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Conceptual Core Designs with a Variant Thickness Clad or Enrichment-Split Fuel for a 1200MWe Sodium Cooled Fast Reactor

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1. Introduction

The conceptual core design for a 1200MWe sodium cooled fast reactor (SFR) is being developed by Korea Atomic Energy Research Institute (KAERI) in the framework of Gen-IV SFR development program. In order to enhance the economic potential, the rated power is increased to 1200MWe from 600MWe of the KALIMER-600. Since the KALIMER-600 has been adopted as a reference SFR system by the Gen-IV International Forum, and the development of a core design concept for a 1200MWe SFR is being performed based on the design feature of the KALIMER-600[1].

Three types of core design for 1200MWe SFR have been investigated during the development of conceptual core: 1) a core with enrichment split fuel, 2) a core with a single-enrichment fuel with a region-wisely varying clad thickness, and 3) a core with single-enrichment fuel with non-fuel rods. The core concept with single-enrichment fuel with region-wisely varying clad thickness is one of the intrinsic features of KALIMER-600[2,3]. The purpose of using the concepts of an enrichment split, varying clad thickness, and non-fuel rods is to flatten the power distribution over the core.

Two core design concepts with a region-wisely varying clad thickness and enrichment-split are proposed in this paper. The core design concept with non-fuel rods is described in another paper. Detailed core neutronic, fuel behavior, thermal, and safety analyses will be performed for the proposed core concepts.

2. Design Targets for 1200MWe SFR Core

The design targets for a 1200MWe SFR core have evolved as follows in order to enhance the safety and the economy of a system: 1) breakeven breeding without blanket (conversion ratio is about 1.0), 2) required fissile plutonium mass less than 6.0 ton/GWe, 3) burnup reactivity swing smaller than 1.0 $, 4) cycle length longer than 18 months, 5) average discharge burnup higher than 80 GWd/tHM, 6) sodium void reactivity worth smaller than 7.5 $, 7) peak fast neutron fluence less than 5.0×10^{23} n/cm^2, 8) sufficient control rod worth larger than 16.0 $, and 9) maximum linear heat generation rate lower than 350W/cm. Compared to the core design values of the KALIMER-600, the target value for the required fissile plutonium mass is decreased from ~6.5 ton/GWe to enhance the economic potential, and the target value for the sodium void reactivity is also decreased from 8.0 $ of the KALIMER-600 to enhance the safety. The target value for a fast neutron fluence is also raised with the expectation of the development of an advanced cladding.

3. Conceptual Cores for 1200MWe SFR

The conceptual cores to meet the design targets have been developed. The sensitivity calculation of the core design parameters; core height, fuel rod diameter, fuel rod pitch, clad thickness, and the thickness of moderator layer, were performed to find the optimal design for the conceptual core. The configuration of the core with a single-enrichment fuel with region-wisely varying clad thickness is shown in Fig. 1. As seen in Fig. 1, the total number of fuel assembly (FA) in a core is 600: 192 FAs in inner core, 144 FAs in middle core, and 264 FAs in outer core. The conceptual core with an enrichment split also has 600 fuel assemblies: 204 FAs in inner core, 156 FAs in middle core, and 240 FAs in outer core. The conceptual core has 31 control rod assemblies, however, the optimization of a control rod design including the control rod grouping and the optimal positioning will be performed further.

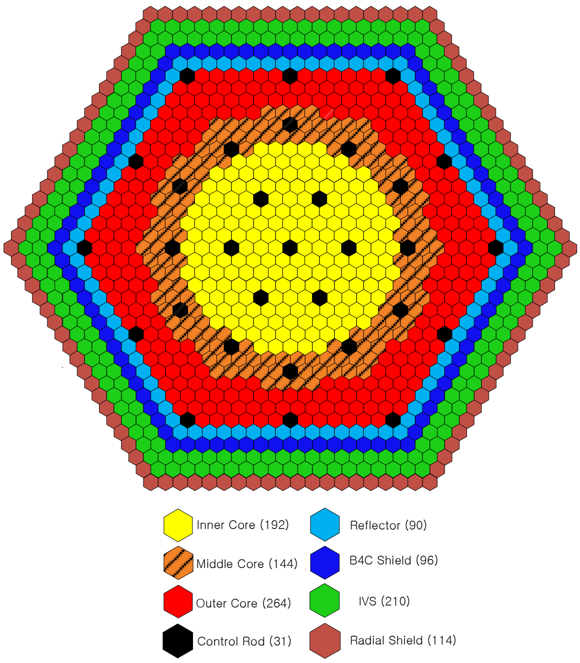

Figure 1. Configuration of conceptual core with single-enrichment fuel with region-wisely varying clad thickness.

