Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

CFD Evaluation of SFP Cooling Capacity during Normal Operating Conditions

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1. Introduction

In Fukushima nuclear accident, due to earthquake, the cooling system of the spent fuel pool failed and the safety issue of the spent fuel pool (SFP) generated. Because of the unavailability of offsite storage for spent nuclear fuel in Korea, the spent fuel should be placed in storage at specially designed facilities, kept and monitored in the plant. In recent years, spent fuel storage racks are being replaced with high density racks due to the lack of storage capacity. For the above reasons, the necessity is felt to analyze the safety of the spent fuel pool. Hence, to evaluate the safety of spent fuel pools, in case of loss of offsite power like the Fukushima nuclear accident, the safety analysis was conducted for Gori Unit 1 and Ulchin unit3 in order to estimate the time it takes for nuclear fuels to be uncovered, when water in the pool evaporated by decay heat of spent fuels[1]. In addition, there are some researches evaluating heat removal, thermal-hydraulic behaviors and accident circumstances in the spent fuel pool with system thermal-hydraulic codes, such as RELAP, TRACE and ASTEC[2-3]. Some researchers [4] are attempting to carry out 3D CFD analysis.

In this study, thermal-hydraulic characteristics of the spent fuel pool of Ulchin unit 3 are investigated by using ANSYS-CFX-13[5] which is a commercial CFD code. Three-dimensional fluid flow and heat removal capacity of the spent fuel pool are evaluated by 3-D CFD simulation, while carrying out comparative analysis with the multi-D analysis of MARS-KS.

2. Numerical Modeling

The geometry of the SFP of Ulchin unit 3[6] is schematically shown in Fig. 1. The pool is 10.4m long, 8.6m wide, and it is divided into two regions; Region I is composed of 266 cells, the freshly discharged spent fuels and the defected fuels are stored in this region; Region II is composed of 1,232 cells, the depleted spent fuels are stored in this region. The cooling system of the SFP consists of two identical cooling loops with 100% designed capacity, and each cooling loop is connected in opposite direction. During normal operation, one of them is operated with 3000gpm flow rate. The storage rack is elevated to have its lower end 0.225m above the pool bottom and its height is 4.72m. The spent fuel is covered with 7.32m of water above the storage racks.

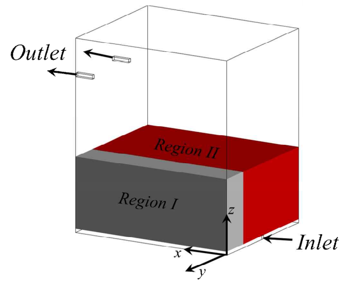
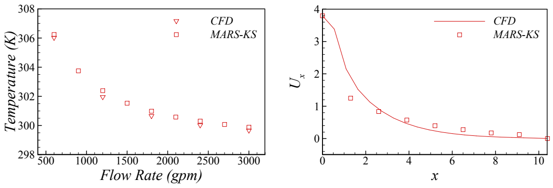


Fig. 1 Flow configuration of the spent fuel pool(Ulchin unit 3).

To effectively model the complex geometry of the fuel assemblies, porosity scheme is used in the Region I and II. For considering the flow resistance in the fuel assemblies, the following loss model is used.

$$-\frac{dp}{dz} = \frac{\mu}{K}\vec{V} \quad (1)$$

The loss coefficient K of a sub-channel among the fuel rods in the Region II is used as a value of 10^{-3}. As the fuel racks prevent any lateral flow in the Region I and II, a very small value of K is assumed to ensure the flow is mainly in the z-direction. In Region I, the z-axial pressure loss was excluded, only with the lateral pressure loss considered. A recent research [1] calculated decay heat as 1.51MW with ORIGEN code in consideration of the actual storage condition (869 fuel assemblies) of Ulchin unit 3, and this value is applied in the Region II as a heat source. For boundary conditions, no-slip condition and adiabatic condition were used for the wall, and slip condition was used for the free-surface of SFP. Moreover, released heat to the air from the free surface was applied in consideration of its correlation with convective heat transfer as well as evaporation heat transfer [7], which consists of functions of free surface temperature and air temperature and humidity, but in this calculation, it was set as -500W/m^2 on the premise that the air temperature, humidity and the free surface temperature were 25°C, 20% and 30°C, respectively. It corresponds to about 3% of total decay heat. The inlet temperature was set as 25°C, and this study compared its result with MARS-KS by decreasing the inlet flow rate from 3,000gpm, which is the flow rate of normal operation, to 600gpm, while investigating the thermal-hydraulic characteristics based on the CFD simulation.



(a) (b)

Fig. 2 Comparison of CFD and MARS-KS; (a) Bulk mean temperature, (b) x-direction velocity component along the x-axis at the center of the inlet.

