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Gas Pressure Buildup in a Coated Fuel Particle of Deep Burn-High Temperature Reactors

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1. Introduction

The deep burn-high temperature reactor (DB-HTR) was conceived to convert the transuranic (TRU) radionuclides, recovered from spent light water reactor (LWR) fuel, into shorter-lived fission products (FPs) [1]. It can reduce the long-term storage requirements for the high-level waste generated from currently operating nuclear power plants.

The DB-HTR fuel uses a tri-isotropic (TRISO) coated fuel particle (CFP) which consists of a kernel, low-density pyrocarbon as a buffer, inner high-density pyrocarbon (IPyC), silicon carbide (SiC), and outer high-density pyrocarbon (OPyC). The kernel produces free oxygen and various toxic fission gases during the heat generation through the fission of nuclear materials in it. CO gas is generated through the interaction of the free oxygen with carbon atoms of the inner region of the coating layers. The CO and fission gases gather in the void volume in the kernel and buffer of an intact TRISO CFP. The pressure buildup in the volume should be estimated since it is one of factors deteriorating CFP integrity.

This study describes the gas pressure buildup in the void volume in a CFP of 450 and 600 MW_{th} block-type DB-HTRs.

2. Design and Operation of DB-HTRs

The considered DB-HTR kernel materials are 1) 0.2% UO_2 + 99.8% (5% NpO_2 + 95% $PuO_{1.8}$) mixed with 0.6 moles of SiC per mole of heavy metal (“TRU” fuel) and 2) 30% UO_2 + 70% (5% NpO_2 + 95% $PuO_{1.8}$) mixed with 0.6 moles SiC per mole of heavy metal (“U+TRU” fuel). The SiC is mixed with the heavy metal oxide in order to capture the free oxygen which is generated in a kernel during the irradiation. Two thermal powers of the DB-MHR, 600 and 450 MW_{th}, are taken into account.

Table 1 gives the thicknesses and densities of layers in a CFP of the DB-HTRs. In order to simulate the severe condition of the DB-HTR fuel, it was assumed that the DB-HTRs were operated at the constant coolant temperature and the constant kernel power for three cycles, and then were subjected to a low pressure conduction cooling (LPCC) accident for 250 hours. The detailed design parameters and operation conditions of the DB-HTRs are given in Ref. [2].

3. Physico-chemical Models for Gas Pressure Calculation

The generation of gas species in the kernel is calculated in the form of fission yield with the HSC software [3] and the McCARD code [4]. The approximate expression obtained from the Booth model gives the release amount of gases from the kernel into the void volume in the kernel and the buffer [5]. The void volume is the open-pore volume in the kernel and the buffer. The solid and gaseous swelling of the kernel occurs with burnup, and it causes the buffer to become dense, and reduces the void volume. The gas pressure in the void volume was estimated with the ideal gas law.

Table 1 Thicknesses and Densities of Layers in a Coated Fuel Particle

Layers	Thickness (μm)	Density (g/cm^3)
OPyC	40	1.90
SiC	35	3.20
IPyC	35	1.90
Buffer	100	1.05
Kernel	[a]350	9.46

[a] Diameter.

4. Calculation Results

The gas pressure buildup in a CFP strongly depends on the temperature of the CFP. The temperature distribution in the DB-HTR fuel has been calculated using the COPA code [6]. Figs. 1 and 2 show the variations of temperature at the kernel center during normal operation and LPCC accident, respectively. The temperatures at the kernel center are between 900 and 925 ^oC during normal operation, and increase to high values between 1550 and 1900 ^oC during LPCC accident. The gas species that are generated in significant quantities during normal operation and in an accident condition are xenon, cesium, helium, and krypton [7]. Figs. 3 and 4 present the gas pressure buildup in the void volume of a CFP during normal operation and LPCC accident, respectively. The total gas pressures are between 25 and 33 MPa at the end of normal operation. They then increase to high values between 90 and 200 MPa during LPCC accident.

