Core Performance Comparisons in TRU Burning Large Fast Reactors

Hoon Song, Sang Ji Kim and Yeong Il Kim
Korea Atomic Energy Research Institute, 150 Duckjin-Dong, Yuseong-Gu, Daejon, 305-353, hsong@kaeri.re.kr

1. Introduction

To investigate the performance parameters and safety implications of reactivity coefficients in large monolithic sodium cooled fast reactors for TRU burning, cores whose powers range from 600 MWe to 1,800 MWe were designed. With the design data accumulation accompanied by the safety analysis, the results of this study would help to identify the most limiting factor for scaling up conceptual burner cores. Instead of the traditional enrichment zoning approach to flatten the power distribution, the design concept of a single fuel enrichment was adopted.

For the core design concepts, three power levels of 600, 1200 and 1,800 MWe were selected to investigate the dependency of the core performance parameters and reactivity coefficients on the power level.

2. Core Design and Performance Analysis

2.1 Description of the Core Design

Core designs used the design constraints related to the current technology database with the TRU enrichment limit (30.0 w/o) and fast neutron irradiation limit (4.0×10^{23} n/cm^2). A single enrichment concept, adopted in the KALIMER-600 breakeven core design[1], was used. As a means to flatten the power distribution, fuel pin designs of different cladding thickness are used in different core regions, while the same cladding outer diameter is adopted throughout the core.

For a consistent comparison, the active core height was adjust to make the sodium void worth lower than 7.5\$, and the number of assemblies was adjusted to attain a similar linear power around 180 W/cm. The fuel pin diameter and the number of fuel pins were fixed at 7 mm and 271, respectively. But, the pitch to diameter of fuel rods is allowed to vary. In order to demonstrate a high TRU consumption rate, a core design is tried to attain TRU enrichment to be 30 w/o. The major design variables to be used in changing the conversion ratio of a given core design are the variation of core height and fuel cladding thickness. The cladding thickness was increased to decrease the fuel volume fraction. At the same time, the core design was confirmed to have maximum inner cladding temperatures below 650 ℃ and maximum pressure drops below 0.15MPa.

All the nuclear designs and evaluations were performed with the nuclear calculation module packages in the K-CORE System which is an integrated modular program. Global reactivity feedbacks were calculated using a series of neutron flux solution calculations for a hexagonal-z geometry.

