Thermal Hydraulic Analysis of 49-2 Swimming Pool Reactor with a Passive Siphon Breaker

Zhiting Yue[1], Songtao Ji[1]

1) China Institute of Atomic Energy(CIAE), Beijing 102413, China

Corresponding author: songtaoji@139.com

Abstract: In order to improve the safety of the reactor, a passive siphon breaker has been added to the primary cooling system of 49-2 Swimming Pool Reactor (SPR). The thermal hydraulic of the reactor with a siphon breaker of diameter 1.6 cm was analyzed by RELAP5/MOD3.3 code. The results show that: under the conditions of steady-state operation, small break loss of coolant accident (SBLOCA) and large break loss of coolant accident (LBLOCA), the siphon breaker is able to break the siphon phenomena, and maintain the pool water level above the reactor core when the reactor and the pump shutdown.

1. Introduction

49-2 Swimming Pool Reactor (SPR) is a research reactor moderated and cooled by light water in China, whose designed rated power is 3500 kW. It has been operated for 52 years [1] since March, 1965. The primary cooling system of 49-2 Swimming Pool Reactor is showed in figure 1.

In usual, the outlet pipe of pool reactor is set in the bottom of the pool. To break siphon effects which lead to the core uncovering, a siphon breaker is set at the highest point in the outlet pipe. 49-2 SPR has a siphon breaker as other Swimming Pool Reactors do. However, it is a manual valve and under the pool cover plate, which needs a crane to lift. If an accident happens, it is difficult for the operators to enter the operational area to lift the cover plate and manually open the valve. Since the Fukushima accident, China has carried out series of comprehensive safety inspections for existing nuclear facilities. For the capacity improvement of the 49-2 pool reactor to deal with severe accidents such as earthquakes, a passive siphon breaker has been added to its primary cooling loop. Due to the decrease of the water level in the pool under loss of coolant accidents, the siphon breaker consequently emerges from the water, thus breaking the siphon effects and avoiding core uncovering.

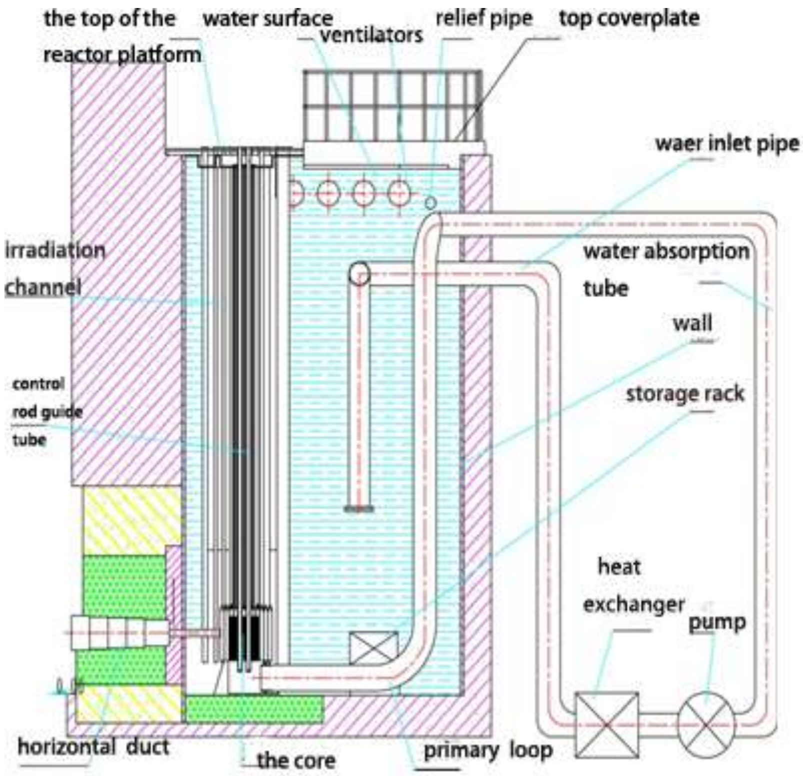

FIG. 1. Diagrammatic sketch of primary system of 49-2 SPR

2. Design of Siphon Breakers

2.1. Siphon Phenomenon and Siphon Break

As shown in figure 2, the structure of outlet pipe in the primary loop of the 49-2 swimming pool reactor is inverted U-shaped (called a siphon), which makes the liquid to be pushed over the highest point and discharged to the other end with liquid pressure differences of pipe ends. When the elevation of the breach in the outlet of the primary loop is lower than the core, the water level of the swimming pool decreases continually until it becomes the same with the breach.