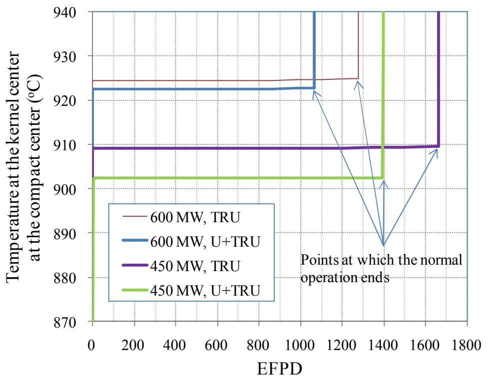

Fig. 1 Variation of Temperature at Kernel Center during Normal Operation

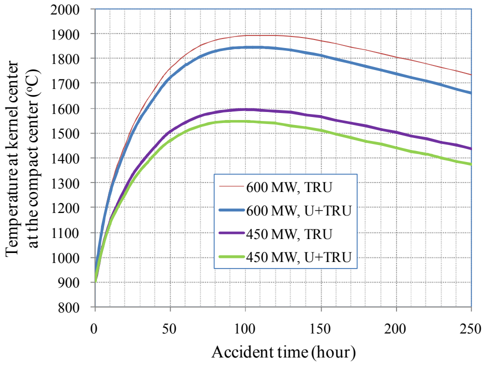

Fig. 2 Variation of Temperature at Kernel Center during LPCC Accident

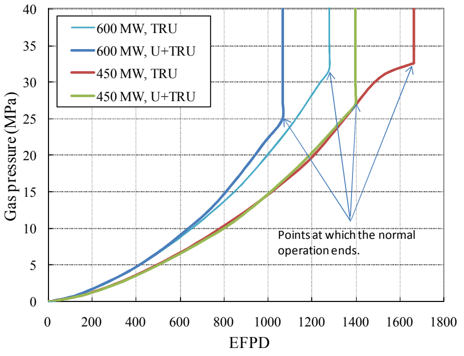

Fig. 3 Gas Pressure Buildup in the Void Volume of a CFP during Normal Operation

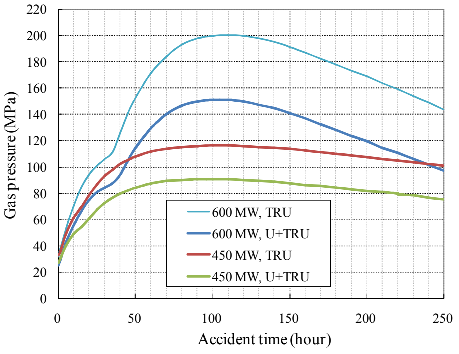

Fig. 4 Gas Pressure Buildup in the Void Volume of a CFP during LPCC Accident

4. Summary

For 450 and 600 MW_{th} block-type DB-HTRs, the gas species that are generated within a CFP in significant quantities are xenon, cesium, helium, and krypton. The total gas pressures are between 25 and 33 MPa at the end of normal operation. The maximum gas pressures are between 90 and 200 MPa during LPCC accident.

REFERENCES

[1] GA and ORNL, *Deep-Burn Modular Helium Reactor Fuel Development Plan*. ORNL/TM-2002/135, GA-224-0-TRT-000167. General Atomics and Oak Ridge National Laboratory (2002).

[2] Y. M. Kim, C. K. Jo, J. S. Jun, M. S. Cho, and F. Venneri, "A Fuel Performance Analysis for a 450 MW_{th} Deep Burn-High Temperature Reactor," *Nucl. Eng. Des.* (2011), doi:10.1016/j.nucengdes.2011.07.031.

[3] Outokumpu Research Oy, Outokumpu HSC Chemistry® for Windows, Version 5.1 (2002).

[4] Shim, H. J., Kim, C. H., "Error Propagation Module Implemented in the McCARD Monte Carlo Code," *Transactions of the American Nuclear Society* **86**, 325 (2002).

[5] Beck, S. D., *The Diffusion of Radioactive Fission Products from Porous Fuel Elements*, BMI-1433 (1960).

[6] Kim, Y.M., Cho, M.S., Lee, Y.W., Lee, W.J., "Development of a Fuel Performance Analysis Code COPA," Paper 58040, Proceedings of 4th International Conference on High Temperature Reactor Technology HTR 2008, Washington D.C., USA, 28 Sept. – 1 Oct. (2008).

[7] Venneri, F., Jo, C.K., Noh, J.M., Kim, Y., Filippone, C., Chang, J., Hamilton, C., Kim, Y.M., Jun, J.S., Cho, M.S., Lim, H.S., Pople, M.A., Ougouag, A.M., Descotes, V., *High Temperature Reactor* (*HTR*) *Deep Burn Core and Fuel Analysis. Design Selection for the Prismatic Block Reactor*, INL/EXT-10-19973, Idaho National Laboratory (2010).