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The Model Establishment and Analysis of TRACE/FRAPTRAN for Chinshan Nuclear Power Plant Spent Fuel Pool

J. R. Wang, H. T. Lin, Y. S. Tseng, W. Y. Li, H. C. Chen, S. W. Chen, C. Shih

***Abstract*—**TRACE is developed by U.S. NRC for the nuclear power plants (NPPs) safety analysis. We focus on the establishment and application of TRACE/FRAPTRAN/SNAP models for Chinshan NPP (BWR/4) spent fuel pool in this research. The geometry is 12.17 m × 7.87 m × 11.61 m for the spent fuel pool. In this study, there are three TRACE/SNAP models: one-channel, two-channel, and multi-channel TRACE/SNAP model. Additionally, the cooling system failure of the spent fuel pool was simulated and analyzed by using the above models. According to the analysis results, the peak cladding temperature response was more accurate in the multi-channel TRACE/SNAP model. The results depicted that the uncovered of the fuels occurred at 2.7 day after the cooling system failed. In order to estimate the detailed fuel rods performance, FRAPTRAN code was used in this research. According to the results of FRAPTRAN, the highest cladding temperature located on the node 21 of the fuel rod (the highest node at node 23) and the cladding burst roughly after 3.7 day.

***Keywords*—**TRACE, FRAPTRAN, SNAP, spent fuel pool.

I. Introduction

THERE is more concern for the NPPs safety in Taiwan after Japan Fukushima NPP disaster. The spent fuel pool cooling system failed and the safety issue generated in Fukushima NPP due to the tsunami and earthquake happened. In this research, the analysis for Chinshan NPP (BWR/4) spent fuel pool was performed by using TRACE and FRAPTRAN codes. Chinshan NPP is the first BWR NPP in Taiwan. The original licensed power is 1775 MWt for each unit. However, the SPU (Stretch Power Uprate) was finished in Chinshan NPP. Hence, its power is 1840 MWt now. Chinshan NPP has two spent fuel pools which can store about 3100 fuel bundles for each one [1].

TRACE is the advanced thermal-hydraulic code and is developed by U. S. NRC for the best-estimate analyses of the transients for NPPs. According to TRACE user's manual [2], the development of TRACE is based on TRAC and RELAP5. TRACE can model the reactor vessel with 3-D geometry which could support a more accurate and detailed safety analysis for NPPs. FRAPTRAN can calculate the performance of fuel rods during the transients and hypothetical accidents such as loss-of-coolant accidents (LOCAs), anticipated transients without scram (ATWS), and reactivity-initiated accidents (RIAs) [3]. SNAP (Symbolic Nuclear Analysis Program) is a graphic user interface program and can process the inputs, outputs, and animation models for TRACE, and FRAPTRAN [4].

There are three TRACE/SNAP models (one-channel, two-channel, and multi-channel model) considered in this study. The failure of spent fuel pool cooling system was simulated and analyzed by the above models. The fuel rod analysis was performed by using FRAPTRAN code.

II. Methodology

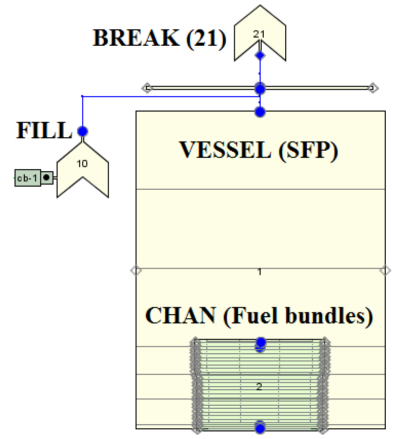
We established successfully the spent fuel pool TRACE/SNAP models of Chinshan NPP by using SNAP v 0.26.7 ~ v 2.2.1 and TRACE v 5.0 ~ v 5.0 patch 3 in our previous research [5]-[7]. In 2014, SNAP v 2.2.9 and TRACE v 5.0 patch 4 was released by U. S. NRC. Therefore, we updated the TRACE/SNAP model of Chinshan NPP spent fuel pool. The width × depth was 12.17 m × 7.87 m with the initial conditions (water temperature 51.7 °C and the water level 11.61 m) for Chinshan NPP spent fuel pool. The fuels decay power was about 8.99 MWt initially [8].

