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An Estimation of Chemical Compounds in a UCO Kernel of an HECTAR TRISO under a Normal Operation Condition

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1. Introduction

The HECTAR (Helium Cooled Thermal Application Reactor) is a 90 MW_{th} block-type high-temperature gas-cooled reactor entirely intended for heat production. Its fuel particle is a TRISO (tri-structural isotropic coated fuel particle) which consists of a UCO kernel at its central region and four coating layers surrounding the kernel: buffer, IPyC (inner pyrocarbon), SiC (silicon carbide), and OPyC (outer pyrocarbon), from the inside.

The maximum allowable burnup of the HECTA TRISO is 20 %FIMA. A UCO kernel is a mixed fuel of UO_2 and UC_2 for a reduced CO pressure. Gases and radioactive materials generated in the UCO kernel during an irradiation can deteriorate the integrity of a TRISO. Fission products, carbon, oxygen, uranium, transuranic radionuclides, UO_2, UC, and UC_2 exist in a UCO kernel during irradiation. It can be assumed that the above species instantly attain their chemical equilibrium. There are five possible phases in the UCO fuel kernel: gases, iodides, oxides, carbides, and the other condensed compounds.

This study deals with the quantitative analysis of chemical compounds existing in a UCO kernel of the HECTAR TRISO under a normal operation condition.

2. Calculation Methods

Table I shows the layers of the TRISO used in a HECTAR fuel and their thicknesses and densities. The enrichment of the UCO kernel is 15.5 weight %. The packing fraction is 35 %. The fuel temperature is assumed to be 1200 °C. The fuel burnup and nuclide inventory according to the fuel burnup was calculated using the McCARD code [1]. The HSC software [2] was used to calculate the thermo-chemical equilibrium. For a simpler equilibrium calculation, the single elements were classified into groups of similar chemical behavior, as shown in Table II, and their amounts were summed. The COPA code [3] calculated the gas pressure in a TRISO.

Table I: Thicknesses and densities of layers in a TRISO

Layers	Thickness, μm	Density, g/cm^3
OPyC	40	1.9
SiC	35	3.2
IPyC	40	1.9
Buffer	100	1.05
UCO kernel	[a] 425	10.4

[a] This figure means kernel diameter.

Table II: Element groups used in a thermo-chemical equilibrium calculation

Group	Element
C	C
Sr	Sr
Zr	Zr, Nb
Mo	Mo
Tc	Tc
Ru	Ru, Rh
Pd	Pd, Ag
Cd	Cd
Sn	Sn, In, Sb
Te	Te, Se
I	I, Br
Cs	Cs, Rb
Ba	Ba
La	Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho ,Er
O	O
Np	Np
Pu	Pu
Am	Am
Cm	Cm

3. Calculation Results

Fig. 1 shows the variation of burnup and fast fluence. The final burnup and fluence are about 198 GWd/tHM and about 18.4×10^{21} n/cm^2 (E_n > 0.1 MeV), respectively.

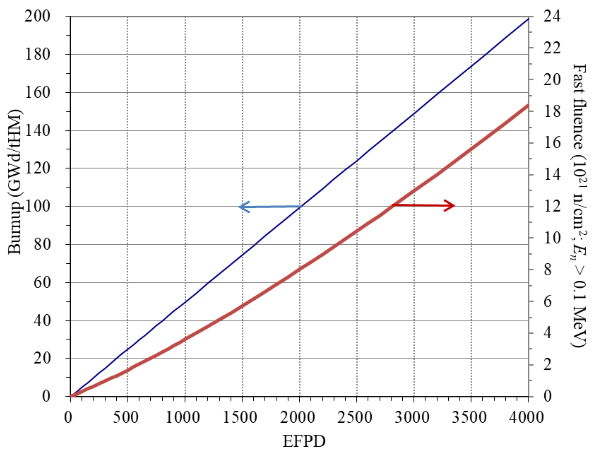

Fig. 1. Variation of burnup and fluence.

Figs. 2 and 3 present the generated gas species and their pressure evolution at 1200 ℃, respectively. Below 1200 ℃, the major gas species are xenon and krypton. No CO gas is not generated. Maximum gas pressure is 11 MPa.

