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# Analysis for the Coolability of the Reactor Cavity in a Korean 1000 MWe PWR Using MELCOR 1.8.3 Computer Code

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## Abstract

The analysis for the coolability of the reactor cavity in typical Korean 1000 MWe Nuclear Unit under severe accidents is performed using MELCOR 1.8.3 code. The key parameters molten core-concrete interaction(MCCI) such as melt temperature, concrete ablation history and gas generation are investigated. Total twenty cases are selected according to ejected debris fraction and coolant mass. The ablation rate of concrete decreases as mass of the melt decreases and coolant mass increases. Heat loss from molten pool to coolant is comparable to total decay heat, so concrete ablation is delayed until water is absent and crust begins to remove. Also, overpressurization due to non-condensible gases generated during corium and concrete interacts can cause to additional risk of containment failure. It is concluded that flooded reactor cavity condition is very important to minimize the cavity ablation and pressure load by non-condensible gases on containment.

## I. Introduction

In a severe accident associated with light water reactors(LWRs), loss of normal and emergency cooling systems can lead to melting and slumping of the core. If uninterrupted, this is followed by failure of the pressure vessel and deposition of molten core and associated structural materials onto the concrete floor of the reactor cavity. For this Molten Core-Concrete Interaction(MCCI), the debris is maintained at high temperature by decay heat from non-volatile fission products retained in the melt. The temperature and heat fluxes involved are sufficient to decompose and ablate concrete. Containment failure by basemat penetration could occur. Besides, the large amounts of water vapor and carbon dioxide produced by the decomposition of concrete, which can react with metals to produce the hydrogen and carbon monoxide, can lead to the overpressurization of containment. Hydrogen and carbon monoxide are also combustible, giving an additional risk of sudden overpressurization if they are ignited. For this situation, the cooling system for the reactor cavity should be provided to mitigate the MCCI and therefore to ensure a long-term integrity of containment,

In the previous study[1], the analysis for SWISS Experiment showed the overlying coolant has a little influence on the concrete ablation history and the production of non-condensible gas. But this result from the small-scale experiment may be not extended for the reactor cavity of plant-scale. It is necessary to simulate the reactor cavity of the Nuclear Power Plant under the experience based on the benchmarking of MCCI experiments. In this study, the MELCOR1.8.3 computer code[2] is used to model the contact between molten corium and concrete of MCCI phenomena and to examine the coolability of the reactor cavity of typical Korean Nuclear Unit. The MELCOR 1.8.3 which includes the complicated updated CORCON/MOD3 models for MCCI, is a fully integrated, relatively fast-running code that models progressions of severe accidents.

## II. Calculation Matrix and Initial Condition

Table 1 is a test matrix for MELCOR 1.8.3 code calculation to predict the responses of the reactor cavity of typical Korean 1000 MWe Nuclear Unit. From the concepts that the risks associated with the reactor cavity concrete may be diminished by the overlying cooling water, total twenty cases are selected according to ejected debris fraction and coolant mass where 200 ton of the coolant mass is determined by four units of safety injection tank(SIT). It is assumed that the melt and cooling water are initially present in cavity at starting time of calculation. Also, the initial temperature of cooling water is assumed to be 363 K, which considers the cool-down of the primary system. Major initial conditions for calculation are listed in table 2.

TABLE 1
Calculation matrix of MELCOR

| Coolant Mass<br>Melt Mass | No Water | 50 ton | 100 ton | 200 ton |
|---|---|---|---|---|
| 100 % of Core Inventory | CASE 1 | CASE 2 | CASE 3 | CASE 4 |
| 80 % of Core Inventory | CASE 5 | CASE 6 | CASE 7 | CASE 8 |
| 60 % of Core Inventory | CASE 9 | CASE 10 | CASE 11 | CASE 12 |
| 50 % of Core Inventory | CASE 13 | CASE 14 | CASE 15 | CASE 16 |
| 30 % of Core Inventory | CASE 17 | CASE 18 | CASE 19 | CASE 20 |