The one-channel model was presented in Fig. 1 (a). The spent fuel pool was simulated by the 3-D VESSEL component. The 7 axial levels, 1 X dimension cell, and 1 Y dimension cell were in this VESSEL component. The water was at the axial level 1~6. The fuels were simulated by the CHAN component. This CHAN component was connected to the axial level 2~4 of the VESSEL component. The decay heat of the fuels was the heat source of the pool. It was simulated by a POWER component of TRACE. The decay heat data were calculated from the ASB 9-2 decay heat correlation [8].

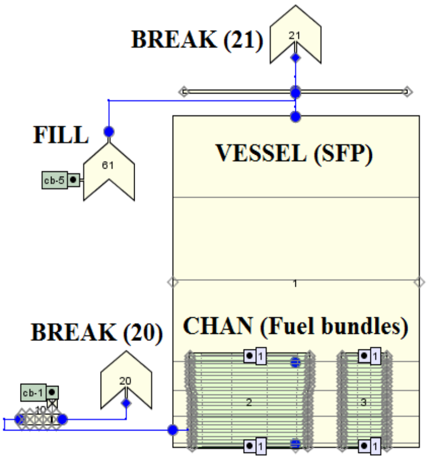
The two-channel model was depicted in Fig. 1 (b). The pool was simulated by the 3-D VESSEL component which had 7 axial levels, 1 X dimension cell, and 1 Y dimension cell. The axial level 1~6 of the VESSEL component was the water. The fire water spray system of the spent fuel pool was simulated by the FILL component. A hole on the side of the spent fuel pool wall as the leakage location was simulated by the BRAKE (20) component. The BREAK (21) component was used as the boundary condition. The fuels were simulated by two CHAN components. The newest batch (408 fuel bundles) was presented in the CHAN (3) component. All the other batches was shown in the CHAN (2) component.

J. R. Wang, Y.S. Tseng, W. Y. Li, H. C. Chen, S. W. Chen, C. Shih are with the Institute of Nuclear Engineering and Science, National Tsing Hua University; Nuclear and New Energy Education and Research Foundation; Nuclear Science and Technology Development Center, R.O.C., Taiwan (e-mail: jongrongwang@gmail.com, yungshintseng@gmail.com, fermmy@hotmail.com, km8385@gmail.com, chensw@mx.nthu.edu.tw, ckshih@ess.nthu.edu.tw).

H.T. Lin is with the Institute of Nuclear Energy Research, Atomic Energy Council, R.O.C., Taiwan (e-mail: htlin@iner.gov.tw).



