Prediction of Fission Product Plateout Distributions in the Primary Circuit of the MHTGR-350 Using the POSCA Code

Nam-il Tak*, Sung Nam Lee, Chang Keun Jo
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon 34057, Korea
**Corresponding author: takni@kaeri.re.kr*

1. Introduction

In a high temperature gas-cooled reactor (HTGR), fission products may deposit on cooling surfaces of the primary circuit over long periods of reactor operation. This deposition activity is referred as a plateout activity. The prediction of the plateout activity is important for the design of a HTGR. It is used for the shielding, maintenance scheduling of the components, and safety analysis. Korea Atomic Energy Research Institute (KAERI) has developed a computer code named POSCA [1] for the prediction of the fission product plateout distribution. The POSCA code was verified and validated using the analytic solutions and experimental data available [2]. However, the existing works were limited to conceptual problems and experimental loops.

In this work, plateout distributions of the key fission products in the primary circuit of the MHTGR-350 [3] were analyzed using the POSCA code.

2. POSCA Model

The thermal power of the MHTGR-350 is 350 MWth and the coolant inlet/outlet temperatures of the reactor core are 258 and 687 °C, respectively. Fig. 1 shows the simplified flow diagram for the primary circuit of the MHTGR-350.

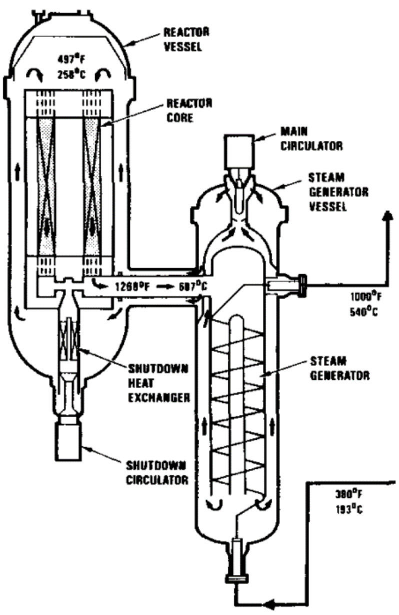

Fig. 1. Simplified flow diagram for the primary circuit of the MHTGR-350 [3].

The primary loop of the MHTGR-350 mainly consists of the reactor core, the cross duct, the circulator, and the steam generator. The heat transfer section of the steam generator can be further divided by the finishing superheater, the superheater, the evaporator, and the economizer. The POSCA model to simulate the primary circuit of the MHTGR-350 is shown in Fig. 2. The number in round bracket represents the region number used for the x-axis of the figures used in this paper. (See Figs. 3, 5~10). The bypass flow to the side reflector was assumed to be 11% and the purification flow rate of 0.1 kg/s was applied. The bypass flow to the shutdown cooling system was neglected. Fig. 3 shows the applied temperature distributions along the circuit.

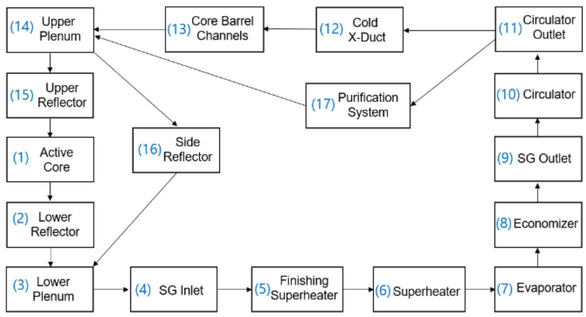

Fig. 2. POSCA model to simulate the primary circuit of the MHTGR-350.

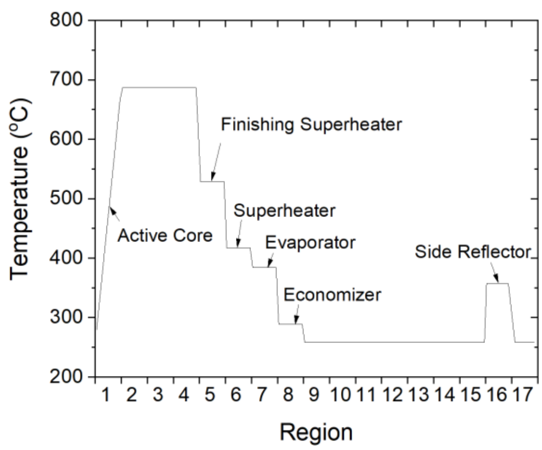

Fig. 3. Applied temperature distribution in the primary circuit of the MHTGR-350.

The sorption models of the General Atomics [4] were used. It was assumed that the structural surfaces are not oxidized. For the sorption isotherms on graphite, it was assumed that the entire mass of graphite (i.e., the entire Brunauer-Emmett-Teller (BET) surface area) is available for sorption.

Gaseous precursors are considered to predict the plateout distributions of Cs-137 and Sr-90. The precursors of Cs-137 and Sr-90 are shown in Fig. 4.

