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The Mitigation Strategy Analysis of Kuosheng Nuclear Power Plant Spent Fuel Pool Using MELCOR2.1/SNAP

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Abstract**—**Kuosheng nuclear power plant (NPP) is a BWR/6 plant in Taiwan. There is more concern for the safety of Spent Fuel Pools (SFPs) in Taiwan after Fukushima event. In order to estimate the safety of Kuosheng NPP SFP, by using MELCOR2.1 and SNAP, the safety analysis of Kuosheng NPP SFP was performed combined with the mitigation strategy of NEI 06-12 report. There were several steps in this research. First, the Kuosheng NPP SFP models were established by MELCOR2.1/SNAP. Second, the Station Blackout (SBO) analysis of Kuosheng SFP was done by TRACE and MELCOR under the cooling system failure condition. The results showed that the calculations of MELCOR and TRACE were very similar in this case. Second, the mitigation strategy analysis was done with the MELCOR model by following the NEI 06-12 report. The results showed the effectiveness of NEI 06-12 strategy in Kuosheng NPP SFP. Finally, a sensitivity study of SFP quenching was done to check the differences of different water injection time and the phenomena during the quenching. The results showed that if the cladding temperature was over 1600 K, the water injection may have chance to cause the accident more severe with more hydrogen generation. It was because of the oxidation heat and the "Breakaway" effect of the zirconium-water reaction. An animation model built by SNAP was also shown in this study.

Keywords**—**MELCOR, SNAP, spent fuel pool, quenching.

I. Introduction

AFTER Fukushima event, the safety analysis of SFP became one of the most important issue in Taiwan. Although the decay heat was very small compared to the operating core, the Fukushima event showed that a long term SBO can still cause risk to the SFP.

Kuosheng NPP is a type of BWR/6 designed and built by General Electric in Taiwan. There are two units in Kuosheng NPP. After the project of Stretch Power Uprate, the operating power of Kuosheng NPP is 3001 MWt now.

The purpose of this study is to calculate the mitigation strategy of Kuosheng 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 SFP model was built in the MELCOR code this years for the increasing demand of SFP safety analysis. The latest version MELCOR2.1 was used and combined with Symbolic Nuclear Analysis Package (SNAP). With 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.

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There were four steps in this study. First, the data of Kuosheng NPP SFP were collected from the FSAR and training material of Taiwan Power Company [1], [2]. Second, a MELCOR SFP model was built by using those data with the SNAP interface. The model was used to calculated a single SBO accident and compared to the thermal-hydraulic code TRACE in previous works [3]. The comparison showed that the results of Kuosheng SFP MELCOR model was very close to the TRACE results. Third, the mitigation strategy followed by NEI 06-12 was set into the MELCOR SFP model and simulated the SBO accident to check the effectiveness of this strategy for the Kuosheng NPP SFP. Finally, a quenching analysis of the mitigation strategy was done for a sensitivity study. Fig. 1 shows the working flow chart of this study.

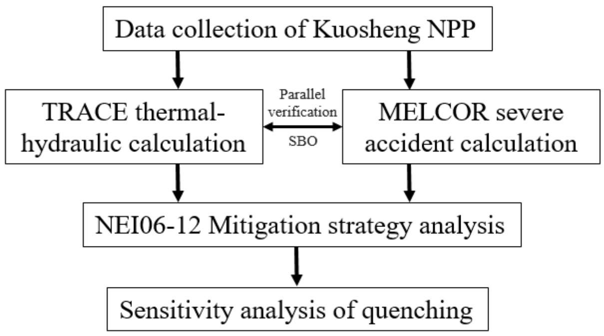

Fig. 1 Flow chart of the SFP analysis

II. Methodology

The code versions used in this study were SNAP 2.5.1 and MELCOR2.1. The MELCOR SFP model was a stand-alone model just like the SFP model of MAAP code. The fuel assemblies were separated by COR component into several rings to simulate the different location and decay heat inside the SFP. The geometry of Kuosheng NPP SFP was 11.16 m × 11 m × 12.19 m. The initial condition of water temperature was 311 K (BWRT9-1-10), and the pressure was 1.013×10^5 Pa. The total power of the fuels was roughly 10.26 MWt initially.

