MELCOR ANALYSIS ON HYDROGEN BEHAVIORS OF CHINSHAN NPP SPENT FUEL POOL

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After Fukushima Daiichi accident, more and more safety analyses of severe accident were done for Spent Fuel Pool (SFP) in Taiwan. The experience of Fukushima showed that a long term Station Blackout (SBO) may cause the rising of fuel temperature and hydrogen generation. Most of the SFPs do not have the equipment for hydrogen control, such as igniter, inert containment. For a case of severe accident, hydrogen may lead to deflagration or detonation. Thus, Hydrogen became one of the most important issues of SFP analysis.

The purpose of this study is to calculate the hydrogen phenomena in severe accident of Chinshan nuclear power plant (NPP) SFP by MELCOR2.1/SNAP. MELCOR is a code developed by Sandia National Lab and it can calculate the severe accident phenomena such as core relocation, hydrogen generation, hydrogen burn and detonation, etc. The latest version MELCOR2.1 was used and combined with Symbolic Nuclear Analysis Package (SNAP). In this combination, MELCOR was used with a graphical user interface (GUI) that users can easily modify any detail of the model. An animation model of SNAP can also show the results of analysis easily.

In this study, the Chinshan NPP SFP was set to be a conservative situation that full core was put inside the pool. There were three steps in this study. First, the MELCOR2.1/SNAP model was built and the results were compared to TRACE, CFD and MAAP. The results of Chinshan NPP SFP model were consistent with other codes. Second, two cases were calculated by this model. One was the case of long term SBO and the other was loss of coolant accident (LOCA). The heat and hydrogen generation were different in two cases because of the different between Zirconium-water reaction and Zirconium oxidation. The results were discussed in details in this study. The final step was the sensitivity study of the separation of MELCOR control volume (CVH). The calculation of hydrogen burn was done in each CVH component. So the sensitivity study separated the CVH component in this model to several smaller control volumes. The results showed that the hydrogen burned more locally in the new model and the cladding temperature was more conservative. But the CPU time was much longer than the old model in this case.

I. INTRODUCTION

The safety analysis of the nuclear power plant (NPP) is a very important work in the NPP safety. Especially after the Fukushima NPP accident occurred, the importance of NPP safety analysis has been raised and there is more concern for the safety of NPPs in Taiwan. Because the earthquake and tsunami occurred, the cooling system of spent fuel pool (SFP) failed and the safety issue of spent fuel pool generated in Japan's Fukushima NPP. Chinshan NPP finished SPU (stretch power uprate) and the operating power is 103.66% of the OLTP, which is 1840 MWt now. The geometry of Chinshan NPP SFP is 12.17 m × 7.87 m × 11.61 m and the initial condition is 60℃ (water temperature) / 1.013×10^5 Pa. And, the total power of the fuels is roughly 9 MWt initially.

The purpose of this study is to calculate the hydrogen phenomena in severe accident of Chinshan NPP SFP by MELCOR2.1/SNAP. MELCOR is a code developed by Sandia National Lab and it can calculate the severe accident phenomena such as core relocation, hydrogen generation, hydrogen deflagration and detonation, etc. The latest version MELCOR2.1 was used and combined with Symbolic Nuclear Analysis Package (SNAP). In this combination, MELCOR was used with a graphical user interface (GUI) that users can easily modify any detail of the model. An animation model of SNAP can also show the results of analysis easily. Figure 1 shows the user interface of MELCOR2.1/SNAP.

