Analysis of Severe Accident for the SFP under the Condition of Drainage using MELCOR

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1. Introduction

In a commercial nuclear power plant, highly radioactive spent fuel assemblies unloaded from the nuclear reactor core are typically stored for a period of time in the spent fuel pool to reduce the radioactivity. The spent fuel assemblies are usually placed in long square racks. It is known that in the progress of the Fukushima nuclear power plant accident, the cooling water in the spent fuel storage was completely lost and the fuel was heated up and damaged. This study aims to analyze the effect of a LOCA of the spent fuel pool. We use the MECORE 1.8.6 code to compute the variation of the fuel cladding temperature after a completer loss of the cooling water in the spent fuel pool.

2. Analysis Methods

2.1 Spent Fuel Pool Model

Since we could not obtain detailed design data of the spent fuel pool for a domestic nuclear power plant, the spent fuel pool(SFP) model and fuel assembly model used in this study were taken from a study conducted by SNL[1]. The pool has a dimension of 10.44 m X 8.64 m X 12.65 m. The whole volume of the pool 1,075.06 m^3. The height of the storage rack is 4.19 m and the water level is 7.66 m above the floor. We modeled the pool area into three ring-type zones, assigning 792 racks in the innermost ring (Ring 1), 440 racks in the second ring (Ring 2), and 266 racks in the outermost ring (Ring 3) with a total number of 1,498 racks. The fuel assembly is a 17x17 array PWR type consisting of 264 fuel rods and other rods. The pitch between two adjacent rods is 0.01256 m, the cladding thickness is 0.000057 m each [2]. The total amount of UO_2 in each fuel assembly is 461 kg. The initial temperature of the pool water is set 333.15 K. The air vent rate of the SFP building is set 29,769.48 m^3/hr.

2.2 Decay Heat Source

We consider a PWR reactor loaded with 104.735 tons of UO_2, which has a thermal power of 3,500MWt . We assume all the fuel in the SFP has been burned for 2 years in this reactor and cooled for 1.2 years after reactor shutdown. The decay power is computed by ANSI/ANS5.1 model and the specific decay power is calculated by diving the total decay power by the total amount of UO_2 in the reactor. The decay heat source for each ring is then computed from the specific decay power and the amount of UO_2 in each ring.

2.3 Nodalization

For MELCOR calculation, the whole space inside SFP building is nodalized as shown in Fig. 1. Nodes 117, 127, 137 are the space occupied by spent fuel assemblies, i.e., ring 1, ring 2, ring 3, respectively. Nodes 130 and 310 are the space below and above the fuel, respectively. Nodes 299 and 301 are the pool space surrounding the fuel. Node 409 is the space for fuel shipping, and node 422 is the space above the pool. The nodalization data are input in the CVH package of MELCOR. [3]

The whole length of a fuel assembly is divided into 17 axial computational segments to calculate the axial variation of the cladding temperature. This modeling data are input in the CORE package.[4]

The hydrodynamic flow paths between nodes are represented by arrows in Fig.1. Flow paths 942, 590 and 595 are modeled between node 422 and the environment to simulate the building leakage, vent-in and vent-out, respectively. The inflow of the outside air is also considered with flow path 940 in node 409. Flow path 139 is modeled in node 130 to allow drainage of the pool water.[5] Hydrodynamic material allowed to flow includes water, vapor and fog, and non-condensible gases, but it does not include any solid material, aerosol and water films on heat structures. The flow path data are input in the FL package.

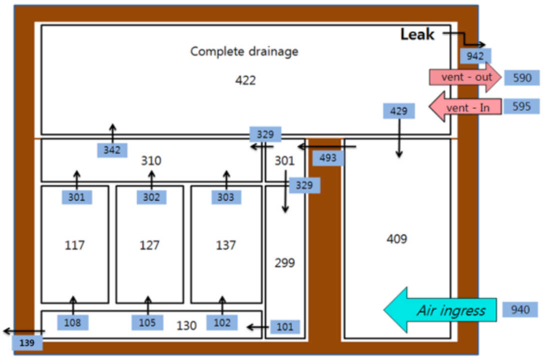

Fig. 1. Nodalization of SFP and Building

3. Simulation Results

In order to see the effect of LOCA in SFP, we simulate the case where the SFP water suddenly starts to escape with a rate of 22.8m^3/s at time 500 seconds through flow path 139 connected to node 130. We present the simulation results carried out for 100,000 seconds.

