Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

An Evaluation of Thermal Margin Analysis Model for SMART

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1. Introduction

A subchannel analysis code MATRA-S, which has been developed at KAERI(Korea Atomic Energy Research Institute), was applied to thermal margin analysis in SMART core. The lumping model for a whole core is generally used in the design calculation. In SMART design, 1/8 lumped subchannel model(hereafter, lumping model) was also used to evaluate a core thermal margin. The lumping model should be more conservative than a real reactor. There are some conditions such as a radial peaking distribution of a hot fuel assembly, power distribution of fuel assemblies including the lumping model itself, etc., which should be selected and fixed in order to satisfy conservatism. Besides, it was difficult to calculate a pin-by-pin whole core model(hereafter, Pin-by-Pin model)due to several limitations that the previous subchannel code of a serial version had. However, MATRA-S code of a parallel version has been developed and significant advances have been made in terms of performance[1]. In this paper, the several lumping model for SMART are proposed and are compared with the Pin-by-Pin model under normal operating condition and 200% core power condition. When the normal operating condition is used to calculate MDNBR, three distributions of radial peaking for hot fuel assembly are considered.

2. Methods and Results

In this section some of the methods used to model, a Pin-by-Pin and lumping model for SMART are described. The calculation results are also described.

2.1 A Pin-by-Pin Whole Core Model

A Pin-by-Pin model for SMART consists of 16,780 subchannels and 15,048 fuel rods except for guide tubes. This model is modeled considering gaps between the outermost fuel assembly and a shroud of core. A core averaged axial power shape was considered and radial peaking factor of each fuel rod was used. The radial power distributions in an initial and equilibrium core were considered. A uniform axial node was used and the number of nodes is 40. The SMART CHF correlation was applied to calculate MDNBR and MATRA-S code of the parallel version was used in each calculation. It took about 8 hours to calculate 68 cases when 21 CPUs were used in cluster environment.

2.2 1/8 Lumped Subchannel Model

<u>Lumping Model</u>

In this paper, 6 lumping models as shown in Fig.1 were used. The left and right column of Fig.1 means the boundary of lumped subchannels of 1/8 core and hot fuel assembly, respectively. The information of each lumping models are summarized in Table I. As being summarized in Table I, each hot fuel assembly consisted of 20, 26, 23, 19, 15, and 13 subchannels, respectively. In case of #1-39Ch, hot channel is assumed as a thimble channel. The thimble and typical channel are simultaneously considered as the hot channel in other cases(#2-45Ch ~ #6-26Ch). #1-39Ch ~ #3-37Ch consisted of 3 layers neighboring the hot channel as a subchannel not lumping. There are 2 layers adjacent the hot channel as a subchannel in cases of #4-38Ch ~ #6-26Ch. Besides, the case #3-37 decreased the number of subchannels in the hot fuel assembly as lumping subchannels outside 3 layers. As the same way, #5-29Ch lumped #4-38Ch and #6-26Ch lumped #5-29Ch.

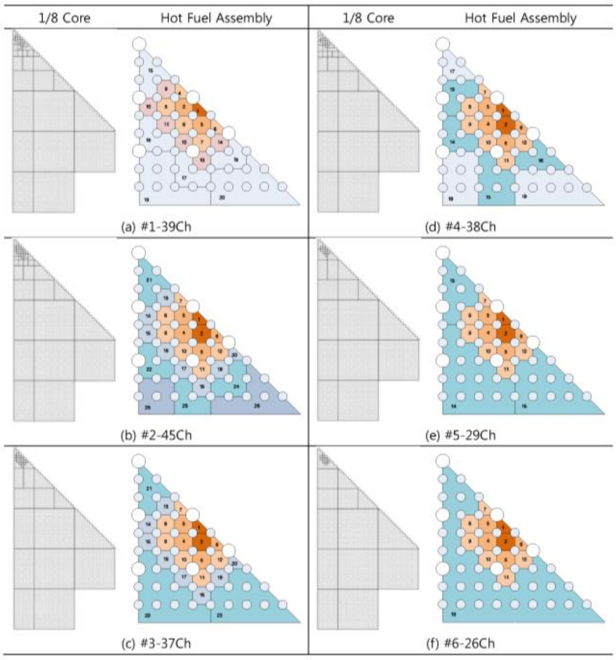


Fig. 1. 1/8 Lumping Models(Left: 1/8 Core, Right: Hot fuel assembly)

