

Analysis of In-vessel Melt Progression Scenarios for an Advanced PWR using MELCOR 1.8.6

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1. INTRODUCTION

The research and development for identify the bottom head failure mechanisms [1] is one of the long term issues for the establishment of severe accident management strategies for light water reactors after TMI 2 accident. A LBLOCA scenario for an advanced power reactor developed in Korea is analyzed in order to obtain an overall insight into a severe accident progression from an initiating event to the reactor vessel failure in detail by using the MELCOR Versions 1.8.5 and 1.8.6 computer codes [2].

MELCOR computer code is developed by Sandia National Laboratories for Nuclear Regulatory Commission of USA for the analysis of severe accident phenomena in Light Water Reactor (LWR) nuclear power plant.

2. NODALIZATION BY MELCOR CODE

A large LBLOCA scenario as an example for the advanced power reactors developed Korea is analyzed with MELCOR code to understand the bottom head failure phenomena, to get the idea for designing severe accident mitigation hardware such as cavity flooding or ex-vessel core catcher, and finally to establish the severe accident management strategy. In this analysis MELCOR versions 1.8.5 and 1.8.6 is used [4,5]. The nodalization model (control volumes) of the reactor coolant system of APR-1400 for the MELCOR code is modeled as of Figure 1.

The active fuel is modeled as to have 5 radial rings and 10 axial nodes (50 cells). The lower head is modeled as to have 5 radial rings and 5 axial nodes (25 cells). If the active core is melt and dropped to lower head, the corium is dispersed at the lowest axial cells. If some cell is heated to a certain temperature, the equivalent cell of bottom head is molten and the corium is dropped to cavity bottom. The lower head is modeled as cylinder in MELCOR 1.8.5 and hemisphere in MELCOR 1.8.6.

Notations of Control Volumes of Containment and Reactor Cavity ;

CV001 : Reactor Cavity (Rx Cavity + ICI Chase)
CV002 : Corium Chamber Room (Corium Chamber Room + Cavity Access Area)

CV003 : Reactor Vessel Annulus

CV011 : HVT (Hold-up Volume Tank)

CV012 : IRWST (In-containment Refueling Storage Tank)

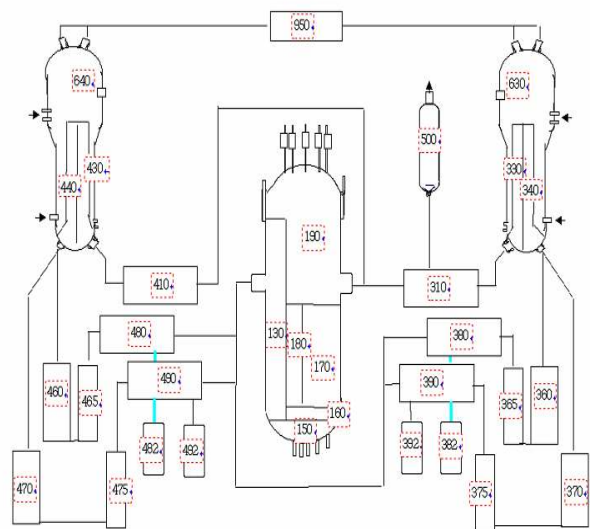


그림 11-1 실험실 12호기의 1차계통 Nodalization

Figure 1. MELCOR Nodalization for Reactor Coolant System of Advanced Power Reactor

3. ANALYSIS OF A LOCA SCENARIO

A double ended break, the size of which is 0.5 ft² (0.0465 m²), is occurred at time 0 second at a cold leg which is connected to the pressurizer. Table 1 shows the chronology of this event analyzed by MELCOR code.

If LOCA occurs the reactor and turbine trip by the high containment pressure signal. The decay heat is assumed to be generated according to the ANS 79 curve. The main feed water and auxiliary feedwater is assumed to be tripped. The safety injection system is assumed to be not working. It is assumed that the four safety injection tanks are only working to make up the inventory of reactor coolant system which is lost by the break.

Table 1. Chronology of Event (0.5 ft² LOCA)

| Time (sec) | Event Description |
|------------|--------------------|
| 0.0 | LOCA occurs |
| 7.25 | STOP TO SUPPLY MFW |

