Core Design for TRU Burner Reactors

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1. Introduction

Conceptual core designs were developed for large monolithic sodium cooled fast reactors for TRU transmutation. The core power under investigation ranges from 1,500 MWt (600 MWe) to 4,500 MWt (1,800 MWe). These cores are loaded with a ternary metallic alloy fuel (TRU-U-10Zr) of a single enrichment. All the burner reactor concepts in this study utilize a recycled LWR feed and adopt pancake reactor geometry.

The results of this study enable us to identify the most limiting factor in scaling up transmutation core concepts if they exist. Thereby, it would be possible to provide the guidance to future R&D directions for an economic transmutation of TRU, and to achieve a maximum benefit from the viewpoints of a size and an economy.

2. Core Design and Performance Analysis

2.1 Description of the Core Design

In order to design reactor cores with a medium-to-large core power, an increase in the effective radius of the core is mandatory, while the core average liner heat generation rate is kept as that of a lower power one. The feed TRU enrichment was chosen to be ~30 w/o, reflecting the currently established ternary metallic fuel database. This feed TRU enrichment turned out to result in a conversion ratio of about 0.57.

The radial power distribution control is achieved by using a variable cladding thickness, accompanied with a concurrent adjustment of the fuel slug diameter, while using a single enrichment for the whole core region. The benefit of using a single enrichment in a TRU core is that it helps to maintain the maximum-charged TRU enrichment lower than the case for an enrichment zoning. Therefore, on average, TRU burning can be maximized within the given TRU enrichment limit.

The three respective core layouts for 600, 1,200, and 1.800 MWe are depicted in Figure 1. Regardless of the power level, the fuel cladding thickness is limited to three different thicknesses. The active core height was adjusted to make the sodium void worth around 7.5 $, and they are 89 cm, 74 cm, and 71 cm for the 600 MWe, 1,200 MWe, and 1,800 MWe cores, respectively. A clad outer diameter of 7.0 mm is adopted over all the designs, and the cladding thicknesses are adjusted to make the TRU enrichment close to 30 w/o. The fuel pitch was allowed to vary in order to cause no more than 0.15 MPa that is the nominal (w/o uncertainty) maximum (among channels) pressure drop across the axial fuel rod section.

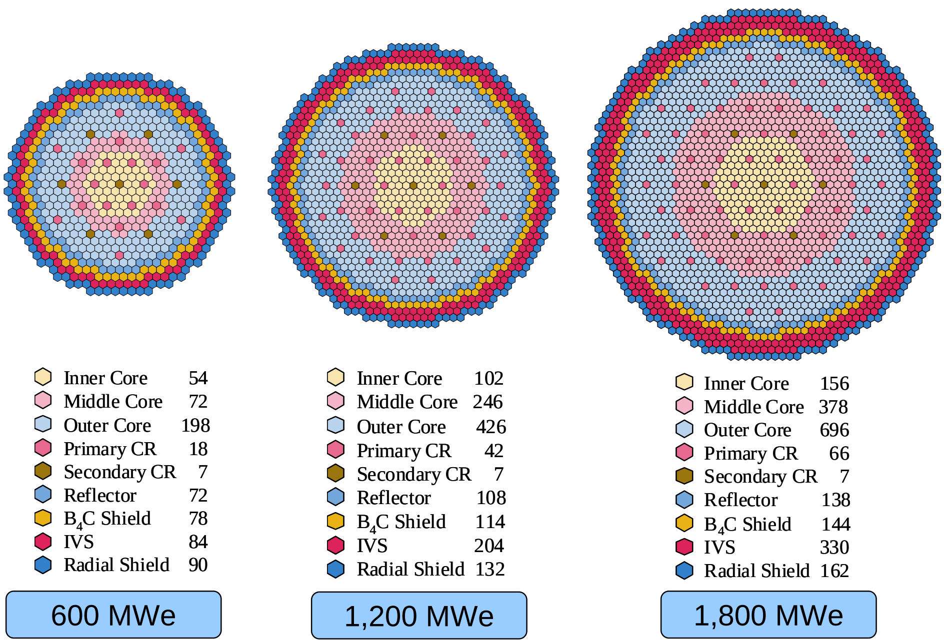

Fig. 1. Core layout.

