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Design Improvements for a 1,200MWe SFR Breakeven Core

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1. Introduction

According to the draft road map for a sodium cooled fast reactor (SFR) development program in Korea, the operation of a demonstrative prototype reactor will be started in 2028. For this end, a preliminary conceptual design will be developed until 2010. The rated power and the type of core, breakeven core or TRU burner, of a commercial SFR in the future have not been determined. Therefore, various design concepts for a SFR core are being developed by the Korea Atomic Energy Research Institute (KAERI) under the framework of the Gen-IV SFR development program.

Through the studies on the effect of the rated power on the nuclear core design[1] and on the zoning of a fuel fraction in a core to flatten the core power distribution[2], a 1,200MWe enrichment-split core design has been proposed as a conceptual core for a Gen-IV SFR. This conceptual core adopted an axial moderator or absorber layer in order to reduce the sodium void reactivity. This induced an unnecessary neutron absorption by an additional material, and the property of the core reactivity is deteriorated. Therefore, a reduction of the core height was examined in stead of using an axial moderator or absorber. And a zoning with two sub-regions in a core was also investigated to mitigate the complexity of a fuel fabrication by reducing the number of required TRU enrichment levels to two from three of the core with three sub-regions.

2. Description of the Conceptual Core

The conceptual core with an enrichment-split fuel utilized a radially heterogeneous core configuration with an annular loading of region-wise driver fuel assemblies. The total number of fuel assemblies in a core was 600: 192 FAs in the inner core, 144 FAs in the middle core, and 264 FAs in the outer core.

The core height of the conceptual core was reduced to 92.0 cm from 94.0 cm for KALIMER-600[3]. The reduced core height was effective for achieving a smaller sodium void worth. Each assembly includes 271 fuel pins and has a close-packed lattice. The assembly pitch was 18.22 cm for the enrichment-split fuel at a cold state. The fuel's outer diameter was 0.85 cm in the enrichment-split core. The gap between the fuel rods is maintained with a 1.4 mm thick wire wrap. The clad thickness of the enrichment-split fuel is 0.60 mm. The fuel slug outer diameter was determined to have a smear density of 75 %TD. With these design features of the fuel assemblies, the volume fraction of the enrichment-split fuel is 30.0 %. An axial moderator below the fuel region was required to reduce the sodium void worth to within the limit. The thickness of the axial moderator layers was 15 cm for the enrichment-split core.

3. Design Improvements of the Conceptual Core

3.1 Development of a Core with a Reduced Height

It was observed that a larger core size following the increased rated power improves the fuel economy. A large core, however, has an increased positive sodium void reactivity due to the reduced neutron leakage effect when a sodium void occurs. In order to reduce the sodium void reactivity, the use of an additional moderating material[4] in a neighboring region, just below the active core, to the effective core has been examined. The moderator or absorber materials that are under investigation are BeO, graphite, stainless steel, sodium, and B_4C. After adding a 15cm-thick axial layer of these materials to below the active core, its effect on the sodium void reactivity was evaluated. The use of graphite, stainless steel, and sodium do not have an effect on the sodium reactivity significantly. The sodium void reactivity was reduced by 0.5$ with BeO and 1.5$ with B_4C, respectively. However, since BeO and B_4C deteriorate the core reactivity, an increased TRU loading is required to maintain the cycle length.

An alternative way to decrease the sodium void reactivity is to reduce the core height. The core height was reduced to 80cm to satisfy the design target for the sodium void reactivity; the core height of the original configuration with a B_4C axial layer was 92cm. The decreased fuel inventory caused by the reduced core height did not achieve a conversion ratio of ~1.0. Therefore, the number of fuel assemblies and the fuel rod diameter were increased to maintain the breakeven capability. The main design parameters and neutronic characteristics of the reduced height core are given in Tables I and II.

3.2. Development of a Core with Two Sub-regions

The purpose of dividing the core into several sub-regions is to have a more flattened power distribution over the core by adjusting the fuel inventory for each core region. Generally, the more sub-regions the core is divided into, the easier the power distribution control is. However, many of the sub-regions in a core require as many kinds of fuel assemblies as the sub-regions, which makes a fuel fabrication complicated. Therefore, it is preferable to control the core power distribution by a fuel zoning with a lesser number of sub-regions.

Table I. Comparison of the design parameters

Design Parameter	Reduced height core design	Two sub-regions core design
Core Height (cm)	80.0	80.0
Fuel Assembly Pitch (cm)	18.45	18.45
Fuel Rod Outer Dia. (mm)	8.7	8.7
Fuel Slug Outer Dia.	6.50	6.50
(mm)	0.60	0.60
Clad Thickness (mm)	1.03	1.03
Fuel Pin Pitch (cm)	1.184	1.184
Pin P/D Ratio		
No. of Fuel Assemblies	198	318
- IC	180	-
- MC	246	306
- OC		

Table II. Neutronic characteristics of the improved cores

Core Characteristics	Reduced height core design	Two sub-regions core design
Burnup Reactivity Swing ($)	0.64	0.63
Conversion Ratio	0.993	0.993
TRU wt% (BOEC)		
- Inner Core	13.05	13.16
- Middle Core	14.33	-
- Outer Core	16.90	16.79
Core average feed TRU wt%	14.94	14.94
Fissile Pu Inventory (ton/GWe, BOEC)	5.06	5.06
Cycle Length (EFPD)	540	540
Peak Linear Heat Generation Rate (W/cm)	319	320
Average Discharge Burnup (MWD/kg)	100.1	100.1
Sodium Void Worth ($)	7.26	7.25
Peak Fast Neutron Fluence (n/cm^2)	4.74x10^{23}	4.72x10^{23}
Effective Delayed Neutron Fraction	0.00353	0.00353

The zoning with two sub-regions in a core was investigated in stead of the three sub-regions concept which was used in previous core designs. Fig. 1 shows the core configuration with two sub-regions. As shown in Tables I and II, the design parameters and core neutronic characteristics of the two sub-region core are not much different from those of the core with three sub-regions. Even though a steep increase of ~15% in power across the interface between inner core and outer core compared with 7% in the three sub-regions core was occurred in two sub-region case, it is noted that the maximum linear power of this core is close to that of three sub-region core. The grouping of the coolant flow would be expected to maintain the thermal performance of the core within the operable ranges.

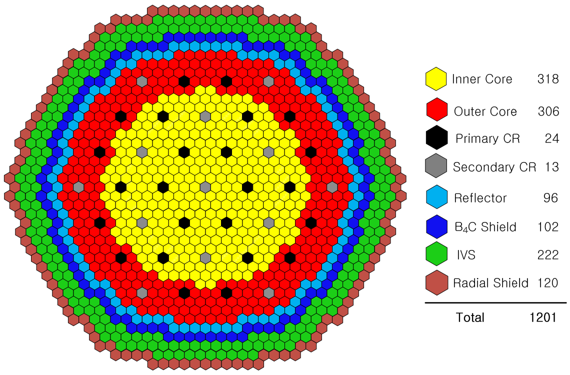

Fig. 1. Configuration of the Core with a Reduced Height and Two sub-region Zoning

4. Conclusion

For an alternative to reduce the sodium void reactivity, the concept of a reduced core height is preferable to the use of an axial moderator or an absorber layer below the active core by reducing the fuel inventory by ~5%. And a zoning with two sub-regions in a core was also proposed as a SFR breakeven core design concept.

The detailed core neutronic, fuel behavior, thermal, and safety analyses will be performed for the proposed candidate core concepts to finalize the core design concept for a 1,200MWe SFR.

ACKNOWLEDGMENTS

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