TABLE 2
Initial conditions of MELCOR calculation

| | |
|---|---|
| Initial Composition of Melt<br>(100% of Core Inventory) | $UO_2$ 86448.0 kg  $ZrO_2$ 21719.0 kg<br>Zr 2816.0 kg  Fe 35149.0 kg<br>Cr 7210.0 kg  Ni 2703.0 kg |
| Initial temperature of Melt | 2700 K |
| Decay Heat of Melt | $P_d(t) = 0.0622\, P_o[\ t^{-0.2} - (t_o + t)^{-0.2}]$<br>Where $P_d(t)$ = Power generation due to beta and gamma rays<br>$P_o$ = Reactor power before shutdown<br>$t_o$ = time, in seconds, of power operation before shutdown<br>t = time, in seconds, elapsed since shutdown |
| Cavity Geometry | Fig. 1 |
| Concrete Composition | $SiO_2$ 61.37%  $TiO_2$ 0.41%  MnO 0.07%<br>MgO 1.11%  CaO 10.82%  $Na_2O$ 1.66%<br>$K_2O$ 2.28%  $Fe_2O_3$ 4.19%  $Al_2O_3$ 10.95%<br>$Cr_2O_3$ 0.01%  $CO_2$ 1.87%  $H_2OCHEM$ 2.24%<br>$H_2OEVAP$ 3.02% |
| Initial Condition of Containment | Pressure 30 psia (0.2067MPa)<br>Steam mass 40 ton<br>Gas temperature 390 K<br>Hydrogen mass 560 kg |
| Initial Condition of Cavity | Coolant temperature 363 K<br>Gas temperature 440 K |

## Ⅲ. Results and Discussions

The coolability of the reactor cavity of typical Korean 1000 MWe Nuclear Units is investigated using MELCOR 1.8.3 code. The integrity of cavity can be expressed in terms of temperature of the melt, concrete ablation rate and distance and flow rate of concrete decomposition gases. In this study, aerosol concentration will not be considered.

Fig. 2 shows that the temperature history of all cases is the similar except for the period of initial cooling. From the result of CASE 20, in which melt mass is of the smallest quantity and water mass is of the largest quantity, it is indicated that the melt is cooled at the temperature that is lower than ablation temperature of concrete(1500 K) until cooling water is dried out totally. In initial contact between high-temperature melts and the concrete, fast downward erosion and the very high downward heat transfer are responsible for the rapid cooling of the melt. This fact is supported by many earlier experiments such as TURC[3], SWISS[4], BETA[5], SURC[6], etc. The concrete ablation rate is predicted to be a range of 3 - 8 cm/hr as shown in Fig. 3. It is confirmed that if more and more water should be provided the concrete ablation might be mitigated. Radial ablation distance of concrete is shown in Fig. 4.

On the other hand, because the water in cavity is depleted within almost 36 hours for all cases as shown in Fig. 5, it is calculated that the basemat melt-through has happened finally. But, if in early stage of MCCI sufficient cooling water is provided, rapid cooling of the molten pool makes the melt solidified in spite of very high decay heat power. Hence, the concrete ablation is delayed during the water is present in cavity. In CASE 20, for instance, the concrete ablation initiates about 36 hours after interaction. and the crust has been formed during the time of water evaporation. The heat fluxes from the melt to concrete and coolant respectively are shown in Fig. 6.

Fig. 7 shows the generated amounts of hydrogen in MCCI. Within one day more or less, the metal layer in the melt is consumed totally and generated mass of hydrogen is saturated, depending on the quantities of overlying water. But, the generation rate is slow when the mass of the water is of small quantity. As seen in Fig. 7, the more corium is in cavity, the more hydrogen is created. This is the same in carbon dioxide. It is generally accepted that pressure load of non-condensible gas on containment is proportional to their generation rate and, therefore, overlying water can mitigate the pressure load. But, in this study, it is steam that substantially affects the overpressurization of containment(Fig. 8). This fact is confirmed by Fig. 9 that presents that pressure history of containment and generated steam history have same trend.