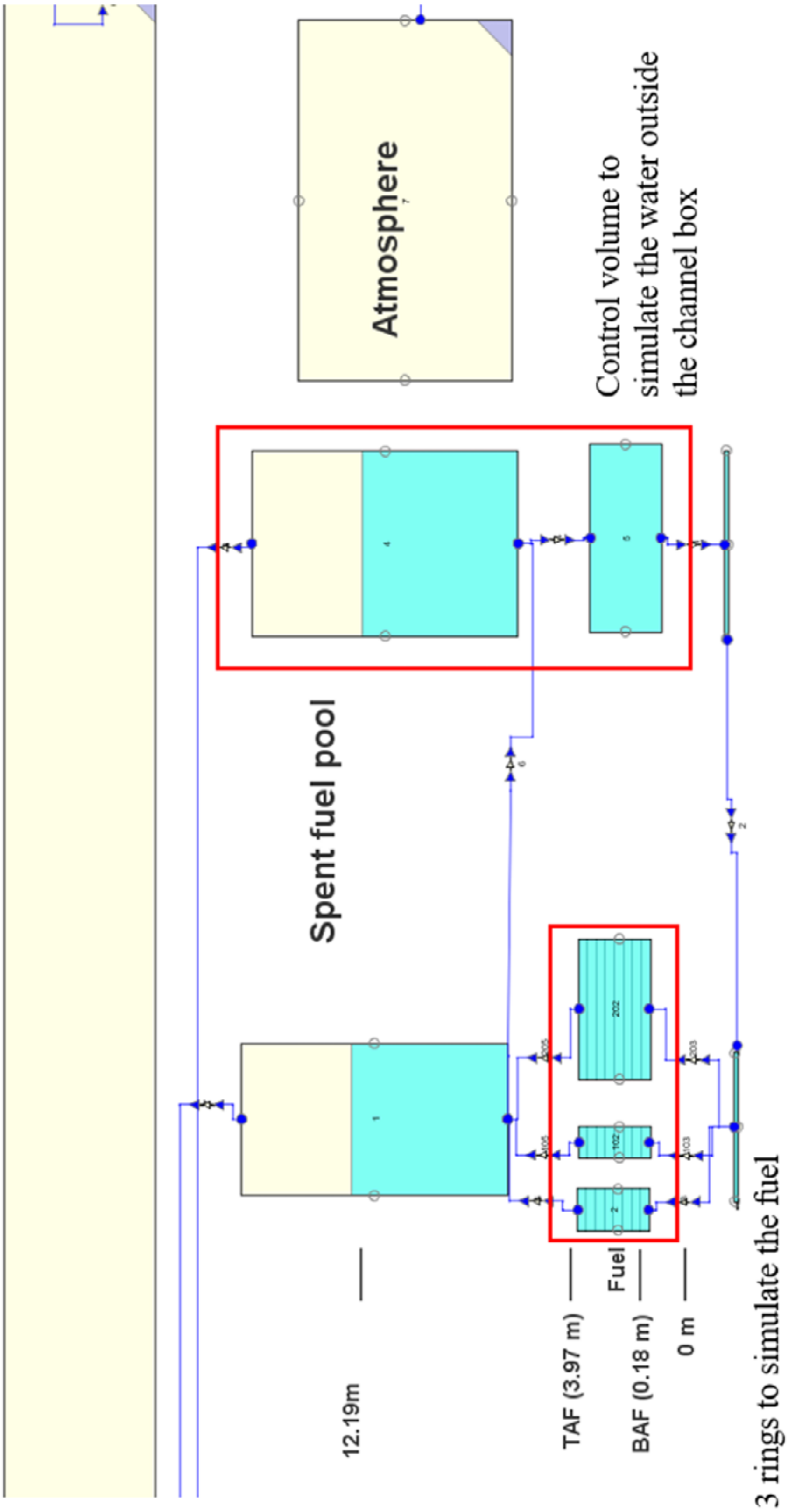

Fig. 2 MELCOR2.1/SNAP model of Kuosheng SFP

In this study, the SFP was assume to be "Full-core storage" to simulate the most conservative situation. The thermal power of the 624 fuel bundles which were unloaded from core was 8.6359 MWt. It was totally 4856 fuel bundles in the Kuosheng NPP SFP, combined with the 4232 bundles in the SFP (624 from core plus 4232 that initially inside the pool). Fig. 2 shows the MELCOR model of Kuosheng NPP SFP. This model included one core component, ten control volume components, 22 heat structure components, and several control/tabular function components. According to the MELCOR manual [4], two new features of the core component that are specific to SFP model: (1) a rack component, which permits modeling of a SFP racks, and (2) an enhanced air oxidation model. The SFP rack component permits separate modeling of the rack and radiative heat transfer between the rack and the existing COR components. The air oxidation kinetics model predicts the transition to "Breakaway" oxidation kinetics in air environments on a node-by-node basis. An oxidation experiment was done by Sandia to best estimate the cladding temperature with MELCOR [5].

The water of SFP was modeled by using the control volume components (CVH package). The core component was divided into ten axial levels and three radial rings. The fuels were divided into eight axial nodes. The decay heat data in this study are shown in Fig. 3. The decay heat was assumed to be a linear decay for a more conservative heat source.

The mitigation strategy in this study was followed by the report of NEI 06-12. Fig. 4 shows the mitigation strategy of NEI 06-12. The main issue of this strategy is to have a 200GPM (12.61kg/s) spray water source in a SFP accident. In Kuosheng NPP, the SFP building has a quick connector which can connect with the fire truck outside the SFP building. The water injection can be lined up very fast in a SFP accident. The 200GPM (12.61kg/s) water injection was simulated by the extra source package in MELCOR which is shown in Fig. 5. The extra source component simulates the water injection as a homogeneous injection. It means the results of MELCOR calculations were more conservative than a spray water injection.

