A LONG-TERM COOLING METHOD FOR A RESEARCH REACTOR

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ABSTRACT

A new and simple device was developed and designed to consider the long-term cooling of research reactors. It consists of a long-term cooling dam and long-term cooling pipes in a guide wall between the reactor pool and service pool. During a siphon break, the water drain from the service pool is stopped at the top of the long-term cooling dam even though the water in reactor pool is still drained. After breaking the siphon the water level of reactor pool is lower than the top of the dam and higher than the top of the core. The remaining water in the service pool is passively moved into the reactor pool through the long-term cooling pipes. Therefore, this extra water supply is very helpful for removing the residual heat of the core over a long time period without any follow-up actions by the operators.

1. Introduction

In research reactors, the core of the reactor shall always be submerged inside water, and the pool water has a role as an ultimate heat sink. During an accident, the reactor shall be immediately shut-down, and the residual heat of the core is then removed through natural circulation. The heat is transferred to the pool water and the water is evaporated continuously. From a nuclear safety standpoint, it is therefore very important to secure a sufficient amount of water considering the evaporation rate.

In open-pool type research reactors with a down-ward flow in the core, some equipment or pipes of the Primary Cooling System(PCS) can be installed below the core owing to the Net Positive Suction Head required(NPSHr) of the PCS pumps. If there are pipe breaks below the core, the whole pool water will be drained through a siphoning and the core will be exposed to air. To limit draining of the pool water, a siphon breaker is installed at the highest point of the PCS pipe. After a siphon break, the water level will be higher than the core, and natural circulation is guaranteed. However, as mentioned above, the water level becomes lower by evaporation owing to the residual heat of the core. If it is impossible to access and resolve this problem for several days, the pool will be empty and the reactor will undergo a severe accident.

In addition, there are two limitations to determine the highest point of the PCS pipe. If the point is too low, the siphon breaker will start to operate late, and the final pool water level will be too low. If it is too high, on the other hand, the pressure at the highest PCS pipe will be too low and some vapors will be generated. This is severe for research reactors that have high thermal powers of more than about 10MWt because a large pressure drop is introduced in the core. In summary, the highest PCS pipe should be located between the lowest height limitation by siphon breaking phenomena, and the highest height limitation by vaporization pressure. Unfortunately, when the thermal capacity of the research reactor increases, it is impossible to select the highest PCS pipe point and design the open-pool type research reactor with the down-ward flow in the core because the PCS pipe size and core pressure drop increase. In this situation, an additional cooling water supply for the long-term cooling of the reactor can release the lowest height limitation, and the possibility for the PCS design can be increased.

2. Long-term cooling safety facility

A safety facility for the long-term cooling of research reactors by adding supplementary water into the reactor pool passively was developed. A schematic diagram of the open-pool type research reactor with a down-ward flow in the core is shown in Figure 1. The PCS pumps can be located below the core to satisfy their NPSHr. A flap valve around the core is installed in the PCS pipe inside the reactor pool to remove residual heat from the core by natural circulation. A siphon breaker is installed in the highest PCS pipe to cope with a pipe rupture of the PCS pipe. The pool consists of a reactor pool and service pool, and a pool gate between two pools can separate them if required.

Here, the long-term cooling safety facility of the research reactor is shown in Figures 1 and 2. A guide wall of the pool gate between two pools has an opening at the center, and thus some irradiated targets can move through it. A long-term cooling dam is installed at the bottom of the opening near the reactor pool side and two long-term cooling pipes are inserted through the dam at the lowest position.