Table I: Core performance

	600 MWe	1,200 MWe	1,800 MWe
Burnup reactivity swing(pcm)	3,496	3,703	3,722
Conversion ratio(fissile/TRU)	0.74/0.57	0.75/0.57	0.75/0.57
Charged TRU(w/o)	30.00	30.00	30.00
Fuel inventory (HM/TRU)[ton]	17.29/5.03	32.59/9.46	48.59/14.10
Average linear power(W/cm)	179	179	178
Power peaking factor	1.52	1.47	1.55
Average assembly discharge burnup(MWd/kg)	128	135	135
Peak fast neutron fluence(n/cm2x1023)	4.25	4.40	4.49
Cycle length(EFPD)	332		
Max. pressure drop(MPa)	0.15	0.15	0.15
Max. cladding inner wall temp.(℃)	613	624	628
TRU consumption rate(kg/cycle)	201	402	601

Table II: Reactivity coefficient

Doppler coefficient [pcm/ oC]	$-821.9\ T^{-1.113}$	$-819.6\ T^{-1.109}$	$-816.2\ T^{-1.113}$	$-815.2\ T^{-1.109}$	$-805.5\ T^{-1.110}$	$-808.2\ T^{-1.107}$
Axial expansion coefficient [pcm/ oC]	-0.171	-0.181	-0.120	-0.128	-0.112	-0.118
Radial expansion coefficient [pcm/ oC]	-0.708	-0.743	-0.731	-0.768	-0.739	-0.776
Sodium density coefficient [pcm/ oC]	0.706	0.763	0.695	0.754	0.685	0.751
Control rod worth [pcm/control rod]	-475	-496	-203	-213	-124	-131
Sodium void worth[$]	6.90	7.50	6.87	7.49	6.80	7.50
Effective delayed neutron fraction	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032

All the designs maintain an average linear power of 180 W/cm. The numbers of fuel assemblies of the 600, 1,200, and 1,800 MWe designs are 324, 774, and 1,230, respectively. The depletion analysis is done with an equilibrium model of the REBUS-3 code system[1], where the DIF3D module solves the neutron diffusion equation with the HEX-Z nodal method and uses a 25-group cross-section set to obtain the neutron flux and power distributions.

2.2 Core Performance and Reactivity Coefficients Result

The calculation results show that large monolithic sodium cooled fast reactors for TRU burning, whose power ranges from 600 MWe to 1,800 MWe, can be successfully designed while meeting all the design constraints. As shown in Table I, the core designs have almost the same TRU burning rate per power and a burnup reactivity swing of ~3,500pcm. The TRU consumption rate is 201 kg/year for the 600 MWe core, 402 kg/year for the 1,200 MWe core, and 601 kg/year for the 1,800 MWe.

Global reactivity feedback resulting from the Doppler effects, uniform radial expansion, and sodium voiding in the equilibrium core are given. As shown in Table II, the core with an increased power rating has almost the same Doppler coefficient, a less negative axial expansion coefficient, a less negative control rod worth per rod, and a more negative radial expansion coefficient. The worth of sodium void has fixed to be close to 7.5$ for the three cores by reducing the active core height with increasing of the neutron leakage rate so that almost the same positive sodium density coefficient is observed for three cores.

3. Conclusions

Conceptual fast reactor core designs with a sodium coolant are developed at 600, 1,200, and 1,800 MWe, which are configured to transmute the recycled transuranics (TRU) elements with external feeds consisting of an LWR spent fuel.

The calculation results show that the TRU consumption rate can be made to be proportional to the core power level without any significant adverse effects in the core performance at higher power levels.

REFERENCES

[1] B. J. Toppel, A User's Guide to the REBUS-3 Fuel Cycle Analysis Capability, ANL-83-2, Argonne National Laboratory, 1983.