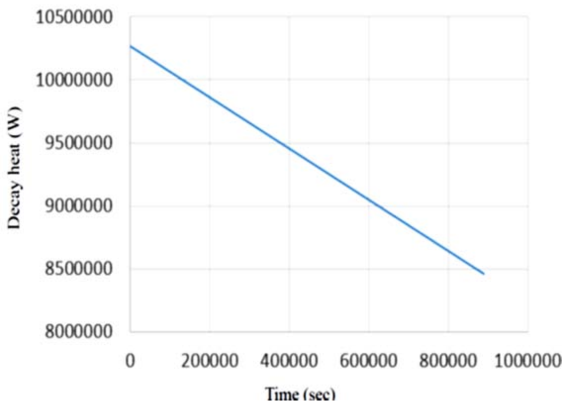

Fig. 3 Decay heat

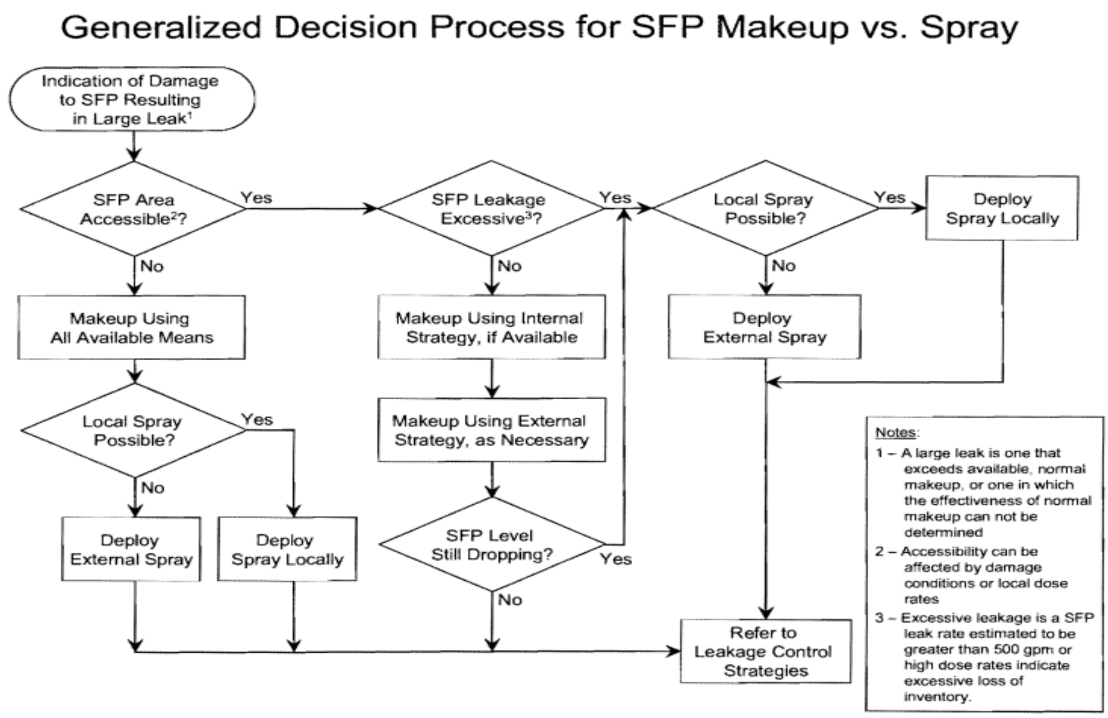

Fig. 4 Mitigation strategy of NEI 06-12

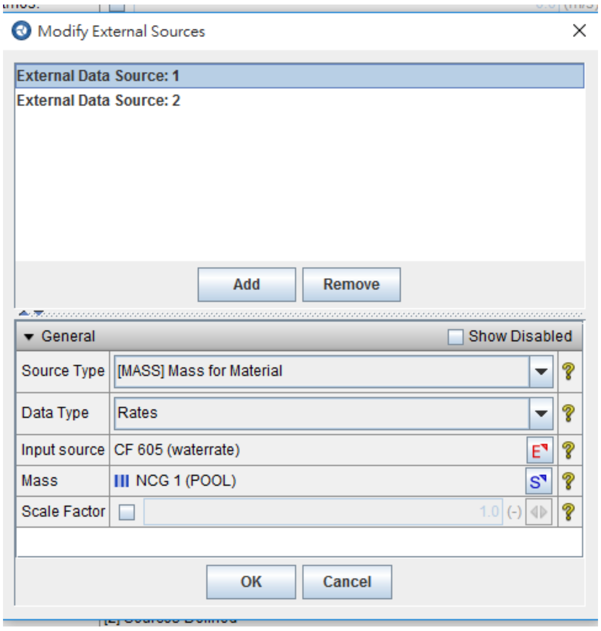

Fig. 5 Water injection settings of MELCOR

III. Results

The results were separated into two parts. One was the case of SBO. In the accident like SBO, all normal water injection systems were failed, and the pool water level kept going down because of decay heat. When the water level drops to Top of Active fuel (TAF), the cladding temperature may rise over 1088.7 K and may cause the release of radiation nuclides inside the fuel cladding. The estimated pool uncover time can be shown through the SBO simulation and give Kuosheng NPP SFP a time magin for preparing the water injection.

The other case was the calculation of mitigation strategy. The SFP building of Kuosheng NPP has a quick connector which can connect to the fire truck outside the SFP building. In this study, the water injection started when the water level dropped to TAF, 2/3 of the fuel and 1/2 of the fuel. For the calculation of MELCOR, the cladding temperature can be calculated during the mitigation strategy and checked whether it is over the regularity limit 1088.7 K.

Figs. 6 and 7 show the MELCOR results of SBO case. Fig. 6 is the water level. The water level costs three days to reach TAF. Fig. 7 is the peak cladding temperature. The result showed that the cladding temperature reached 1088.7 K at 4th day and caused the releasing of radiation nuclides. It means that, in a SBO situation like this study, the Kuosheng NPP SFP may have four days to find the water source for preventing the failure of fuel cladding inside the SFP.

Figs. 8 and 9 are the results of mitigation strategy simulations. A 200GPM water injection started when the water level dropped to TAF, 2/3 fuel and 1/2 fuel. Fig. 8 is the result of water level. The water level rose back to TAF in all three cases and kept the SFP in a safe situation. Fig. 9 shows the cladding temperature of three mitigation strategy. It shows that if the water injection started when the water level dropped to 1/2 fuel, the cladding temperature rose to a peak values of 420 K. At this temperature, the cladding was still safe, and no hydrogen was generated. The results of the mitigation strategy analysis of Kuosheng NPP SFP show that a 200GPM water injection can bring back the water level and keep the cladding temperature in a safe value. It also shows that the SFP of Kuosheng NPP had four days safety margin in a conservative situation like this study.