(a) One-channel



(b) Two-channel

Fig. 1 One-channel and two-channel TRACE/SNAP model

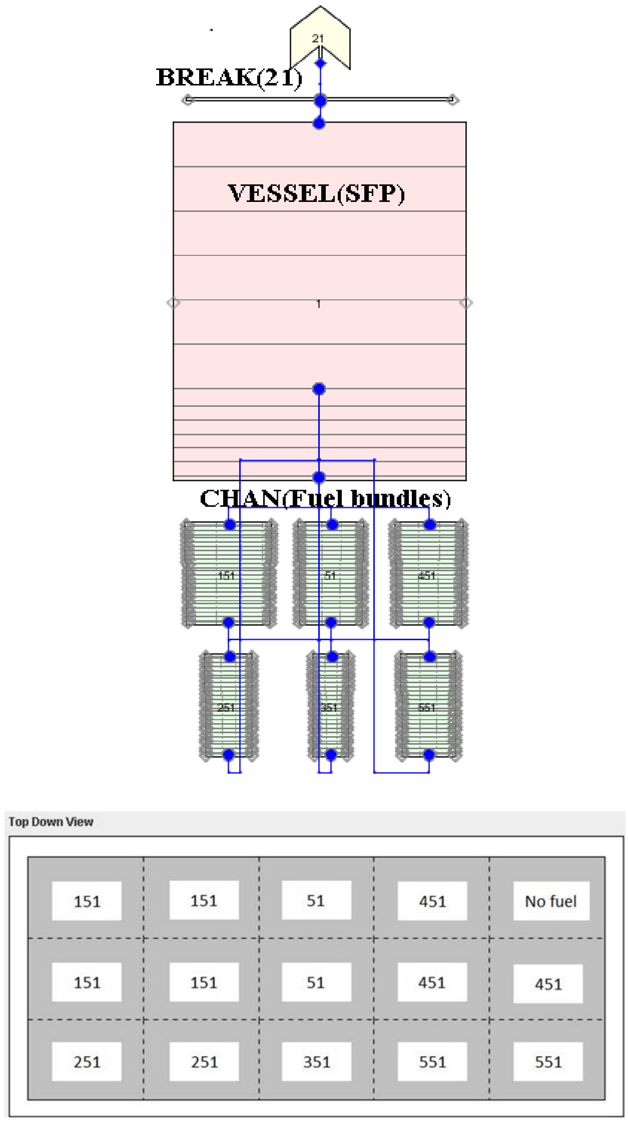


Fig. 2 Multi-channel TRACE/SNAP model

Fig. 2 depicts the multi-channel model. The 3-D VESSEL component which had 13 axial levels, 1 X dimension cell, and 1 Y dimension cell was used to simulate the spent fuel pool. The water was at axial level 1~11 of the VESSEL component. The FILL component was used to simulate the fire water spray system. The BREAK (21) component was used as the boundary condition. The CHAN (51) component represented the newest batch. All the other batches were shown in the other CHAN components.

After the analysis of TRACE, the input file of FRAPTRAN is established by using the fuel rod geometry data and the results of TRACE (ex: heat transfer coefficients, coolant conditions, power history data). There are 23 nodes in the fuel rod (node 23 is the highest node) which was shown in Fig. 3. Subsequently, the analysis of the fuel rod performance was performed by FRAPTRAN code. In order to avoid the inconsistency in the results of TRACE and FRAPTRAN, the cladding temperature predictions of TRACE and FRAPTRAN were checked. Finally, the analysis results were obtained from the FRAPTRAN output file.

III. Results

The TRACE/SNAP models were used to simulate the failure of cooling system without any water replenishment in this study. Additionally, the sensitivity study was performed to investigate the effect of the timestep size.

Figs. 4 and 5 present the water level and cladding temperature results of TRACE/SNAP multi-channel model for the different timestep size cases. In Fig. 4, for the timestep size 10 sec and 1 sec case, the timing to uncover fuels is faster than the other cases. Consequently, it can affect the response of the cladding temperature (see Fig. 5). In addition, the case with timestep size 0.1 sec was ended with no reason. Table I lists the problem time and the computational time for the cases with different timestep size. We stopped to run the case with timestep size 0.001 sec after 20.75 days (computational time).

