Neutronics Analysis of SMART Small Modular Reactor using SRAC 2006 Code

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Abstract. Small modular reactors (SMRs) are part of a new generation of nuclear reactor being developed worldwide. One of the advantages of SMR is the flexibility to adoptthe advanced design concepts and technology. SMART (System integrated Modular Advanced ReacTor) is a small sized integral type PWR with a thermal power of 330 MW that has been developed by KAERI (Korea Atomic Energy Research Institute). SMART core consists of 57 fuel assemblies which are based on the well proven 17x17 array that has been used in Korean commercial PWRs. SMART is soluble boron free, and the high initial reactivity is mainly controlled by burnable absorbers. The goal of this study is to perform neutronics evaluation of SMART core with UO_2 as main fuel. Neutronics calculation was performed by using SRAC 2006 code with JENDL 3.3 as nuclear data library.

1. Introduction

The world's energy sector is currently driven by a majority of fossil fuel power plants. In order to address and meet national and global requirements for clean, efficient, and consistent energy production designed to meet a growing demand for energy from developing nations, new and innovative nuclear reactor technologies will need to be developed. Part of this initiative includes the potential for smaller, modular nuclear reactors (SMRs) [1].

Korea Atomic Energy Research Institute (KAERI) has been developing a small-sized integral reactor called SMART for two purposes: seawater desalination and electricity generation [2,3]. The conceptual design and the basic design of SMART with a desalination system were completed in March of 1999 and in March of 2002, respectively [4]. SMART has been developed as a small-sized integral reactor, hence most of its major components is housed within the reactor vessel. Major components including 4 main coolant pumps, 12 steam generator cassettes, a self-pressurizeras well as active core are placed in a single reactor vessel as shown in Fig.1. This integral design eliminates large break LOCA (Loss of Coolant Accident). In its development, SMART also adopted the soluble boron free operation concept. Hence there is no need to control the boron concentration of the primary coolant and the system can be further simplified. However, an emergency boron storage tank is provided in case of scram failure [5].

Nuclear calculation for SMART reactor has been performed using CASMO-3/MASTER system and MCNAP code system. At first burnup period, effective multiplication factor for SMART core is 1.000162 calculated using CASMO-3/MASTER [6] system and 1.00641 with MCNAP code [7]. In this study, nuclear calculation for SMART reactor will be performed using CITATION module of SRAC 2006 code [8] that was developed by Japan Atomic Energy Agency (JAEA) with JENDL 3.3 as its nuclear data library [9].

2. Nuclear Core Design

As shown in Fig.2, the reactor core consists of 57 FAs with a 17 x 17 fuel rod array. The fuel assembly is based on the design of KOFA (Korean Standard Fuel Assembly) that was designed by KAERI/Siemens-KWU and used in the 900 MWe Westinghouse type Korean PWR's [3]. The fuel rods are arranged in rectangular lattices, as in KOFA but the FA's length has been reduced to 200 cm. The fuel rod contained uranium dioxide and the uranium enrichment for all the FAs is 4.95%.

Other than normal fuel rods, each FAs also consist of burnable absorber rods. There are two burnable absorber rods that are used in SMART's fuel assemblies, Gadolinia rods and Shim rods. Gadolinia rods are fuel rods with Gd_2O_3 as an integral part of the fuel matrix. Burnable absorber material in shim rods are B4C in Al_2O_3.

