92/100

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

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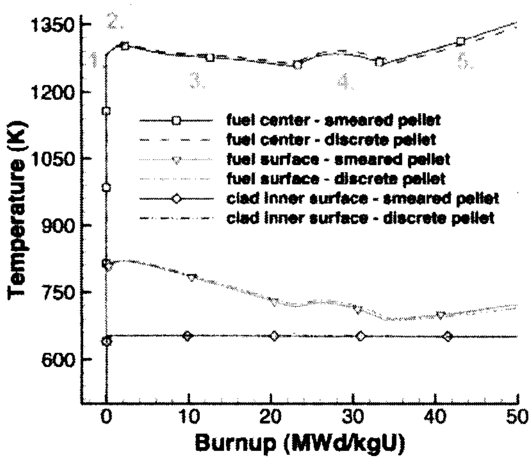
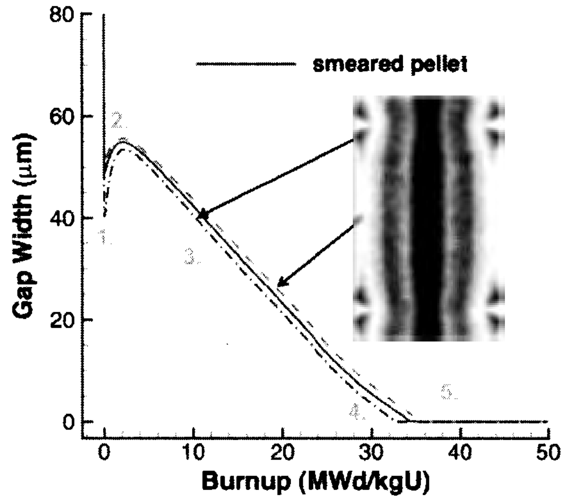
-4, 21/25

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. cladding: the cladding is heating up
gap: the gap is shrinking
pellet: the fuel is expanding due to temp. increase + fracturing

2. cladding: the cladding is staying relatively the same
gap: the gap is increasing
pellet: the fuel is going through densification
-1, how does this impact T

3. cladding: the cladding is staying the same
gap: the gap is decreasing
pellet: the fuel is swelling + fission gas is segregating to grain boundaries
-1, how does this impact T

4. cladding: the cladding begins to creep
gap: fills with fission gas
pellet: fuel releases fission gas + creeps

5. cladding: interacts w/ pellet, corrodes, and cracks
gap: closes
-2, T increases because fuel k decreases with burnup
pellet: interacts w/ cladding

Question 2 (30 points) 29/30

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)

$k_b = 8.6173303 e^{-5}$ eV/K

$\dot{F} = 2.0\times10^{13}$ fissions/cm³·s

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

$D = D_1 + D_2 + D_3$

$D_1 = 7.6\times10^{-6}\, e^{\frac{-3.03\,eV}{k_b\cdot1173}} = 7.285\times10^{-19}$

$D_2 = 1.41\times10^{-18}\, e^{\frac{-1.19}{k_b\,1173}}\sqrt{2.0\times10^{13}} = 4.863\times10^{-17}$

$D_3 = 2.0\times10^{-30}(2.0\times10^{13}) = 4.0\times10^{-17}$

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)

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

$N_{gas} = (0.3017)(2.0\times10^{13})(63072000)$ (fission/cm³·s, s)

$N_{gas} = 3.806\times10^{20}$

$f = 4\sqrt{\frac{Dt}{\pi a^2}} - \frac{3}{2}\frac{Dt}{a^2} = 4\sqrt{\frac{(8.94\times10^{-17})(63072000)}{\pi(8\times10^{-4})^2}} - \frac{3}{2}\left(\frac{(8.94\times10^{-17})(63072000)}{(8\times10^{-4})^2}\right)$

$f = 0.199$

$N_{released} = fN_{gas} = (0.199)(3.806\times10^{20}) = \boxed{7.57\times10^{19}\ \text{atoms/cm}^3\ \text{released}}$

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)

$D = D_1 + D_2 + D_3$, $D = 7.5988\times10^{-12} + 1.449\times10^{-14} + 4\times10^{-17}$