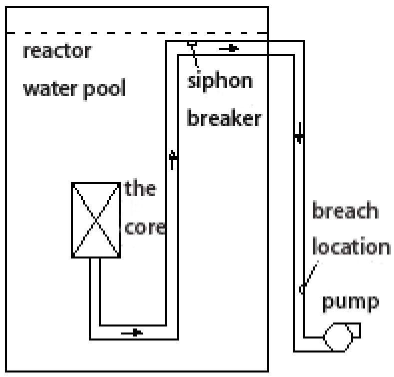

FIG. 2. Sketch of the siphon break phenomenon

The water level decreases under LOCA conditions, the siphon breaker set at the highest point of the outlet consequently emerges from the water surface. Then gases enter the primary loop system through the siphon breaker with pressure differences. As accumulation of the gases, the pressure difference gradually reaches balance to break the flow. This phenomenon is called siphon break

2.2. Breaker Position and Size Selection

In usual, siphon breaker is supposed to set at the highest point in the outlet pipe of coolant loop for the time response concern. Since the siphon breaker is designed to be passive and always open, it is necessary to analyze the effect of siphon breaker under the normal operation of the reactor.

According to the design, the highest point of outlet pipe in the reactor coolant loop is only 5 cm from the water level in the reactor pool, and the water level fluctuates frequently during normal operation. The pipe elbow area is not a suitable place for siphon breaker, but it finds its location below the pipe elbow, where is 65 cm lower than the water level of normal operation.

The siphon breaker is always open, which causes a bypass loop under operation. In order to ensure the coolant flow through the core, the siphon breaker's diameter should be as small as possible but large enough to break siphon phenomenon. After analysis, the diameter of passive siphon breaker is selected to be 1.6 cm while the diameter of original manual siphon breaker in 49-2 SPR is 1.8 cm[2].

3. System Modeling

The main system of the primary loop in 49-2 SPR is modeled by using the modeling method of RELAP5 / MOD3.3[3]. It mainly includes reactor pool and hot leg section. The simulation model is presented in figure 3. The reactor pool is divided into two parts, entitling 160 and 170 from bottom to the top. The top of the pool is connected to the atmosphere. Only the inlet and outlet pressure are considered during the calculation, so the core can be simulated as the hydraulic components. The inverted U-shaped core outlet hot leg section is divided into 11 sections to analyze the density changes respectively when the siphon breaker works. The spot connecting the sixth section (110-6) of the hot leg and the bottom part of reactor pool (170) is the position of the siphon breaker. And 120, 130, 140 are pipes connecting to three main pumps.

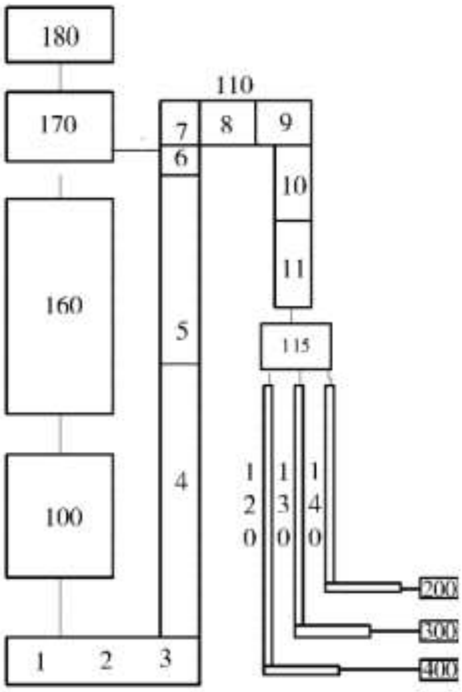

FIG. 3. System nodes of 49-2 SPR

100—reactor core 110—heat pipe section of primary coolant loop

120、130、140—branch pipes connecting to three main pumps

160、170—swimming pool over reactor core 110-6—siphon breaker

180—atmosphere over swimming pool

4. Calculation and Analysis

Three different operation conditions are analyzed:

1. Under steady-state operating condition, due to the passive siphon breaker is always open, there is a bypass flow as the reactor is running, which causes part of the primary coolant doesn't flow through the reactor core but enters the primary loop through the passive siphon breaker directly. To make sure sufficient coolant flow through the core, the steady-state calculation of siphon breaker is required to determine the effect of the bypass flow caused by the siphon breaker on the core cooling capacity.
2. Under the condition of LBLOCA, all engineered safety features are supposed to be shut down and no intervention from operation, the analysis are performed to clarify whether the design of passive siphon breaker can guarantee that the water level in the pool submerges the core and meets the design requirements when the reactor shutdown.
3. Under the condition of SBLOCA, all engineered safety features are supposed to be shut down and no intervention from operation, the analysis are performed to prove whether the passive siphon breaker can break the siphon phenomena when

the reactor shutdown, and the calculation results are compared with the experimental results.