Table I: Information of 1/8 Lumping Models

ID	Number of Subchannels			Layers	Hot Ch.
	Total	HFA	Others		
#1-39Ch	39	20	19	3	Thimble
#2-45Ch	45	26	19	3	Thimble/ Typical
#3-37Ch	37	23	14	3	Thimble/ Typical
#4-38Ch	38	19	19	2	Thimble/ Typical
#5-29Ch	29	15	14	2	Thimble/ Typical
#6-26Ch	26	13	13	2	Thimble/ Typical

Fr Distribution

A representative Fr distribution of the hot fuel assembly is needed to be determined. In this paper, 3 Fr distributions were applied to generate the lumping model. As considering a symmetric distribution, radial peaking of an assembly E5 at BOC, MOC, and EOC of the initial core were selected. As burnups proceed, pin-to-box ratio would be decreased and the radial power distribution would be flat.

FA Power Distribution

In design calculation, FA power distribution of the lumping model is fixed. FA power distributions of each burnup were used in this paper to evaluate conservatisms. At this time, FA power distribution goes through several stages, whose are relocated, reinforced, targeting and renormalized stage. The detail description to generate FA power distribution is omitted in this paper.

Maximum Fr

The radial peaking of the hot rod of the lumping model should be greater than or equal to the maximum Fr of the whole core model to guarantee the conservatism. Thus, the radial peaking of the hot rod of 1/8 lumped subchannel model is set as the maximum Fr of the whole core model as burnup.

Inlet Flow Reduction of HFA

To get more conservative MDNBR of 1/8 lumped subchannel model than a real reactor, flow reduction of hot fuel assembly was considered

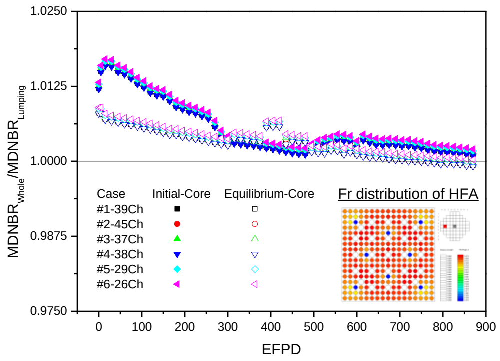
2.3 Calculation Result

Normal Operating Condition

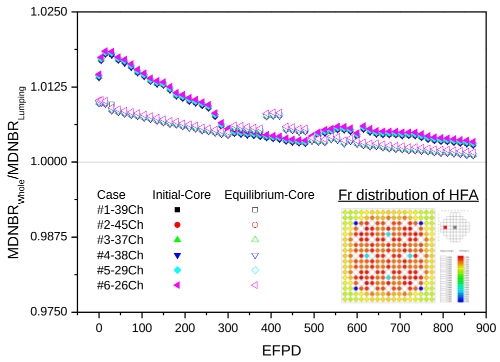
The calculation results under normal operating condition are depicted in Fig. 2 as the applied Fr distribution of the hot fuel assembly. In Fig. 2 closed and open symbol means MDNBR ratio at the initial and equilibrium core, respectively. Contours of the radial peaking factor of assembly E5 at BOC, MOC, and EOC of the initial core are included in Fig. 2. At this time, MDNBR ratio defines as:

$$MDNBR_{Whole} \Big/ MDNBR_{Lumping}$$

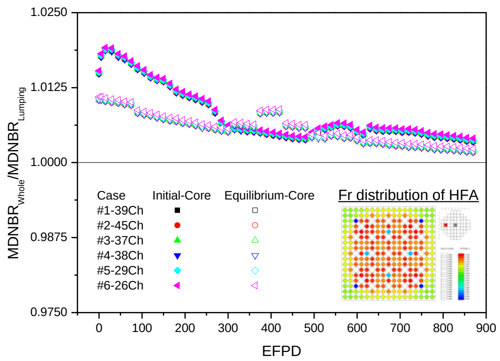
Thus, cases that the ratio is greater than 1 means that the lumping model is more conservative than the Pin-by-Pin model.



(a) Radial peaking distribution: BOC of an initial core



(b) Radial peaking distribution: MOC of an initial core



(c) Radial peaking distribution: EOC of an initial core

Fig. 2 Comparison of MDNBR ratio between Pin-by-Pin model and lumping model under normal operating condition.