3.1 Water Level

Fig. 2. shows the change of water level in SFP. The water level drops from the initial level 7.66 m to the top of the fuel assembly about 500 seconds. At about 600 seconds, the pool water has been completely lost and the fuels are fully uncovered.

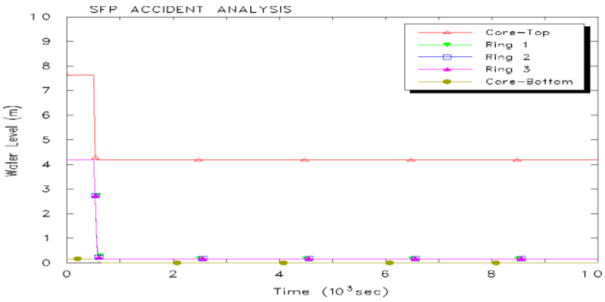

Fig. 2. Water Level in SFP

3.2 Gas Velocity

Fig. 3. shows the gas velocity in the fuel assembly area. The gas flow is principally generated by pressure difference between the air inside the fuel assemblies the incoming air entering through the door. Except several fluctuations the gas velocity generally stays flat during the simulation time. The flat velocity is about 0.7 m/s, in the innermost region (Ring 1), 0.35 m/s in the second region (Ring 2) and 0.1 m/s in the outermost region (Ring 3). Since the decay removal is less efficient in the inner regions, the result is what we have expected.

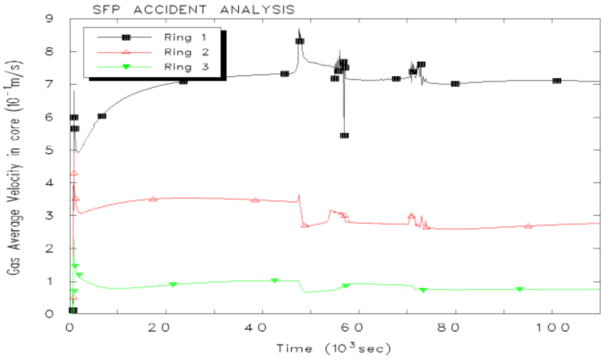

Fig. 3. Gas Average Velocity in Core

3.3 Cladding Temperature

Figs. 4 and 5. show the variation of cladding temperature of Ring1 and Ring 2, respectively. The whole length of a fuel rod is divided into 12 axial computational segments, and they are numbered in ascending order from the lower end. In both rings, the cladding temperature tends to increase gradually toward the upper end. This is because heat transfer between the cladding and air decreases as the air temperature increases up along the axis. The sudden rise of the cladding temperature is caused by rapid oxidation of the cladding, which occurs around 47,150 seconds in Ring 1 and 53,790 seconds in Ring 2. Since the sharp drop patterns of the cladding temperature well coincides with the lower points of the oxygen concentration as shown in Fig. 6.

In almost all fuel rods, the temperature of the cladding exceeds the cladding rupture point (1173 K) after the oxidation in both rings. The lower portions of some fuel rods in Ring 1 even exceeds the melting temperature of the cladding(2180 K).

