A Suggestion of a New Strategy Coping with MCCI for Shin-kori 5 and 6

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1. Introduction

Korean NPPs adopt pre-flooding strategies to cope with MCCI (Molten Core Concrete Interaction or Melt Coolability and Concrete Interaction), while there are some risks provoked by the contact of dropping melt and pre-flooding water such as steam explosion and steam spike. Shin-kori 5 and 6 which are 5th and 6th APR1400 NPPs have some countermeasures like CFS (Cavity Flooding System) and sacrifice limestone concrete to keep the integrity of steel liner. Shin-kori 5 and 6's capacity to cope with MCCI will be improved significantly compared to that of predecessors, because the thickness of the sacrifice limestone concrete thickness will be increased from 1 ft to 3 ft. Therefore, it is thought that there is an enough margin in handling MCCI issue, so it is quite doubtable to keep pre-flooding strategies for Shin-kori 5 and 6 which only concentrates only on MCCI issue and may cause other risks from FCI (Fuel Coolant Interaction). Therefore, the authors suggest a new strategy for cooling ex-vessel melt to minimize the risk from FCI such as steam explosion.

2. Simple Explanation on MCCI and Shin-kori 5, 6's countermeasure against MCCI

When an accident like LOCA occurs and ESFs such as SIT and ECCS don't work, the accident would get worse because decay heat from nuclear fuel is accumulated in RPV. Firstly, the fuel would get ballooned and ruptured, then the fuel and structure would be liquefied and relocated into the lower part of RPV [1]. If heat removal systems are not restored until then, most decay heat would go to RPV lower head causing it degraded and eventually it would be ruptured. Finally the breach makes it possible that the melt discharges into reactor cavity.

If corium in reactor cavity has a contact with concrete and there is no water overlying the corium, most of decay heat will go to the concrete and little of it is transferred to other containment part via natural convection or radiation. The substantial decay heat around 30 MWth cause the concrete to be pyrolyzed or ablated. If the ablation depth is larger than the thickness of sacrifice concrete, then containment barrier integrity as leakage tightness would be damaged.

Therefore, everybody would agree to supply water into reactor cavity to cool it. If water is supplied into cavity, the much part of decay heat would go to the water by the mechanism of film boiling, nucleate boiling or natural convection. This water injected into cavity cause generation of steam, which in turn increases containment pressure, however, if containment spray systems are available then containment pressure could be easily controlled. Korea NPP operators usually adopt pre-flooding strategies to make it possible for melt to contact with water as soon as the melt is discharged into the cavity.

However, the pre-flooding cavity strategies have some immanent disadvantages like causing steam explosion or steam spike. The containment integrity may be damaged by shock wave from the steam explosion and by rapid pressure increase from the steam spike.

The reactor cavity design of Shin-kori 5 and 6 which are 5th and 6th APR1400 NPP will be changed a little from the APR1400 predecessors like Shin-kori 3, 4 and Shin-hanul 1, 2. The depth of Korean limestone concrete acting as sacrifice material will be increased from 1 ft of the predecessors to 3 ft of Shin-kori 5, 6 [5, 6]. It has been known that limestone concrete reduces ablation depth during MCCI compared to siliceous concrete which is widely used concrete in Korea. This means that the capacity to cope with MCCI in Shin-kori 5, 6 are much improved, therefore, the authors think that the SA mitigate strategy for Shin-kori 5, 6 needs to be changed to rule out other risks caused by pre-flooding. Fig. 1 is a schematic comparison of concrete composition underneath reactor cavity between Shin-kori 3, 4, Shin-hanul 1, 2 and Shin-kori 5, 6

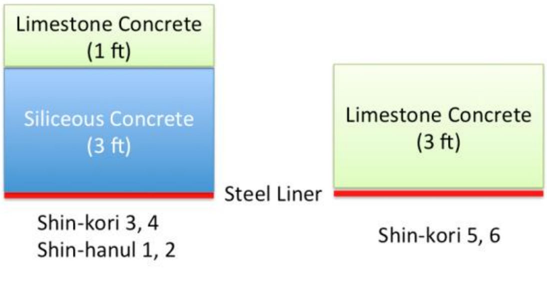

Fig. 1. Comparisons of composition underneath reactor cavity between Shin-kori 3, 4, Shin-hanul 1, 2 and Shin-kori 5, 6.

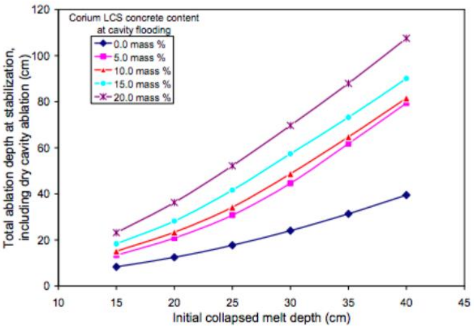

Fig. 2. Prediction of Maximum Basemat Penetration after Cavity Flooding for LCS Concrete [2]

