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# International Agreement Report

# Spent Fuel Pool Safety Analysis of TRACE in Chinshan NPP

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# ABSTRACT

In this research, loss of spent fuel pool cooling system and loss of pool coolant inventory accident in Chinshan nuclear power plant (NPP) were simulated by using TRACE code, the latest best-estimate thermal-hydraulic system code developed by the U.S.NRC. Besides, the mitigation capability of spray system during the accidents was discussed.

In TRACE input model, the calculation of decay thermal power of spent fuel was based on ASB 9-2 decay heat correlation of U.S.NRC standard review plan report. To simulate the accident mitigation, spray system initiation time, spray flow rate, and spray flow temperature sensitivity studies were performed in the loss of pool cooling system accident simulation. In the simulation of concurrent loss of pool cooling system and pool inventory, the focus was mainly on the excessive inventory loss which the initial leakage rate was beyond 500 gpm.

The capability of mitigation strategy was evaluated by using simulation results including spent fuel pool water level and fuel cladding temperature variation. The results depicted that in the loss of pool cooling system cases, the earlier the spray system initiated, the shorter pool inventory recover time was needed, and the cladding temperature was lowered effectively by performing a larger spray flow rate. In the loss of both pool cooling system and pool inventory cases, the cladding temperature was controlled even the fuels were partially uncovered, and the spray flow should not less than 200 gpm to avoid the sharp increase of cladding temperature.

# FOREWORD

The US NRC (United States Nuclear Regulatory Commission) is developing an advanced thermal hydraulic code named TRACE for nuclear power plant safety analysis. The development of TRACE is based on TRAC, integrating RELAP5 and other programs. NRC has determined that in the future, TRACE will be the main code used in thermal hydraulic safety analysis, and no further development of other thermal hydraulic codes such as RELAP5 and TRAC will be continued. A graphic user interface program, SNAP (Symbolic Nuclear Analysis Program) which processes inputs and outputs for TRACE is also under development. One of the features of TRACE is its capacity to model the reactor vessel with 3-D geometry. It can support a more accurate and detailed safety analysis of nuclear power plants. TRACE usually used in the nuclear power plants analysis. This report showed TRACE can also do the calculation of small system such as dry-storage cask.

Taiwan and the United States have signed an agreement on CAMP (Code Applications and Maintenance Program) which includes the development and maintenance of TRACE. INER (Institute of Nuclear Energy Research, Atomic Energy Council, R.O.C.) is the organization in Taiwan responsible for the application of TRACE in thermal hydraulic safety analysis, for recording user's experiences of it, and providing suggestions for its development. To meet this responsibility, TRACE/SNAP spent fuel pool model of Chinshan NPP has been built. In this report, the loss of pool cooling system and pool inventory accidents were performed in order to evaluate mitigation strategy.

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# EXECUTIVE SUMMARY


The safety analysis of the NPP is very important work in the NPP safety. Especially after the Fukushima NPP event occurred, the importance of NPP safety analysis has been raised and there is more concern for the safety of the NPPs in the world. Because the earthquake and tsunami occurred, the cooling system of the spent fuel pool failed and the safety issue of the spent fuel pool generated in Japan's Fukushima NPP. In this study, the safety analysis of the spent fuel pool for Chinshan NPP was performed by using TRACE.

Chinshan NPP is the first NPP in Taiwan which is BWR/4 plant and the original licensed thermal power (OLTP) for each unit is 1775 MWt. After the project of MUR (Measurement Uncertainty Recapture) for Chinshan NPP, Unit 2 started MURPU (Measurement Uncertainty Recovery Power Uprate) from April 6, 2008 for Cycle 23 and Unit 1 started MURPU from November 8, 2008 for Cycle 24. The operating power was 101.7% of the original designed rated power, which was 1805 MWt. 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 the Chinshan NPP spent fuel pool is 12.19m × 7.87 m × 11.61 m and the initial condition is 51.7 ℃ (water temperature). Besides, the total power of the fuels is roughly 8.99 MWt initially. In this research, loss of spent fuel pool cooling system and loss of pool coolant inventory accident were simulated by using TRACE. Besides, the mitigation capability of spray system during the accidents was discussed. In TRACE model, the calculation of decay thermal power of spent fuel was based on ASB 9-2 decay heat correlation of U.S.NRC standard review plan report. To simulate the accident mitigation, spray system initiation time, spray flow rate, and spray flow temperature sensitivity studies were performed in the loss of pool cooling system accident simulation. In the simulation of concurrent loss of pool cooling system and pool inventory, the focus was mainly on the excessive inventory loss which the initial leakage rate was beyond 500 gpm.

The capability of mitigation strategy was evaluated by TRACE results. The results depicted that in the loss of pool cooling system cases, the earlier the spray system initiated, the shorter pool inventory recover time was needed, and the cladding temperature was lowered effectively by performing a larger spray flow rate. In the loss of both pool cooling system and pool inventory cases, the cladding temperature was controlled even the fuels were partially uncovered, and the spray flow should not less than 200 gpm to avoid the sharp increase of cladding temperature.

# ABBREVIATIONS

| | |
|---|---|
| BWR | Boiling Water Reactor |
| CAMP | Code Applications and Maintenance Program |
| INER | Institute of Nuclear Energy Research Atomic Energy Council, R.O.C. |
| MUR | Measurement Uncertainty Recapture |
| MURPU | Measurement Uncertainty Recovery Power Uprate |
| NPP | Nuclear Power Plant |
| NRC | Nuclear Regulatory Commission |
| OLTP | Original Licensed Thermal Power |
| ORNL | Oak Ridge National Laboratory |
| SBO | Station blackout |
| SNAP | Symbolic Nuclear Analysis Package |
| SPU | Stretch Power Uprate |
| TRACE | TRAC/RELAP Advanced Computational Engine |

# 1. INTRODUCTION

During the Fukushima accident in Japan, the spent fuel pool (SFP) suffered continuous loss of cooling due to severe accidents. Since then, the safety issue for the SFP has been widely discussed, even though later evidence showed that the SFP loss of cooling didn't result in the explosion.

In this research, Taiwan power company Chinshan nuclear power plant (NPP) loss of spent fuel pool cooling system as well as loss of pool coolant inventory accident were simulated by using TRACE code, and the mitigation capability of spray system during the accidents were discussed. Chinshan NPP is a BWR/4 plant in Taiwan. There are two SFPs in Chinshan NPP and each one can store about 3100 fuel bundles.

In this research, we first analysed the transient that the spent fuel pool cooling system failed in Fukushima-like accident. In the loss of pool cooling system accident simulation, spray system initiation time, spray flow rate, and spray flow temperature sensitivity studies were performed to examine the accident mitigation. Moreover, we also analysed the accident with concurrent loss of pool cooling system and pool inventory, the focus was mainly on the excessive inventory loss which the initial leakage rate was beyond 500 gpm. In cases with excessive leakage rate, the preferred mitigating process was local spray. The purpose of this study was to evaluate the effectiveness of emergency spray mitigation of NEI 06-12 [1] during a loss-of-coolant inventory accident occurring in the SFP of Chinshan NPP.

# 2. DESCRIPTION OF SPENT FUEL POOL TRACE MODEL

The computer code used in this research is TRACE (TRAC/RELAP Advanced Computational Engine) Version 5.0 Patch 4 which is a best-estimate thermal-hydraulic system code developed by U.S.NRC, and the input model is edited by using SNAP (Symbolic Nuclear Analysis Package) V2.2.7.

## 2.1 <u>Chinshan NPP SFP One-Channel TRACE Model</u>

The width × depth of Chinshan NPP SFP was 12.19 m × 7.87 m with the initial conditions of pool water temperature 51.7 °C and pool water level 11.61 m. Besides, the total decay power of the fuels was roughly 8.99 MWt initially. Figure 1 presents the TRACE model used to simulate the loss of cooling system accident. The pool was modelled by the 3-D VESSEL hydraulic component. In this study, the Cartesian representation had been selected and the VESSEL component was of dimensions with 7 axial levels, 1 X dimension cell, and 1 Y dimension cell. In the axial direction, the SFP water was from the axial level 1 to level 6. The fuels were modelled by the CHAN component which inlet was connected to axial level 2 of the VESSEL component and outlet was connected to axial level 4 of the VESSEL component, and the CHAN component was divided into 25 cell levels.

The heat source of the spent fuel pool was the decay heat of spent fuels and was simulated by a power component of TRACE, using the power table to simulate the power varying during the transient. The decay heat data was calculated from decay energy correlations which were taken from ASB 9-2 decay heat correlation of U.S.NRC standard review plan report [2].

Furthermore, the normal cooling system of the spent fuel pool was failed so that the coolant inlet and the coolant outlet in the normal cooling system were not modelled. Therefore, the FILL component was used as the water spray system into the spent fuel pool, and the BREAK component was used as the pressure boundary condition.