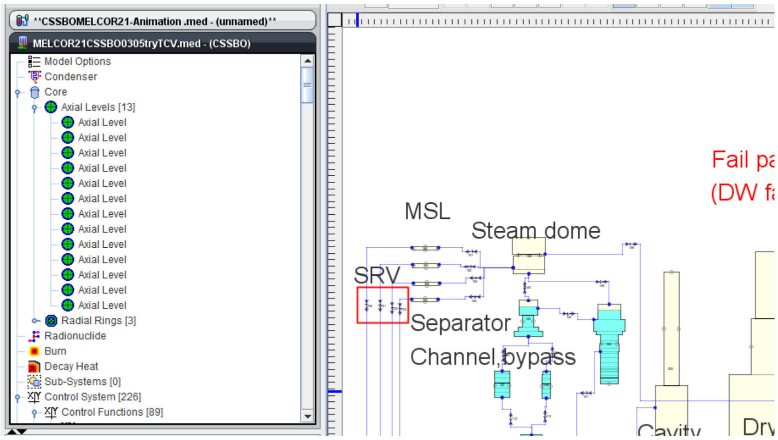


Fig. 1. MELCOR2.1/SNAP user interface.

There were three steps in this study. First, the data of Chinshan NPP SFP was collected from the FSAR and training material of Taiwan Power Company (Ref. 1) (Ref. 2) (Ref. 3). The MELCOR2.1/SNAP model was built by following the geometric data and thermal power from those data. The full core was put into the SFP for a conservative situation and the total thermal power of the pool was about 9MWt. After the establishment of Chinshan NPP SFP model, the calculation of station blackout (SBO) was done and compared to the thermal-hydraulic codes such as CFD, TRACE. The comparison between MELCOR and MAAP was also done in this step. Second, the Loss of coolant accident (LOCA) was simulated by this model. The heat and hydrogen generation were different in two cases because of the differences between Zirconium-water reaction and Zirconium oxidation. The differences and results will be shown in the following sections. The final step was the sensitivity study of the separation of MELCOR control volume (CVH). The calculation of hydrogen burn was done in each CVH component. So the sensitivity study separated the CVH component in this model to several smaller control volumes, which the total volume was the same. Figure 2 is the flow chart of this study.

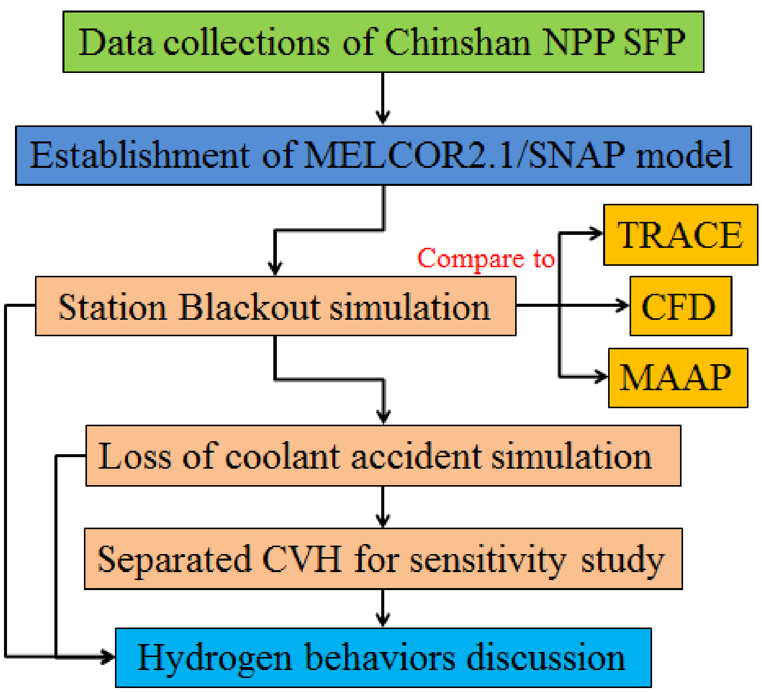
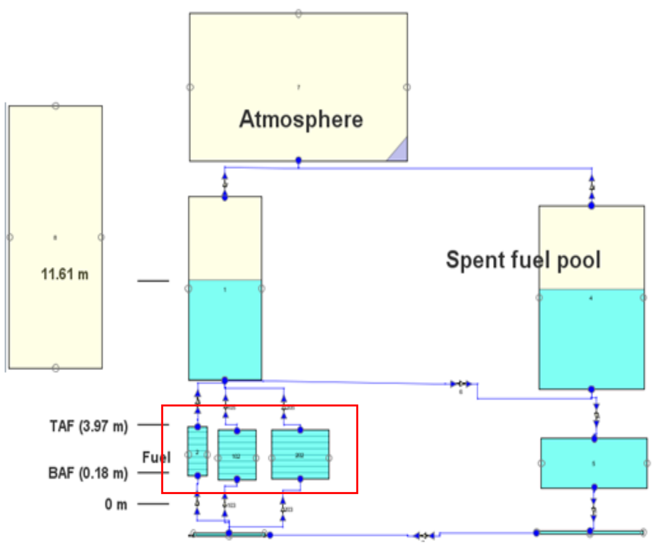


