Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

The KALIMER-600 Reactor Core Design Concept with Varying Fuel Cladding Thickness

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1. Introduction

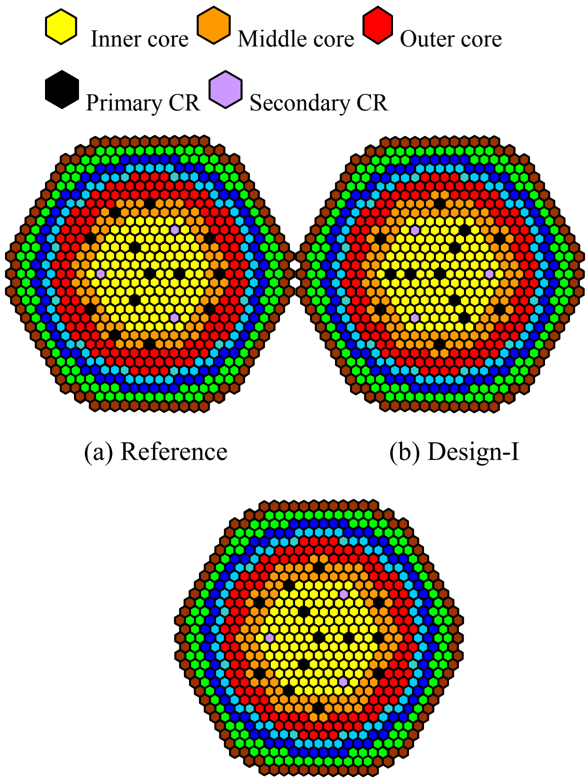
Recently, Korea Atomic Energy Research Institute (KAERI) has developed a 600MWe sodium cooled fast reactor[1,2], the KALIMER-600 reactor core concept using single enrichment fuel [3]. This reactor core concept is characterized by the following design targets : 1) Breakeven breeding (or fissile-self-sufficient) without any blanket, 2) Small burnup reactivity swing (<1$), 3) High discharge burnup (≥80MWD/kg), 4) Cycle length (≥18EFPM), 5) Sodium void worth (<8$), 6) Peak discharge fast neutron fluence (<$4.0x10^{23}$ n/cm^2). In the previous design, the single enrichment fuel concept was achieved by using the special fuel assembly designs where non-fuel rods (i.e., $ZrH_{1.8}$, B_4C, and dummy rods) were used. In particular, the moderator rods ($ZrH_{1.8}$) were used to reduce the sodium void worth and the fuel Doppler coefficient. But it has been known that this hydride moderator possesses relatively poor irradiation behavior at high temperature.

In this paper, a new core design concept for use of single enrichment fuel is described. In this concept, the power flattening is achieved by using the core region-wise cladding thicknesses but all non-fuel rods are removed to simplify the fuel assembly design.

2. Core Design and Performance Analysis

2.1 Description of Core Design

To start this study, a reference core is designed. The total number of control assemblies are increased from 9 (previous design) to 12 in order to increase the shutdown margin of the control system because our previous study has shown that the control system consisting of 9 control assemblies doesn't satisfy the control system requirement (i.e., the shutdown margin of primary control system ≥1%Δρ). After studying on the optimal cladding thicknesses and the fuel rod outer diameter, the selected cladding thicknesses for the inner, middle, and outer core regions are 1.07, 0.81, and 0.60mm, respectively. The fuel outer diameter is increased from 8.5mm (previous design [3]) to 9.0mm in order to achieve the breakeven breeding. Figure 1(a) shows the configuration of this reference core. The active core height is 100cm at cold state. Additionally, two core designs are developed to reduce sodium void worth. In these cores, a moderator region is placed below fuel in order to soften the neutron spectrum in the lower fuel region and so that the power in the lower fuel region increases. The first core of these two designs (Design-I) uses a 25cm thick $^{11}B_4C$ region below fuel while the second one (Design-II) a 15cm thick graphite region below fuel. The active core heights of Design-I and –II are 100cm and 94cm, respectively. The main design parameters of these cores are given in Table I. The fuel rod outer diameter of Design-I and –II is the same as that of the reference core. But Design-I has its cladding thicknesses of 1.03, 0.76, and 0.59mm for inner, middle, and outer core regions, respectively and Design-II has 1.02, 0.72, and 0.59mm thick claddings for inner, middle, and outer core regions, respectively. Figures 1(b) and (c) show the core configurations of Design-I and –II, respectively.