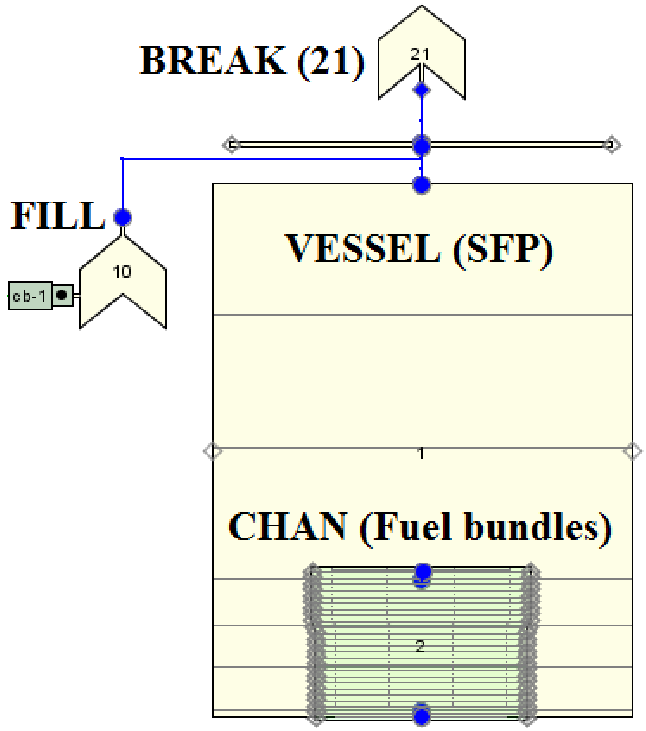


**Figure 1 Chinshan NPP spent fuel pool one-channel TRACE model**

## 2.2 Chinshan NPP SFP Two-Channel TRACE Model

Figure 2 depicts the TRACE model used to simulate the loss of cooling system and pool coolant inventory accident. The pool was also modelled by the 3-D VESSEL hydraulic component which was of dimensions with 7 axial levels, 1 X dimension cell, and 1 Y dimension cell. From axial level 1 to level 6 of the VESSEL component was the SFP water. The FILL component was used as the fire water spray system into the SFP. The BREAK component 20 was used to simulate a hole on the side of the SFP wall as the leakage location and the BREAK component 21 was used as pressure boundary condition. Moreover, in this model, spent fuel bundles were modelled by two CHAN components. The CHAN component 3 represented the newest batch, and the CHAN component 2 represented all the other batches, which had been cooled for a period of time, in the pool.

Furthermore, the heat source of the SFP was the decay heat of fuel bundles and was simulated by a power component, using the power table to simulate the power varying during the transient. The decay heat data was calculated from decay energy correlations which were taken from ASB 9-2 decay heat correlation of U.S.NRC standard review plan report [2]. The initial conditions are summarized in Table 1. The model was initiated from normal conditions.

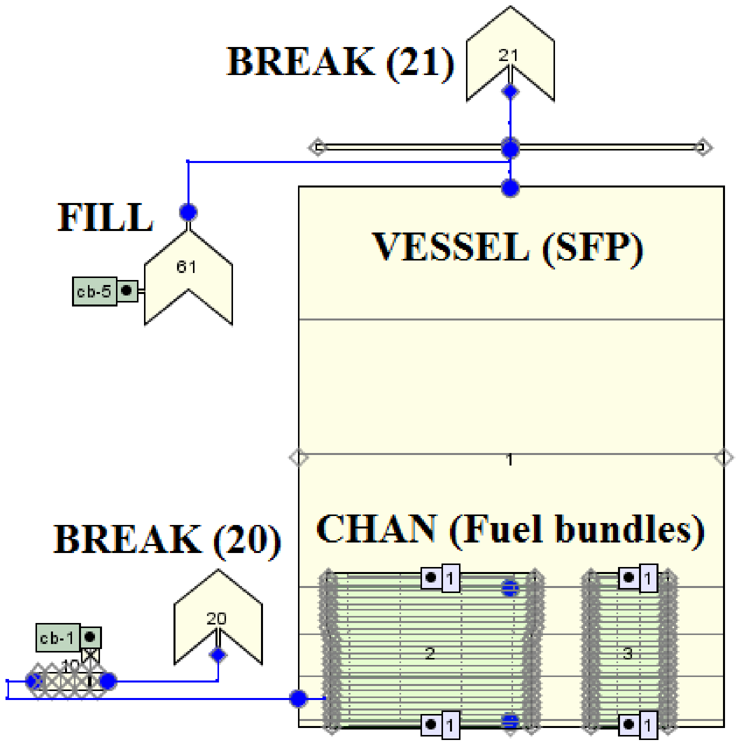


**Figure 2 Chinshan NPP spent fuel pool two-channel TRACE model**

**Table 1 Summary of initial conditions for SFP two-channel model**

| Parameter | Value |
|---|---|
| **Decay power** | 8.99 MW |
| **Pool water temperature** | 333 K |
| **Water level** | 11.61 m |
| **Spray flow rate** | Usually 200 gpm |
| **Spray temperature** | 298 K |
| **Spray initiation time** | 2 hours after SFP start leaking |
| **Initial leakage rate (Leak size)** | 500, 550, 600, 650, 700 gpm (5.78,6.06,6.32,6.57,6.82 cm) |

## 2.3 Chinshan NPP SFP Multi-Channel TRACE Model

Figure 3 shows the TRACE model used to simulate the loss of cooling system accident. The pool was modelled by the 3-D VESSEL hydraulic component which was of dimensions with 13 axial levels, 1 X dimension cell, and 1 Y dimension cell. The SFP water was from axial level 1 to level 11 of the VESSEL component. The FILL component was used as the fire water spray system into the SFP. The BREAK component 21 was used as pressure boundary condition. Moreover, in this model, spent fuel bundles were modelled by six CHAN components. The CHAN component 51 represented the newest batch. The other CHAN components represented all the other batches, which had been cooled for a period of time, in the pool, and their decay heat power was calculated depending on different locations of batches in the pool.

Furthermore, the heat source of the SFP was the decay heat of fuel bundles and was simulated by a power component, using the power table to simulate the power varying during the transient. The decay heat data was calculated from decay energy correlations which were taken from ASB 9-2 decay heat correlation of U.S.NRC standard review plan report [2].

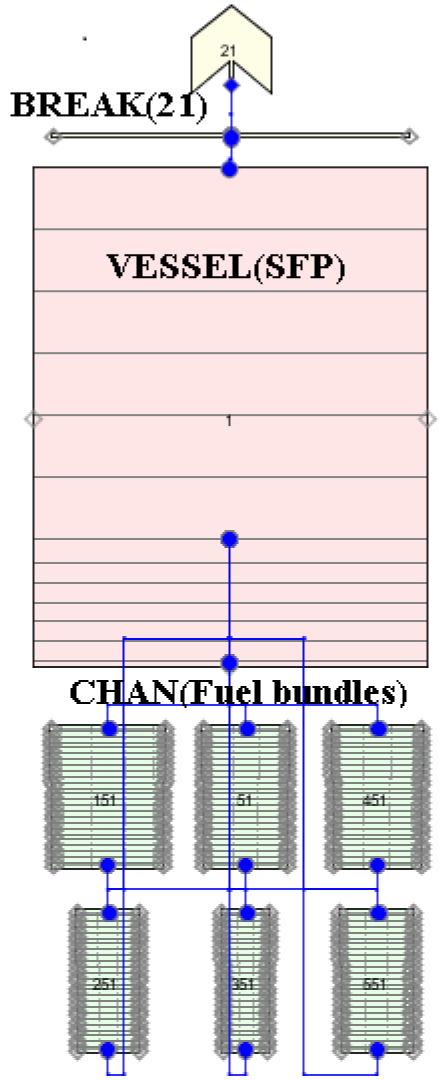


**Figure 3 Chinshan NPP spent fuel pool multi-channel TRACE model**

# 3. SIMULATION RESULTS OF FUKUSHIMA ACCIDENT AT DAIICHI NUCLEAR POWER STATION UNIT 4 SPENT FUEL POOL

A study on the Fukushima Daiichi nuclear power plant spent fuel pool at Unit 4 was presented in the paper of Dean Wang et al. at Oak Ridge National Laboratory (ORNL) [3]. This study predicted SFP level and temperature which were in good agreement with measured data and Tokyo Electric Power Company evaluation results. The agreement allows us to compare our simulation results with Dean Wang's data.

In this study, all the essential data needed to perform Fukushima accident at Daiichi NPP Unit 4 spent fuel pool (SFP4) were from Dean Wang's study. The width × depth of SFP4 was 12.2 m × 9.9 m with the initial conditions of pool water temperature 27 °C and pool water level 11.58 m. Besides, the total decay power of the spent fuels was also collected from Dean Wang's study.

