Considerations for Closed-loop Heavy Water System Design in the Research Reactor

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1. Introduction

For the design and construction of an open pool research reactor, a detailed design for the reactor itself and the main systems relevant to the reactor have been proceeding at the Korea Atomic Energy Research Institute. The main systems are composed of the primary cooling system, the pool water management system, the emergency water supply system, the hot water layer system and the heavy water system. Unlike the nuclear power plant, the research reactor is constructed and operated for a multi-purpose utilization: radio-isotope production, irradiation facility operation, cold or thermal neutron production for neutron scattering instruments and etc. For these multi-purposes, the heavy water system or other reflector is required to moderate fast neutrons into thermal neutrons effectively.

In this paper, the design considerations of the heavy water system are discussed at the aspect of design bases.

2. Design Considerations

The heavy water system is designed to remove the heat generated in the heavy water vessel and heavy water inside by gamma-ray or neutron moderation under the reactor operation at any thermal power. The heat removed by heavy water circulating in the closed loop is transferred to the secondary cooling system in the heat exchanger. The closed loop system has a purification component to remove traces of corrosion or radioactive impurities to control the heavy water chemistry, such as pH, conductivity, and isotopic purity.

2.1 Design bases

Firstly, the system shall remove the heat generated in heavy water and the heavy water vessel (HWV) in order to maintain heavy water temperature within operational limits for power operation. Secondly, the system shall control and maintain the chemical quality of heavy water within specified limits. Thirdly, a cover gas shall be provided to an expansion tank of the system to accommodate the volume change and to dilute the deuterium generated by heavy water radiolysis in the HWV. Fourthly, the system shall provide overpressure protection to limit the deflection of HWV inner shell within the allowable range during and after accidental conditions. Fifthly, the deuterium concentration in a cover gas of the expansion tank shall be monitored. Sixthly, the system equipment shall be designed to minimize the loss of heavy water and installed in a leak-tight room. Seventhly, the system shall provide means for draining and refilling the system equipment including the HWV for heavy water purity upgrade or equipment maintenance. Lastly, the tritium concentration of the heavy water equipment room shall be controlled under an allowable limit for a personnel access. [1]

2.2 Considerations for the heavy water system design

The HWS is a closed circuit and consists of two circulation pumps, one heat exchanger, two ion exchangers, one expansion tank, one heavy water collection tank, several sight glasses for heavy water leakage monitoring, one tritium removal unit (TRU), and associated pipes, valves, and instruments. The schematic diagram of the HWS is shown in Fig. 1. [2]

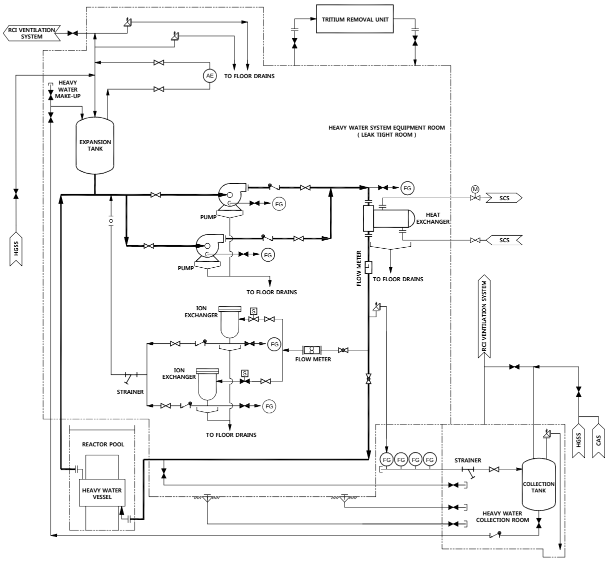

Fig. 1. Schematic diagram of the heavy water system.

The heavy water is circulated in the closed loop including the HWV in order to transfer the heat removed from the HWV to the Secondary Cooling System (SCS) through the heat exchanger at a nominal reactor power. The heavy water freezing temperature is higher than the light water, a secondary coolant, so that the adaption of the throttling valve on the secondary side of the heat exchanger shall prevent the heavy water from freezing below zero temperature at the ambient in the winter.

