Preliminary Tritium Transport Analysis in the 90MWth HTGR system

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1. Introduction

High Temperature Gas-cooled Reactor (HTGR) has been selected among the Gen-4 reactors in Korea Atomic Energy Research Institute (KAERI) due to its many merits including inherent safety. The HTGR can be used for hydrogen production, process heat supply and power generation thanks to its high outlet coolant temperature. KAERI has launched a public-private partnership project to develop a 90MWth HTGR for process heat supply. The heated steam will be supplied to industrial complexes. There are many design limitations to utilize HTGR safely and efficiently. One of the design limits is to assess tritium amount in the primary loop and the process heat system. The HTGR uses a helium gas as coolant. Therefore, a released tritium to the primary loop might leak or transport to the secondary system due to high permeability through the heat exchanger (HX) tubes. Therefore, it is important to estimate the tritium amount because the process heat will be delivered to private industries, which are located outside the nuclear island. The present study explains the tritium generation process and the preliminary prediction of the tritium amount in the process steam.

2. Methods and Results

Figure 1 shows the drawing of HECTAR (KAERI's HTGR concept). The power is 90MWth and the outlet temperature is 750℃.

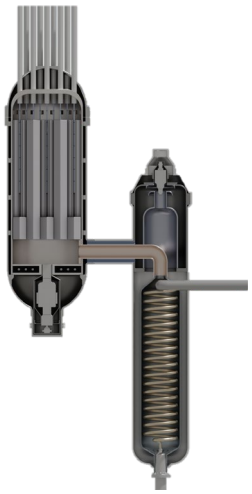

Fig. 1 HECTAR system drawing

The fluid in the third loop is steam with an outlet temperature of 500℃

2.1 Tritium production estimation

The tritium product can be calculated using the following three mechanisms.

- Ternary fission
- Neutron reaction with the impurities in the graphite block
- Neutron reaction with He-3 in coolant

However, as the core design has not yet been determined, the tritium production rate has been assumed using VHTR350 (350MWth) system. KAERI has developed a high-fidelity tritium production model using Monte-Carlo calculation[1]. The calculated tritium amount was compared with the calculated results by TROPY code[2]. The calculated results are summarized in Table I.

Table I: Birth rate in the VHTR350

	McCARD [Bq/yr/MWth]	TROPY [Bq/yr/MWth]	Diff. [%]
Fission	2.285E11	2.133E11	6.6
Helium	3.161E10	3.138E10	0.733
Graphite	1.203E11	1.101E11	8.52

The conservative scenario is the release of all tritium from the sources. However, based on the HTR-10 experiences[3], the tritium release fraction from fission was set as the initially broken or contaminated fuel fraction of 8.E-4. Therefore, the release rate to the primary loop was assumed as 1.086E13 Bq/yr for the 90MWth HECTAR.

2.2 Modelling and Results

There are tritium regulations for the drinking water and summarized in Table II[4].

Table II: Tritium regulation for the drinking water[4]

Tritium Regulation	Bq/Kg
Australia	76,103
Finland	30,000
WHO	10,000
Switzerland	10,000

Russia	7,700
Canada	7,000
U.S.A(EPA)	740
U.S.A(NRC)	40,000 *onsite
NSSC(Korea)	40,000 *onsite
MOF(Korea)	100 *Sea
EU	100

However, there is no regulation for the tritium contamination for the product hydrogen or process heat. In Germany, the programmatic limit for the Project Nuclear Process Heat (PNG) of the FRG was developed as 370Bq/kg (in syn gas) [5]. During the NGNP project in the U.S.A, the limit was described as 740 Bq/kg (in hydrogen or steam) [5]. JAEA gives the programmatic limit as 55,900Bq/kg for the product hydrogen[5].

