A Criticality Evaluation of Corium Arranged in the Reactor Cavity of OPR1000

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1. Introduction

A concern over a nuclear severe accident has been increased lately since the Fukushima accident. In a core melting accident, the feasibility of a criticality accident exists due to the fissionable materials in the molten core (corium), and re-criticality in corium also can cause another severe accident. Accordingly, in the previous studies, the analyses on the corium re-criticality were conducted for a core melting accident [1-2]. It is well known that the layer separation of the corium is generated by the delay of the corium cooling. The possibility of a re-criticality accident in a stratified corium can increase because absorber material tends to be separated with fissionable material. However, the criticality variation caused by the layer separation is not clearly researched with the individual initiating events. In this study, a criticality evaluation of the stratified corium with several accident scenarios is performed on corium rearranged in a reactor cavity of OPR1000.

2. Criticality Analysis

In this study, criticality calculation is conducted for three accident scenarios which are considered the most probable. In Scenario A, corium which caused vessel failure is poured into a rector cavity and forms a flat layer. Providing cooling water, corium becomes a porous structure and could make interaction with bottom concrete. In Scenario B, corium could have an irregular shape in a cavity with provided water beforehand. The corium is assumed in a cone shape in this scenario. In Scenario C, the condition without a control rod material in corium is considered.

2.1 Conservative Assumptions Required for Criticality Evaluation

There are plenty of variables to be considered in corium criticality evaluation, and the variables are not clear to be predicted. Hence, conservative assumptions are employed in several variables. It is assumed that the corium temperature is 300K, and the nuclear fuel is not nearly consumed, that is 4.3w/o. Pure water without boron is assumed for a coolant. The concrete erosion rate is considered to be 0.073 mm/s, and the highest value is used for the porosity of corium [4].

2.2 Scenario A: Reflection of the Effect of Initiating Events on Neutron Multiplication Factor

Corium mass is variant among initiating events as shown in Table I. Simulation results for APR 1400 were used as a reference for the corium mass in OPR 1000 severe accidents [5]. In Scenario A**,** the effect of initiating events on neutron multiplication factor is considered, and specifications for Scenario A are as follows.

- Corium is rearranged in a flat shape which consists of metallic and oxidic layer.
- Porosity of the corium is 50% and 74% for the metallic and oxidic layer.
- Estimated concrete erosion is about 6.05ton

Table I. Gemini Code Analysis Results for Severe APR1400 Accidents [5] [Units: tons]

Nuclear Element	TLFW		SBO		SBLOCA (2.0 inch)		MNLOCA (4.28 inch)		LBLOCA (9.6 inch)	
	Metallic	Oxidic	Metallic	Oxidic	Metallic	Oxidic	Metallic	Oxidic	Metallic	Oxidic
B	1.01	0.09	0.8	0.08	0.73	0.12	1.00	0.10	0.67	0.22
C	0.30	0.00	0.01	0.00	0.01	0.00	0.30	0.00	0.01	0.00
Cr	8.76	0.24	2.1	0.12	2.33	0.10	8.81	0.19	2.97	0.09
Fe	35.88	0.12	25.38	0.19	26.35	0.15	35.91	0.09	28.27	0.13
Ni	3.92	0.08	3.14	0.11	3.16	0.09	3.94	0.06	3.34	0.07
O	0.30	17.84	0.28	16.84	0.23	14.10	0.29	13.70	0.21	12.37
U	14.65	85.14	14.68	81.13	12.64	73.51	16.04	71.41	14.40	78.70
Zr	6.05	19.12	5.95	18.84	3.96	12.61	5.23	12.14	2.09	4.66
Sum	193.5		169.65		150.09		169.21		148.2	

2.3 Scenario B: Corium with an Irregular Shape

In case of a cavity filled by water before core melt ejection, the corium could have an irregular shape. In Scenario B, the effect of corium shape on neutron multiplication factor is considered as following:

- Corium is in a cone shape which is homogenized with the metallic and oxidic layer in Table I.
- Porosity of the corium is 50% and 74% for the metallic and oxidic layer.
- Estimated concrete erosion is about 6.05ton.

2.4 Scenario C: Control Rod Insertion Failure

A control rod insertion failure is also possible in a core melting accident. In Scenario C, boron is not included in a corium composition.

- Corium is rearranged in a flat shape which consists of metallic and oxidic layer.
- Porosity of the corium is 50% and 74% for the metallic and oxidic layer.
- Estimated concrete erosion is about 6.05ton.
- Boron is not included in a metallic and oxidic layer.

3. Results and Discussions

The results from criticality calculations are shown in Tables II and III. The multiplication factor of corium in the SBO (Station Black Out) event showed the highest value among the events. Comparison of multiplication factors are made between stratified (Scenario A) and homogenized (Scenario B) corium cases in Table II. The multiplication factors of stratified corium in Scenario A are higher than those of homogenized corium in Scenario B. In homogenized corium, the boron element that was separated in a metallic and oxidic layer is mixed evenly, which decreases the multiplication factors. From the results of Table III, multiplication factors are increased in Scenario C compared to Scenario A. It is obvious that the multiplication factors are raised in case of the control rod insertion failure. It is shown that criticality safety is secured in all three scenarios.

Table II. Comparison of Multiplication Factors between Scenario A and B

Events	k_{eff}	
	A	B
TLFW	0.63537±0.00060	0.24727±0.00020
SBO	0.63950±0.00058	0.28447±0.00022
SBLOCA	0.55411±0.00060	0.27137±0.00020
MNLOCA	0.57704±0.00062	0.22685±0.00018
LBLOCA	0.45966±0.00044	0.28310±0.00020

Table III. Comparison of Multiplication Factors between Scenario A and C

Events	k_{eff}	
	A	C
TLFW	0.63537±0.00060	0.84295±0.00072
SBO	0.63950±0.00058	0.83462±0.00078
SBLOCA	0.55411±0.00060	0.81565±0.00072
MNLOCA	0.57704±0.00062	0.81002±0.00074
LBLOCA	0.45966±0.00044	0.85183±0.00072

4. Conclusions

Corium criticality evaluation for the reactor cavity in OPR1000 was performed in severe nuclear accidents. The effect of initiating events on a multiplication factor was considered, and comparison of multiplication factors was made between homogenized and stratified corium cases. Criticality calculation was also performed in corium without a control rod material. From the results, it was found that multiplication factors showed higher values in stratified corium than those of homogenized corium. Furthermore, critical state was not reached even in the case of a control rod insertion failure. It is expected that the results could be used as a reference data for criticality safety analysis in a severe nuclear accident.

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