Transactions of the Korean Nuclear Society Spring Meeting
PyeongChang, Korea, May 27-28, 2010

Improvements of Physical Models in TRITGO code for Tritium Behavior Analysis in VHTR

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1. Introduction

Since tritium is radioactive material with 12.32 year of half-life and is generated by a ternary fission reaction in fuel as well as by neutron absorption reactions of impurities in Very High Temperature gas-cooled Reactor (VHTR) core, accurate prediction of tritium behavior and its concentration in product hydrogen is definitely important in terms of public safety for its construction.

In this respect, TRITGO code [1] was developed for estimating the tritium production and distribution in high temperature gas-cooled reactors by General Atomics (GA). However, some models in it are hard-wired to specific reactor type or too simplified, which makes the analysis results less applicable. Thus, major improvements need to be considered for better predictions. In this study, some of model improvements have been suggested and its effect is evaluated based on the analysis work against PMR600 design concept.

2. General Features of TRITGO Code and Limitations

2.1 Features and Basic Phenomena to be considered

TRITGO can calculate the mass balance of tritium in VHTR systems, which basically takes into account of following phenomena:

(1) Tritium production by ternary fission of the fuel and neutron reactions with graphite impurities, boron control materials in the reflector blocks, and ^{3}He naturally occurring in the helium coolant.
(2) Chemisorption on the graphite
(3) Tritium removal by the purification system
(4) Tritium leakage to the atmosphere
(5) Tritium permeation through the steam generator

2.2 Limitations of previous method

Although TRITGO code is useful in predicting the tritium behavior in VHTRs with a certain degree, there still exist large uncertainties resulting from assumptions for simplification or limited physical models. Specifically, this is mainly related to tritium release model from TRISO fuel particles or control rod materials, graphite chemisorption model, permeation model, and tritium recoils model, etc. Among theses, two models, tritium release from TRISO fuel and control materials (B_4C) are considered to be improved in this study and their effects are analyzed. For the purpose, PMR600 is selected as a reference plant (See Fig. 1).

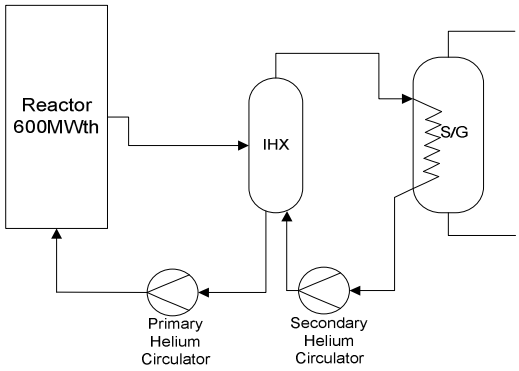

Figure 1. Schematic Diagram of PMR600

3. Model Improvements and Analysis

3.1 Tritium Release from B_4C Materials

Tritium release fraction from solid materials in the core is given by users as a constant in the original TRITGO code. In addition, retention fraction of 0.99 is recommended by GA because the transport of tritium which is bound interstitially in graphite is expected to quite slow since a temperature of at least 1200℃ is required for tritium desorption from graphite [1]. However, this simplistic approach may cause large uncertainties on tritium distribution, and then more reasonable method needs to be considered based on experiments. In this respect, a model for tritium release from B_4C pellets which is developed by GA is applied in this study.

Figure 2 shows the difference of tritium activities in primary coolant when applying two different methods for tritium release from B_4C materials. It is found that GA model causes larger amount of tritium release than the case of using 0.99 bound rate, but smaller than that of using 0.5 bound rate. Obviously, this will result in the difference of ultimate tritium release to the IS process system or environment. Therefore, it can be concluded that that additional efforts should be made for obtaining sufficient experimental data or uncertainty quantification to increase the reliability of predicting these phenomena.

