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Simulation of Fission Product Liftoff Behavior During Depressurization Transients

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1. Introduction

For a smooth success of the nuclear hydrogen production and demonstration (NHDD) project, the Korea Atomic Energy Research Institute (KAERI) has been developing key technologies for the design of a prismatic very high temperature reactor (VHTR) [1]. As one of crucial technologies for the NHDD project, the development of the GAMMA-FP code [2] is on-going. The GAMMA-FP code is targeted for fission product transport analysis under accident conditions.

A well-known experiment named COMEDIE [3,4] considered two important phenomena, i.e., fission product plateout and liftoff, for fission product transport within the primary circuit of a prismatic high temperature gas cooled reactor. In the previous work [5], the capability of the GAMMA-FP code for the fission product platout was validated against the COMEDIE experiment. The accumulated fission products on the structural material via the plateout can be liftoff during a blowdown phase after a pipe break accident. Since the fission product liftoff can increase a radio-activity risk, it is important to predict the amount of fission product liftoff during depressurization accidents.

In this work, a model for fission product liftoff is implemented into the GAMMA-FP code and the GAMMA-FP code with the implemented model is validated using the COMEDIE blowdown test data.

2. COMEDIE Experiment

The COMEDIE loop was a test facility in the SILOE material test reactor in France. The general assembly of the COMEDIE loop is shown in Fig. 1. The experiment was conducted by CEA in 1992 under the US Department of Energy (DOE) sponsorship to obtain integral test data to validate the design methods used to predict fission product release from the TRISO fuel and plateout in the primary coolant loop of a prismatic gas cooled reactor and liftoff during rapid depressurization transients. The major test parameters are summarized in Table I. The loop consisted of an in-pile section and an out-of-pile section. The in-pile section included a prismatic fuel block which was the source of fission products. The fuel block contained fuel compacts seeded with "designed-to-fail" low enriched uranium UCO TRISO particles. Graphite reflector block was placed at the downstream of the fuel block. The reflector block was followed by a straight tube gas-to-gas heat exchanger. Downstream of the heat exchanger were a full-flow filter to trap condensable radionuclides including iodine and circulating particulate matter, and four filters and associated valves for blowdown tests after the plateout experiment.

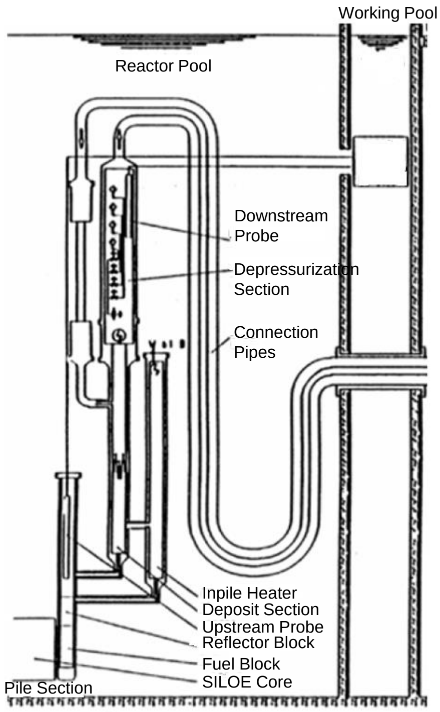

Fig. 1. General assembly of the COMEDIE loop [4].

Table I: Major Test Parameters of COMEDIE experiment [4]

Steady-State Operating Conditions	
Loop power	30 kW
TRISO fuel particle	LEU UCO
Primary coolant	helium
Thermal neutron flux	~10^{17} n/m^2-s
Max. fuel temperature	1250~1350 ^{o}C
Test duration	63 days
Coolant flow rate	38 g/s
Purification flow rate	0.3 g/s
Coolant temperature	200~880 ^{o}C
Primary coolant pressure	60 atm
HX temperature (primary side) - Gas inlet - Gas outlet	 720 ^{o}C 300 ^{o}C
Depressurization Tests	
Liftoff duration	≥ 2 min
Shear ratio (SR)	0.7,1.7,2.8,5.6
Max. depressurization rate	1.1/atm/sec
Pressure range	≥ 45, < 7.0 atm

3. Method and Results

For a fission product liftoff model of the GAMMA-FP code, an empirical model developed by Myers [6] was adopted. The Myers model expresses the fission product liftoff by using the shear ratio defined as:

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

where P = pressure, V = velocity, T = temperature. 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:

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

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

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

Table II: Empirical constants for Myers model [6]

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

Using the GAMMA-FP code with the Myers model the COMEDIE depressurization tests were simulated. Figs. 2~4 show the predicted and measured pressures during the blowdown periods of the COMEDIE experiment. A good agreement can be seen. It means that the GAMMA-FP model reliably simulates the pressure transients during the blowdown tests.

