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Performances of a CERCER Fuel for a Nuclear Thermal Propulsion

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1. Introduction

A nuclear thermal propulsion (NTP) uses a nuclear reactor to provide the necessary energy to power a spacecraft [1]. The NTP simply uses nuclear fission to heat a propellant to a high exit velocity. Major nuclear fuel designs for an NTP that have been studied or are currently being studied are a NERVA/Rover fuel, a ceramic-metallic (CERMET) fuel, and a ceramic-ceramic (CERCER) fuel. The NERVA/Rover fuel is a graphite matrix with dispersed fuel (GMWDF) [2]. The CERMET fuel consists of ceramic fuel particles embedded in a metallic matrix [3]. The CERCER fuel consists of ceramic fuel particles embedded in a ceramic matrix [3]. The recently proposed CERCER fuel design is a high-assay-low-enrichment uranium (HALEU) nitride kernel embedded in zirconium carbide (ZrC) matrix [4].

The CERCER fuel designs treated in this study is bi-structural isotropic coated fuel particles (BISOs) embedded in ZrC matrix. Its fuel burnup and fast fluence, gas pressures in a BISO, thermal power and packing fraction according to BISO designs are evaluated.

2. A CERCER fuel

Fig. 1 shows a CERMET fuel element that can be installed in an NTP core [5]. There are 61 subchannels in which hydrogen flows. The bulk region originally consists of W and UO_2 in Ref. [5], but it was assumed in this study that it consisted of ZrC and UN BISO for a CERCER fuel performance evaluation. Table I presents the thicknesses and densities of BISO components. Table II the major design parameters of the CERCER fuel element. The particle power is about 4 W. It is one hundred times higher than the particle power of a high temperature gas-cooled reactor (HTGR). The thermal power per heavy metals in a kernel is 4541 W/g.

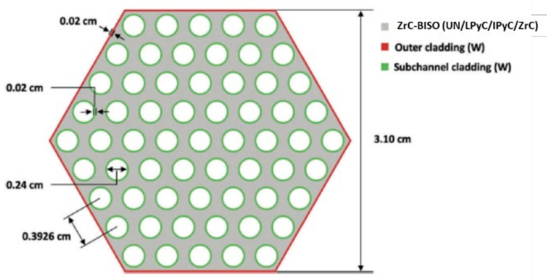

Fig. 1. A fuel element of an NTP.

Table I: Thicknesses and densities of BISO components

	Material	Thickness (μm)	Density (g/cm^3)
Kernel	UN	250[a]	14.32
Buffer	Low-density pyrocarbon	100	1.00
PyC	High-density pyrocarbon	40	1.90
ZrC	Zirconium carbide	35	6.59

[a] Radius

Table II: Design parameters of a CERCER fuel element

Design parameter	Data
Fuel region (bulk):	
matrix	ZrC
Fuel particle	BISO (UN/buffer/PyC/ZrC)
Height (cm)	1
Packing fraction	0.4
Matrix density (g/cm^3)	6.59
Power density, (W/cm^3)	5000
Operation time (hour)	10

3. CERCER Fuel performances

Neutronics and depletion calculations were performed using the McCARD code [6]. Fig. 2 shows the fuel burnup and fast fluence of a CERCER NTP fuel. The maximum burnup and fast fluence are 1377 MWd/tU (5.2×10^{-5} %FIMA) and 1.343×10^{21} n/cm^2 (E_n > 0.1 MeV), respectively. For an HTGR, the three-year fast fluence over three years is about 3.5×10^{21} n/cm^2 (E_n > 0.1 MeV). The fast fluence of the CERCER fuel reaches about 40 % of the three-year fast fluence of the HTGR in ten hours.

Fig. 3 shows the gas pressure in a buffer of a BISO. The considered gases are Xe, Kr and He. The gas pressure is very low, less than 0.1 MPa.