$D = 7.613\times10^{-12}$ cm²/s

-1, Math error, D = 1.46e-12

$t = \pi a^2\left(\frac{f^2}{36\cdot D}\right)$

$t = \pi(8\times10^{-4})^2\left(\frac{0.10}{36\cdot7.613\times10^{-12}}\right)$

$t = 733.59$ seconds

$\boxed{t = 12.23\ \text{min}}$

$N_{gas} - N_{released} = N_{pellet}$

$N_{pellet} = 3.031\times10^{20}$ atoms/cm³

$N_{released} = fN_{pellet}$

$N_{released} = (0.10)(3.031\times10^{20}$ atoms/cm³$)$

$\boxed{N_{released} = 3.031\times10^{19}\ \text{atoms/cm}^3\ \text{released}}$

Problem 3 (30 points)

-2, 28/30

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)

$$t^* = 6.62\times10^{-7}\, e^{\left[\frac{11949}{600}\right]} = 295 \text{ days} \qquad k_L = 7.48\times10^{6}\, e^{\left[\frac{-12500}{600}\right]}$$

$$\delta^* = 5.1 e^{\left[\frac{-550}{600}\right]} = 2.04 \text{ um} \qquad k_L = 0.0067$$

$$\delta = \delta^* + k_L(t - t^*)$$

$$\delta = 2.04\,\text{um} + (0.0067)(365 - 295)$$

$$\delta = 2.509 \text{ um}$$

$$\delta = \frac{W}{14.7}$$

$$W = \delta \cdot 14.7$$

$$\boxed{W = 36.88 \text{ mg/dm}^2}$$

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

$$\delta_{zirlo} = \delta_0 - \delta_{oxidation} \qquad 0.6\text{ mm} = 600 \text{ um}$$

$$\delta_{zirlo} = 600\,\text{um} - 2.509\,\text{um} = \boxed{597.5 \text{ um}}$$

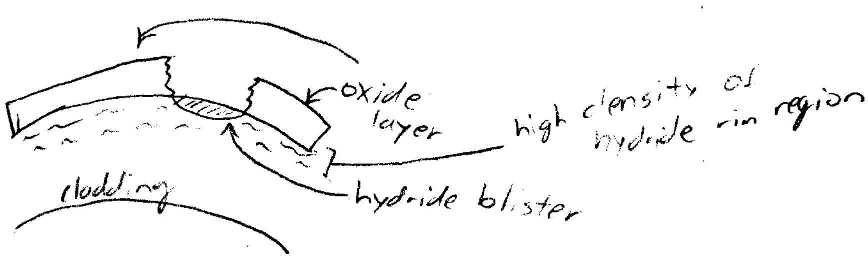
-2, metal lost = oxide thickness/1.56

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

$$C_H^{clad} = \frac{(2f)(\delta)(\rho_{oxide})(f^0_{ZrO_2})\left(\frac{M_H}{M_O}\right)}{\left(t - \frac{\delta}{PBR}\right)(\rho_{metal})} \times 10^6 = \left[\frac{(2\cdot0.15)(2.509\,\text{um})(5.68\,\text{g/cm}^3)(0.26)\left(\frac{1}{16}\right)}{\left(600 - \left(\frac{2.509\,\text{um}}{1.56}\right)\right)(6.5\,\text{g/cm}^3)}\right] \times 10^6$$

$$C_H^{clad} = \frac{0.06947421}{3889.546} \times 10^6 = \boxed{17.86 \text{ wt. ppm of hydrogen}}$$

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



-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)

In a RIA, because the change in fuel temperature is so quick the fuel shatters into small peices & the cladding balloons or bursts depending on ductility. In, a LOCA, the fuel cracks, into larger peices & the cladding may rupture due to large changes in temp. from loss of coolant & quenching.

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

In both accidents the fuel pellets crack into peices, and there is a risk of fuel dispersal if the cladding cracks or ruptures.

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)

One accident tolerant fuel concept is a silicon carbid composite cladding which does not creep under high temp. and does not become activated under irradiation

-1, Less oxidation so less H production