The tritium transport in the loop for the HECTAR has been preliminary analyzed to investigate tritium transport phenomena during normal operation. Figure 2 represents the nodalization for TROPY calculation. For the present study, it was assumed that the primary and secondary loop are filled with helium coolant. The third loop is steam. The pressure in the primary is 6.5MPa. The coolant replacement rate and purification rate in the primary loop are 0.027389 [%/day] and 1.79E-6 [1/s], respectively.

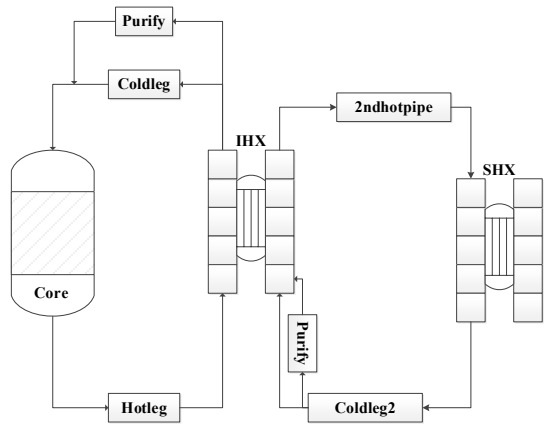

Fig. 2 HECTAR TROPY nodalization

Table III represents the calculation scenarios for the present study over 60 years operation. The condition of Case 6 in Table III is same as Case 1 but the different purification rate of 1.39E-5 based on HTR-PM[6] was applied.

Table III: Tritium transport run case

Run case	HX Temp. [°C]	Release Fraction
Case 1	500.0	0.0008 in fuel All in others
Case 2	700.0	0.0008 in fuel
		All in others
Case 3	500.0	All release
Case 4	Case 1	1.39E-5[1/s]

Table IV represents the tritium concentration in the primary and secondary loops. As the temperature of heat exchanger increased, more tritium was permeated to the secondary loop. Therefore, the tritium concentration in the primary loop was reduced in the Case 2 of Table IV. The tritium concentration of Case 4 is much lower than that of the Case 1 due to higher purification rate.

Table IV: Tritium inventory in primary and secondary loop

Run case	Primary [Bq/m^3-stp]	Secondary [Bq/m^3-stp]
Case 1	1.78E7	8.14E6
Case 2	4.18E6	2.1E6
Case 3	7.24E7	1.48E7
Case 4	4.39E6	1.01E6

Table V shows the tritium concentration in the different reactors. The data of HTR-10, HTTR and AVR are experimental results. The data of HTR-PM are numerical results. The result of HTR-10 was measured during 26 hours after restarting at 2015[3]. The data of HTTR were obtained by sampling 50 days for full power operation[7]. The tritium concentration in AVR is the highest. The reason may come from that the AVR used BISO particles and experienced water ingress accident[8]. The calculated results in Table IV are reasonable compared to the other experimental and calculated results in Table V.

Table V: Tritium in reference loop

Run case	Primary [Bq/m^3-stp]	Power [MWth]	Sampling /Operation
HTR-10[4]	1.09E4	2.9	26 [hour]
HTTR[7]	1.6E5	30	50 [day]
AVR[8]	3.70E7	46	3 [year]
HTR-PM[9]	3.69E6	250	40 [year]

The calculated results for the present study are based on the secondary loop using the helium fluid. If the secondary loop uses the water, most of the tritium might exist as HTO state. Therefore, the tritium permeation to the 3rd loop would be reduced. Also, the tritium concentration in the secondary loop through heat exchanger may vary depending on the HX materials or coating technique. Those effect will be studied in the future studies.

3. Conclusions

The tritium concentration in the primary and the secondary loop were analyzed using TROPY code for the HECTAR-90MWth reactor. The tritium concentration in the loops vary depending on the temperature of heat

exchanger and purification rate. If the temperature of heat exchanger increases, more tritium may permeate. In the future, the tritium permeation analysis for different loop arrangements will be necessary to investigate the tritium contamination ratio in the process heat.

Acknowledgements

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