Figure 4 shows the comparative results in water level simulated by TRACE code with predicted by Dean Wang. In the simulation of nine days, there was no spent fuel being uncovered. According to the comparison, it can be found that the pool water level changing trends in two predicted results were similar. The main difference was the time that the pool water level began to decrease.

Figure 5 presents the fuel cladding temperature history during the Fukushima accident. Because there was no fuel being uncovered, the temperature changes of the fuel cladding and water were supposed to be closely related.

The above comparison results indicated that TRACE could simulate the SFP well in Fukushima accident. Subsequently, based on the successful experience from the above model, this research focuses on the establishment of Chinshan NPP SFP TRACE models and the applications of TRACE models in Fukushima-like accident.

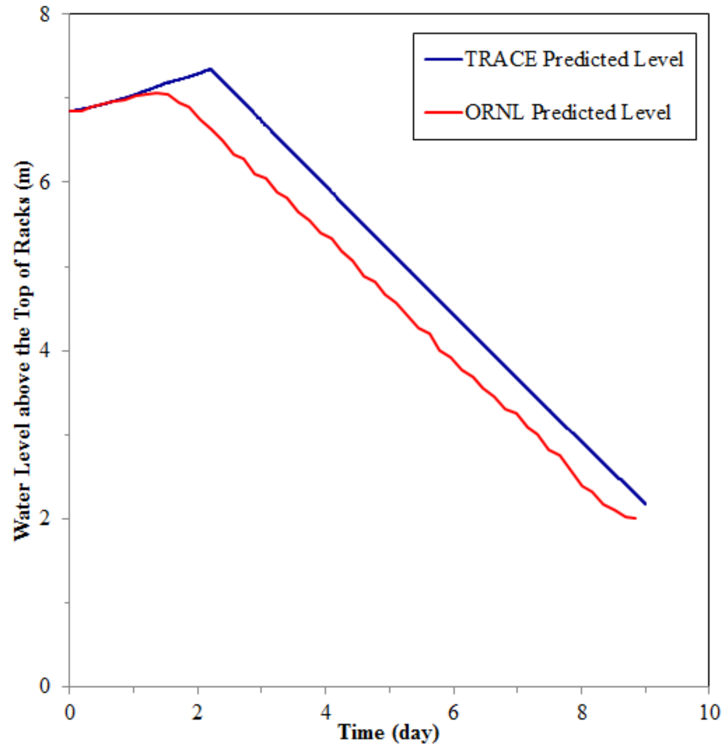


**Figure 4  The water level of SFP4**

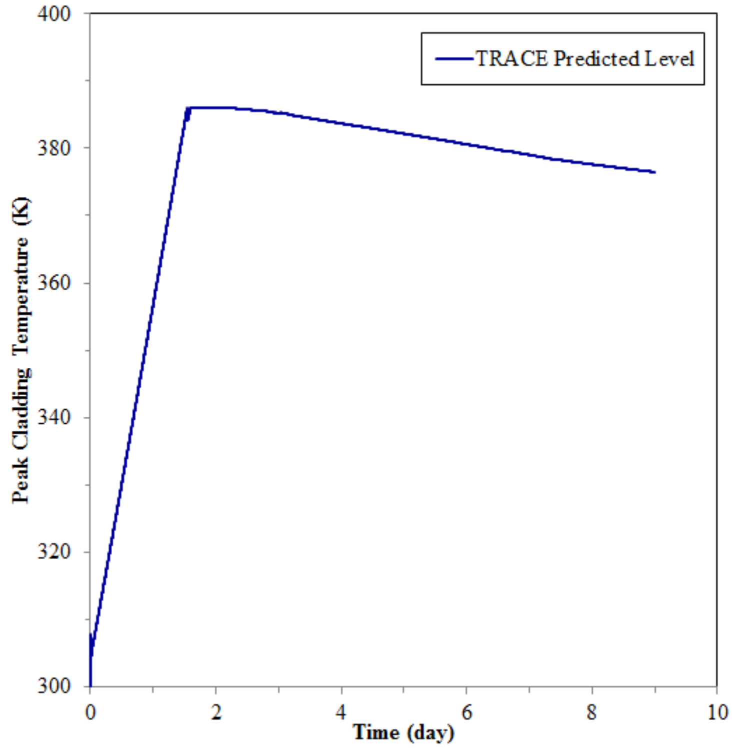


**Figure 5 The peak cladding temperature of SFP4**

# 4. SIMULATION RESULTS OF CHINSHAN SFP LOSS OF COOLING SYSTEM ACCIDENT

In order to investigate the different parameters affecting to mitigate the consequences in the loss of cooling system accident, there were three topics in the sensitivity studies which included: (a) spray system initiation time, (b) spray flow rate, and (c) spray flow temperature. The detailed settings in these sensitivity studies were described in Table 2-4.

**Table 2  Study of spray system initiation time**

| (a) Spray system initiation time | | |
|---|---|---|
| Spray initiation time | pool level reaching top of fuel | pool level reaching 2/3 fuel height |
| Spray flow rate | 200 gpm | |
| Spray temperature | 298.15 K | |

**Table 3  Study of spray flow rate**

| (b) Spray flow rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spray initiation time | pool level reaching top of fuel | | | | pool level reaching 2/3 fuel height | | | |
| Spray flow rate | 100 gpm | 150 gpm | 200 gpm | 250 gpm | 100 gpm | 150 gpm | 200 gpm | 250 gpm |
| Spray temperature | 298.15 K | | | | | | | |

**Table 4  Study of spray flow temperature**

| (c) Spray flow temperature | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spray initiation time | pool level reaching top of fuel | | | | pool level reaching 2/3 fuel height | | | |
| Spray flow rate | 200 gpm | | | | | | | |
| Spray temperature | 288.15 K | 293.15 K | 298.15 K | 303.15 K | 288.15 K | 293.15 K | 298.15 K | 303.15 K |

## 4.1 Study of Spray System Initiation Time

According to the analysis results, if the SBO accident occurred without any alternate water replenishment measure, fuel bundles were uncovered. In order to verify how the effect mitigates the consequence of the SBO, the spray system initiation time were selected to be analysed. In this sensitivity study, there were concerns about spray time, which included the spray system initiation time with the cases of pool level reaching top of fuel and 2/3 fuel height. Additionally, there were some settings for spray system, including spray flow rate with 12.66 kg/s (= 200 gpm), spray flow temperature with 298.15 K, and spray system stopped when the pool level reached 11 m.

Figure 6 shows the different changes in water level under the different setting of fire water spray time. The water level decreased to the top of fuel rods at 66 hours and the 1/3 fuel rods were exposed at 77 hours after an SBO occurred.

Figure 7 presents the fuel cladding temperature history during the accident in this sensitivity study. It could be found that if spraying at the moment that the fuel rods were just uncovered, it could effectively restrain the rise of the fuel cladding temperature; however, if spraying at the 1/3 fuel rods exposed, the fuel cladding temperature increased about 112 K. But peak cladding temperature was still at a very low level and away from the temperature that induced the metal-water reaction. Also, if the fire water spray time was later than the pool level reaching to the 2/5 fuel height, the fuel cladding temperature went up to the temperature generating the metal-water reaction.

