-12.5, 12.5/25

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

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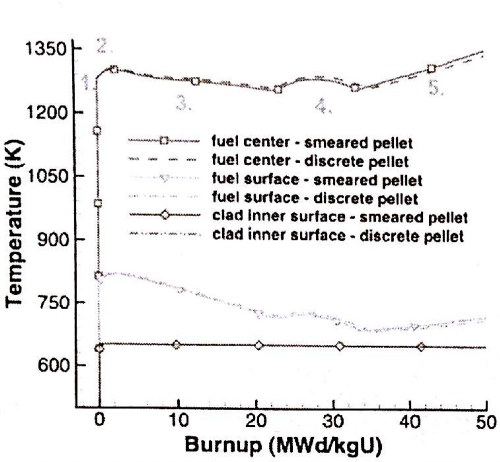
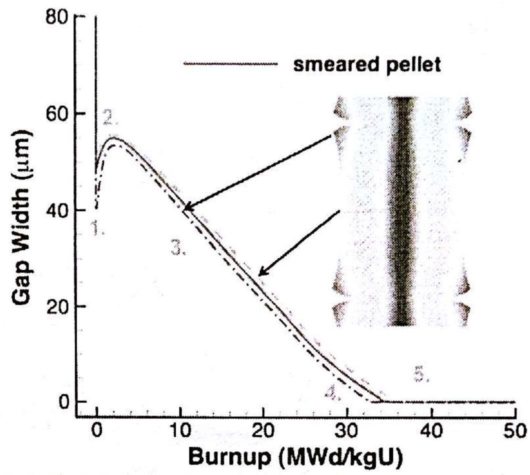
Question 1 (25 points):

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.

-5, You didn't discuss how these things impact temperature

1. Reactor Startup
   - gap with lessens
   - pellet swells

-2.5, Thermal expansion, not swelling

2. Fuel pellet densification (gaseous swelling)
   - gap swells pushing pellet closer to cladding

3. Fuel pellet swelling (fission gas release in gap)
   - Cladding creep
   - gap thickness decreases

4. High burnup swelling in pellet
   - Transition to breaking away

-2 Fission gas release causes T to increase before gap closure

   - Cladding, gap and pellet are reaching steady-state
   - pellet is almost touching cladding

-1, They have been at steady state since #1

5. Steady-state
   - pellet and cladding touch
   - no gap

-2, fuel k goes down with burnup, so T increases

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-12, 18/30

Question 2 (30 points) $k_b = 8.6173303\times10^{-5}$ eV/K $T = 900°C + 273.15 = 1173.15$ K

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)

$D_1 = (7.6\times10^{-6})\exp\left(\frac{-3.03}{k_bT}\right) \Rightarrow D_1 = (7.6\times10^{-6})\exp\left(\frac{-3.03}{(8.617\times10^{-5})(1173.15)}\right)$

$\hookrightarrow D_1 = 7.31342\times10^{-19}$

$D_2 = (1.41\times10^{-18})\exp\left(\frac{-1.19}{k_bT}\right)(\dot{F})^{1/2}$

$\hookrightarrow D_2 = (1.41\times10^{-18})\exp\left(\frac{-1.19}{(8.617\times10^{-5})(1173.15)}\right)(2.0\times10^{13})^{1/2}$

$\hookrightarrow D_2 = 4.8704\times10^{-17}$

$D_3 = (2.0\times10^{-30})\dot{F} \Rightarrow D_3 = (2.0\times10^{-30})(2.0\times10^{13})$

$\hookrightarrow D_3 = 4.0\times10^{-17}$

$\Rightarrow D = D_1 + D_2 + D_3 \Rightarrow D = (7.3\times10^{-19}) + (4.9\times10^{-17}) + (4.0\times10^{-17}) \Rightarrow \boxed{D = 8.944\times10^{-17}}$

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)

2 years $= 2(365)(24)(3600) = 63072000$

$a = 8\ \mu m = 8\times10^{-4}$ cm

$N_{gas} = y\dot{F}t \Rightarrow N_{gas} = 0.3017(2.0\times10^{13})(6307200) \Rightarrow N_{gas} = 3.8058\times10^{20}$ fission/cm³

$N_{released} = fN_{gas}$ -2, Wrong equation

$\hookrightarrow f = 6\sqrt{\frac{Dt}{\pi a^2}} - 3\frac{Dt}{a^2} \Rightarrow f = 6\sqrt{\frac{(8.94\times10^{-17})(6307200)}{\pi(8.0\times10^{-4})^2}} - 3\left(\frac{(8.94\times10^{-17})(6307200)}{(8.0\times10^{-4})^2}\right)$

