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A Preliminary Evaluation of the Shutdown Margin of KALIMER-600

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1. Introduction

We are in the progress of preliminary conceptual design of KALIMER-600. The reactivity control system should be designed to satisfy the sufficient shutdown margin under the conditions of normal operation and anticipated operational occurrences. To consider the control system requirements in nuclear design and to set up the reasonable design procedure of satisfying the required reactivity, we performed preliminary evaluation of the maximum required reactivity and the shutdown margin of the reactivity control system for KALIMER-600.

2. Preliminary Evaluation of the Shutdown Margin

2.1 Reactivity Control Requirements

We have suggested the requirements of two reactivity control systems, which can meet the general design criterion 26 regulated in the 10CFR50 appendix A [1].

The primary control system should be capable of controlling reactivity changes from the operation condition, such as normal operation, 115% overpower condition and reactivity fault, to cold sub-critical at refueling temperature with the most reactive control assembly stuck at full power operating condition.

The secondary system should be capable of controlling reactivity changes from the operation condition including reactivity fault of one primary control assembly to hot standby condition with the most reactive control assembly stuck at full power operating condition.

2.2 Required Reactivity and Control Assembly Worth

We calculated temperature defects from hot full power to hot standby and from hot standby to refueling temperature using the pre-calculated reactivity coefficients [2], and calculated control assembly worths to evaluate the reactivity worth of the system and 1 stuck assembly.

Fig. 1 shows the layout of KALIMER-600. The primary control system has 9 control assemblies: 3 assemblies at 6th hexagonal ring and 6 assemblies at 9th hexagonal ring. The secondary control system has 3 assemblies at 6th hexagonal ring. Natural boron (19.8% ^{10}B) is employed for the absorbing material of the control assemblies.

Table 1 shows the temperature and power defects at BOEC. The core outlet temperature of the coolant is 545.0℃, the hot standby temperature is 370.4℃, and the refueling temperature is 200.0℃. The temperature defect from hot full power to hot standby is 0.55$ (β=0.00357) and the temperature defect from hot standby to refueling is 0.64$.

Table 2 shows the control assembly worths at BOEC calculated from the DIF3D code [3] in hexagonal-z geometry with 9 energy groups. The primary and secondary system worths are 9.03$ and 3.24$ respectively, and the worths of 1 stuck assembly of two systems are 1.44$ and 1.36$ respectively.

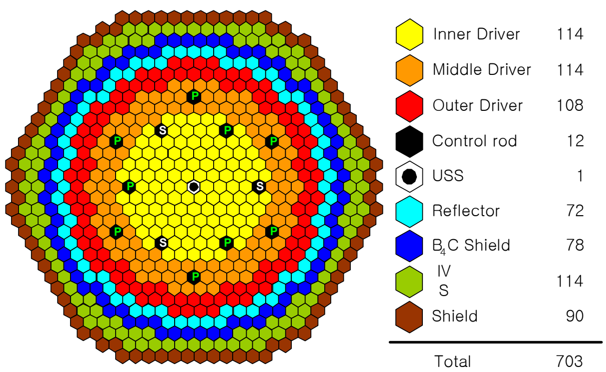

Fig. 1. Layout of KALIMER-600

Table1. Temperature and power defects ($)

	Hot full power to hot standby	Hot standby to refueling
Fuel Doppler	0.46	0.47
Axial expansion	0.10	0.19
Radial expansion	0.18	0.36
Sodium density	-0.19	-0.38
Sum	0.55	0.64

Table 2. Control assembly worths ($)

	Number of CRs	
Secondary	2 (ring 6)	1.89
	3 (ring 6)	3.24
Primary	2 (ring 6)+ 6(ring 9)	7.59
	3 (ring 6)+ 6(ring 9)	9.03

2.3 Shutdown Margin

We calculated maximum required reactivity and performed preliminary evaluation of the shutdown margin of the reactivity control system of KALIMER-600.

Table 3 shows the reactivity control requirements. Temperature defect is the summated worth of each control systems in table 1 and overpower reactivity is 15% of temperature defect to consider the reactivity of 115% overpower. The uncertainties of reactivity are assumed because the amounts are not evaluated yet. Also, the worth of reactivity fault is assumed to be 0.3$[4]. Total reactivity is the sums of temperature defect, overpower, uncertainties and reactivity fault.

Table 4 shows the shutdown margins of primary and secondary control system. The available reactivity worth is the subtracted worth of 1 stuck assembly from the worth of system. Shutdown margin is the subtracted worth of maximum requirement from available reactivity worth. The result shows that the shutdown margins of primary and secondary control system are 3.96$ and 0.95$ respectively. The shutdown margin of primary control system is appropriate but the shutdown margin of secondary control system is not sufficient.

The evaluation of an alternative control system at different control assembly positions (6 control assemblies of 6th hexagonal ring is placed at 4th hexagonal ring) with same numbers of control assemblies is performed. Table 5 shows that the shutdown margins of primary and secondary control system are 4.61$ and 0.92$ respectively. The shutdown margin of primary control system is increased, whereas the shutdown margin of secondary control system is decreased. The alternative control system can affect the shutdown margin but the effectiveness is minor, because the increased shutdown margin of alternative system is 0.6 with the decreased margin of secondary control system.

Table 3. Reactivity control requirements ($)

	Primary	Secondary
Temperature defect	**1.19**	**0.55**
Full power to hot standby	0.55	0.55
Hot standby to refueling	0.64	
Overpower	**0.08**	**0.08**
Fuel cycle excess reactivity	**0.59**	
Uncertainties (RMS)	**1.46**	
Temperature defect (20%)	0.24	
Burnup reactivity (50%)	0.29	
Criticality prediction	1.00	
Fissile loading	1.00	
Reactivity fault	**0.30**	**0.30**
Total	**3.63**	**0.93**

Table 4. Shutdown margin of control systems ($)

	Primary	Secondary
Reactivity worth of system	9.03	3.24
Worth of 1 stuck assembly	1.44	1.36
Reactivity worth available	7.59	1.89
Maximum requirement	3.63	0.93
Shutdown margin	3.96	0.95

Table 5. Shutdown margin of alternative control assembles position ($)

	Primary	Secondary
Reactivity worth of system	9.48	2.85
Worth of 1 stuck assembly	1.24	1.00
Reactivity worth available	8.24	1.85
Maximum requirement	3.63	0.93
Shutdown margin	4.61	0.92

3. Conclusion

We have suggested the requirements of two reactivity control systems, and performed preliminary evaluation of the maximum required reactivity and the shutdown margin of the reactivity control system for KALIMER-600. The shutdown margin of primary control system is appropriate, but the shutdown margin of secondary control system needs to be increased to assure sufficient margin. The effect on the position change of control assemblies is minor to increase the secondary control system without sacrificing the margin of primary control system although the shutdown margin of alternative control system is increased than that of originally proposed one. To increase the shutdown margin of secondary control system, the control system needs to increase the number of secondary control assemblies.

The evaluation of control system with increased number of control assemblies, calculation of the worth of reactivity fault with single rod withdrawal and estimation of the uncertainties will be performed as the further study.

ACKNOWLEDGEMENT

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