## Ⅳ. Conclusions

In this study, the coolability of the reactor cavity of typical Korean 1000 MWe Nuclear Unit under severe accidents. is analyzed. With the aid of MELCOR 1.8.3, the response of the cavity to basemat penetration is simulated. For this, it is assumed that melt and water are initially present in cavity at starting time of calculation, and total twenty cases are selected according to ejected debris fraction and coolant mass.

The following results are obtained:

- The temperature of the melt drops rapidly during initial contact between the core debris and the concrete in spite of very high decay heat power.

- Coolant and crust behavior have an important role to prevent cavity ablation or basemat melt-through, but overpressure load on containment may be resulted from evaporization of the water in cavity. Also, overpressurization due to noncondensible gases generated during corium and concrete interacts can cause to additional risk of containment failure.
- Ablation rate of concrete decreases as mass of the melt decreases and coolant mass increases. Heat loss from molten pool to coolant is comparable to total decay heat, so concrete ablation is delayed until water is absent and crust begins to remove.
- Hydrogen is generated until metal layer disappears and steam concentration evolved governs the pressure history of the containment.

## Reference

[1] 이병철, 김주열, 정창현, "MCCI 실험에 대한 검증계산을 통한 MELCOR 코드 평가 및 취약점 도출", 한국원자력학회 95'추계학술대회 vol. 2, 556-561, 1995.

[2] "MELCOR1.8.3 Computer Code Manuals", Sandia National Laboratories, Jul., 1994.

[3] J.E. Gronager, A.J. Suo-Anttila and J.E. Brockmann, "TURC2 AND 3: Large Scale $UO_2/ZrO_2/Zr$ Melt-Concrete Interaction Experiments and Analysis", NUREG/CR-4521, SAND86-0318, Sandia National Lab., Jun., 1986.

[4] R.E. Blose, J.E. Gronager, A.J. Suo-Anttila and J.E. Brockmann, "SWISS: Sustained Heated Metallic Melt/Concrete Interactions with Overlying Water Pools", NUREG/CR-4727, SAND85-1546, Jul., 1987.

[5] H. Alsmeyer, "BETA Experiments in Verification of the WECHSL Code: Experimental Results on the Melt-Concrete Interaction", Nuclear Engineering and Design, 103, 115-125, 1987.

[6] E.R. Copus, R.E. Blose, J.E. Brockmann, R.B. Simpson and D.A. Lucero, "Core-Concrete Interactions Using Molten $UO_2$ with Zirconium on a Basaltic Basemat: The SURC-2 Experiment", NUREG/CR-5564, SAND90-1022, Sandia National Lab., Aug., 1992.

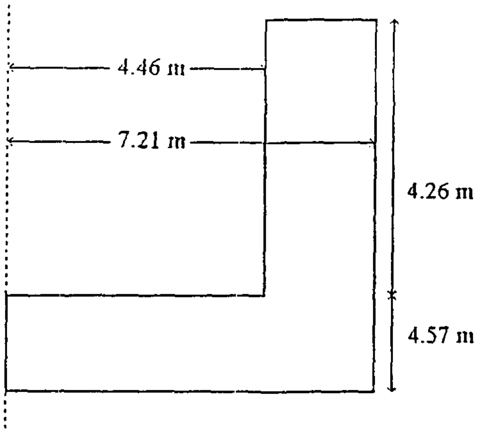

Fig. 1. Initial Geometry of the Cavity.

