Numerical Approach for Tritium Release in the Very High Temperature System Core

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1. Introduction

As carbon neutrality is getting more important with climate change issue, a hydrogen economy is attracting more interest. Because, the hydrogen energy does not emit COx and dust Korea Atomic Energy Research Institute (KAERI) has been studying very high temperature system (VHTS) to produce hydrogen without carbon issue. Various studies are being conducted for a safe and optimized design. A tritium modelling for production, release and transport is one of those researches. The generated tritium by ternary fission and neutron reaction may release into the coolant. The VHTS uses helium gas as a coolant. The circulating tritium in a primary loop is easy to permeate due to its small size. The permeated tritium transports to the hydrogen production system, which may result in contaminating the hydrogen. Therefore, the accurate modelling for the tritium production and release into the coolant is necessary. THYTAN[1] code developed by Japan Atomic Energy Agency (JAEA, Japan) uses a fractional release by user option. Idaho National Laboratory (INL) has also developed TPAC[2] code to predict the tritium transport behaviors. However, TPAC code also used user supplied fractional release to estimate the release fraction. Tsinghua university calculated a release rate with the contamination and broken coated particle fraction which were obtained from the HTR-10 experiences[3]. KAERI has been developing TROPY code [4] to analyze the tritium transport. The tritium release in the previous TROPY code was also calculated by user option or simple diffusion equation. On the present study, the improved diffusion module with the failure and contamination fraction was studied to investigate release rate from the triso particles to the primary coolant.

2. Methods and Results

The adopted diffusion model in the previous TROPY code solves diffusion equation in the only triso particle layers. The released tritium from triso particle again releases into the coolant through graphite block with the analytical solution model in Eq. 2. Therefore, two step approaches were applied below.

$$\frac{\partial C_i(r,t)}{\partial t} = \dot{B}_i(r,t) - \lambda_i C_i(\mathrm{r,t}) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D_i \frac{\partial C_i(r,t)}{\partial r}\right)$$
$$\text{in triso particle (1)}$$

$$F_{gr,ij} = 1 - \sum_{n=1}^{\infty}\frac{4}{a^2\alpha_n^2}\exp(-D_{ij}\alpha_n^2 t)$$
$$J_0(a\alpha_n) = 0 \text{ in graphite block (2)}$$

C = concentration(mol/m3)
$\dot{B}$ = volumetric birth rate (mol/m3/s)
D = diffusion coefficient(m2/s)
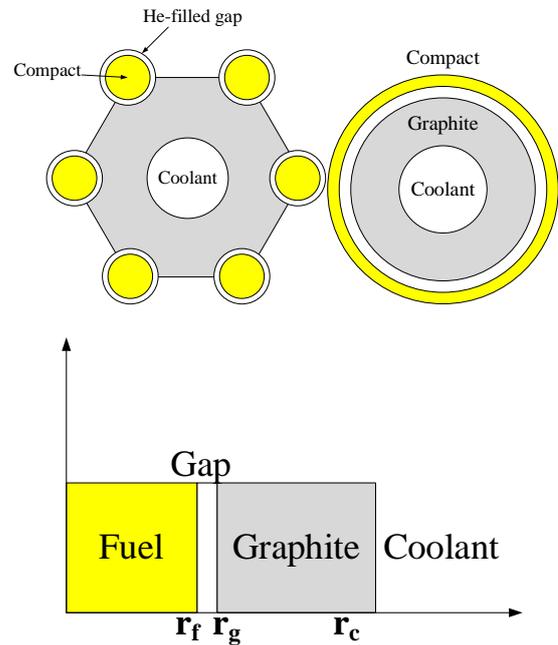i = layer of a triso particle

2.1 Improved Model

Fig. 1. Tritium release unit cell diagram

To calculate tritium transport through a fuel element, a following equation of COPA[5] was adopted.

$$\frac{\partial C_i(r,t)}{\partial t} = \dot{S}_i(r,t) - \lambda_i C_i(\mathrm{r,t}) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D_i \frac{\partial C_i(r,t)}{\partial r}\right)$$
$$(3)$$

where $\dot{S}_i(r,t) = \mathrm{n}\sum_{i=0}^{M} f_i \dot{R}_{CFP,i} + f_{HM}\dot{B}_{fission}$

n = Particle density $\left(\frac{\text{particles}}{m^3}\right)$
i = failure mode
M = number of failure mode
f = failure fraction
$\dot{R}_{CFP,i}$ = release rate
f_{HM} = *heavy metal contamination*
$\dot{B}_{fission}$ = volumetric birth rate due to fission

The contamination fraction and failure fraction were newly considered in the present module. Diffusion coefficient used in the model is tabulated in Table I[6].

