Core Design Optimization for a 600 MWe TRU Burner Reactor

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1. Introduction

The conceptual core design for a sodium cooled fast reactor(SFR) for TRU burning is being developed by the Korea Atomic Energy Research Institute(KAERI) and the core design concept of a 600-MWe SFR for TRU burning has been implemented based on the design feature of the KALIMER-600[1].

In this paper, a new core design concept for use of a single-enrichment fuel is described as a reference core. After the reference core design, a progressive design change is performed for optimization.

2. Core Design and Performance Analysis

2.1 Reference Core

The reference 600 MWe core has pursued the use of a single-enrichment fuel to simplify fuel fabrication processes and to eliminate the power shifting from the BOEC(beginning of equilibrium cycle) to the EOEC(end of equilibrium cycle). The elimination of power shifting makes it possible to simplify the orifice design for the flow redistribution. The core design parameter is shown in Table I. In order to use a single-enrichment fuel, three different cladding thicknesses of 1.01/0.93/0.73 mm were applied at the inner/middle/outer cores, respectively, as shown in Table II. The active core height was adjusted to make the sodium void worth around 7.5 $, and they are 89 cm. A clad outer diameter of 7.0 mm is adopted over all the designs, and the cladding thicknesses are adjusted to make TRU enrichment close to 30 w/o.

The depletion analysis is done with an equilibrium model of the REBUS-3 code system where the DIF3D[2] module solves the neutron diffusion equation with the HEX-Z nodal method and uses a 25 group cross-section set to obtain the neutron flux and power distributions.

2.2 Variable Sodium Bond Thickness Core

As a first design option, variable sodium bond thickness was adapted to find the difference in the core performance between the reference core and the variable sodium bond thickness core. The constant cladding thickness of 0.56 mm is adopted in the variable sodium bond thickness core. The design improvement to reduce the three subregions to two subregions was preformed by varing the number of fuel assembly. Fuel slugs with the different outer fuel diameters are used to control power distribution. Thicker sodium bonding was applied to fill up the thicker gap between a fuel slug and a cladding. In the reference core, a smeared density is fixed at the 75 v/o for the fuel slug swelling by fission products. On the contrary, in the variable sodium bond thickness core, different smeared densities of 53/56/66 v/o for 3 core region and 56/66 v/o used for 2 core regions.

Table I: Core Design Parameter

	Reference Core
Core Thermal Power(MWt)	1,500
Coolant Temperature (℃) -Inlet/Outlet	390/545
Cycle Length(EFPD)	332
Active Core Height(cm)	89
Eq. Core Diameter(m)	3.08
Eq. Reactor Diameter(m)	4.43
Number of Fuel Assemblies	324

Since a lot of bond sodium still remained inside fuel pin rods even though all sodium coolant vanished from a core region, sodium void worth can drop down to 6.56$ and 6.61$ at EOEC in both variable sodium bond thickness cores. The other advantage by thicker sodium bonding is low cladding inner temperature, which is the main reason for using this option. The produced heat from the fuel slug can be transferred quickly to the sodium coolant in the variable sodium bond thickness option because of its thin cladding thickness of 0.56 mm and the fact that the thermal conductivity of sodium is 3 times higher than that of the cladding material of HT-9. The drawback of this core is that the smear density in inner core may become too small to suspend the fuel inside cladding.

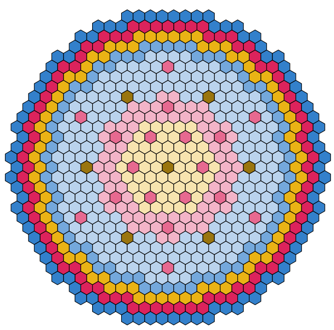

Fig. 1. Core Layout.