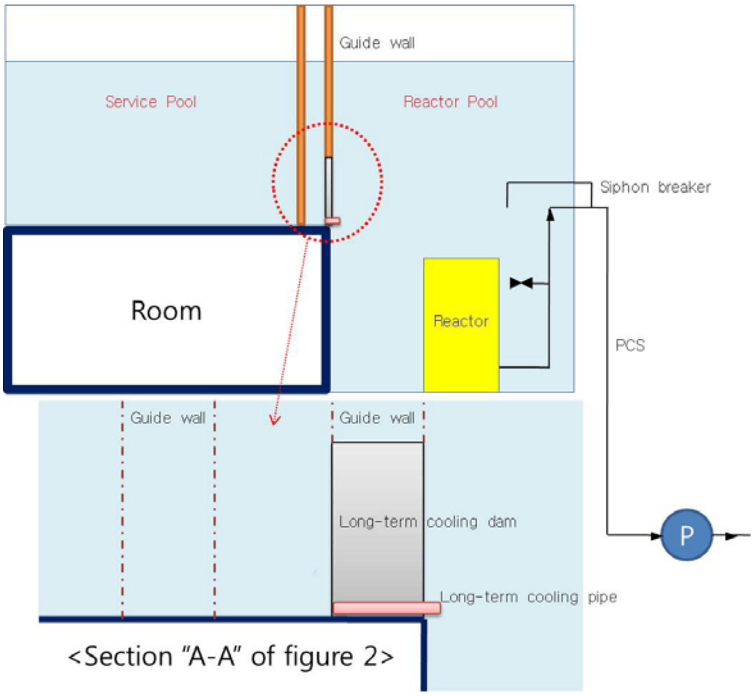

Fig 1. Pool water level under normal operation

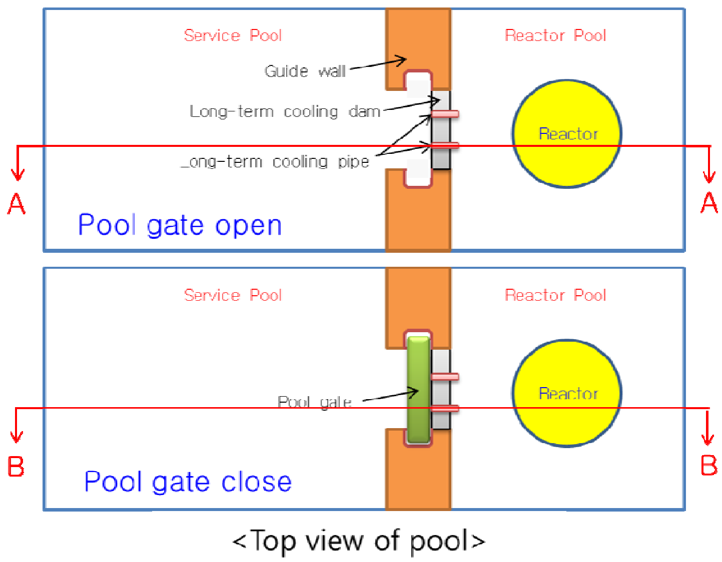

Fig 2. Long-term cooling safety facility of a research reactor

The flow rate through the long-term cooling pipe should be larger than the evaporation rate of the reactor pool from the residual heat of the core, and is small owing to the high latent heat capacity of water. Therefore, two long-term cooling pipes have a small inner-diameter, but each pipe has a sufficient flow capacity larger than the evaporation rate. Two pipes are to consider a situation that one of them is blocked by some foreign materials.
The lowest height limitation of the Long-term cooling dam is determined considering a long-term cooling period, the residual heat of the core, and the area of the service pool. In addition, the highest height limitation is determined considering the shielding thickness of water for irradiated targets when they are moved from the reactor pool to the service pool.

3. Operation

3.1 Normal operation condition of research reactor

Under normal operation of a research reactor, the reactor pool and service pool are fully opened without a pool gate, and have the same pool water levels, as shown in Figure 1. The water can move freely through the opening between two pools.

3.2 PCS pipe rupture accident

If the PCS pipe is ruptured by an accident, the pool water will be drained and the siphon breaker will act to break the siphoning. At the final point of time of the siphon breaking, the pool water in the reactor pool has a little reduced level from the siphon breaker and the water level in the service pool has the same level with the top of the long-term cooling dam, as shown in Figure 3. An important point is that several days are considered for the long-term cooling even though the siphon breaking phenomena is finished after several minutes. In other words, the water in the service pool is transferred into the reactor pool through the long-term cooling pipe owing to a level difference between two pools during several days.

