Pre-Conceptual Design for a Sodium Cooled Transmutation Core

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1. Introduction

The radiotoxicity reduction of the LWR spent fuel under the level of the natural uranium radiotoxicity is becoming a heavy environmental load because there is no national policy for the permanent spent fuel disposal. The main purpose of this study is to develop a new core design concept for efficient transmutation and to analyze the preliminary feasibility. This paper describes the core configuration, nuclear and core thermal hydraulic characteristics for a pre-conceptual design of a sodium cooled transmutation core.

2. Core Configuration

Three 600MWe reference sodium cooled fast reactor cores for TRU (transuranics) transmutation were designed based on the KALIMER-600 breakeven core concept which was developed under the national long-term nuclear R&D program[1]. In these cores, the non-fuel rods such as B_4C, moderator and vacancy rods are used in the fuel assemblies to achieve the power flattening under the single enrichment fuel.

The TRU support ratio which means the number of LWRs of the same thermal power and cycle length that the one transmutation reactor can transmute their discharged spent fuel is estimated to be 2.1~2.2. This core can transmute over 300kg TRU per one cycle. The average fuel discharge burnups are estimated to be ~116MWD/kg. After the design of these reference cores the various core design studies were performed for, i.e., a central annular region of non-fuel assemblies or void ducts heterogeneously arranged in the core. This concept has the objective of reducing the sodium void worth, improving the transmutation capability and power flattening without non-fuel rods under a single enrichment fuel.

And it is shown that the concept, where the Ca_3N_2 containing assemblies are heterogeneouly arranged throughout the core, has sodium void worth less than 2$.

3. Basic Design and Nuclear Characteristics

The selected core concept in this study can transmute 313kg TRU per one cycle (11months) which corresponds to the support ratio of 2.2. This core is estimated to have the sodium void worth less than 3$.

Figure 1 shows the configuration of the transmutation core using void ducts. The core has a radial homogeneous configuration which consists of 294 fuel assemblies (66 IC, 102 MC and 126 OC assemblies). Each fuel assemblies have 271 rods in the duct in which 6 ZrH_4 rods are included. Table 1 shows the basic design data of this core.

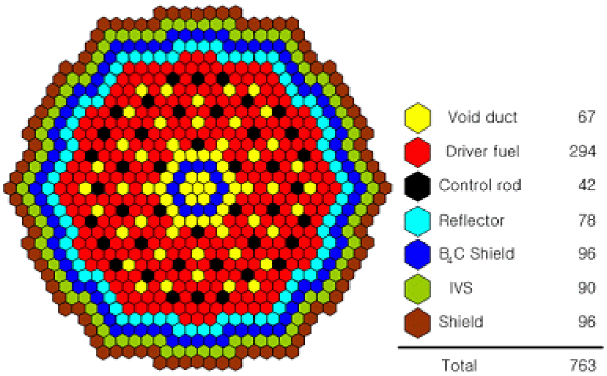

Figure 1. Transmutation core using void ducts

Table 1. Basic design data for the transmutation core using void ducts

Basic design data	
Core electric power [MWe]	600.0
Net plant thermal efficiency [%]	38.4
Core inlet/outlet temperature [℃]	370.3/515.0
Total flow rate [kg/s]	8,453.5
Cooling time after discharge and preloading time	14 months
Fabrication and reprocessing time	16 months
Cycle length [EFPD]	332
Number of fuel management batches	6
Number of rods/FA (fuel rods/$ZrH_{1.8}$ rods)	271(265/6)
Active core height [cm, cold]	90.0 (ref.)
B_4C region height below fuel [cm, hot]	30.0
Boron enrichment of B_4C region below fuel	50.0wt%
Cladding material	Mod.HT9
Fuel type	TRU-U-10Zr
Fuel smeared density	75%TD
Assembly pitch [cm, cold]	16.57
Rod outer diameter [mm]	7.5
Clad thickness [mm]	0.53
Wire wrap diameter [mm]	1.60
P/D ratio	1.23
Volume fractions[%] (Fuel/Coolant/Structure)	36.3/38.9/24.0

Table 2 shows nuclear characteristics for the core of Ca_3N_2 containing assemblies which has the sodium void worth less than 2$.

