Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

A conceptual study of an Integrated Passive Safety System for a Research Reactor

Kwon-Yeong Lee [a*], Hyun-gi Yoon [b]
[a]*Handong Global University, 558 Handong-Ro, Buk-gu, Pohang, Gyung-buk, 37554, Republic of Korea*
[b]*Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 34057, Republic of Korea*
[*]*Corresponding author: kylee@handong.edu*

1. Introduction

Research reactor is a nuclear facility to produce neutron transmutation doping (NTD) and radioisotope (RI) and to research using neutron in the reactor, such as neutron radiography (NR). Korea Atomic Energy Research Institute (KAERI) is now designing KIJANG Research Reactor (KJRR), that is a 15MWt reactor. Before KJRR project, KAERI had designed and exported 5MWt research reactor to Jordan named Jordan Research and Training Reactor (JRTR). The safety related devices in JRTR were decay tank and siphon breaker.

Decay tank is the device to provide sufficient flow residence time to decrease N-16 activity in the primary coolant passing the reactor core. N-16 has the most high-strength ɣ-rays among many kinds of radionuclides in the primary coolant. The N-16 dose rate at the inlet of the decay tank is much larger than those of other radionuclides. Fortunately, its half-life is very short, only 7.13 second, and the dose rate of N-16 decreases as flow residence time increases dramatically. Therefore, it could be helpful to design other equipment, such as pumps, heat exchangers, valves, etc., in primary cooling system of the research reactor if the coolant is delayed in the decay tank to reduce the radiation level of N-16 sufficiently in normal operation of research reactor.

Also, siphon breaker is a safety device to prevent a severe accident in a loss of coolant accident (LOCA) in research reactors. In the event of an accident such as a pipe rupture, all the cooling water inside the decay tank will be leaked out by siphon phenomenon caused by the pressure difference. Then, the water level of the reactor pool becomes lowered and the core located at the bottom of the reactor pool is exposed to the air. As the possibility of secondary damage due to overheating of the core increases, the siphon breaker is operated rapidly after accident and an inrush of air through siphon breaker can prevent water efflux by siphon phenomenon. So that, the level of the reactor pool is maintained at an appropriate level to prevent overheating of the core.

Jeong et al.[1] estimated flow residence time using a computational fluid dynamics (CFD) code, ANSYS-CFX, in a decay tank that consists of a cylinder and two elliptic hemi-spheres with three perforated plates. Even though they recommended to adopt unsteady simulation of a user-defined scalar method to estimate the minimum flow residence time, its results are almost same with the values by the particle tracking method. Also, Jeong et al.[2] studied the decay tank using another CFD code, FLUENT, to check the relationship between the fluid distribution along the residence time and the total dose rate. The flow residence time was estimated by the particle tracking method, such as the discrete phase model (DPM) in FLUENT.

To investigate the siphon breaker, Kang et al.[3][4] performed real-scale verification experiments by using a large-sized pipe. Its results could be applied to the actual siphon breaker design in JRTR. Seo et al.[5] proposed an analytical model for the experimental results of siphon breaker by using CFD. However, previous studied have not presented a satisfactory theoretical model because the calculation of siphon breaking is excessively complex. Lee and Kim[6] developed a theoretical model which can predict the progress and the result of the siphon breaking phenomenon well. The established theoretical model is based on Bernoulli's equation and includes the Chisholm model to analyze two-phase flow. Moreover, Lee and Kim[7] developed the siphon breaker simulation program to utilize the established model by using MFC (Microsoft Foundation Class) programming.

For 15MWt research reactor, the sizes or numbers of decay tank and siphon breaker should be increased. However, it is a big burden to design and manufacture such kinds of huge devices. Also, long-term cooling after reactor shutdown in an accident should be considered because the decay heat for 15MWt research reactor is much larger than 5MWt research reactor. So, Lee et al.[8] suggested a new design for long-term cooling of research reactor with a dam and small pipes between the reactor pool and the service pool.