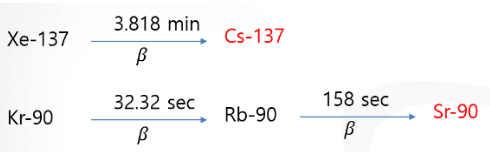

Fig. 4. Precursors of Cs-137 and Sr-90.

The total simulation time for the fission product plateout was set to 40 years and the calculations were performed for the "maximum expected" plateout inventories. Any shutdown period during the reactor operation was neglected. The temperature profile (shown in Fig. 3) was not changed during the calculation. Such assumptions are not realistic but widely used for predicting the lifetime plateout activities of a HTGR.

3. Results and Discussions

The results of the POSCA calculations are presented in Figs. 5 ~ 8. They show the 40-year plateout distributions of the selected key fission products.

Higher plateout activity was predicted to occur in the evaporator-economizer sections (= region numbers of 7 and 8) of the steam generator owing to their relatively low surface temperatures and large surface areas. Except Sr-90, very low plateout activity was predicted at the hot graphite regions. Relatively flat plateout profile is shown in the Sr-90 result. It was found that such a flat behavior is mainly due to the gaseous precursor (= Kr-90).

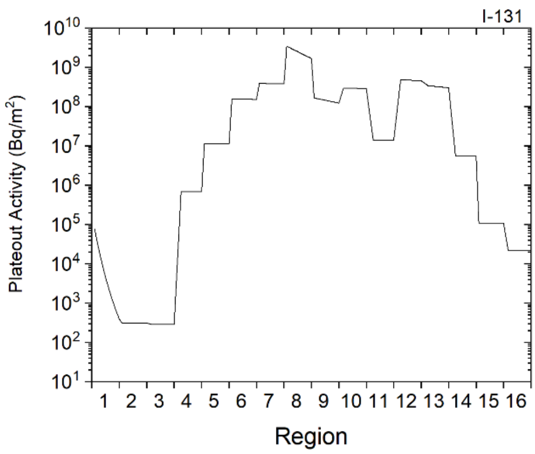

Fig. 5. 40-year plateout distribution of I-131 in the primary circuit of the MHTGR-350.

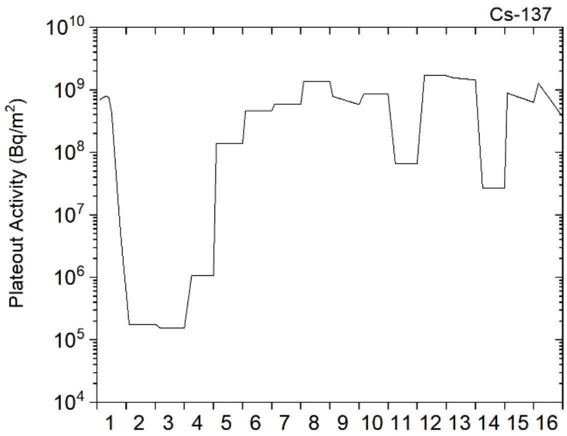

Fig. 6. 40-year plateout distribution of Cs-137 in the primary circuit of the MHTGR-350.

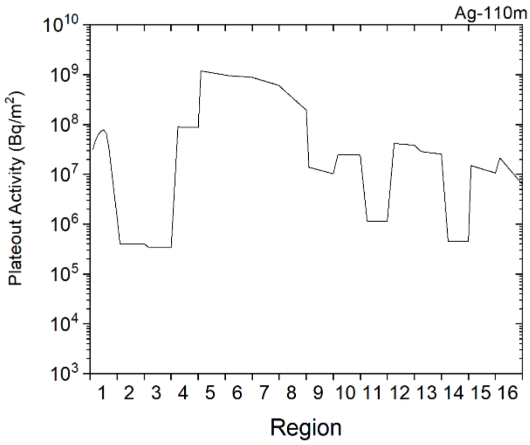

Fig. 7. 40-year plateout distribution of Ag-110m in the primary circuit of the MHTGR-350.

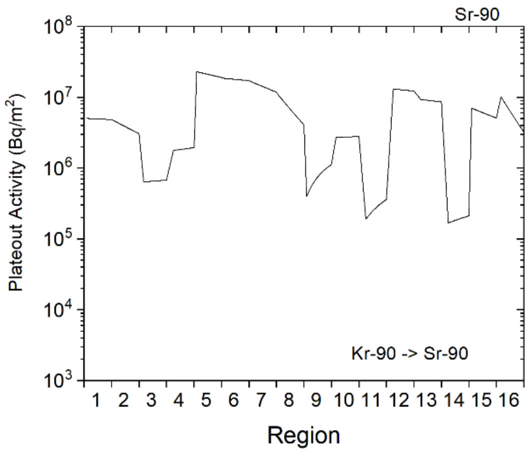

Fig. 8. 40-year plateout distribution of Sr-90 in the primary circuit of the MHTGR-350.

