Design Parameter Assessment on the Tritium Release in the VHTR

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1. Introduction

Very High Temperature Reactor (VHTR) has been studied as one of the Gen-4 reactors in Korea. The high coolant temperature of the VHTR might be applied for both electrical and non-electrical applications. The gas-turbine can be used to the VHTR due to high temperature coolant of single phase. The large heat capacity of the coolant might provide process heat and make hydrogen. However, the high operation temperature of helium within graphite moderators might generate and release the tritium into the environment and the systems. The tritium is one of the fission products to be controlled according to the regulatory guide. Therefore, the amount of the production, decay and release during operation should be predicted accurately to use the VHTR safely.

There are numerous fission products in the reactor core of VHTR. The present study focuses on the tritium overall phenomena. The tritium exists as a gas phase and does not have decay chain reaction. Because the tritium leakage or the percentage in the water during the normal operation is more important than the accident condition, the independent codes have been being developed. JAERI developed THYTAN[1] to predict the tritium distribution in the reactor core and IS system. Idaho National Laboratory (INL) has developed the Tritium Permeation Analyses Code (TPAC)[2] using the MATALAB S/W. Korea Atomic Energy Research Institute(KAERI) has been developing the Tritium Overall Phenomena analysis(TROPY) to predict the tritium production, bound, release, permeation between the loops and leakage to the environment and IS system. Present study compared the tritium leakage rate with the results of TRITGO[3] of General Atomic[GA] and assessed the leakage rate depending on the design parameter.

2. Methods and Results

2.1 Methods

Fig. 1 shows a simple diagram of tritium behavior. Tritium is produced by ternary fission, neutron reactions in the solid structures and ^{3}He reaction in the primary coolant. The tritium generated in the solid release to the coolant or bounds in the solid. The tritium in the coolant might leak to the containment or environment.

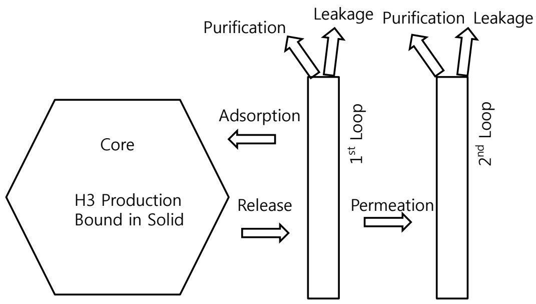

Fig. 1 Tritium behavior

The production of the tritium can be modeled by the following equation.

$$\left[\frac{d(N_T)_r}{dt}\right]_{Prod} = \left[\frac{d(N_T)_r}{dt}\right]_{fuel} + \left[\frac{d(N_T)_r}{dt}\right]_{Li-6} + \left[\frac{d(N_T)_r}{dt}\right]_{Li-7} + \left[\frac{d(N_T)_r}{dt}\right]_{Be-9} + \left[\frac{d(N_T)_r}{dt}\right]_{C-12} + \left[\frac{d(N_T)_r}{dt}\right]_{B-10\,fast} + \left[\frac{d(N_T)_r}{dt}\right]_{B-10therm} + \left[\frac{d(N_T)_r}{dt}\right]_{He3} \quad (1)$$

The sources of the tritium production are ternary fission, Li-6, Li-7, Be-9, C-12, B-10 and He-3 in helium.

The tritium in the coolant can be calculated by following equation.

$$\left[\frac{d(N_{T,NS})_r}{dt}\right]_{Prod} = \frac{b}{a}\pi\sigma\Phi N_{NS}(t) - \Lambda \cdot N_{T,NS} \quad [2]$$

Λ means purification, leakage, permeation, sorption and decay rate. *NS* represents the tritium source.

A permeation rate through the heat exchanger can be calculated by two models in TROPY code.

CEGA model[4]

$$R_{perm} = \left(R_o/\tau_w\right) C_T \left(P_{pri}\right)^{1/2} (ppmv_{H_2})^{-1/2} \exp(B/T) \left[\mu Ci/m^2 - hr\right] \quad [3]$$

Rechardson model[5]

$$R_{perm} = \frac{A}{l} k_{p,T} \left(1 - \frac{P_{H_{2,l}}}{P_{total,l}}\right)\left(\frac{P_{HT,h}}{\sqrt{P_{H_{2,h}} + P_{HT,h}}} - \frac{P_{HT,l}}{\sqrt{P_{H_{2,l}} + P_{HT,l}}}\right) \quad [4]$$

2.2 Verification

To verify the developed TROPY code, the calculated results for the MHTGR350 were compared with the data obtained by the TRITGO code. The leakage rate from containment was 100%vol/day. The bounded ratio which is the fraction of the tritium that was generated and remains in the solid structures was set to 99%

The design parameter for MHTGR system is written in Table I.

