Consideration on the Leak Rate of the Heavy Water System Equipment Room in the Research Reactor

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1. Introduction

For the design and construction of an open pool research reactor, a detailed design of 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 a primary cooling system, a pool water management system, a emergency water supply system, the hot water layer system, and a heavy water system. Unlike a 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, etc. For these multi-purposes, a heavy water system (HWS) or other reflector is required to moderate fast neutrons into thermal neutrons effectively.

In this paper, the leak rate of the HWS equipment room is described in terms of its effect on the design of heavy water system and ventilation system.

2. Results and Discussion

Although the heavy water system is designed to minimize the leakage of the heavy water vapor by the application of the canned motor pump, non-leak valves, and many possible welding points on the connection, the heavy water vapor including the tritium water vapor leaks lightly out the HWS equipment room (hereinafter the HWS room). To avoid the tritium spreading out of the reactor hall, the HWS room is equipped with an air cooling system separate from the RCI ventilation system.

When heavy water leaks out of the system into the air in the HWS room, the tritium activity variation of the HWS room depends on the difference between the heavy water leakage rate and the leak rate of the HWS room considered in the activity. In addition, the tritium activity variation of the adjacent room counts on the difference between the leak rate of the HWS room and the ventilation rate of the adjacent room considered in the activity. At the steady state, the tritium activity in the adjacent rooms is proportion to the heavy water leakage amount and inversely proportion to the ventilation rate. [1] From this reference, the tritium activity of the adjacent rooms has no relation with the leak rate of the HWS room which affects the elapsed time to approach the saturated tritium activity in the HWS room.

2.1 Maximal heavy water vapor in the HWS room under the leakage event

Through the air conditioning system, the HWS room environment is regulated at less than 50 % of the relative humidity, and around 26 ℃ of the room temperature. To estimate the maximal heavy water vapor in the air, all moisture in the air is assumed as a heavy water vapor and the moisture sensors installed at the possible leakage point are supposed as under a malfunction. The heavy water mole fraction in the air can be calculated from the saturation pressure of heavy water at the considered temperature and the pressure in the HWS room. By applying the free volume of the HWS room, the maximal heavy water vapor in the air is estimated at 2.54 kg-heavy water.

2.2 Evaporation time of the maximal heavy water vapor

Under the normal operation of the air conditioning system in the HWS system, the evaporation time of the heavy water leakage amount, calculated in section 2.1, can be estimated from the following equation [2]:

$$Q = A_h \times (95 + 0.425 \times V_a) \times (P_h - P_a) \times C \quad (1)$$

where Q is the evaporation heat; A_h is the evaporation surface area of heavy water; V_a is the air flow rate of the air conditioning system; P_h is the saturated vapor pressure at heavy water temp.; P_a is the saturated vapor pressure of the air dew point in the room; and C is the unit correction factor.

In the calculation, the evaporation surface area is assumed as a tray area under a heat exchanger and the temperature of the leaked heavy water is considered as the average temperature of the system. To conservatively figure out the evaporation time, the heat transfer by convection is ignored between the leaked heavy water in the tray and the circulated air in the HWS room. With these assumptions, the evaporation time is estimated at less than 2 hours.

2.3 Ventilation in the adjacent room at steady state

According to the Korea Nuclear Act, the personnel can access an area less than 1 DAC (3.0E5 Bq/m^3) without any protection device. To satisfy this regulation, the adjacent rooms shall be ventilated with enough ventilation capacity. The ventilation counts for less than 1 DAC are shown in the following table along the heavy water leak time under the assumption of max. designed leakage amount of heavy water.

Leak time	*Ventilation counts*
1 day	583 counts/hr
10 days	58.3 counts/hr
20 days	29.2 counts/hr
30 days	19.4 counts/hr
41 days (official operation period)	14.2 counts/hr

To reduce the ventilation counts in case of a heavy water leakage event, the heavy water vapor shall be removed by the removal unit. When the radiation source in the HWS room is decreased, the concentration in the adjacent rooms increased by heavy water vapor leakage from the HWS room can be decreased.

2.4 Tritium activity in the HWS room

The tritium activity or heavy water vapor concentration trends in the HWS room are considered along the elapsed time when the heavy water vapor including the tritium water vapor is removed at a proper rate.

