Core Design of a 1200 MWe Sodium Cooled Fast Reactor by Using Non-Fuel Rods

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has developed a 600MWe sodium cooled fast reactor [1], the KALIMER-600 reactor core concept using a single enrichment fuel [2] without blanket assemblies. 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 [3]. Also, a power flattening is achieved by using the core region-wise cladding thickness without non-fuel rods [4]. The design concept of KALIMER-600 was chosen as a reference design of a Gen IV Sodium cooled Fast Reactor (SFR). As an on-going study of a Gen IV SFR development to enhance the economics and safety characteristics, the 1200 MWe design concept is being developed by KAERI.

In this paper, a new core design concepts for a 1200 MWe SFR with single enrichment fuels by using non-fuel rods such as vacancy rods, steel rods and graphite rods are described.

All the neutronic calculations are done with the K-CORE system. The depletion analysis is done with the equilibrium model of the REBUS-3 code system where the DIF3D module solves the neutron diffusion equation with the HEX-Z nodal method and a 25-group cross section set to obtain the neutron flux and power distributions. The cross section set is prepared based on the ENDF/B-VI library.

2. Core Design and Performance Analysis

2.1 Core Design Targets and Design Description

The main design targets of the 1200 MWe SFR breakeven core are summarized as follows: 1) no external feed requirement of TRU materials (CR~1.0) without blanket, 2) small required quantity of Pu fissile isotopes less than 6.0 tons/GWe, 3) small burnup reactivity swing less than 1$, 4) cycle length longer than 18EFPM, 5) high fuel discharge burnup of larger than 80MWD/kg, 6) low sodium void worth less than 7.5$, 7) low peak discharge fast neutron fluence less than $5.0x10^{23}$ n/cm^2, 8) sufficient control rod worth larger than 16$, 9) low linear heat generation rate less than 350 W/cm.

The core is loaded with a ternary metallic fuel of TRU-U-10Zr and it is designed to have a breakeven breeding characteristic (CR~1.0) so as to enhance the proliferation resistance. To reduce the sodium void worth, a moderator region is placed below the fuel. To enhance the economic potential of 1200 MWe, a compact core design with as small number of fuel assemblies as possible, and a small inventory of Pu fissile less than 6.0 ton/GWe are being searched for to enhance the fuel economy and the proliferation resistance at the same time. To achieve the design targets, the core power distribution is flattened by using non-fuel rods. The 1200 MWe SFR core is divided into three regions (Inner, Middle, Outer core regions) loaded with three kinds of fuel assemblies with a different number of non-fuel rods. Figure 1 shows the position of vacancy rods in the fuel assemblies loaded in the Inner and Middle core regions. The fuel assemblies in the Outer core region are all composed of fuel rods.

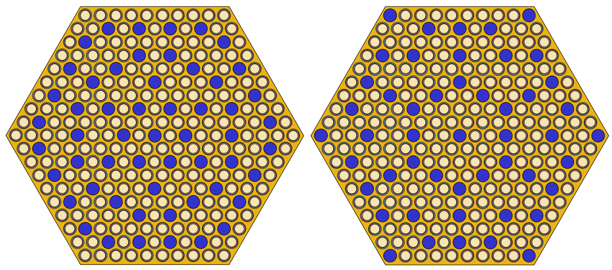

Figure 1 Non-Fuel Rods Position In an Assembly

2.2 Sensitivity Studies of Core Dimensional Variables

In order to search for the core loading pattern satisfying the design targets, the sensitivity studies for diverse core dimensional parameters such as the fuel rod diameter, cladding thickness, fuel rod pitch and core height are carried out. Figure 2 through Figure 5 show the results of the sensitivity studies for the case of a core design using vacancy rods. As shown in Figure 2, fuel outer diameter should be larger than 0.89 cm to satisfy the cycle length and the limit of the Na void worth when other design parameters are fixed.

