Large Burner Core Design with a Varying Fuel Cladding Thickness

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1. Introduction

To develop the conceptual core designs of large monolithic sodium cooled fast reactors for TRU burning, cores with power range from 1,500 MWt to 3,000 MWt were designed. Instead of the traditional enrichment zoning approach to flatten power distribution, the design concept of a single fuel enrichment was adopted. As a means to flatten the power distribution, fuel pin designs of different cladding thicknesses are used for different core regions, with the same cladding outer diameter. For the TRU burner core design, the design approach of a variable cladding thickness was investigated.

For the core design concepts, three power levels of 600, 900 and 1,200 MWe were selected to investigate the dependency of the core performance parameters and the reactivity coefficients on the power level.

2. Core Design and Performance Analysis

2.1 Description of the Core Design

In the breakeven core design[1], the purpose of a varying cladding thickness was to flatten the power distribution. For the burner core design, in order to reduce the conversion ratio through an increased enrichment, the cladding thickness was further increased to decrease the fuel volume fraction while preserving the coolant volume fraction and the assembly size of the reference breakeven core.

Because the burnup reactivity swing is considerably larger in a burner core than a breakeven core, the number of control assemblies is increased from 16 to 19. In this study, the peak linear power limit is conservatively set to a value of 350 W/cm that yields a cladding inner wall temperature less than 650°C for a 30 w/o TRU enrichment fuel.

The active core height is 94 cm and the cladding outer diameter is 9.0 mm. A breakeven core can be transformed into a TRU burner core by a fuel rod design change only. The cladding thicknesses are adjusted to necessitate the TRU enrichment of 30 w/o for the inner(CORE1), middle(CORE2) and outer(CORE3) core regions, respectively. The core has a 15 cm thick B_4C region to reduce the sodium void worth that is placed below the fuel region

With the adjusted cladding thicknesses, the peak to average power ratio that occurs at the BOEC is determined to be 1.55, yielding a peak linear power density of 346 W/cm for the 600 MWe core. Since a smear density of 75% is assumed, the fuel slug diameter in the inner core region is just 0.592 cm

Higher power designs were developed by maintaining the pin pitch to diameter ratio in the 600 MWe core. Using the fuel rod design of each region determined in the 600 MWe design, the number of assemblies in each region was determined to minimize the peak-to-average power ratio in the core.