Table I: Tritium diffusion coefficient($D = D_0\exp(-\frac{Q}{RT})$)

Layer	$D_0[m^2/sec]$	Q[J/mol]
Kernel	1.E-6	0.0
Buffer	1.E-6	0.0
IPyC	1.E-6	0.0
SiC	4.7E-15	76500.0
OPyC	1.E-6	0.0

2.2 Domain and Boundary Condition

Figure 2 shows the KAERI VHTS core layout. The active fuel blocks consist of 9 block layers in axial. A power of VHTS is 350MWth. The inlet and outlet coolant temperatures were designed as 490 and 950 ℃, respectively.
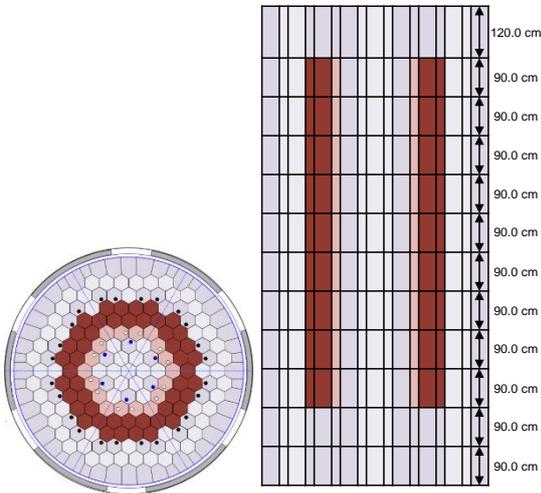

Fig. 2. KAERI VHTS layout

The computational domains were divided in 9 sections in Table II. The coolant temperature was obtained by GAMMA+ calculation.

Table II: VHTS section

Axially	Radially	Coolant Temp[℃]
Top	Inner	536.5
	Middle	548.8
	Outer	526.7
Middle	Inner	904.6
	Middle	814.0
	Outer	698.9
Bottom	Inner	1143.5
	Middle	1019.6
	Outer	909.6

The average fission rate per kernel volume was obtained by the McCARD calculation

2.3 Tritium Fractional Release

Figure 3 represents a release fraction of intact fuel element from triso particle to coolant through fuel element and moderator. At the top of the core, the release fraction is almost zero due to low coolant temperature. The meaningful results come from the bottom core where the fuel temperature is high.
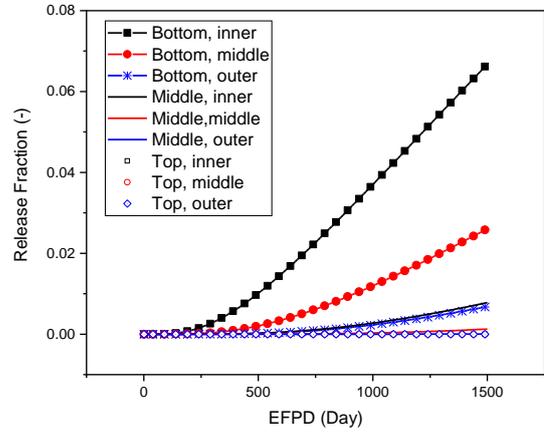

Fig. 3. Release Fraction of intact particle

The contamination effect was calculated in Table III. The contamination fraction was extruded from the data from HTR-10 study[3] of ~8.E-4. The normal contamination fraction did not show large effect on the fractional release.

Table III: Contamination effect

Contamination fraction	Release Fraction
0	6.677e-2
1.e-4	6.69e-2
1.e-3	6.81e-2

Figure 4 shows the particle coating layer failure effect during operation by thermal stress in the bottom region. The failure fraction calculated by COPA was applied in Fig. 4. The inner bottom region where the fuel temperature is maximum showed the dramatic increase in the release fraction due to the particle failure. Therefore, the flatted temperature control during normal operation is necessary.
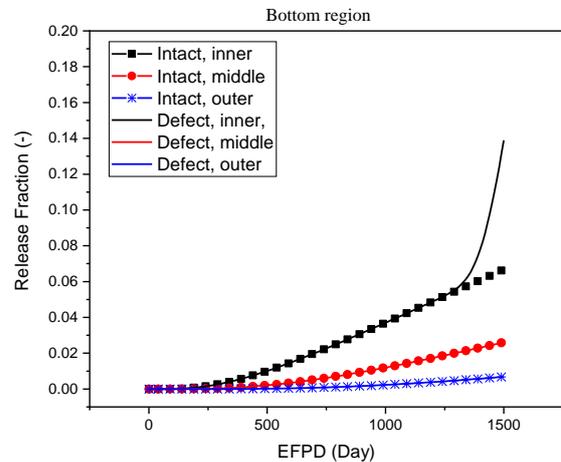
Fig. 4. Particle coating layer failure effect

3. Conclusions

The tritium fractional release using diffusion model was investigated. The diffusion model may provide realistic tritium release into the coolant compared to the user input option. The maximum release fraction was about 6.7% at the bottom core. The contamination fraction did not affect much to the release fraction. The important parameter to the release fraction was failed fraction due to high temperature. Therefore, it will be necessary to predict temperature profile in the core precisely. In the future study, the tritium release from graphite block due to neutron reaction with the impurities will be investigated.

Acknowledgements

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