Fig. 2. Flow chart of the simulations.

II. MODEL DISCRIPTION

The code versions used in this research were SNAP 2.4.3 and MELCOR2.1. The MELCOR SFP model was a stand-alone model just like the SFP model of MAAP5.0, but it can still show some important behaviors of SFP in the severe accident.

Figure 3 shows the Chinshan NPP SFP model in this study. Right-up of Figure 3 shows the fuel of SFP and it was separated to 3 rings in the COR model of MELCOR. The power distribution of each ring was also shown in Figure 3. Total thermal power was about 9MWt and the pressure was set to be 1 atm. The initial water level of Chinshan NPP SFP was 11.6m. The control volume of each ring was first set to a single CVH.



MELCOR area	Power fraction (%)	Fuel bundles
Ring 1	49.67	353
Ring 2	34.35	862
Ring 3	15.98	1861

Fig. 3. Chinshan NPP SFP MELCOR2.1/SNAP model.

III. RESULTS

III.A. Station Blackout calculations

In the case of station blackout, all the water injection system of SFP was set to be failed. There was no water added into the SFP in this simulation. In this situation, the water level of SFP went down by evaporation and cause the cladding temperature rising.

Figure 4 and Figure 5 show the water level and peak cladding temperature of TRACE, CFD and MELCOR2.1. The simulation started at 0 sec with initial water level 11.6m. The water level dropped to Top of Active Fuel (TAF) at about 3 days and the cladding temperature went up because of fuel uncover. The cladding temperature rose rapidly because of water-zirconium reaction. The oxidation heat of this chemical reaction was ten times more than the decay heat of the spent fuel. These results also show the thermal-hydraulic calculation of MELCOR in the early accident time line, which feet the thermal-hydraulic codes well.

Figure 6 and Figure 7 show the comparisons of MELCOR2.1 and MAAP5.0. The SBO calculation started at 0 sec. The water level kept going down due to decay heat. Figure 6 shows that the fuel relocation happened at almost same time. Figure 7 shows the hydrogen generation of MELCOR and MAAP. MELCOR calculated that in the SBO case of Chinshan NPP SFP, there was about 2500kg hydrogen. But for MAAP calculation, there was only 500kg. In the calculations of MELCOR, it seems the oxidation of metal are quicker than MAAP. The hydrogen difference was also observed in the other calculations of MELCOR and MAAP.

Figure 8 is the animation model of this SFP model built by SNAP. The animation model can show the data of water level, cladding temperature, zirconium oxidation, hydrogen generation. User can easily understand the phenomena happened in the case right after the calculation of MELCOR2.1/SNAP was done.

