Core Performance Comparisons of Sodium- and Lead-Cooled Large TRU Burners

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1. Introduction

To investigate the performance parameters and safety implications of reactivity coefficients in large monolithic sodium and Pb-Bi cooled fast reactors for a TRU burning, cores whose powers range from 600 MWe to 1,800 MWe were designed. With the design data accumulation, accompanied by a safety analysis, the results of this study would help to identify the most limiting factor for scaling up conceptual burner cores. Instead of the traditional enrichment zoning approach to flatten the power distribution, the design concept of a single fuel enrichment was adopted.

2. Result and discussion

Core designs used the design constraints related to the current technology database with the TRU enrichment limit (30.0 w/o) and fast neutron irradiation limit (4.0×10^{23} n/cm^2). The sodium cooled reactor was designed first. A single enrichment concept, adopted in the KALIMER-600 breakeven core design[1], was used. As a means to flatten the power distribution, fuel pin designs with a different cladding thickness were used in different core regions, while the same cladding outer diameter was adopted throughout the core.

For a consistent comparison, the active core height was varied to make the sodium void worth lower than 7.5$, and the number of assemblies was adjusted to attain a similar linear power around 180 W/cm. In order to demonstrate a high TRU consumption rate, a core was designed to attain a TRU enrichment of 30 w/o. The major design variables to be used in changing the conversion ratio of a given core design are variation of the core height and fuel cladding thickness. At the same time, a core design was confirmed to have its maximum inner cladding temperatures below 650 ℃ and maximum pressure drops below 0.15 MPa.

The number of fuel assemblies for the 600, 1200, and 1800 MWe designs were 336, 786 and 1230, respectively. After obtaining the sodium cooled reactors designs, in order to have a consistent comparison for two coolants on a common basis, this study used exactly the same reactor core layout, fuel design parameters, and compositions for the structure material for the design of the Pb-Bi cooled reactors by replacing the sodium coolant in the sodium cooled ractors with Pb-Bi coolant respectively. Only driver fuel enrichments were adjusted respectively for these two coolants. Because the Pb-Bi coolant has a lower heat capacity compared with the sodium coolant, the pitch to diameter was increased until the coolant volume of the Pb-Bi cooled reactor had a flow area for the same cooling capacity with the sodium cooled reactors.

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

The calculation results for the sodium cooled reactors show that large monolithic sodium cooled fast reactors for a TRU burning, of which the power ranges from 600 MWe to 1,800 MWe can be successfully designed, while meeting all the design constraints. The calculated TRU conversion ratio is 0.57 for the 600 MWe core, 0.58 for the 1,200 MWe core, and 0.59 for the 1,800 MWe. The 600 MWe core requires a charged TRU enrichment of 29.9 % and yields a reactivity swing of 3,671 pcm over a 332 EFPD. Compared with the sodium cooled reactor, the Pb-Bi cooled reactor has a higher TRU conversion ratio and a smaller TRU enrichment. The calculated TRU conversion ratio is 0.59 for the 600 MWe core, 0.61 for the 1,200 MWe core, and 0.62 for the 1,800 MWe.

The core designs for the sodium cooled reactors have almost the same TRU burning rate per power and a burnup reactivity swing of ~3,500 pcm. The TRU consumption rate is 221 kg/year for the 600 MWe core, 423 kg/year for the 1,200 MWe core, and 626 kg/year for the 1,800 MWe core. Thus the

TABLE 1 Core Performances of Variable-Cladding-Thickness Designs

Design parameter	1,800MWe		1,200MWe		600MWe	
Core Thermal Power(MWt)	4,500		3,000		1,500	
Coolant Temperature(℃)-Inlet/Outlet	390/545					
Number of Fuel Assemblies	1230		786		336	
Assembly Pitch(cm)	15.9	17.4	15.9	17.6	16.1	18.0
Coolant	Na	Pb-Bi	Na	Pb-Bi	Na	Pb-Bi
Fuel Outer Diameter(mm)	7.0					
Pin Pitch(mm)	8.792	9.649	8.792	9.773	8.890	9.994
P/D Ratio	1.256	1.378	1.256	1.396	1.270	1.428
Cladding Thickness(mm)-Inner/Middle/Outer	1.05/0.91/0.77					
Eq. Core Diameter(m)	5.86	6.41	4.68	5.19	3.09	3.47
Eq. Reactor Diameter(m)	7.61	8.33	6.31	7.00	4.51	5.06
Charged TRU (w/o)	28.9	27.6	29.2	28.4	29.9	29.4
Conversion Ratio(Fissile/TRU)	0.76/0.59	0.78/0.62	0.76/0.58	0.77/0.61	0.74/0.57	0.75/0.59
Burnup Reactivity Swing(pcm)	3,508	3,509	3,512	3,543	3,671	3,715
Cycle Length(EFPD)	332					
Sodium Void Worth(BOEC/EOEC)	6.9/7.6	-1.7/-1.3	6.9/7.5	-1.9/-1.6	6.7/7.3	-2.5/-2.2
Peak Fast Neutron Fluence(n/cm^2)	4.4	5.0	4.3	4.8	4.6	5.0
Max. Pressure Drop(MPa)	0.13		0.14		0.16	
Max. Cladding Inner Wall Temp.(℃)	572		576		591	
Average Linear Power(W/cm)	179.1	179.6	178.1	178.5	180.4	
Power Peaking Factor	1.55	1.54	1.48	1.50	1.52	
Active Core Height(cm)	70.0		73.5		85.0	
TRU Consumption Rate(kg/year)	626	590	423	412	221	218

consumption rate is increased by 1.91 times for the 1,200 MWe core and by 2.82 times for the 1,800 MWe core, compared to the 600 MWe core. However, these differences are so small that it is judged that the consumption rate per power is invariant. In all three designs, the sodium void worth upon a core plus fission gas plenum voiding, turned out to be less than 7.5$. Compared with the sodium cooled reactor, the Pb-Bi cooled reactor has also almost the same reactivity swing and transmutation capacity The reactivity swing is 3,543 pcm for the 1,200 MWe core and 3,509 pcm for the 1,800 MWe core.

The coolant void worth does become smaller when sodium is substituted by Pb-Bi coolant in all the cases. As can be seen in Table 1, the Pb-Bi coolant void worths are negative for all the cases where the sodium void worths are highly positive. The increasing trends of the void worth for sodium and Pb-Bi as a coolant with an increasing power are similar for all the cases. The Pb-Bi cooled reactors have an improved coolant void reactivity worth over the sodium cooled reactors. However, the increased pitch to diameter ratio in Pb-Bi cooled reactors leads to an increased core volume which reduces the economy benefit.

3. Conclusion

To investigate the performance parameters and safety implications of reactivity coefficients in large monolithic sodium and Pb-Bi cooled fast reactors for a TRU burning, cores whose powers range from 600 MWe to 1,800 MWe were designed.

The calculation results show that large monolithic sodium and Pb-Bi cooled fast reactors can be designed satisfactorily. In addition they have almost the same TRU burning rate per power. Although the Pb-Bi cooled reactor had an improved coolant void worth over the sodium cooled reactor, the increased core dimension of the Pb-Bi cooled reactor is a disadvantage from a seismic and economics design point of view.

REFERENCES

[1] Ser Gi Hong et al., "The KALIMER-600 Reactor Core Design Concept with Varying Fuel Cladding Thickness", Proceedings of the Korean Nuclear Society Autumn Meeting(2006).

[2] B. J. TOPPEL, "A User's Guide for the REBUS-3 Fuel Cycle Analysis Capability," ANL Report, Argonne National Laboratory 83-2, March (1983).