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Evaluation Methodology of External Corium Cooling System

Kwang Soon Ha [a*], Hwan Yeol Kim[a], Jongtae Kim [a], Jong Hwa Park[a]
[a]*Thermal Hydraulics Safety Research Department, KAERI, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: tomo@kaeri.re.kr*

1. Introduction

Even though possibility of a core melt accident in a nuclear power plant is extremely low, it may cause a major threat to the public safety if it happens. Therefore, it is important to develop and evaluate some adequate measures for the severe accident in a pressurized water reactor (PWR). In-Vessel corium Retention (IVR) through an External Reactor Vessel Cooling (ERVC) has been considered an effective means for maintaining the integrity of a reactor vessel during a severe accident in the nuclear power plant. However, it is not certain if the heat transfer from the reactor vessel wall to the coolant in the reactor cavity is sufficient to retain the molten corium inside the reactor vessel especially for the high-power reactors. If the retention of the molten core debris inside the reactor vessel is not assured during the postulated severe accident, the molten core debris will attack the concrete wall and basemat of the reactor cavity. Thus, an ex-vessel corium cooling system, such as an external core catcher, should be required for catching and long-term cooling of the molten corium outside the reactor vessel.

In this paper, an evaluation methodology of the ex-vessel core catcher system of a sample advanced light water reactor (ALWR) is introduced.

2. Evaluation Methods and Results

A target plant in this study is a 4,000MWt pressurized light water reactor. The reactor cooling system (RCS) has 2 hot legs, 2 U-tube steam generators, 4 reactor pumps, and 4 cold legs. The target plant is designed to promote a retention of, and heat removal from, a postulated core debris during a severe accident. The large cavity floor area ($80m^2$) allows for a spreading of the core debris thus enhancing its coolability within the reactor cavity region.

For catching and long-term cooling of the molten corium outside the reactor vessel, the reactor cavity floor is composed of a sacrificial concrete layer, coolant injection nozzles, and basemat. The corium is mixed with the sacrificial concrete located at the bottom wall and two side walls. The sacrificial concrete depth is assumed as 58mm. When the ablation is reached at the coolant injection nozzle, the coolant is passively injected into the corium by gravitational force difference between the corium and IRWST. Hence, corium quenching is accomplished. This bottom coolant injection system is similar to COMET[1] and COMET-PCA[1] concept. In this study, it is assumed that the compositions and properties of the sacrificial concrete and the basemat are the same that ones of the reactor cavity.

An accident scenario analysis is performed by MELCOR code to get the mass, composition, and decay power level of the ejected molten corium from the reactor vessel during the vessel breach time. The sequence simulated as a base case is one of loss of coolant accidents (6 inches diameter break LOCA), which would result in sufficient depressurization to prevent the high pressure melt ejection phenomena. Following a LOCA, the reactor trips and the high pressure safety injection systems are not available to deliver water from the IRWST to the cold legs. The only available water to make up the primary side is the inventory of the four safety injection tanks. By the accident scenario analysis, all melts are ejected from 18,500 seconds to 19,000 seconds after the reactor scram.

After the vessel breach, the sacrificial concrete ablation by the molten corium is analyzed by MELCOR code. By the analysis, it finds that the concrete ablation time to the coolant injection nozzle top, is about 19,400 seconds. At time 19,400 seconds, the vertical ablation depth reaches the sacrificial concrete depth, 58mm, and the ablation depth of the side wall is 71mm. At the coolant injection time, the molten corium is mixed with 8.5wt% sacrificial concrete, and the molten corium temperature is estimated at 2,160K.

The corium cooling history in the core catcher after the coolant injection is evaluated to calculate the temporal steam generation rate by considering an simple energy conservation equation. After the coolant injection time, 19,400 seconds after the reactor scram, the specific heat(c), freezing temperature, and melt specific enthalpy of the mixture with 8.5wt% sacrificial concrete are assumed as 650K/kg·K, 2,000K, and 1.43MJ/kg, respectively. During the corium cooling by the coolant, the decay heat per UO_2 mass with time is also simulated. As shown in Table 1, two cases are selected to confirm the coolant injection effect. In case2, the 90 volume percent water, as compared with case 1, is injected till all corium is solidified completely, to evaluate the containment pressurization effect by the reduced water injection rate.

Figure 1 shows the corium temperature during the corium cooling process in the core catcher. In Fig. 1, when the time is zero, the major corium components such as UO_2, Zr, ZrO_2, and Fe are released, i.e. 18,625 seconds after the reactor scram. And, at 775 seconds (19,400 seconds after the reactor scram) in Fig. 1, all sacrificial concretes are ablated, and then the coolant starts to be injected. As mentioned in Table 1, in case 2, the water injection rate is smaller than in case 1, so the corium quenching rate is lower. As shown in Fig. 1, the corium is completely solidified at 1,598 seconds in case 1, at 1,691 seconds in case 2. After all, the corium is completely solidified within 1,000 seconds after injecting the coolant in all cases.

