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# An Estimation of Gas Pressure in a TRISO of 350 $MW_{th}$ Block-type HTR

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## 1. Introduction

A 350 $MW_{th}$ block-type HTR (high temperature reactor) is an option to generate electricity and process heat for hydrogen production. The HTR will be operated for an extended fuel burnup of more than 150 GWd/MTU. Its fuel should survives the long irradiation. The block-type HTR fuel is a cylindrical graphite compact in which a large number of tri-isotropic coated fuel particles (TRISOs) are embedded. A TRISO consists of a 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.

In a usual $UO_2$ TRISO, a very high gas pressure builds up due to the extended operation of a HTR. Nuclear fissions in a kernel produces free oxygen. Due to the free oxygen, $UO_{2+x}$ is formed during burnup. At the interface between kernel and buffer, the $UO_{2+x}$ reacts with carbon of buffer which causes to produce CO. The high gas pressure can cause a pressure vessel failure of a TRISO. For a reduced pressure, a mixed fuel of $UO_2$ and $UC_2$ called UCO can be used instead of $UO_2$. In the UCO, the free oxygen reacts with $UC_2$ which produces pure carbon, not CO [1].

This study treats the quantitative analysis of gas buildup in a UCO TRISO of 350 $MW_{th}$ block-type HTR according to the fuel PF (packing fraction) and temperature.

## 2. Modeling on Gas Buildup in a TRISO

Many fission products, carbon, oxygen, transuranic radionuclides, $UO_2$, 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. 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 Methods

Table 1 shows the layers of the TRISO used in a HTR fuel and their thicknesses and densities. The enrichment of the UCO kernel is 15.5 weight %. Table 2 describes a HTR fuel element for estimating gas pressure. Three PFs were considered: 25, 30, and 35 %. It was assumed that the fuel temperature was 1000 K. The fuel burnup and nuclide inventory according to the fuel burnup was calculated with 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 3.

Table 1 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 | 1.0 |
| UCO kernel | [a] 425 | 10.5 |

[a] This figure means kernel diameter.

Table 2 Simple Description of a HTR Fuel Element

| Compact sizes | $\phi$ 1.245 cm × $H$ 1 cm |
|---|---|
| Compact materials | graphite (1.83 $g/cm^3$) + TRISO (PF=25/30/35 %) |
| Compact hole | $\phi$ 1.27 cm |
| Large coolant hole | $\phi$ 1.588 cm |
| Pitch | 1.8796 cm |
| Coolant | He |
| Coolant pressure | 7 MPa |

Table 2 Element Groups used in a Thermochemical Equilibrium Calculation

| Groups | Elements | Chemical states |
|---|---|---|
| C | C | gases, carbides |
| O | O | gases, oxides |
| Sr | Sr, Ba | gases, iodides, oxides, carbides |
| Te | Te, Se | gases, iodides, oxides |
| I | I, Br | gases, iodides |
| Cs | Cs, Rb | gases, iodides, oxides |
| Zr | Zr, Nb | gases, iodides, oxides, carbides |
| Mo | Mo | gases, iodides, oxides, |

| | | |
|---|---|---|
| | | carbides |
| Tc | Tc | gases, oxides |
| Ru | Ru, Rh, Pd, Ag | gases, iodides, oxides |
| Cd | Cd | gases, iodides, oxides |
| Sn | Sn, In, Sb | gases, iodides, oxides |
| U | U | $UO_2$, $UC_2$ |
| Np | Np | gases, iodides, oxides, carbides |
| Pu | Pu | gases, iodides, oxides, carbides |
| Am | Am | gases, iodides, oxides, carbides |
| Cm | Cm | gases, oxides |

## 4. Calculation Results

Fig. 1 shows the variation of burnup and fast fluence according to the PFs of TRISO. The final burnups are about 152, 127 and 109 GWd/MTU at the PFs of 25, 30 and 35%, respectively. The final fluence is about $8\times10^{21}$ n/cm$^2$ ($E_n$ > 0.1 MeV) for all PFs.

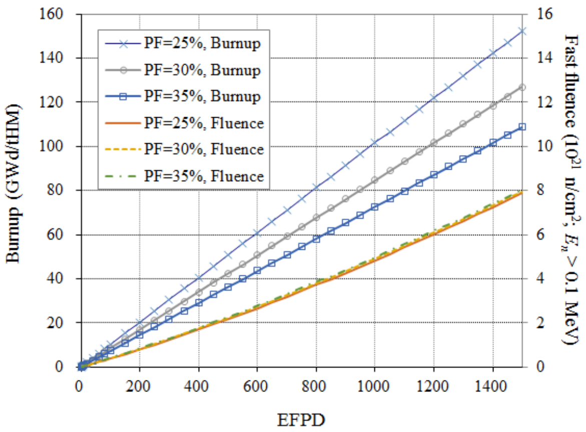


Fig. 1 Variation of Burnup and Fluence

Figs. 2 and 3 present the generated gas species and their pressure evolution at temperatures of 1000 and 1100 °C, respectively, when the PF is 35%. Below 1000 °C, the major gas species is xenon. Cesium gas starts to build up between 1000 and 1100 °C near 1400 EFPD. Fig. 4 shows the variation of total gas pressure within a TRISO at PF of 35%. The final pressure is about 18.5 MPa at 1300 °C. The rapid slope changes in the graphs of Fig. 4 mean that cesium begins to form at those positions.