The mean and standard deviation including the minimum and maximum value of MDNBR ratio for whole cycle were tabulated in Table II. In Fig. 2 and Table II, it is evaluated that the most of all results of the lumping model are conservative. When Fr distribution of BOC was used as radial peaking of the hot fuel assembly, it is evaluated that MDNBR of the lumping model is less than that of the Pin-by-Pin model at EOC of the equilibrium core. This means that Fr distribution of BOC may not be suitable in the view of conservatism. In this case, the required conservatism can be obtained as increasing the inlet flow reduction. As using the flatter Fr distribution, there has been an increase of conservatism. It is noted that the difference of results between the lumping models is not much.

Table II: Summary of results(Normal operating condition)

Fr Distribution		#1-39Ch	#2-45Ch	#3-37Ch	#4-38Ch	#5-29Ch	#6-26Ch
BOC	MEAN	1.00350	1.00353	1.00376	1.00333	1.00414	1.00441
	STD.	0.00319	0.00320	0.00320	0.00319	0.00320	0.00319
	MIN	0.99932	0.99935	0.99957	0.99915	0.99996	1.00025
	MAX	1.01610	1.01614	1.01637	1.01586	1.01669	1.01703
MOC	MEAN	1.00543	1.00530	1.00548	1.00532	1.00558	1.00581
	STD.	0.00321	0.00321	0.00321	0.00320	0.00320	0.00319
	MIN	1.00122	1.00109	1.00127	1.00113	1.00138	1.00164
	MAX	1.01813	1.01801	1.01819	1.01803	1.01829	1.01847
EOC	MEAN	1.00610	1.00596	1.00614	1.00602	1.00626	1.00655
	STD.	0.00325	0.00326	0.00326	0.00325	0.00326	0.00325
	MIN	1.00181	1.00166	1.00184	1.00173	1.00197	1.00229
	MAX	1.01879	1.01865	1.01882	1.01871	1.01887	1.01918

<u>200% Core Power Condition</u>

The comparison results under 200% core power condition were depicted Fig. 3 and tabulated in Table III, where Fr distribution of EOC at the initial core was used. The operating conditions except for core averaged power are equal to the normal operating condition. From the results, it is noted that there has been an increase of conservatism compared to 100% core power condition. It is noted that the difference of results between lumped subchannel models is not much although it has increased slightly

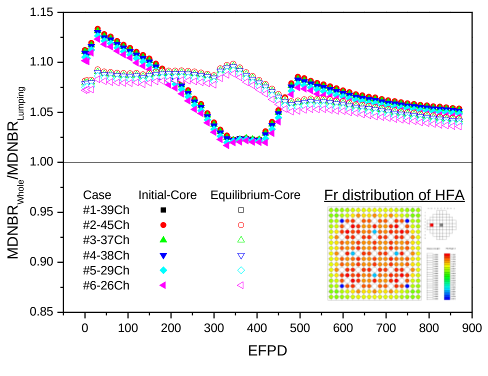


Fig. 3 1/8 Comparison of MDNBR ratio between Pin-by-Pin model and lumping model under 200% core power condition(Radial peaking distribution: EOC of an initial core)

Table III: Summary of results(200% core power condition)

	#1-39Ch	#2-45Ch	#3-37Ch	#4-38Ch	#5-29Ch	#6-26Ch
MEAN	1.07223	1.07325	1.07133	1.07062	1.06716	1.06385
STD.	0.02148	0.02154	0.02137	0.02135	0.02114	0.02097
MIN	1.02259	1.02266	1.02224	1.02226	1.01996	1.01695
MAX	1.13242	1.13354	1.13140	1.13022	1.12652	1.12336

3. Conclusions

In this paper, several 1/8 lumped subchannel model were evaluated from MDNBR point of view. It was evaluated that 1/8 lumped subchannel model is more conservative than the pin-by-pin whole core model if the Fr distribution of the hot fuel assembly is properly flat. It was shown that the lumped subchannel model does not have much effect on the results as far as maintaining radial peaking of the hot rod. Moreover, it was concluded that 2 layers adjacent the hot channel are enough to reflect cross flow effect to maintain conservatism.

REFERENCES

[1] S. J. Kim, et al. Development of Parallel Algorithm for MATRA - Improving Parallelization of an Outer Iteration, TR-6185, KAERI, 2015.