The steam which is generated by the corium cooling process is transferred to the containment. If the steam generation rate is larger than the steam condensation rate, the containment pressure should increase, and then, the containment safety is threatened by the steam pressure. In order to analyze the steam distributions, steam condensation, and containment pressure, the GASLOW code is used. The initial containment conditions for the GASFLOW calculation are assumed as pressure of 0.2MPa, temperature of 323K, and released steam temperature of 1,000K when the major corium components are released in the core catcher, i.e. 18,625 seconds after the reactor scram.

Figure 2 shows the temporal pressure variation of the containment by GASFLOW analysis. In Fig. 2, when the time is zero, the major corium components are released, i.e. 18,625 seconds after the reactor scram. After injected the coolant through the molten corium in the core catcher, i.e., after 775 seconds (19,400 seconds after the reactor scram), the containment pressure and temperature abruptly increase due to the huge steams which are generated during the corium cooling process. As shown in Fig. 2, the pressure of the containment in case 2 are lower than in case 1 because the coolant is injected smaller. Therefore, it is confirmed that the containment pressure decreased effectively by the 10% volume reduction of the injected water rate.

3. Conclusion

In this paper, an evaluation methodology of ex-vessel core catcher system of a sample advanced light water reactor (ALWR, 4000MWt) was introduced. The core catcher was designed to cool down the molten corium through water from the bottom of the molten corium. By using the MELCOR code, the calculations of molten core and sacrificial concrete interaction phenomena were performed for a representative severe accident scenario of the ALWR, that is, the 6-inch large break loss of coolant accident without safe injection. The composition of the molten corium, the decay power level, and the concrete ablation depth with time were obtained by the MELCOR calculations. The corium cooling history in the core catcher after the coolant injection was evaluated to calculate the temporal steam generation rate by considering a simple energy conservation equation. The temporal steam generation rate were used as the major inputs for the temporal calculations of containment pressure which was performed by using the GASFLOW code. As a result of this study, it was confirmed that the containment pressure decreased effectively by the 10% volume reduction of the injected water rate

ACKNOWLEDGMENTS

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REFERENCES

[1] W. Wildmann, M. Burger, G. Lohnert, H. Alsmeyer, and W. Tromm, Experimental and Theoretical Investigation on the COMET Concept for Ex-vessel Core Melt Retention, Nuclear Engineering and Design, Vol.236, p.2304, 2006.

Table 1. Calculated cases for the corium cooling

Case	Coolant injection condition
Case1	100 vol% water
Case2	90 vol% water

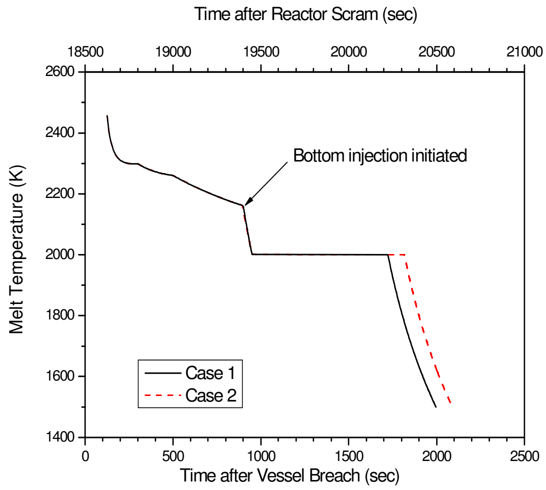

Fig. 1 Temporal corium temperature from coolant injection time in core catcher

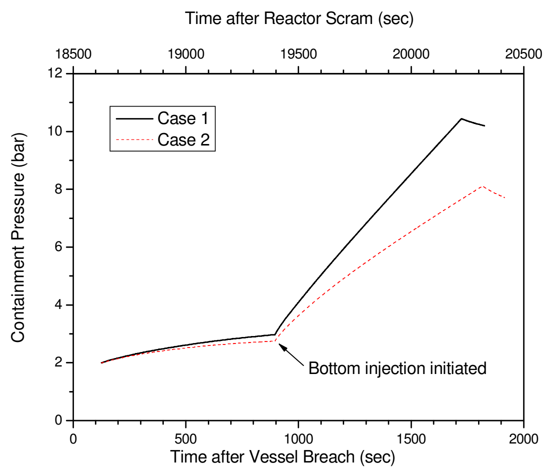

Fig. 2 The temporal pressure in containment building