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FBNR BASIC DATA FOR NEUTRONICS CALCULATIONS

Fixed Bed Nuclear Reactor – FBNR (Brazil)

Fuel Element Description

The 15 mm diameter spherical fuel elements are made of compacted coated particles in a graphite matrix. The coated particles are similar to TRISO fuel with outer diameters about 2mm. They consist of 1.58 mm diameter uranium dioxide spheres coated with 3 layers. The inner layer is of 0.09 mm thick porous pyrolitic carbide (PYC) with density of 1 g/cm3 called buffer layer, providing space for gaseous fission products. The second layer is of 0.02 mm thick dense PYC (density of 1.8 g/cm3) and the outer layer is 0.1 mm thick corrosion resistant silicon carbide (SiC, density of 3.17 g/cm3). The fuel element is cladded by 1mm thick SiC. ***Fuel enrichment 5%.***

Table 1. Fuel particle (2 mm diameter)

Material	density (g/cm³)	d. inside (cm)	d.outside (cm)	volume (cm³)	mass (gr)
UO2	10.5	0	0.158	0.002065237	0.021684988
PYC (porous)	1	0.158	0.176	0.000789306	0.000789306
PYC (dense)	1.8	0.176	0.18	0.000199085	0.000358353
SiC	3.17	0.18	0.2	0.001135162	0.003598464
Average for microsphere	**6.3099629**		**0.2**	**0.00418879**	**0.026431111**

Table 2. Fuel Element (15 mm diameter)

Material	Mass (gr)	Volume (cm3)	Density (g/cm3)	Mass fraction	Volume fraction	Thermal conductivity (W/m.°C)	Specific heat (kJ/kg.°C)
UO2	3.578	0.341	10.5	0.501	0.193	5.2	
PYC porous (amorfo) 600K	0.130	0.130	1	0.0182	0.0737	2.19	1406
PYC dense (amorfo) 600K	0.887	0.493	1.8	0.124	0.279	2.19	1406
SiC	2.549	0.804	3.17	0.357	0,455	77.5	1300
fuel element	**7.145**	**1.768**	**4.041**	**1**	**1**	**30.566**	**1400**

(60% fuel particles and 40% dense graphite matrix cladded by 1 mm thick SiC)

Unit cell description

Specification of Micro Fuel Elements (MFEs) used in the design of FBNR is shown in Table 1 and Table 3. The volume fraction of fuel particles (MFE) inside the 15 mm diameter spherical fuel elements (FE) in the graphite matrix and the volume fraction of fuel elements (FE) inside the water bed of the core is set to **60%** in a realistic situation.

The 68% would be by assuming that particles are packed in graphite or water so as to form a lattice just like body-centered cubic structure of a crystal. Namely, one fuel particle contacts another only in diagonal direction.

One-dimensional square lattice (**A** in Fig.1) with 9.632mm sides has been selected as a unit-cell for FBNR. It is expected to use this geometry for depletion calculations with all the materials homogenized in the cell. On the other hand, in order to consider the heterogeneity of fuel particles in the graphite matrix, it is expected to use the geometry **B** in