4.1. Calculation Results and Analysis under Steady-state Operating Condition

Under the normal operating condition, the pressure difference between core inlet and outlet is about 8950 Pa, and the flow rate of the core flow is 277.76 kg/s. When the siphon breaker's diameter is 1.6 cm, the pressure at the siphon breaker is about 87485 Pa, the flow through the siphon breaker is about 1.90 kg / s, the flow rate of the coolant flowing through the core is 277.45 kg / s, which indicates its impact on the core flow is only 0.11%.

It can be seen from the calculation that a siphon breaker with diameter of 1.6 cm has a very small effect on the core coolant, and has no influence on the normal operation of the reactor.

4.2. Calculation Results and Analysis under LBLOCA Condition

The following assumptions are made for the analysis:

1. LBLOCA occurs in the front part of the primary loop pump during the reactor shutdown period, and the break diameter is 265 mm, the elevation is 0.07 m.
2. It is assumed that the elevation of the water in the pool is 7.15 m (distance between the water surface and the upper surface of the core is 5.91 m).
3. All engineered safety features cannot be put into operation.
4. There is no flow resistance in the pipe when siphon occurs.

The results under LBLOCA condition with a 1.6 cm siphon breaker are shown in figure 4. The LBLOCA accident happens in the 0 second with a flow loss about 400 kg/s near the break, the water level in the pool begins to drop rapidly from the initial level which is 5.91 m to the upper surface of the core, and the pressure of the siphon breaker decreased quickly. 10 seconds later, the siphon breaker is no longer sank in the water and gases start to enter the loop, the pressure near the siphon breaker is proximately 60000 Pa, With the influence of the siphon breaker and the decrease of water level in the pool, the flow of coolant near the break reduces. 160 seconds later, the flow at the break almost reaches zero and gases stop to enter the loop though the siphon breaker, and the pressure of the siphon breaker is about atmospheric pressure. Since then, the water level of the pool remains stable, about 1.38 m above the core, which proves the break of siphon and makes the core submerged in water pool as the design requirement.

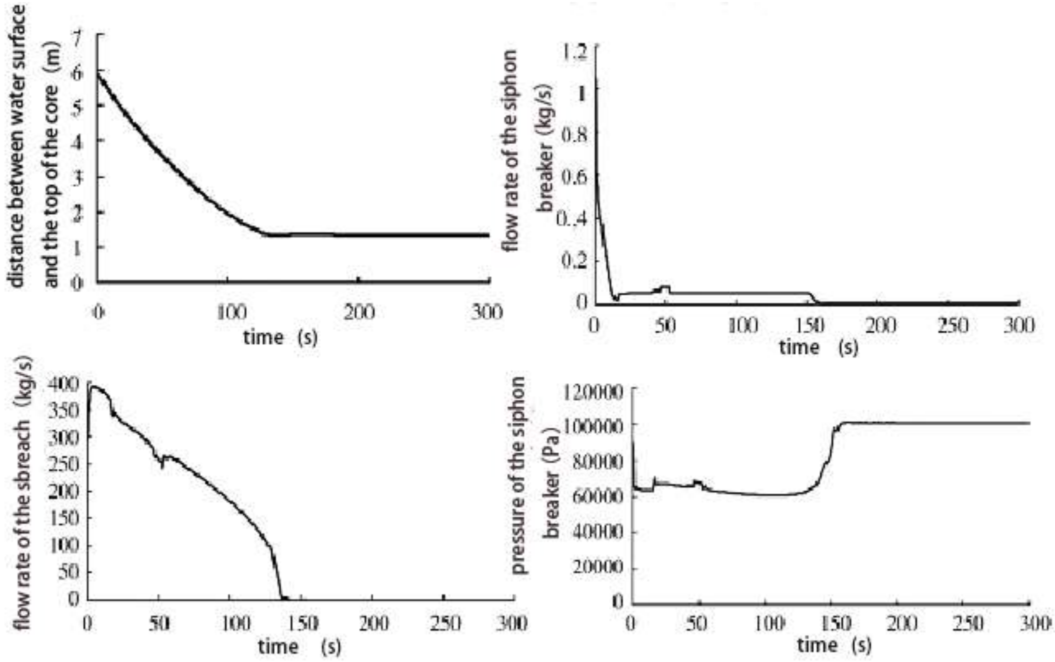

FIG. 4. Calculation result of LBLOCA with 1.6 cm of passive siphon breaker diameter

According to the calculation results, a 1.6 cm passive siphon breaker can stop the effect of siphon and prevent core uncovering when LBLOCA accident occurs as the reactor and pump shutdown.