Table 2. Nuclear characteristics for the core of Ca_3N_2 containing assemblies

Nuclear characteristics	
Average conversion ratio	0.6533
Burnup reactivity swing (pcm)	3,288
Average discharge burnup (MWD/kg)	145.2
Average TRU wt% in HM (BOEC/EOEC)	36.9/36.5
TRU inventory (BOEC/EOEC, kg)	7,018.9/6,730.7
TRU consumption rate (kg/cycle)	290.4
U consumption rate (kg/cycle)	234.5
TRU support ratio	2.05
Average power density (W/cc)	267.3
Average linear power (W/cm)	243.0
Peak linear power (W/cm, BOEC/EOEC)	346.8/339.7
3D power peaking factor (BOEC/EOEC)	1.427/1.398
Peak discharge fast neutron fluence (n/cm^2)	3.909E+23
Sodium void reactivity (pcm, BOEC)	783

4. Flow Group and Cladding Midwall Temperatures

This transmutation core has 9 flow groups as shown in table 3. In addition to those flow groups there are 2 groups reserved: 1 for the CTL assemblies and 1 for the USS.

The equalized cladding midwall temperature with 2σ uncertainty is estimated to be 640°C. It does not exceed the limit value for the Mod.HT9 cladding which is expected to be greater than 650°C. Less flow fraction is given to the IC region (20.9%) in this transmutation core than the ordinary breakeven core in which 40% of the core flow passes to the IC region. Otherwise, 1.5% of the primary coolant is reserved for the non-grouped region, but there needs to optimize the flow grouping to have more reserved flow up to 6~8%.

Table 3. Flow groups and cladding midwall temperatures

Flow Group No.	Assy Type	No. of Assy	Assy Flow [kg/s]	Group Flow [kg/s]	Assembly Zone Fraction [%]	Cladding Midwall (2σ) [°C]
1	IC	24	30.8	739.2	20.9	640
2	IC	30	27.2	816.0		640
3	IC	12	17.7	212.4		640
4	MC	90	32.8	2,952.0	38.9	640
5	MC	12	28.5	342.0		640
6	OC	12	30.4	1,638.0	38.7	640
7	OC	60	27.3	655.2		640
8	OC	48	24.3	1,166.4		640
9	OC	6	17.3	103.8		640

Total primary loop flow including bypass flow : 8,453.5 kg/s
Non-grouped flow fraction : 1.5%
(CR, non-fuel assemblies, inter-assembly region, IVS)

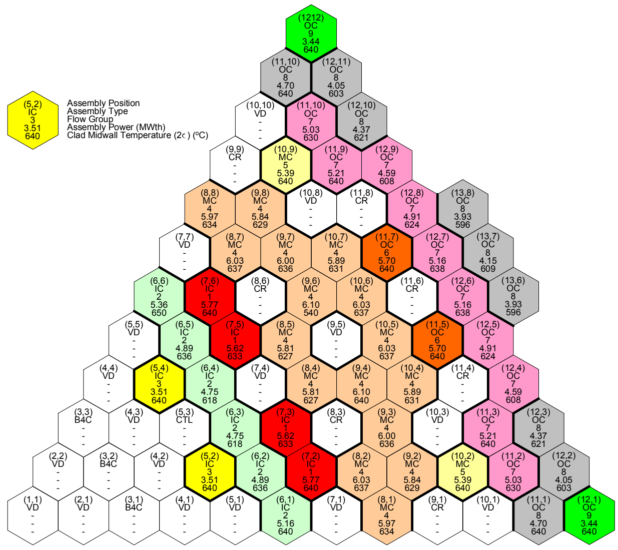

Figure 2. Flow groups and cladding midwall temperatures (2σ) (1/6 Core)

Figure 2 shows one of the calculation results on the 1/6 core configuration map.

The bundle pressure drop is estimated to be 0.207MPa with 20% uncertainty in the peak power assembly located in the 9th row which has the flow of 32.8kg/s.

5. Conclusion and Further Studies

Pre-conceptual design for a sodium cooled transmutation core was performed. Nuclear and thermal hydraulic design characteristics were given for the equilibrium core. The core has 9 flow groups for the fuel assemblies, and the equalized cladding midwall temperature with 2σ uncertainty is estimated to be 640°C. The estimated bundle pressure drop is 0.207MPa with 20% uncertainty. A transmutation core concept using Ca_3N_2 containing assemblies heterogeneously arranged throughout the core is considered to be very efficient which has the sodium void worth less than 2$. These calculation results will be served for the further nuclear and core thermal hydraulic design improvements.

Acknowledgement

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REFERENCES

[1] Y. G. Kim et al., Thermal Hydraulic Analysis of the KALIMER-600 Single Enrichment Core, ICAPP'05, Seoul, Korea, 2005.