Core Thermal-Hydraulic Design for the Sodium Cooled TRU Burner Reactor

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1. Introduction

Korea has 20 nuclear power plants as of year 2009 and 6 new nuclear power plants are under construction.

The spent fuels are still stored in the plant site, but eventually they should be disposed of. But, in this case, it takes a few million years for the radiotoxicity to come to a level of the natural uranium radiotoxicity due to the long-lived transuranics(TRU) and fission products in the spent fuels.

The Korea Atomic Energy Research Institute developed conceptual core designs for sodium-cooled fast reactors to transmute the recycled TRU elements which are the dominant contributors to spent fuel radiotoxicity, long-term heat and dose.

This paper describes the core thermal-hydraulic characteristics for a sodium cooled TRU burner core.

2. Core configurations

Three sodium cooled fast reactor cores ranging from 600 MWe to 1,800 MWe for TRU transmutation were designed based on the KALIMER-600 breakeven core which was developed under the national long-term nuclear R&D program[1]. In these cores, the core region-wise variable cladding thickness concept is used to achieve the power flattening under the single enrichment fuel with U-TRU-10%Zr ternary alloy.

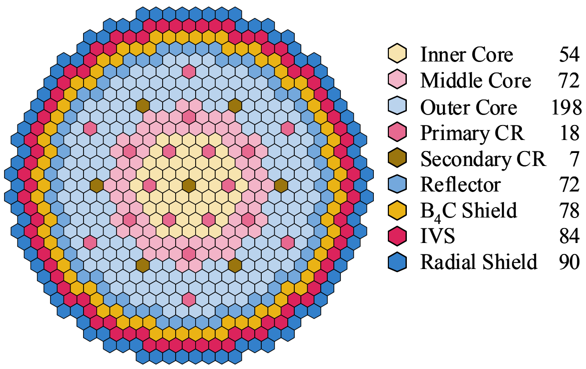
Figure 1 shows the configuration of the 600, 1,200, and 1,800 MWe TRU burner core, respectively. Cores have a radial homogeneous configuration which consists of 324, 774, and 1,230 fuel assemblies, respectively. Each fuel assemblies have 271 rods in the duct. The fuel outer diameter is fixed to 0.7cm and three kinds of cladding thickness were applied at the inner/middle/outer core. In the case of the 600MWe TRU burner core, the cladding thickness of inner/middle/outer cores was 1.007/0.927/0.727 mm. In the case of the 1,200MWe TRU burner core, the cladding thickness of inner/middle/outer cores was 1.081/0.941/0.801 mm. In the case of the 1,800MWe TRU burner core, the cladding thickness of inner/middle/outer cores was 1.101/0.961/0.821 mm.

Table 1 shows the basic design data and operation condition of the 600, 1,200, and 1,800 MWe TRU burner core.

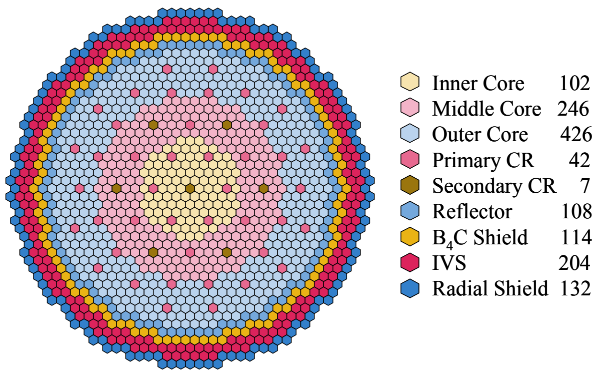
3. Thermal-hydraulic Design

Thermal-hydraulic design of TRU burner cores was made using the SLTHEN code which was based on the ENERGY model [2] specifically developed for sodium cooled wire-wrapped fuel rod assemblies with a simplified energy equation mixing model.

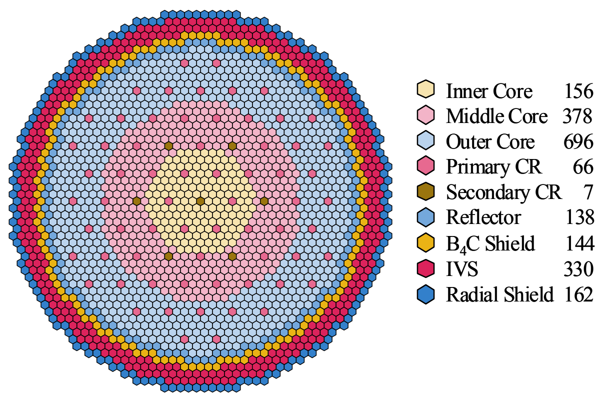
Tables 2-4 show flow groups and maximum cladding mid-wall temperature with 2σ uncertainty.



(a) 600 MWe TRU burner core



(b) 1,200 MWe TRU burner core



(c) 1,800 MWe TRU burner core

Figure 1. Configuration of the TRU burner cores

Table 1 The basic design data and operation condition of TRU burner cores.