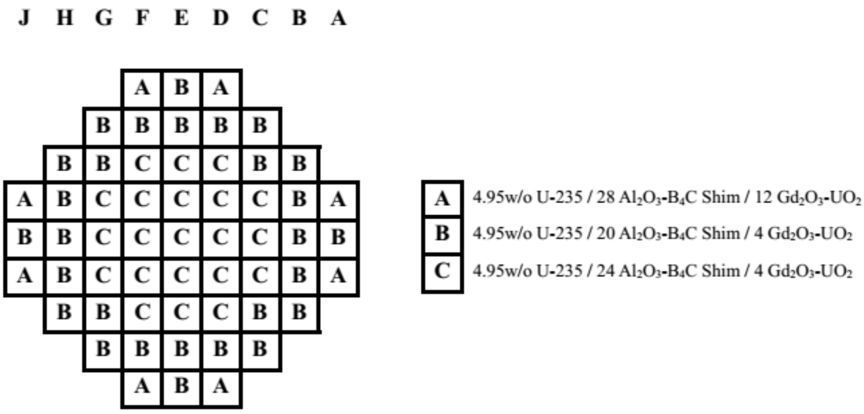

Figure 1. SMART core loading pattern [4].

In Fig. 1, SMART core loading pattern is presented, which consist of 3 fuel types. Since the neutron fluxes are higher in the core central region than in the peripheral region, more burnable absorber rods with a higher concentration of B-10 are used in fuel type C than in fuel type B. The number and concentration of the burnable absorber rods in each fuel type are selected so that reactivity of each assembly can be as flat as possible

Table 1. SMART major parameters

Parameter	Value
Thermal Output	330 MWt
Electric Output	100 MWe
Fuel Material	< 5 wt% UO2
Refueling Cycle	3 years
Active Length	200 cm
Cladding Material	Zircaloy-4
Cladding Thickness	0.57 mm
Pellet Diameter	8.05±0.01 mm
Pin Pitch	1.26 cm
Fuel rod to fuel rod	21.10 x 21.10
Material Absorber	Gd_2O_3-UO_2&Al_2O_3-B_4C

3. Methodology

3.1 Fuel assembly designs

There are three fuel assembly designs in this study. Each assembly has different configuration and specification. As mentioned above all the fuel assembly that was used in this study were developedbased on KOFA fuel assembly. In Fig. 2, we can see the difference in each fuel assemblies.

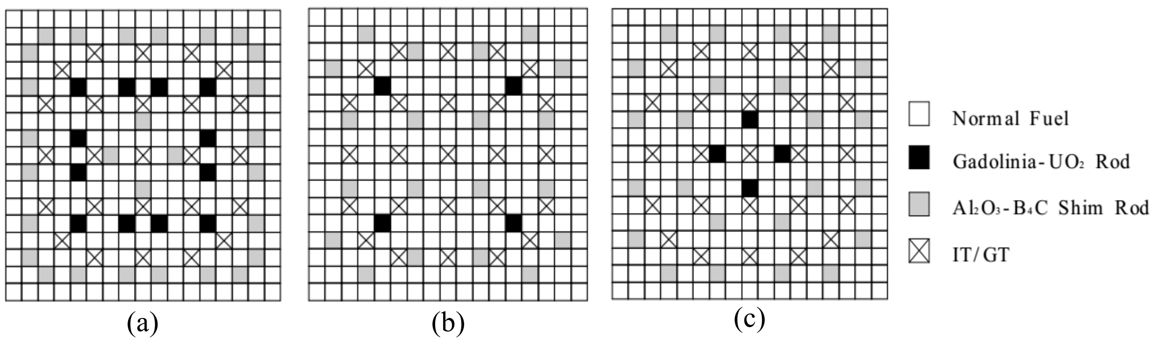

Figure 2. Fuel assembly designs used in this study (a) FA type A (b) FA type B (c) FA type C[7].

The number and concentration of burnable absorber rods in each FAs are selected so that reactivity of each FAs can be as flat as possible. The specification of each FA in this study can be seen in Table 2.

Table 2. Fuel Assembly Specification

Assembly Type	No. of Assembly	No. of Fuel Rods	No. AL_2O_3- B_4C rods	No. of Gd_2O_3-UO_2 rods
A	8	224	28	12
B	28	240	20	4
C	21	236	24	4

The fuel rod consisted of a uniform cylindrical pellet stacked together within a zircaloy-4 clad tube. Between the fuel stack and the cladding, a clearance was provided in order to accomodate the fuel swelling due to the accumulation of fission products. The gap was filled with helium gas to improve heat conduction from fuel to cladding.

