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Thermal analysis for the integrated spent fuel pool of the Chinshan plant in the decommissioning process

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ABSTRACT

The Chinshan plant in Taiwan will start decommissioning in December 2018. However, the remaining storage capacity of the spent fuel pool (SFP) is insufficient to load one full-core fuel into it. In addition, the dry cask storage facility has not been approved and cannot be used to load the old fuel that has been in the SFP for years. Thus, the reactor core will be used to contain fuel and the reactor cavity is planned to remain connected with the SFP at the beginning of decommissioning. The alternative decay heat removal strategy will be applied to the integrated SFP cooling. Thermal analyses for the integrated SFP are performed with GOTHIC in this study. The period that the Residual Heat Removal (RHR) system should be operable is evaluated. A lumped model is developed to calculate the pool temperature during normal condition, and the results are in good agreement with those from the simplified energy balance equations. A detailed model is also developed for the loss-of-coolant accident of the integrated SFP. Based on the results of the most limiting case which is the recirculation line break accident, the RHR system should be remained operable for 1800 days after the decommissioning starts. Currently, both of the Chinshan units are not in operation. The real shutdown period is sufficiently longer than that assumed in this study. Safety of the integrated SFP in the decommissioning process is further ensured.

1. Introduction

The Chinshan plant owned by Taiwan Power Company is located in the north-east coast of Taiwan. Two identical BWR/4 units of this plant began commercial operation in 1978 and 1979, respectively. The reactor core of each unit comprises 408 fuel assemblies and the original core thermal power was 1775 MWt. The core thermal power was uprated to 1804 MWt in 2008 and further uprated to 1840 MWt in 2012 (Taiwan Power Company, 2012). However, the life extension project for the Chinshan plant was withdrawn in 2016. The operation license of the Chinshan unit 1 will expire in December 2018. Unfortunately, the dry cask storage facility of this plant is opposed by the local government and its operation license has not been approved. After operating for 39 years, every spent fuel discharged from the reactors is still stored in the spent fuel pools (SFPs) of the Chinshan plant. No spent fuel is allowed to be removed from the SFP yet.

During the last outage of the Chinshan unit 1 (December 2014), handler failure of one fuel assembly in the core was found and reported. Although this failure was fixed, unit 1 cannot return to operation by the order of the Legislature. Moreover, unit 2 was tripped on June 2017 because a transmission tower on a nearby hilltop toppled in heavy rain. The reactor and the steam supply systems are not damaged. However, the failed transmission tower cannot be fixed in short time. Thus, both Chinshan units are not in operation now. Although the 40-years operation licenses of the two units are currently available, this plant cannot return to operation anymore. The decommissioning of this plant will start in recent years. It will be an issue that the fuel in the SFP cannot be removed.

In addition to the Chinshan plant, the Kuosheng plant also owned by Taiwan Power Company has the same problem of insufficient SFP storage capacity. By implementing more fuel racks in the cask loading pool (Chen and Yuann, 2017), the Kuosheng unit 1 returned to operation in June 2017 (Atomic Energy Council, 2017). However, there is no extra space to install more racks in the Chinshan SFPs. Furthermore, the dry cask storage facility has not been approved. The existing spent fuel in the SFP cannot be

Abbreviations: *BWR*, Boiling Water Reactor; *FSAR*, Final Safety Analysis Report; *HX*, Heat Exchanger; *PCT*, Peak Cladding Temperature; *RCLB*, Recirculation Line Break; *RHR*, Residual Heat Removal; *SFP*, Spent Fuel Pool; *SFPACS*, Spent Fuel Pool Additional Cooling System; *SFPCCS*, Spent Fuel Pool Cooling and Cleanup System; *SGTS*, Standby Gas Treatment System; *TAF*, Top of the Active Fuel.

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removed, and the fuel in the core cannot be moved into the SFP either. Thus, Taiwan Power Company proposes that the spent fuel still remains in the reactor core, i.e., the reactor and the SFP are merged into an integrated pool. The integrated pool will be managed as a SFP in the Chinshan decommissioning process.

For operating plants, the SFP heat-up analysis is a necessary part of the Final Safety Analysis Report (FSAR) of each plant (U.S. NRC, 2007). The cooling capability of the SFP should be analyzed again for the decommissioning plants. The advanced and passive SFP cooling systems are investigated in recent years (Ye et al. (2013), Fu et al. (2015) and Xiong et al. (2015)), but it is not likely that a decommissioning plant will install such advanced devices. The spent fuel will be cooled by the existing cooling systems. Chen and Yuann (2017) have performed the thermal analysis for the SFP of the Kuosheng plant. The pool temperature under different cooling-system configurations was calculated.

Although there is no evidence supporting that the SFPs in the Fukushima Daiichi plant was damaged (D. Wang et al., 2012; Jäckel, 2015), the loss-of-coolant and loss-of-cooling accidents of the SFPs have become notable. The U.S. NRC issued NUREG-2161 (2014) to enhance the SFP safety for the Mark I plants. Mitigations as providing makeup water of 500 gpm and the spray of 200 gpm suggested. Studies for the SFP analyses have been published after the Fukushima accident. Wang et al. (2012) combined TRACE and CFD model to analyze the loss-of-cooling accident. Groudev et al. (2013) has investigated the dry-out time of the SFP connecting with the refueling cavity for the Kozloduy nuclear plant. Their results show that dry out of the connection between the SFP and the refueling cavity takes 34,000 s. Ognerubov et al. (2014) and Fleurot et al. (2014) analyzed the loss-of-coolant accident with various system codes for the Ignalina plant. Wu et al. (2015) analyzed the loss-of-cooling and loss-of-coolant accidents for a PWR SFP using MAAP5. Similar SFP accident scenarios were also simulated by Ahn et al. (2016) with MELCOR. Zhang et al. (2017) performed the SFP accident analyses with RELAP5 and MELCOR. Interaction between the adjacent bundles is considered in their RELAP5 model, and the results are in good agreement with the MELCOR results. Mochizuki (2017) analyzed the SFP of the Hamaoka Advanced Boiling Water Reactor during a blackout accident, and the obtained boiling time is in good agreement with the hand calculation result.

