MELCOR Calculation for Fission Product Plateout under High Temperature Gas-Cooled Reactor Conditions

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1. Introduction

A high temperature gas-cooled reactor (HTGR) uses a helium gas to cool down the reactor core. Fission products (FPs) may release into the helium coolant during long time operation. The released FPs could be deposited (plateout) while the FPs circulate in the primary system via chemisorption, thermal diffusion and so on. It is important to calculate the amount of the plateout activities. The predicted plateout activities are used to design a shielding in accord with the regulation. Korea Atomic Energy Research Institute (KAERI) has been developing POSCA [1] to investigate the amount of plateout activities in the primary system. Meanwhile, MELCOR [2] code has been applied to a HTGR system to calculate the FPs transport and compare the results with those of POSCA. MELCOR has been developed to analyze the accident scenario of the water cooled reactor. Therefore, it is needed to assess the validity of the code in the gas-cooled reactor. On the present studies, the data of OGL-test [3,4] and VAMPYR [5] were compared with the calculation results of the POSCA and the MELCOR

2. Numerical Modeling

2.1 POSCA

The three regions (coolant flow, boundary layer, solid surface) modeling are implemented in the POSCA code to investigate the FPs sorption to the wall surface [1].

The main equation of the POSCA code [1]

$$\frac{\partial C_i}{\partial \mathrm{t}} = \dot{q}_{c,i} + \sum_{j=1}^{\eta_T} a_{i,j}^{*} C_j - \frac{P_w}{A_F} h_i (C_i - B_i) - \frac{1}{A_F}\frac{\partial}{\partial x}(A_F v C_i) \quad (1)$$

The equation for reversible nuclide on the wall surface is following

$$\frac{\partial S_{R,i}}{\partial \mathrm{t}} = \dot{q}_{r,i} + \sum_{j=1}^{\eta_T} b_{i,j}^{*} S_{R,j} + h_i (C_i - B_i) \quad (2)$$

where $\dot{q}_{c,i}$ = source term, $\dot{q}_{r,i}$ = reversible nuclide generation source, η_T = total number of nuclides, $a_{i,j}^{*}$ /$b_{i,j}^{*}$ = decay chain and removal, P_w = wetted perimeter, A_F = flow area, and v = flow velocity. The temperature information in each node is user input. In case of sorption, the following models by the GA[3] has applied in the POSCA as term of B_i.

$$B_i = \frac{N_A p_{BL}}{RT}$$

where

$p_{BL} = \sum_{i=1}^{3} X_i^0 exp\left(\frac{-Q_i}{RT}\right) S_i^{\sigma i}$ for cesium

$p_{BL} = \frac{S}{(k-S) X_i^0 exp\left(\frac{-Q_i}{RT}\right)}$ for iodine

2.2 MELCOR

The fission product vapors in the MELCOR code are simulated with following equation. Each equations are coupled explicitly.

$$\frac{dM_a}{dt} + \sum_i \frac{dM_i}{dt} = 0 \quad (3)$$

$$\frac{dM_i}{dt} = A_i k_i (C_a - C_i^s) = 0 \quad (4)$$

The chemisorption of the nuclides are simulated with chemisorption coefficient.

$$k_{ij} = a_{ij} e^{-E_{ij}/RT_i} \quad (5)$$

The default sorption coefficients of MELCOR are provided in Table I.

Table I: Chemisorption Transport Coefficients [2]

Species	Surface	a_{ij}(m/s)	E_{ij}(J/kg)
CsOH	SS*	0.139	5.96E7
CsOH	Inconel	0.035	5.95E7
CsI	SS	2.E-7	0.0
CsI	Inconel	2.E-6	0.0
HI	SS	5.5E-7	2.49E7
I_2	SS	9.E-10	3.39E7

*SS (Stainless Steel)

The test facility of OGL and the measured temperature profiles are shown in Fig. 1 and 2.

