82/100

*NucE 497 Fuel Performance Exam 2 covering modules 4 – 6*

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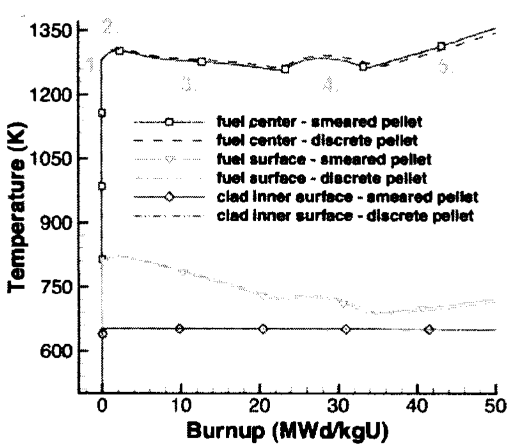
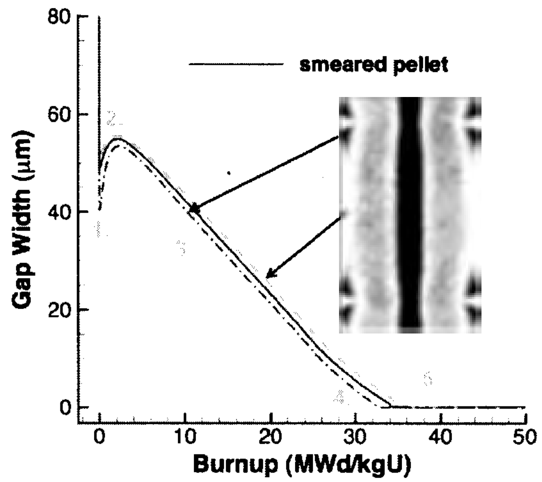
-10, 15/25

**Question 1 (25 points):**
The temperature and gap width of a fuel pellet, as predicted by a fuel performance code, is shown below. Using the plots as your guide, determine what is currently occurring within the cladding, gap, and pellet at each number. Note that the numbers are at the same burnups on the two plots.




For each number, describe what is occurring in the cladding, gap, and pellet. Also, describe what features in the plots indicated these behaviors.

1. Point defect / fission gas generation
   Fuel densification

   -4, T increase due to fission, gap closure due to thermal expansion

2. Thermal expansion
   Point defect clustering (gap increases)
   Bubble nucleation

   -4, Densification, causing pellet to shrink and thus gap to increase

3. Fuel begins to swell (temp decrease)
   Creep throughout causes the gap to shrink

4. Fission release / Swelling (temp bows)
   Cladding creep (Gap is filled)
   Fuel creep

5. PCMI (no gap width)
   Fission gases corrode cladding
   may cause fracture + eventual failure

   -2, T continues to increase to due decrease in k with burnup

-3, 27/30

**Question 2 (30 points)** $T = 1173K$

$a = 8e{-4}$
$\dot{F} = 2e13$
$T = 900°C$
$k_B = 8.6173303e^{-5}$

A fuel pellet with an average grain size of 8 microns is irradiated with a volumetric neutron flux of 2.0e13 fissions/(cm³ s). Assume the pellet is at a uniform temperature of 900 °C.

a) What is the fission gas diffusion coefficient at this temperature? (5 pts) $D = ?$

$$D = D_1 + D_2 + D_3$$

$$D_1 = 7.6\times10^{-6} e\left[\frac{-3.03eV}{(8.6173303\times10^{-5})(1173K)}\right] = 7.285\times10^{-19}$$

$$D_2 = 1.41\times10^{-18} e\left[\frac{-1.19eV}{(8.6173303\times10^{-5})(1173K)}\right](\sqrt{2e13}) = 4.863\times10^{-17}$$

$$D_3 = 2.0\times10^{-30}(2e13) = 4.0\times10^{-17}$$

$$\boxed{D = 8.94\times10^{-17}\ cm^2/s}$$

b) How many gas atoms/cm³ are released from the fuel after 2 years of irradiation? Assume the chain yield y = 0.3017. (10 pts) $N_{rel} = f N_{gas}$

$0.7118$ $2.09\times10^{-10}$

$N_{gas} = y\dot{F}t V_{fuel}$

$$f = 4\sqrt{\frac{(8.94\times10^{-17}cm^2/s)(63072000s)}{\pi(8\times10^{-4})^2}} - \frac{3}{2}\frac{(8.94\times10^{-17}cm^2/s)(63072000s)}{(8\times10^{-4})^2} = 0.198$$

$$N_{gas} = (0.3017)(2\times10^{13} fissions/cm^3 \cdot s)(63072000)$$

$$N_{gas} = 3.805\times10^{20} atoms/cm^3$$

$$N_{rel} = (0.198)(3.805\times10^{20}\frac{atoms}{cm^3}) = \boxed{7.535\times10^{19}\frac{atoms}{cm^3}}$$

c) After 2 years of irradiation, the pellet is removed from the reactor and from its cladding, venting all released gas. It is then moved to a furnace and annealed at 2000 °C. Estimate how long before 10% of the gas trapped in the pellet is released. How many gas atoms/cm³ will have been released during this time? (15 pts)