To control the water quality, a by-pass flow is circulated through one of the two ion exchangers for purification. The ion exchanger shall be designed under the considerations: minimum bed depth (more than 800 mm), maximum flow velocity (less than 60 m/hr), and appropriate bed volume flow rate within 8 and 50 BV/hr. The purified flow goes into the strainer to avoid the resin scrap flowing into the heavy water vessel and activating under the gamma ray or neutron. When the resin in the operating ion exchanger have deteriorated, the operating one shall be remotely switched to the standby one because the heavy water system room is not accessible during the operation of the reactor. For a periodical analysis of heavy water isotopic purity, the sampling port with the valve is branched from the main pipe from the outlet nozzle of the HWV in the HWS equipment room and extended to the glove box, located as near as possible to minimize the sampling amount.

In terms of the deuterium collection and system pressure control, the expansion tank shall be located at the highest point to vent non-condensable gases in the system. The minimum pressure, above the atmospheric pressure, shall be maintained by the helium supply pressure controlled from the helium gas supply unit to prevent oxygen intrusion in the system. When the tank pressure drops below a low set point, the helium gas supply unit shall automatically supply helium gas to the tank up to its minimum pressure. The tank shall accommodate the pressure variations, without opening of the pressure safety valves, in the normal range of HWS temperature changes from low to maximum reachable temperatures during normal operation. In the case of the SCS or HWS pumps failure, the volume expansion of heavy water from low reachable temperature to 120℃, heavy water boiling temperature, can be taken in the expansion tank with opening of the pressure safety valves.

The deuterium gas analyzer shall be installed to monitor the deuterium volumetric concentration in the gas hovering at the top of the expansion tank. When the volumetric concentration reaches a limit of 2 vol%, the tank shall be purged to the RCI ventilation system to prevent the deuterium and oxygen chemical reaction.

All the possible leakage from each individual component in the heavy water equipment room is designed to be collected to each floor drain or collected to the leakage collection header, depending on the location of leak point. The leaked heavy water collected to the floor drain is detected and alarmed by a moisture element. The heavy water leaked from the components is collected to the collection tank through the leakage collection header. Four possible leakage points connected on a leakage collection line with a sight glass are identified as follows: a drain line of the pumps, the heat exchanger, and the ion exchangers and the discharge line of the pressure relief valve.

During the equipment maintenance, the heavy water is drained out from the each equipment through the leak collection header and stored in the collection tank. To transport the drained heavy water in the collection tank to the expansion tank, compressed air and helium gas are supplied to the collection tank under each required pressure. The compressed air is used to pressurize the drained heavy water in order to transport it to the expansion tank. After the heavy water make-up, the collection tank and the heavy water make-up line are purged to the RCI ventilation by the helium gas in order to avoid deterioration of residual heavy water in the make-up line.

Under the low isotopic purity of the heavy water circulated in the system, the neutron detectors by the depressed neutron flux mislead the control rod withdrawal to increase the neutron flux. Therefore, the heavy water purity shall be within the allowable ranges to have no effect on the measured neutron flux. For upgrade of the heavy water isotopic purity, the separate drain line is branched from the upstream of the heavy water vessel and extended to be stored in separate drums. The floor pits with an isolation valve in the HWS equipment room are separately connected to drain lines extended to the collection room. If it is necessary to collect the heavy water leakage on the floor, the leaked heavy water shall be stored in a separate container. The ends of all these drain lines with an isolation valve are plugged with a cap.

The TRU shall be equipped to reduce the tritium and heavy water vapor concentration in an equipment room within the allowable limit for personnel access. The TRU is an integrated unit consisting of a leak-tight compressor, a coalescing filter, dehumidifier chambers with a heater, a particulate filter, and all associated pipes, valves, instruments, and etc. The air contaminated with tritium goes into the water lubricant compressor and is pressurized into the high pressure air with the condensed water. Then, the air flows into the dehumidifier to remove tritium and residual moisture by adsorption.

3. Conclusions

The heavy water is one of the reflectors used in the research reactor. Due to economical reasons and radioactive property, a system containing heavy water shall be installed in a leak-tight room during normal operation of the reactor. Accordingly, the heavy water system shall be designed under various considerations as above-mentioned: no freezing of heavy water, appropriate ion exchanger design, accommodation of the volume expansion, over pressure protection, deuterium monitoring, leak-tight design, and tritium control.

REFERENCES

[1] Jungwoon Choi, “Design Requirement of Heavy Water System”, JR-321-KF-413-001, R0.

[2] Jungwoon Choi, “System Description for Heavy Water System”, JR-321-KF-414-001, R0.