Tritium Permeation in the Heat Exchanger for Nuclear Hydrogen Development and Demonstration Reactor

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The Korea Atomic Energy Research Institute (KAERI) has studied to develop a Nuclear Hydrogen Development and Demonstration(NHDD) reactor which are high temperature gas cooled reactor since 2004. Tritium which is generated by fission and neutron reaction will be diffused to the primary He coolant. Because the main purpose of this reactor is to produce the hydrogen gas, tritium permeation from the primary coolant to the hydrogen production system through the heat exchanger is an important problem. In the previous study[1], Tritium activity in the primary coolant was estimated and shown in the figure 1. Figure 2 shows an outline of tritium permeation process in the NHDD. As shown in Figure 2, Tritium permeates a heat transfer pipe of an intermediate heat exchanger(IHX) and transfers from a primary cooling system to a secondary cooling system. Finally, it seems to be probable that tritium permeates a second IHX of iodine-sulfer process(IS) which is the hydrogen production process and mixes in hydrogen as a product. For the IHX, the effectiveness must be no lower than 90%, and for the recuperator, it is 95%. To limit the size, the compact heat exchangers are the attractive solution tothe IHX design. In this study, Incoloy 800 is assumed to be used as a constructing material for the IHX because of its high strength and corrosion resistance properties in the presence of high-temperature water or steam. The permeation rate of tritium through a metallic barrier may be expressed as

$$J_i(t) = \frac{K_{pi}}{PRF}\left((P_i(t)^{0.5} - (P_{i+1}(t)^{0.5}\right) \quad (1)$$

$$K_{pi} = D_s \cdot S = F_0 \cdot \exp(-E/RT_{IHX,i}) \quad (2)$$

$$Q_i = \frac{A_i}{l_i}\int J_i(t)dt \quad (3)$$

where

J_1, J_2 : Permeation flux of primary and secondary side[$molm^{-2}s^{-1}Pa^{-0.5}$]

K_{p1},K_{p2} : Permeability of primary and secondary side[$molm^{-1}s^{-1}Pa^{-0.5}$]

S : Solubility [$molm^{-3}Pa^{-0.5}$]

D_s: Diffusivity of tritium in a solid metal [m^2s^{-1}]

F_0: Pre-exponential factor of tritium permeability [$molm^{-1}s^{-1}Pa^{-0.5}$]

P_1,P_2: Tritium partial pressure of primary and secondary side [Pa]

A_1,A_2: Heat transfer area of primary and secondary IHX [m^2]

l_1,l_2: Thickness of heat transfer of primary and secondary IHX [m]

Q_1, Q_2: Amount of permeated tritium of primary and secondary IHX [mol]

PRF : Permeation reduction factor [-]

Generally, PRF value is about 10 ~ 1000 in case of Incoloy 800. Tritium partial pressure with respect to the operating time is shown in Figure 3. Figure 4 shows the specific activity of tritium in the hydrogen production system with respect to the PRF. Even if the PRF is not considered (that is, PRF=1.0), tritium specific activity suffice to meet the regulatory requirement[2] which is the 1.0×10^{6} Bq/g. As stated above, PRF values are usually about 10~1000 so the tritium specific activity in the hydrogen production system will be expected as 76 ~ 0.23 Bq/g-H_2.

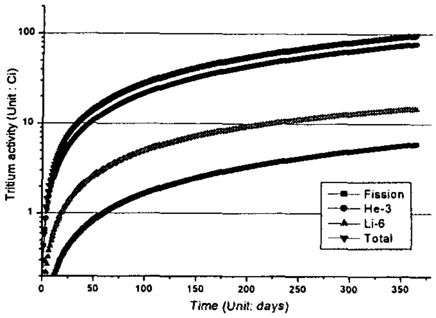

Fig. 1. Tritium activity in the primary coolant with respect the production sources in case of Pebble

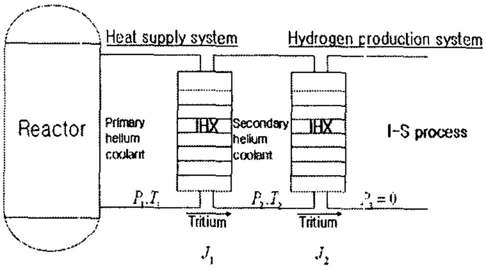

Fig. 2 Tritium permeation process in the NHDD plant for hydrogen production system

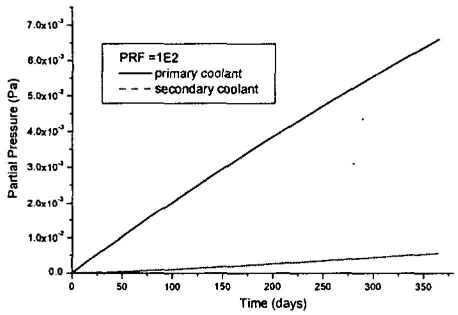

Fig. 3 Calculated tritium partial pressure in each system

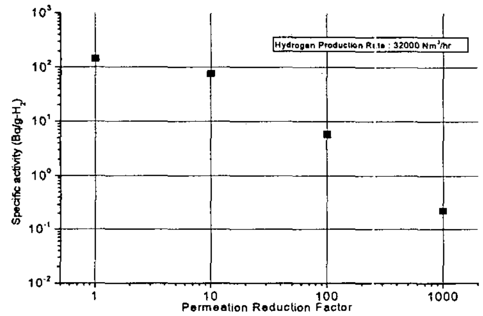

Fig. 4. Calculated specific activity of tritium in the H_2 Gas production system

Table 1. Necessary parameters for calculation of the tritium permeation through the IHX in case of the 300 MWth pebble type gas cooled reactor

Parameter	Value	Unit
Inlet temperature (Primary/secondary)	900/488.8	℃
Outlet temperature (Primary/secondary)	509/879.4	℃
Heat transfer Area	1749	m^2
Thickness of heat transfer	1.6	mm
Mass of coolant (Primary, Secondary)	10830	kg
Pre-exponential permeation factor	2.11×10^{-11}	mol $m^{-1}s^{-1}Pa^{-0.5}$
Activation energy	56.6	kJ·mol^{-1}

Reference

1. Daesik Yook and Kunjailee, "Tritium Behavior in The Primary Coolant of Pebble and Prism Type Gas Cooled Reactor", *Proceeds. of KRWS*, Gyeongju, Korea, Nov. 17-18, 350~351(2005)

2. IAEA, *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Râdiation Sources*, Safety series No. 115, (1996).