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A HIGH-PERFORMANCE SOLUBLE-BORON-FREE SMALL MODULAR REACTOR CORE

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ABSTRACT – This paper documents results of a neutronic design study of a soluble-boron-free (SBF) small modular reactor (SMR) core. The design specifically utilizes region-wise BigT absorbers as substitute for the soluble-boron reactivity control. The analyses clearly demonstrate high-performance potential of the SBF SMR design as burnup reactivity swing over its 52-month cycle is well within the desired range for a successful SBF operation (i.e., < 1,000 pcm). In addition, relatively uniform power profiles, both radially and axially, are obtained throughout the simulated cycle. All assembly branch and multi-physics core calculations in this study were completed using the Monte Carlo Serpent and Coredax diffusion codes with ENDF/B-V7.1 library.

1. Introduction

Removal of soluble-boron reactivity control from PWRs offers many significant improvements. Firstly, the risk of boric acid-induced corrosion in the primary system can be effectively eliminated. Secondly, an SBF core is possibly simpler in design, operation and maintenance than the conventional design. Thirdly, elimination of borated water from the primary loop greatly reduces radioactive waste volumes and water processing requirement associated with the deboration operation. Fourthly, an SBF core desirably maintains a large negative moderator temperature coefficient (MTC) at all times.

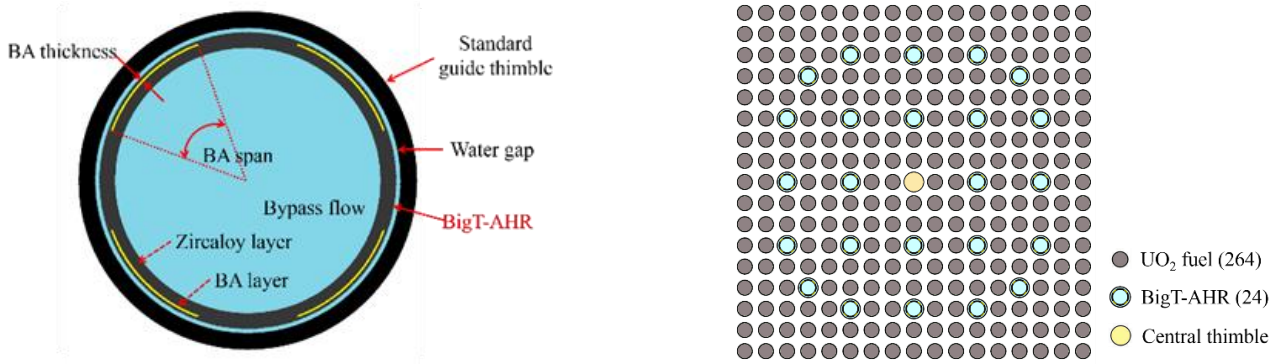
Feasibility of an SBF PWR is generally accepted to be higher as the core power (hence core size) is reduced [1]. In addition, it is also known that cold shutdown is very challenging without the soluble-boron reactivity control, even for a small-sized core. Nonetheless, a new approach for a high-performance SBF SMR core was recently proposed [2]. This paper aims to highlight results of the said investigation, which were completed using the Monte Carlo Serpent [3] and Coredax [4] diffusion codes with ENDF/B-7.1 nuclear data library.

2. SBF SMR Core Design

The SMR core modeled in this study is based on KEPCO NF's small modular PWR design. Rated power of the reactor is 200 MWth while targeted cycle length for the single-batch fuel management operation is about 48 months. Active core height is 2 m. The core is consisted of 37 fuel assemblies, each loaded with 4.9 w/o UO_2 fuel rods. Stainless steel reflector assemblies are used in place of the conventional baffle-reflector to reduce radial neutron leakage and, thus, enhance the core neutron economy. For a successful SBF operation, the burnup reactivity swing (BRS) throughout its operational cycle should be < 1,000 pcm [1].

2.1 BigT Absorber

The main reactivity control system replacing soluble-boron in the SMR core is the "Burnable absorber-Integrated Guide Thimble" (BigT) absorber [2] as depicted in Figure 1. In this configuration, the BigT is simply a zircaloy ring embedded with azimuthally heterogeneous burnable absorber (BA) materials. Thickness and span of the BA can easily be adjusted per design requirement. The said ring is to be installed within the annulus hole of a standard PWR guide thimble as illustrated in Figure 1. The BigT conceptually permits insertion of control rod in its thimble. In this study, the BA material of choice is 90 w/o enriched boron carbide (B_4C).