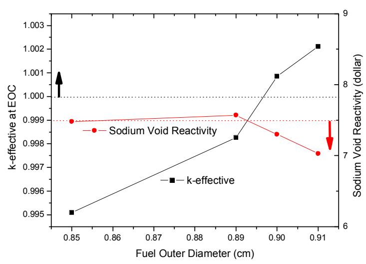

Figure 2 Effect of Fuel Outer Diameter Variation

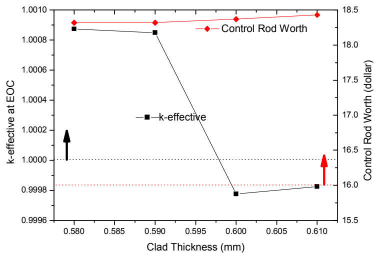

Figure 3 Effect of Cladding Thickness Variation

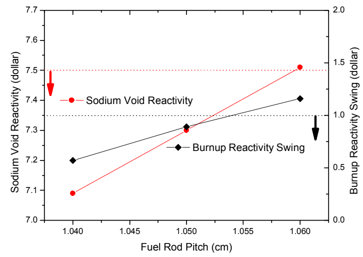

Figure 4 Effect of Fuel Rod Pitch Variation

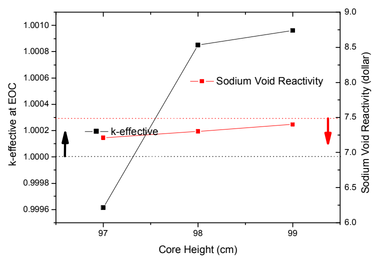

Figure 5 Effect of Core Height Variation

Based on the results of the sensitivity studies, a preliminary core design including a loading pattern search is carried out. Table I shows the value of the core design parameters for the case of the core with vacancy rods. Figure 6 shows the configuration of the core with vacancy rods. There are no big differences when steel rods or graphite rods are used instead of vacancy rods.

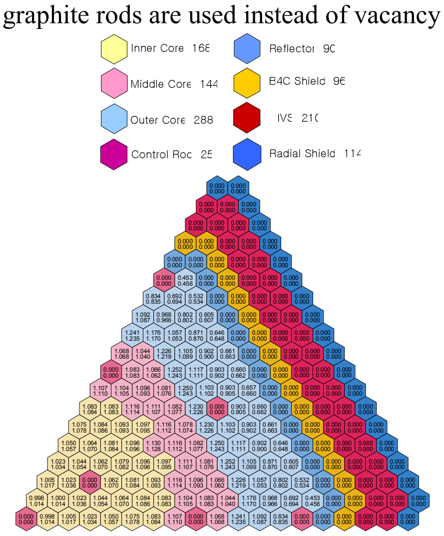

Figure 6 Core configurations

Table I Design Parameters and Characteristics

Parameters	Core with Vacancy Rods
Core height (cm)	94.0
Fuel rod outer diameter (mm)	9.0
Cladding thickness (mm)	0.59
Fuel assembly pitch (cm)	18.88
Fuel Rod Pitch (cm)	1.05
Number of fuel assemblies , IC/MC/OC	168/144/288
Material and thickness(cm) of the region below fuel	B4C, 14
Cycle length (EFPD)	540
Fuel management batches	4
TRU wt% (BOEC/EOEC)	14.9/15.3
Minimum β_{eff} (EOEC)	0.00353

2.3 Candidate Cores Satisfying the Design Targets

Table II compares the core performance characteristics for the three candidate cores with vacancy rod, steel rods and graphite rods, respectively.

Table II Performance of Candidate Cores

Core with	Pu-fiss Inventory at BOEC	Max. Na Void Reactivity	BU Reactivity Swing	Min. Control Rod Worth	Max. Linear Power Density	Peak High E. Neutron Fluence
	Ton/GWe	\$	\$	\$	W/cm	#/cm^2
	<6.0	<7.5	<1.0	>16.0	<350.0	<5.0x10^{23}
Vacancy Rods	5.65	7.09	0.57	18.34	305.4	4.68x10^{23}
Mod.HT9 Rods	5.70	7.37	0.76	16.75	303.5	4.60x10^{23}
Graphite Rods	5.75	7.33	0.67	18.93	294.7	4.53x10^{23}

3. Conclusion

In this paper, based on the sensitivity studies for diverse core dimensional parameters, a conceptual core design for a 1200 MWe SFR by using non-fuel rods and single enrichment fuel rods were investigated and the basic core performances were analyzed to find the core candidates. The proposed core design candidates satisfy all the design targets. The final 1200 MWe SFR core design will be determined after detailed core neutronic, fuel performance, thermal, and safety analyses.

REFERENCES

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