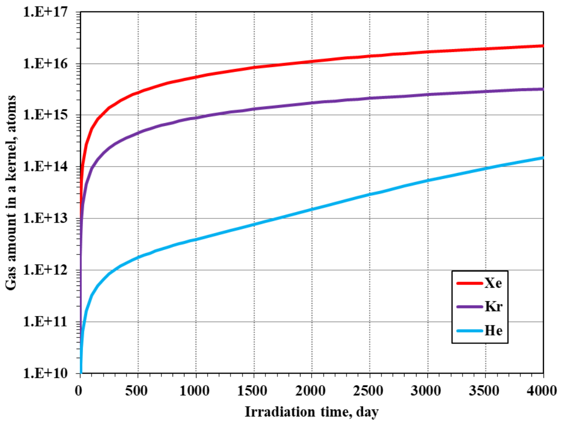

Fig. 2. Variation of gas amounts in a kernel at 1200 ℃.

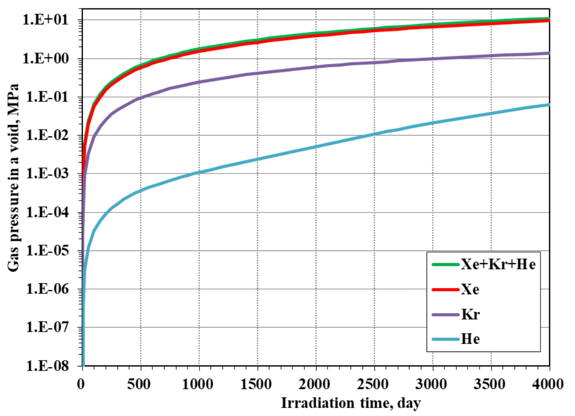

Fig. 3. Variation of gas pressure in a TRISO at 1200 ℃.

Fig. 4 shows the variation of fuel material amounts in a kernel at 1200 ℃. The generated nine fuel materials are C, U, U_2C_3, U_4O_9, UC, UC_2, UO, UO_2, and UO_3. Figs. 5 to 8 show the amount variation of oxide, carbide, single element and other condensed compounds in a kernel at 1200 ℃, respectively. Twenty-five oxides, twelve carbides, sixteen single elements, twenty-three other condensed compounds are generated. No iodides are produced. According to Table II, the generated ungrouped single elements are Am, Ba, Cd, Cm, Cs, Rb, I, Br, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Mo, Np, Pd, Ag, Pu, Ru, Rh, Sn, In, Sb, Sr, Tc, Te, Se.

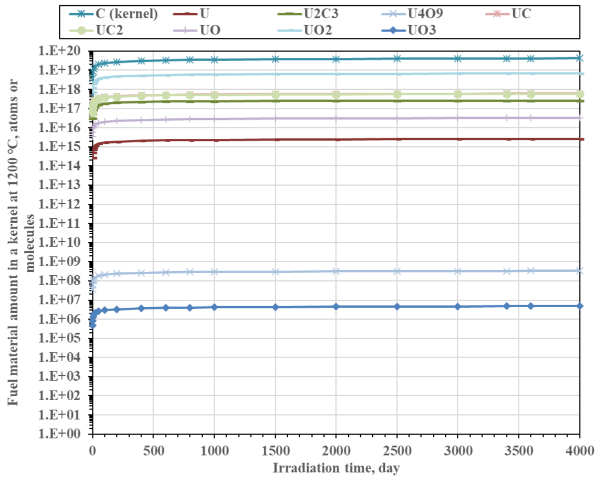

Fig. 4. Variation of fuel material amounts in a kernel at 1200 ℃.

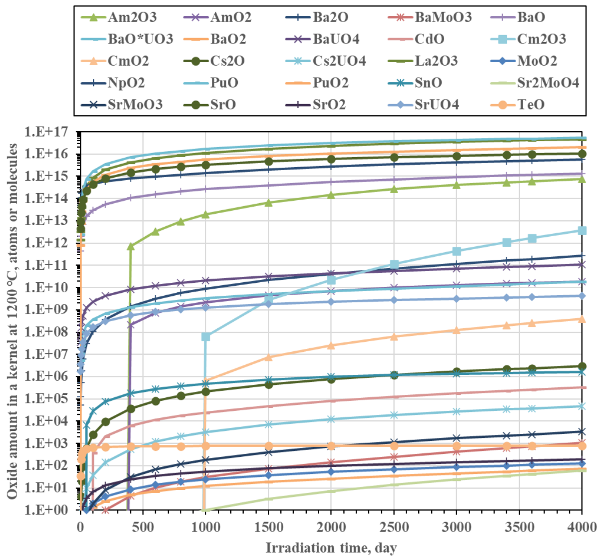

Fig. 5. Variation of oxide amounts in a kernel at 1200 ℃.