The insufficient SFP storage capacity of the Chinshan units results in that the fuel in the reactor cannot be removed. The reactor cavity will remain connected with the SFP in the decommissioning process. This study will perform the thermal analysis of the integrated SFP for the Chinshan plant. Normal and accident conditions are analyzed using GOTHIC (EPRI, 2014). A lumped model is developed to calculate the bulk temperature and the results are compared with that obtained from the simplified energy equations. As the duration needed to keep the existing cooling systems, including the Residual Heat Removal (RHR) system, in operable condition to provide sufficient cooling is an important concern in the decommissioning process, it is addressed in this study. A detailed model is developed for the loss-of-coolant accident analysis. Thermal response with various shutdown time is calculated. The results can be used to determine the period that the existing cooling systems should remain operable.

2. Spent fuel pool of the Chinshan plant

Both of the Chinshan units are BWR/4 units with the Mark I containments. The reactor vessel is inside a bulb-shape drywell. The space above the reactor head is the reactor cavity. The SFP is adjacent to the reactor cavity and there is a channel between them. The SFP is normally isolated from the reactor cavity. During the outage, the reactor head is opened and then the SFP is merged with the reactor cavity, as shown in Fig. 1 which is based on the plant drawing (Taiwan Power Company, 1971).

The SFP storage capacity of each Chinshan unit is 3083 fuel assemblies. The SFP is 12.17 m in length and 7.87 m in width (Taiwan Power Company, 2016). The top of the fuel racks is 4.47 m from the pool bottom. The normal pool level is maintained at 11.6 m to ensure that there is sufficient water covering the spent fuel (Taiwan Power Company, 2016). The current licensing SFP heat-up analysis assumes that 25% of the volume is occupied by solid components, and the initial free volume is 834 m^3 (Taiwan Power Company, 2012). The bottom of the reactor cavity is 3.66 m above the SFP bottom. The connecting channel is 5.03 m above the SFP bottom (Taiwan Power Company, 1971). If the channel is blocked or the liquid level drops below the channel, the water inventory of the SFP and the reactor cavity is no longer connected.

In the original plant design, the Chinshan SFP was only cooled by two trains of Spent Fuel Pool Cooling and Cleanup System (SFPCCS). Each train of the SFPCCS has its own heat exchanger (HX). The SFPCCS takes suction from the surge tanks which are connected to the SFP and the reactor cavity, as shown in Fig. 1. Water cooled by the HX is then injected to the SFP. After expanding the storage capacity, two trains of the Spent Fuel Pool Additional Cooling System (SFPACS) were installed to enhance the cooling effect. The SFPACS directly takes suction from the pool. Water cooled by the SFPACS HX is vented to the SFPCCS piping and then

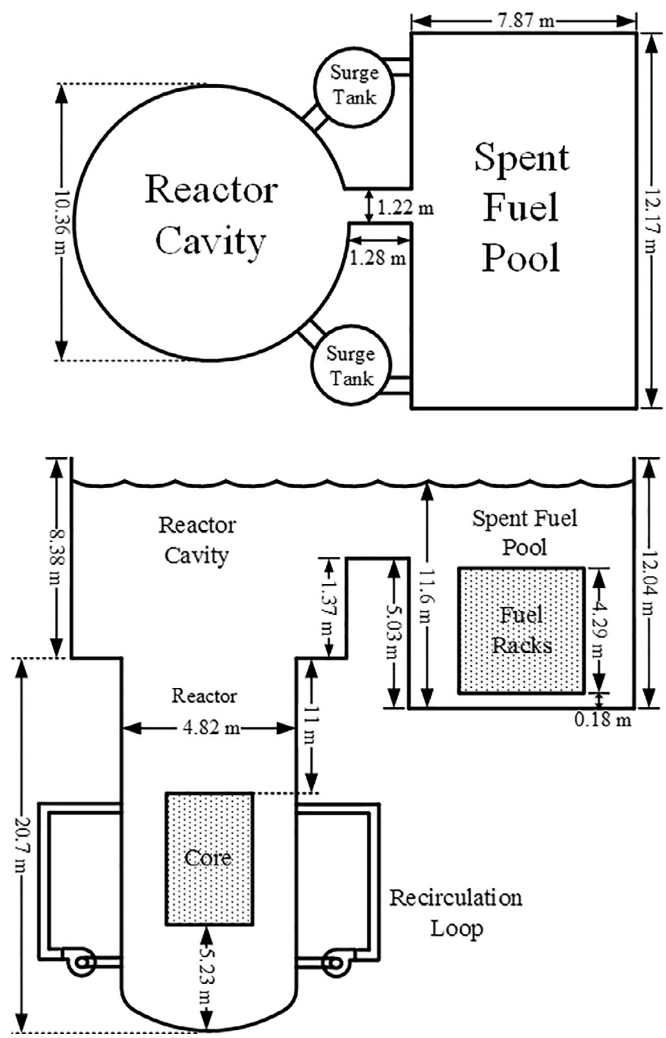

Fig. 1. (a) Top view and (b) side view of the Chinshan SFP and the reactor well.