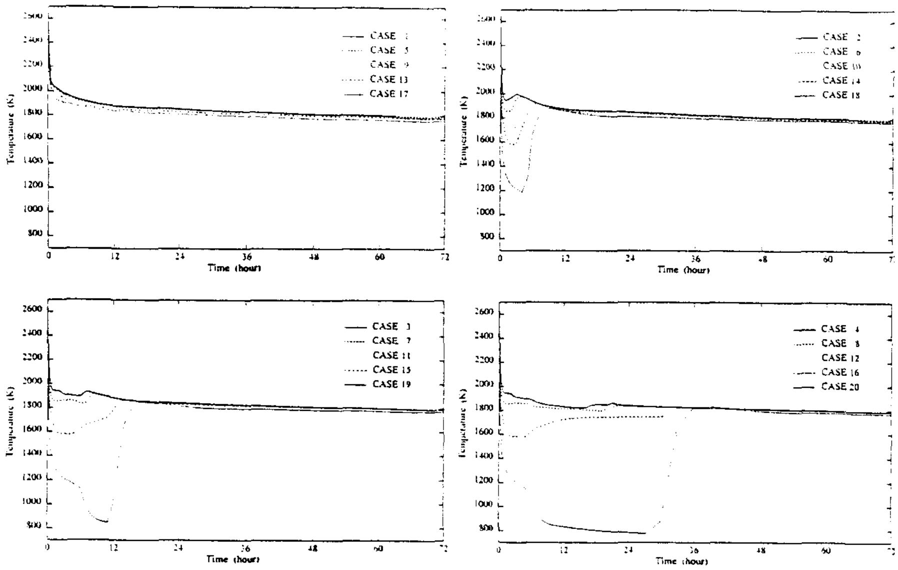

Fig. 2 The history of Melt Temperature in the First 72 Hours.