$f = 10\%$

$f = 6\sqrt{\frac{Dt}{\pi a^2}}$

$t = \frac{f^2\pi a^2}{36D}$

$$D_1 = 7.6\times10^{-6} e\left[\frac{-3.03}{(8.6173303\times10^{-5})(2273K)}\right] = 1.45\times10^{-12}$$

$$D_2 = 1.41\times10^{-18} e\left[\frac{-1.19}{(8.6173303\times10^{-5})(2273K)}\right] = 3.24\times10^{-21}$$

$$D_3 = 4\times10^{-17} \qquad D = 1.45\times10^{-12} cm^2/s$$

$$t = \frac{(.1)^2\pi(8\times10^{-4})^2}{36(1.45\times10^{-12}cm^2/s)} = \boxed{385s}$$

$$N_{rel} = f N_{gas}$$

$$N_{rel} = (0.1)(2.32\times10^{15}\frac{atoms}{cm^3})$$

$$N_{gas} = (0.3017)(2e13)(385s)$$

$$N_{gas} = 2.32\times10^{15}\frac{atoms}{cm^3}$$

$$\boxed{N_{rel} = 2.32\times10^{14}\frac{atoms}{cm^3}}$$

-3, No new gas is produced, should be gas produced - gas released form part b

-2, 28/30

**Problem 3 (30 points)**

$t = 365$

$t^* = ?$

$\delta^* = ?$

$\delta = ?$

A ZIRLO cladding tube is in reactor at 600 K for one year. The initial wall thickness is 0.6 mm.

a) What is the oxide weight gain in mg/dm² after this time? (10 pts) $\delta(\mu m) = \frac{w(mg/dm^2)}{14.7}$

$$\delta = \delta^* + K_L\left[t - t^*\right]$$

$$\delta^* = 5.1\exp\left(\frac{-550}{600K}\right) = 2.039\ \mu m$$

$$t^* = 6.62\times10^{-7}\exp\left(\frac{11949}{600K}\right) = 295\ \text{days}$$

$$K_L = 7.48\times10^{6}\exp\left(-\frac{12500}{600K}\right) = 0.0067$$

$$\delta = 2.039 + 0.0067(365 - 295)$$

$$\delta = 2.508\ \mu m$$

$$W = (2.508)(14.7) = \boxed{36.86\ mg/dm^2}$$

b) What is the ZIRLO wall thickness after this time? (5 pts)

$$600\ \mu m - 2.508\ \mu m = \boxed{597.492\ \mu m}$$

-2, metal lost = oxide thickness/1.56

c) Assuming the hydrogen pickup fraction is 15%, what is the weight PPM of hydrogen in the cladding after one year? (10 pts)

$f_{Zr} = 0.26$

$f = 0.15$

$\delta = 2.508\ \mu m$

$\rho_{ox} = 5.68\ g/cm^3$

$\rho_{metal} = 6.5\ g/cm^3$

$m_H/m_O = 1/16$

$t = 600\ \mu m$

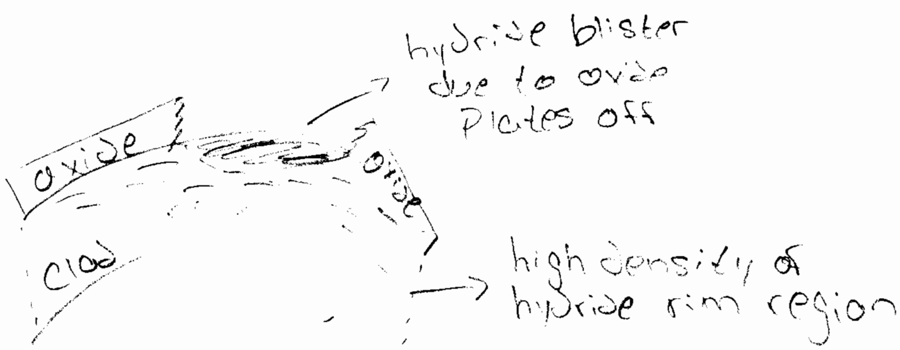
$PBR = 1.56$

$$C_H^{clad}[wt.ppm] = \frac{2f\times\delta\times\rho_{oxide}\times f_{ZrO_2}\times\frac{m_H}{m_O}}{\left(t - \frac{\delta}{PBR}\right)\times\rho_{metal}}\times10^6$$

$$C_H^{clad} = \frac{2(0.15)(2.508)(5.68\ g/cm^3)(0.26)(\frac{1}{16})}{\left(600 - \frac{2.508}{1.56}\right)(6.5\ g/cm^3)}\times10^6$$

$$\boxed{C_H^{clad} = 17.85\ wt\ ppm}$$

d) Draw a section of the cladding, showing the various microstructure changes (5 pts)



-3, 12/15

**Problem 4 (15 points)**

a) What are the primary differences between a loss of coolant accident and a reactivity insertion accident, regarding the fuel and cladding behavior? (5 pts)

RIA

- Jump in temp causes pressure jump + cracking
- PCMI failures cause clad to break
- fission gas increase
- Reactivity decrease

LOCA

- Pressure drops
- Cladding rupture
- Ballooning / burst of clad
- Thermal stress
- Relocation in fuel

b) What are similarities between the fuel and cladding behavior in a RIA and a LOCA? (5 pts)

- Induced fisson gas release
- temp increase

-3, Fuel fragmentation, cladding ballooning and burst

c) List a potential accident tolerant fuel concept and describe how it could meet the primary goal of the accident tolerant fuel program. (5 pts)

Advanced steel cladding

- high strength + ductility
- corrosion resistant
- low creep