Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Analysis of Spent Fuel Assembly Thermal Behaviors in Boil-off Accident Scenarios

Hye-Min Kim[a], Tae-Hyun Chun[a], Sun-Ki Kim[a]
[a]KAERI, 989 Daedeokdaero, Yuseung-Gu, Daejeon, Korea, 305-353
**corresponding author: thchun@kaeri.re.kr*

1. Introduction

An importance of understanding the spent fuel coolability in the storage pool under the loss of coolant inventory accidents has arisen after the Fukushima NPP accident. The spent fuel pool (SFP) accidents would occur due to many different postulated scenarios, for example a SBO (Station Black Out) at SFP storage or an attack from external factor. In this study, we focused on the SFP boil off accident and analyzed the thermal behaviors of spent fuels following this accident, using MELCOR 1.8.6. version. MELCOR, originally the severe accident code, has been developed to also be appropriate to the SFP accident.

This paper provides the spent fuel heatup characteristics in terms of decay heat, water level and fuel arrangement. The SFP model is based on 17x17 PWR assembly designed by Westinghouse.

2. MELCOR models and Nodalizations

Two MELCOR models were constructed in accordance with the analysis purposes: one with single assembly for decay heat and water level effects and the other with 1x4 assemblies for spent fuel loading arrangement effect. Single assembly nodalization is shown in Figure 2. Water is initially filled up to a certain level of the assembly height according to the analysis conditions. Heated region in assembly is from Cor104 to 115 which indicates active fuel range, and the others are nozzles and the bottom plate.

Spatial representation of five assemblies in a 1x4 configuration was fundamentally limited by the MELCOR's restriction to vertical, cylindrical geometry. As shown in the Figure 1, five assemblies are lumped into 2 rings, each of them represents center and periphery assemblies. Each of the rings has their own control volumes which enable steam/water flow into the assemblies. An insulator surrounds the assemblies. In this case, coolant is initially filled up to the exact height of spent fuel assemblies. With given decay heat, coolant starts to boil off and steam goes to upper pool as well as filling control volumes corresponding to the spent fuel assemblies.