3.2 Computational procedure

All the fuel assemblies and reactor core were modelled using SRAC (ver. 2006). The cross section for all materials (i.e. fuel, burnable absorber material, cladding, moderator and structural) were taken from JENDL 3.3 libraries. SRAC (*Standard Reactor Analysis Code system*) was developed by JAERI (*Japan Atomic Energy Research Institute*). This programme was used to analyze reactor design, especially for its neutronic analysis.

The study was carried out by referencing SMART fuel assembly and core design from previous studies. The fuel assembly burnup was calculated by using octant symmetric square with square array of pin rods geometry and the core calculation for 3D cylinder geometry.

4. Results and Discussion

The neutronic behaviour of the reactor was studied on three types of fuel assembly for 990 Effective full power days (EFPD). Figure 3 demonstrates the neutron infinite multiplication factor (k-infinity) for all assemblies which given in Fig. 2. The fuel assembly type C gives the highest infinite multiplication factor compared to others.

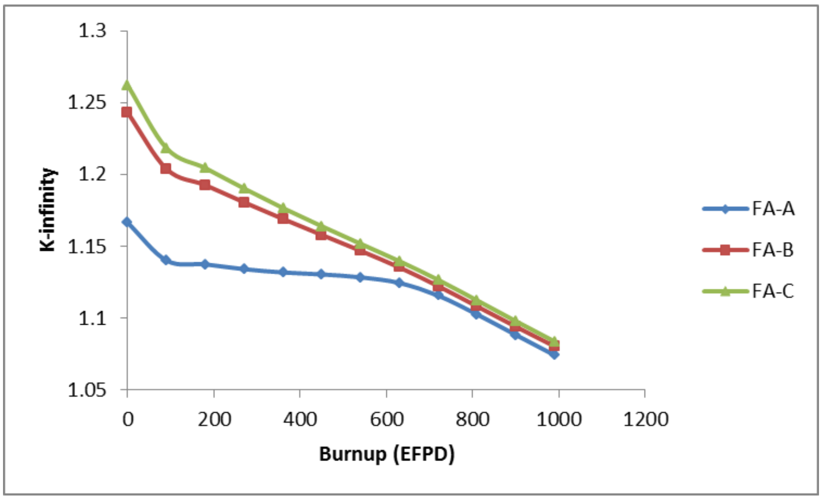

Figure 3. Infinite multiplication factors (k_∞) of fuel assemblies.

Figure 4 shows the conversion ratio for all FAs. As can be seen tfrom this figure, the conversion ratio for FA type C has the lowest value compared to other FAs with the same fuel enrichment. This profile shows that the trend of the infinite multiplication factor is inversely proportional with that of the conversion ratio.

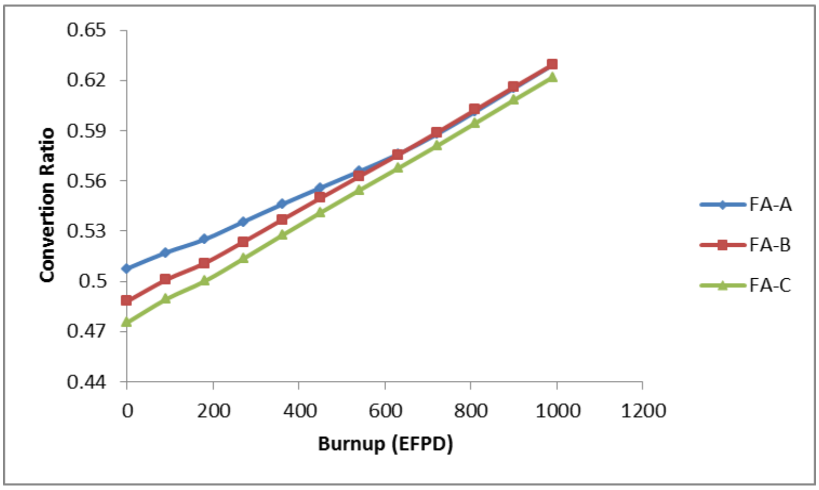

Figure 4. Convertion ratio of fuel assemblies.