Table I: Design Parameter of MHTGR 350

	1st loop	2nd loop
Mass [kg]	3175.1466	58967.008
Pressure[atm]	69.75	
Temperature[^{o}C]	490	490
Loop leakage rate[1/s]	3.17e-9	8.88141e-7
Purification rate[1/s]	1.79e-4	0.0
Containment leakage rate[1/s]	1.2659e-4	1.2659e-4
Bound(%)	99	

Table II shows the tritium amount in the each core region and permeation rate at heat exchanger during 1 year operation. The calculated results by the TROPY well agreed with the calculated data by the TRITGO code

Table II: Tritium distribution

region		TROPY	TRIGO
Core(Top)	1st coolant[Ci]	2.2722e-2	2.2724e-2
	2nd coolant[Ci]	4.2132e-3	4.2095e-3
Core(Mid)	1st coolant[Ci]	1.3099e-5	1.3092e-5
	2nd coolant[Ci]	2.3346e-6	2.3311e-6
Core(Bottom)	1st coolant[Ci]	9.1268e-6	9.1218e-6
	2nd coolant[Ci]	1.6264e-6	1.6238e-6
Heat exchanger	permeation [1/s]	1.625e-7	1.6233e-7

The tritium is easy to permeate and leak through the system. Therefore, it is important to know which design parameter is sensitive to the leakage amount into the environment. Fig. 2 shows the total tritium leakage to the environment during the normal operation. Fig. 3 indicates the tritium leakage by the each inventory. From the Fig. 3, the inventory of He-3 in the helium coolant is dominant.

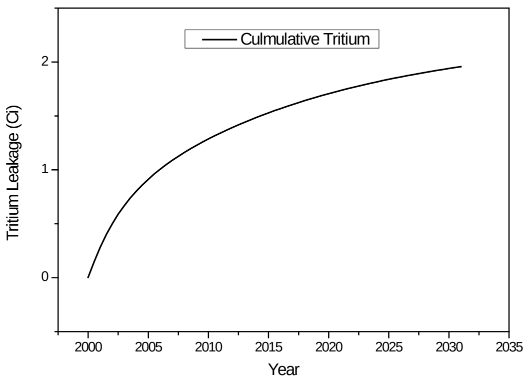

Fig. 2 Total tritium leakage into environment

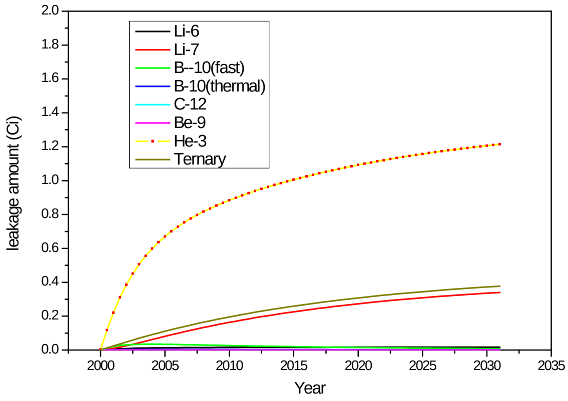

Fig. 3 Tritium leakage by the inventory

The generated tritium in the graphite is considered to be bounded in the graphite block. The results of Fig. 2 and 3 were calculated with 99% bound in the graphite block. Therefore, He-3 inventory in the coolant was main source of release into the environment. With small bound fraction, the large inventories in the graphite release into the environment. Fig. 4 shows the tritium leakages with 9% bound in the graphite. Most of the Li-7 inventories released into the environment. Fig. 5 shows the results by changing the containment leakage rate from 100%vol/day to 1%vol/day. Comparing to the results in the Fig. 3, the containment leakage rate does not affect largely in the results.