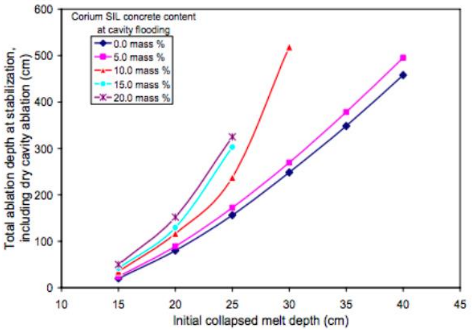

Fig. 3. Prediction of Maximum Basemat Penetration after Cavity Flooding for Siliceous Concrete [2]

Fig. 2 and Fig. 3 show the prediction of ablation depth for LCS (Limestone Common Sand) concrete and Siliceous concrete, respectively [2], and these results are deduced from some related experiments and analysis. The first insight from the results is that the ablation depth for LCS case is one degree order less than that for siliceous concrete case, and it is presumed larger generation rate of carbon monoxide promotes natural circulation inside melt and melt eruption for LCS. Because Korean limestone generates more non-condensable gases than LCS concrete, it could be assumed that the ablation depth is less than that of LCS concrete. The second insight is that, in order to reduce ablation depth for each concrete, the melt should be spread uniformed because accumulation of melt would locally increase the ablation depth. The third insight is that water should be injected into cavity as soon as possible in order to decrease ablation depth.

From Fig 1 to 3 it is easily deduced that Shin-kori 5, 6's capacity to cope with MCCI is much higher than that of the predecessors. This point has caused the authors to suggest a new strategy which more concentrates on minimizing other aspects of risk, ruling out the possibility of steam explosion and steam spike. The authors has thought that because there is a large margin with respect to MCCI it seems unreasonable to adopt pre-flooding strategies bearing steam explosion risk. The suggested cavity-flooding strategy is described in the later part of this paper.

3. Comparison between Wet Cavity and Dry Cavity

Pre-flooding cavity strategies, which all Korean NPPs currently adopt, have obvious advantages such that melt has a contact with water as soon as it is discharged into reactor cavity. Therefore, much part of decay heat is transferred to water not to concrete from the moment of the discharge, so the accumulated heat transferred to the concrete could be minimized. Also, because of jet breakup [3] some of the melt could be fragmented into small size particles, and the increase of surface to volume ratio of the melt due to the jet breakup would surely increase heat transfer to water and in turn promote to cool the particles.

The possibility of steam explosion and steam spike could be cause by melt dropping into a pre-flooding cavity. Steam explosion is a kind of FCI (Fuel Coolant Interaction) in which part of corium energy is transferred so rapidly to water that explosive vapor release occurs [4], and this generates shock wave which could make some damage on containment. The steam spike is a phenomenon that particles generated during dropping which do not cause steam explosion make a rapid generation of steam, which causes rapid pressure increase in containment.

The advantage of dry cavity when melt is discharged into cavity is to rule out the possibility of the steam explosion and steam spike. In addition, melt spread is much easer in dry cavity than wet cavity, because crust and viscosity increase due to rapid cooling in wet cavity impede melt spread. It's easily known from the insight of Fig. 2 and 3 that it needs to spread melt uniformly to decrease the ablation depth.

However, as also shown in Fig. 2, 3, if flooding of water onto the melt is delayed for a while, then some amount of decomposed concrete would be merged into the melt, and this would increase the ablation depth.

4. A Suggestion to change flooding strategy

When considering flooding strategies for cooling corium, it is necessary to consider the risk of steam explosion, spreading melt as uniform as possible, and supplying water as soon as possible. Therefore, keeping in mind that Shin-kori 5 and 6 have an enough margin to protect steel liner, the authors suggest a new strategy for cooling ex-vessel melt cooling.

<u>Installation of additional instruments for monitoring reactor cavity status</u>

If additional instruments such as a water level meter, a thermocouple, and a radiation monitor in cavity region and a thermal imagery camera are installed, it would be helpful for operators to estimate cavity status at accidents. A level meter is needed to know how much a cavity is submerged. A thermocouple, a radiation monitor, and thermal imagery camera let operators know whether corium is discharged or not. If these instruments were installed, operators at accident conditions would get valuable information in containment, so it is sure that the possibility to do proper actions would increase.

Keeping Cavity Dry until melt spreading finished

Because Shin-kori 5 and 6 have an enough margin to keep the containment integrity from MCCI, it is possible to let the cavity dry until melt spreads uniformly and completely. The advantages of this are to rule out the occurrence of steam explosion and steam spike and to keep the melt from accumulating somewhere locally.

Flooding cavity

From information form the new instruments and some technical background, operators could know if melt is discharged or not and estimate how long it take for melt to spread completely. If operators have confidence that melt spreading is finished, they could do actions to supply water to reactor cavity.

5. Conclusions

Shin-kori 5 and 6 have some countermeasures against MCCI such as CFS (Cavity Flooding System) and limestone concrete as sacrifice materials. The thickness of the limestone concrete is increased from 1 ft of the predecessors NPPs to 3 ft, so the capacity to cope with MCCI is improved significantly. Considering the experiment results conducted by OECD, Shin-kori 5 and 6 seems to have an enough margin for MCCI issue. Therefore, the authors think that cavity flooding strategies should be chosen based on minimizing another risks like steam explosion, so flooding after melt spreading is more suitable than the current pre-flooding strategies. However, this suggestion is only based on qualitative analysis and not yet based on detail and quantitative analysis. Therefore, a lot of more research should be required to adopt this suggestion.

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