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Fission Product Transport Assessment on VHTR350 during Normal Operation

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1. Introduction

A very high temperature gas-cooled reactor (VHTR) uses triso particles as a fuel. The triso particle captures most of the fission products (FPs) during the normal operation. Nevertheless, some FPs release to the helium coolant by the diffusion mechanism. The diffusion of FPs increase as the fuel temperature goes up. The released FPs circulate and deposit inside coolant pipe. The amount of FPs in the coolant loop may be used to design shield and safety analysis. The FPs in the primary loop may release to environment under the accident scenario. Therefore, it is important to predict FPs diffusion and release into the coolant precisely. MELCOR[1] has been improving to analyze the non-LWR source term. MELCOR added PMR (Prismatic Modular Reactor) and PBR (Pebble Bed Reactor) core model and FPs diffusion model in the COR_INPUT. Korea Atomic Energy Research Institute (KAERI) has been developing COPA[2] code to calculate the amount of FPs released from the fuel to the coolant.

In this work, the FPs fractional release by the MELCOR and the COPA code calculation were compared. The deposited FPs were also predicted for the normal operation.

2. Modeling

The diffusion equation of the MELCOR[1] code for the HTGR core is following

$$\chi \frac{\partial C}{\partial t} = \frac{1}{r^n}\frac{\partial}{\partial r}\left(r^n D \frac{\partial C}{\partial r}\right) - \lambda C + \beta \qquad (1)$$

where C is concentration of FP [kmol/m^3], D = diffusion coefficient[m^2/s], r = radial coordinate[m], λ = decay constant[1/s], β = FP generation/source term[kmol/m^3/s], n = 1 for cylindrical and 2 for spherical, χ = 0 for steady and 1 for transient.

The form of the diffusion coefficient adopts the Arrhenius type

$$\mathrm{D(T)} = D_0 e^{-Q/RT} \qquad (2)$$

D_0 = Precoefficient[m^2/s]
Q = Activation energy[J/mol]
R = Gas constant = 8.314 [J/mol]

Fig. 1 represents MELCOR radionuclide release model[1]

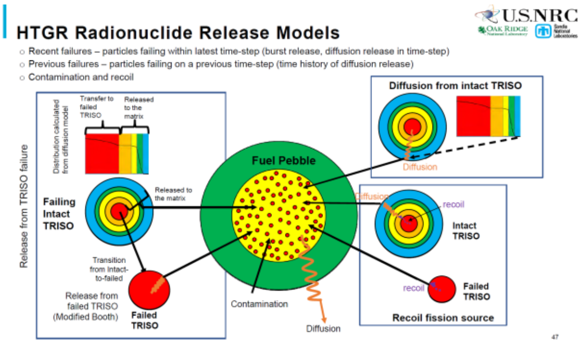


Fig. 1. MECOR radionuclide release model [3].

The FPs diffusion of MELCOR is calculated by the 4 stage. First, MELCOR gets normal operation thermal state. Second, it calculates diffusion model for normal operation. Thus, χ term is 0 for the second stage. Third, FPs transport is run for normal operation. Last, accident diffusion and transport is run to estimate FPs release into the environment.. Using those stages, the MELCOR code may predict FPs release from core to containment and environment.

The MELCOR deposition model follows the MAEROS four contributions : Brownian diffusion, thermophoresis, diffusiophoresis and gravitational deposition[1]. The turbulent deposition model in pipe and bend are also implemented in the recent MELCOR version[1].

The diffusion equation of the COPA[2] code is following

$$\frac{\partial C(r,t)}{\partial t} = \dot{S}_{i,j}(r,t) + \lambda_{j-1} C_{i,j-1}(r,t) - \lambda_j C_{i,j}(r,t) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D \frac{\partial C_{i,j}(r,t)}{\partial r}\right) \qquad (3)$$

The COPA code has additional term of decay chain to model FP transformation. The COPA code calculates FPs release into coolant only. Therefore, the results from COPA calculations may be applied as the input of RN1_INPUT of MELCOR.

3. Fission Product Transport

To simulate FPs release under the accident conditions, IAEA coordinated research program (CRP) – 6[4] has been established and compared the calculated results by the various computer codes for the triso particle and fuel. To compare the MELCOR results on the IAEA-CRP-6 data, the simple case of 6a has been chosen. The case 6a uses intact fuel. The fuel was irradiated for 8424 hour and heated again for 304 hour at 1600°C.

The coefficients for the diffusion are written in Table I ($D = \sum_i D_{0,i} \exp(-\frac{Q_i}{RT})$).