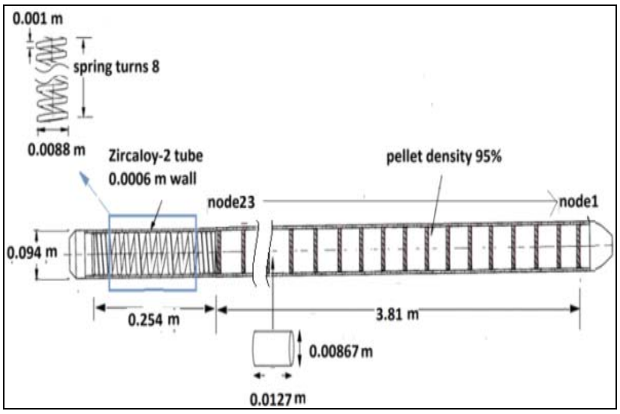


Fig. 3 FRAPTRAN fuel rod model

According to the above results, the case with the timestep size 0.01 sec was chosen in order to compare with the results of one-channel model, two-channel model, and multi-channel model. Figs. 6 and 7 depict the water level and the cladding temperature results of TRACE. In Fig. 6, the trends of the water level for three models were the same. However, the cladding temperature responses were different (see Fig. 7). The possible reason was from the different simulation of fuels in the CHAN components. The result of multi-channel model was similar to the result of two-channel model. It may be caused by the reason that the newest batch was simulated in one CHAN component for two-channel model and multi-channel model. Therefore, the actual location of fuels in the spent fuel pool was considered in the multi-channel model which was the better meth of the simulation.

According to the predictions of TRACE, the time which reached 100 °C was about 2.9 hours after the cooling system failed (shown in Fig. 7). Subsequently, the water dried out, which caused the water level lower than the top of fuel rods. The uncovered of the fuels happened roughly after 2.7 days. After 3.6 days, it indicated that the cladding temperature went up and was larger than 1088.7 K. It depicted that the zirconium-water reaction was able to occur. The cladding temperature sharply went up because the zirconium-water reaction occurred. It may cause the failure of the fuel rod cladding.

According to the output file of FRAPTRAN, the highest cladding temperature was at the node 21. Therefore, Figs. 8-12 only show the results of the node 21. Fig. 8 presents that the zirconium-water reaction energy happened after 3.7 days. Hence, the oxide thickness went up (see Fig. 9). Fig. 10 depicts the results of the cladding hoop strain. The cladding hoop strain increased sharply after 3.7 days. In Fig. 11, the cladding hoop stress decreased to zero after 3.7 days. The radial gap also went up after 3.7 days (see Fig. 12). Combining the above results, it indicated that the failure of the cladding may generate after 3.7 days. Additionally, Chinshan NPP spent fuel pool animation model is presented in Fig. 13. By using TRACE analysis results and the animation function of SNAP, the variation of the transient can be observed in this model.