Once each fuel assembly calculation finished, the next step is placing each fuel assemblies into its correct pattern according to Fig. 1. The core was surrounded by a stainless steel barrel. The 3D core calculation has been conducted by using with CITATION module in SRAC (ver. 2006). The calculation were carried out in order to find the effective multiplication factor (k-eff) and other parameters. The k- eff value for the first burn up periode which obtained from this simulation is 1.006119. Tabel 3 presents the comparation of k-eff values for the present research compared to different codes.

Table 3. Comparation of k_{eff} values

Burnup (days)	MASTER	MCNAP	CITATION
0	1.000162	1.00641	1.006119
90	1.000107	1.00186	1.00589

Another important nuclear parameters from this core calculation is average burnup. The number of fuel that was depleted in each burnup period is almost the same. The cycle average burn up from this calculation is 25.625 MWD/kgU. This means that the energy produced from this reactor design for 990 EFPD are equal to 2.5625 x 10^4 MWD for a ton of fuel.

Figure 5 shows the neutron spectrum for this reactor design. This graph shows that SMART reactor is a thermal reactor with slightly harder neutron spectrum. The harder neutron spectrum means that the spectrum shifts to high energy region [10-11].

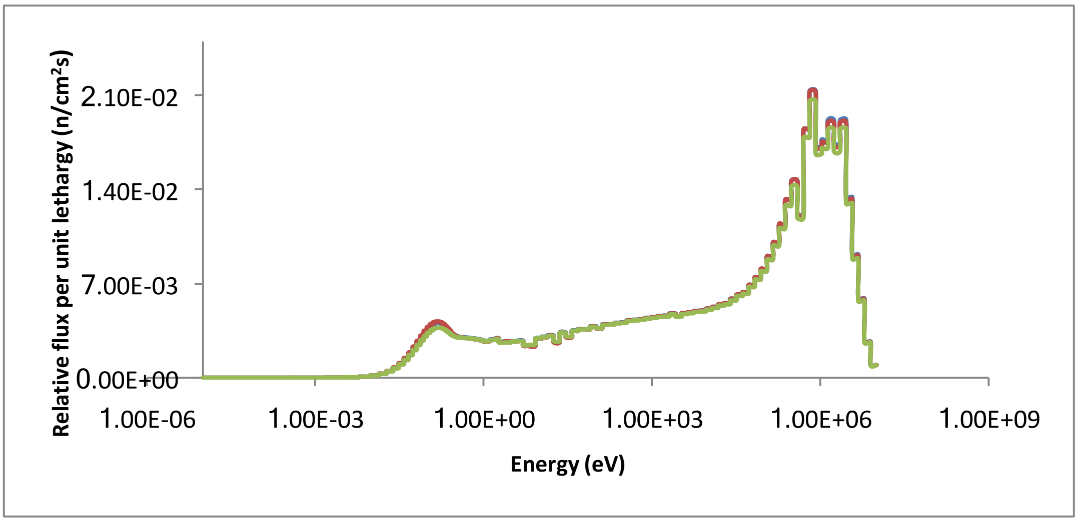

Figure 5. Neutron spectrum of SMART core

5. Conclusion

The study on SMART core design description and nuclear characteristics have been performed. Using 4.95wt% UO2 fuel, a 3-years cycle length is accomplished with the cycle average burn up from this design is 25.625 MWD/kgU. The obtained results show similar values compared to the references.

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