Combining the functions of all devices mentioned above, the new concept of integrated passive safety facility for research reactor is developed in this study. This system can play three roles of decay tank that reduces the radioactivity by delaying the passing time of the coolant in normal operation of the research reactor, siphon breaker that prevents the coolant loss when a LOCA occurs, and long-term cooling tank that can remove the decay heat of the core by supplying the coolant to the reactor pool passively.

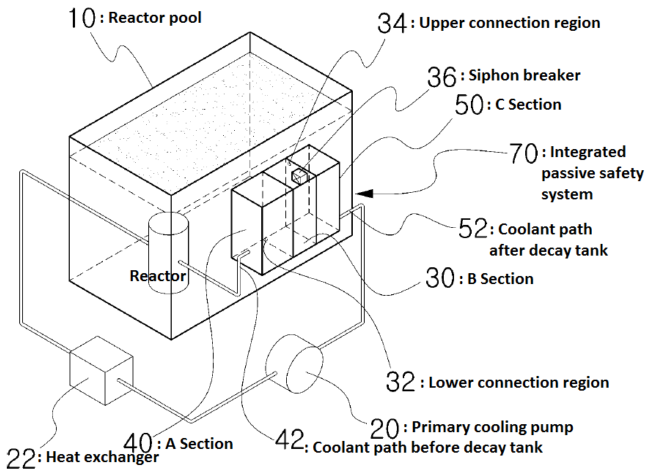

Fig. 1. Schematic diagram of integrated passive safety system

2. System Description

A new safety system for a research reactor, which integrated decay tank, siphon breaker, and long-term cooling tank as single facility, is suggested as shown in Fig. 1 to improve the space efficiency and the simplicity of maintenance. The number and size of Sections of the facility could be decided by the amount of evaporated water during long-term cooling and the flow residence time. The details of each function are as below.

2.1 Decay Tank

In normal operation of a research reactor, the coolant passing the reactor core is containing N-16, that has high radioactivity, but short half-life. So, a decay tank in a primary cooling system should be able to contain the coolant for enough time to satisfy the design requirement of delaying flow. One of the existing method is using perforated plates inside a hemi-spherical cylinder as studied by Jeong et al.[1][2]. Another existing method suggested by Seo et al.[9] can increase the flow residence time through the internal vertical baffle, the outer vertical baffle and the dispersion pipe connected to the internal vertical baffle. However, the maintenance of existing decay tank models is difficult because of complicated internal parts. Therefore, the internal parts of decay tank should be simplified for the convenience of maintenance. The internal part of the suggested decay tank model in this research is much simpler than that of the existing decay tank design. The Sections A, B, and C have a role of the decay tank in normal operation. As shown in Fig. 2, the coolant flown into the Section A will stay inside Section A for enough flow residence time. After that, it will flow into the Section B through the connection region at the bottom of Section B. Then, the coolant will flow into the Section C through the connection region at the top of Section C and to outside through the main pipe of primary cooling system (PCS) at the bottom of Section C. Therefore, the simpler model than the existing design ensures the flow residence time and is convenient to keep the maintenance.