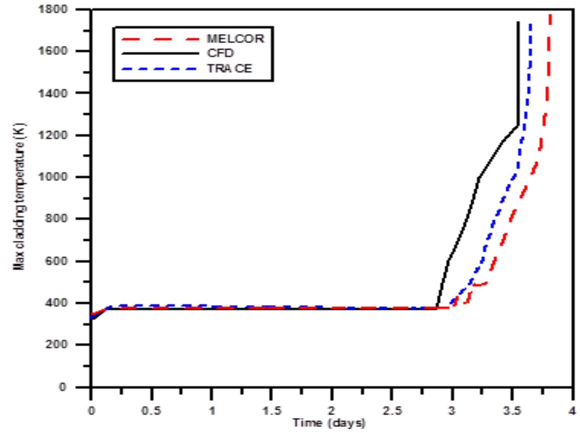


Fig. 4. Peak cladding temperature of MELCOR/TRACE/CFD.

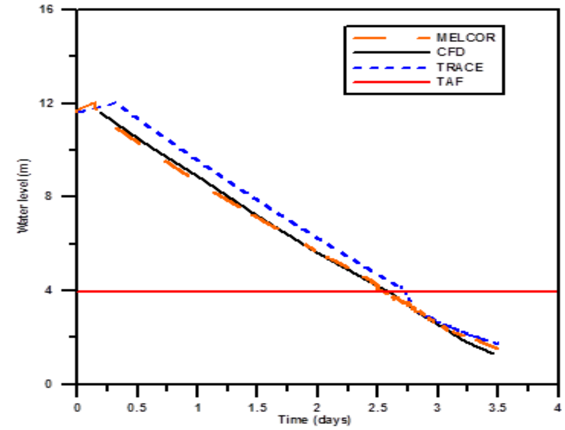


Fig. 5. Water level of MELCOR/TRACE/CFD.

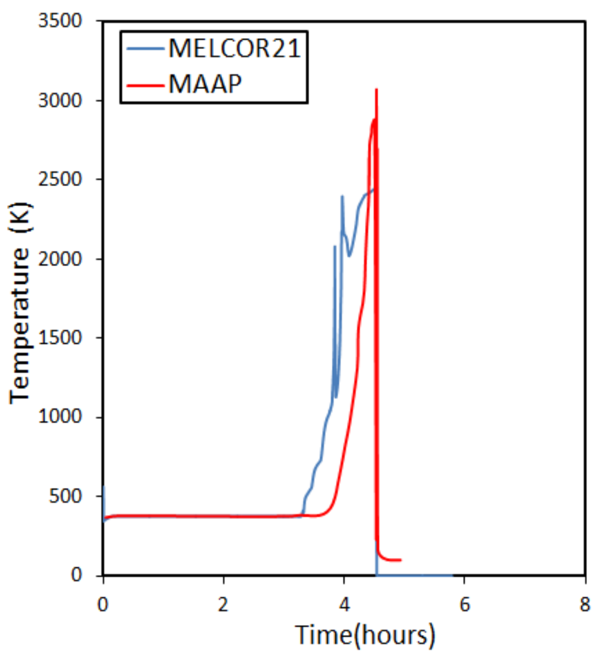


Fig. 6. Peak cladding temperature of MELCOR/MAAP.

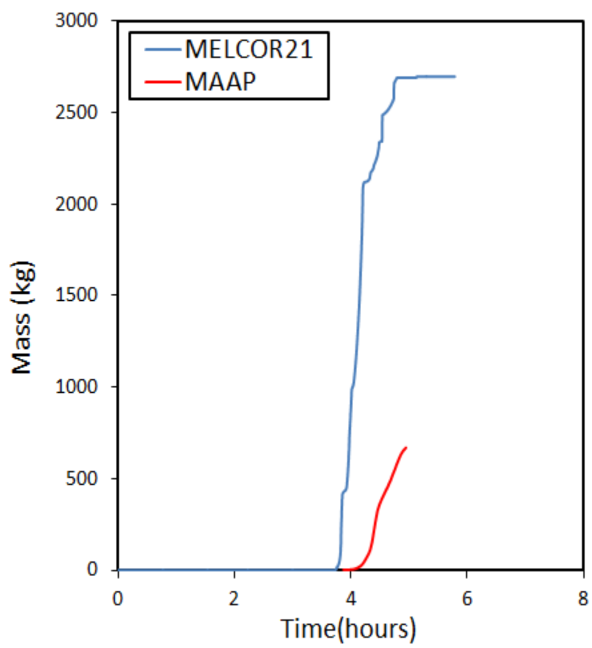


Fig. 7. Hydrogen generation of MELCOR/MAAP.