Power		600	1,200	1,800
Core Thermal Power (MWth)		1500	3000	4500
Plant Thermal Efficiency (%)		40	40	40
Coolant Mean inlet Temp. (℃)		390	390	390
Coolant Mean outlet Temp. (℃)		545	545	545
Number of Pins per Assembly		271	271	271
Fuel smeared density (%)		75.0	75.0	75.0
Duct Wall Thickness (mm)		3.70	3.70	3.70
Duct Inner Flat to Flat (mm)		151.33	146.40	145.91
Active Length (cm)		89.07	74.16	70.51
Fuel Element Length (cm)		364.53	349.62	345.97
Gap Distance between Ducts (mm)		4.00	4.00	4.00
Pin Outer Diameter (mm)		7.00	7.00	7.00
Cladding Thickness (mm)	IC	1.007	1.081	1.101
	MC	0.927	0.941	0.961
	OC	0.727	0.801	0.821
Pin Pitch (mm)		9.00	8.72	8.69
Pin P/D ratio		1.286	1.246	1.242
Wire Wrap Diameter (mm)		1.40	1.40	1.40
Wire Wrap Pitch (cm)		20.49	20.49	20.49

Table 2. Flow groups and cladding mid-wall temperature of 600 MWe TRU burner core.

Flow Group No.	Assy Type	No. of Assy	Assy Flow rate (kg/s)	Group Flow rate (kg/s)	Fraction (%)	Cladding Midwall (2σ)(°C)
1	IC	54	23.4	1263.6	16.3	648
2	MC	72	24.8	1785.6	23.1	649
3	OC	24	27.2	652.8	50.2	649
4	OC	30	25.2	756.0		648
5	OC	12	23.1	277.2		648
6	OC	30	21.4	642.0		648
7	OC	12	19.9	238.8		648
8	OC	24	17.9	429.6		648
9	OC	18	15.9	286.2		648
10	OC	12	14.1	169.2		648
11	OC	24	12.3	295.2		649
12	OC	12	11.3	135.6		648

Table 3. Flow groups and cladding mid-wall temperature of 1,200 MWe TRU burner core.

Flow Group No.	Assy Type	Assy. No.	Assy Flow rate (kg/s)	Group Flow rate (kg/s)	Fraction (%)	Cladding Midwall (2σ)(°C)
1	IC	72	17.6	1267.2	11.4	649
2	IC	30	16.4	492.0		649
3	MC	246	21.3	5239.8	33.9	650
4	OC	54	22.8	1231.2	45.2	650
5	OC	66	21.4	1412.4		650
6	OC	42	19.7	827.4		649
7	OC	36	18.0	648.0		650
8	OC	54	16.8	907.2		650
9	OC	24	14.3	343.2		649
10	OC	30	13.2	396.0		649
11	OC	18	12.4	223.2		649
12	OC	24	11.6	278.4		648
13	OC	24	10.0	240.0		650
14	OC	24	9.3	223.2		648
15	OC	12	8.6	103.2		649
16	OC	18	8.1	145.8		647

Table 4 Flow groups and cladding mid-wall temperature of 1,800 MWe TRU burner core.

Flow Group No.	Assy Type	Flow rate (kg/s)	Assy No.	Group flow rate (kg/s)	Fraction (%)	Claddin g Midwall Temp. (2σ)(oC)
1	IC	14.8	90.0	1332.0	9.41	649
2	IC	13.4	66.0	884.4		649
3	MC	20.1	240.0	4824.0	31.34	649
4	MC	18.5	138.0	2553.0		649
5	OC	22.8	180.0	4104.0	50.26	650
6	OC	20.8	90.0	1872.0		650
7	OC	18.9	90.0	1701.0		650
8	OC	16.7	60.0	1002.0		650
9	OC	15.4	42.0	646.8		649
10	OC	14.2	42.0	596.4		648
11	OC	12.4	48.0	595.2		649
12	OC	10.6	54.0	572.4		648
13	OC	9.5	24.0	228.0		648
14	OC	8.5	24.0	204.0		649
15	OC	7.7	24.0	184.8		649
16	OC	7.0	18.0	126.0		650

4. Conclusion

Thermal-hydraulic designs for sodium cooled TRU burner cores were made.

600/1,200/1,800 MWe TRU burner core has 12/16/16 flow groups for the fuel assemblies, respectively.

Also, the estimated bundle pressure drop of 600/1,200/1,800 MWe TRU burner core is about 0.14/0.14/0.15MPa with 20% uncertainty, respectively.

In all cases, the maximum cladding mid-wall temperature with 2σ uncertainty does not exceed the design limit value for the Mod. HT9 cladding material which is expected to greater than 650℃.

The results show that the conceptual design for sodium cooled TRU burner cores satisfy the design requirement such as maximum cladding temperature(< 650℃) and pressure drop(< 0.15MPa).

ACKNOWLEDGEMENT

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