An Estimation of Gas Pressure in a UN-TRISO Coated Fuel Particle

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1. Introduction

A coated fuel particle (CFP) with a uranium mononitride (UN) kernel is recently considered as one of advanced fuel options such as a fully ceramic micro-encapsulated (FCM) replacement fuel for pressurized water reactors (PWRs). In the FCM fuel, a large number of tri-isotropic coated fuel particles (TRISOs) are embedded in a silicon carbide (SiC) matrix.

The gas pressure in a TRISO of the FCM fuel is guessed to be very low because the fuel temperature of a PWR is much lower than that of a high temperature reactor (HTR). Thus, it is not expected that the gas pressure causes severe mechanical failure of the TRISOs during a reactor normal operation. This study treats the quantitative analysis of gas buildup in a TRISO of a FCM PWR fuel.

2. Modeling on Gas Buildup in a TRISO

A TRISO in a FCM fuel consists of a kernel at its central region and four coating layers surrounding the kernel. The kernel material is UN. Many fission products and gases, nitrogen gas, transuranic radionuclides, and UN exist in a kernel during irradiation. It can be assumed that the above species instantly attain their chemical equilibrium. There are four possible phases in the UN fuel kernel: gases, metals, nitrides, and condensed compounds. The gas species that are generated in a kernel diffuse into the void volume of a kernel and a buffer. The void volume is the open-pore volume in the kernel and the buffer. 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 [1]. 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 can be estimated with the ideal gas law.

3. Calculation Results

Table 1 shows the layers of the CFP used in a FCM fuel and their thicknesses and densities. The enrichment of the UN kernel is 11.8 atom %. It was assumed that the fuel temperature was 1000 ^{o}C. The maximum fuel burnup is 171 GWd/tHM at 1700 EFPD. The nuclide inventory according to the fuel burnup was calculated with the McCARD code [2]. The HSC software [3] was used to calculate the thermo-chemical equilibrium. It is very difficult to calculate the thermochemical equilibrium for all nuclides. For simpler equilibrium calculation, the radionuclides of an element were summed, and they were classified into groups of similar chemical behavior, like Table 2.

Fig. 1 presents the generated gas species and their pressure evolution. The major gas species is cesium, and its final pressure is about 16 MPa. The minor species are cadmium, cesium monoioide, xenon, krypton, helium. The gas pressure is about 21 MPa at 1700 EFPD.

Table 1 Thicknesses and Densities of Layers in a TRISO

Layers	Thickness, μm	Density, g/cm^3
[a] OPyC	20	1.90
SiC	35	3.18
[b] IPyC	35	1.90
Buffer	50	1.05
UN kernel	[c] 700	14.32

[a] OPyC means outer pyrocarbon.
[b] IPyC means inner pyrocarbon.
[c] This figure means kernel diameter.

Table 2 Element Groups used in a Thermochemical Equilibrium Calculation

Groups	Elements	Chemical states
B	B	BN
Sr	Sr, Ba	[a] $(AE)_3N_2$
Te	Te, Se	Volatile
I	I, Br	Volatile
Xe	Xe, Kr	Volatile
Cs	Cs, Rb	Volatile
La	Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Ho, Er	[b] (RE)N
Zr	Zr	ZrN
Nb	Nb	Nb_2N
Mo	Mo	Mo_2N
Pd	Tc, Ru, Rh, Pd, Ag	Metal phase
Cd	Cd, In, Sn, Sb	Metal phases

[a] AE means alkali earth metal.
[b] RE means rare earth.

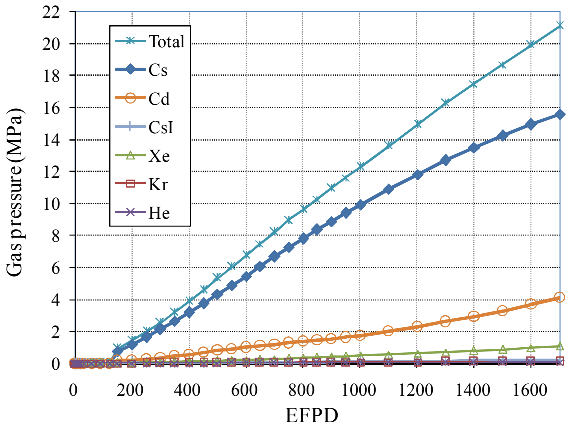

Fig. 1 Variation of Gas Pressure within a TRISO

4. Summary

An estimation of gas pressure in a TRISO with a UN kernel has been performed under the normal operation conditions of a PWR. The following conclusions are drawn through the analysis.

- The gas species that are generated in significant quantity is cesium.

- The total gas pressure in a TRISO is about 13 MPa at the end of reactor operation.

- Further analysis on the gas pressure is necessary under the accident conditions of a PWR, which causes high temperature in the fuel rod.

REFERENCES

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

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

[3] Outotec Oy, 2009. Outotec HSC Chemistry® 7.1. Outotec Oy, Finland.