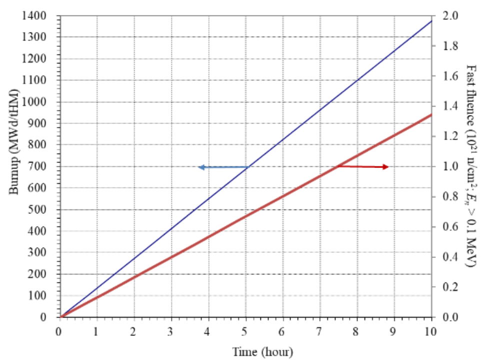

Fig. 2. Fuel burnup and fast fluence of a CERCER NTP fuel.

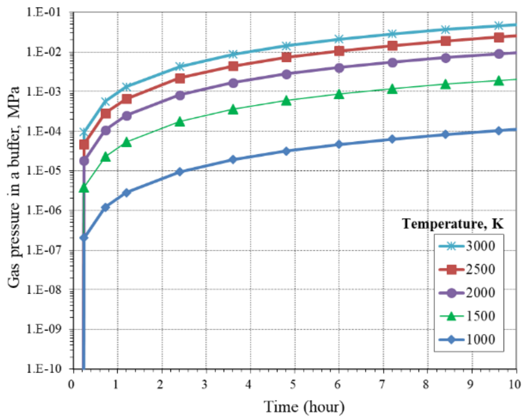

Fig. 3. Gas pressures in a buffer of a BISO.

Fig. 4 shows the thermal power per heavy metal according to sizes of the kernel and coating layers. The kernel size was increased while keeping the BISO packing fraction constant. The larger the kernel size, the lower the thermal power per heavy metal. Fig. 5 shows the BISO packing fraction according to the size of coating layers. The sizes of the coating layers were decreased while keeping the kernel size constant. Naturally, the smaller the coating layers, the lower the BISO packing fraction. It is necessary to fine the optimum thicknesses of the coating layers of a BISO.

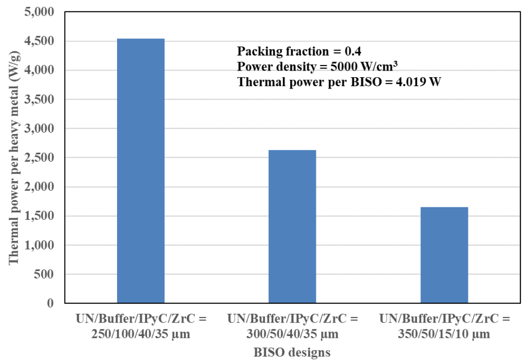

Fig. 4. Thermal power per heavy metal according to sizes of the kernel and coating layers.

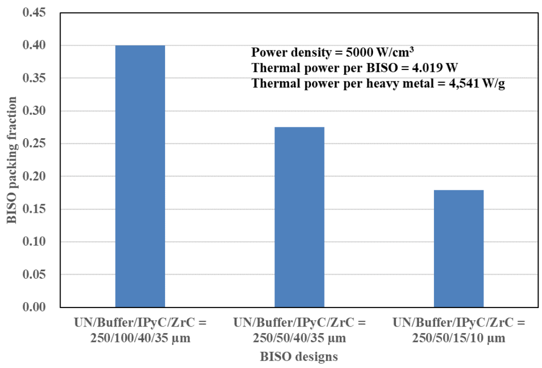

Fig. 5. BISO packing fraction according to the size of coating layers.

4. Summary

A performance analysis for a UN BISO CERCER fuel has been done. The power density of the fuel is 5000 W/cm^3 and the fuel is operated for ten hours. Its maximum burnup and fast fluence are 1377 MWd/tU and 1.343×10^{21} n/cm^2 (E_n > 0.1 MeV), respectively. The gas pressure in a buffer of a BISO is less than 0.1 MPa. Increasing the kernel size reduces the thermal power per BISO. Decreasing the sizes of the coating layers of a BISO reduced the packing fraction of BISOs.

No kernel migration occurs because no CO gas is produced in a UN BISO. Mechanical stress due to the gas pressure is negligible. Thermal stress can be significant because of high temperatures.

ACKNOWLEDGEMENTS

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