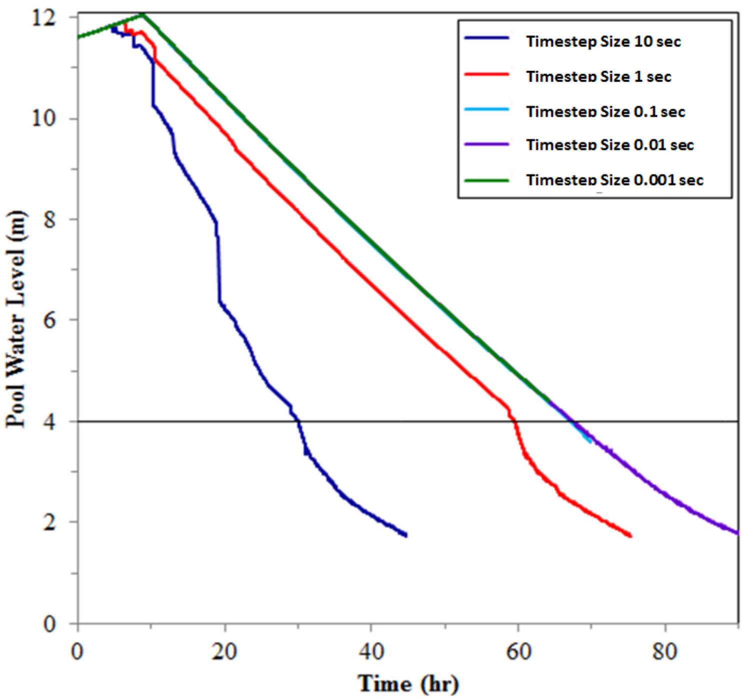


Fig. 4 The water level results for different timestep sizes

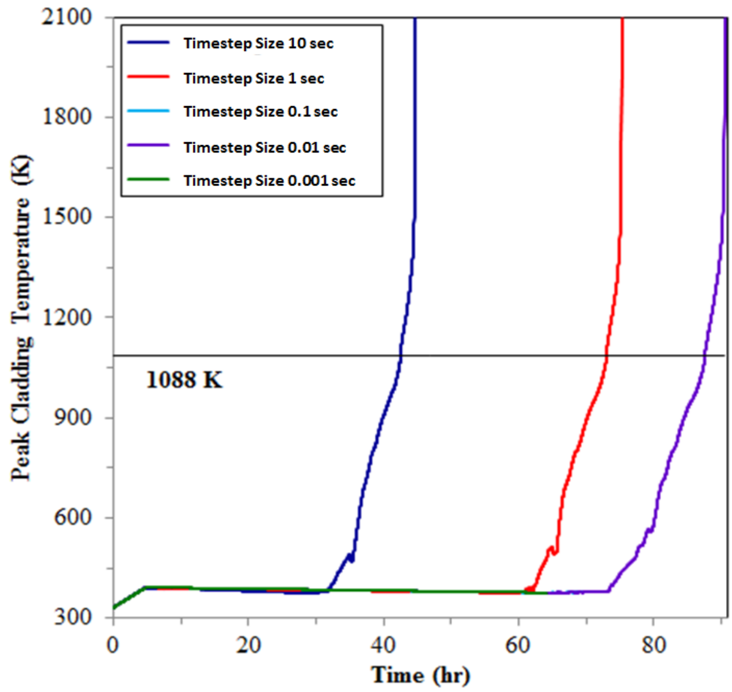


Fig. 5 The cladding temperature results for different timestep sizes

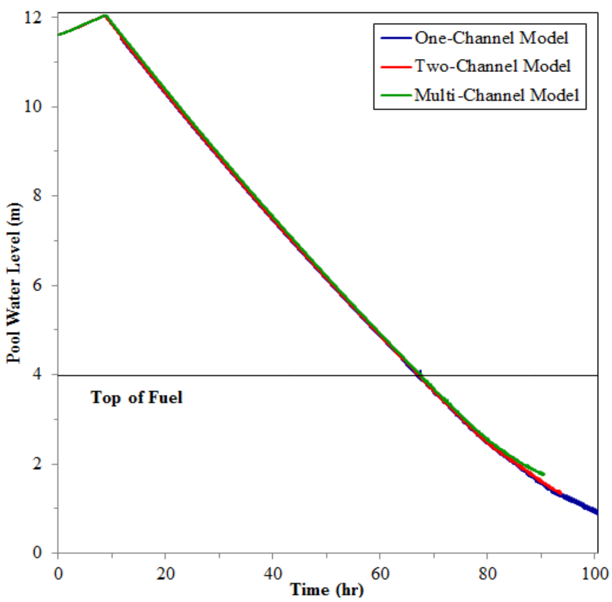


Fig. 6 The water level results for three models

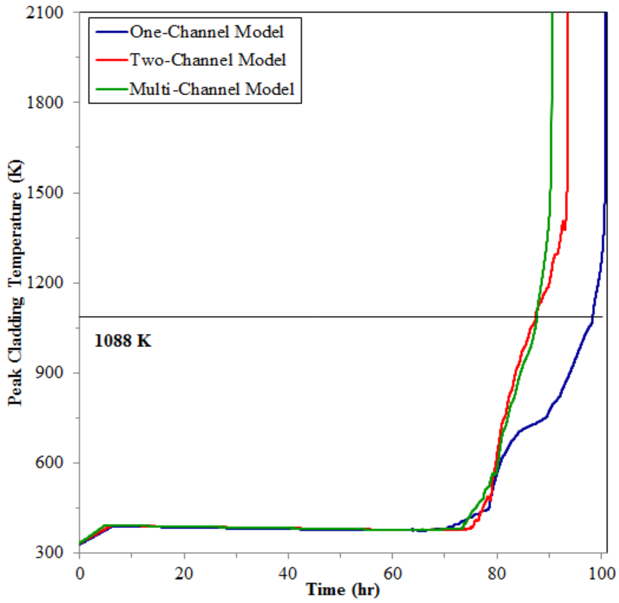


Fig. 7 The cladding temperature results for three models

TABLE I
THE PROBLEM TIME AND CPU TIME FOR DIFFERENT TIMESTEP SIZE

Timestep Size	Problem Time	CPU Time
10 sec	44.74 hours	13.08 hours
1 sec	75.28 hours	14.7 hours
0.1 sec	69.72 hours	6.5 hours
0.01 sec	90.53 hours	92.43 hours
0.001 sec	64.05 hours	20.75 days