Figures 1 BigT design concept (left), and BigT-loaded fuel assembly (right).

2.2 BigT Loading Pattern

This research took advantage of the neutronic flexibilities of the BigT design, in which thickness and span of its B_4C were adjusted to attain the desired assembly reactivity suppression and depletion trend. Figures 2 clearly depict this idea: three different BigT designs are loaded **region-wise** into the SMR core, whose effective combination possibly enables the SBF operation of the core.

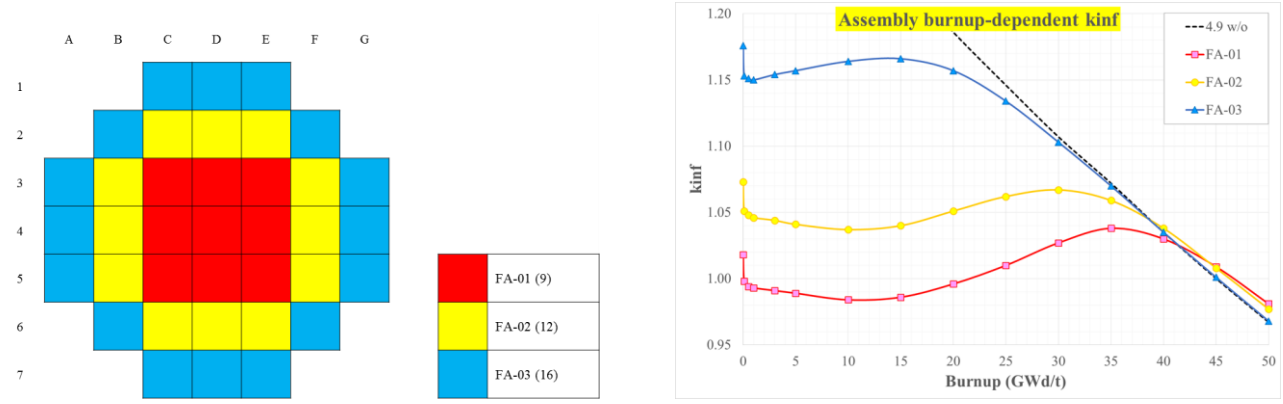


Figure 2 BigT loading pattern (left), and assembly neutronic characteristics (right)

3. Characteristics of a High-Performance SBF SMR Core

Figure 3 depicts burnup dependent k-eff trends of the BigT-loaded against the reference SMR core. The core BRS is clearly < 1,000 pcm as required. The BigT-loaded core also becomes subcritical earlier (29.8 GWd/t) than reference (31.5 GWd/t), indicating some B_4C may have not been completely depleted at EOC. Nevertheless, the 53-month cycle actually exceeds the initial target.

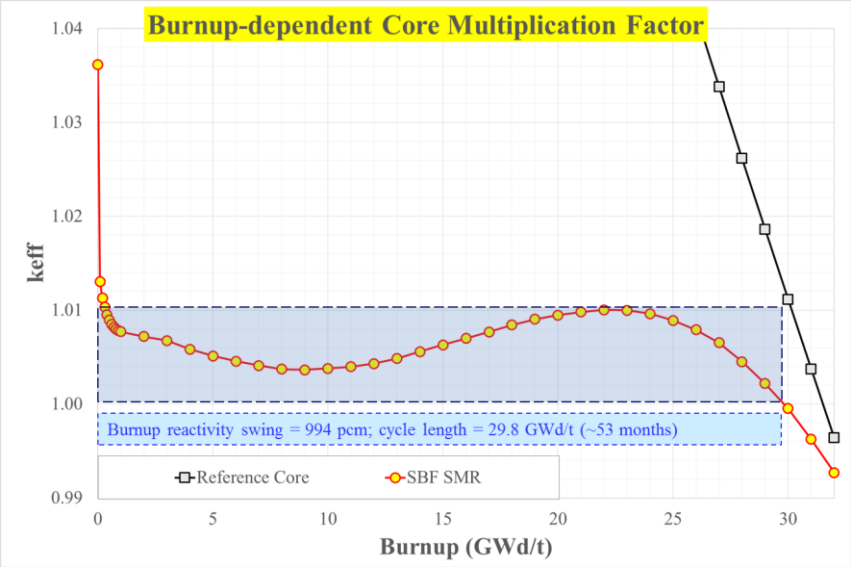


Figure 4 Burnup-dependent k-eff trends of the SMR cores.

