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Core Design Studies for a 600 MWe TRU Burner Reactor

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1. Introduction

The conceptual core design for a 600-MWe sodium cooled fast reactor(SFR) for TRU burning is being developed by the Korea Atomic Energy Research Institute(KAERI) under the frame of the Gen-IV SFR development program. The KALIMER-600 has been adopted as a reference SFR system by the Gen-IV International Forum. Therefore, the development of the core design concept for 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 for a reference core. In this concept, power flattering is achieved by using the core region-wise cladding thickness. After the reference core design, a progressive design change of 600 MWe for TRU burning is performed for optimization. The core performance, including the reactivity coefficients, are analyzed and inter-compared.

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. 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 I. 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 fuel pitch was allowed to vary in order to cause no more than 0.15 MPa that is the nominal maximum pressure drop across the axial fuel rod section. All the designs maintain an average linear power of 180 W/cm. The number of assemblies in each region was determined to minimize the peak-to-average power ratio in the core. Fig. 1 shows the radial core configuration

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 SD-1 Core

As a first design option, a use of variable sodium bond thickness was adapted to find the difference in 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 SD-1 option. Fuel slugs with three different outer 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 which is considered with a fuel slug and a sodium bonding gap is fixed at the 75 v/o for the preparation of fuel slug swelling by fission products. On the contrary, three different smeared densities of 53.9/57.4/66.7 v/o were used in inner/middle/outer core region in this SD-1 option.

Since a lot of sodium bonding still remained inside fuel pin rods even though all sodium coolant vanished from a core region, sodium void worth can drop down to 6.64 $ at EOEC. 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 SD-1 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. A detailed subchannel analysis by MATRA-LMR was performed with the following procedures. The assembly power distribution of the 1/6 core of the SD-1 option was calculated by a DIF3D code, and nine flow groups were specified depending on these power distributions. The hottest assembly with a peak power density was chosen, and the pin power reconstruction procedure was accomplished.

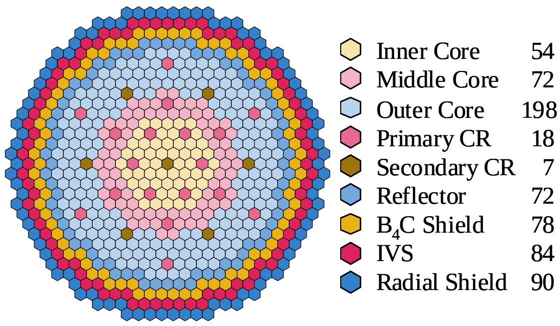

Fig. 1. Core layout.

Table I: Core performance

	Reference core	SD-1 core	SD-2 core
Fuel/coolant/structure volume fraction			
(%,inner core)	23.1/42.1/34.8	23.1/51.1/25.8	22.5/51.6/25.8
(%,middle core)	24.6/42.1/33.3	24.6/49.6/25.8	24.1/50.1/25.8
(%,outer core)	28.5/42.1/29.4	28.5/45.7/25.8	28.0/46.2/25.8
Smeared Density[v/o][IC/MC/OC]	75.0/75.0/75.0	53.9/57.4/66.7	52.7/56.2/65.5
Core Thermal Powerl(MWt)	1,500	1,500	1,500
Coolant Temperature.(℃)'-Inlet/Outlet	390/545	390/545	390/545
Cycle Length(EFPD)	332	332	332
Active Core Height(cm)	89	89	89
Eq. Core Diameter(m)	3.08	3.08	3.08
Eq. Reactor Diameter(m)	4.43	4.43	4.43
Number of Fuel Assemblies	324	324	324
Fuel Outer Diameter(mm)	7.0	7.0	7.0
Pin Pitch(mm)	9.00	9.00	9.00
P/D Ratio	1.29	1.29	1.29
Cladding Thickness(mm)-Inner/Outer	1.01/0.93/0.73	0.56/0.56/0.56	0.56/0.56/0.56
Burnup Reactivity Swing(pcm)	3,496	3,462	3,593
Conversion Ratio(Fissile/TRU)	0.74/0.57	0.75/0.59	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	1.52
Peak Fast Neutron Fluence(1023 n/cm2)	4.25	4.34	4.32
Sodium Void Worth($)	7.5	6.64	6.56
Max. Pressure Drop(MPa)	0.15	0.149	0.149
Max. Cladding Inner Wall temp. (℃)	613	604	605

Using relative pin power distributions, the coolant inlet/outlet temperature, the flow rate, the assembly geometry information, the temperatures of each subchannels and fuel pins, the pressure drop, the mass flow rates, etc, were calculated by MATRA-LMR. The hottest fuel pin was located in the center of the assembly, and it was confirmed that the maximum cladding inner wall temperature was reduced at this pin.

2.3 SD-2 Core

The previous SD-1 core shows the reduced maximum cladding inner wall temperature and sodium void worth, but the TRU enrichment does not reach 30%. So, the SD-2 core was designed for the increasing of TRU enrichment. The role of the advanced burner is to transmute the recycled TRU enrichments which are the dominant contributors to spent fuel radio-toxicity. In order to demonstrate a high TRU consumption ratio, it is desirable to have a low conversion ratio. However, a low conversion ratio requires a high TRU enrichment. For increasing TRU enrichment, the major design variable to be used is the smeared density. The smeared density was decreased until the TRU enrichment reached 30%. As shown in Table I, the resulting fuel slug smearing fractions are decreased from 53.9/57.4/66.7% in the SD-1 core to 52.7/56.2/65.5% in the SD-2 core for the inner/middle/outer core fuels. The reduced smear density is affected to fuel volume fraction. As a result, the core performance parameter has changed. As compared with the SD-1 core, the TRU enrichment is increased to 30% for the SD-2 core. The resulting TRU conversion ratio is reduced to 0.57 from 0.59, and the burnup swing is increased to 3,593 pcm from 3,462 pcm over the 332 EFPD.

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 smeared density option was introduced and shows that the maximum cladding inner wall temperature can be reduced.

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.