4.3. Calculation Results and Analysis under SBLOCA Condition

The following basic assumptions are made in the analysis:

1. SBLOCA occurs in the front part of the primary loop pump during the reactor shutdown period, and the break diameter is 1.6 cm, the elevation is 0.07 m.
2. It is assumed that the elevation of the water in the pool is 6.65 m (distance between the water surface and the upper surface of the core is 5.41 m).
3. All engineered safety features cannot be put into operation.
4. There is no flow resistance in the pipe when siphon occurs.

The SBLOCA accident happens in the 0 second, and the flow loss is about 0.8 kg/s near the break, the water level in the pool begins to drop rapidly from the initial surface whose distance to the upper surface of the core is 5.41 m; 1450 seconds later, the siphon breaker begins to emerge, and gases start to enter the loop; 1600 seconds later, the siphon breaker emerges completely, its pressure and flow rate remain unchanged; 2700 seconds later, with the accumulation of gases in the loop, flow causing by the siphon is cutoff, and water in pipes of the hot leg (node 110-4,5,6 and 7 in figure 3) reverses to the pool due to the gravity, which causes fluctuation of pressure and flow near the siphon breaker; after the stop of siphon, distance between the water surface of the core and the upper surface of the core is 5.22 m, and its elevation is 6.46 m. Because a large amount of coolant remains in the pipes of the hot leg (node 110-9, 10 and 11 in figure 3), water still coming out of the small break. The results indicate that a 1.6 cm passive siphon breaker has sufficient margin to break siphon and ensure the core safety under SBLOCA accident when the reactor and pump shutdown.

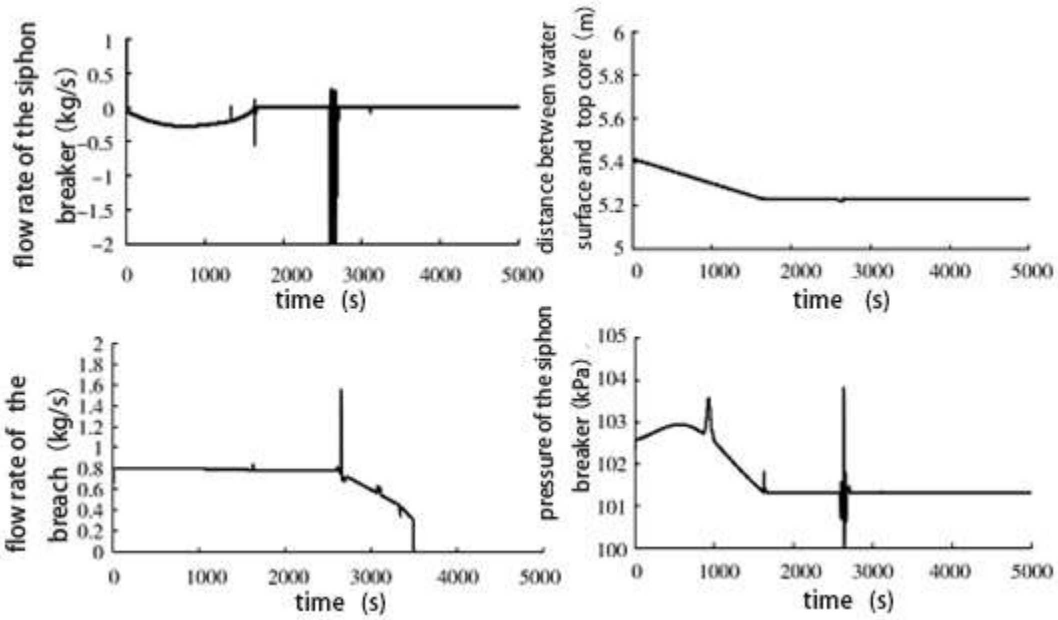

FIG. 5. Calculation result of SBLOCA with 1.6 cm of passive siphon breaker diameter

To validate the capability of passive siphon breaker under the condition of SBLOCA in the front of the pump, a test has been launched by opening water-release bolt of primary coolant pump [4]. The results of the test show that under the SBLOCA condition, the 1.6 cm passive siphon breaker has enough margin to break the siphon when the reactor and pump shutdown. The calculation results are basically in line with the calculation results.

5. Conclusion

Thermal hydraulic analysis of 49-2 reactor with the passive siphon breaker has been performed for three different conditions: steady-state operating condition, LBLOCA and SBLOCA condition. The results show that: the 1.6 cm passive siphon breaker basically has no negative effect on the steady-state operation of the reactor; it can break siphon and prevent core uncovering when LBLOCA accident occurs as the reactor and pump shutdown; it has sufficient margin to break siphon and ensure the core safety when SBLOCA accident occurs when the reactor and pump shutdown. The calculation results are reliable and reasonable in the light of siphon break capability test under the condition of SBLOCA occurs in the front of the pump.

6. References

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