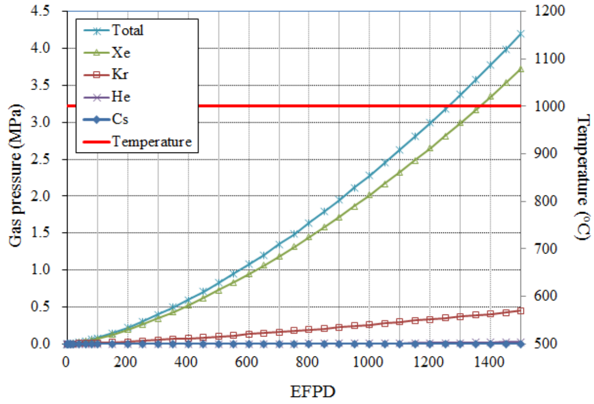


Fig. 2 Variation of Gas Pressure within a TRISO at temperature of 1000 °C and PF of 35%

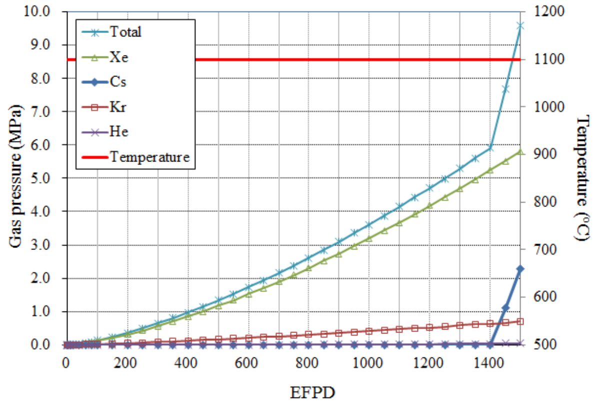


Fig. 3 Variation of Gas Pressure within a TRISO at temperature of 1100 °C and PF of 35%

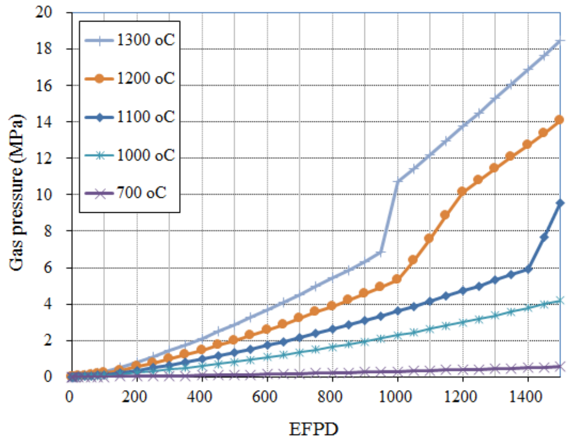


Fig. 4 Variation of Total Gas Pressure within a TRISO at PF of 35%

Figs. 5 and 6 present the generated gas species and their pressure evolution at temperatures of 1000 and 1100 °C, respectively, when the PF is 30%. Below 1000 °C, the major gas species is xenon. Cesium gas starts to build up between 1000 and 1100 °C near 1200 EFPD.

Fig. 7 shows the variation of total gas pressure within a TRISO at PF of 30%. The final pressure is about 22 MPa at 1300 ºC. The rapid slope changes in the graphs of Fig. 7 mean that cesium begins to form at those positions.

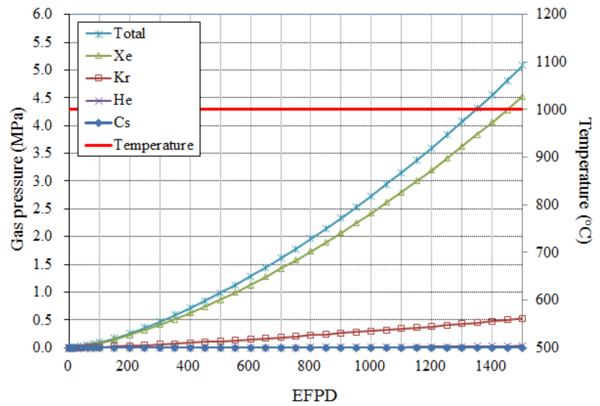


Fig. 5 Variation of Gas Pressure within a TRISO at temperature of 1000 ºC and PF of 30%

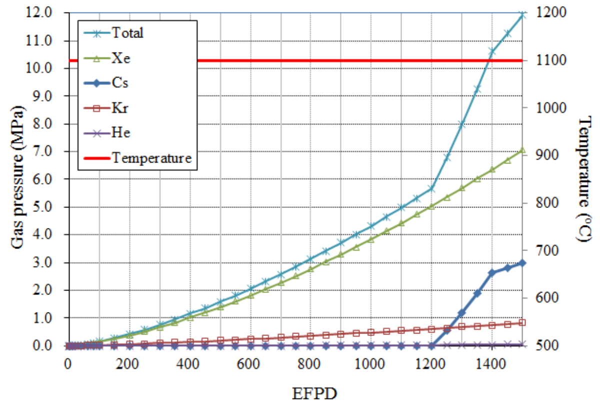


Fig. 6 Variation of Gas Pressure within a TRISO at temperature of 1100 ºC and PF of 30%