2.3 Fuel Diameter Variation Core

The previous variable sodium bond thickness core shows that the minimum sodium smear density is below 60% which is the limit of fuel smear density. So, in this option, the variation of fuel diameter was tried. As shown in Table III, the calculation results show that, for 1.29 of the pitch to diameter ratio, which is the same value as the reference core, the fuel diameter should be reduced to 6.2mm to maintain the TRU enrichment to be 30 wt% in case of fixed outer core smear density to be 75% and the fuel diameter to 6.5mm in case of fixed inner core smear density to be 60%. For the case of reducing the pitch to diameter ratio to be 1.25 from 1.29, which is the same value as the reference core, the fuel diameter should be reduced to 6.3mm in case of fixed inner smear density to be 60%.

Table II: Core Performance for the Variable Sodium Bond Thickness (VSBT) Core

	Reference Core	VSBT Core (3 region)	VSBT Core (2 region)
P/D Ratio	1.29	1.29	1.29
Smear Density (Inner/Middle/Outer Core,%)	75/75/75	53/56/66	56/66
Fuel Rod Outer Diameter(mm)	7.0	7.0	7.0
Cladding Thickness(mm) -Inner/Middle/Outer Core	1.01/0.93/0.73	0.56/0.56/0.56	0.56/0.56
Burnup Reactivity Swing(pcm)	3,496	3,593	3,604
Conversion Ratio(Fissile/TRU)	0.74/0.57	0.74/0.57	0.74/0.57
Charged TRU enrichment(w/o)	30.00	29.14	30.00
Average Linear Power(W/cm)	179	179	179
Power Peaking Factor	1.52	1.52	1.51
Peak Fast Neutron Fluence(10^{23} n/cm^2)	4.25	4.32	4.41
Sodium Void Worth($)	7.5	6.56	6.61
Max. Nominal Bundle Pressure Drop(MPa)	0.150	0.149	0.148
Max. Nominal Cladding Inner Wall temp. (℃)	613	605	604

Table III: Core Performance for the Fuel Diameter Variation (FDV) Core

	FDV Core 1	FDV Core 2	FDV Core 3
P/D Ratio	1.29	1.29	1.25
Smear Density (Inner/Middle/Outer Core,%)	64/75	60/71	60/71
Fuel Rod Outer Diameter(mm)	6.2	6.5	6.3
Cladding Thickness(mm)-Inner/Outer	0.56/0.56	0.56/0.56	0.56/0.56
Burnup Reactivity Swing(pcm)	4,351	4,035	4,455
Conversion Ratio(Fissile/TRU)	0.74/0.56	0.74/0.57	0.73/0.56
Charged TRU enrichment(w/o)	30.00	30.00	30.00
Average Linear Power(W/cm)	179	179	179
Power Peaking Factor	1.50	1.51	1.51
Peak Fast Neutron Fluence(10^{23} n/cm^2)	5.55	5.06	5.66
Sodium Void Worth($)	6.58	6.60	6.19
Max. Nominal Pressure Drop(MPa)	0.238	0.197	0.297
Max. Nominal Cladding Inner Wall temp. (℃)	600	605	604

3. Conclusions

A new core design concept using a single-enrichment fuel was presented for the 600 MWe sodium cooled reactor KALIMER-600. In this concept, the power flattering under a single-enrichment fuel was achieved by using the core region-wise cladding thickness. As an alternative design option, the variable sodium bond thickness option was introduced and shows that the maximum cladding inner wall temperature can be reduced and the sodium void worth can be dropped, but too low smear density is the drawback of this design. To overcome this aspect, the variable fuel diameter option was tried and found that the minimum diameter is 6.2 mm to maintain the TRU enrichment to be 30 wt%.

REFERENCES

[1] S. G. Hong, et al., A New Design Concept of the KALIMER-600 Core, Proc. Of ICAPP'07, Nice, France, 2007.
[2] K. D. Derstine, DIF3D: A Code to Solve One-, Two-and Three-Dimensional Finite Difference Diffusion Theory Problems, ANL-82-64, Argonne National Laboratory, 1984.