	3157
Calculated SDM (c) – (f)	**7852**	**8476**	**7501**
Requirement SDM	> 5500	> 5500	> 5500

* Inclusion of RIA = 40% of C5 insertion was taken from FSAR of APR1400

Conclusions

- It was investigated the possibility of initial core loading pattern for iPOWER reactor, which currently is still under design stage.
- This is a proposed design for a suitable core that could be loaded 50% of the FA with MOX fuel and the rest of the FA with UO_2 fuel.
- Cycle length, peaking factor, CBC, reactivity coefficients, and SDM calculation were investigated. In conclusion, the iPOWER reactor core design with a mixture of fuel is capable to maintain the design specifications and safety requirements for the initial cycle.
- Further work should be conducted to continue this design study for the equilibrium cycle stage, in order to prove that the core will be capable to operate for more cycles during these conditions.