Fig. 1 shows that the moisture mole fraction in the HWS room is decreasing along the elapsed time after the heavy water vapor removal. The initial condition of the HWS room is filled with the 50% relative humidity of gas. Also, the return gas from the removal unit is a dry gas of a -40℃ dew point. After 16 hrs of removal unit operation, the internal mole fraction no longer changes more by the removal unit operation.

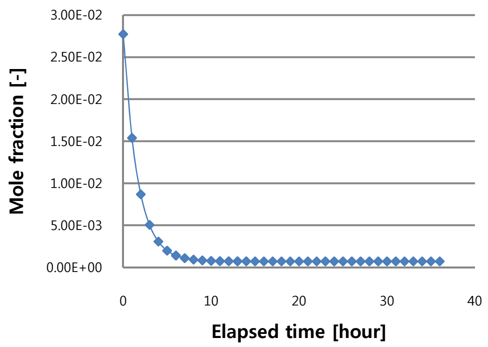

Fig. 1 Moisture mole-fraction variation in the HWS room over the elapsed time

Fig. 2 and Fig. 3 present the tritium activity trend in the HWS room under a heavy water leakage event. As shown in Fig. 2, heavy water is leaking continuously into the HWS room with the maximum tritium activity after 40 years of operation. Although the removal unit is normally operating, the average concentration in the HWS room cannot be lower than a certain value. Therefore, the operator equipped with the proper protection device shall enter the HWS room to deal with the leakage point, and the removal unit shall then be operated again to decrease the heavy water vapor concentration. Fig. 3 shows that the initial high tritium activity in the air can be decreased along the operation time of the removal unit if there is no more radioactive source increase.

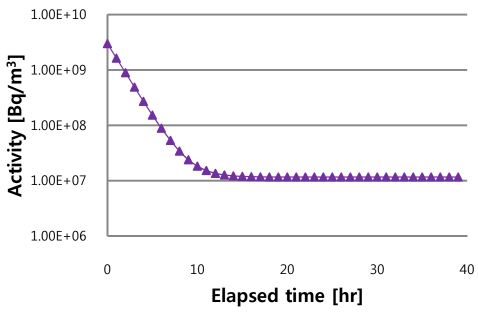

Fig. 2 Activity trend in the HWS room in the case of radioactive source increase

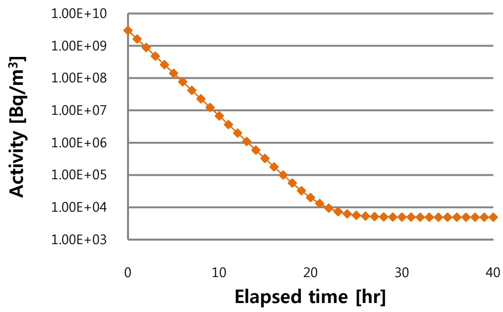

Fig. 3 Activity trend in the HWS room in the case of no more radioactive source increase

3. Conclusions

The leak rate of the HWS equipment room is discussed in terms of its effect on the design of heavy water system and ventilation system.

The HWS room shall be designed as a leak tight room such that the tritium diffusion rate to the reactor hall shall be minimized under a heavy water leakage event because the leak rate has no relationship with the tritium activity in the reactor hall. Also, in the case of a nominal minor leak, the leak rate of the HWS room does not need to be set at a tight value because the heavy water vapor concentration can be decreased under the allowable leakage rate by flowing out to the adjacent rooms, which are ventilated by the RCI ventilation system.

For maintenance, the heavy water system is equipped with a component to remove the heavy water vapor including tritium effectively under a leakage event or normal minor leak case. In addition, to optimize the ventilation capacity in the adjacent rooms, the removal unit shall be equipped in the HWS since the internal concentration in the HWS room is a dominant factor of the concentration in the adjacent rooms.

Based on the performance results of the removal unit, a countermeasure shall be chosen against a heavy water leakage event.

REFERENCES

[1] Jonghark Park, "Estimation of the leak rate in the leak tight room", HAN-TH-CR-033-05-044.
[2] ASHRAE Handbooks, pp.4.7, 1991.