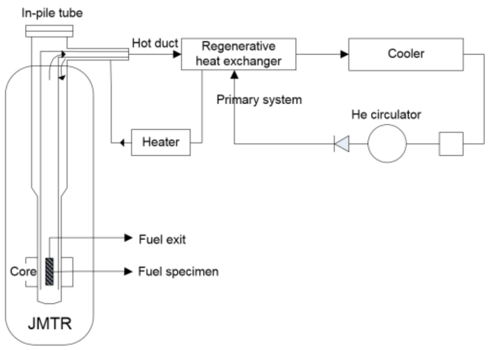


Fig. 1. OGL test diagram[3]

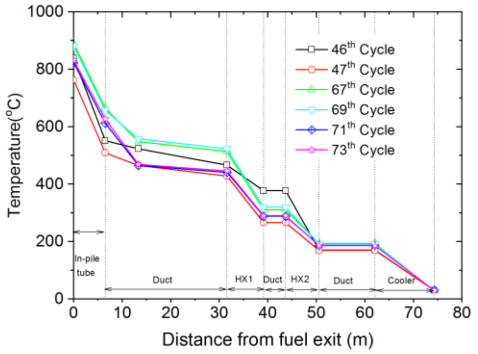


Fig. 2. Measured temperature of OGL test[3]

The test facility of VAMPYR and the measured temperature profiles are shown in Fig. 3 and 4.

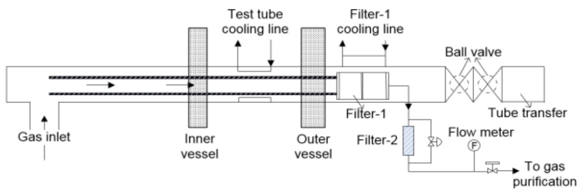


Fig. 3. VAMPYR test diagram[5]

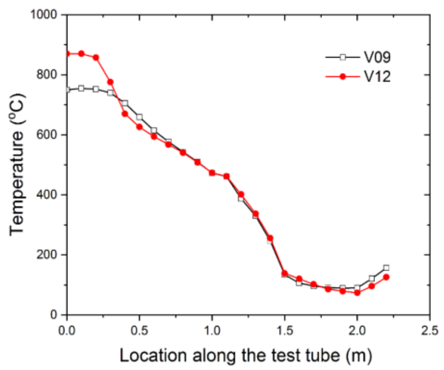


Fig. 4. Measured temperature of VAMPYR test[5]

3. Numerical Simulation

The flow boundary conditions of OGL test are written in Table II.

Table II: OGL test boundary conditions[3]

	Flow rate (kg/s)	Source (kg/s)
Cs-137 / 46th cycle	39.0E-3	1.24E-15
Cs-137 / 47th cycle	45.0E-3	5.25E-15
I-131 / 67th cycle	59.6E-3	2.63E-16
I-131 / 69th cycle	58.5E-3	2.05E-15

To simulate Cs-137 sorption in the pipe wall, the values of CsOH-SS are used on the present study. The I-131 sorption value used the I_2 – SS sorption.

The sorption mechanism in POSCA uses the model developed by GA[3].

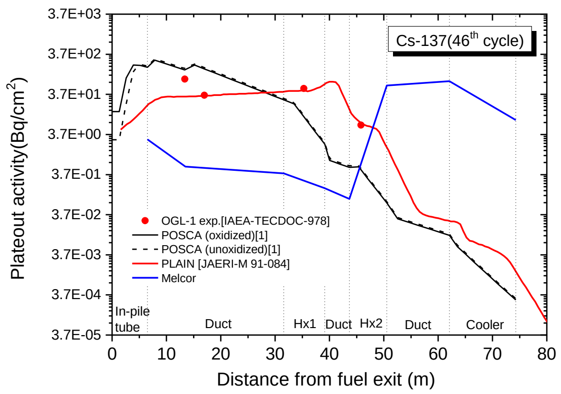
$$B_i = \frac{N_A p_{BL}}{RT} \quad (5)$$

where

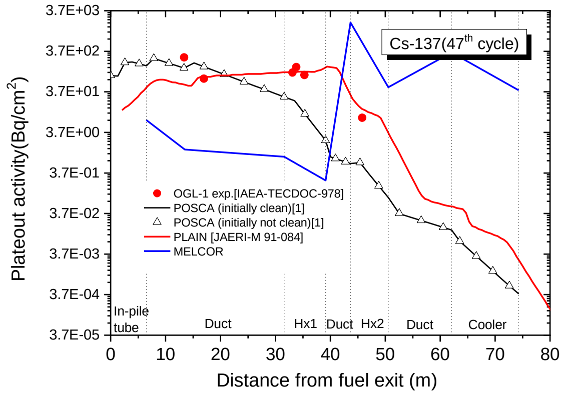
$$P_{BL} = \sum_i^3 X_i^0 \exp\left(\frac{-Q_i}{RT}\right) S_i^{\sigma_i} \text{ for cesium} \quad (6)$$

$$P_{BL} = \frac{S}{(\kappa - S) X_1^0 exp\left(\frac{-Q_1}{RT}\right)} \text{ for iodine} \quad (7)$$