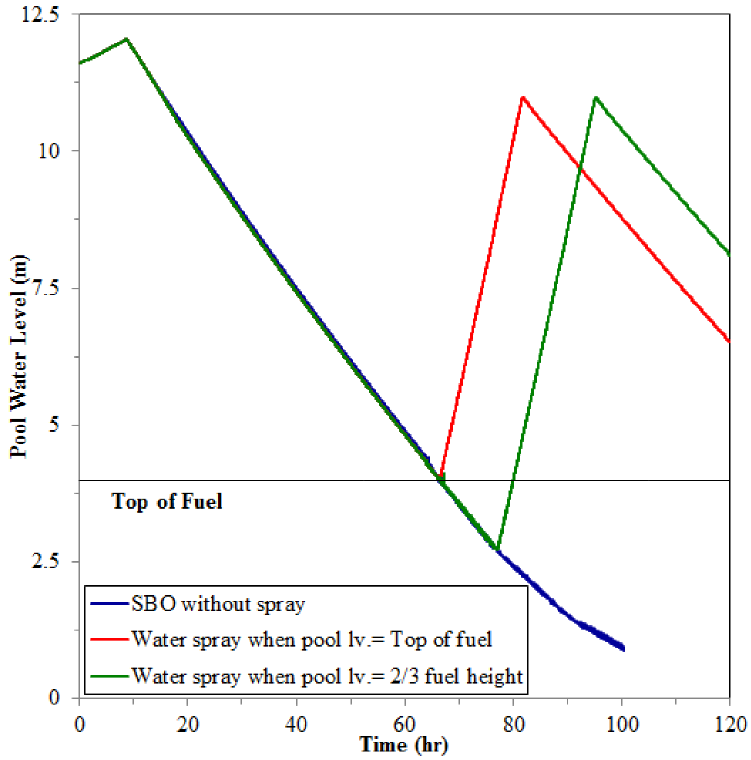


**Figure 6 The water level of the SFP for sensitivity study of spray system initiation time**

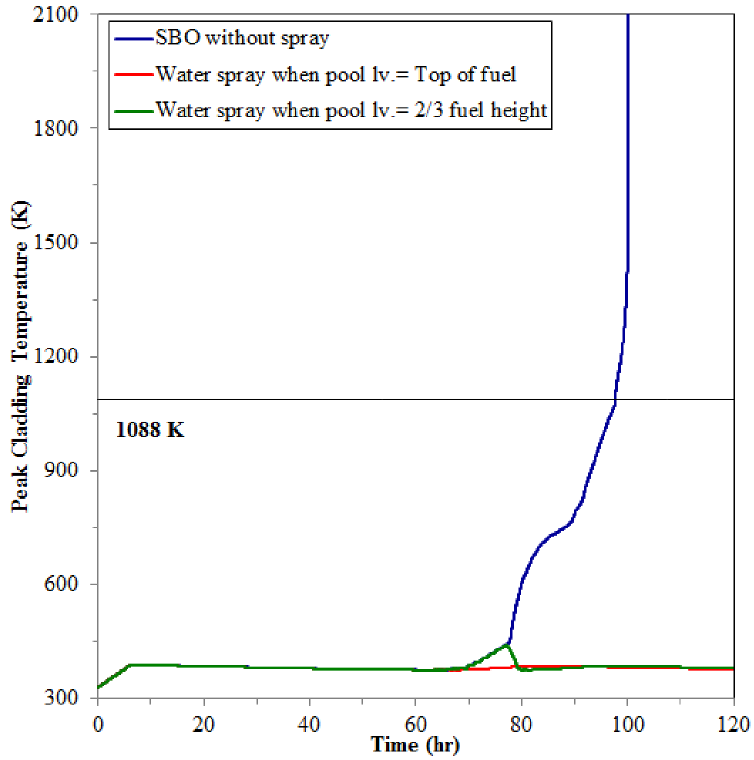


**Figure 7 The peak cladding temperature for sensitivity study of spray system initiation time**

## 4.2 Study of Spray Flow Rate

During the SBO accident, the situation becomes more complicated as fire water capacity must be restricted to control the spray flow rate. Therefore, a sensitivity study was performed to investigate the impact of controlling the spray mass flow rate. In this sensitivity study, there were divided into two parts: (1) spray system initiated while pool level reached top of fuel (case 1), (2) spray system initiated while pool level reached 2/3 fuel height (case 2). Also, the spray flow rate were selected with cases of 6.33 kg/s (= 100 gpm), 9.49 kg/s (= 150 gpm), 12.66 kg/s (= 200 gpm), and 15.82 kg/s (= 250 gpm) for both of two parts.

In case1, the water level change is shown in Figure 8. It could be clearly seen that while fire water flow rate was getting lower, it took a longer time to restore the pool water level. Figure 9 shows the fuel cladding temperature results. It can be found that the fuel cladding temperature oscillates in about 5 degrees after starting spraying. That is because the fuel rods are just uncovered but coming into contact with the spray water, and then producing the vibrations. Although the water temperature in spent fuel pool and channel is not presented, the temperature changes of the fuel cladding and water are supposed be closely related. Moreover, after starting spraying, the water temperature increased towards the saturation temperature corresponding to static pressure in each level. And then after stopping spray, the pool water level decreased due to evaporation of the water, causing the decrease of static pressure and saturation temperature in each level.

In case 2, from Figure 10 and 11, before starting to spray, the fuel bundles were getting uncovered for about 11 hours. As the result, the fuel cladding temperature had already risen to 440 K. Additionally, at the beginning of spraying, it could reduce the cladding temperature effectively, and the cladding temperature was still away from the temperature that induces the metal-water reaction. After that, the fuel cladding temperature of each case decreased.

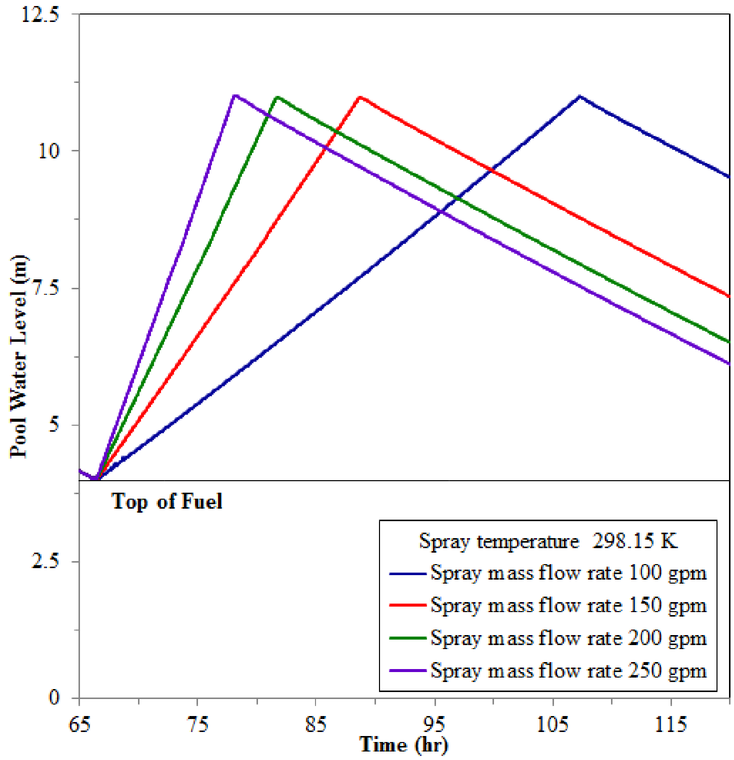


**Figure 8 The water level of the SFP for sensitivity study of spray flow rate (beginning to spray while pool level reached top of fuel)**

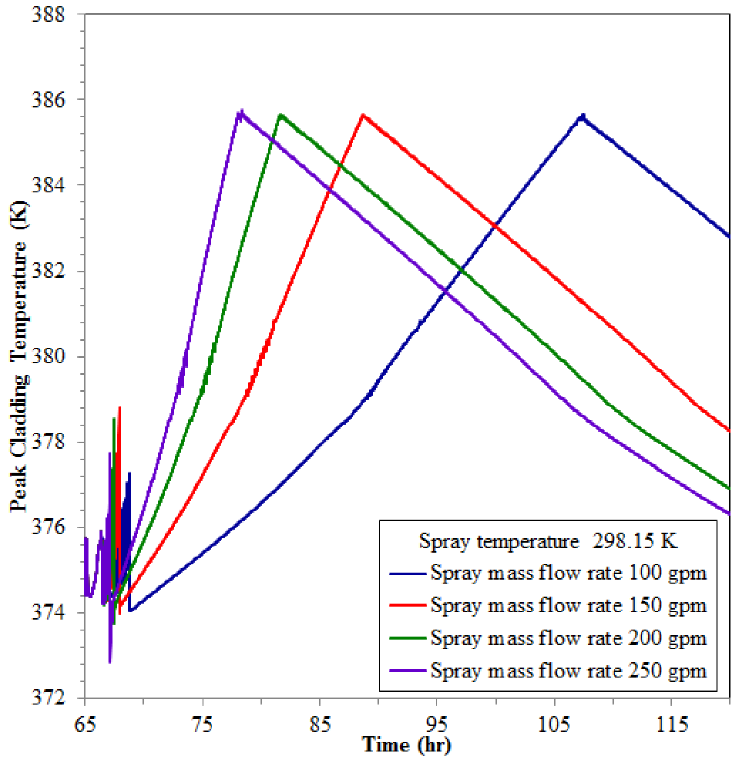


**Figure 9 The peak cladding temperature for sensitivity study of spray flow rate (beginning to spray while pool level reached top of fuel)**

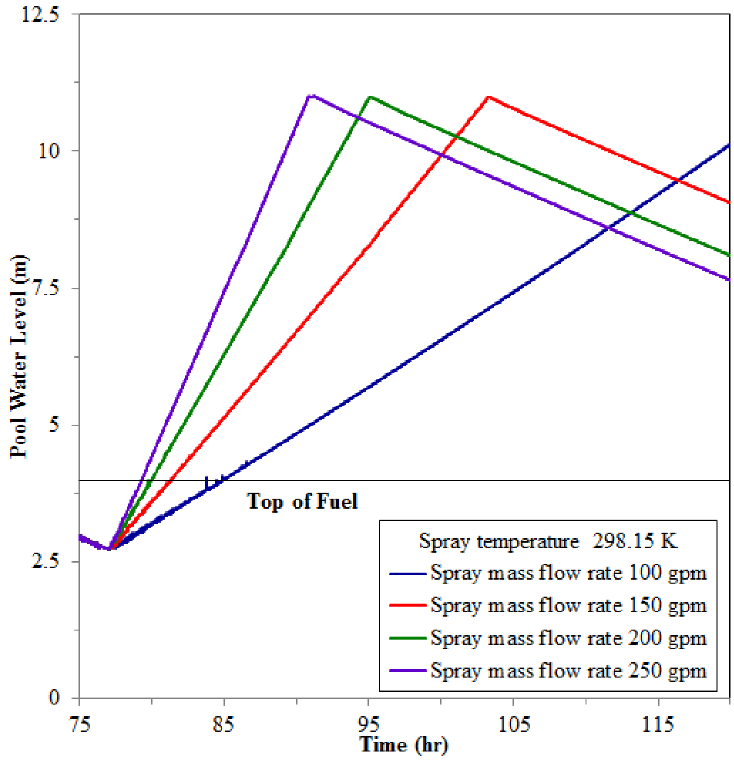


**Figure 10 The water level of the SFP for sensitivity study of spray flow rate (beginning to spray while pool level reached 2/3 fuel height)**