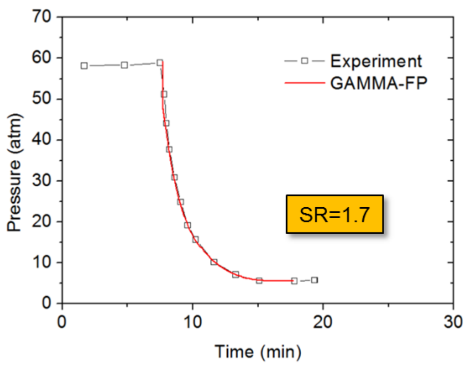

Fig. 2. Predicted and measured pressures during the blowdown period under SR=1.7.

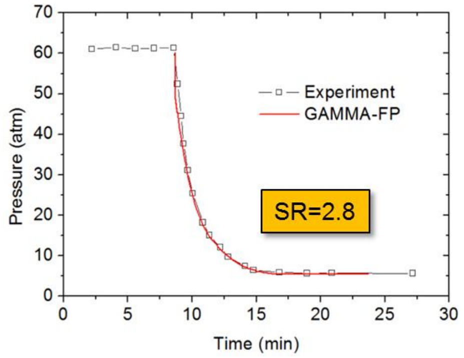

Fig. 3. Predicted and measured pressures during the blowdown period under SR=2.8.

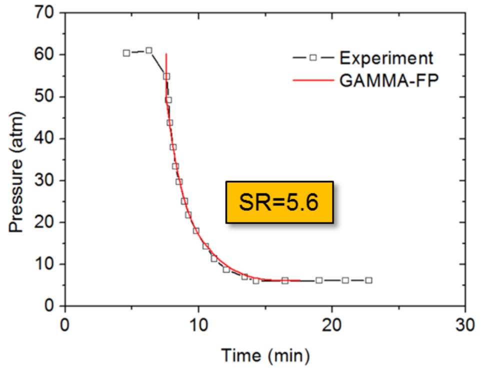

Fig. 4. Predicted and measured pressures during the blowdown period under SR=5.6.

Table III provides the predicted and measured liftoff fractions. The measured liftoff fraction was obtained based on the trapped activities on the filters. For a comparison, the predicted results by POLO are added. Somewhat large differences between the experimental data and the GAMMA-FP results are observed except the case with SR=5.6. However, the differences are less than a factor of 10. It should be noted that such accuracy is much better than that of POLO which is a General Atomics code.

Table III: Predicted and measured liftoff fractions

		Ag-110m	Cs-137
SR=1.7	Experiment [4]	1.9E-4	2.1E-4
	POLO [4]	3.2E-3	2.9E-3
	GAMMA-FP	6.4E-4	5.2E-4
SR=2.8	Experiment [4]	4.3E-4	3.0E-4
	POLO [4]	9.0E-3	4.8E-3
	GAMMA-FP	4.2E-3	1.9E-3
SR=5.6	Experiment [4]	2.3E-3	1.1E-3
	POLO [4]	2.8E-2	1.1E-2
	GAMMA-FP	2.1E-3	1.1E-3

4. Conclusions

In this work, the Myers model for fission product liftoff was implemented into the GAMMA-FP code and the GAMMA-FP code with the Myers model was validated using the COMEDIE blowdown tests. The results of GAMMA-FP show that the GAMMA-FP code can reliably simulate a pressure transient during blowdown phase after a pipe break accident. In addition, a reasonable amount of fission product liftoff was predicted by the GAMMA-FP code. The maximum difference between the measured and predicted liftoff fraction was less than a factor of 10. More in-depth study is required to increase the accuracy of prediction for a fission product liftoff.

Acknowledgements

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