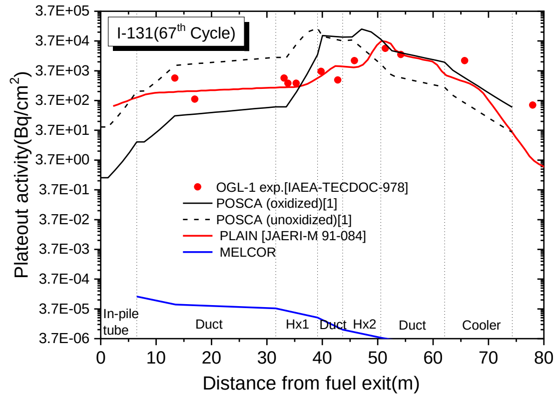
The comparison results for default option on the OGL test are plotted in Fig. 5. The calculated data by MELCOR were not match well with the other data. The MELCOR was developed based on water cooled reactors. Therefore, it is thought that there are some difficulties in the FP transport under the gas coolant flow.



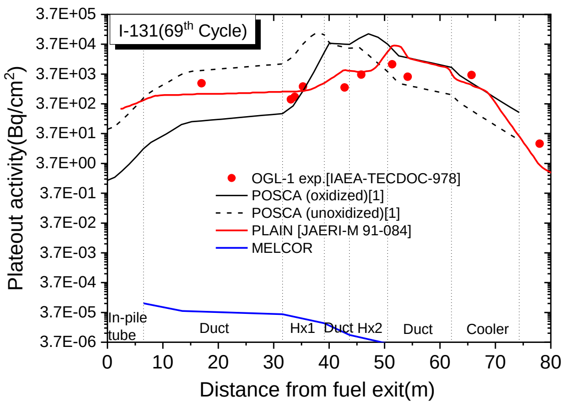
(a) Cs-137 / 46th cycle comparison



(b) Cs-137 / 47th cycle comparison



(c) I-131 / 67th cycle comparison



(d) I-131 / 69th cycle comparison

Fig. 5. Plateout comparison with default option of MELCOR

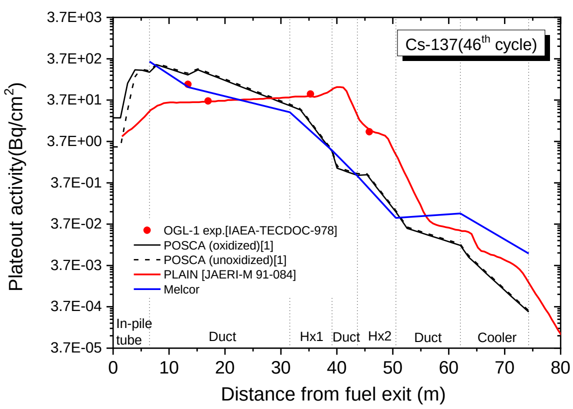
The sorption coefficients were changed by using sensitivity coefficient input to investigate the plateout amount variances.

The sorption coefficients of Cs-137 and I-131 have been modified to fit the results.

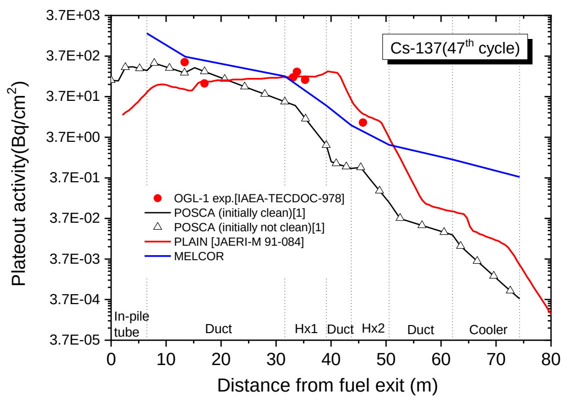
$a_{ij} = 0.139, E_{ij} = 1.192E7$ for Cs-137 (8)

a_{ij} =1.E-3, $E_{ij} = 1.192E7$ for I-131 (9)