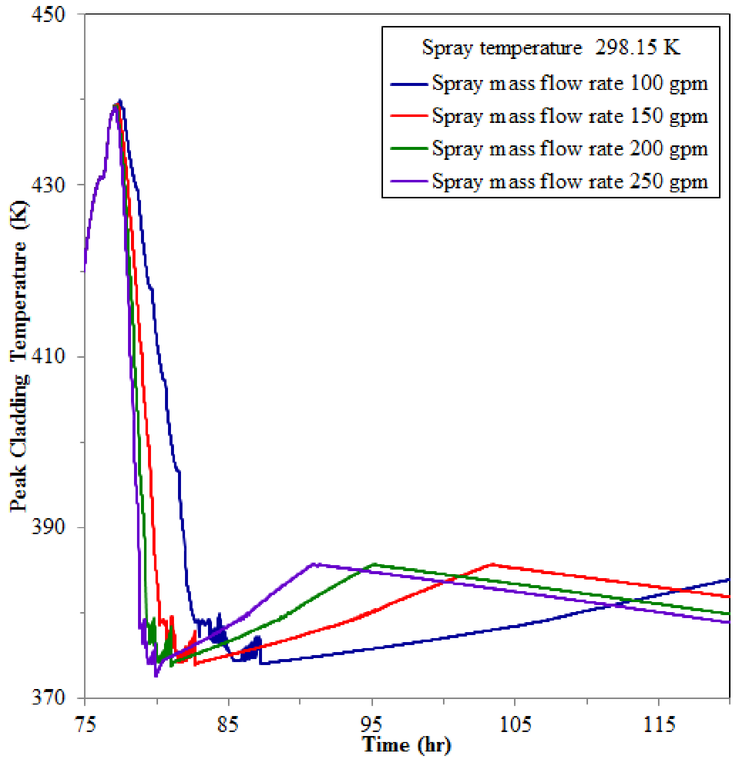


**Figure 11 The peak cladding temperature for sensitivity study of spray flow rate (beginning to spray while pool level reached 2/3 fuel height)**

## 4.3 Study of Spray Flow Temperature

The water temperatures are different in summer and winter. Therefore, a sensitivity study was selected to investigate the impact of spray flow temperature. In this sensitivity study, there were also divided into two parts: (1) spray system initiated while pool level reached top of fuel, (2) spray system initiated while pool level reached 2/3 fuel height. Additionally, there were cases with spray temperature of 288.15 K, 293.15 K, 298.15 K, and 303.15 K for both of two parts.

It can be found that the results of different spray temperature are quite similar, as shown in Figure 12-15. The likely reason for the similarity is that the mass flow rate of 12.66 kg/s (= 200 gpm) to spraying can be described as a drop in the bucket, comparing with the volume of spent fuel pool. Accordingly, there is no significant difference in the temperature. In fact, even the maximum temperature difference is only 15 degrees.

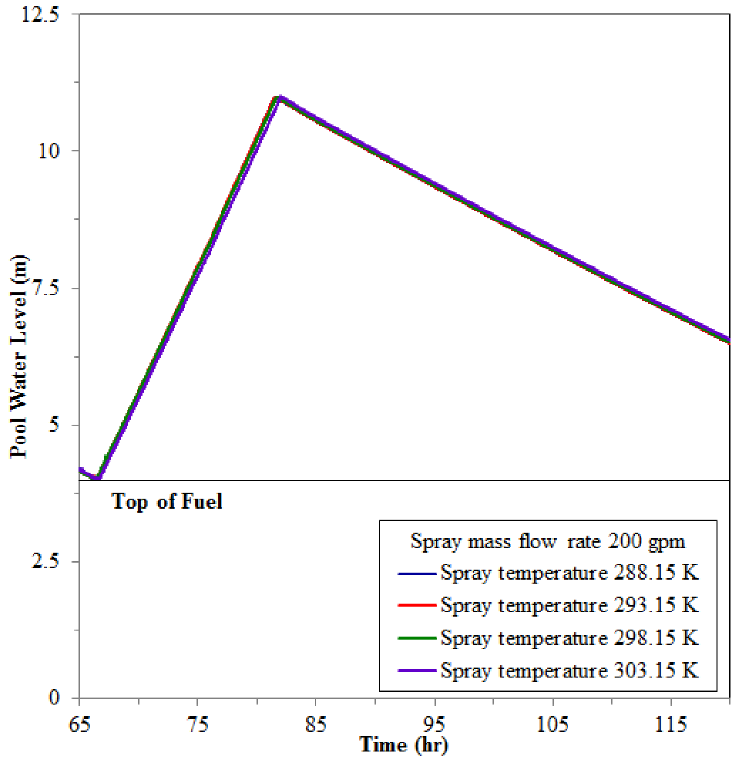


**Figure 12 The water level of the SFP for sensitivity study of spray flow temperature (beginning to spray while pool level reached top of fuel)**

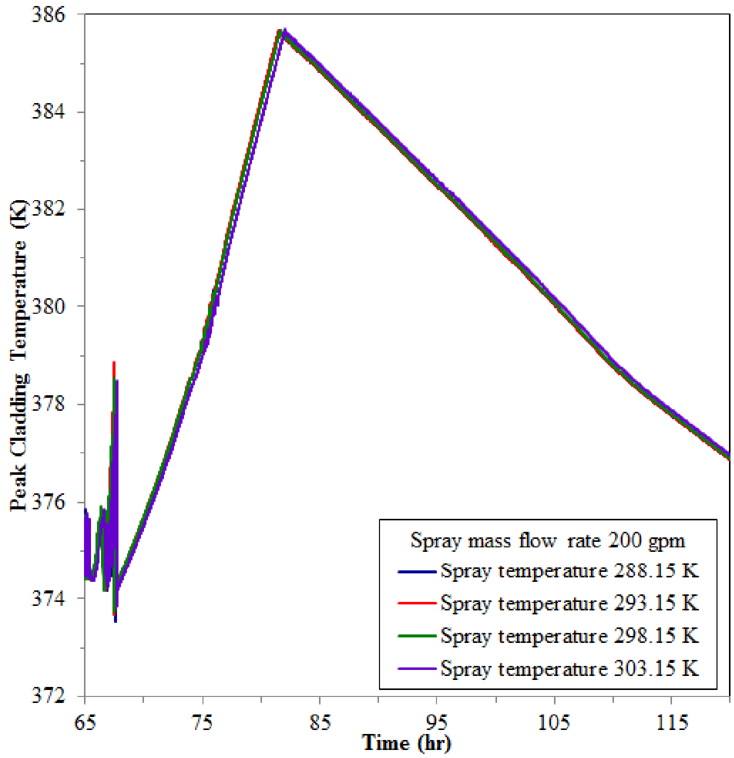


**Figure 13 The peak cladding temperature for sensitivity study of spray flow temperature (beginning to spray while pool level reached top of fuel)**

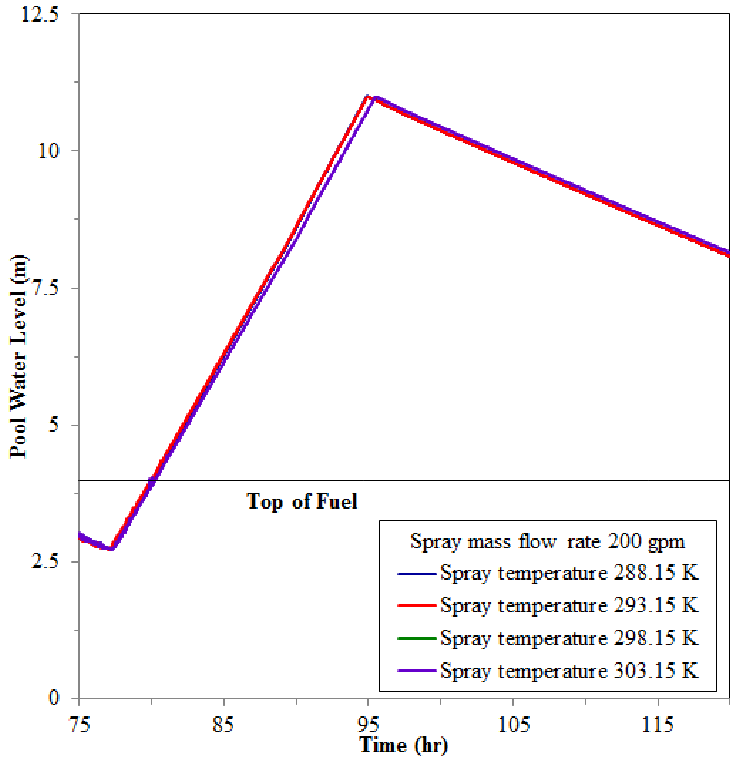


**Figure 14 The water level of the SFP for sensitivity study of spray flow temperature (beginning to spray while pool level reached 2/3 fuel height)**

