Trade-off study of prototype SFR core design in Korea

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1. Introduction

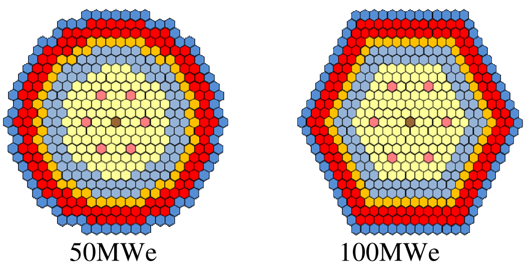
The Sodium-cooled Fast Reactor (SFR) named KALIMER-600 has been developed in KAERI. And a construction of small reactor was discussed as a way of reducing SFR construction period in Korea. As a technical support of such a discussion, trade-off studies were performed from the viewpoint of the neutronics for determining an appropriate power level of small reactor and for confirming the performance of small reactors.

2. Methods and Results

Major roles of the prototype SFR is to provide irradiation test capability for fuel and structure materials and to obtain operational experience of the system and components. Therefore the prototype SFR should provide the fast neutron flux its level is as high as possible within the design constraint. Most limiting design constraint is the uranium enrichment which is limited below 20 wt% because the initial reactor loading should be uranium fuel due to an insufficiency of TRU fuel irradiation database. Only several test assemblies of TRU fuel will be loaded into the initial core. Accordingly, the design target of prototype SFR is to make the fast neutron flux as high as possible within design constraint and with a reasonable construction and cycle cost. The core size and discharge burnup will be a key parameter of the cost assessment.

2.1 Model

The designed prototype SFR has similar configuration to the demonstration SFR. But more reflector regions are added for test assembly of low energy range neutrons. The core configurations are shown in Fig. 1 for each power scale.



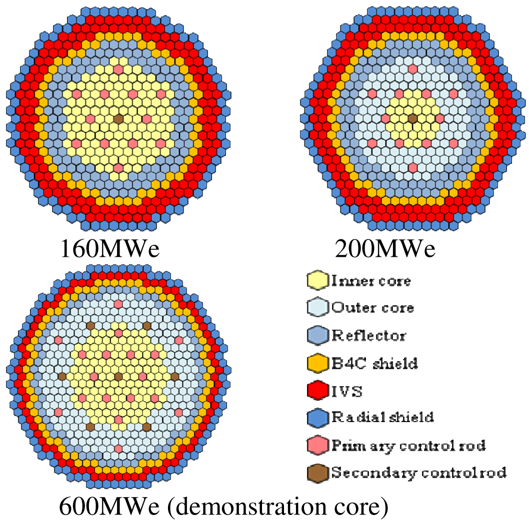


Fig.1. Core configurations followed power level.

Small reactor having the power level up to 160MWe was designed as a single enrichment core for maintaining the core average enrichment as high as possible. But the enrichment was split into two regions for the reactor having the power level more than 200MWe to control the radial power distribution. The number of fuel rod in an assembly is 217 for the reactor up to 100MWe and 271 for the reactor more than 160MWe to make the various test assembly in a small reactor.

2.2 Calculation

The nuclear data is ENDF/B-VI.6 for the calculation and the core model has hexagonal geometry. The calculation is performed by equilibrium cycle analysis about 1/6 core model using REBUS3 code.

2.3 Design parameter

Design was performed by using the similar design parameter with demonstration SFR such as metal fuel (U-10Zr), smear density 75%, cladding thickness 0.56mm, duct thickness 3.7mm, assembly gap thickness 4mm and etc. The pressure drop along the fuel bundle was maintained below 0.25MPa for all cores and cycle length was kept as 290 effective full power days with 5 batch operation. The design parameters are shown in Table I.

Table I: The uranium core design parameters

Power (MWe)	50	100	160	200	600
Pin Diameter (cm)	0.74	0.74	0.74	0.74	0.74
Enrichment (w/o) (inner/outer)	20	20	20	17/20	15/20
Core Diameter (cm)	141	154	185	200	319
Core height (cm)	73	77	83	85	93
Pin number in a assembly	217	217	271	271	271
P/D	1.065	1.12	1.173	1.16	1.22
Pressure drop (MPa)	0.25	0.25	0.25	0.25	0.25

2.4 Results

Because of the uranium enrichment limit (<20w/o), the uranium core requires more fuel loading for keeping a critical state at the EOEC than TRU fueled core due to the relatively low reactivity contribution of uranium fuel. The fuel loading is also increased as the power capacity gets smaller for compensating increasing neutron leakage. As a result, the power density and discharge burnup are decreased as the reactor power gets smaller, which requires more operation period for the irradiation test and makes the operation costly. The performance of the uranium core is shown in Table II.

Table II: The performance of the uranium core

Power (Mwe)	50	100	160	200	600
Average linear power density (W/cm)	68	110	130	138	159
Average power density (W/cm^3)	103	150	166	180	188
Power peaking factor	1.88	2.00	1.99	1.74	1.70
Average discharge burnup (GWd/tHM)	33.4	53.4	63.6	67.2	77.2
Peak fast fluence (X10^{24} n/cm^2)	1.47	2.42	2.80	2.81	3.05
Burnup reactivity swing (pcm)	978	1631	1992	1867	1832
Sodium void coefficient at EOEC (pcm)	-1079	-1180	-1256	-771	516

The average discharge burnups for the powers of 50, 100, 160 and 200MWe are about 43%, 69%, 82% and 87% of 600MWe core (77.2 GWe/tHM), respectively.

As shown in Fig. 2, the average fast neutron flux level is gradually increased and the fuel inventory is decreased when the power gets larger. However, there is a point that the change of the flux and inventory gets slowed at around 150~200MWe.

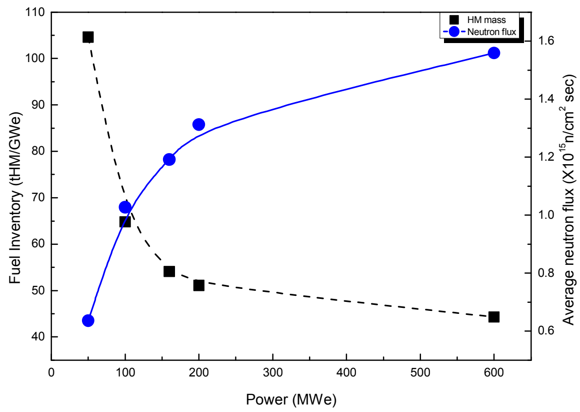


Fig.2. Average fast neutron flux and fuel inventory followed power level.

The average neutron flux levels for the powers 50, 100, 160 and 200MWe are about 37%, 62%, 73% and 81% of the 600MWe core (1.56X10^{15} n/cm^2 sec), respectively. And the fuel inventories are about 2.4, 1.5, 1.2 and 1.2 times more than the 600MWe core (44 tHM/GWe), respectively.

3. Conclusions

Trade-off study on the power level of prototype SFR was carried out in the neutronics aspect. Due to the constraint of uranium enrichment, larger core shows better neutronics performance for prototype SFR in terms of the irradiation capability and operation cost. However, the performance indices were insensitive for the power of around 150~200MWe and became more drastic between 50 and 100MWe. Accordingly, the power level of prototype SFR will be appropriate at around 200MWe and should be over 100MWe at least. It should be noted that this study only take into account for the neutronics aspect on the power level of the prototype SFR. Final decision will be made in the near future considering other aspects of the protype SFR and with more detailed analysis.

Acknowledgement

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