The main design parameters of the conceptual cores are listed in Table I. The core height is reduced to 93.0

cm and 92.0 cm for the cores with a varying clad-thickness and with a single-enrichment, respectively; the core height of KALIMER-600 is 94.0 cm. The reduced core height is effective for achieving a lower sodium void reactivity worth. The cladding thicknesses for the inner, middle, and outer core regions ranges from 0.59 to 0.88 mm. The fuel outer diameter is 0.85 cm in the enrichment-split core; however, it is increased to 0.90 cm for the core with a varying clad-thickness to have a conversion ratio close to 1.0. The gap between the fuel pins in the enrichment-split core is designed to be larger than that of the core with a varying clad-thickness in order to maintain an acceptable pressure drop along the coolant channel.

Table I. Comparison of the design parameters

Design parameter	Varying Clad Thickness	Enrichment Split
Core height (cm)	93.0	92.0
Fuel rod outer diameter (mm)	0.90	0.85
Fuel pin pitch (cm)	1.05	1.01
Fuel assembly pitch (cm)	18.88	18.22
Pin P/D ratio	1.1667	1.1882
Clad thickness (mm)		
IC/MC/OC	0.88/0.79/0.59	0.595
Number of fuel assemblies		
IC/MC/OC	192/144/264	204/156/240

4. Characteristics of Conceptual Cores

The REBUS-3 equilibrium model with a 25 group cross section was used to perform the neutronic analysis for the selected conceptual cores. Four batch reload scheme was assumed as a fuel management strategy for the conceptual cores. The neutronic characteristics of the conceptual core are summarized in Table II. The required TRU enrichment of the fuel is 14.64 wt% for the core with varying clad thickness; and they are 13.08 wt% for inner core, 13.99 wt% for middle core, and 16.49 wt% outer core with enrichment-split fuel. The core average TRU enrichment of the core with an enrichment-split fuel is about 14.68 wt%, which is very similar to that of the core with varying clad thickness. Both cores have the conversion ratio close to 1.0. The required fissile plutonium inventories are 5.66 and 5.28 ton/GWe, which are less than the target values of 6.0 ton/GWe. The burnup reactivity of the core with varying clad thickness (0.99 $) is larger than that of enrichment-split fueled core (0.58 $) due to smaller conversion ratio. The sodium void reactivity worths of both cores are close to the target value limit of 7.5 $. The design targets for peak fast neutron fluence, peak linear heat generation rate, and control rod worth are also satisfied with both conceptual core designs. Both conceptual cores satisfy all the design targets. Comparing the fissile plutonium inventory and discharge burnup, the enrichment split fueled core shows more attractive aspect in neutron economy. However, the core concept for a 1200MWe SFR would be determined by considering many aspects including its safety, fabrication cost, and fuel economy. Detailed neutronic core analysis, fuel behavior analysis, thermal analysis, and safety analysis will be performed for the proposed core concepts.

Table II. Neutronic characteristics of the conceptual cores

Design parameter	Varying Clad Thickness	Enrichment Split
TRU wt% (BOEC)		
Inner Core	14.64	13.08
Middle Core	14.64	13.99
Outer Core	14.64	16.49
Conversion Ratio	~1.000	~1.004
Fissile Pu inventory (ton/GWe, BOEC)	5.66	5.28
Burnup reactivity swing ($)	0.99	0.58
Cycle length (EFPD)	540	540
Average discharge burnup (MWD/kg)	88.6	95.5
Sodium void worth ($)	7.44	7.49
Peak fast neutron fluence (n/cm^2)	4.38×10^{23}	4.75×10^{23}
Peak linear heat generation rate (W/cm)	300	312
Control rod worth ($)	17.55	17.40
Effective delayed neutron fraction	0.00347	0.00352

5. Conclusion

The conceptual core designs with an enrichment-split concept or with a single-enrichment fuel with a region-wisely varying clad thickness have been investigated and proposed for the development of the core for a 1200MWe SFR. The proposed conceptual cores satisfy the design targets on the conversion ratio, fissile plutonium mass, burnup reactivity swing, cycle, discharge, sodium void reactivity worth, peak fast neutron fluence, control rod worth larger, and linear heat generation.

Detailed core neutronic, fuel performance, thermal, and safety analyses will be performed for the proposed core concepts in order to determine the final 1200 MWe SFR core design.

REFERENCES

[1] Dohee Hahn, et al., KALIMER-600 Conceptual Design Report, KAERI/TR-3381/2007, Korea Atomic Energy Research Institute (2007).

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[3] S. G. Hong, et al., “A New Design Concept of the KALIMER-600 Core,” Proceedings of ICAPP 2007, Nice, France, May 13-18 (2007).