IV. CONCLUSION

TRACE/FRAPTRAN/SNAP models of Chinshan (BWR/4) NPP spent fuel pool were established successfully in this research. The results of multi-channel TRACE/SNAP model were compared with the results of one-channel model and two-channel model under the condition which was the cooling system failure and no water replenishment for the spent fuel pool. According to the results of the comparison, the peak cladding temperature response was more accurate in the multi-channel model. In the sensitivity study of timestep size, we choose the timestep size 0.01 sec according to the TRACE analysis results. The results of TRACE and FRAPTRAN indicated that the uncovered of the fuels occurred at 2.7 day and the zirconium-water reaction of the fuel rods occurred roughly at 3.7 days after the cooling system failed. The above results presented that the failure of the fuel rod cladding happened after 3.7 days.

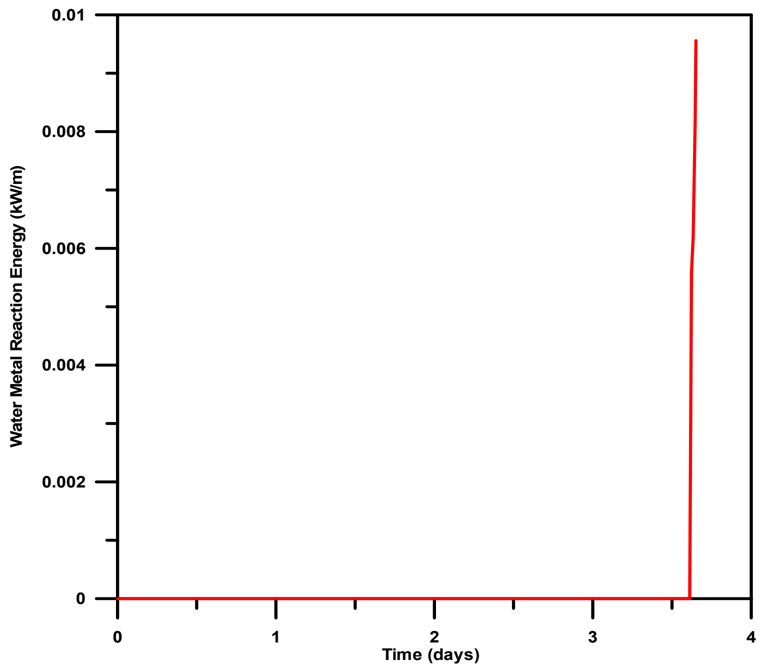


Fig. 8 The zirconium-water reaction energy result