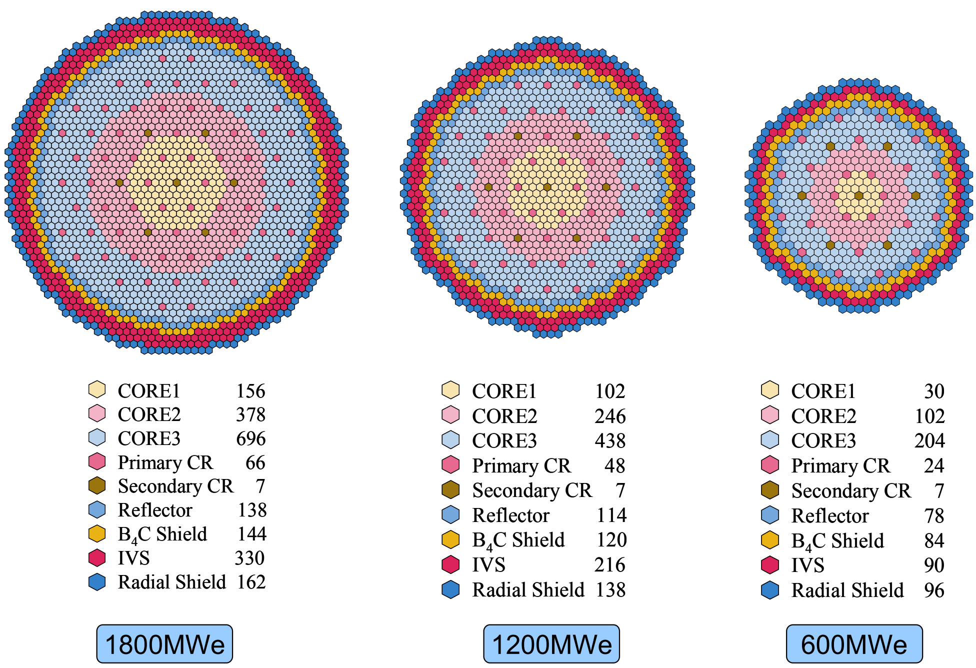

Fig. 1 Core Layout for the Variable-Cladding-Thickness Designs

TABLE 1 Core Performances of Variable-Cladding-Thickness Designs

Design parameter	1,800MWe	1,200MWe	600MWe
Core Thermal Power(MWt)	4,500	3,000	1,500
Coolant Temperature(℃)-Inlet/Outlet	390/545	390/545	390/545
Number of Fuel Assemblies	1230	786	336
Assembly Pitch(cm)	15.9	15.9	16.1
Fuel Outer Diameter(mm)	7.0	7.0	7.0
Pin Pitch(mm)	8.792	8.792	8.890
P/D Ratio	1.256	1.256	1.270
Cladding Thickness(mm)-Inner/Middle/Outer	1.05/0.91/0.77	1.05/0.91/0.77	1.05/0.91/0.77
Eq. Core Diameter(m)	5.86	4.68	3.09
Eq. Reactor Diameter(m)	7.61	6.31	4.51
Charged TRU (w/o)	28.92	29.16	29.92
Conversion Ratio(Fissile/TRU)	0.76/0.59	0.76/0.58	0.74/0.57
Burnup Reactivity Swing(pcm)	3,508	3,512	3,671
Cycle Length(EFPD)	332	332	332
Sodium Void Worth(BOEC/EOEC)	6.87/7.55	6.91/7.52	6.68/7.28
Peak Fast Neutron Fluence(n/cm^2)	4.42	4.31	4.64
Max. Pressure Drop(MPa)	0.134	0.136	0.156
Max. Cladding Inner Wall Temp.(℃)	571.73	576.02	591.27
Average Linear Power(W/cm)	179.1	178.1	180.4
Power Peaking Factor	1.545	1.476	1.516
Active Core Height(cm)	70.0	73.5	85.0
TRU Consumption Rate(kg/year)	626	423	221

The numbers of fuel assemblies of the 600, 1200, and 1800 MWe designs are 336, 786 and 1230, respectively. Figure 1 shows the radial core configuration.

2.2 Core Performance Analysis Results

Burning characteristics and performance parameters are listed in Table 1 for the three cores. The REBUS-3[2] equilibrium model with a nine group cross section was used to perform the core depletion analysis.

The calculation results show that large monolithic sodium cooled fast reactors for TRU burning, of which power range from 600 MWe to 1,800 MWe can be successfully designed, while meeting all the design constraints. The calculated TRU conversion ratio is 0.57 for the 600 MWe core, 0.58 for the 1,200 MWe core, and 0.59 for the 1,800 MWe. The 600 MWe core requires a charged TRU enrichment of 29.3 % and yields a reactivity swing of 3,671pcm over a 332 EFPD. The charged TRU enrichment is 29.2% for the 1,200 MWe core and 28.9% for the 1,800 MWe core.

The core designs have almost the same TRU burning rate per power and a burnup reactivity swing of ~3,500pcm. The reactivity swing is 3,512pcm for the 1,200 MWe core and 3,508 pcm for the 1,800MWe core. The TRU consumption rate is 221 kg/year for the 600 MWe core, 423 kg/year for the 1,200 MWe core, and 626 kg/year for the 1,800 MWe. Thus the consumption rate is increased by 1.91 times for the 1,200 MWe core and by 2.82 times for the 1,800 MWe core, compared to the 600 MWe core. However, these differences are so small that it is judged that the consumption rate per power is invariant. In all three designs, the sodium void worth upon a core plus fission gas plenum voiding, turned out to be less than 7.5$.

3. **Conclusion**

To investigate the performance parameters and safety implications of reactivity coefficients in large monolithic sodium cooled fast reactors for a TRU burning, cores whose powers range from 600 MWe to 1,800 MWe were designed. With the design data accumulation accompanied by the safety analysis, the results of this study would be able to identify the most limiting factor for scaling up burner core concepts.

The calculation results show that large monolithic sodium cooled fast reactors for a TRU burning whose power ranges from 600 MWe to 1,800 MWe can be designed satisfactorily. In addition they have almost the same TRU burning rate per power. The detailed calculations including the kinetic parameters, reactivity feedback coefficients, and reactivity control requirements are also accessed.

Acknowledgement

This study was supported by the Korean Ministry of Science & Technology through its National Nuclear Technology Program.

REFERENCES

[1] Ser Gi Hong et al., "The KALIMER-600 Reactor Core Design Concept with Varying Fuel Cladding Thickness", Proceedings of the Korean Nuclear Society Autumn Meeting(2006).

[2] B. J. TOPPEL, "A User's Guide for the REBUS-3 Fuel Cycle Analysis Capability," ANL Report, Argonne National Laboratory 83-2, March (1983).