The effects of the precursors on the plateout distributions are summarized in Figs. 9 and 10. In the case of Cs-137, the effect of the precursor (= Xe-137) is negligibly small. However, the effect of the precursors is significant in the case of Sr-90. The difference in the effects can be explained by Table I which shows the mass balance and distribution of each nuclide after 40-year reactor operation. The total release inventories into the primary coolant are based on the "Maximum Expected" activities reported in the safety report of the MHTGR-350. In the case of Cs-137, the contribution of Xe-137 to the total Cs-137 generation is only 0.4%. On the other hand, Sr-90 of 39.4% is generated from Kr-90. Table I also shows that the circulating and purified activities are very small and more than the generated nuclides of 99% are either plated out or decayed.

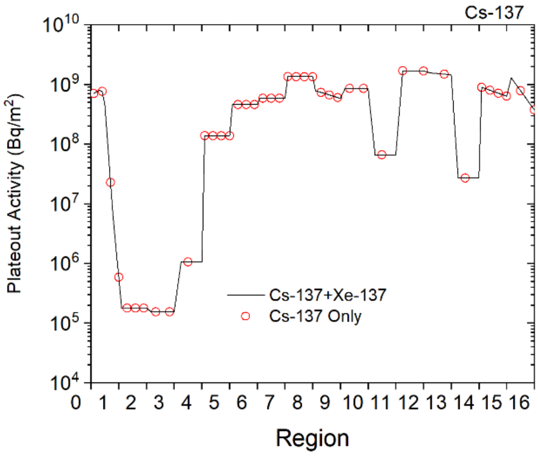

Fig. 9. Effect of precursor on 40-year plateout distribution of Cs-137.

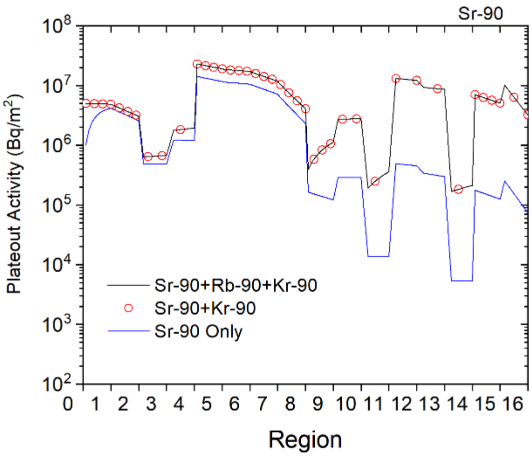

Fig. 10. Effect of precursors on 40-year plateout distribution of Sr-90.

Table I: Nuclide Mass Balance and Distribution after 40-year Reactor Operation

	Cs-137	Sr-90
Total release inventory into primary circuit (Bq)	3.97E+12	3.19E+10
Generation from precursors (Bq)	1.41E+10 (0.4%)	1.26E+10 (39.4%)
Circulating activity (Bq)	1.20E+04 (3.0E-7%)	3.94E+01 (1.2E-7%)
Plateout activity (Bq)	2.60E+12 (65.5%)	2.49E+10 (78.1%)
Removal by purification (Bq)	1.29E+09 (0.03%)	6.12E+07 (0.2%)
Removal by decay (Bq)	1.37E+12 (34.5%)	6.93E+09 (21.7%)

4. Conclusions

In this paper, the POSCA code was applied to analyze the plateout distributions of the key fission products in the primary circuit of the MHTGR-350. The results obviously show the applicability of the POSCA code to the entire components of the primary circuit of a practical HTGR. It was confirmed that Kr-90 has to be considered to predict the plateout distribution of Sr-90. On the other hand, Xe-137 may be omitted to predict the plateout distribution of Cs-137. It was also found that most of the key nuclides are either plated out or decayed after the generation in the primary circuit.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2020M2D4A2067322).

REFERENCES

[1] N. I. Tak, J. H. Lee, S. N. Lee, and C. K. Jo, "POSCA: A Computer Code for Fission Product Plateout and Circulating Coolant Activities within the Primary Circuit of a High Temperature Gas-Cooled Reactor," *Nuclear Engineering and Technology*, Vol. 52, pp. 1974-1982, 2020.
[2] N. I. Tak, J. H. Lee, and S. N. Lee, "Verification and Validation of the POSCA Code Using Analytic Solutions and Plateout Experimental Data," KAERI/TR-7731/2019, KAERI, 2019.
[3] P. M. Williams et al., "MHTGR Development in the United States," *Progress in Nuclear Energy*, Vol. 28(3), pp. 265-346, 1994.
[4] R. Martin, "Compilation of Fuel Performance and Fission Product Transport Models and Database for MHTGR Design," ORNL/NPR-9 1/6, Oak Ridge National Laboratory, 1993.