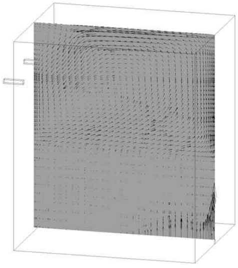


Fig. 3 Velocity vectors at the vertical (x-z) mid-plane, Q_{in}=1,200 gpm.

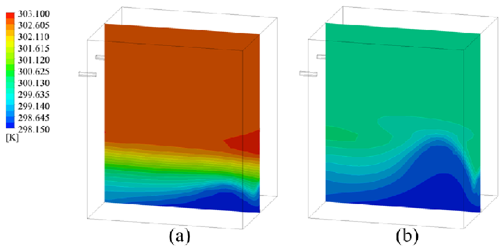


Fig. 4 Contours of temperature at the vertical (x-z) mid-plane; (a) Q_{in} =1,200 gpm, (b) Q_{in} =3,000 gpm.

3. Results and Discussion

This study comparatively evaluated the results of CFD and multi-D analysis of MARS-KS through the thermal-hydraulic analysis of spent fuel pool. Fig 2(a) shows the variation of bulk mean temperature depending on the flow rate in the spent fuel pool. It is seen that in the temperature decrease depending on an increase of flow rate, the results of both MARS-KS and CFD correspond well to each other. When the flow rate is 3,000gpm during normal operation, it is observed that there is an about 2°C increase of bulk mean temperature from 298.15(K) that is the inlet temperature, and even though the flow rate is decreased to 600gpm, it is found that an about 10°C increase of temperature is sustained. Fig. 2(b) shows the x-axial velocity distribution along the x-axis from the inlet. Since the inlet size is 0.05m^2 which is much smaller than the size of the pool, the flow characteristics became similar to those of jet flow. It is also observed that the inlet flow velocity is rapidly decayed along the x-axis, which shows that the result of MARS-KS corresponds well to that of CFD.

Fig. 3 shows the velocity distribution at the mid-plane of the spent fuel pool when the inlet flow is 1,200gpm. As shown in Fig. 1, cold water at the inlet is observed to flow into Region II while getting buoyancy force by the temperature difference provided through decay heat in Region II. Especially near the inlet, z-axial velocity is observed to increase by the temperature difference, which seems to cause a great decrease of x-axial flow velocity near the inlet from the velocity distribution shown in Fig. 2(b). It is also found that due to the large z-axial flow velocity from the domain of 0m<x<4m, a counter-clockwise circulation is formed above the storage racks. Fig. 4 shows the temperature distribution when the inlet flow rate is 1,200gpm and 3,000gpm. It is seen that cold water comes to rise because of the buoyancy force around the inlet. In addition, it is observed that the bulk pool temperature greatly decreased due to an increase of inlet flow rate.

4. Conclusions

In this investigation, CFD analysis was performed on thermal-hydraulic characteristics of Ulchin unit 3 SFP and compared the result with MARS-KS. As a result, it was found that both the results of MARS-KS and CFD corresponded to each other, in the bulk mean temperature and velocity distribution of spent fuel pools. Besides, when 1.51MW of decay heat was analyzed, this study confirmed the safety since the temperature increase was around 10°C inside the spent fuel pool, although flow rate in the cooling system was reduced to 600gpm. It seems necessary to perform the transient analysis of SFP in case of loss of offsite power as well as additional analyses of further decay heat increase and emergency reactor core storage conditions, and a further study will be conducted in the near future.

ACKNOWLEDGEMENTS

This work was supported by the Nuclear Safety and Security Commission.

REFERENCES

[1] KINS, Safety Evaluation of core and spent fuel pool in case of loss of offsite power, Korea Institute of Nuclear Safety, Regulatory Research Report, KINS/AR-928, 2011.
[2] A. Kaliatka, V. Ognerubov and V. Vileiniskis, Analysis of the processes in spent fuel pools of Ignalina NPP in case of loss of heat removal, Nucl. Eng. Des., Vol.240, pp. 1073-1082, 2010.
[3] J. P. V. Dorsselaere, C. Seropian, P. Chatelard, F. Jacq, J. Fleurot, P. Giordano, N. Reinke, B. Schwinges, H. J. Allelein, W. Luther, The ASTEC integral code for severe accident simulation, Nucl. Technol., Vol. 165, pp. 293-307, 2009.
[4] T. Hung, V. K. Dhir, B. Pei, Y. Chen and F. P. Tsai, The development of a three-dimensional transient CFD model for predicting cooling ability of spent fuel pools, Applied Thermal Engineering, In Press, 2012.
[5] Ansys CFX-13.0, Ansys Inc., 2010.
[6] KHNP, Final Safety Analysis Report: Ulchin Nuclear Power Plant Units 3 and 4, Korea Hydro & Nuclear Power.
[7] T. Fujii and H. Imura, Natural convection heat transfer from a plate with arbitrary inclination Int. J. Heat Mass Transfer, Vol. 17, pp. 755-767, 1972