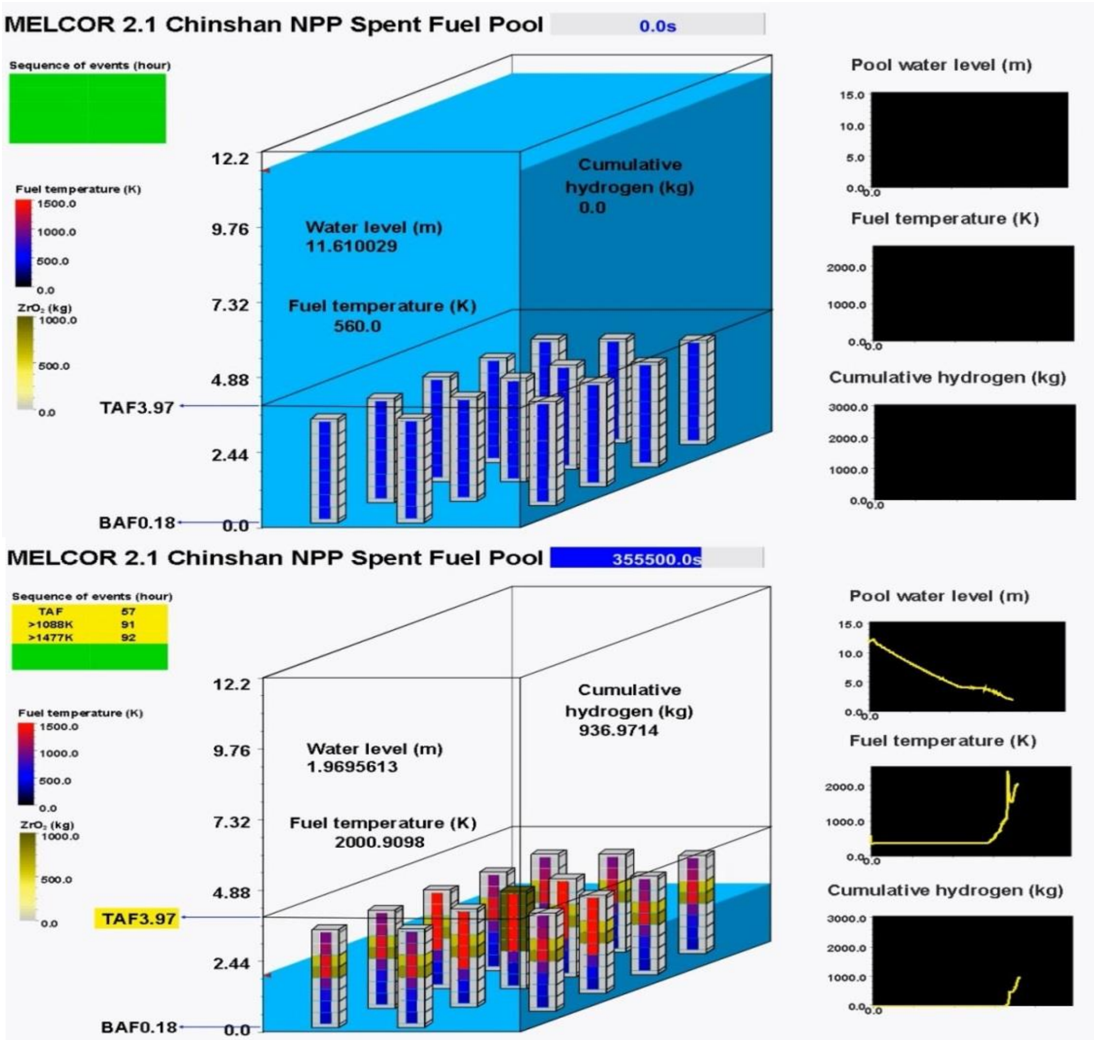


Fig. 8. Animation model of MELCOR2.1/SNAP.