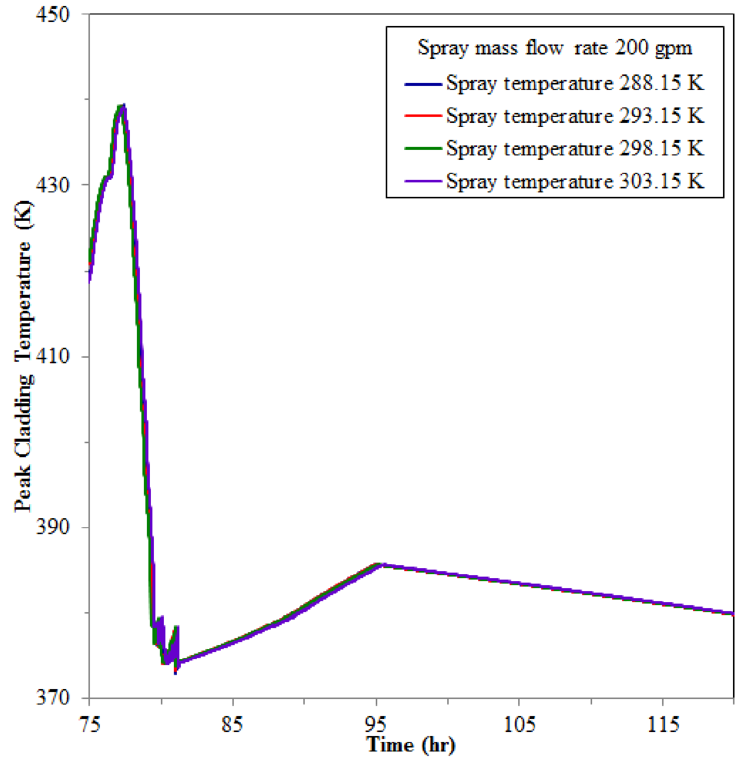


**Figure 15 The peak cladding temperature for sensitivity study of spray flow temperature (beginning to spray while pool level reached 2/3 fuel height)**

# 5. SIMULATION RESULTS OF CHINSHAN SFP LOSS OF COOLING SYSTEM AND POOL COOLANT INVENTORY ACCIDENT

According to NEI 06-12, TRACE calculations focus on cases with excessive leakage rates of 500 gpm, 550 gpm, 600 gpm, 650 gpm, and 700 gpm. This study examines differences in the response with and without spray. Moreover, the leakage location is at the level 2 of the VESSEL component which is the same level of the bottom of fuel bundles, as shown in Figure 2. In this study, the resultant water level and peak cladding temperature were two major concerning parameters which were used to evaluate the effectiveness of emergency spray mitigation. These calculation results are shown in Figure 16-20.

Figure 16 shows the water level results of cases with different leakage rates and without spray. The water level dropped in response to the leakage. It could be clearly seen that while the leakage rate was getting larger, it took a shorter time to cause fuel bundles to be uncovered.

Figure 17 shows the cladding temperature responses for cases with different leakage rates and without spray, respectively. All the cases reached to 1088 K (1500 °F) where the cladding metal water reaction was able to generate. The cases without sprays had the fastest heat up due to the absence of any spray cooling.

Figure 18 and Figure 20 show the water level changes and the cladding temperature responses for the different leakage rates cases with spray. From Figure 18, with 500 gpm leakage rate, the timing to uncover fuel bundles (at 15 hr) is slower than the other cases. Consequently, the spray had been operating for over 12 hours before fuel bundles start to be uncovered. In addition, as the water level is dropping, which means that the pressure head above the leak location is dropping, the leakage rate is steadily decreasing, as shown in Figure 19. However, after the 200 gpm emergency spray started, emergency spray had little impact in slowing the level dropping due to the high leakage rate. Finally, while the water level dropped to a specific value, the leakage rate, water evaporation rate and spray flow rate were reaching equilibrium. The long-term water levels of all cases except for 700 gpm leakage rate were reaching the steady state levels.

As shown in Figure 20, the 550 gpm case oscillates near 1088 K (1500 °F). The peak cladding temperatures in 600 and 650 gpm cases were almost increasing to 1477 K (2200 °F) where the cladding metal water reaction dramatically reacts, and then cladding temperatures began to decrease to about 1200 K. The peak cladding temperature in the 500 gpm case was only 945 K at 53 hr and less than 815 K long-term. Although oscillating near 1088 K or maintaining at almost 1200 K, the results show the ability of a higher spray to prevent unmitigated heat-up to the cladding metal water reaction. However, with 700 gpm leakage rate, fuel bundles went into a rapid oxidation and heated from 1088 K at 16.5 hr to exceed 1500 K at 21.8 hr.