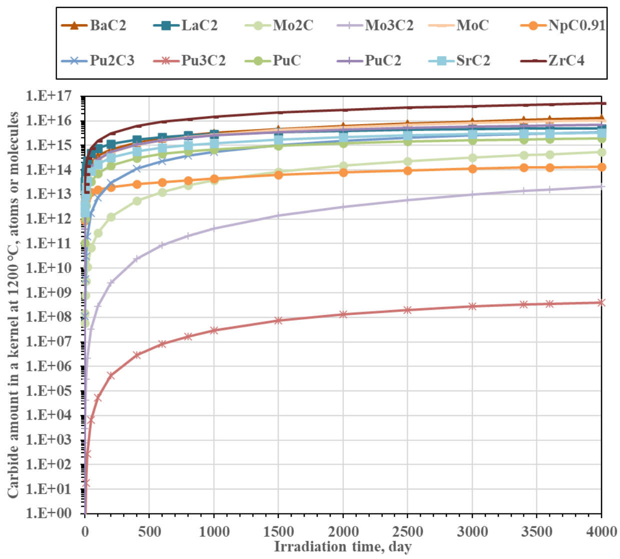

Fig. 6. Variation of carbide amounts in a kernel at 1200 ℃.

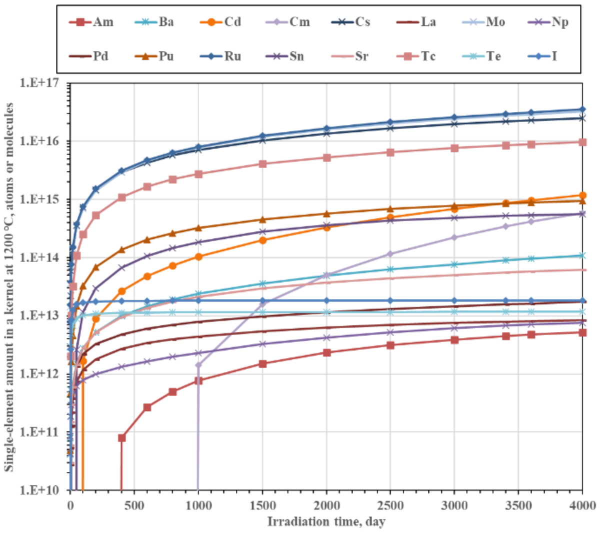

Fig. 7. Variation of single-element amounts in a kernel at 1200 ℃.

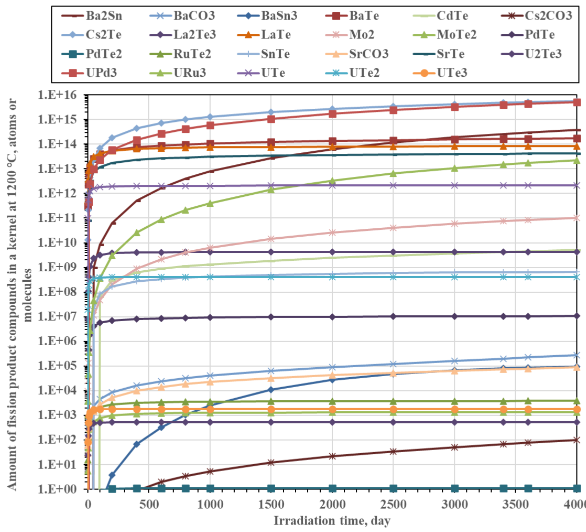

Fig. 8. Variation of single-element amounts in a kernel at 1200 ℃.

4. Summary

Amounts of chemical compounds in a UCO kernel of an HECTAR TRISO during the irradiation at 1200 ℃ has been evaluated. Below 1200 ℃, the major gas species are xenon and krypton and their maximum gas pressure is 11 MPa. The pressure is so low that it is considered very unlikely to damage the coating layers of a TRISO. Below 1200 ℃, the fuel materials generated or originally existed in a kernel are C, U, U_2C_3, U_4O_9, UC, UC_2, UO, UO_2, and UO_3. And twenty-five oxides, twelve carbides, sixteen grouped single elements, twenty-three other condensed compounds are generated, but no iodides are produced. The generated single elements are Am, Ba, Cd, Cm, Cs, Rb, I, Br, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Mo, Np, Pd, Ag, Pu, Ru, Rh, Sn, In, Sb, Sr, Tc, Te, Se. These single elements are released from a TRISO.

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