III.B. Loss of coolant accident calculations

Loss of coolant accident is another accident could cause a severe accident to SFP. In this case, the water injection was also set to be failed and a 0.1m^2 hole was simulated by a flow path component in the model. Figure 9 is the water level in this simulation. The pool water dried out in 30 minutes and caused the fuel temperature went up very fast. Figure 10 shows the peak cladding temperature of each fuel ring. The temperature of ring 1 (hottest ring) rose rapidly and caused the zirconium fire in 3 hours. In the case of LOCA, the zirconium reacted with the oxygen in the air and caused a fire. Not like the case of SBO, the oxidation heat of zirconium fire was more than the heat of zirconium-water reaction. Eq. (1) and Eq. (2) show the different chemical reactions of SBO and LOCA. Sandia National Lab did a zirconium fire experience in the air and the fire continually burn for days (Ref. 4). The case of LOCA only generated 400kg hydrogen due to less steam in the pool region. The SBO case generated 2500kg hydrogen by zirconium-water reaction which was shown in Figure 7.

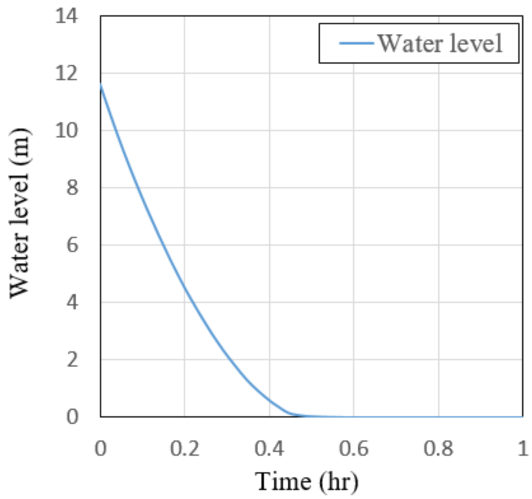


Fig. 9. Water level in the case of LOCA.

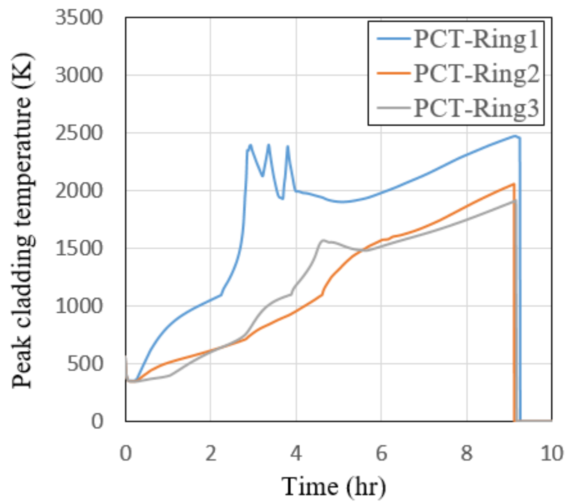


Fig. 10. Peak cladding temperature in the case of LOCA.

