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Sensitivity Investigation of Reactivity Induced Accidents for a 5MW Research Reactor

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1. Introduction

From the safety analysis point of view, a sensitivity test to confirm the most severe event in each reactor is important. Reactivity induced accidents (RIAs) occur due to several initiating events [1]. An inadvertent withdrawal of a control rod during normal operation can occur due to an operator error or a failure of control rod drive system. Another initiating event of the RIA is a withdrawal of an experimental material in the core. In some research reactors, there are several irradiation holes to carry out various experiments. If an experimental sample is withdrawn suddenly, this could result in an insertion of positive reactivity into the core. In research reactor, there is a reactor protection system (RPS) to keep the reactor in safe condition. In relation to the RIAs, the RPS has power trip and power lograte trip variables.

The results of RIAs are affected by not only the initial reactor power but also the reactivity insertion rate. Therefore, we selected the parameters of the initial reactor power and the reactivity insertion rate for the sensitivity investigation in this study. Especially, a research reactor with a normal power of 5MW was considered. This sensitivity study was carried out by using RELAP5/MOD3.3 [2, 3].

2. Test Matrix for Sensitivity Study

Table 1. Test Matrix

		Initial reactor power		
		100%FP	50%FP	1.5%FP
Reactivity insertion rate	0.3mk/s	P1R1	P2R1	P3R1
	0.2mk/s	P1R2	P2R2	P3R2
	0.1mk/s	P1R3	P2R3	P3R3
	0.01mk/s	P1R4	P2R4	P3R4
	1.5mk	P1R5	P2R5	P3R5

Table 1 is the test matrix used in this sensitivity study. Because the initial reactor power and the reactivity insertion rate affect the response of reactor power subseqent to the fuel temperature and critical heat flux ratio, the test matrix was composed of these factors. The initial reactor power varies from 1.5%FP to 100%FP. And the reactivity insertion rate varies from 0.01mk/s to 0.3mk/s. The 0.3mk/s is the maximum value because of the inherent design feature of the reactor power control system. The 1.5mk is the maximum reactivity that could be inserted by a withdrawal of an experimental material. It was assumed that the reactivity was inserted instantaneously within 0.001 seconds.

To check the effect of each factor only, reactivity feedback caused by fuel temperature coefficient and moderator temperature coefficient was not included in the present calculation.

3. Results and Discussions

3.1 Comparison factors

The maximum fuel temperature and the minimum critical heat flux ratio (CHFR) are the safety parameters to ensure the fuel integrity. Therefore, they are calculated and compared in each case to find out the most severe case.

The correlation package developed by Kaminaga et al. [4] was used to calculate the CHFR. It was developed from the series of experiments using a narrow rectangular duct similar to the coolant channels of plate type fuel assemblies used in many research reactors. This calculation was accomplsished by using control variables in RELAP5/MOD3.3.

3.2 Results of Sensitivity Test

Figure 1 to 4 show the CHFR and fuel temperature comparison results for all cases. The solid lines represent CHFR and the dotted lines represent fuel temperature. Table 2 shows the CHFR for all cases. For the initial power of 100%FP, as the reactivity insertion rate becomes larger, the CHFR becomes smaller. The minimum CHFR appears at the reactivity insertion rate of 0.3mk/s. In this initial power the reactor is tripped by the power trip setpoint regardless of the reactivity insertion rates. Therefore, the larger reactivity insertion rate is the larger reactor peak power is.

