Prediction of Fission Product Liftoff in a Depressurization Accident of Very High Temperature Reactor

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1. Introduction

In a very high temperature reactor (VHTR), a small amount of fission products may be released from nuclear fuels into the primary circuit during normal operating conditions. The released fission products are either plated-out on the surfaces of the primary circuit or removed from the primary circuit by decay and purification. The build-up of the plateout activities during a long period of reactor operation is one of the key considerations for the VHTR design [1].

Under a depressurization accident, moreover, the plated-out fission products may be enforced to liftoff and discharge into the confinement building. It is important to quantify the amount of fission product liftoff during a depressurization accident since it contributes an early potential hazard of radiation exposure to the environment [2].

In this work, a methodology to calculate fission product liftoff activities in a depressurization accident is presented and an example calculation was performed to illustrate its applicability and usefulness. The present methodology uses two computer codes (i.e., the POSCA code [3] and the GAMMA+ code [4]) developed by Korea Atomic Energy Research Institute (KAERI) for the VHTR design. The POSCA code provides the plateout distribution of fission products and the GAMMA+ code is used to determine a crucial parameter (named as shear stress ratio) for the fractional liftoff of fission products.

2. Numerical Approach

For a fission product liftoff model, an empirical model developed by Myers [5] is adopted in this work. The Myers model expresses the fission product liftoff by using the shear stress ratio defined as:

$$SR = \left(\frac{P_1}{P_0}\right)^{0.75} \left(\frac{V_1}{V_0}\right)^{1.75} \left(\frac{T_0}{T_1}\right)^{0.58} \quad (1)$$

where P = pressure, V = velocity, T = temperature (in K). Subscripts 0 and 1 represent the values under steady-state and blowdown conditions, respectively. The amount of fission product liftoff (L) is evaluated as follows:

$$L = L_0 + \Delta L \quad (2)$$

$$\Delta L = \frac{100m(SR-1)}{100+m(SR-1)} \quad (3)$$

where L_o and m are the empirical constants. The available constants are provided in Table I.

Table I: Empirical constants for the Myers model [5]

Nuclide	L_0 (%)	m_i
Cs	0.19	0.4
I	0.15	1.2
Sr	0.54	2.6
Ag	0.01	1.2
Te	0.09	1.2
Sb	0.09	1.2

Fig. 1 presents a methodology to calculate fission product liftoff in a depressurization accident of VHTR.

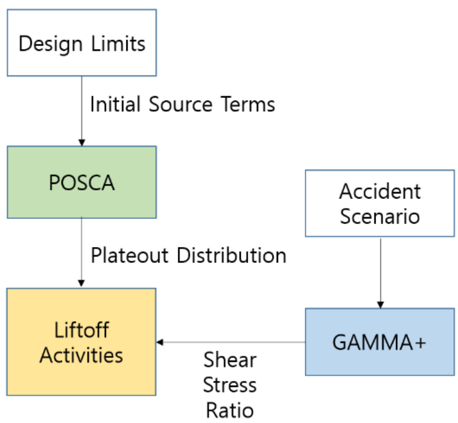

Fig. 1. A methodology to calculate fission product liftoff activities in KAERI.

During normal operation of a VHTR, the amount of fission products in the primary circuit is controlled and limited by the design limits specified in the design document. These limits are the maximum expected circulating and plateout activities in a primary circuit. Such design limits are used for the initial source terms of the plateout activities and used as the boundary conditions of the POSCA code. The POSCA code predicts the plateout distribution along the primary circuit of a VHTR. Independently, a GAMMA+ model is set-up based on a depressurization accident scenario. And the GAMMA+ calculation is performed to obtain the shear stress ratio defined in Eq. (1). Using the fractional liftoff correlation shown in Eq. (2) and the plateout distribution obtained by the POSCA code, the liftoff activities of fission products can be predicted.

3. Example and Results

An example calculation was performed to illustrate the applicability and usefulness of the methodology (shown in Fig. 1) to calculate fission product liftoff. A VHTR system under development in KAERI is considered as the reference system in this work. The thermal power of the system is 350 MWth. The coolant inlet and outlet temperatures are 490 and 950 ^{o}C, respectively. A printed circuit heat exchanger (PCHE) is adopted for the intermediate heat exchanger (IHX).

Figs. 2~4 show the results of the POSCA code. They show the predicted plateout activity distributions in the primary circuit of the reference system after 40-year operation. Higher plateout activities are observed in the PCHE channels.