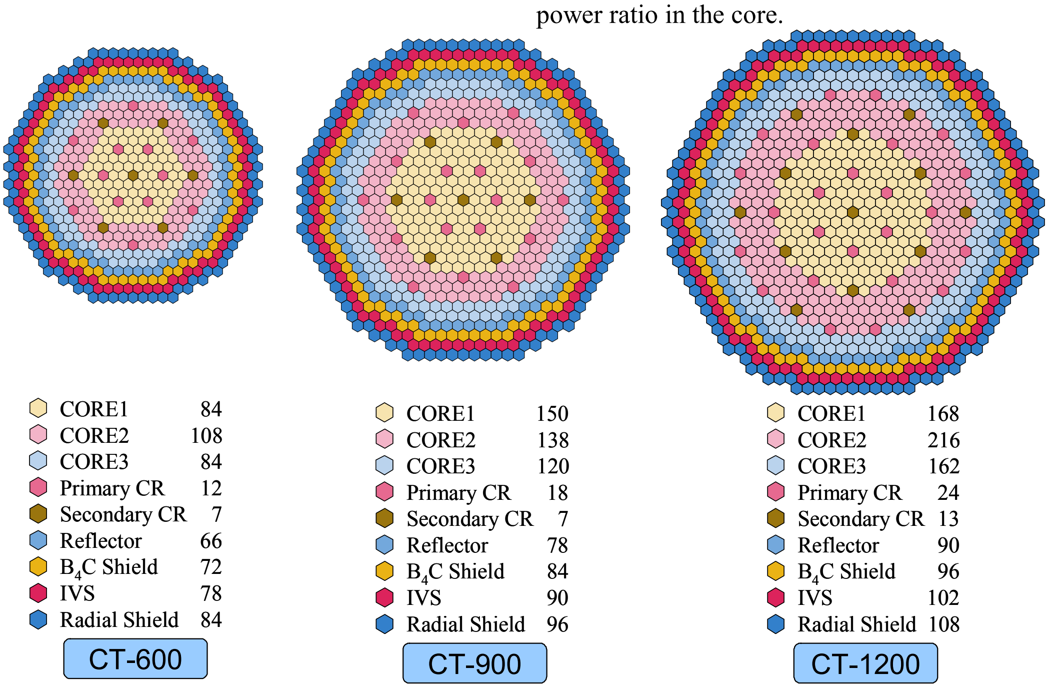

Fig. 1 Core Layout for the Variable-Cladding-Thickness Designs

TABLE 1 Core Performances of Variable-Cladding-Thickness Designs

	CT-600	CT-900	CT-1200
Electrical Power [MWe]	600	900	1,200
Cycle length [EFPD]	332	332	332
Number of batch	5	5	5
Charged TRU enrichment [w/o]	30.00	30.00	29.99
Conversion ratio [fissile/TRU]	0.74 / 0.57	0.74 / 0.57	0.75 / 0.58
Peak fast neutron fluence [10^{23} n/cm^2]	3.80	3.82	3.81
TRU consumption rate [kg/year]	229	338	445
TRU support ratio	1.42	1.39	1.37
Core average power density [W/cc]	179.3	181.9	181.3
Power peaking factor	1.55	1.53	1.54
Burnup reactivity swing [pcm]	2,886	2,981	3,002
Peak linear power [W/cm]	345.55	351.49	348.40
Average linear power [W/cm]	202.29	205.32	204.62

The total number of control assemblies is determined to maintain the ratio of the fuel assembly area to the control rod area, with the assumption that the burnup reactivity swing in the higher power cores would be similar to that of the 600 MWe core. The number of fuel assemblies of the 600, 900, and 1200 MWe designs are 276, 408 and 546, respectively. The respective numbers of control assemblies are 19, 25 and 37. Figure 1 shows the radial core configuration.

2.2 Core Performance Analysis Results

Burning characteristics and performance parameters are listed in Table 1 for the variable-cladding-thickness designs. The REBUS-3[2] equilibrium model with a nine group cross section was used to perform the core depletion analysis.

TRU enrichments are tried to obtain the maximum values at the limits of the current irradiation experience. The peak linear power is well around the estimated limit of 350 W/cm. The burnup reactivity swing over a cycle of 332 effective full power days (EFPD) is around 3,000 pcm for all three power levels.

The peaking factors are below 1.6 and from 1.55 for CT-600 to 1.53 for CT-900. The charged TRU enrichment also maintains the maximum allowable values. Because of the fixed TRU enrichment, the conversion rate has the same values. The same TRU enrichment of the higher power core is reflected in almost the same burning rate per power

When the reactor power is doubled from 600 MWe to 1200 MWe, the consumption rate is increased by 1.94 times, maintaining almost the same consumption rate per power. In case that there is a TRU enrichment limit that must be obeyed at the time of a reactor deployment, the best burner is the one that utilizes fuels of this limit. Likewise, if a TRU enrichment of 30 w/o must be kept for any design concept, the core design that uses the smallest fissile loading quantity per power among them can be the optimum choice. For these points of view the CT-1200 core is the best one because it shows the smallest fuel volume among the 3 cores even though 3 cases have the same enrichment limit, around 30 w/o. However, these differences of the fuel volume fraction are so small that the effect is minor in these cases.

The core with an increased power rating has almost the same Doppler coefficient, a lesser negative axial expansion coefficient, a more positive sodium density coefficient, a lesser negative control rod worth per rod and a lesser negative radial expansion coefficient.

3. **Conclusion**

To develop the conceptual core designs of large monolithic sodium cooled fast reactors for a TRU burning, cores ranging from 1,500 MWt to 3,000 MWt were designed. With the design data accumulation accompanied by the safety analysis, the results of this study would be able to identify the most limiting factor for scaling up burner core concepts.

The calculation results show that the burnup reactivity swing can be retained around 3,000 pcm and the consumption rate is increased at almost the same rate as the increased power so it seems to have no preference at any power level. But a core with a higher power has a disadvantage from a reactivity aspect due to its increased sodium density coefficient.

Acknowledgement

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