$$Zr + 2\ H_2O \rightarrow ZrO_2 + 2\ H_2 + 598kJ/mole \quad (1)$$

$$Zr + O_2 \rightarrow ZrO_2 + 1080kJ/mole \quad (2)$$

IV. SENSITIVITY STUDY

The calculation of hydrogen burn was done in each CVH component of MELCOR code. So the sensitivity study separated the CVH component in this model to several smaller control volumes which the total volume was the same. Figure 11 is the model with separated CVH in the fuel zone. The total volume and the flow path inside the channel were still the same compared to the single CVH model. The case simulated with this new model was LOCA. Figure 12-15 show the comparisons between single CVH and separated CVH. Figure 12 is the water level. The water level is quite the same between two models because the channel volume was still the same size. Figure 13 shows the peak cladding temperatures. The dotted line is the results of separated CVH and the cladding temperature rose faster than the single CVH model. The reason is maybe because that the separated CVH caused the temperature gradient in the fuel channel more different compared to the uniform temperature distribution of the single CVH one. Figure 14 is the hydrogen generation and the separated CVH model generated 50 kg hydrogen more than the single CVH one. Figure 15 shows the hydrogen burn in the roof region of SFP room. The hydrogen was generated by fuel and burn in this region because the MELCOR burn model only ignited by hydrogen concentration but not the temperature of the CVH. For the case of single CVH, the hydrogen concentration was not enough for burns in the fuel region. For the model with separated CVH, there was no hydrogen burn at this area. But the burn messages showed that the burns in this model happened very locally in the fuel regions. Hydrogen burns in the fuel region before it floats to the roof area of the SFP room. These results showed that the hydrogen burned more locally in the separated CVH model and the cladding temperature was more conservative. But the CPU time was changed from hours calculations to more than 3 days due to the model improvement of separated CVH.

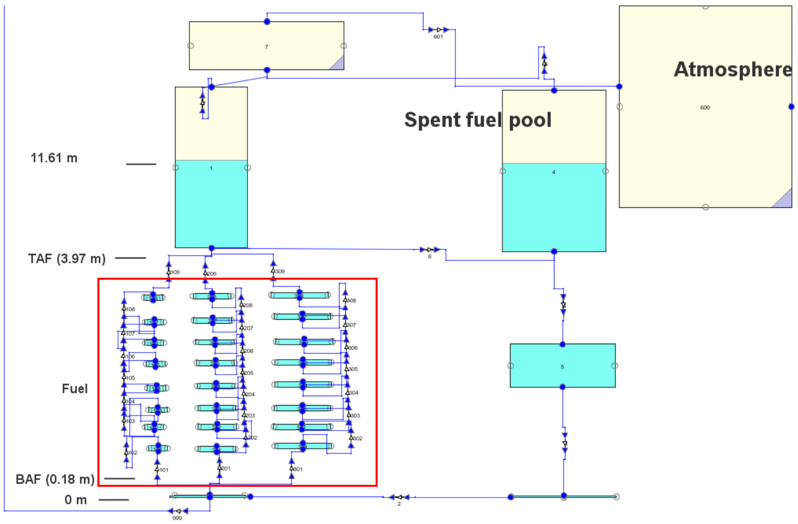


Fig. 11. MELCOR model with separated CVH in the fuel zone.

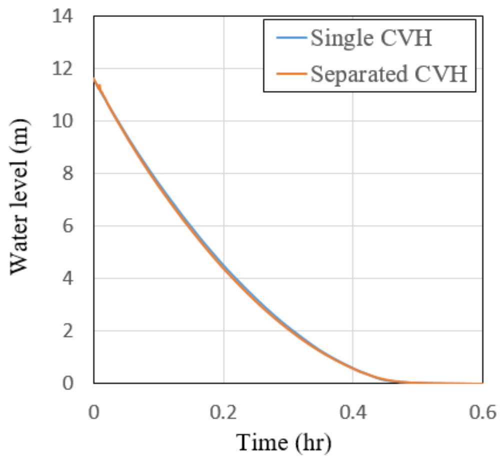


Fig. 12. Water level in the case of LOCA.

