Pool Cooling Evaluation in the Open-Pool Research Reactor

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1. Introduction

Since research reactors are usually utilized with the multi-purposes, such as radioisotope production, material irradiation facility, NTD production, cold and thermal neutron production for the neutron scattering, etc., most of them are designed with the open-pool type. In order to minimize the operator's radiation exposure from the pool surface, the bulk temperature of pool water shall be maintained below an allowable limit during the reactor operation. In addition, the hot water layer on the top part of the reactor pool is considered to prevent the uprising radioactive material from the pool bottom by the stable thermal stratification. The pool water temperature beneath the hot water layer shall be also controlled to minimize radioactivity by variation of the radioactive dissolved gas solubility on the pool surface. For this requirement, the pool water management system (PWMS) is designed to maintain the pool water temperature lower than an allowable limit. In this paper, the pool cooling capacity of the PWMS is studied whether or not it is enough to maintain the pool temperature

2. Results and Discussion

The PWMS, shown in Fig. 1, is designed to satisfy requirements for the purification and cooling capacity. For the purification of the pool, the ion exchangers and filters are equipped on the loop, and the plate type heat exchanger is located in the system for the cooling of the pool.

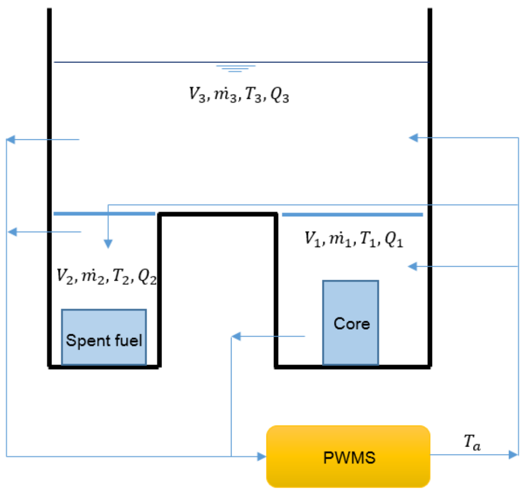

Fig. 1 Geometry of the pool connected to the PWMS

During the reactor power operation, the Primary Cooling System (PCS) removes the heat generated from the core, and the PWMS is operating for the purification of each pool and for the cooling of spent fuels and irradiated objects. After the reactor is shutdown, the decay heat from the core is still too high to be removed by the PWMS. It is not an efficient design of the PWMS heat exchanger based on that decay heat which is exponentially decreased by the time because it leads the cooling flow rate to be much larger than the current design. On the consideration of those points, the PWMS heat exchanger is designed to have a capacity of 290 kW to remove all heat on the pools and to maintain the pool temperature below 50 ℃ regardless of the reactor operation status. The heat removal capacity of the PWMS heat exchanger is determined based on the estimated heat sources as shown in Table I.

Table I: Estimated heat sources

Heat source	Heat load (kW)	Remark
Decay heat from the core at 2hrs after Rx. S/D	-0.0025t + 345	PCS operation for 2 hours after S/D
Decay heat from one full core	145	at 24 hours after S/D
Irradiated objects	35	Always
Transferred from hot water layer	5	Always
Decay heat from spent fuels	75	Always

2.1 Modeling of the PWMS cooling loop connected to the pool

The pools are physically separated with the working platforms: the section (1) of the pool with the reactor core; the section (2) of the pool with spent fuel; the section (3) of the upper pool. The PWMS takes the pool water from three sections, cools and purifies the pool water and then flows back to the three sections. Each section has a heat generation term shown in Table I.

The transient temperature trend in the each pool can be formulated as follows:

$$\rho V_1 Cp \frac{dT_1}{dt} = \dot{m}_1 Cp(T_a - T_1) + Q_1 \qquad (1)$$

$$\rho V_2 Cp \frac{dT_2}{dt} = \dot{m}_2 Cp(T_a - T_2) + Q_2 \qquad (2)$$

$$\rho V_3 Cp \frac{dT_3}{dt} = \dot{m}_3 Cp(T_a - T_3) + Q_3 \qquad (3)$$

Where ρ is a density of the pool water, V is a control volume of each section, Cp is a thermal capacity, $\dot{m}$ is a mass flow rate of each section, T_a is an outlet temperature of the PWMS heat exchanger, and Q is a heat source in each pool.

To get the T_a, the cooling capacity of the plate heat exchanger is defined as follows.

$$Q = UA(LMTD)$$
$$= \dot{m}_1 Cp(T_1 - T_a) + \dot{m}_2 Cp(T_2 - T_a) + \dot{m}_3 Cp(T_3 - T_a)$$

In here, A is a cross sectional area of the heat exchanger. The log mean temperature difference (LMTD) and the overall heat transfer coefficient is calculated using the recommended methodology [1]

2.2 Temperature variation in each pool during shutdown

The pool temperature calculation is performed with the conservative assumptions. Initial condition of the pool temperature is considered with two temperature points: inlet temperature of the primary cooling system (PCS) and outlet temperature of the PCS. When the reactor is normally shutdown, the PCS is operating for 2 hours to remove the decay heat from the core. After that point, the PWMS takes the cooling duty to remove the decay heat from the reactor core.