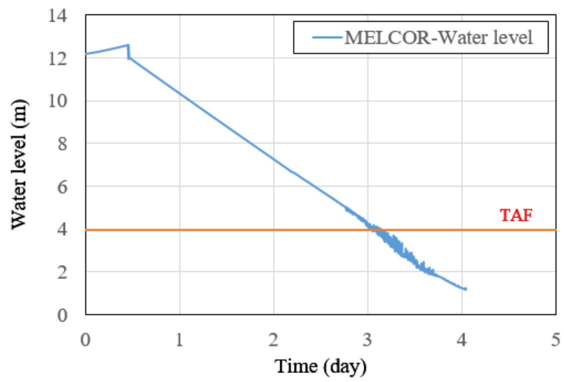

Fig. 6 Water level result of SBO

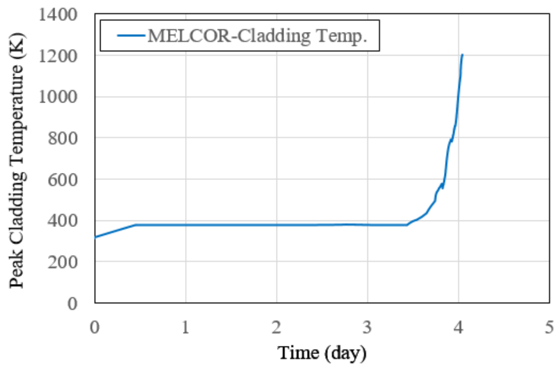

Fig. 7 Cladding temperature result of SBO

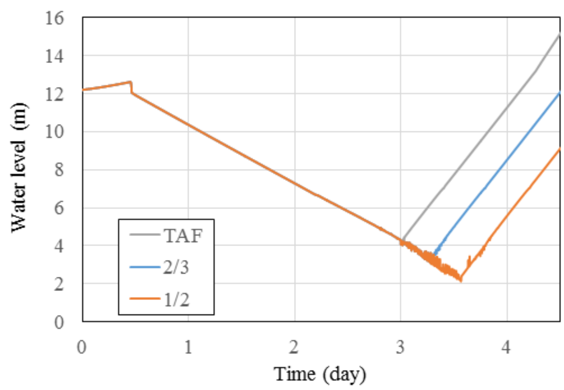

Fig. 8 Water level results of mitigation strategies

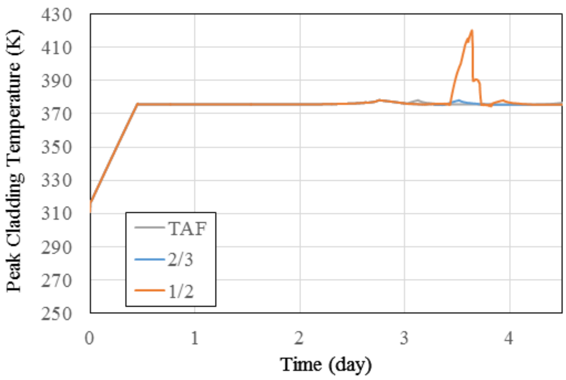

Fig. 9 Cladding temperature results of mitigation strategies

IV. Sensitivity Study

After the effectiveness analysis of NEI 06-12 mitigation strategy, a sensitivity study of SFP quenching was done by delaying the water injection time. With the rising of cladding temperature, the oxidation was more severe and caused more oxidation heat. There were seven cases in this sensitivity study. The water injection started when the cladding temperature reached 800 K, 1000 K, 1200 K, 1600 K, 1800 K, 2000 K, and 2400 K. The water injection was also 200GPM (12.61 kg/s) with homogeneous water injection. Fig. 10 shows the water level of different injection time. It shows that the fuel of all cases was recovered by the water injection and only different by the injection time. It also shows that a 200GPM water injection was enough in a SFP SBO accident even the cladding temperature was over 2000 K. Fig. 11 shows the cladding temperature of the study. For the cases that injection started at 800 K, 1000 K, and 1200 K, the results were very simple that the temperature reached the setting point and cooled down by the water injection immediately. But for the cases where water injection started at over 1600 K, the cladding cannot be cooled down till it reaches 2400 K. The reason which caused these results was that when the water injected into the pool, the water caused the zirconium-water reaction more severe and generated more oxidation heat. Equations (1) and (2) show the zirconium-water calculation of MELCOR2.1. The oxidation rate may speed up after the temperature over 1853 K. It was called "Breakaway oxidation." So, in the case that water injection started after 1600 K, the water caused extra oxidation heat and made the cladding temperature reach breakaway temperature. The cladding temperature then rose immediately to 2400 K. This sensitivity study gave a conclusion of the mitigation strategy. If the water injection started after the cladding temperature was over 1600 K, the oxidation heat may have chance to make the accident more severe with more hydrogen generation and more oxidation heat.