| | |
|--------|---|
| 7.75 | REACTOR TRIP |
| 30.4 | RCP Trip |
| 176.8 | START CORE UNCOVERED |
| 177.1 | START TO INJECTION SIT-392 |
| 987.2 | SIT-392 : INVENTORY EXHAUSTED |
| 2,848 | CORE SUPPORT PLATE HAS FAILED IN CELL 113 |
| 3,066 | START TO MELT FUEL |
| 3,499 | UO2 RELOCATED TO LOWER HEAD |
| 7,830 | START OF DEBRIS QUENCH IN RADIAL RING 1 |
| 8,156 | LOWER HEAD PENETRATION IN RADIAL RING 2 HAS FAILED. |
| 8,156 | BEGINNING OF DEBRIS EJECTION TO CAVITY |
| 8,218 | START OF DEBRIS QUENCH IN RADIAL RING 3 |
| 8,301 | LOWER HEAD PENETRATION IN RADIAL RING 3 HAS FAILED |
| 8,409 | LOWER HEAD PENETRATION IN RADIAL RING 1 HAS FAILED |
| 8,433 | START OF DEBRIS QUENCH IN RADIAL RING 4 |
| 8,568 | LOWER HEAD PENETRATION IN RADIAL RING 4 HAS FAILED |
| 9,600 | END OF DEBRIS QUENCH IN RADIAL RING 1 |
| 9,960 | END OF DEBRIS QUENCH IN RADIAL RING 2 |
| 10,201 | END OF DEBRIS QUENCH IN RADIAL RING 5 |
| 10,267 | END OF DEBRIS QUENCH IN RADIAL RING 3 |
| 10,267 | END OF DEBRIS QUENCH IN RADIAL RING 4 |
| 10,740 | LOWER HEAD PENETRATION IN RADIAL RING 5 HAS FAILED |

As time goes on, the pressure and the water level of RCS are continuously decreasing. At 177 seconds into the transient the water level decreased to top of active fuel. At this time the water of SIT starts to enter into the RCS. But the water inventory of SIT is exhausted at 798 seconds. At about 2,000 second into the transient, the fuel temperature starts to increase due to the decreased water level. The core support plate starts to melt at 2,848 seconds. At 3,066 seconds the fuel starts to melt due to the uncovering of the core. At 3,499 seconds the melted fuel and structural materials (corium) start to be relocated from the upper core nodes (axial nodes 11 to 15) to the lower core nodes (axial nodes 6 to 10) and finally to the lower head volumes (axial nodes 1 to 5). The next three figures (Figures 5 to 7) show the movement of melted UO₂ from the higher axial nodes to the lower axial nodes in radial ring 1 as an example.

From 8,156 seconds the lower head ICI (In-Core Instrumentation) tube penetrations start to melt and the corium dropped to the floor of cavity. When the lower head penetration occurs, the initial diameter of the hole is assumed as 0.1524 meter. That is the size of the ICI cable penetration. When the temperature of penetration reaches 1275K, the penetration is assumed to be failed. It is shown in Figure 2 that the penetration tubes in radial rings 1 to 4 fails at around 8,000 seconds, but the penetration tubes radial ring 5 fails about 13,000 seconds. From about 8,000 to about 15,000 seconds into the transients, you can see the multiple pores of corium release from the Figure 2. This is because the failure

times of ICI tube penetrations are different among the 5 radial rings of bottom head of the reactor.

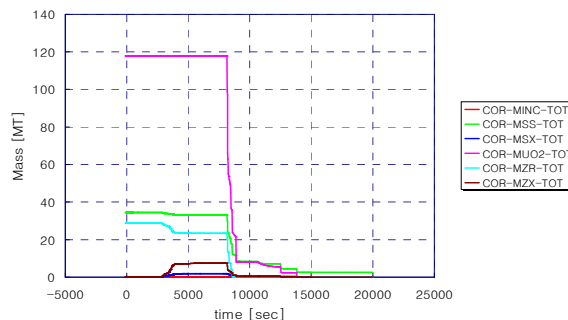


Figure 2. Total Mass of Core Materials melted and relocated in the core and lower plenum

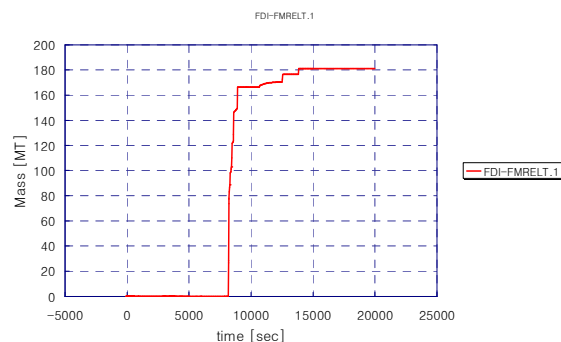


Figure 3. Total Mass of Core Materials ejected from the Lower Head to Cavity

4. CONCLUSIONS

The present results (the amount of molten corium) would be used as input for the establishment of severe accident management strategies or for the design of core catcher of advanced power reactor. The MELCOR results showed that the lower head instrumentation tube penetration model and internal structure in the advanced reactor had influence on the amount of corium ejected and the timing of reactor vessel failure. MELCOR 1.8.5 and 1.8.6 give similar results in the timing of penetration failures. It is concluded that a lot of sensitivity analyses would be needed for the various physical modeling parameters to get more sound insights on the failure mechanisms of lower head.

ACKNOWLEDGEMENTS

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REFERENCES

- [1] "MELCOR Computer Code Manuals," Ver. 1.8.5. Rev.2 [2000] & Ver. 1.8.6. Rev.3 [2005], NUREG/CR-6119, SAND2005-5713, Sandia National Laboratories