Cooling Analysis of Spent Fuel Pool with a CFD Method

H. C. Jang, a B. R. Jung, a J. K. Hwang, a

a *Korea Power Engineering Co., Inc. 150 Deokjin-dong Yuseong-gu Daejeon Rep. of Korea 305-353,*

hcjang@kopec.co.kr

1. Introduction

Most of nuclear power plants have a spent fuel pool (SFP) for the wet storage of the spent fuel assemblies (FAs). The methods used to provide cooling for the removal of decay heat from the stored spent FAs vary from plant to plant depending upon the plant specific designs. But the basic safety function remains the same in principle; that is, the spent FAs must be cooled and must remain covered with water during the storage conditions.

NUREG-0800 SRP [1] suggests/recommends guidelines for the acceptance criteria on the design of the spent fuel cooling system. According to the criteria recommended in NUREG-0800 SRP, the design specifications/requirements are prepared for individual plants. The following thermal-hydraulics requirements in terms of discharge scenarios and their cooling acceptance criteria are frequently used to demonstrate the adequacy of the cooling system design:

a) Normal power operation: Each of the two redundant SFP cooling trains is capable of removing the decay heat of one refueling core 150 hours after shutdown, plus the maximum number of refueling batches to maintain a SFP bulk water temperature of 49 °C (120 °F) maximum.

b) Refueling operation: Each of the two redundant SFP cooling trains is capable of removing the decay heat of one full core 150 hours after shutdown, plus the maximum number of refueling batches to maintain a SFP bulk water temperature of 60 °C (140 °F) maximum.

c) Abnormal operation: Two combined redundant SFP cooling trains are capable of removing the decay heat of one full core 150 hours after shutdown, plus one refueling core 480 hours after shutdown in addition to the previous refueling batches to maintain a SFP water temperature of 60 °C (140 °F) maximum.

d) Emergency: None of the redundant SFP cooling trains are available. Under full fuel storage in SFP as described in the above c), the SFP water surface temperature is allowed to reach 100 °C (212 °F) but local boiling within the hottest storage cell shall not occur.

To demonstrate that the requirements should be met, bulk pool temperature, time-to-boiling, maximum local water temperature are estimated for each discharge scenario. A set of analysis was made to show that the requirements are satisfied. In this paper a computational fluid dynamics (CFD) analysis to estimate the maximum local water temperature in the SFP is presented with its results. The basic parameters of APR1400 SFP design were used in the analysis.

2. Method

To calculate the maximum local water temperature in SFP using CFD, the different characteristics of flow resistances and decay heat loads in different rack locations should be considered in the CFD analysis modeling. The rack region was modeled as porous media and divided into several regions with appropriate flow resistances and heat loads. The FLUENT version 6.2.16 [2] was used as a CFD analysis tool.

2.1 Decay Heat Loads

The rack region is generally divided into two regions: Region I and Region II. Several damaged fuel canisters are located in Region I. The freshly discharged spent fuels are stored in Region I and old discharged fuels are stored in Region II. The modeled porous media region was divided into four regions to appropriately represent the amount of decay heat load which depends on the discharge scenario as shown in Fig.1. The decay heat load was estimated per USNRC Branch Technical Position ASB 9-2 [3]. The estimated decay heat loads for each region are: hot region=218240W/m^3, medi region= 117520W/m^3, cold region=98790W/m^3, back region= 10301W/m^3. Hot region is assumed to store the spent FAs of half full core after 150 hours of shutdown with maximum peaking factor. Medi region stores half full core spent FAs after 150 hours of shutdown. Cold region stores one refueling batch of core after 480 hours of shutdown. And back region stores the previously discharged FAs. Some conservatism were included in the heat load estimation.

2.2 Porous Media Properties

The viscous resistance (the reciprocal of the permeability) and inertial resistance are required to define the characteristics of porous media. These were estimated for different kinds of racks: i.e., normal rack on normal location, normal rack on pedestal support location of Regions I and II, and damaged fuel canister on pedestal support location. Among these, both the viscous resistance and inertial resistance values of damaged fuel canister on pedestal support location were the largest. These values were applied to all porous media for conservatism because larger flow resistance produces higher maximum local water temperature in the analysis result. The estimated viscous resistance and inertial resistance are 3.8232e5 m^{-2} and 334.7129 m^{-1}, respectively.

