An Evaluation on Criticality Safety of Corium Arranged in a Core Catcher

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1. Introduction

The core catcher, which is required for the NPP construction in Europe, is a representative provision against the core melting accident. The criticality accident of corium arranged in the core catcher can cause the severe accident. Therefore, the criticality safety in the core catcher, which is being developed in Korea, must be verified with considering the various accident scenarios. A core catcher design developed in Korea was selected for the evaluation of the criticality safety. Some corium conditions and accident scenarios were assumed in this study. The corium criticalities with conservative scenarios and assumptions were evaluated by using MCNP5 code [1].

2. Methods

2.1 Overview of Corium and Core Catcher

After the severe core melting accidents, the corium can penetrate the reactor vessel due to its very high temperature. The liquefied corium is reached in the core catcher, which is shown in Fig. 1. The core catcher has a rectangular bottom (6 m x 16 m) which is the large spreading area to cool down the corium effectively. The cooling water is injected for cooling the corium when the corium is spread out in the core catcher. The top layer of the core catcher bottom is composed with a criticality reduction material (Gd_2O_3, 60 kg). The second layer of the bottom is assumed to be a regular concrete [2].

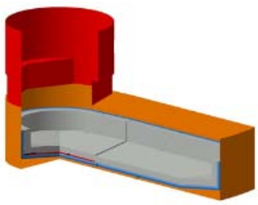

Fig. 1. A View of Core Catcher Developed in Korea

2.2 The Conditions for the Criticality Safety Analysis

The geometry of corium arranged in the core catcher has a large uncertainty because of the accident characteristic and cooling devices. Hence, some variables were rejected by the conservative assumption in this study. The enrichment of U-235 was assumed to be 5w/o, which is the maximum value in $1400MW_{th}$ PWR, and fuel burn-up was not considered. It is assumed that maximum amount of nuclear fuel was molten in the corium as shown in Table I.

Table I. Composition of Corium for $1400MW_{th}$ PWR

Material	UO_2	Zirlo	SS304	B_4C
Weight (unit: ton)	120	34	50	3.2

It is assumed that the corium is homogeneously mixed. It is well known that the corium is rapidly spread out in the core catcher and well mixed with the sacrificial material [3]. Therefore, the slab arrangement is assumed to be homogeneous mixture in this study. The high temperature of the corium reduces the criticality; therefore, it is not considered in this study.

As referred in a regulation guideline [4], multiplication factor must not exceed 0.95 with considering the uncertainty factors. And, more than two independent conditions generated with an extreme low probability should not be considered for the criticality safety. In considering the regulation guide, the accident scenarios, which can significantly affect to the criticality evaluation, were assumed as shown in Table II.

Table II. Accident Scenarios for Criticality Safety Evaluation

	Main Condition	Sub-condition
Scenario I	- B_4C is not included in corium.	- Gd_2O_3 is well mixed in corium. - Corium has slab shape.
Scenario II	- Gd_2O_3 is not mixed in corium.	- B_4C is included in corium. - Corium has slab shape.
Scenario III	- Corium has not slab shape.	- B_4C is included in corium. - Gd_2O_3 is well mixed in corium.

2.3 Corium Model

In the previous study [5], it was evaluated that the criticality is significantly affected by the corium model and porosity. To determine the model for the criticality evaluation, a sensitivity study was pursued with the various models assumed in this study (see Fig. 2). B_4C is not included in the sensitivity study for the conservative analysis. It is assumed that the holes are uniformly distributed and filled with pure water in the infinite medium. Criticalities with each model were evaluated as the changes of the porosity and unit lattice size. The calculations were performed with MCNP5 code. The criticality results with the models were shown in Fig. 3.

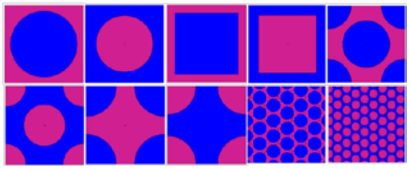

Fig. 2. Models for the Corium Criticality Analysis

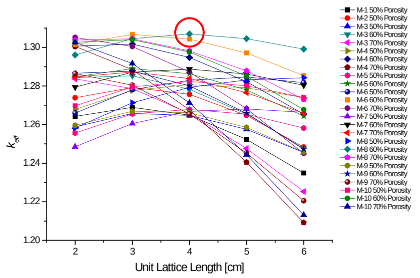

Fig. 3. Result of Sensitivity Study with the Corium Models

From the result of the sensitivity study, a FCC corium model with the 4 cm length of the unit lattice and 60 % porosity, which has a highest k_{eff} in the sensitivity study, was chosen for the conservative evaluation of the criticality safety.

3. Criticality Safety Evaluation

The criticality accident in the planned scenario cannot be happened. Therefore, the criticality in the core catcher was evaluated with the two conditions. In case A, a spherical shape of the corium was assumed and the Gd_2O_3 was excluded to evaluate the accident scenario II and III in a same time. The radius of corium sphere was 244.26 cm and the average density (8.4861 g/cc) of the corium materials was used. The surrounding material of corium is assumed to be pure water with having the 500 cm radius. Calculations using the MCNP5 code were pursued with an ENDF/B-VI cross-section library and used a sab2002 S(α, β) thermal cross-section library. The MCNP modeling of the case A is shown in Figure 4.

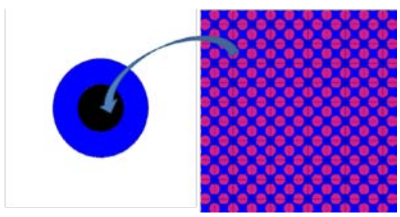

Fig. 4. MCNP Modeling of the Assumed Spherical Corium

The multiplication factor reached 0.20634 ±0.00006, which was sufficiently satisfied by the regulation guideline [5].

In case B, the (6 m x 16 m) rectangular parallelepiped corium shape was used for the analysis of the accident scenario I. The B_4C, which is the composition material of the control rods, was excluded. The 60 kg of the Gd_2O_3 was used for the criticality reduction material on the bottom of the core catcher. It was assumed that the corium and the Gd_2O_3 were homogeneously mixed. The thickness of the corium mixture was 60.30 cm and the density of the corium was 8.8128 g/cc. The thickness of the cooling water was 240 cm and it is assumed to be pure water. The thickness of the core catcher and its material composition were assumed to be 100 cm and regular concrete [7], respectively.

The multiplication factor reached 0.87132 ±0.00018. Although the MCNP code has a good accuracy, the code bias should be evaluated for the assurance of the result. For the bias calculation, criticalities of 262 benchmark problems were evaluated and compared with the results of the experiments. The result of the bias (1-k_{eff}) was 0.00552 and the result of uncertainty (2 σ_{bias}) was 0.01051. The final result of the multiplication factor was performed with the Eq. (1).

$$k_{eff,final} = k_{MCNP} + \Delta k_{bias} + \sqrt{(2\sigma_{bias})^2 + (2\sigma_{stat})^2} \qquad \text{Eq. (1)}$$

The multiplication factor with the considerations of the bias and calculation uncertainty was 0.89786 which was satisfied by the regulation guideline [5].

4. Conclusions

This is a study to evaluate the possibility of re-criticality in the core catcher. For the 1,400MW_{th} light water reactors, the criticality of the corium arranged in the core catcher was evaluated by using MCNP5 code. The calculation was performed with the conservative assumptions including the accident scenarios. The results show that the criticality safety in the core catcher is secured with the given core catcher design. The results can be utilized for the data production of the safety certification in the core catcher.

Acknowledgment

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