An Estimation of Gas Pressure in a UN TRISO of a 12×12 FCM Fuel Assembly

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1. Introduction

A coated fuel particle (CFP) with a uranium mononitride (UN) kernel has been recently considered as an advanced fuel option, such as in fully ceramic micro-encapsulated (FCM) replacement fuel for pressurized water reactors (PWRs). In 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 a 16×16 FCM fuel assembly (FA) whose kernel diameter was 700 μm was estimated to be 12 MPa at 1000 effective full power days (EFPD) [1]. A core design of a 12×12 FA is also an option for the FCM PWR, in which the kernel size increases to 800 μm. This study treats the quantitative analysis of gas buildup in a TRISO of 12×12 FCM PWR FA.

2. Modeling on Gas Buildup in a TRISO

A TRISO in 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 [2]. 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 19.7 atom %. It was assumed that the fuel temperature was 1000 ^{o}C. The maximum fuel burnup is 139 GWd/tHM at 1000 EFPD. The nuclide inventory according to the fuel burnup was calculated using the McCARD code [3]. The HSC software [4] was used to calculate the thermo-chemical equilibrium. It is very difficult to calculate the thermochemical equilibrium for all nuclides. For a simpler equilibrium calculation, the radionuclides of an element were summed, and were classified into groups of similar chemical behavior, as shown in Table 2.

Fig. 1 presents the generated gas species and their pressure evolution. The major gas species is xenon, and its pressure is about 38 MPa at 1000 EFPD. The minor species are krypton and helium, and their gas pressures are negligible.

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] 800	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, Nb	ZrN, NbN
Mo	Mo	Elementary state
Tc	Tc	Elementary state
Pd	Ru, Rh, Pd, Ag	$(U,Pu)(Pd,Ru,Rh)_3$
Cd	Cd	Metal phase
Sn	In, Sn, Sb	Elementary states

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

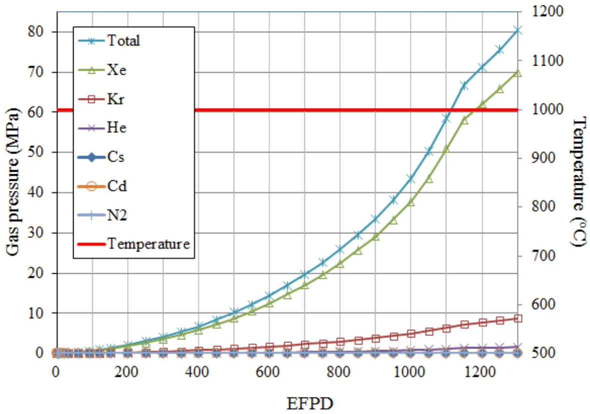

Fig. 1 Variation of Gas Pressure within a TRISO

4. Summary

The gas pressure in a TRISO with an 800-micrometer diameter UN kernel has been estimated under the normal operation conditions of an FCM PWR. The following conclusions were drawn through this analysis.

- The gas species generated in significant quantity is xenon.
- The total gas pressure in a TRISO is about 38 MPa at 1000 EFPD.
- Further analysis on the gas pressure is necessary under the accident conditions of a PWR, which causes high temperature in the fuel rod.

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