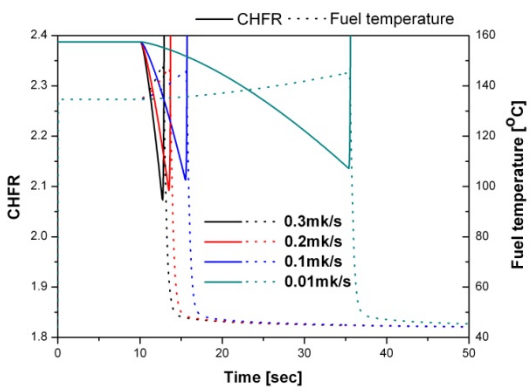

Fig. 1. CHFR and fuel temperature of 100%FP initial condition

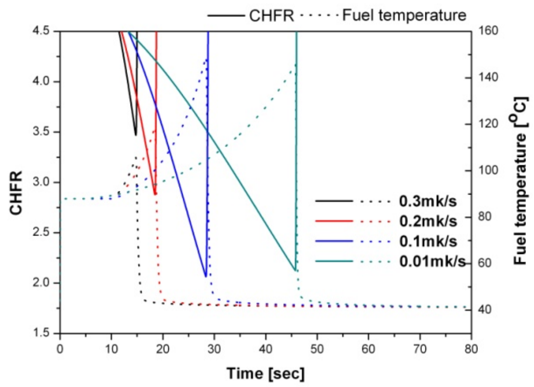

Fig. 2. CHFR and fuel temperature of 50%FP initial condition

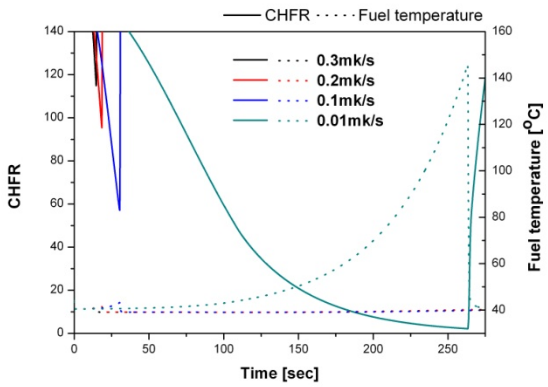

Fig. 3. CHFR and fuel temperature of 1.5%FP initial condition

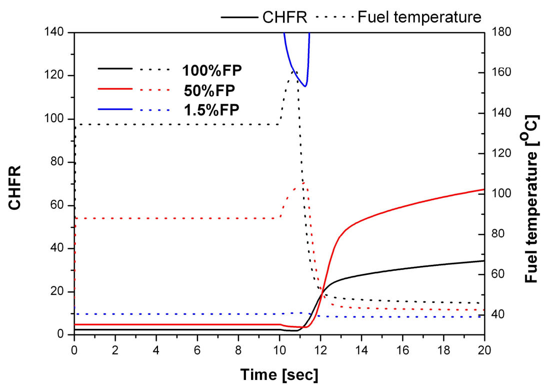

Fig. 4. CHFR and fuel temperature of 1.5mk insertion condition

The fuel temperature trend is opposite to that of the CHFR. As the reactivity insertion rate becomes larger, the CHFR becomes smaller.

For the initial power of 50%FP, the minimum CHFR appears at the reactivity insertion rate of 0.1mk/s. In this initial power, the minimum CHFR depends on the reactor trip conditions. In case the reactor is tripped by the power lograte trip setpoint, the smaller reactivity insertion rate leads more severe result. This is because the reactor is tripped faster at the higher reactivity insertion rate than the lower one, and because the power is smaller at the higher reactivity insertion rate than the lower one. The fuel temperature trend is opposite to that of the CHFR.

In case of the reactivity insertion rate of 1.5%FP and the reactor trip by the power lograte, the trend of CHFR is similar to that in the case of the initial power of 50%FP. However, the minimum CHFR appears at the reactivity insertion rate of 0.01mk/s. This is because the reactor is tripped by the reactor power and the reactor power is the largest at the case of 0.01mk/s.

The complicated trend of the minimum CHFR in the cases is led from the fact that the first reactor trip variables depends on the initial power and the reactivity insertion rate and subsequently the maximum power during the transient is varied.

In case of sudden insertion of 1.5mk reactivity, the CHFR becomes smaller as the reactor initial power becomes larger as shown in Table 2. In this event, the reactor is tripped by the power lograte in all the cases. Therefore, the minimum CHFR appears when the initial power has the maximum value.

Table 2. CHFR comparison result

		Initial reactor power		
		100%FP	50%FP	1.5%FP
Reactivity insertion rate	0.3mk/s	2.07	3.47	114.9
	0.2mk/s	2.09	2.90	95.4
	0.1mk/s	2.11	2.05	57.0
	0.01mk/s	2.14	2.12	2.13
	1.5mk	1.82	3.47	114.9

4. Conclusion

The CHFRs and fuel temperatures were investigated in the various initial reactor powers and reactivity insertions by using RELAP5/MOD3.3. In case of the step insertion of 1.5mk reactivity, the larger the initial reactor power is, the smaller the CHFR is. And in case of the constant reactivity insertion rates, there is a different trend with the initial reactor power. In case of the initial power of 100%FP, the minimum CHFR appears at the maximum reactivity insertion rate. On the other hand, in case of the initial power of 1.5%FP, the minimum CHFR is predicted at the minimum reactivity insertion rate.

REFERENCES

[1] IAEA Safety Standards, Safety requirement No. NS-R-4, 2005

[2] RELAP5/MOD3.3, Code Manual Volume I, Code Structure, System Models, and Solution Methods, NUREG/CR-5535/Rev1, 2001

[3] RELAP5/MOD3.3, Code Manual Volume V, User's Guideline, NUREG/CR-5535/Rev1, 2001

[4] M. Kaminaga et al., Improvement of critical heat flux correlation for research reactors using Plate-Type Fuel, J. of Nuclear Science and Technology, Vol. 35, pp. 943-951, 1998