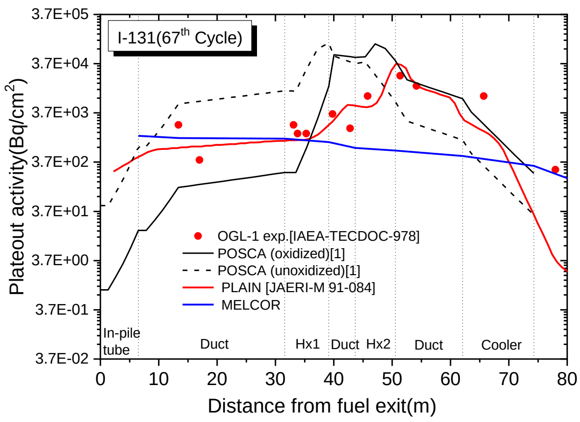
The calculation results for the modified coefficients on the OGL test are plotted in Fig. 6. The calculated results are similar to the other results. Although there are various efforts to adjust the MELCOR code to HTGR system, it still needs care to apply the code.



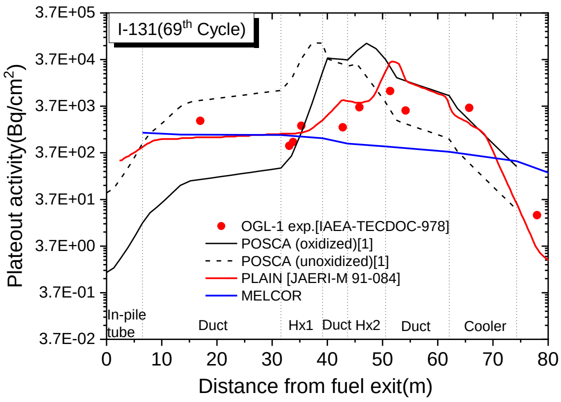
(a) Cs-137 / 46th cycle comparison



(b) Cs-137 / 47th cycle comparison



(c) I-131 / 67th cycle comparison



(d) I-131 / 69th cycle comparison

Fig. 6. Plateout comparison with modified option of MELCOR

Table III represents the flow boundary conditions of the VAMPYR test. The Cs-137 plateout was compared on the present study.

Table III: VAMPYR test boundary conditions[5]

	Flow rate (kg/s)	Source (kg/s)
Cs-137 / V09 cycle	6.6E-4	1.39E-17
Cs-137 / V12 cycle	6.6E-4	2.75E-17

The calculated results with the modified sorption coefficients of Eq. (8) are well matched with the other data like the OGL test.

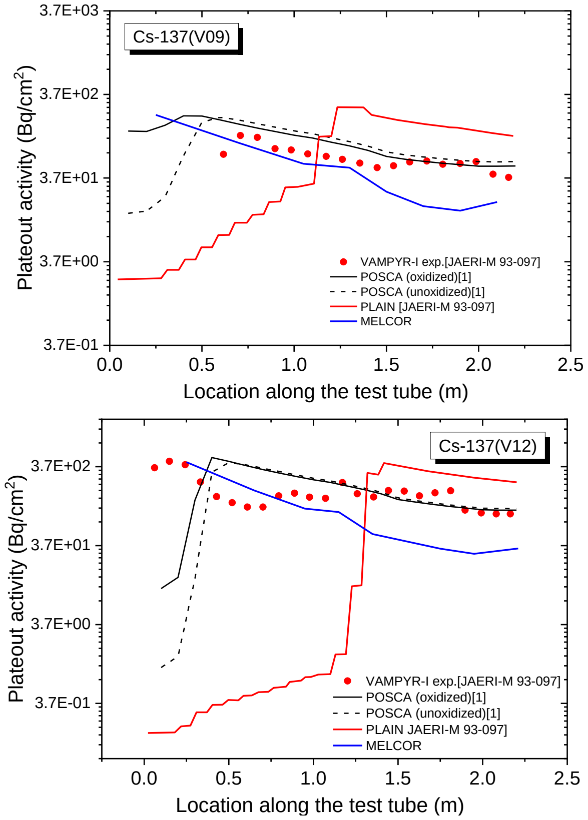


Fig. 7. Plateout comparison for VAMPYR test

4. Conclusion

The fission products plateout test data were compared with the calculated results by the MELCOR code as well as those of the POSCA code. The MELCOR code has been developing based on the water cooled reactor. Therefore, it was needed to modify the sorption coefficients under the gas coolant flow condition. The calculated results with the modified sorption coefficients well matched with for both measured data. It is still necessary to apply sorption coefficients carefully in the HTGR system. In the further study, the plateout calculation will be conducted for a HTGR primary system.

Acknowledgements

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