Table I: Diffusion coefficient[4]

$D_{0,i}$ [m^2/s] / Q_i [kJ/mol]	Cs	Sr	Ag
UO2	5.6E-8/209 5.2E-4/362	2.2E-3/488	6.7E-9/165
Buffer	1.E-8/0	1.E-8/0	1.E-8/0
PyC	6.3E-8/22	2.3E-6/197	5.3E-9/154
SiC	5.5E-14$e^{\phi/5}$/125 1.6E-2/514	1.2E-9/205 1.8E6/791	3.6E-9/215
In matrix graphite	3.6E-3/189	1.E-2/303	1.6/258
In structural graphite	1.7E-6/149	1.7E-2/268	1.6/258

Table II shows the benchmark results and MELCOR data. The data obtained by MELCOR code are similar to IAEA-CRP results.

Table II: Benchmark results

Case	US/INL[4]	COPA [4]	MELCOR
6a : Cs-137	4.47E-3	2.78E-3	3.3E-3
6a : Ag-110m	0.651	0.536	0.236
6a : Sr-90	1.12E-2	3.89E-2	6.66E-2

Fig. 2 represents the VHTR350 reference core proposed by KAERI to get 950℃ coolant outlet temperature. The FPs releases and depositions are calculated with MELCOR and COPA code for the VHTR 350 core.

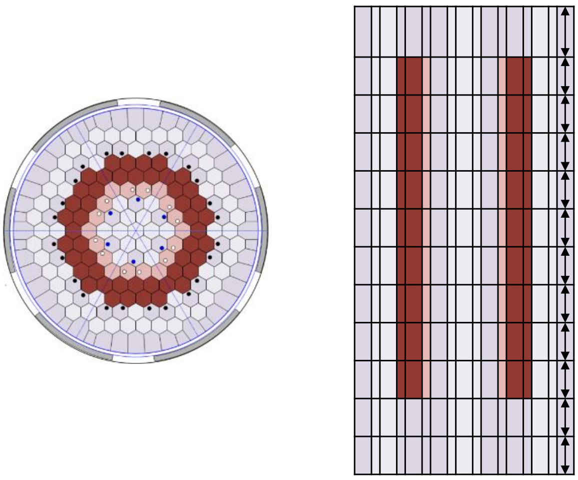


Fig. 2. VHTR350 reference core

Fig. 3 represents the MELCOR nodalization for the VHTR350 system to predict FPs transport.

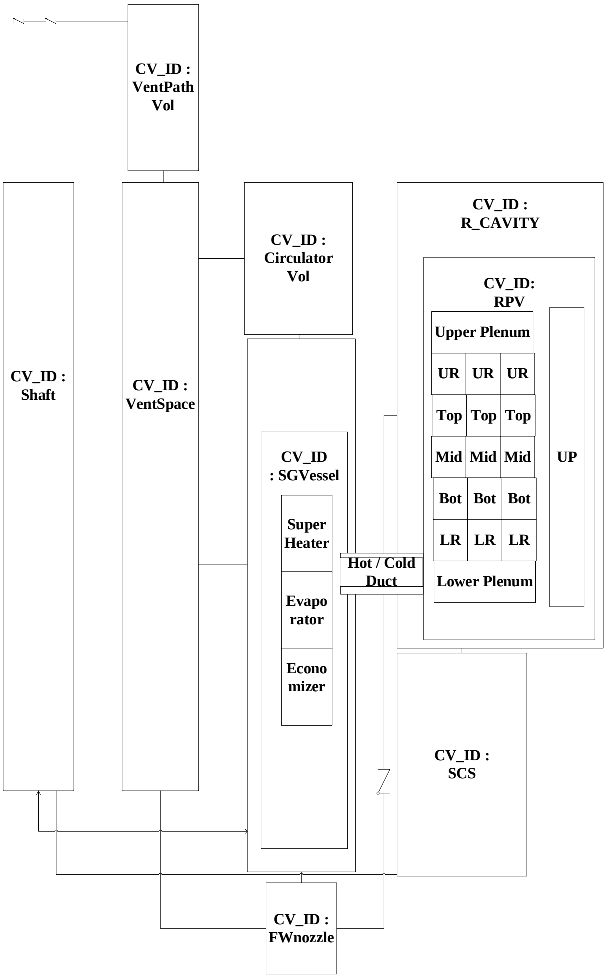


Fig. 3. MELCOR CV_INPUT

The calculated results of fractional release of Cs-137 by the MELCOR code and COPA code for the VHTR350 were shown in Table III. The MELCOR fractional release of Cs-137 was obtained by the option which is recently implemented for HTGR FP diffusion model.