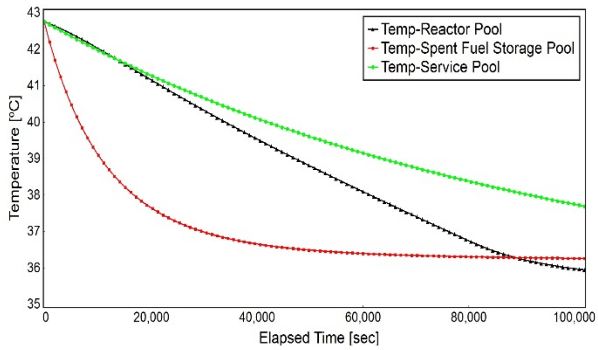

Fig. 2 Pool temperature variation at PCS inlet temperature

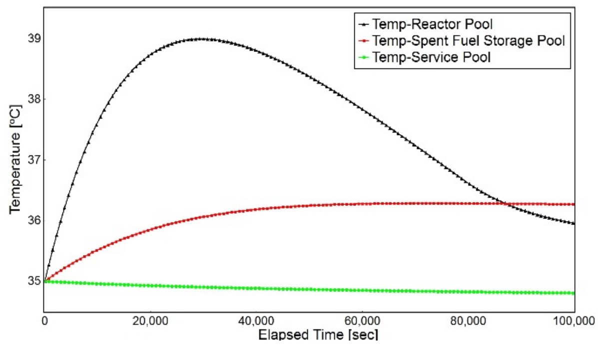

Fig. 3 Pool temperature variation at PCS outlet temperature

During the reactor shutdown, the pool temperature variations are shown in Fig. 2 and Fig. 3. In the case of the PCS inlet temperature, all temperatures of the pools start to decrease and get saturated at certain temperature. For the PCS outlet temperature, the temperature in the reactor pool starts increasing up to near 39 ℃ and then gradually decreases. The temperature of other pools are saturated below 37 ℃ since the cooling flow rate is enough to remove the generated heat from each pool.

2.2 Temperature variation in each pool during maintenance

During the maintenance in the reactor pool (section 1), the one full core, cooled for 24 hours after shutdown, is transported to the fuel rack in the spent fuel storage pool (section 2). Due to no more heat generation in the reactor pool, the PWMS takes the pool water from the section 2 and the service pool (section 3) to cool and purify. To obtain more conservative results, the heat generation rate from one full core is used at the fixed value in Table I. With the current heat exchanger, the temperature in section 2 and 3 is confirmed to be below the limit as shown in Fig. 4 and Fig. 5.

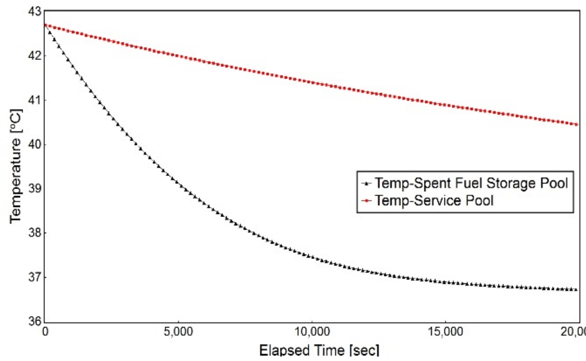

Fig. 4 Pool temperature variation at PCS inlet temperature

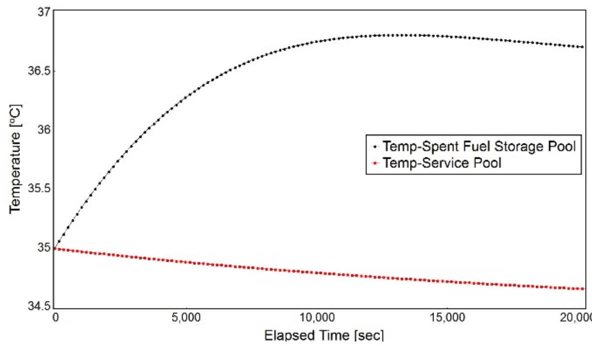

Fig. 5 Pool temperature variation at PCS outlet temperature

3. Conclusions

To confirm the pool temperatures under an allowable limit regardless of the reactor operation status, the cooling capability of the PWMS was evaluated and the results shows that the designed PWMS heat exchanger has enough the capacity with the design margin.

REFERENCE

[1] Sunil Lee and et al, "Design Guideline for Primary Heat Exchanger in a Research Reactor", Transaction of the KNS Spring Meeting, Jeju, Korea, May 12-13, 2016.