Annals of Nuclear Energy 109 (2017) 120–134

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Evaluation of cooling capacity with more fuel stored in the spent fuel pool of the Kuosheng plant

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ARTICLE INFO

Article history:
Received 8 August 2016
Received in revised form 4 September 2016
Accepted 8 May 2017

Keywords:
Spent fuel pool
Bulk temperature
GOTHIC

ABSTRACT

The storage capacity of the spent fuel pool (SFP) of the Kuosheng plant will be insufficient in recent years. Fuel racks are suggested to be installed in the cask loading pool to increase the capacity by more 440 assemblies. Thus, the design-basis analysis for the SFP cooling should be performed. The pool temperature under normal and abnormal conditions is analyzed by solving the simplified energy equation. Furthermore, a lumped model and a detailed model have been developed using GOTHIC in this study. The bulk pool temperature calculated from the lumped model is in good agreement with that from the energy balance, and is below the required limit set by regulatory authority. The detailed model can be used to determine the local temperature during the transient events, which is beyond the capability of the lumped model. The analyzed result meets the requirement that no boiling shall occur in the normal condition. The time available for corrective actions after loss of forced cooling is also evaluated. With makeup water, the time when the SFP level drops to 3 m above the fuel top is considerably extended. The cooling capability of the Kuosheng SFPs still meets the safety requirements with storing more assemblies.

1. Introduction

The Chinshan plant and the Kuosheng plant owned by Taiwan Power Company are two operating nuclear plants located in the north-east coast of Taiwan. The Chinshan plant has two BWR/4 units which began commercial operation in 1978 and 1979, respectively. The Kuosheng plant has two BWR/6 units which began commercial operation in 1981 and 1983, respectively. Since the beginning of operation, the spent fuels discharged in each cycle are stored in the spent fuel pools (SFPs) of the plants. After serving for more than thirty years, the SFP storage capacity is becoming insufficient. Moreover, the local government is against the licensing applications for using the dry cask storage facility to store the spent fuels. Both plants are likely to be suspended before the expiration of their 40-year operation licenses.

Taiwan Power Company is trying to find the alternative ways for spent fuel storage. The first idea proposed by the Kuosheng plant is to store the spent fuel in the upper pool in the Mark III containment (Chen and Yuann, 2016), as shown in Fig. 1. However, Atomic Energy Council, the nuclear regulatory authority in Taiwan, is against this idea because the original containment design does not allow permanent storage of the spent fuel in the upper pool. The second solution is to install more fuel racks in the SFP. The current storage capacity of each Kuosheng SFP is 4398 assemblies. However, there are already 4364 assemblies in the unit 1 (Table 1) and 4252 assemblies in the unit 2. The SFPs will be full soon. To increase the storage capacity, it is suggested that four sets of racks with a total capacity of 440 assemblies are planned to be installed in the cask loading pool (CLP) which is a part of the Kuosheng SFP area.

Loss of coolant or cooling accident analysis of the SFPs becomes notable after the Fukushima accident. However, there is no evidence supporting that the SFPs in the Fukushima Daiichi plant was damaged (Wang et al., 2012a,b; Jäckel, 2015). To enhance the SFP safety, the U.S. NRC has issued NUREG-2161 (2014). Makeup water of 500 gpm (0.0315 m^3/s) and the spray of 200 gpm (0.0126 m^3/s) are suggested to be used to mitigate the severity of the SFP during the beyond-design-basis accidents. Kaliatka et al. (2010), Ognerubov et al. (2014) and Fleurot et al. (2014) used RELAP5, ATHLET-CD and ASTEC to analyze both loss-of-cooling and loss-of-coolant accidents for the SFP of the Ignalina

Abbreviations: BWR, boiling water reactor; CLP, cask loading pool; FSAR, Final Safety Analysis Report; FSB, Fuel Storage Building; HX, heat exchanger; OLTP, original licensed thermal power; PWR, pressurized water reactor; RHR, Residual Heat Removal; SFP, spent fuel pool; SFPCCS, spent fuel pool cooling and cleanup system.

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http://dx.doi.org/10.1016/j.anucene.2017.05.026
0306-4549/