Figure 4 depicts normalized radial power distributions in the BigT-loaded SMR core. Radial power distribution in the SBF core is clearly uniform (0.742~1.288) and, thus, quite practical.

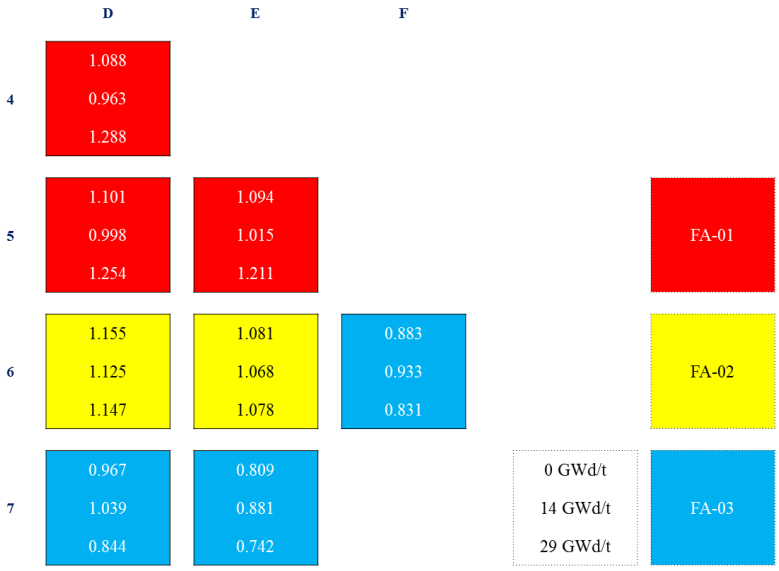


Figure 5 Normalized radial power distribution in the SBF SMR core.

Figure 5 shows evolution of the normalized axial power profiles of the BigT-loaded SMR core. As expected in a typical PWR design, the BigT-loaded core is bottom-skewed at BOC but gradually becomes slightly top-skewed at EOC.

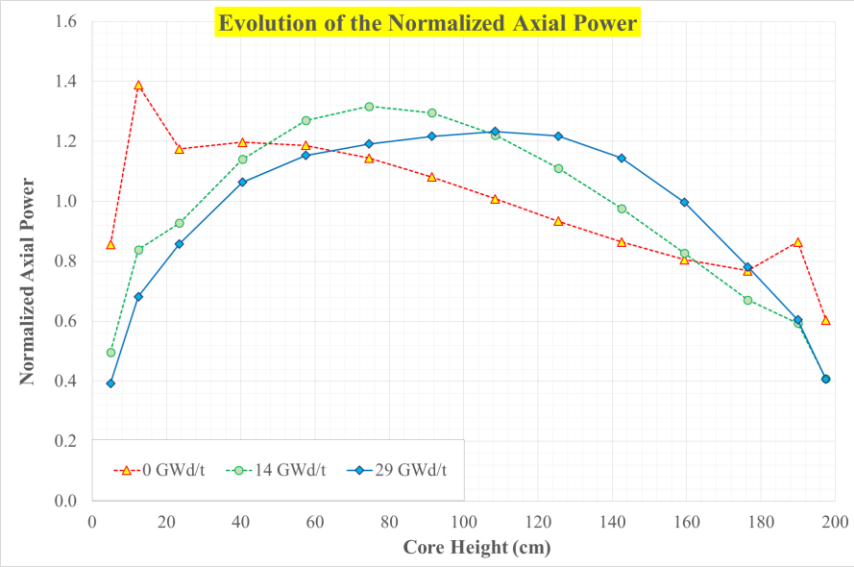


Figure 6 Evolution of the normalized power profiles of the SBF SMR core.

4. Conclusions

Elimination of soluble-boron reactivity control from PWRs offers operational advantages especially for a small-sized core. This study describes results of the preliminary investigation on one such design, in which BigT absorbers are loaded **region-wise** into a single-batch 200 MWth SMR configuration. Results of the calculations show very promising potential of the SBF core operation as its BRS ranges between 360~990 pcm throughout the cycle. In addition, the BigT-loaded SMR core also exceeds the targeted cycle length (48 months) by about 5 months. Nonetheless, demonstration of core arrangements capable of higher discharge burnups should be pursued in the future.

5. References

[1] Electrical Power Research Institute, “Elimination of Soluble Boron for a New PWR Design”, EPRI NP-6536, 1989.

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