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Core Design Studies for a 600 MWe Demonstration TRU Burner Reactor

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1. Introduction

The conceptual core design of the demonstration sodium cooled fast reactor (SFR) for TRU burning is being developed by the Korea Atomic Energy Research Insititute (KAERI). The main objective of demonstration reactor for the construction and operation is to test and demonstrate the TRU fuel, the operaton of the large sized (1500 MWth) sodium fast reactor and the TRU burning capability of commercial burner reactor.

In this paper, a 600 MWe demonstration burner core design is presented. It is scheduled to use the uranium fuel for start core due to the uncertainty of the demonstration of TRU fuel, and to change core fuel to the LTRU core fuel from LWR spent fuel and core fuel to the MTRU core which consists of the LMR spent fuel and the self recycled fuel progressively so that total 4 cores having the different function, which consists of uranium core, LTRU core, MTRU core and Mod.MTRU core, were designed.

2. Core Design and Performance Analysis

2.1 Uranium Core

The uranium core was designed maintaining the same dimension of core with reference core[1] to replace the TRU fuel of the reference TRU core to uranium fuel. Fig. 1 shows the layout of 600 MWe core as a uranium 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 for uranium core.

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 89 cm.

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 uranium core. The burnup reactivity swing was estimated to be 2,957 pcm. This relatively large value of burnup reactivity swing is due to the small conversion ratio.

2.2 LTRU core

As next core, LTRU core was designed. The core uses the spent fuel from LMR and adapts the option for once–through cycle. The dimension was maintained the same as the previous uranium core. Through the core region-wise enrichment searching and the loading strategy searching to find the minimum peaking factor for flatting the power distribution over the entire core region, we found that when the TRU enrichment of outer core and outer core region reaches 26% and 19.4%, the best results was found showing that the minimum peaking factor was 1.55 at BOEC and 1.53 at EOEC which are well below 1.60 of the predetermined design limitation. The core design was confirmed by the fact that the maximum inner cladding temperatures are below 650 ℃.

2.3 MTRU Core

MTRU core uses the mixed TRU fuel with LMR spent fuel and the self recycled fuel. The same dimension was used as the previous uranium core. The cladding fluence and power peaking factor was satisfied but the increased sodium void is quite large value for safety aspect so that the effort may be needed for reduction of this value. TRU consumption rate was estimated to 239 kg/cycle and the burnup reactivity swing 3,922 pcm. The average TRU enrichment in the core was 30.7%.

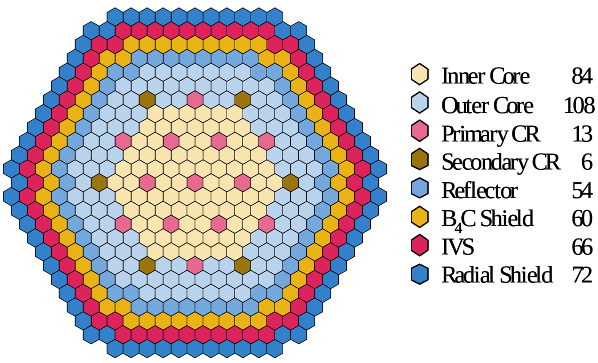

Fig. 1. Core Layout.

Table I: Core Performance

	Uranium core	LTRU core	MTRU core	Mod.MTRU core
Fuel Loading Cycle(Batch, Inner/Outer core)	4/3	3/3	3/3	3/3
Charged Fuel Enrichment (U,TRU) wt% (Inner/Outer/Avg. core)	16.3/20.0/18.5	19.4/26.0/23.4	25.4/34.1/30.7	34.6/46.3/41.7
Conversion Ratio (Fissile/TRU)	0.53/-	0.77/0.68	0.76/0.54	0.65/0.38
Burnup Reactivity Swing (pcm)	2,957	3,207	3,922	5,468
Cycle length (EFPD)	365	365	365	365
Avg. Discharged Burnup (MWD/kg) (Inner/Outer core)	109.6/65.9	90.0/79.7	102.9/95.8	123.3/122.6
Peak Fast Neutron Fluence(n/cm^2)	3.63	3.18	3.28	3.30
Power Peaking factor (BOEC/EOEC)	1.60/1.58	1.55/1.53	1.55/1.56	1.54/1.62
TRU Consumption Rate(kg/cycle)	-	163.2	239.7	339.0
Max. Nominal Bundle Pressure Drop(MPa)	0.31	0.31	0.31	0.31
Max. Nominal Cladding Inner Wall Temp.(℃)	-	567	568	567
Sodium Void Worth(EOEC,$)	-0.55	7.92	8.67	7.98

2.4 Mod.MTRU Core

From MTRU core, Mod.MTRU core was designed to find the maximum allowable TRU consumption rate in case that the maximum allowable design limitation is used. In this case, the design limitation is that the fuel is to use the fuel with 20% Zr content and maximum 60% allowable smear density is used using the core dimension of uranium core as reference. The calculation results show that the cladding fluence and the power peaking factor were satisfied but the burnup reactivity swing was increased to 5,468 pcm. Therefore, it is necessary to reduce this value. The TRU consumption rate was increased 2 times to 339 kg/cycle compared the 239 kg/cycle of MTRU core. The average TRU enrichment was increased to 42% as compared to with 30% of MTRU core.

3. Conclusions

A series of core design were performed, ranged from the uranium core to LTRU, MTRU, and Mod.MTRU for a 600 MWe demonstration burner core design. The core design show that it is feasible to design the uranium core having the maximum allowable enrichment of 20% and LTRU core and MTRU core is possible to convert to a TRU core from a uranium core maintaining the same dimension as uranium core but the enough burner capacity is not satisfied in the TRU core so that Mod.MTRU core has designed to enhance the burning capacity of the burner reactor. The Mod.MTRU core, which maintains the maximum allowable design limitation, has the capacity for consuming TRU quantity 2 times as compared MTRU core but still large sodium void worth can be problem to the core safety. Therefore, a future optimization is required to reduce the sodium void reactivity and the burnup reactivity swing.

REFERENCES

[1] H. Song et al., "600~1,800 MWe Sodium Cooled Reactor Core Design for a TRU Burning", Proceedings of the Korean Nuclear Society Autumn Meeting, 2007.
[2] B. J. Toppel, A User's Guide to the REBUS-3 Fuel Cycle Analysis Capability, ANL-83-2, Argonne National Laboratory, 1983.