Flow Grouping Study for KALIMER-600 Single Enrichment Core with Varying Fuel Clad Thickness

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1. Introduction

KALIMER-600 breakeven single enrichment core has been developed through national nuclear technology program. In the previous design, the single enrichment fuel concept was achieved by using non-fuel rods (i.e., $ZrH_{1.8}$, B_4C, and dummy rods) in the fuel assemblies. In particular, the moderator rods ($ZrH_{1.8}$) were used to reduce the sodium void worth and the fuel Doppler coefficient. But it has been known that this hydride moderator possesses relatively poor irradiation behavior at high temperature [1].

A new concept of KALIMER-600 single enrichment equilibrium core has been proposed [2]. In this reactor core, the power flattening is achieved by the concept of varying clad thicknesses and all non-fuel rods are removed to simplify the fuel assembly design.

This paper describes the core configuration and nuclear design, the core thermal hydraulic characteristics and the calculation results for this core. The core has three zones of single enrichment fuel assemblies without blanket assemblies.

2. Core Configuration and Nuclear Design

KALIMER-600 breakeven single enrichment core concept has the design targets as followings: a) breakeven breeding (or fissile-self-sufficient) without blanket assemblies, b) burnup reactivity swing less than 1$, c) average discharge burnup greater than 80MWd/kg, d) cycle length longer than 18EFPM, e) sodium void reactivity worth less than 8$, f) peak discharge fast neutron fluence less than $4.0x10^{23}$ n/cm^2.

The fuel region has been divided into three enrichment zones in order to flatten the radial power distribution caused by a single enrichment. In the previous design, moderator rods, burnable absorbers and neutron streaming tubes are introduced to reduce the power peaking factor. But this new core uses the concept of varying fuel clad thickness in three assembly regions. The core has fuel claddings of 1.02, 0.72 and 0.59mm in thickness for inner, middle and outer core assembly regions, respectively.

Figure 1 shows the configuration of this core and table 1 shows the basic design data. The core has a radial homogeneous configuration which consists of 114 inner, 78 middle and 138 outer core assemblies. All the fuel assemblies have 271 rods in the assembly duct.

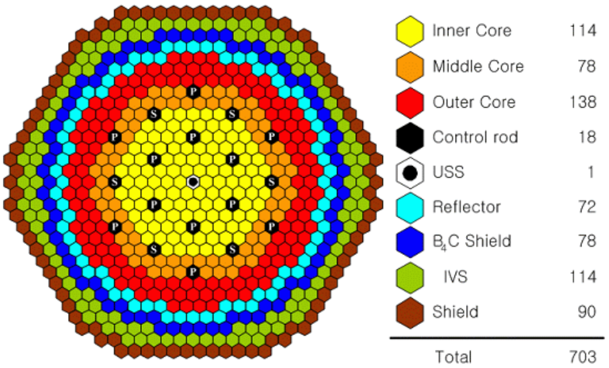

Figure 1. Core configuration (KALIMER-600 single enrichment core with varying fuel clad thickness)

Table 1. Basic design data for KALIMER-600 single enrichment core with varying fuel clad thickness

Operating condition	
Core thermal output (MWth)	1,523.4
Core electric power (MWe)	600.0
Net plant thermal efficiency (%)	39.4
Core inlet/outlet temperature (℃)	390.0/545.0
Total flow rate (kg/s)	7,731.3
Number of core enrichment zones	1
Feed fuel enrichments (w/o%)	14.94
Fuel form	U-TRU-10%Zr
Refueling interval (months)	21
Refueling batches (IC/MC/OC)	4/4/4
Core and fuel design parameters	
Active core height (cm)	94.0
Maximum core diameter (cm)	524.00
Core configuration	Homogeneous
Duct inside flat to flat distance (mm)	171.68
Duct thickness (mm)	3.70
Duct gap (mm)	4.00
Pins per fuel assembly	271
Pin outer diameter (mm)	9.0
Clad thickness (IC/MC/OC) (mm)	1.02/0.72/0.59
Pin P/D ratio	1.167
Average/peak fuel burnup (MWD/kg)	80.4/125.4
Avg/peak linear power (BOEC) (W/cm)	168.3/252.2
Peak fast neutron fluence (E>0.1 MeV) ($x10^{23}$n/cm^2)	3.919
Clad material	Mod.HT9

The inlet and outlet temperatures of the core are 390.0℃ and 545.0℃, respectively with the use of Mod.HT9 as clad material, which is expected to have a clad midwall temperature limit of 650℃ in place of 635℃ for HT9. The net plant thermal efficiency of this core is 39.4%.