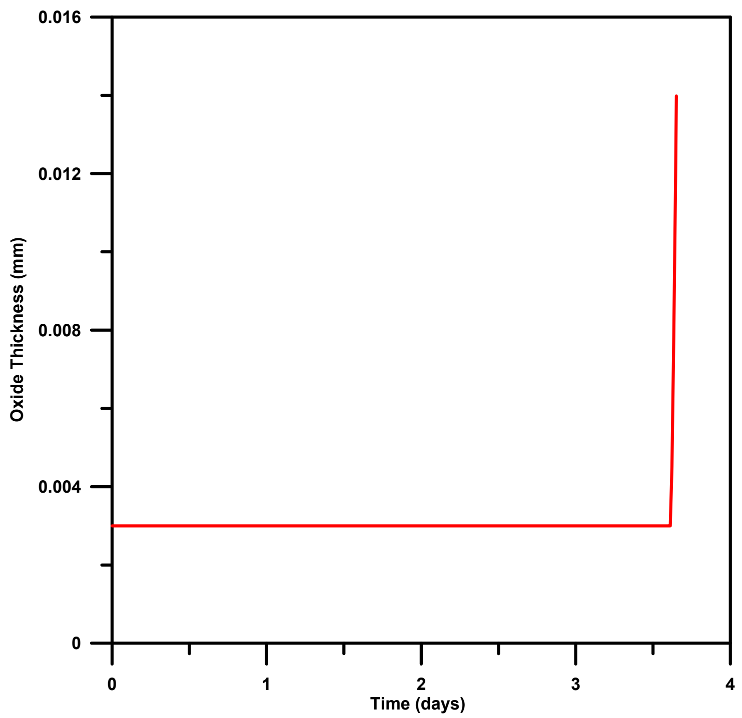


Fig. 9 The oxide thickness result

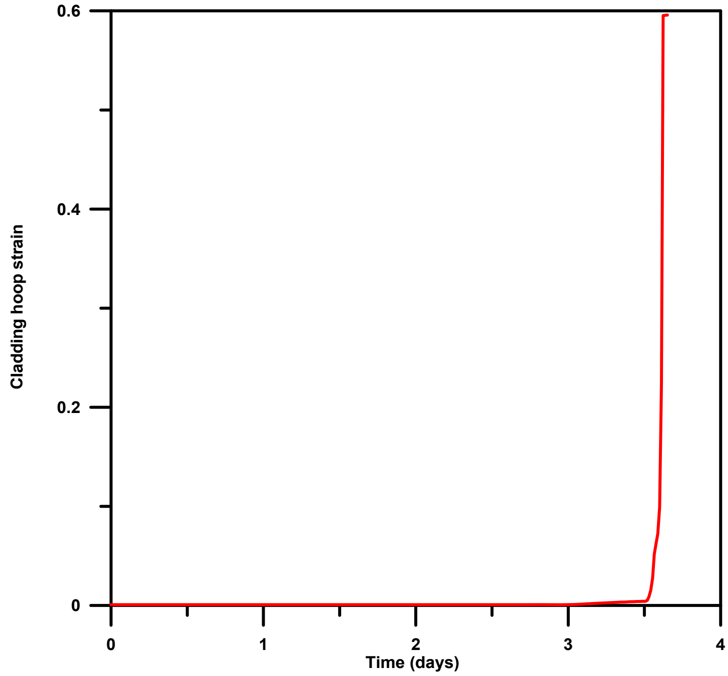


Fig. 10 The cladding hoop strain results

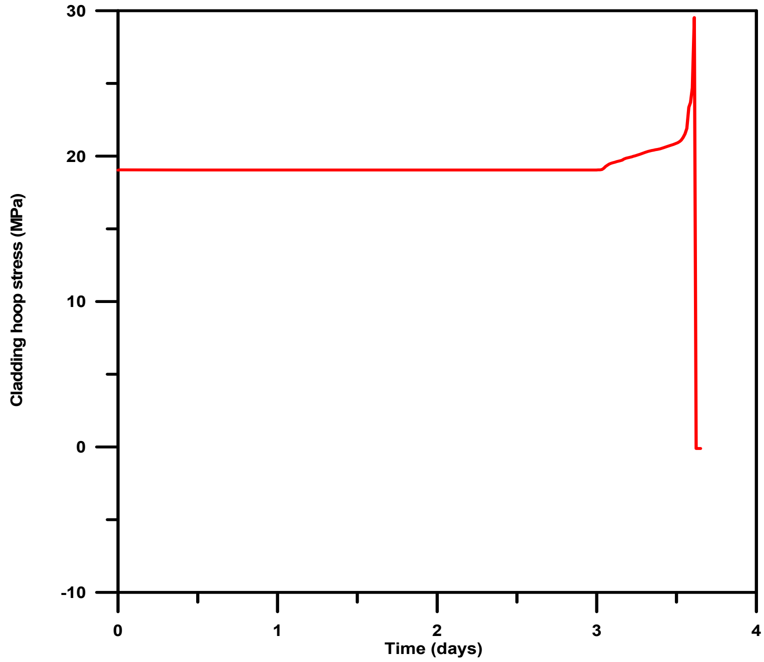


Fig. 11 The cladding hoop stress results

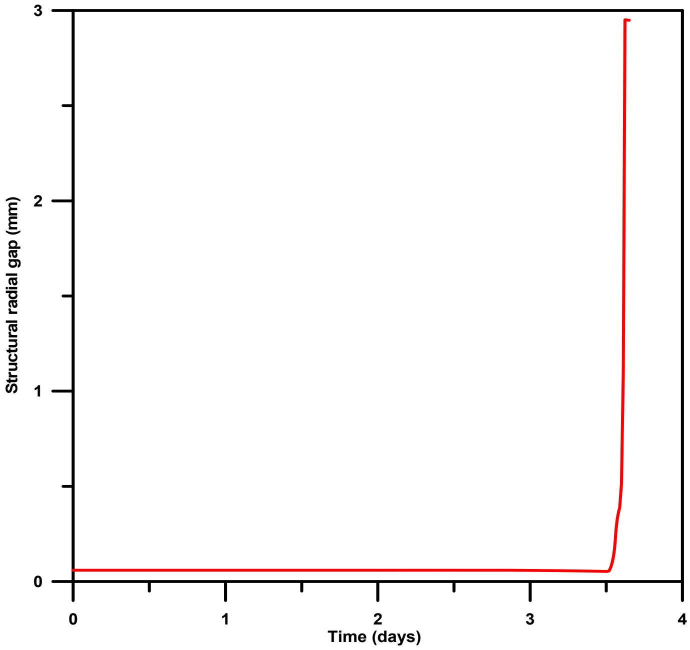


Fig. 12 The radial gap results

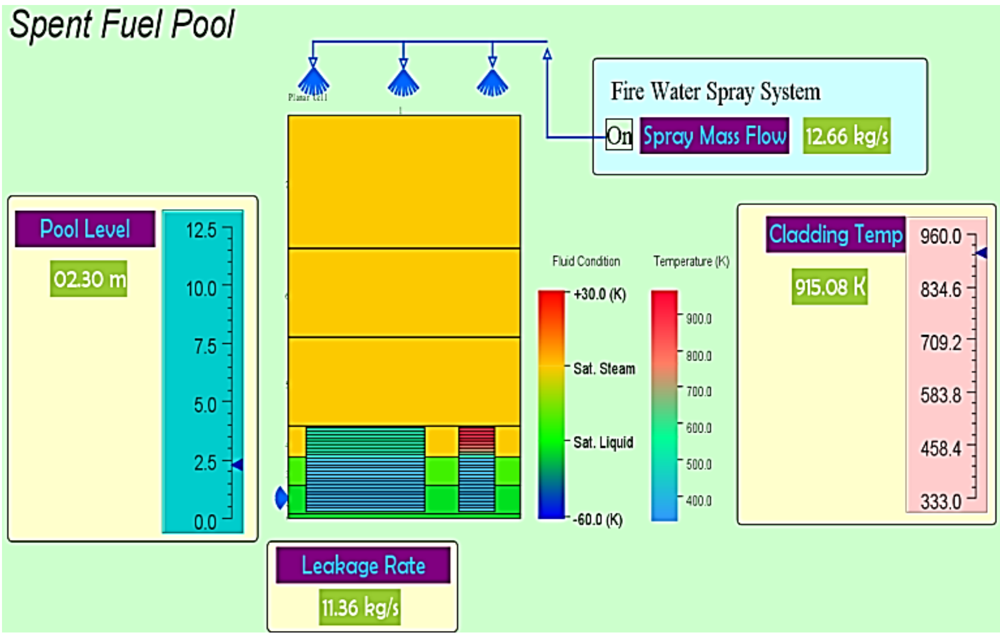


Fig. 13 Chinshan NPP spent fuel pool animation model

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