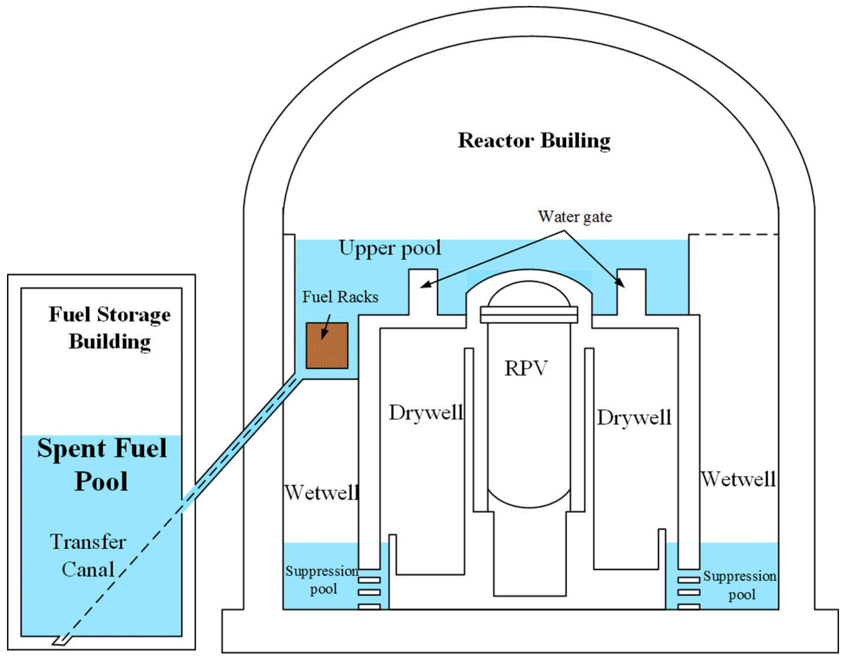

Fig. 1. Schematics of the Kuosheng reactor building and fuel storage building.

Table 1
Fuel stored in the SFP of Kuosheng unit 1.

Batch	Cycle	Date of the reactor shutdown	Full-power of one assembly before shutdown (MW)	Number of assemblies
1	EOC-1	1983/07/11	4.6378	212
2	EOC-2	1984/10/05	4.6378	156
3	EOC-3	1985/10/20	4.6378	216
4	EOC-4	1987/03/10	4.6378	192
5	EOC-5	1988/04/19	4.6378	191
6	EOC-6	1989/09/27	4.6378	216
7	EOC-7	1991/01/27	4.6378	132
8	EOC-8	1992/05/01	4.6378	200
9	EOC-9	1993/09/06	4.6378	171
10	EOC-10	1994/11/12	4.6378	133
11	EOC-11	1996/01/03	4.6378	169
12	EOC-12	1997/04/02	4.6378	224
13	EOC-13	1998/11/04	4.6378	220
14	EOC-14	2000/03/04	4.6378	196
15	EOC-15	2001/09/07	4.6378	184
16	EOC-16	2003/02/24	4.6378	192
17	EOC-17	2004/09/09	4.6378	152
18	EOC-18	2006/03/04	4.6378	160
19	EOC-19	2007/10/28	4.7163	172
20	EOC-20	2009/03/09	4.7163	180
21	EOC-21	2010/10/07	4.7163	160
22	EOC-22	2012/03/16	4.7163	196
23	EOC-23	2013/12/11	4.7163	156
24	EOC-24	2015/04/24	4.8093	184
Total				4364

RBMK-1500 plant. Wang et al. (2012a,b) combined a TRACE model and a three-dimensional CFD model to analyze the loss-of-cooling accident for the Chinshan SFP. Chen et al. (2014) used CFD to investigate the detailed temperature distribution of a PWR fuel bundle during the loss-of-cooling accident. Wu et al. (2014, 2015) analyzed the loss-of-cooling and loss-of-coolant accidents for a PWR SFP using MAAP5. Similar accident scenarios for a PWR SFP were also simulated by Ahn et al. (2016) with MELCOR.

On the other hand, investigation of the SFP cooling capability which ensures the safety during normal operation receives less attention. Ye et al. (2013) and Xiong et al. (2015) performed numerical and experimental studies about a passive cooling system with heat pipes for a CAP1400 SFP. Fu et al. (2015) investigated a passive cooling system with thermosyphon loops. However, the transient SFP heat-up scenario needed for license application was not discussed in the previous studies. As pointed out by Boyd (2016), detailed CFD model involving hundreds of bundles subjected to a long-term transient scenario is not practical.

The SFP heat-up analysis is a part of the license application and addressed in chapter 9.1.3 in the Final Safety Analysis Report (FSAR) of each nuclear plant (U.S. NRC, 2007a). The purpose of this analysis is to ensure the capability of the cooling system to keep the SFP from being overheated. For the Kuosheng plant, the SFP heat-up analysis is performed by solving the energy equation for the bulk temperature (Taiwan Power Company, 2008). The analysis must be re-performed if the condition of the SFP is changed, such as reracking (Taiwan Power Company, 2003) or power uprate (Taiwan Power Company, 2014). Taiwan Power Company is planning to install more fuel racks in the Kuosheng SFP. Thus, the SFP heat-up analysis must be performed again. The analysis is aimed at evaluating whether or not the SFP cooling capacity is enough. This study uses GOTHIC (EPRI, 2014) to perform the Kuosheng SFP heat-up analysis. A lumped model and a detailed model are developed. The SFP temperature is calculated assuming that 440 more spent fuel assemblies are to be stored in the pool. The results are compared with that obtained by solving the energy conservation equation.

2. Spent fuel pool of the Kuosheng plant

The SFP in the Fuel Storage Building (FSB) consists of four area: west pool, transfer canal, east pool, CLP and cask wash-down area, as shown in Fig. 2. The top of the racks is 4.7 m from the pool bottom. The normal water level is maintained at 12.19 m to provide sufficient cooling to the fuel and act as a radioactive shielding to the site staff. Assuming that 25% of the pool volume is occupied by solid components (Taiwan Power Company, 2003), the initial water volumes of the west pool, east pool and the CLP are