(a) Reference (b) Design-I

(c) Design-II

Figure 1 Core configurations

2.2 Core Performance Analysis

The REBUS-3 equilibrium model with a nine group cross section was used to perform the core depletion analysis. All the cores use the four batch fuel management scheme. The reference and Design-I cores use the cycle length of 19EFPM but the Design-II core uses 18EFPM cycle length. Table II compares the core performances. The reference core has largest discharge burnup but largest sodium void worth that is larger than 8$. For this core, the primary and secondary control assemblies have the reactivity worth of 12.4$ and 3.4$, respectively. In comparison with the previous design core developed in 2005 [3], the reactivity worth of primary control assemblies is increased by ~3.4$ because of the increased number of control assemblies while there is no difference in the reactivity worth of the secondary control assemblies. The Design-I core using a $^{11}B_4C$ region below fuel has smallest burnup reactivity swing and lower TRU (transmuranics) contents in fuel. This core has smaller value of sodium void worth than the reference core and its values are less than 8$ both at BOEC and EOEC. But its decrease is small (~105pcm). The Design-II core has smallest value of the sodium void worth (i.e., 7.6$ at EOEC) and this value is smaller by ~210pcm than that of the reference core. It is noted that the reactivity worth of the control systems of the Design-I and –II cores are slightly smaller than those of the reference core.

Table I Comparison of the design parameters

Design parameter	Reference	Design-I	Design-II
Core height (cm)	100.0	100.0	94.0
Fuel rod outer diameter (mm)	9.0	9.0	9.0
Fuel assembly pitch (cm)	18.71	18.71	18.71
Pin P/D ratio	1.1667	1.1667	1.1667
Cladding thickness (mm)			
IC/MC/OC	1.07/0.81/0.60	1.03/0.76/0.59	1.02/0.72/0.59
Number of fuel assemblies			
IC/MC/OC	117/78/138	117/93/123	117/96/120
Material of the region below fuel	N/A	$^{11}B_4C$	Graphite
Thickness (cm) of the region below fuel	N/A	25	15

Table II Core performance comparison

Parameters	Reference	Design-I	Design-II
Cycle length (EFPD)	570	570	540
Fuel management batches	4	4	4
Average discharge burnup (MWD/kg)	81.3	80.5	80.4
Peak discharge burnup (MWD/kg)	126.9	125.9	125.4
Burnup reactivity swing (pcm)	304	147	344
TRU wt% (BOEC/EOEC)	15.4/15.8	15.1/15.4	15.5/15.9
Fissile Pu inventory (ton/GWe, BOEC)	6.50	6.49	6.23
Average linear heat rate (W/cm)	158.2	158.3	168.3
Average power density (W/cc)	139.6	139.7	148.5
Peaking factors (BOEC/EOEC)	1.506/1.486	1.471/1.465	1.498/1.489
Sodium void worth (BOEC/EOEC)	7.9/8.2	7.6/7.8	7.3/7.6
Control rod worth (BOEC, $)			
Primary/Secondary	12.4/3.4	12.0/3.2	12.0/3.2
Effective delayed neutron fraction (BOEC)	0.00349	0.00352	0.00351
Peak fast neutron fluence (n/cm^2)	3.99×10^{23}	3.95×10^{23}	3.92×10^{23}

3. Conclusion

In this paper, a new core design concept of the sodium cooled fast reactor using single enrichment fuel is introduced and the core performances are analyzed. In this concept, the power flattening under a single enrichment is achieved by using the core region-wise cladding thicknesses. To reduce the sodium void worth, a moderator ($^{11}B_4C$, graphite) region below fuel is introduced. It is shown that the core having a graphite region below fuel and 94cm core height has its sodium void worth of 7.6$ at EOEC and satisfies all design targets. Also, it is shown that the increase of primary control assemblies from 9 to 12 leads to an increase of reactivity worth of primary control assemblies by 3.4$.

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