Table III: Fractional release from fuel to coolant

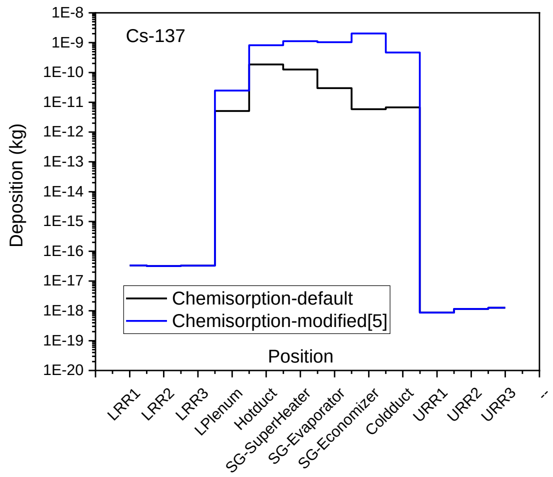
Case	Cs-137
MELCOR	2.77E-3
COPA	5.71E-4

The average release rates for Cs-137, Ag-110m and Sr-90 at EFPD1500 were written in Table IV by the COPA code.

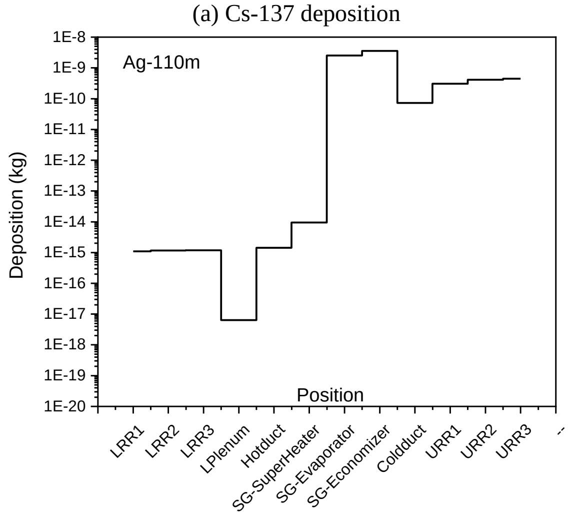
Table IV: Average release rate calculated by COPA

Case	Cs-137	Ag-110m	Sr-90
Release rate[kg/s]	4.4150E-18	7.9512E-18	6.9989E-18

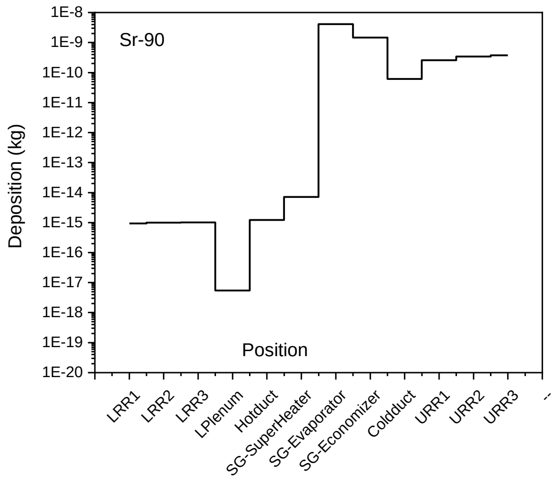
The FPs depositions to the primary loop were calculated by MELCOR code using the COPA code results in Table IV. Due to the computational time limit, the 40 years release for the normal operation was replaced as 1000 second release. Fig. 4 shows the fission product deposition mainly in the primary loop. However, the results may not be considered as a reference because the FPs transport of the VHTR with the MELCOR code is still under developing process. Cs-137 deposited from lower plenum by the chemi-sorption because there are only Cs and I chemisorption models in the MELCOR. The deposition with modified sorption coefficient [5] was additionally calculated for Cs-137. Most of Ag-110m and Sr-90 are deposited on the heat structures in Table V. However, the Cs-137 remained mainly in the control volume. The deposition logics of Cs-137 need to be investigated more carefully on the further studies.



(a) Cs-137 deposition



(b) Ag-110m deposition



(c) Sr-90 deposition

Fig. 4. FPs depositions in VHTR350

Table V: FP Distribution

Case	Cs-137	Ag-110m	Sr-90
Deposited Fraction[%]	6.422 98.441*	96.786	95.398
Circulating Fraction[%]	93.578 1.559*	3.214	4.602

* deposition with modified sorption coefficient [5]

4. Conclusion

The MELCOR code was used to predict the fission products fractional release and depositions in the primary loop. The boundary condition for the release rate was obtained by the COPA code. The phenomena on the release and deposition of the FPs need more studies to assure the results. The MELCOR and COPA code will be used to predict the FPs resuspension under the accident scenario.

Acknowledgements

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