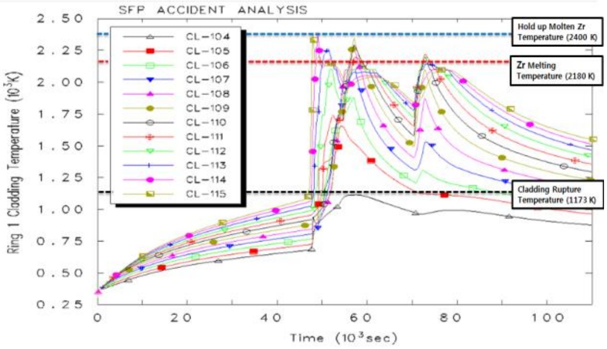

Fig. 4. Cladding Temperature at Ring 1

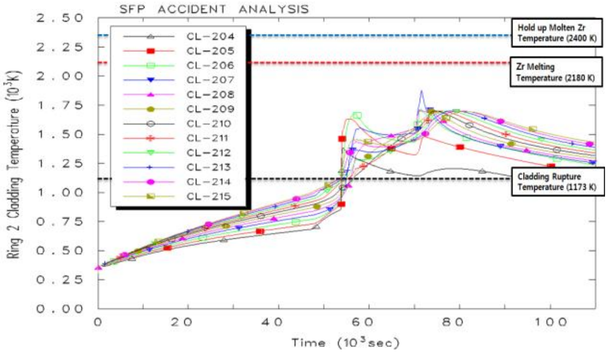

Fig. 5. Cladding Temperature at Ring 2

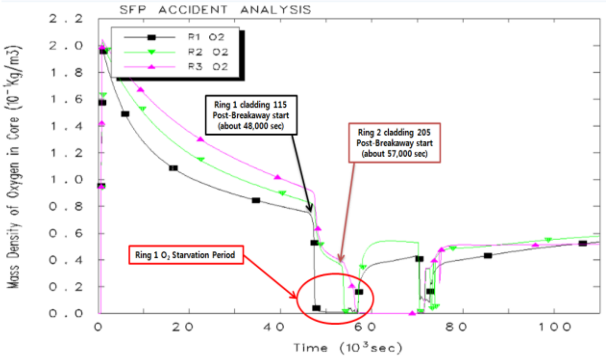

Fig. 6. Mass Density of Oxygen in Core

3.4 Relocation of Fuel

The simulation shows partial relocation of fuel rods in Ring1 and Ring2, as shown in Figs. 7 and 8. Considering the melting temperature of UO_2(3138 K) and the calculated peak temperature far below it, we interpret that the relocation might be resulted from dissolution of UO_2 into the molten mixture of molten Zr and ZrO_2. Thin layer of the molten mixture flows down to bottom like candle drops.

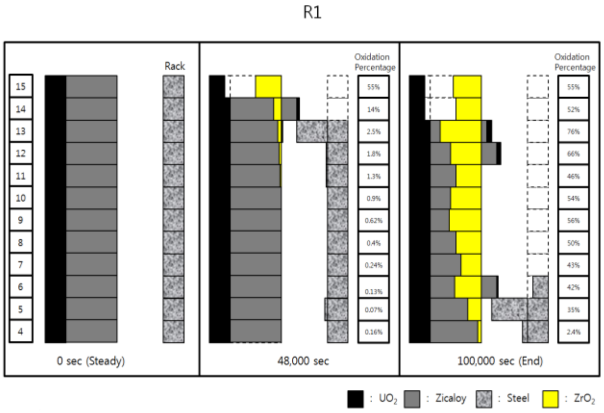

Fig. 7. Relocation of Ring 1

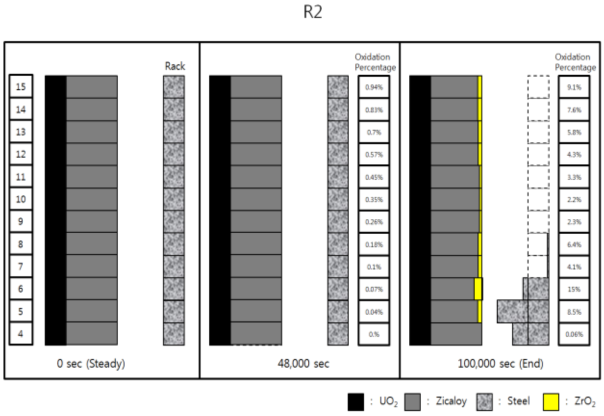

Fig. 8. Relocation of Ring 2

4. Summary

A loss of coolant accident in a typical spent fuel pool has been simulated using the MELCOR 1.8.6 code to see the variation of key parameters such as the oxygen concentration in the fuel assembly region and the cladding temperature. The simulation result shows that the cladding temperature exceeds the rupture temperature in most of the fuel rods and some part of the fuel rods suffers melting of the cladding. Since the sudden rise and drop of the cladding temperature well coincides with those of the oxygen concentration, the oxidation of Zr seems to be a governing factor affecting the melting of cladding. The simulation also shows partial relocation of UO_2, which is caused by dissolution of UO_2 into molten Zr and ZrO_2.

ACKNOWLEDGEMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and Future Planning (No. NRF-2015-0020077)

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