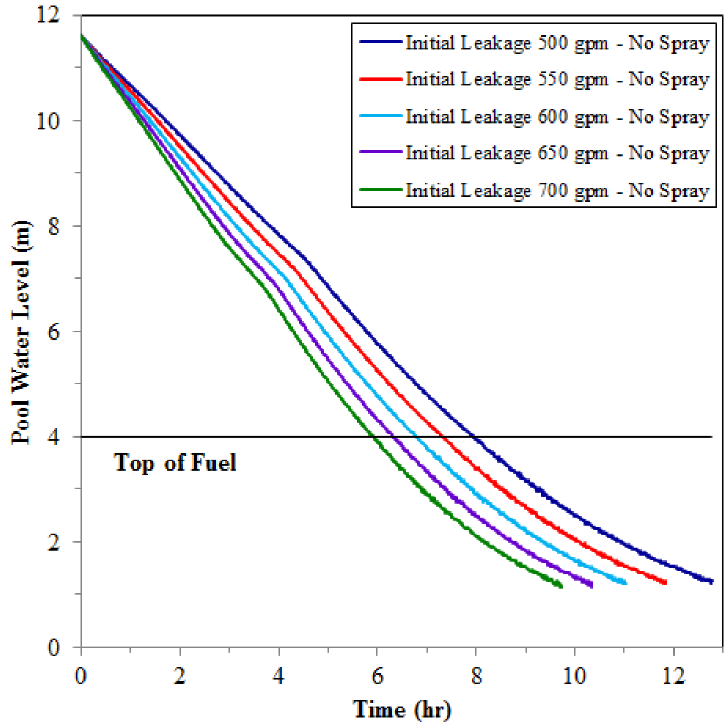


**Figure 16 The water level for different leakage rates without spray**

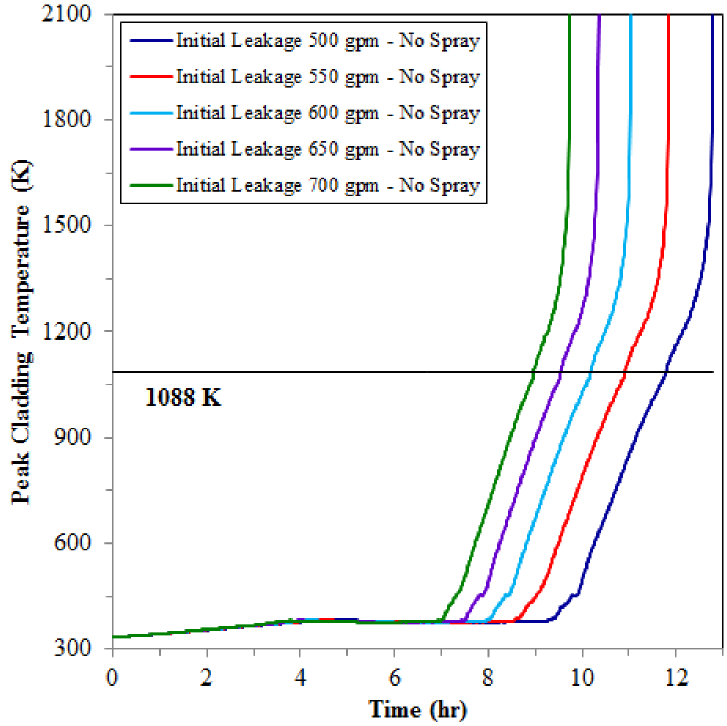


**Figure 17 The peak cladding temperature for different leakage rates without spray**

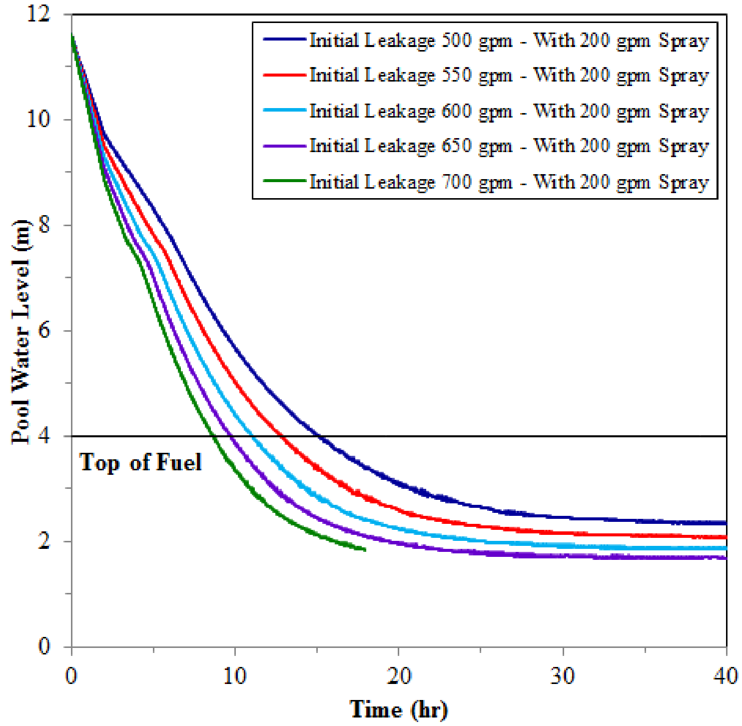


**Figure 18    The water level for different leakage rates with spray**

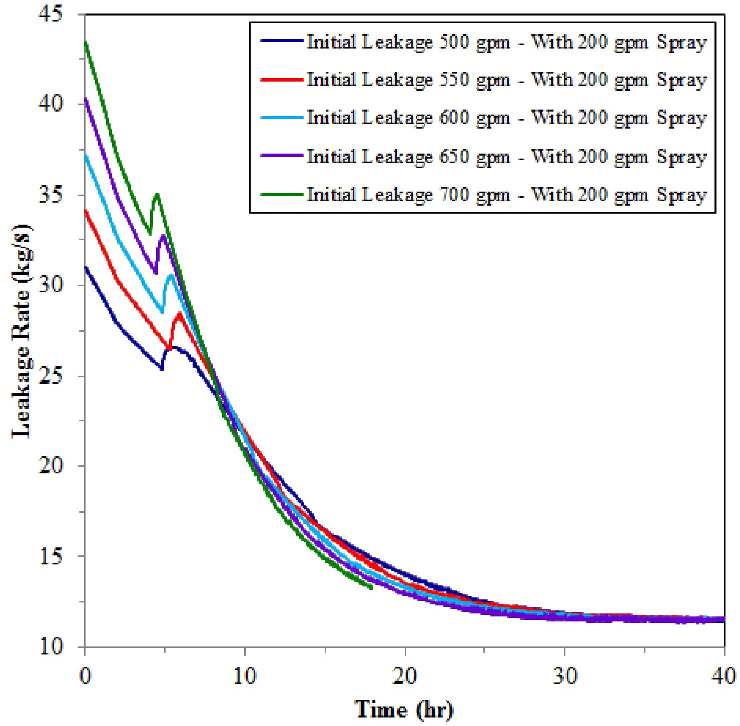


**Figure 19 The changes of different leakage flow rates with spray**

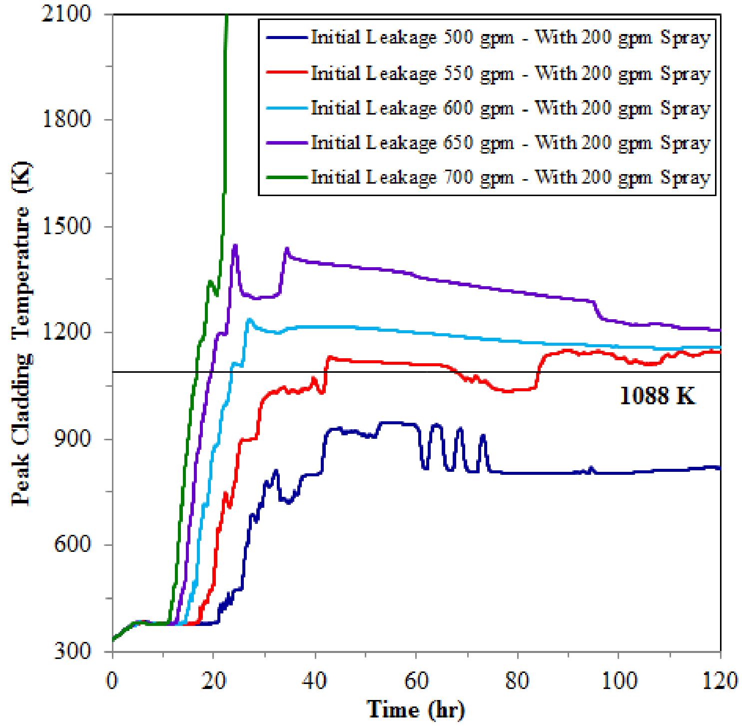


**Figure 20 The peak cladding temperature for different leakage rates with spray**

# 6. SIMULATION RESULTS OF CHINSHAN SFP LOSS OF COOLING SYSTEM ACCIDENT USING MULTI-CHANNEL TRACE MODEL

In this section, we used multi-channel TRACE model to simulate loss of cooling system accident without any water replenishment. Besides, there was the sensitivity study conducted to investigate how the timestep size affected the simulation results. Furthermore, in this study, we also compared the results simulated by multi-channel TRACE model with the results simulated by one-channel model and two-channel model.

Figure 21 and Figure 22 show the water level changes and the cladding temperature responses for different timestep size settings.

From Figure 21, with timestep size 10 sec and 1 sec, the timing to uncover fuel bundles is faster than the other three cases which the simulation results are almost the same, only different in the ending time of these three cases. Consequently, the timing to uncover fuel bundles can affect the peak cladding temperature response, as shown in Figure 22.

Table 5 shows the problem time and the computational time for cases with different timestep size. As shown in Figure 22, cases with timestep size 10 sec, 1 sec and 0.01 sec ended due to the peak cladding temperature reached the calculated limit in TRACE. However, the case with timestep size 0.1 sec ended with no reason, which needs to be further investigated. Besides, we stopped to simulate the case with timestep size 0.001 sec after 20.75 days in computational time.

According to the results provided above, we choose the case with timestep size 0.01 sec to compare with the results simulated by one-channel model and two-channel model. Figure 23 and Figure 24 show the water level changes and the cladding temperature responses simulated by three models. From Figure 23, the changes in pool water level are almost the same in these three models. However, as shown in Figure 24, it can be found that the peak cladding temperature responses are slightly different in the timing that cladding temperature starts to increase. According to the calculation, the possible reason was that we considered the actual location of spent fuel bundles in the spent fuel pool to calculate the decay heat power for each CHAN component. To sum up, if we use more CHAN components, the peak cladding temperature response can be more accurate.