$\hookrightarrow f = 0.291$

$\hookrightarrow N_{released} = (0.291)(3.8058\times10^{28}) \Rightarrow \boxed{N_{released} = 1.1089\times10^{20}\ \text{atoms/cm}^3}$

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)

$t = \frac{f^2 a^2 \pi}{36D} = \frac{(0.1)^2(8\times10^{-4})^2\pi}{36(8.944\times10^{-17})} \Rightarrow t = 6244169$ s

$\hookrightarrow \boxed{t = 72.3\ d}$

-4, D from wrong temp, T = 2273 K

-6, You need to calculate the number of gas atoms produced during the time

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-9, 21/30

Problem 3 (30 points)

$t = 365$ d

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)

$$\delta^* = 5.1 \exp\left(\frac{-550}{T}\right) \rightarrow \delta^* = 5.1 \exp\left(\frac{-550}{600}\right) \rightarrow \delta^* = 2.0392 \, \mu m$$

$$t^* = (6.62 \times 10^{-7}) \exp\left(\frac{11949}{T}\right) \rightarrow t^* = (6.62 \times 10^{-7}) \exp\left(\frac{11949}{600}\right) \rightarrow t^* = 295.007 \, d \approx 295 \text{ days}$$

$$K_L = (7.48 \times 10^6) \exp\left(\frac{-12500}{T}\right) \rightarrow K_L = (7.48 \times 10^6) \exp\left(\frac{-12500}{600}\right) \rightarrow K_L = 0.0067 \, \frac{\mu m}{d}$$

$$\delta = \delta^* + K_L (t - t^*) \rightarrow \delta = 2.0392 + 0.0067 (365 - 295) \rightarrow \delta = 2.508 \, \mu m$$

$$\delta = \frac{w}{14.7} \rightarrow w = 14.7(2.508) \rightarrow \boxed{w = 36.87 \, mg/dm^2}$$

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

$$\delta_{ZIRLO} = \delta + 0.6 mm$$
$$= 2.508 \, \mu m + 0.6 mm$$
$$= 0.002508 mm + 0.6 mm$$
$$\rightarrow \boxed{\delta_{ZIRLO} = 0.602508 \, mm}$$

-2, metal lost = oxide thickness/1.56
-2, thickness lost not gained

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

-5, use the equation, should be in wgt PPM

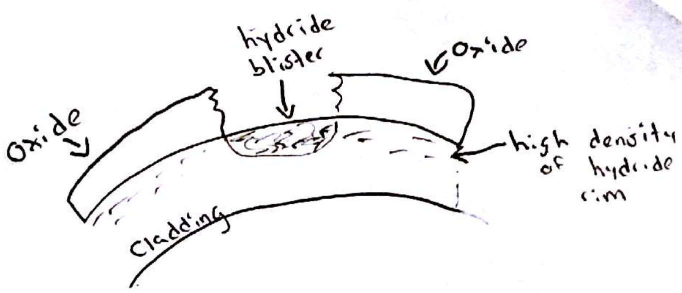
$$N_O = \frac{w N_a}{m_O} = \frac{0.03687 (6.022 \times 10^{23})}{16} \rightarrow N_O = 1.38769 \times 10^{21} \, \frac{\text{atom } O_2}{dm^2}$$

$$N_H = 2 N_O = 2(1.388 \times 10^{21}) \rightarrow N_H = 2.7754 \times 10^{21} \, \frac{\text{atom } H}{dm^2}$$

$$N_{H-Zr} = f N_H = 0.15 (2.775 \times 10^{21}) \rightarrow N_{H-Zr} = 4.1631 \times 10^{20}$$

$$w_H = \frac{N_{H-Zr} \, m_H}{N_{av}} = \frac{4.1631 \times 10^{20} (1)}{6.022 \times 10^{23}} \rightarrow w_H = 6.913 \times 10^{-4} \, g \rightarrow \boxed{w_H = 0.691 mg}$$

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



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-1, 14/15

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)

LOCA	RIA
• relocation in fuel	• higher pressure
• fission gas release in fuel	• higher impact on high burnup fuel
• decrease in coolant pressure	• fuel breaks into pieces
• undergoes α and β transition	• faster (large consequence quicker)
	• PCMI

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

- ballooning
- fuel temperature rise

-1, Fuel fragmentation

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)

Microencapsulated fuel

• This has a high thermal conductivity, so it's good as a fuel.

• Resistant to melting, therefore can withstand higher temperatures if an accident were to occur.

• Has excellent fission product retention, so it's a safe material