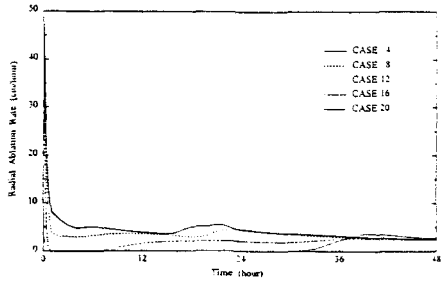

Fig. 3 Radial Ablation Rate for Water Mass
of 200 ton in Cavity

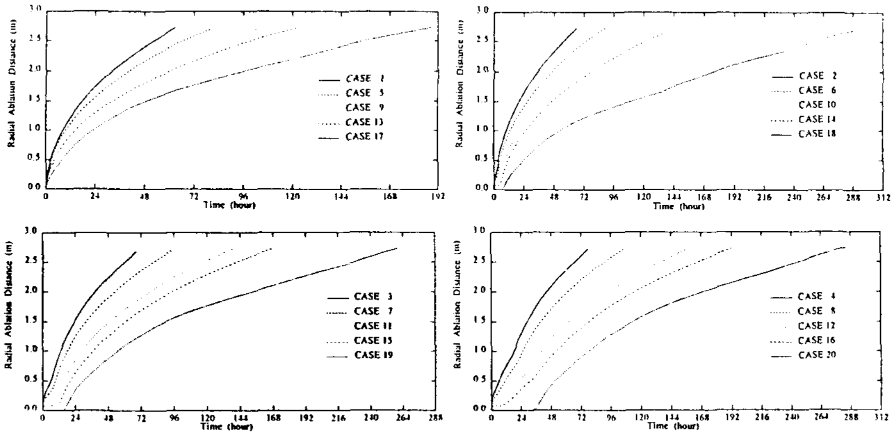

Fig. 4 Radial Ablation Distance of Concrete in Test Calculation

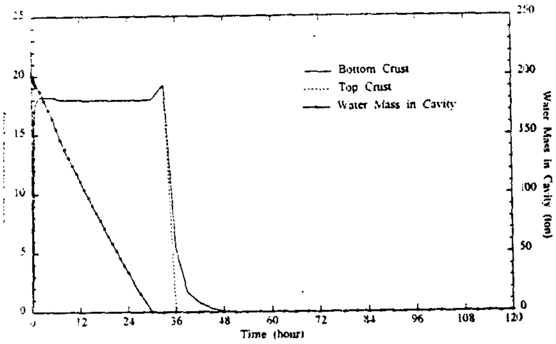

Fig. 5 The Variation of Crust Thickness and Water Mass in CASE 20

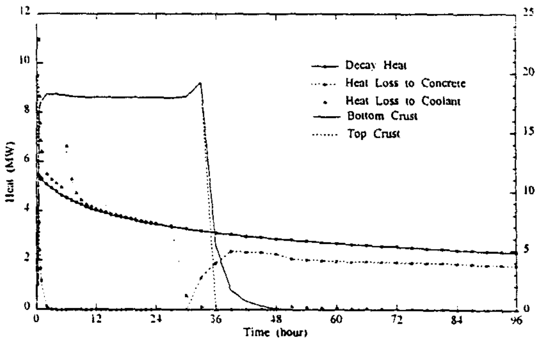

Fig. 6 The Various Energy Variation in CASE 20

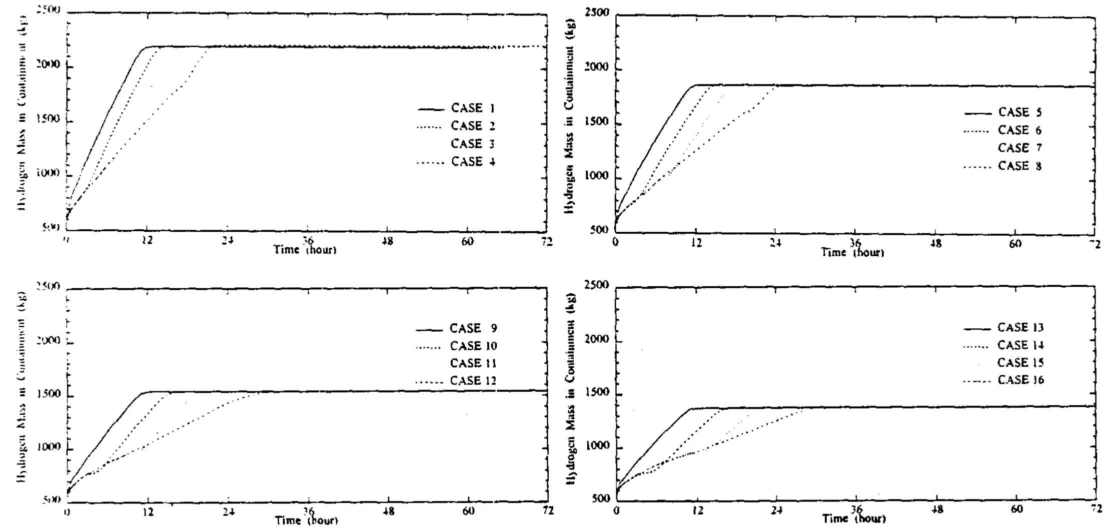

Fig. 7 The Generated Amounts of Hydrogen in MCCI

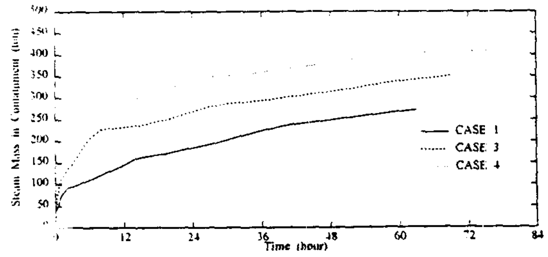

Fig. 8 Mass of Steam in Containment for the 100% Melt Ejection in Cavity

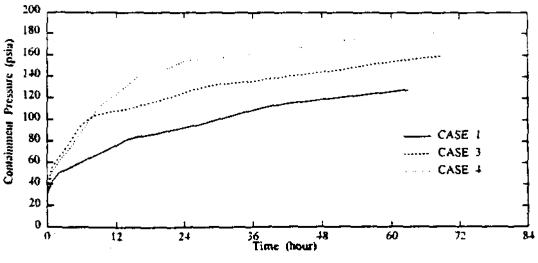

Fig. 9 Containment Pressure for the 100% Melt Ejection in Cavity