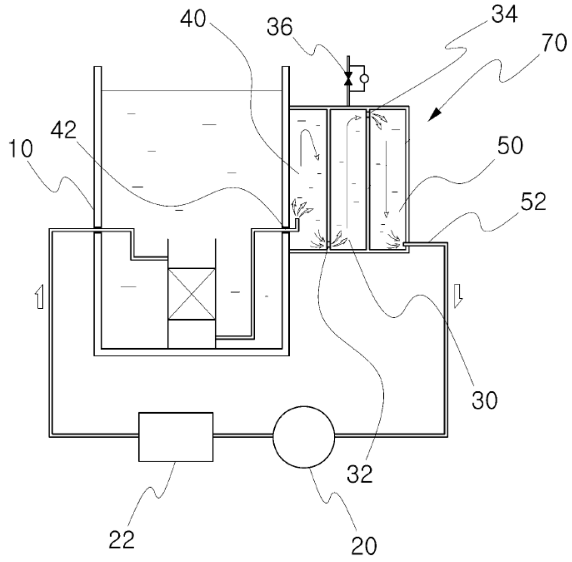

Fig. 2. Decay tank operation mode of integrated passive safety system

2.2 Siphon breaker

In research reactor, the reactor core is cooled by natural circulation through the flap valves to the reactor pool after the Primary Cooling Pump (PCP) is turned off. The pool water itself is the ultimate heat sink of the residual heat. Thus, it is very important to guarantee that the pool water level be higher than the minimum level from a safety point of view. The JRTR and KJRR are open pool-type research reactors and have downward core flows. To meet the required net positive suction head (NPSHr) of the PCPs, some components of the PCS are installed below the core level. When a postulated pipe break occurs at below the reactor core position, the pool water can be drained below the core by siphon phenomena, and the core cannot be cooled by natural circulation. Therefore, siphon breakers are installed in the PCS to limit the pool water drain during and after all postulated initiating events. Because the open-type reactor is operating at low pressure and low temperature conditions, guillotine break LOCA is almost impossible. However, for a design purpose, a pump casing rupture by a failure of moving part could be considered.

In this study, a new type of siphon breaker was suggested. It consists of siphon breaking shut-off valves and a differential pressure transmitter in Section B of Fig. 1. At the roof of Section B, the air will pour in by opening siphon breaking shut-off valves when siphon occurs. The air will fill the Section B until the connection region at the top and stop siphon phenomenon by shutting the coolant flow off as shown in Fig. 3.

The larger diameter of the primary cooling pipe, the more air is required to break the siphon. The size of siphon breaking valve increases proportionally. Actually, it has some difficulties in design, production, and experiment. Therefore, it will be easy installing multiple small siphon breaking valves through securing space above Section B. In addition, this method also help lower the risk of valve malfunction. When installing multiple valves, the rest of the valves except mal-functional valve can be opened to stop siphon breaking phenomenon. To detect the malfunction of the valves, a differential pressure transmitter is installed to measure differential pressure between the upstream and the downstream of the valves. The upstream of the valves is exposed to the air and has atmosphere pressure while the downstream of the valves connected to the Section B has negative pressure and the transmitter always measure the constant value. However, if the valve is opened in normal operation, the gauge will detect the difference and hence check the malfunction of the valve. In addition, high power research reactors can have some components of the PCS installed below the core level because of special restrictions, even though they have upward core flows. In this case, this new type of siphon breaker can be used without the siphon breaking shut-off valves and a differential pressure transmitter. It means that this safety system can be operated as a perfectly passive system.

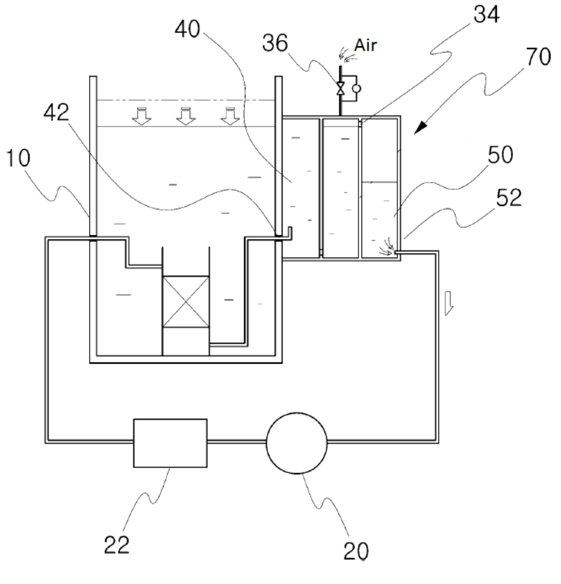

Fig. 3. Siphon breaker operation mode of integrated passive safety system

2.3 Long-term Cooling Tank

On stopping siphon breaking phenomenon, the rapid loss of coolant will shut off in the reactor as shown in Fig. 3. At the moment, the water level of Section B and the research pool are the same. However, the siphon breaking phenomenon lasts only for several minutes while the core long-term cooling takes several days. Therefore, as soon as the siphon breaking phenomenon stops, the water evaporates for days due to remaining decay heat of the core. The enough coolant need to be filled. The Section A and Section B will act as long-term cooling tank and compensate for the evaporated water in the research pool as shown in Fig. 4.