3. Flow Groups and Clad Midwall Temperatures

Sodium coolant flow has to be supplied to the assemblies based on the peak pin linear heat generation rate for their whole lifetime to ensure the structural integrity of the fuels, clads and ducts [3].

Flow Groups: This core has 9 flow groups, i.e., 1 for inner core, 3 for middle core and 5 groups for outer core assemblies as shown in table 2. And figure 2 shows one of the calculation results on the 1/3 core configuration map.

Table 2. Flow groups and clad midwall temperatures

Flow Group No.	Assy Type	No. of Assy	Assy Flow [kg/s]	Group Flow [kg/s]	Zone Flow Fraction [%]	Clad Midwall (2σ) [^oC]
1	IC	117	23.6	2,761.2	35.7	645
2	MC	54	25.5	1,377.0	30.2	645
3	MC	30	23.3	699.0		645
4	MC	12	21.4	256.8		645
5	OC	24	22.0	528.0	26.3	645
6	OC	12	19.0	228.0		645
7	OC	33	17.8	587.4		645
8	OC	15	15.5	232.5		645
9	OC	36	12.8	460.8		645

Total primary loop flow including bypass flow 7,731.3 kg/s
Non-grouped flow fraction 7.8 %
(CR + non-fuel assemblies + inter-assembly region + IVS)

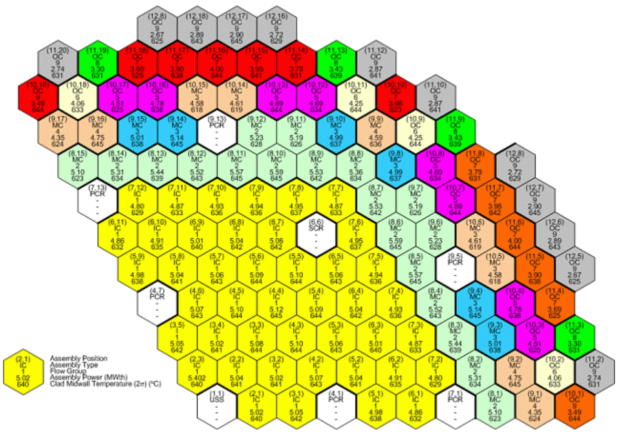

Figure 2. Flow groups and clad midwall temperatures (2σ) (1/3 Core)

Clad Midwall Temperature: The equalized clad midwall temperature with 2σ uncertainty is estimated to be 645^{o}C. The coolant flow fraction is as follows: 35.7%, 30.2% and 26.3% for inner, middle and outer core assembly regions, respectively. And 7.8% of the primary coolant is reserved for the non-grouped flow fraction.

Bundle Pressure Drop: The bundle pressure drop in the peak power assembly of 25.5kg/s located in the 8th row, average velocity of 3.31m/s, is estimated to be 0.12MPa with 20% uncertainty from the rough pressure drop modeling.

4. Conclusion

Flow groupings and temperature calculations for KALIMER-600 breakeven single enrichment core with varying clad thickness without blanket assemblies were performed. And the thermal hydraulic design characteristics and the calculation results of the equilibrium core were given. The core has 9 flow groups for the fuel assemblies, and the equalized clad midwall temperature is estimated to be 645^{o}C with 2σ uncertainty. The estimated core pressure drop is 0.12MPa with 20% uncertainty. These calculation results will be served for the further nuclear and core thermal hydraulic design improvements.

Acknowledgement

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