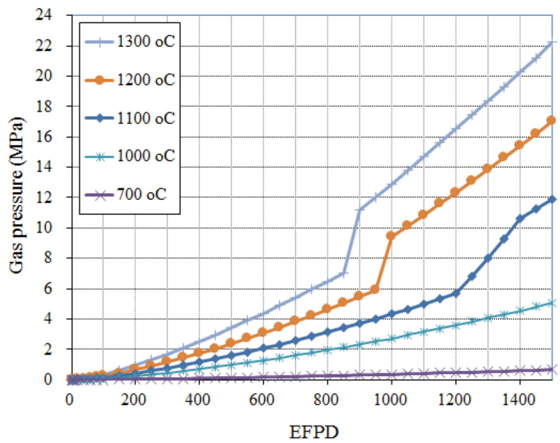


Fig. 7 Variation of Total Gas Pressure within a TRISO at PF of 30%

Figs. 8 and 9 present the generated gas species and their pressure evolution at temperatures of 1000 and 1100 ºC, respectively, when the PF is 25%. Below 1000 ºC, the major gas species is xenon. Cesium gas starts to build up between 1000 and 1100 ºC near 1000 EFPD. Fig. 10 shows the variation of total gas pressure within a TRISO at PF of 25%. The final pressure is about 28 MPa at 1300 ºC. The rapid slope changes in the graphs of Fig. 10 mean that cesium begins to form at those positions.

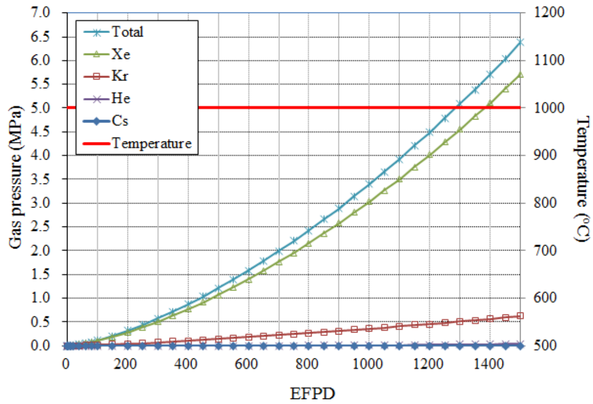


Fig. 8 Variation of Gas Pressure within a TRISO at temperature of 1000 ºC and PF of 25%

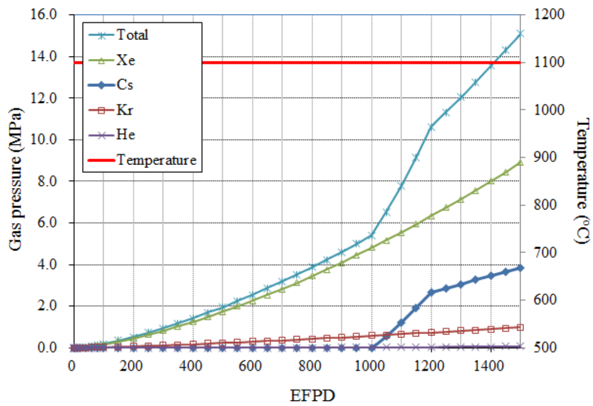


Fig. 9 Variation of Gas Pressure within a TRISO at temperature of 1100 ºC and PF of 25%

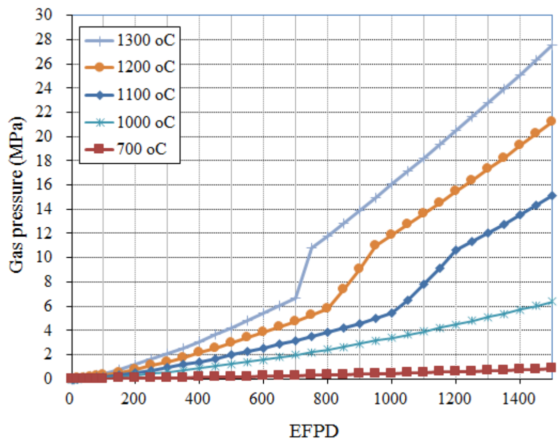

Fig. 10 Variation of Total Gas Pressure within a TRISO at PF of 25%

## 4. Summary

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

- The major gas species is xenon below 1000 ºC, and cesium starts to significantly build up between 1000 and 1100 ºC.
- The lower the PF is, the earlier cesium gas begins to form and the higher the total gas pressure is.
- The total gas pressure in a TRISO is about 28 MPa at temperature of 1300 ºC, PF of 25%, and EFPD of 1500.
- The low PF is desirable on fuel economy. The analyses of stress and failure of TRISOs will be used to determine whether the pressures are tolerable or not.

## REFERENCES

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