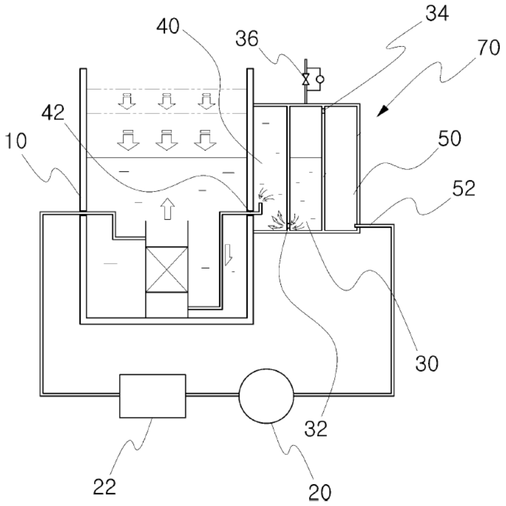

Fig. 4. Long-term cooling operation mode of integrated passive safety system

3. Conclusions

An innovative integrated passive safety system for a research reactor is suggested to improve the safety of the research reactor. This integrated system has three roles in a facility as a decay tank, siphon breaker, and long-term cooling tank. The process to design and optimize the decay tank and the siphon breaker of the integrated passive safety system will be continued.

REFERENCES

[1] N.G., Jeong, K.W., Seo, D.Y., Chi, and J.H., Yoon, Estimation of flow residece time in a decay tank for a pool type research reactor using CFD, Nuclear Engineering and Design, Vol. 255, pp. 162-168, 2013.

[2] N.G., Jeong, G.H., Roh, S.H., Kim, and J.H., Yoon, Design evaluation of decay tank for a pool-type research reactor from the required minimum flow residual time point of view, Journal of Nuclear Science and Technology, Vol. 51, No. 9, pp. 1064-1072, 2014.

[3] S.H., Kang, H.S., Ahn, J.M., Kim. H.M., Joo, K.Y., Lee, K.W., Seo, D.Y., Chi, J.H., Yoon, G.D., Jeon, and M.H., Kim, Experimental study of siphon breaking phenomenon in the

real-scaled research reactor pool, Nuclear Engineering and Design, Vol. 255, pp. 28-37, 2013.
[4] S.H., Kang, K.Y., Lee, G.C., Lee, S.H., Kim, D.Y., Chi, K.W., Seo, J.H., Yoon, and M.H., Kim, Investigation on effects of enlarged pipe rupture size and air penetration timing in real-scale experiment of siphon breaker, Nuclear Engineering and Technology, Vol. 46, No. 6, pp. 817-824, 2014.
[5] K.W., Seo, S.H., Kang, J.M., Kim, K.Y., Lee, N.G., Jeong, D.Y., Chi, J.H., Yoon, and M.H., Kim, Experimental and numerical study for a siphon breaker design of a research reactor, Annals of Nuclear Energy, Vol. 50, pp. 94-102, 2012.
[6] K.Y., Lee and W.S., Kim, Theoretical study on loss of coolant accident of a research reactor, Nuclear Engineering and Design, Vol. 309, pp. 151-160, 2016.
[7] K.Y., Lee and W.S., Kim, Development of siphon breaker simulation program for investing loss of coolant accident of a research reactor, Annals of Nuclear Energy, Vol. 101, pp. 49-57, 2017.
[8] K.Y., Lee, S.H., Kim, and I.C., Lim, A long-term cooling method for a research reactor, in Proceedings of the International Group on Research Reactor (IGORR 15), Daejeon, South Korea, October 2013.
[9] K.W., Seo, Y.C., Park, J.K., Seo, D.Y., Chi, and J.H., Yoon, Decay tank, Korea patent 10-1166136, 2012.