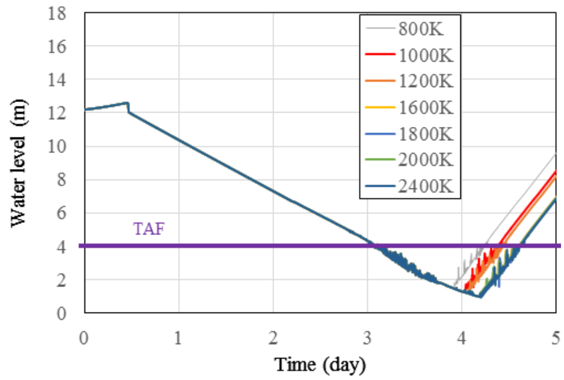

Fig. 10 Water level results of sensitivity study

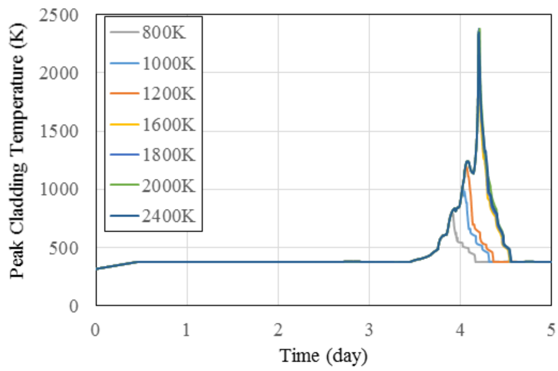

Fig. 11 Cladding temperature results of sensitivity study

$$\mathrm{K}\,(\mathrm{T}) = 29.6 \exp\left(\frac{-16820.0}{T}\right) \; for\ T < 1853.0K \qquad (1)$$

$$\mathrm{K}\,(\mathrm{T}) = 87.9 \, exp\left(\frac{-16610.0}{T}\right) \; for\ T \geq 1873.0K \qquad (2)$$

After all the calculations of MELCOR, the results can be input to an animation model built by SNAP interface. The animation can show the detail analysis results of Kuosheng NPP SFP during the accident. Fig. 12 is the animation model of Kuosheng NPP SFP. The results of water level, cladding temperature, hydrogen generation, and zirconium oxidation can be shown in the animation clearly. The animation can help the user to understand the simulation easily. It can also help the decision making during a real SFP accident in the NPP.

