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Core Design Studies for a 300 MWe TRU Burner Reactor

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1. Introduction

KAERI has been developing the KALIMER-600[1] core design with a breakeven fissile conversion ratio. The core is loaded with a ternary metallic fuel (TRU-U-10Zr), and the breakeven characteristics are achieved without any blanket assembly. As an alternative plan, a KALIMER-600 burner core design has also been performed. In the early days of a fast reactor, the main purpose was an economical use of a uranium resource, but nowadays, in addition to the maximum utilization of a uranium resource, the burning of high level radioactive waste is taken as an additional interest for the harmony with the environment.

In this paper, a 300 MWe burner core design is presented to demonstrate reactor performance for the reference KALIMER-600 burner. As a means to flatten the power distribution, instead of a single fuel enrichment scheme adapted in the design of the KALIMER-600 burner, the two enrichment zoning approach was adapted. Considering that the TRU fuel may not be qualified due to limited database, the uranium core was designed to permit the TRU core operation to cover after the uranium core is operated at an early stage.

2. Core Design and Performance Analysis

2.1 Reference Core

Fig. 1 shows the layout of 300 MWe core as a reference core. As shown in the figure, the core consists of two regions of driver fuel. It consists of 84 fuel assemblies in the inner core and 108 fuel assemblies in the outer core. The TRU enrichments of the inner/ outer cores for the radial power control are 16/20 wt. %, in which the enrichment of 20 wt. % is the maximum allowable enrichment in the commercial market.

Instead of a single fuel enrichment, an enrichment zoning approach was used to flatten the power distribution. The hexagonal driver fuel assembly consists of 271 rods within a duct wrapper. The rod outer diameter is 7 mm. The core configuration is a radial homogeneous one that incorporates annular rings with a zone-wise enrichment variation.

Active core height was adjusted to make the enrichment of the outer core 20 wt. %, and that height is 118 cm. Since the number of assemblies is fixed, a linear power density was reduced to 114 W/cm from 180 W/cm.

The core design was confirmed by the fact that the maximum inner cladding temperatures are below 650 ℃. The REBUS-3[2] equilibrium model with 25 group cross sections was used to perform the core depletion analysis. Table I shows a summary of the core performance analysis results for the reference core. The burnup reactivity swing was estimated to be 1,491 pcm. This relatively large value of burnup reactivity swing is due to the small breeding ratio.

2.2 CH-1 Core

As a first design option, the diameter of the fuel rod was expanded from 7.0m to 7.44m. As shown in Table I, P/D ratio is the same as the reference core. However, the fuel pitch was increased to 9.31, since the fuel diameter was increased. As a result, the core equivalent diameter and reactor diameter were increased to 2.44m from 2.30m, to 3.79m from 3.58m. Since the diameter of fuel rod was increased, the total amount of fuel was increased so that the enrichment was decreased compared to that of the reference core. Therefore, the active core height was decreased to increase the outer core enrichment to 20 wt. %. The investigation of the variation of outer core enrichment with the increase of active core height shows that outer core enrichment reached 20 wt. % in the 104 cm of core height. As a result, the conversion ratio decreased to 0.54 from 0.55. The average discharge burnup decreased to be 62.7 MWD/kg as compared 63.6 MWD/kg of the reference core. Also, the increase of fuel rod diameter was followed by the increase of coolant flow area, so that the maximum press drop decreased to 0.131 MPa from 0.185 MPa.

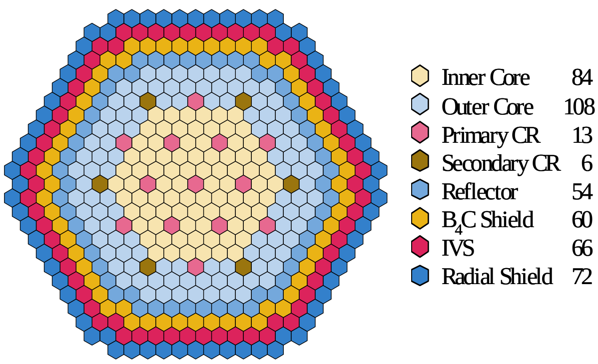

Fig. 1. Core layout.

Table I: Core performance

	Reference core	CH-1 core	Uranium core	TRU core	TRU core (Sodium bond)
Core Electrical Power(MWe)	300	300	300	300	300
Core Thermal Power(MWt)	750	750	750	750	750
Coolant Temperature(℃)'-Inlet/Outlet	390/545	390/545	390/545	390/545	390/545
Cycle Length(EFPD)	309	309	309	309	309
Number of Batches	5	5	5	5	5
Active Core Height(cm)	118	104	115.6	115.6	115.6
Eq. Core Diameter(m)	2.30	2.44	2.34	2.34	2.34
Eq. Reactor Diameter(m)	3.58	3.79	3.64	3.64	3.64
Number of Fuel Assemblies	192	192	192	192	192
Fuel Outer Diameter(mm)	7.0	7.44	7.44	7.44	7.44
Pin Pitch(mm)	8.76	9.31	8.93	8.93	8.93
P/D Ratio	1.25	1.25	1.2	1.2	1.2
Burnup Reactivity Swing(pcm)	1,491	1,452	942	28	1,413
Conversion Ratio[Fissile/TRU]	0.55	0.54	0.59	0.98/0.95	0.81/0.67
Charged TRU wt% [Inner/Outer]	16.00/20.00	16.00/20.00	13.93/19.00	14.10/19.23	22.00/30.00
Average Linear Power(W/cm)	114	130	117	117	117
Power Peaking Factor	1.73	1.67	1.60	1.69	1.54
Average discharge burnup(MWD/kg)	63.6	62.7	56.1	55.8	77.1
Peak Fast Neutron Fluence(n/cm2)	2.76	2.67	2.51	2.97	2.98
Max. Pressure Drop(MPa)	0.185	0.131	0.198	0.204	-
Max. Cladding Inner Wall Temp.(℃)	596	596	596	591	-

2.3 Uranium Core

The reduced pressure drop can be improved by adjusting the P/D ratio. Three cases of P/D ratio, 1.2, 1.25, and 1.3, were investigated. Also the core height was adjusted to make the outer core enrichment 19 wt. %, which is selected to consider the uncertainty of fuel enrichment and allowance. The active core height was increased in all cases of P/D ratio. The core height of 104 cm in case of enrichment 20 wt. % was increased to 116 cm for P/D ratio 1.2, for example. Maximum press drop is increased a little bit compared to that of the enrichment of 20 wt. % since the core height was increased to reduce the outer core enrichment of 20 wt. % to 19 wt. %.

2.4 TRU Core

To be compared with uranium core, TRU core was designed in the same design conditions with the 19 wt. % uranium core. As shown in Table I, the enrichment was increased as compared to that of 19 wt. % uranium core. The outer core enrichment was increased to 19.23 wt. %. The conversion ratio shows the conversion ratio 0.95 irrespective of P/D ratios change, so the aspect of burner seems to approach a breakeven core. Further design optimization with a use of variable sodium bond thickness improves the capability of the burner reactor with the conversion ratio of 0.67.

3. Conclusions

A 300 MWe burner core design was performed with a purpose of demonstrating KALIMER-600 burner, when the TRU core is operated after the uranium core is operated at early stage.

The results indicate that it is feasible to design the uranium core having the enrichment 20% and the enough burner capacity when converted to a TRU core from a uranium core. A further design optimization is required to improve the burning capacity of a TRU core.

REFERENCES

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[2] B. J. Toppel, A User's Guide to the REBUS-3 Fuel Cycle Analysis Capability, ANL-83-2, Argonne National Laboratory, 1983.