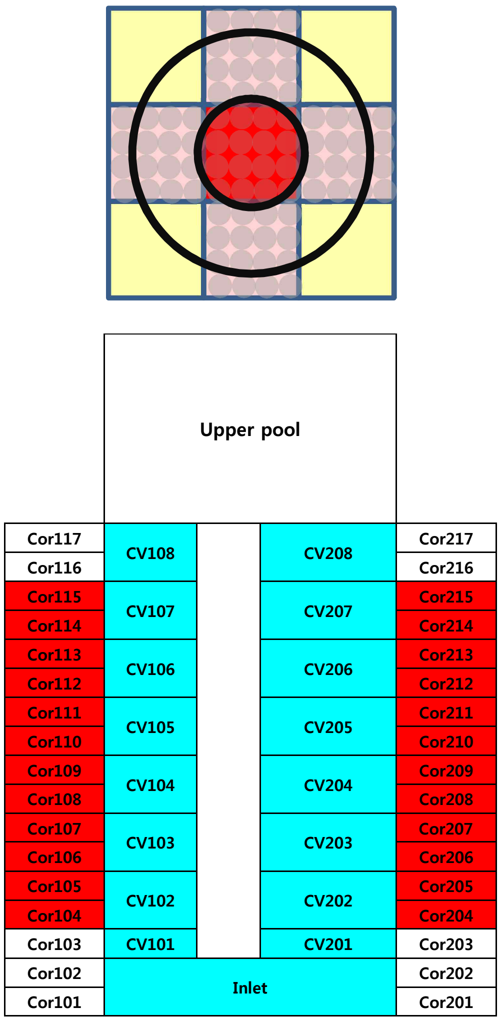

Figure 1 1x4 SFP nodalization and MELCOR model

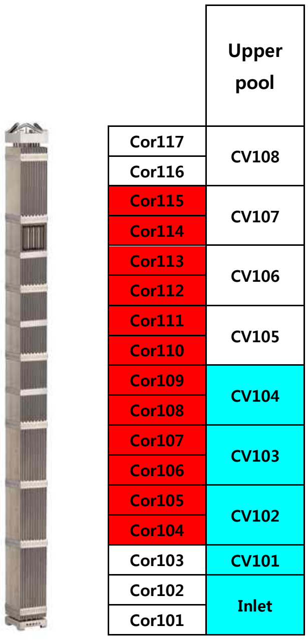

Figure 2 Single assembly nodalization

3. Results

3.1. Decay power effect

In the boil-off accident a steam flow along the spent fuels is one of major cooling mechanisms. Decay power governs the amount of steam generation. To investigate the spent fuel coolability as decay heat varies four different heat loads were given in the single assembly model while the water level was kept constant for 50% of the whole assembly which represents a partial LOCA.

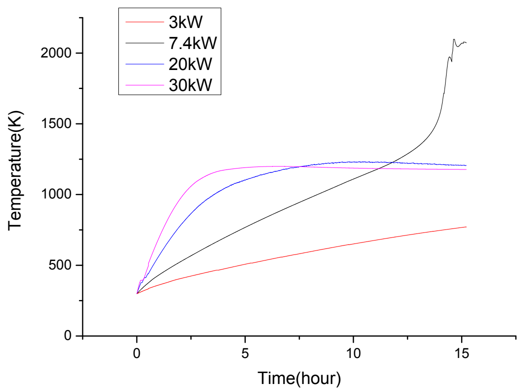

Figure 3 Cladding temperature for 50% water filled single assemblies

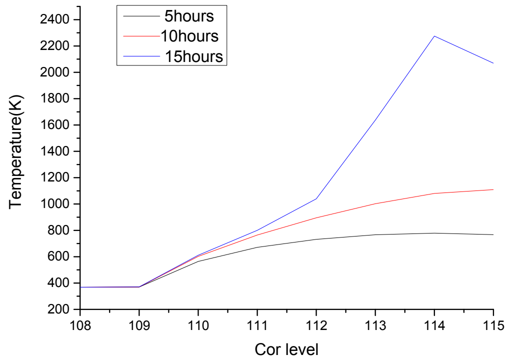

Figure 4 Cladding temperature of the single assembly with 7.4kW decay heat

Figure 3 demonstrates the cladding temperature rise with decay heat for the different heat loads. Cladding temperature of the highest powered assembly in study increased faster than others in the beginning but soon converged to about 1200°K due to steam cooling by the evaporation in the upper part of assemblies and the upper pool. On the other hand, temperature of the 7.4kW assembly grows slower but later reaches at the highest temperature of the four cases. Unlike the previous cases, the temperature of 3kW assembly also grows slowly but it doesn't increase further. These thermal responses resulted from two competing factors that determine the behaviors of temperature growth. One is the steam generation and its cooling effect and the other is the given decay heat power. Higher decay heat yields faster temperature growth but at the same time the assembly generates sufficient amount of steam that can remove the decay heat by the steam flow alone. Consequently, there exists a decay heat range vulnerable to the coolabilty.

Figure 4 shows the cladding temperature with respect to the level of 7.4 kW assembly. After 15 hours, cladding temperature of upper part of assembly reaches the peak.

3.2. *Water level effect*

By examining the spent fuel heatup with respect to their water level in the storage pool, one can determine the coolability when partial loss of coolant accident happens. We used single assembly model with 15kW decay heat, maintaining each of the water level at various positions.

It is shown in Figure 5 that if the water is filled up to the 50% of whole assembly height the fuel assembly could retain its integrity by steam cooling alone. However, if the loss of coolant goes below the 40%, the assembly could be melted down because of insufficient steam cooling.

