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Estimation of fission products plate-out throughout gas-cooling loop systems

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1. Introduction

The estimation of the fission products (FPs) plated out in loops is an essential requirement in nuclear reactors for evaluating the risk during maintenance and repair, and the environmental impact under accidents. In accident condition such as the depressurized loss of forced cooling accident in the high temperature gas-cooled reactor (HTGR) systems, plated-out FPs would be re-entrained into the coolant by chemical and mechanical forces. Such lifted-off FPs are potential hazards for radiation exposure to the environment. It is required to assess the risk at maintenance, repair and transient conditions. Therefore, the purpose of this study is to estimate the amount of FPs plated out in the helium gas cooling loops.

2. Methods

The researches on the FPs plate-out have been investigated since 1960s, and several codes have been written to estimate the plate-out phenomenon in operating reactors and test loops. For light water reactors, VICTORIA was developed in 1990 by US-SNL [1] and, for gas-cooled reactors, PADLOC by US-GA and PATRAS by Germany-KFA were made in 1977. PLAIN was designed by JAERI in 1989 [2], and the result of this is used as one of benchmark index in this study.

The fundamental concept is similar, but the method of modeling the same phenomenon is different. The plate-out-prone sections are a straight tube, gas-to-gas heat exchanger, and the other metallic components in the primary circuit. The rate of plate-out rate is determined by temperature, the mass transfer rates from the coolant to the surfaces, and the sorptivity of the various materials for the volatile FPs. However, the previous models indicate that under typical HTGR normal conditions, most of the plate-out is controlled by mass transfer phenomenon. This means that the surfaces play a role of a nearly perfect sink and that surface concentrations are far from equilibrium. These models mainly concern the mass transfer of FPs and consist of two mass balance equations for the bulk and for the surface. Among them few are supported by the additional correlation, which interconnect the two separate concentrations for the thin boundary layer and for the surface.

The governing equations used in this study are similar to the previous as follows:

$$\left(\frac{\partial N_i}{\partial t} + v\frac{\partial N_i}{\partial z}\right) = -\phi\frac{P_w}{A} - \lambda_i N_i - \kappa N_i \tag{1}$$

$$\frac{\partial S_i}{\partial t} = \phi + D_i\frac{\partial C}{\partial r}\Big|_{r=R_{in}} - \lambda_i S_i \tag{2}$$

$$\frac{\partial C_i}{\partial t} = D_i\left(\frac{\partial^2 C_i}{\partial r^2} + \frac{1}{r}\frac{\partial C_i}{\partial r}\right) - \lambda_i C_i \tag{3}$$

, where N = Concentration in coolant [#/m^3]
S = Number of adsorbed particles on wall surface [#/m^2]
C = Number of diffused FP in wall metal [#/m^3]
Φ = FP flux from coolant to pipe surface [#/m^2.sec]
A = Cooling channel cross sectional area [m^2]
P_w = Wetted perimeter [m]
D_i = Diffusion coefficient of i nuclide in wall [m^2/sec]
λ = Decay constant [/sec]
κ = Removal rate [/sec]
v = Velocity of coolant flow [m/sec]

The numerical method of the implicit finite difference method is employed in order to solve the simultaneous partial differential equations.

3. Results

The result is compared with the two previous experimental data: OGR-1 loop, and VAMPYR-1. OGL-1 is an in-pile helium gas cooling loop in Japan, in order to simulate the HTGR coolant condition. The hot gas sampling tube, VAMPYR-1, was installed at AVR in Germany for obtaining diffusion profiles of deposited fission products on various materials. The conditions of the code simulation with experimental data are listed in Table 1 [3, 4]. The verification process is following the similar way used in the verification of PLAIN.

On the basis of the numerical solution with appropriate boundary value conditions, the estimation on the plate-out FPs is carried out at each case. Figure 1 shows the results is good agreement with the data by experiment and PLAIN. However, as shown in Figure 2, the general model of PLAIN tends not to trace the trend of the experimental data. Even though the Iniotakis model of PLAIN produces the better results, it fails to have the accuracy. The KAIST model is able to give the relatively accurate results.

Table 1: Operating conditions of gas cooling loops

	Unit	OGR-1	VAMPYR-1
Cycle	-	52	V12
P	MPa	2.9	1.079
Time	hr	475	822
Mass flux	kg/sec	73.4	0.66
Initial concentration	#/m^3	6.64E+11	1.68E+11
Diameter of pipe	m	0.0527	0.02
Distance from fuel	m	41~75	0~2.2
Temperature	^{o}C	30~357	552~903

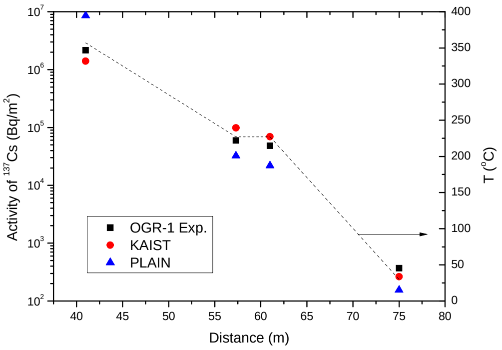

Fig. 1. Comparison of ^{137}Cs surface activity plated-out in the OGR-1 experiment

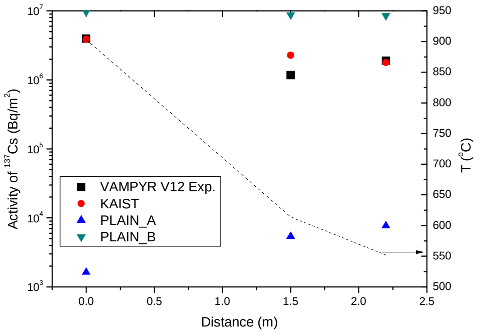

Fig. 2. Comparison of ^{137}Cs surface activity plated-out in the VAMPYR-1 experiment

4. Discussions

For the present work, although considerable effort is made to obtain accurate and objective data, the task of estimating accurately is fraught with the following challenging issues. Most of codes, the model introduced in this study included, did not completely simulate the real deposition behavior in a reactor, because of the presence of dust in coolant and also the ignorance of surfaces-FPs interaction. As for the many material properties, most of the values are not made public. Available correlations which describe the deposition behavior of FPs on wall metals even have large uncertainty. According to metals, the roughness and the penetration coefficients of the specific FP are not well known, and this information even is hardly obtainable. Therefore, it is still required to find the accurate data which replace the assumptions and representative values used in the model.

Since FPs, especially ^{137}Cs or ^{131}I, are perceived as single-atomic form considering the transportation to pipe surfaces, the effect of chemical compound formation is not modeled in this calculation. Up to now the investigation has been conducted as for Cs and I, and the other FPs of interest should be considered together. In addition, it is important to take into account of the effect of precursor nuclides to be activated.

5. Conclusions

The plate-out of FPs has been a challenging problem due to the consequence of its safety relevance. It is required to estimate the potential hazard which may cause to violate the safety limit in HTGRs. Thus, this study has attempted to assess the activity inventory on the surface of coolant pathways.

By the aid of the numerical solving method, the estimation of plate-out could be derived for the behavior of Cs in the gas cooling loop system. It was essential to provide the understanding about the behavior of FPs for the transportation in helium and for the interaction with the surface of the wall materials installed. The results look reasonable, but it is found that the model used here has several pressing matters. However, some of the matters are beyond the scope of the present paper, and thus need to be explored in the future. The further studies are needed on different large-scale assessments.

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