3.2 Tritium Release from TRISO Fuel Particle

In this study, the effect of introducing analytic solution for the total amount of diffusing substance leaving the sphere [2] and the numerical solution for 1-D mass transfer equation is evaluated. This is to obtain realistic value of fractional release rate of tritium from the fuel by considering temperature differences throughout the core, in which significant amount of tritium is created by ternary fission. Also, the results are compared with those of the original method of TRITGO, using constant values of release fraction. 30% of release rate is recommended one by other calculations using TRITGO for GT-MHR600 [3].

Figure 3 shows the difference of tritium amount released to the primary coolant from TRISO fuel. Based on this, we can find that that 30% release of tritium from the fuel is sufficiently conservative compared to other methods.

Here, analytic solution is obtained under the assumption that the tritium initially produced by ternary fission is distributed uniformly throughout the fuel region and constant concentration (0) at the surface. This is because analytic solution exists only for the limited conditions. However, this caused significant over-prediction of tritium release compared to that of numerical solution, which assumes that initially created tritium is located in the kernel region of TRISO fuel. The result from numerical solution indicates that more than 99% of tritium is retained within the fuel.

Figure 4 shows that most tritium produced by ternary fission is retained in the core mainly by two mechanisms: trapped in TRISO fuel and adsorption on graphite. As a result, it can be said that the tritium amount released from the fuel is negligibly small. This indicates that the different approaches above hardly cause meaningful differences in the total amount of tritium released to the primary coolant.

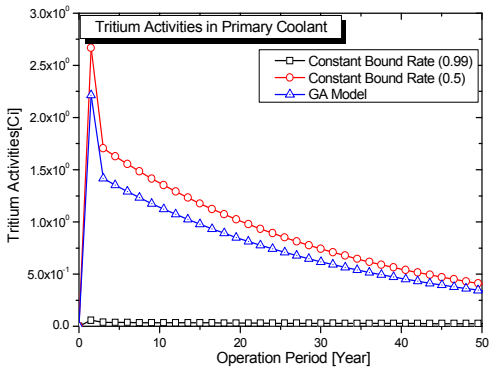

Figure 2. Tritium Release by Different Release Models for B_4C Materials

4. Conclusions

Improved approaches for two major phenomena related to tritium behavior are suggested and the effects on the tritium distribution throughout PMR600 system are evaluated. Based on this, it is concluded that additional efforts should be made for the prediction of the tritium release from B_4C materials. However, the effect of applying different diffusion model for the fractional release rate of TRISO fuel is negligibly small.

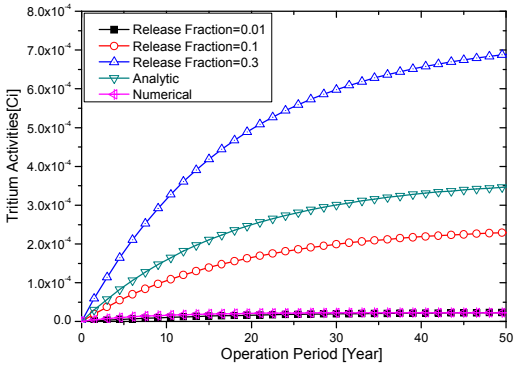

Figure 3. Release Amount of Tritium Produced by Ternary Fission

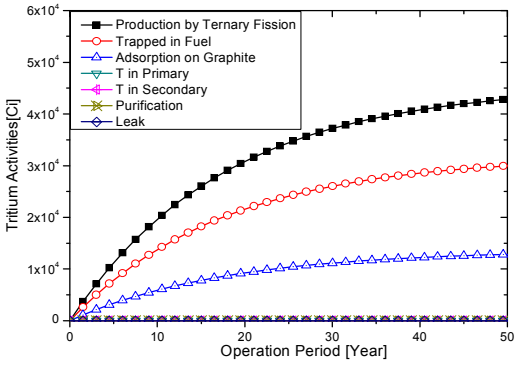

Figure 4. Tritium Production by Ternary Fission and its Distribution throughout PMR600 system

Acknowledgement

This work was supported by Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST). (Grant code: 2009-006258)

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