2.3 Cooling System Heat Exchanger

Two redundant SFP cooling trains are equipped with the following design capacity:

Flow rate (1 train)	4,000 gpm (hot side) 3,500 gpm (cold side)
Cooling capacity (1 train)	55.2×10^6 BTU/hr
Hot side inlet & outlet temp.	140˚F & 112.02˚F
Cold side inlet & outlet temp.	95˚F & 126.7˚F

2.4 Major Assumptions

Many conservative assumptions were made in the analysis. Among them the following assumptions are important: a) Fifty percent of the one full core spent FAs after 150 hours of shutdown are conservatively assumed to emit heat at the peak heat emission rate and be stored together in a concentrated area of hot region; b) The freshly discharged FAs are assumed to be instantaneously stored into SFP after a specified hold time in the reactor, i.e., transfer time from the reactor to the SFP is neglected; c) All rack cells are assumed to be 50% blocked at the top of cells; d) All spent FAs are assumed to be stored entirely in the damaged fuel canister located on the pedestal support whose flow resistance is the largest; e) All discharged FAs are assumed to have the maximum irradiation exposure in the reactor; f) No downcomer flow is assumed to exist between the rack modules; g) Heat loss to the SFP environment is neglected.

3. Results and Discussion

The maximum local water temperature calculations were performed for the refueling, abnormal and emergency operations. The estimation for local water temperature needs information on pool inlet water temperature. Since the pool inlet water temperature is closely correlated with heat load, bulk pool temperature, and the cooling system performance, an estimation on these parameters to obtain the pool inlet temperature was made by analytical methods in advance. The calculated maximum local water temperatures are summarized in Table 1 together with the bulk pool temperature and the pool inlet temperature. The temperature contours of hot region mid-planes for the refueling operation are depicted in Fig.2 and for the abnormal operation in Fig.3. The results show that there are no problems in SFP cooling in spite of many conservative assumptions.

Table 1. Maximum local water temperature

Discharge Scenario	Max. Bulk Temp. (°F)	Pool Inlet Temp. (°F)	Max. Local Temp. (°F)
Refueling	140.0	110.6	152.8
Abnormal	123.0	104.8	136.8
Emergency	212.0	-	239.6

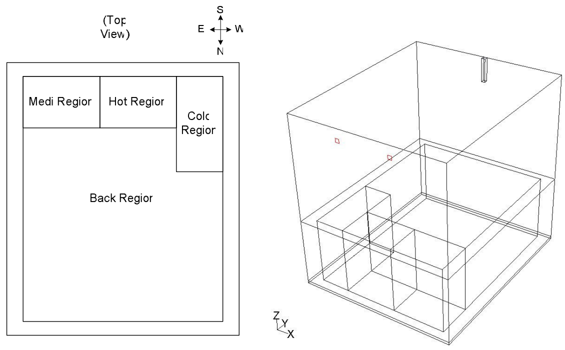

Figure 1. SFP CFD model

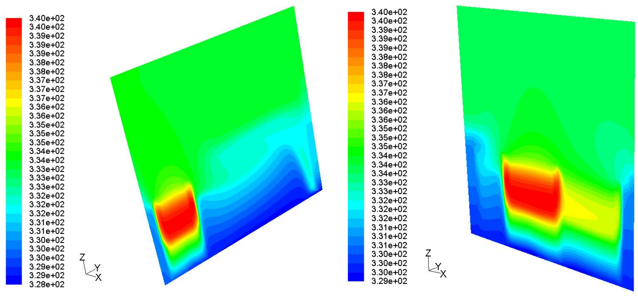

Figure 2. Temperature contours of hot region mid planes (x-, y- planes) for refueling operation

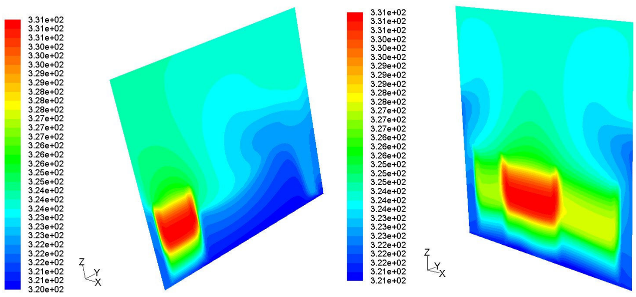

Figure 3. Temperature contours of hot region mid planes (x-, y- planes) for abnormal operation

REFERENCES

[1] NUREG-0800, Standard Review Plan, Sec. 9.1.3, Rev.1, July, 1981.
[2] FLUENT 6.1 User's Guide, Fluent Inc., Feb. 2003.
[3] BTP ASB 9-2, Residual Decay Energy for Light-Water Reactors for Long-Term Cooling, Rev.2, July, 1981.