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Core Function Changes from a Breakeven Core to a TRU Burner Core

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1. Introduction

A 600MWe sodium cooled fast reactor named as KALIMER-600 has been developed with a single enrichment fuel.[1] This reactor is a pool-type reactor with a 1,523MW thermal power. The core is loaded with a ternary metallic fuel of 15 w/o TRU enriched TRU-U-10Zr and it is designed to have breakeven breeding characteristics (CR~1.0). However, a new demand is how to solve a spent fuel disposal problem because nuclear spent fuel storages shall become full by 2016 year. Therefore, a TRU burner concept which can burn out spent fuel actively is needed instead of a breakeven reactor concept. After all spent fuels from LWRs are burned, another issue may be that a TRU burner can not be operated in a breakeven mode any more. In order to overcome this problem, a new concept – a core function change is proposed in this paper. A reactor will operate as a TRU burner at first and then, will play the role of a breakeven core without any core layout change which does not need TRU supply. Since the nuclear conceptual design of a breakeven core - KALIMER-600 is already finished, TRU burner concepts are based on the KALIMER-600 breakeven core and its safety parameters are asked to be compatible with those of the KALIMER-600 breakeven core.

2. Design Criteria for TRU Burner Core Design

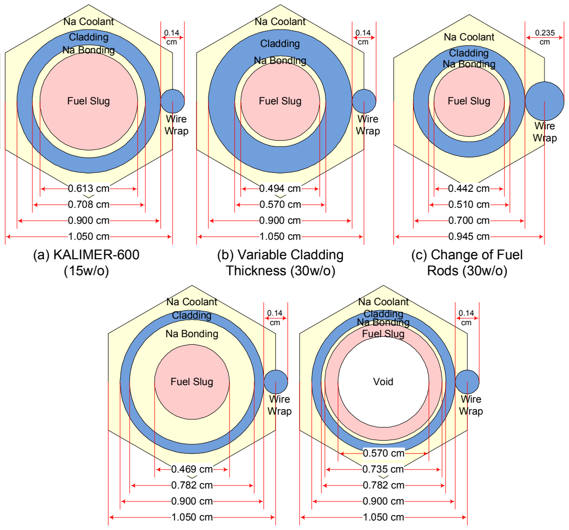
The most important restrictions are the immutable core shape and the fulfillment of the parameters for switching the conversion characteristics at the same power plant.

By the fixation of a core shape, assembly pitch and fuel pin outer diameter, the thermal hydraulic condition can remain the same as that of a breakeven core. The performances of a TRU burner core were evaluated for the following criteria.

- For TRU transmutation capability, the TRU conversion ratio should be less than 0.6.
- For the stability of metallic fuel, the maximum TRU enrichment should be limited under 30 w/o.
- To conserve the safe shutdown capability, the burnup reactivity swing should be limited under 3,000 pcm as low as possible.
- To minimize the effect of a reactivity accident, the maximum sodium void worth should be not exceeding 8.0 $ which is the same criterion for the KALIMER-600 breakeven core.
- To avoid the eutectic melting between fuel slug and cladding, the maximum cladding inner wall temperature should be maintained below 650 ^{o}C.

3. Design Options for TRU Burning

In order to decrease TRU conversion ratio, namely, to increase TRU transmutation capability, various methods can be applied such as a pancake-shape core which can increase neutron leakage. However, under the restriction of not changing a core shape, the reduction of the fuel loading amount by an assembly design change is the only alternative solution. Therefore, four kinds of fuel loading reduction options - 1) the use of thicker cladding, 2) the change of the number of fuel rods from 271 pins to 331 pins per assembly, 3) the use of different smeared density, and 4) annular fuel rods with a central void hole - were evaluated with intra-assembly configuration changes as shown in Fig.1. According to the neutronics calculation results by the K-CORE code system, most of the design options could satisfy above design criteria as shown in Table 1. Additionally, in order to evaluate the cladding inner wall temperature and pressure drop, subchannel analyses were performed by the MATRA-LMR code.



(a) KALIMER-600 (15w/o)
(b) Variable Cladding Thickness (30w/o)
(c) Change of Fuel Rods (30w/o)
(d) Variable Smeared Density (30w/o)
(e) Annular Fuel with Central Void (30w/o)

Fig. 1. Fuel Pin Configurations of Each Candidate Cores

4. Conclusions

Four kinds design options were studied for a core function change from a breakeven core to a TRU burner core. Under the design criteria for the safety aspect and the core performance, analyses about the neutronics performance of the core and the thermal hydraulic aspect of the subchannels were accomplished and compared with each other. Variable cladding thickness option could cause an appreciably high cladding inner wall temperature and the weakness of a high sodium void worth was found at the change of the number of fuel rods option. Variable smeared density option and annular fuel with a central void hole showed superior characteristics for the cladding inner wall temperature and the sodium void worth as well as other design criteria.

Finally, it was confirmed that a breakeven core originally developed for a breakeven conversion ratio can be converted into a TRU burner with only intra-assembly configuration changes, if sufficient control assemblies to override the large burnup swing typical of a TRU burner core are equipped.

Acknowledgement

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Reference

[1]. Dohee Hahn et al., "KALIMER-600 Conceptual Design Report," KAERI/TR-3381/2007, Korea Atomic Energy Research Institute (2007).

Table 1. Core Performance between Breakeven Core and TRU Burners

	Breakeven	TRU Burner			
	KALIMER-600	Variable Cladding Thickness	Change of Fuel Rods	Variable Smeared Density	Annular Fuel with Centeral Void
Assembly pitch [cm]	18.708	18.708	18.698	18.708	18.708
Pins per assembly [n]	271	271	331	271	271
Cladding thickness [mm] [IC/MC/OC]	0.96/0.72/0.59	1.65/1.65/1.20	0.95/0.90/0.60	0.59	0.59
Smeared density [v/o][IC/MC/OC]	75	75	75	36/40/48	75
Burnup reactivity swing [pcm]	131	2,407	3,036	2,668	2,850
External feed TRU enrichment [%]	14.7	29.9	30.0	29.9	29.8
Conversion ratio [fissile/TRU]	1.01 / 1.01	0.76 / 0.59	0.75 / 0.58	0.75 / 0.57	0.72 / 0.54
Peak fast neutron fluence [10^{23} n/cm^2]	3.29	3.21	3.84	3.27	3.45
TRU consumption rate [kg/year]	-9.2	217.8	220.6	224.1	237.1
Core average power density [W/cc]	149.9	149.6	178.6	149.5	149.3
Power peaking factor	1.53	1.48	1.38	1.41	1.40
Peak linear power [W/cm]	257.04	261.55	243.76	250.11	250.40
Average linear power [W/cm]	167.70	167.28	163.39	167.21	166.97
Pressure drop [MPa]	0.154	0.144	0.080	0.135	0.132
Cladding inner wall temp. [^{o}C]	600	627	603	589	589