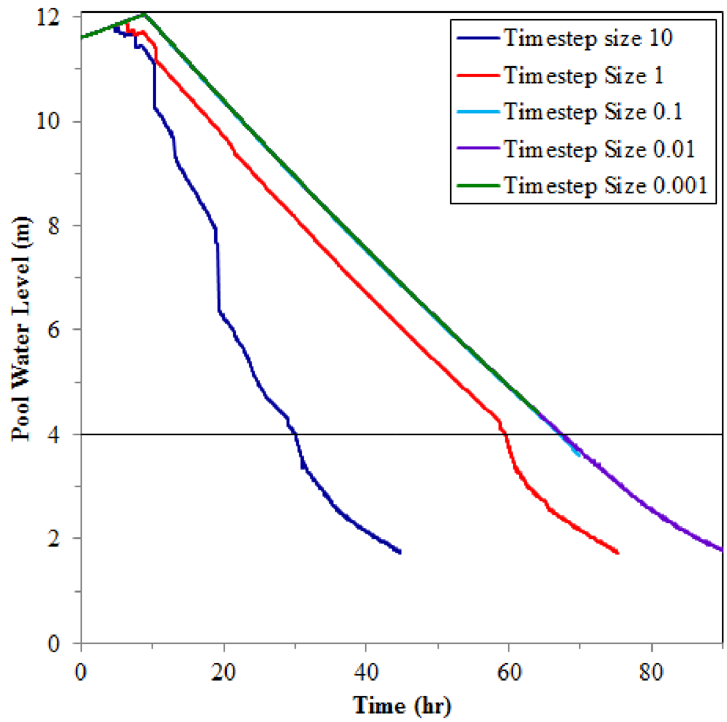


**Figure 21  The pool water level for different timestep sizes**

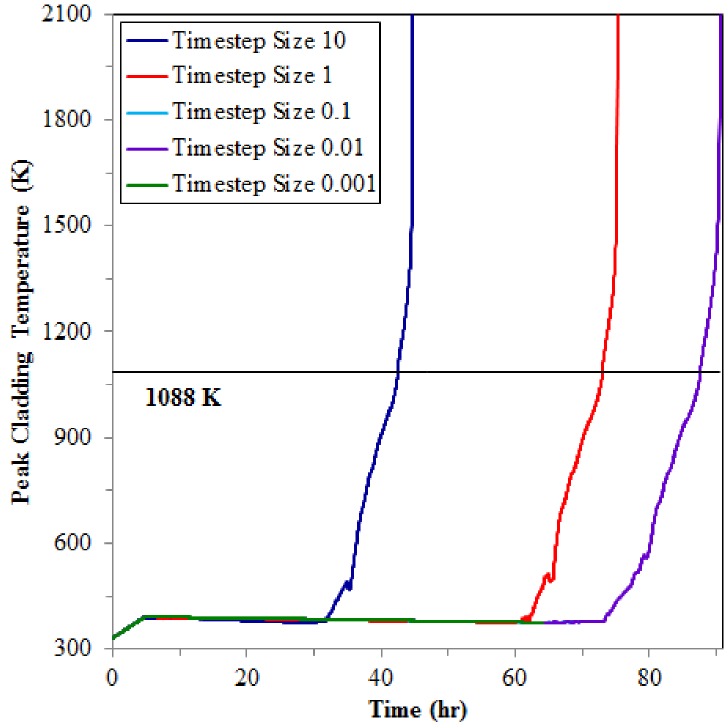


**Figure 22 The peak cladding temperature for different timestep sizes**

**Table 5 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 |

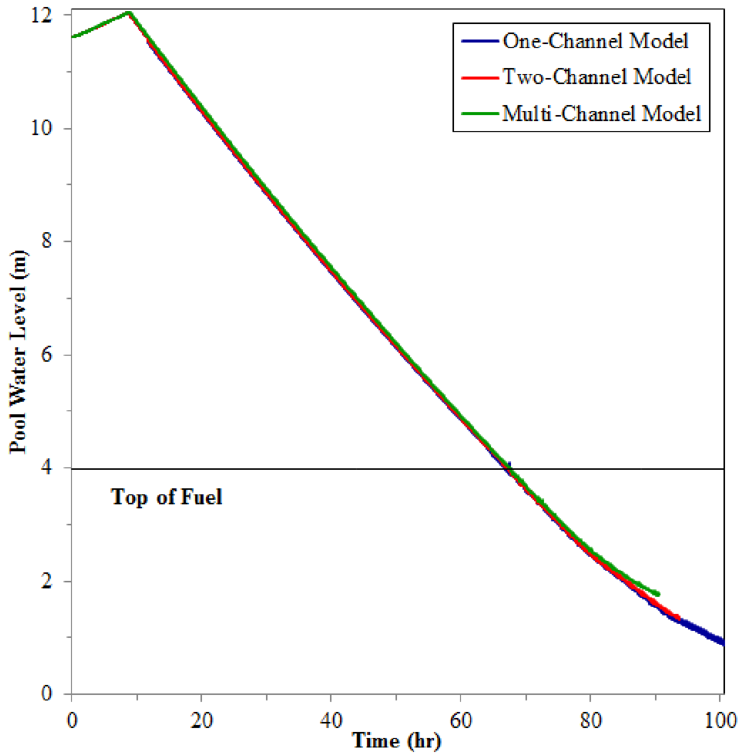


**Figure 23 The pool water level for three models**

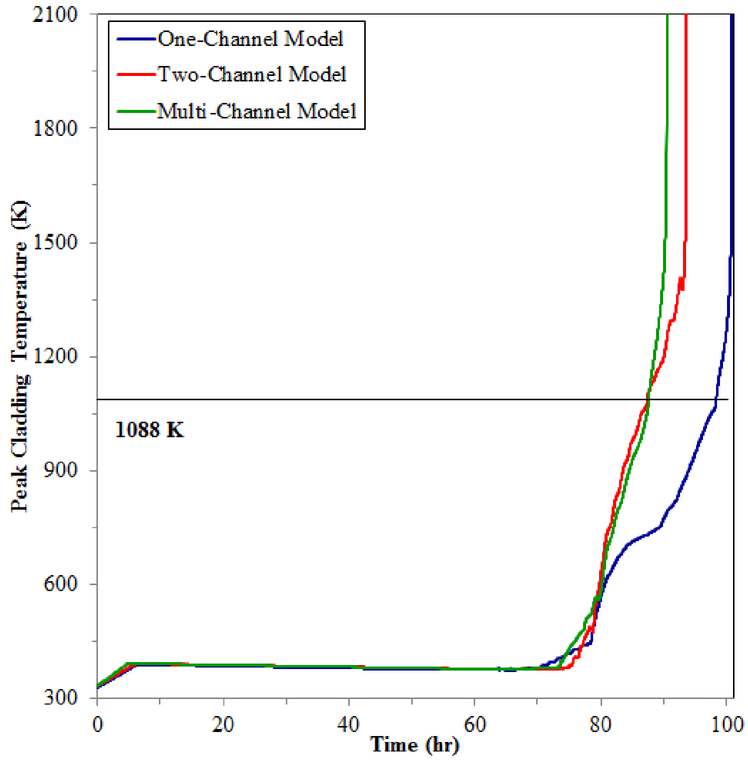


**Figure 24 The peak cladding temperature for three models**

# 7. CONCLUSION

In this study, TRACE/SNAP models of Chinshan NPP spent fuel pool were established successfually by using SNAP 2.2.7 and TRACE v5.0p4. In the analyses of spent fuel pool loss of cooling system accident, several sensitivity studies of the water spray in the spent fuel pool were performed in order to investigate the effect of the spray flow rate, spray flow temperature, and spray initiation time during SBO. According to the sensitivity results, the mass flow rate based on the same spray time was the most sensitive parameter. Besides, if the fire water spray time was later than the pool level reaching to the 2/5 fuel height, the fuel cladding temperature went up to the temperature generating the metal-water reaction. The results can help to evaluate the safety issue of the Chinshan NPP spent fuel pool suffering from Fukushima-like scenarios.

Furthermore, in the study of spent fuel pool loss of cooling system and pool coolant inventory accident, helping to evaluate the effectiveness of emergency spray mitigation of NEI 06-12 in the SFP of Chinshan NPP. Based on the calculation results, one of the important outputs was the final water level. For the range of leakage rates considered in this study, fuel bundles were partially covered. Also, it could be clearly seen that while the initial leakage rate was increasing, the peak cladding temperature was getting higher. The peak cladding temperature of the case with 700 gpm leakage rate and 200 gpm spray flow even exceeded 1500 K. Moreover, those cases near 1088 K required a higher spray to prevent the cladding metal water reaction dramatically reacting due to unmitigated heat-up.

In this report, we also compared the results simulated by multi-channel TRACE model with the results simulated by one-channel model and two-channel model for the loss of cooling system accident without any water replenishment. We used the timestep size 0.01 sec in the above models. According to the comparison results, the peak cladding temperature response was more accurate in the multi-channel TRACE model.

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10. SUPPLEMENTARY NOTES

K.Tien, NRC Project Manager

11. ABSTRACT (200 words or less)


In this research, loss of spent fuel pool cooling system and loss of pool coolant inventory accident in Chinshan nuclear power plant (NPP) were simulated by using TRACE code, the latest best-estimate thermal-hydraulic system code developed by the U.S.NRC. Besides, the mitigation capability of spray system during the accidents was discussed.

In TRACE input model, the calculation of decay thermal power of spent fuel was based on ASB 9-2 decay heat correlation of U.S. NRC standard review plan report. To simulate the accident mitigation, spray system initiation time, spray flow rate, and spray flow temperature sensitivity studies were performed in the loss of pool cooling system accident simulation. In the simulation of concurrent loss of pool cooling system and pool inventory, the focus was mainly on the excessive inventory loss which the initial leakage rate was beyond 500 gpm.

The capability of mitigation strategy was evaluated by using simulation results including spent fuel pool water level and fuel cladding temperature variation. The results depicted that in the loss of pool cooling system cases, the earlier the spray system initiated, the shorter pool inventory recover time was needed, and the cladding temperature was lowered effectively by performing a larger spray flow rate. In the loss of both pool cooling system and pool inventory cases, the cladding temperature was controlled even the fuels were partially uncovered, and the spray flow should not less than 200 gpm to avoid the sharp increase of cladding temperature.


| 12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.) | |
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