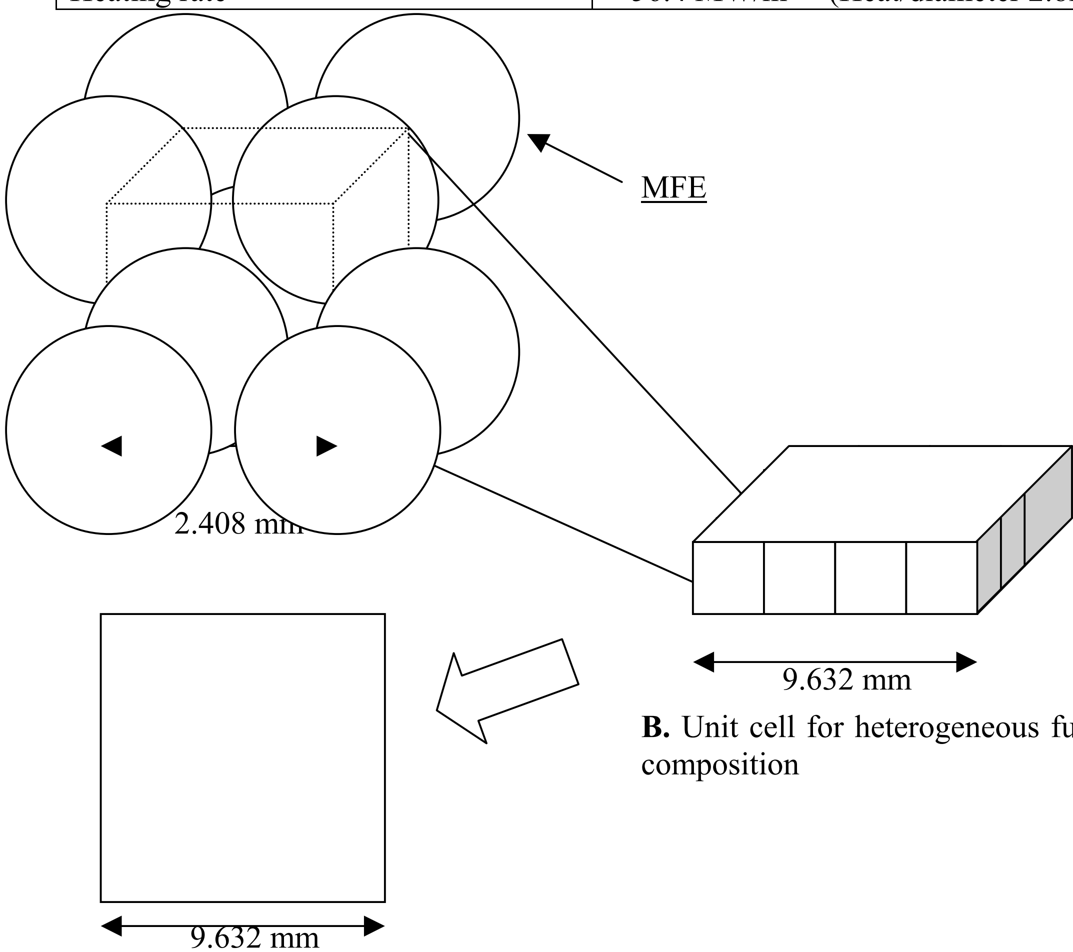
Fig1 if possible. Boundary conditions are listed in Table 4.

Table 3. Specification of MFEs

Layer	Material	Density [g/cm^3]	Dimension [mm]
Fuel kernel	UO2	10.8	1.58 (diameter)
1st coating layer	PYC (porous)	1.0	0.09 (thickness)
2nd coating layer	PYS (dense)	1.8	0.02 (thickness)
3rd coating layer	SiC	3.17	0.1 (thickness)
TOTAL	-	-	2.0 (diameter)

Table 4. Calculation conditions

Geometry	Square	
Boundary Condition	Perfect Reflection	
Enrichment of ^{235}U	5.0wt%	
Water : MFEs	40 : 60	32 : 68
Cell length	9.632	9.237
System average temperature	308 ^{o}C	
System average pressure	16 MPa	
Heating rate	56.4 MW/m³ (Heat/diameter 2.8E-05 MW/cm)	



B. Unit cell for heterogeneous fuel composition

A. Unit cell for homogenized fuel composition

Comments:
Reference to the site:
http://www.sciborg.uwaterloo.ca/~cchieh/cact/applychem/metals.html
What is the fraction of the volume occupied by spheres for a bcc type structure?
Assume the radius of *spheres* be r, and the edge of the body centered unit cell to be a. There are two spheres per unit cell, thus

body diagonal $= 4\,r = 3^{1/2}\,a$

$a = 4\,r\,/\,3^{1/2}$

$V_{sphere} = {}^{4}/_{3}\mathrm{p}r^{3}$

$V_{cell} = a^{3} = 64{*}r^{3}\,/\,3^{3/2}$

Fraction of volume occupied by spheres = $2{*}V_{sphere}/V_{cell}$

$= 3^{1/2}\mathrm{pi}/8 \quad = 0.68$ or 68%.

Discussion

The fraction of **0.68** is slightly less than those (**0.74**) of closest packed structures. Thus, the bcc structures are less densely packed according to the hardsphere model. The cubic unit cell contains only one sphere, and the edge length is exactly equal to the diameter of the sphere. The fraction of space occupied by spheres in such an arrangement is pi/6 (**0.52**), much less than the bcc structure type.

The experiments performed by pouring spherical balls into a cylindrical container, the fraction is found to be about **0.60**. Therefore, It is suggested to use the value of 0.60 that is more realistic. Thus in the FBNR fuel element, the microspheres occupy 60% of the volume and graphite the rest. The fixed bed of FBNR is made of **60%** fuel elements and **40%** water.