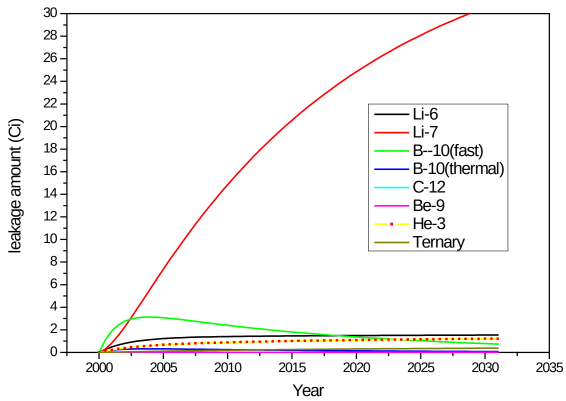

Fig. 4 Tritium leakage by the inventory – 9% bound

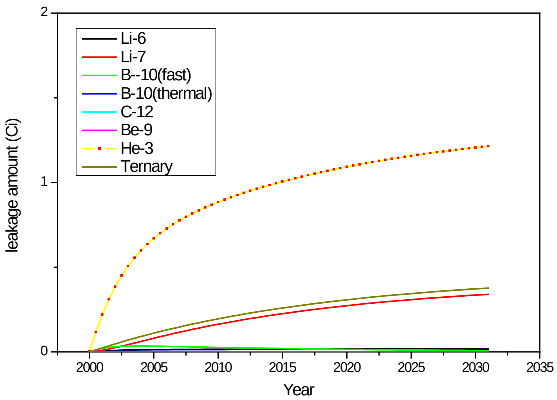

Fig. 5 Tritium leakage by the inventory – 1%vol/day

Fig. 6 represents the tritium leakage by changing the helium replacement rate (helium leakage in the loop) from 3.17e-9(1/s) to 3.17e-7(1/s). The tritium release into the environment increased significantly.

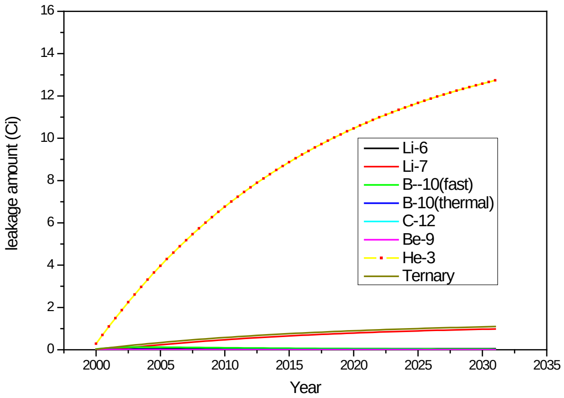

Fig. 6 Tritium leakage by the inventory – replacement

Fig. 7 shows the reactor core temperature effect for the tritium leakage. The active core temperature increased from 480/700/820(^{o}C)(top/middle/bottom) to 600/900/1200(^{o}C). The leakage rate increased slightly. However, the design temperature of the VHTR reactor core does not change significantly. Therefore, the other design parameters like bound, loop leakage should be controlled carefully to reduce tritium leakage.

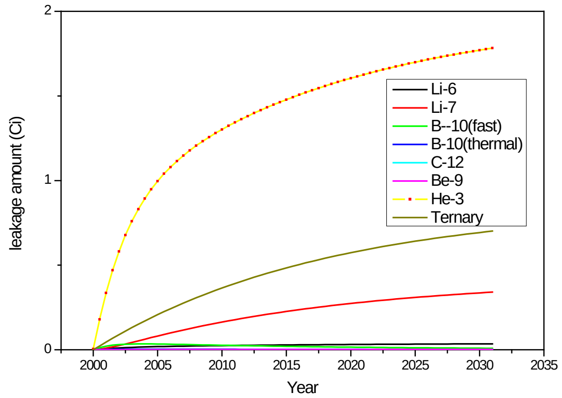

Fig. 7 Tritium leakage by the inventory – temperature effect

3. Conclusions

The tritium production and permeation rate by the TROPY code were compared with the results of TRITGO code. The two codes well agree each other. The dominant effects to the tritium leakage were investigated. The containment leakage rate does not affect significantly in the calculation. The bound percentage, the helium replacement rate were key parameters for the tritium leakage to use VHTR safely. The more studies will be conducted to find key parameters to reduce the tritium leakage.

Nomenclature

A = heat exchanger wall area
b/a = bound ratio
B = constant in permeation rate equation (K)
C_T = tritium concentration ($\mu mCi/m^3$)
$(N_T)_r$ = the number of tritium atoms in region r
$k_p = f \cdot exp\left(-\frac{E}{RT}\right)$
t = time(s)
T = temperature(K)
$ppmv_{H2}$ = hydrogen concentration (ppmv)
π = power level
σ = effective cross section
Φ = thermal neutron flux (atoms/cm^2/s)
P = pressure (atm)
P_{pri} = primary coolant pressure (atm)
R_{perm} = permeation ratio (1/s)
R_o = constant in permeation rate equation (ppmv$^{1/2}$ $- m^3(STP) - mm\ /atm^{1/2} - m^2 - h$)
l = heat exchanger wall depth

Acknowledgements

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