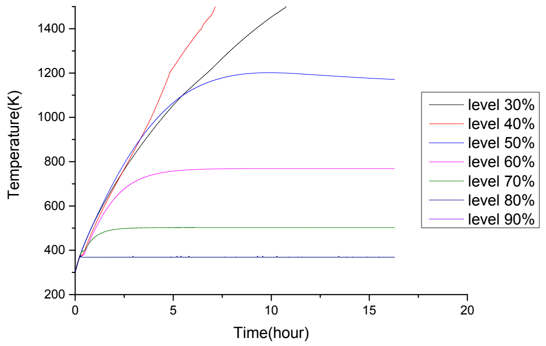

Figure 5 Cladding temperatures of single assemblies with different water level

3.3. Fuel arrangement effect

Spent fuel storage arrangement also influences the heatup behavior during boil-off accident. In this analysis hot and cold neighbors are examined in two 1x4 models. For the hot neighbor effect the hot spent fuel in the center ring is modeled thermally isolated from those in the neighbor ring. On the other hand, for the cold neighbor effect the hot center fuel is allowed to transfer the heat by radiation to the cold neighbors through cladding-to-cladding, rack-to-cladding from center to periphery ring. Total decay heat is 10kW, divided into 7kW and 3kW for center and periphery ring respectively.

Figure 6 shows the water level down in the center and the neighbor rings. The cold neighboring ring with higher coolant density has lower water level than the center ring.

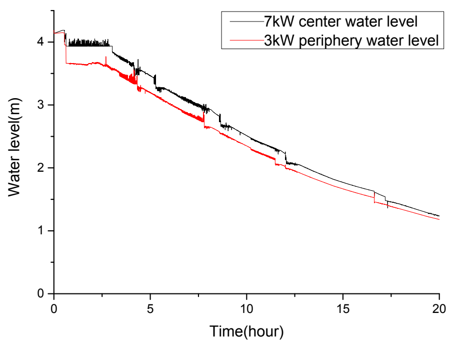

Figure 6 Water level decrement of 1x4 fuel assembly model

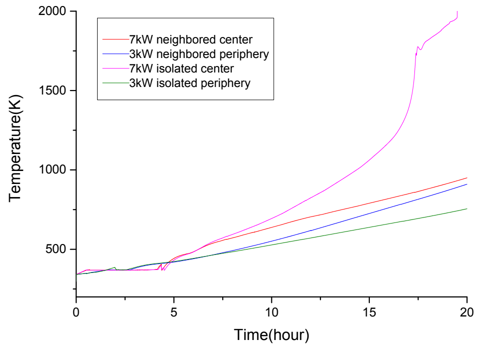

Figure 7 Cladding temperatures of 1x4 fuel assembly models

Figure 7 illustrates the cladding temperature rises according to the fuel arrangements. The temperature of the assembly with lower decay heat starts to increase faster since the swollen water level in the lower decay heat decreases faster as shown in Figure 6. However, the temperature of the assembly with higher decay heat eventually reaches higher temperature after about 5 hours. Since the total decay heat in the 1x4 model is same with 10kW, water level decreases with same speed for both isolated and neighbored case. In the neighbored model, center assembly distributes its decay heat to periphery, so that the temperature difference between the center and the periphery becomes smaller as time goes by. Therefore, the checkerboard arrangement in the spent fuel pool is a desirable loading policy.

4. Conclusion

Spent fuel coolability has been analyzed with single and 1x4 assembly MELCOR models in the case of boil-off accident. It was shown that the low powered spent fuel assembly could be more vulnerable in the partial loss of coolant inventory because of lack of steam cooling and more fuel being uncovered. In addition, it was found that minimum water level has to be maintained above half of assembly height so as not to experience fuel failure, which depends on decay heat power. Until now, SFP analysis using MELCOR has been done only with few representative assemblies. Thus the whole SFP scale analysis has to be done in order to accomplish more realistic assessment

ACKNOWLEDGEMENT

This work was support by Nuclear R&D Program of the National Research Foundation of Korea (NRF) grant, funded by the Korean government, Ministry of

Science and Technology (MEST). Authors would like to express our appreciation to Mr. Sang-Gil Park for his support of the setup of MELCOR model.

REFERENCES

[1] U.S. NRC, Characterization of Hydraulic and Ignition Phenomena of Pressurized Water Reactor Fuel Assemblies, 2013.
[2] Spent Fuel Under Severe Accident Conditions, Bernd Jäckel, 2014.
[3] Sandia National Laboratories, Sandia Fuel Project PhaseⅡ: Pre-Ignition and Ignition Testing of a commercial 17x17 PWR Spent Fuel Assembly under Complete LOCA conditions.