A Preliminary Study on Criticality Evaluation of Corium Re-arranged in the 1400MW$_{th}$ PWR Core Catcher

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1. Introduction

The concept of the core catcher, which is a representative provision against the core melting accident, was developed in Europe. The core catcher has the function of corium retention in the core melting accident. The reaching to the criticality of corium re-arranged in the core catcher can cause the severe secondary accident. Therefore, the criticality in the core catcher should be properly evaluated. To calculate the criticality in the core catcher, some possible corium conditions were assumed in this study. The orienting parameters, which can affect a possible return to the criticality of corium, were determined. The corium criticalities in the core catcher were evaluated with the changes of porosity in corium, average enrichment of uranium and density of water using MCNP5 code [1].

2. Methods and Results

2.1 Overview about the Core Catcher and Corium

After a severe core melting accidents, the corium penetrates the reactor vessel. The corium flows through the pit which locates between the reactor vessel and core catcher. Finally, the corium will be placed in the core catcher (see Fig. 1). The core catcher has a large spreading area to cool down the corium effectively.

The geometry of corium re-arranged in the core catcher has the large uncertainty with depending on the accident characteristic and cooling devices. COMET experiment [2] shows that the corium will be rapidly spread out of the bottom surface of the core catcher and uniformly accumulated with an equal level.

The composition of corium depends on the reactor materials and the accident characteristic. As the result, the uncertainty of corium composition is significantly large. Therefore, some appropriate assumptions of corium composition are needed.

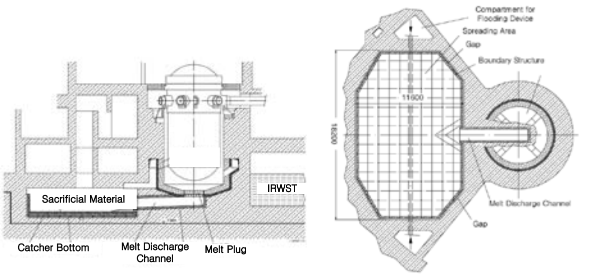

Fig. 1. Vertical and Horizontal Cross Sections View of Core Catcher [3]

In this study, the prototype corium composition [3] of EPR was used. The materials of control rod were not included in the corium composition for the conservativeness evaluation. The detail of the corium composition is shown in Table I.

Table I. Composition of Prototype Corium for EPR [3]

Material	UO_2	ZrO_2	FeO	Cr_2O_3	Fe
Weight Fraction	29%	12%	18%	2%	39%

2.2 Description of Orienting Parameters for the Corium Re-Criticality Calculation in Core Catcher

The criticality of corium re-arranged in the core catcher can be affected by the various parameters. The geometries of core catcher and re-arranged corium, material composition of core catcher and corium, corium porosity, average enrichment of uranium in the core, temperature of corium and density of cooling water are anticipated as the main parameters for criticality calculation in the core catcher.

Holes in corium are produced during the cooling of corium. In the COMET-T experiments, the porosity is changed with the cooling method and material characteristic of corium. After the solidification of corium, the cooling water is filled in the holes. The criticality of corium re-arranged in the core catcher is affected by the water in the holes. The porosities of COMET-T experiments are shown in Table II.

Table II. Porosity of COMET-T Experiments [2]

Experiment COMET-T	2.1	2.2	2.3	7.1	7.2
Porosity (Oxide/Metal)	88/38	65/40	73/40	69/33	67/49
Experiment COMET-T	7.4	7.5	8.2	8.4	8.5
Porosity (Oxide/Metal)	-/54	-/30	-/51	-/30	-/50

For the cooling of corium, the water is overspread on the corium in the core catcher. The waters, which are located in the porosities and upper space of corium, can be boiled by the heat from corium. Finally, the density of water can be changed. It affects to the criticality of corium.

2.3 MCNP Modeling of Corium Re-arranged in the Core Catcher

The core catcher and corium were described by MCNP5. The MCNP modeling for the core catcher is shown in Figure 2. It is assumed that the corium is homogeneously mixed. It is impossible to describe the holes in corium exactly. Therefore, the feature should be assumed to be a specified model. The cubical unit cell, which has one cubical center hole in each, was assumed. The pitch of the unit cell was supposed to be 2.924cm in this study. The corium height is changed by porosity of corium.

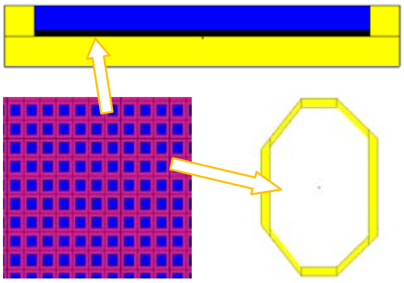

Fig. 2. MCNP Modeling of the Corium and Core Catcher

The water channel is located in the bottom and sides of core catcher for the supplement of water to core catcher. To investigate the effect of the water channel, the criticality in the inundation condition of corium is calculated.

3. Calculation Results and Discussion

The 3w/o, 4w/o, and 5w/o enriched uranium were chosen to calculate the criticality in this study. The criticality calculations of corium were repeated by increasing the porosity each time by 10 from 20 to 80. The material composition of KENO regular concrete standard mix [5] was used for the constitution material of core catcher. The mass of corium was supposed to be about 427,000kg which is an approximate mass of corium for 1,400MW$_{th}$ light water reactor. The results of criticality calculations were shown in Fig. 3.

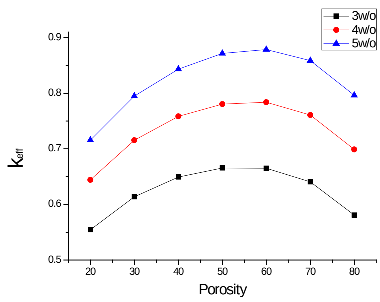

Fig.3 Calculations of the Multiplication Factors as the Changes of Porosity and Enrichment in the Core Catcher

The results show that the multiplication factor, k_{eff}, has a peak adjacent to the corium condition of 60 porosity and the 5w/o fuel average enrichment. However, the peak of k_{eff} was not exceeded over 0.9.

At the peak condition (5w/o enrichment, 60% porosity) of previous results, the corium criticality with the inundation condition was calculated and compared to that of normal condition. The k_{eff} in this condition was 0.8767 which had 0.02% smaller than that of normal condition.

As the change of water density, the k_{eff} at the peak condition was also estimated. The results are shown in Figure 4. The water density did not significantly affect to k_{eff} at the peak condition.

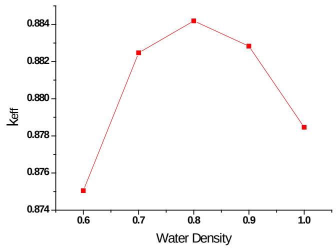

Fig. 4. Calculations of the Multiplication Factors As the Changes of Water Density in the Core Catcher

4. Conclusions

This is a preliminary study to evaluate the possibility of re-criticality in the core catcher. For the 1,400MW$_{th}$ light water reactors, the criticality of corium re-arranged in the core catcher was temporally evaluated as the changes of porosity, fuel enrichment and water density using MCNP5 code. The results show that these parameters can affect the criticality calculation. The methodology proposed in this study can be utilized for the safety analysis from the re-criticality accident caused by corium. Also, the methodology of criticality evaluation in the core catcher can be used for the reference data of core catcher design.

Acknowledgment

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