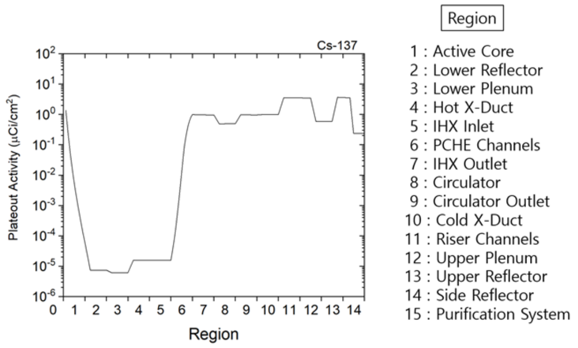

Fig. 2. Predicted plateout activity distribution of Cs-137 in the primary circuit after 40-year operation.

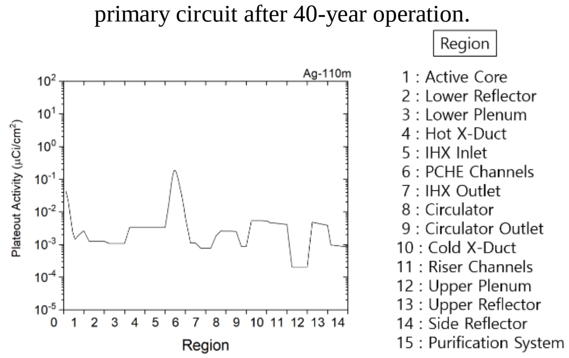

Fig. 3. Predicted plateout activity distribution of Ag-110m in the primary circuit after 40-year operation.

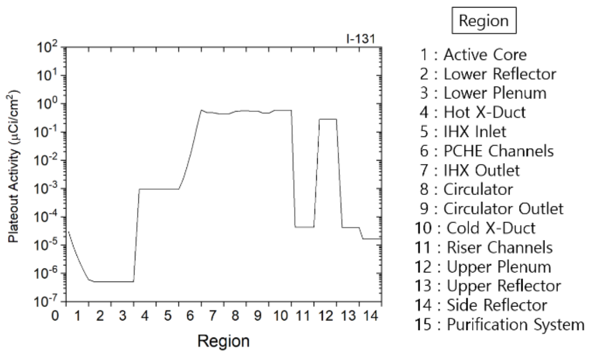

Fig. 4. Predicted plateout activity distribution of I-131 in the primary circuit after 40-year operation.

A GAMMA+ calculation was performed for a depressurization accident of the reference VHTR system. Double-ended-break of the cross-vessel near the reactor vessel was assumed. Fig. 5 shows the calculated shear stress ratio during the depressurization accident. It is shown that the shear stress ratio at the PCHE channels is very high. Discharge duration of the helium coolant is found to be very short. It indicates that large amount of the deposited fission products on the PCHE channels will liftoff promptly after the accident.

Table II summarizes the calculated liftoff activities after the depressurization accident. It is shown that significant amount of the radio-nuclides are promptly released into the confinement due to liftoff. It is obvious that the circulating activities during the normal operation are totally released into the confinement. As shown in Table II, however, these activities are negligibly small compared to the liftoff activities.

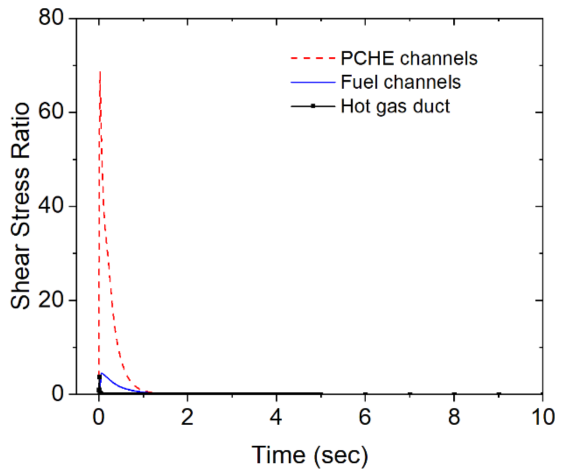

Fig. 5. Calculated shear stress ratio during depressurization accident.

Table II: Calculated liftoff activities after depressurization accident

	Cs-137	Ag-110m	I-131
Plateout (Ci)	67.1	8.43	18.5
Liftoff (Ci)	11.8	3.66	9.01
Liftoff fraction (%)	17.5	43.5	48.6
Circulating & discharge (Ci)	4.16E-6	1.89E-7	1.60E-3

4. Conclusions

In this paper, a methodology to calculate fission product liftoff in a depressurization accident of VHTR was presented. The methodology uses the two computer codes (i.e., POSCA and GAMMA+) developed by KAERI. The results of an example calculation show the applicability and usefulness of the methodology. More validation studies are required for practical applications to the VHTR design.

Acknowledgements

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