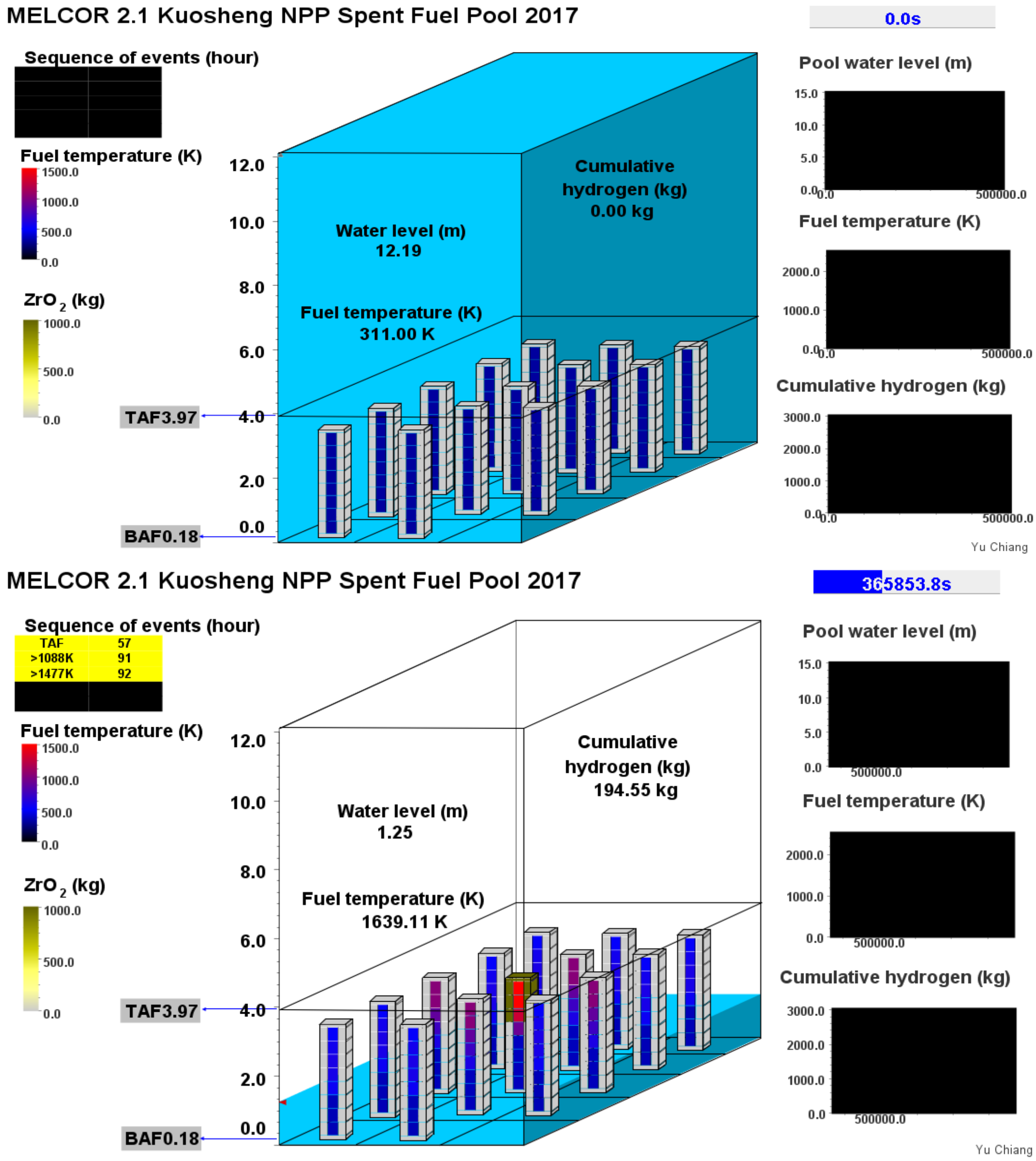

Fig. 12 Animation model of Kuosheng NPP SFP

V. CONCLUSION

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

1. This study successfully established the MELCOR2.1/SNAP model of Kuosheng NPP SFP.
2. In the case of SBO, the analysis results of MELCOR and TRACE were similar. It indicated that there was a respectable accuracy in MELCOR2.1/SNAP model.
3. The water level dropped to TAF in three days in the case of SBO and the cladding temperature rose rapidly due to zirconium-water reaction in four days. It gave a 4-day safety margin to the mitigation strategy of Kuosheng NPP.
4. The mitigation strategy analysis shows that the NEI 06-12 strategy was effective in the accident of Kuosheng NPP SFP.
5. After the cladding reached 1600 K, the water injection should had more concern of the oxidation heat and the breakaway oxidation in high cladding temperature.

REFERENCES

[1] Taiwan Power Company, “Teaching material of Kuosheng BWR/6 Training.” (2007).
[2] Taiwan Power Company, “Final Safety Analysis Report for Kuosheng Nuclear Power Station Units 1&2 (FSAR)”, 2001.

[3] W. S. Hsu, Y. Chiang, Y. S. Tseng, J. R. Wang, C. Shih, S. W. Chen, "The Model Establishment and Analysis of TRACE/MELCOR for Kuosheng Nuclear Power Plant Spent Fuel Pool" International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering Vol:10, No:10, 2016.
[4] Sandia National Laboratories, "MELCOR Computer Code Manual", 2015.
[5] Robert Beaton, Alexander Velazquez-Lozada, Abdelghani Zigh, "Experiments on Ignition of Zirconium-Alloy in Prototypical Pressurized Water Reactor Fuel Assemblies in a Spent Fuel Pool with Complete Loss of Coolant ," Sandia National Lab report.