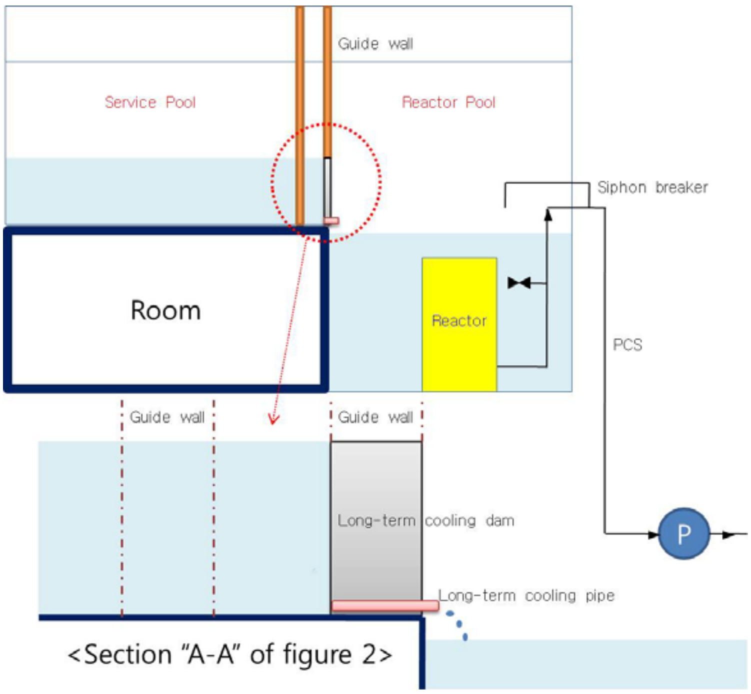

Fig 3. Pool water level in PCS pipe rupture accident

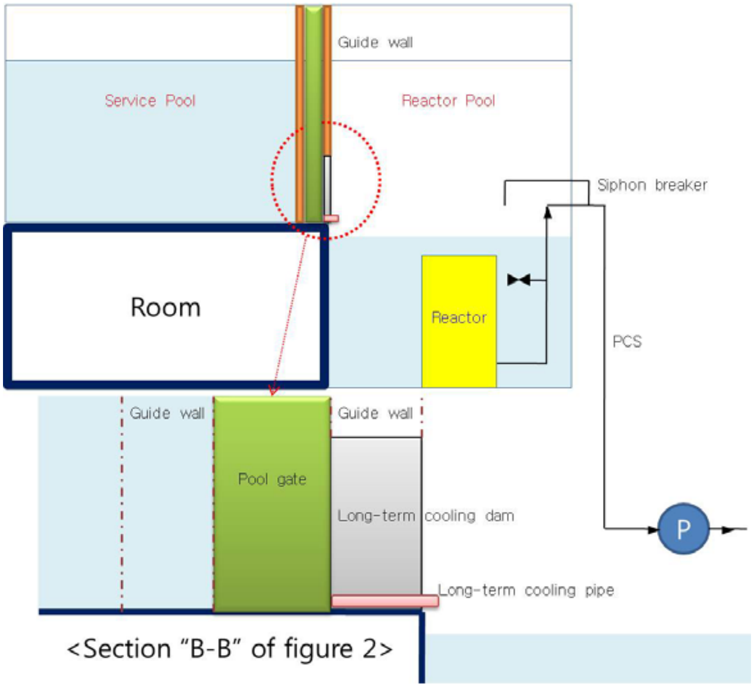

Fig 4. Pool water level in maintenance

3.3 Maintenance of research reactor

Figure 4 shows the pool water level for maintenance works in the reactor pool. The pool gate is closed, and some water in the reactor pool is moved into a pool water storage tank. Two pools are perfectly separated without any leakages because the llong-term cooling pipes are installed in the long-term cooling dam without any interference with the pool gate. In addition, a worker who works inside the reactor pool for maintenance can easily check the conditions of the long-term cooling pipes.

4. Preliminary design

Table 1 shows the shapes and volumes of the reactor pool and service pool for a research reactor with 15 MWt. Let us regard the bottom of a reactor pool at an elevation of 0 m. The height of the reactor structure assembly is 4 m. A long-term cooling dam has a 1 m height, and two long-term cooling pipes have 1-inch NPS sch40. A siphon breaker is installed at the highest point of a PCS pipe with an elevation of 6 m. If the residual heat is assumed as 1 % of full power, the evaporation rate is about 0.0664 kg/s, and the reducing velocity of the reactor pool water level is 1.2 cm/hour from a simple heat balance equation [1].
Let us assume that the pool water level of the reactor pool is higher than the top of the reactor structure assembly with an elevation of 4 m to guarantee natural circulation through a flap valve. After siphon breaking in a large break Loss of Coolant Accident (LOCA), the final reactor pool water level should be higher than an elevation of 5 m by operating the siphon breaker to break siphoning. Under this situation, the water level of the service pool is 1 m above the bottom of the service pool owing to the long-term cooling dam, and the elevation is 7 m. We can think that an averaged hydrostatic head is 0.5 m when the water in the service pool moves into the reactor pool through the long-term cooling pipes. So, the velocity inside each long-term cooling pipe is about 3.1 m/s based on the Bernoulli equation [2], and the flow rate is 1.73 kg/s. This is sufficient to recover the reactor pool level considering the evaporation rate. The reactor pool level will reach the top of the reactor structure assembly 10.5 days after siphon break without any actions by the operators.

	Reactor pool	Service pool
Width, m	4	4
Length, m	5	10
Height, m	12	6
Volume, m^3	240	240

Tab 1: Pool water volumes in normal operation

5. Conclusion

A long-term cooling method was suggested for research reactors to increase their safety by supplying supplementary water into a reactor pool during several days. This is passively operated, and it is therefore very simple and cheap to achieve the goal. This provides the possibility to design an open-pool type research reactor with a down-ward flow in the core, and an increase in high thermal power. The flow rate and time through the long-term cooling pipe are easily controlled by adjusting the height of the long-term cooling dam and the size of the long-term cooling pipe in the design status.

6. References

[1] Sonntag, Borgnakke, Van Wylen, "Fundamentals of Thermodynamics", fifth edition, 1998

[2] Munson, B.R., Young, D.F., and Okiishi T.H., " Fundamentals of fluid mechanics", fourth edition, 1990