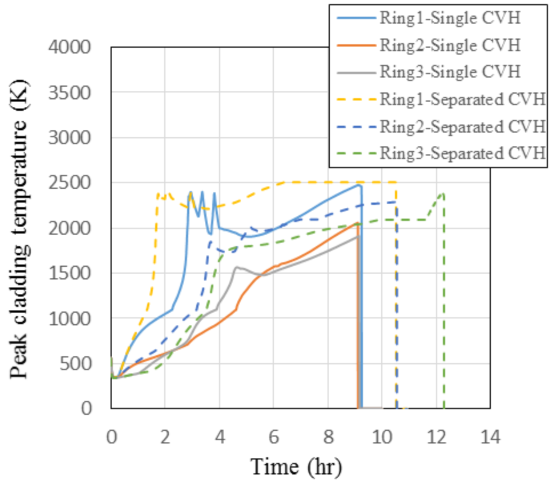


Fig. 13. Peak cladding temperature in the case of LOCA.

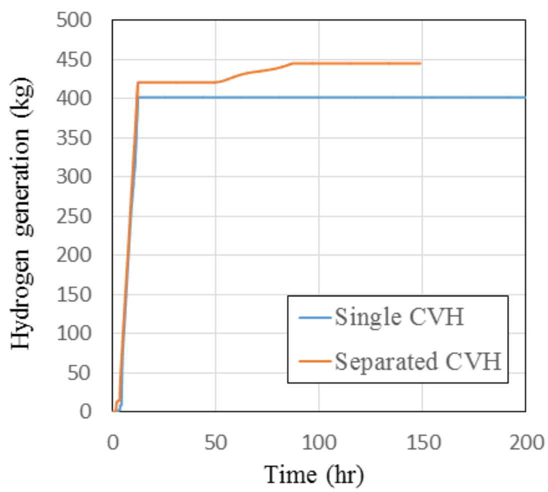


Fig. 14. Hydrogen generation in the case of LOCA.

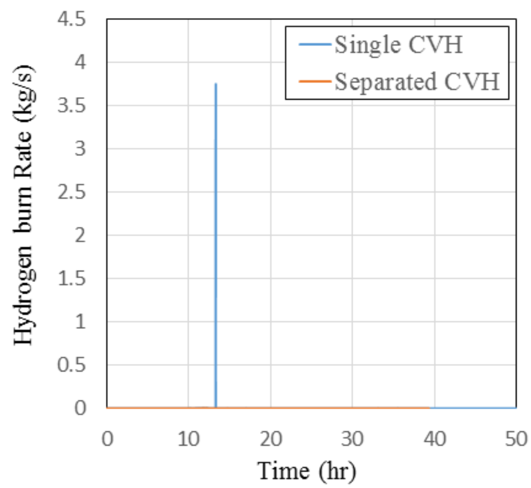


Fig. 15. Hydrogen burn at the roof top in the case of LOCA.

V. CONCLUSIONS

By the calculation of MELCOR2.1/SNAP, this study gives several conclusions:

1. This study successfully established the MELCOR2.1/SNAP model of Chinshan NPP SFP.
2. In the case of SBO, the analysis results of MELCOR, TRACE and CFD were similar. It indicated that there was a respectable accuracy in MELCOR/SNAP model.
3. The cladding temperature rose rapidly due to zirconium-water reaction in 3 days and generated about 2500kg hydrogen in the case of SBO in this study.
4. In the case of LOCA, an environment full of air caused the zirconium fire and generated 500kg hydrogen in the MELCOR calculation.
5. The results showed that the hydrogen burned more locally in the separated CVH model and the cladding temperature was more conservative. But the CPU time was much longer than the single CVH model in this case.

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ACRONYMS

SNAP - Symbolic Nuclear Analysis Package
SPU - Stretch Power Uprate
NPP - Nuclear Power Plant
SFP - Spent Fuel Pool
SBO - Station Blackout
RPV - Reactor Pressure Vessel
TAF - Top of Active Fuel
LOCA - Loss of Coolant Accident
CVH - Control Volume