71/100

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

-5, 20/25

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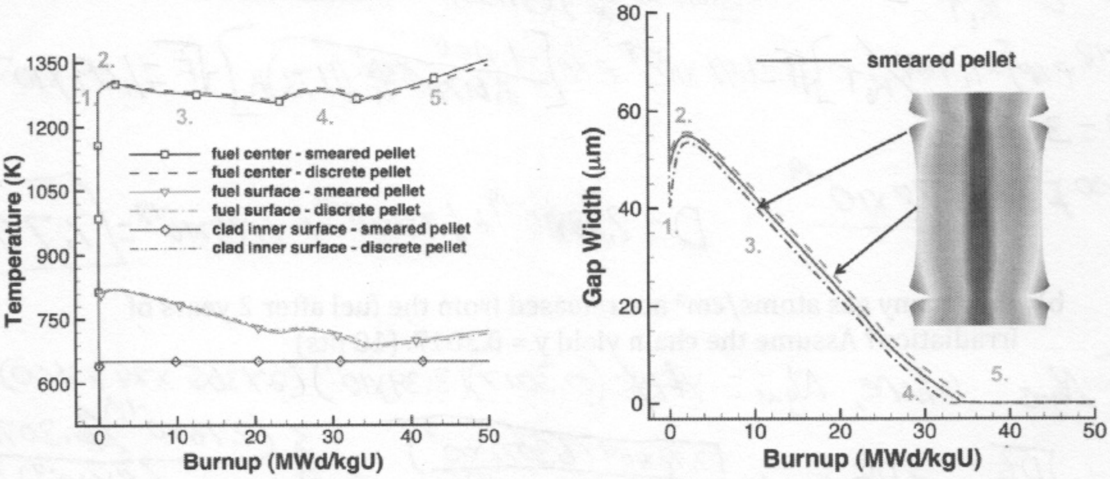
Question 1 (25 points):

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.

1. Cladding: initial thermal creep

-0.5, thermal expansion in the cladding

gap: thermal expansion causes gap to become less.
pellet: thermal expansion

2. Cladding: Irradiation creep begins.
gap: increases in size due to pellet shrinking
pellet: shrinks and becomes more dense.

-0.5, creep has nothing to do with hydride formation

3. Cladding: irradiation and thermal creep may begin to cause hydride formation
gap: decreases as fuel swells and cladding creeps.
pellet: swellings begins.

-3, No hydride cracking, T goes up due to fission gas release and then back down due to continued swelling

4. Cladding: creep continues, hydride cracking
gap: continues to decrease and eventually becomes 0
pellet: swelling towards cladding and completely closes gap.

5. cladding: makes contact with fuel, causing temp increase/failure
gap: non existent.
pellet: begins to push on cladding and fracture or crack

-1, PCMI does not cause the pellet to crack

-6, 24/30

Question 2 (30 points)

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)

$D = D_1 + D_2 + D_3$ where $k_b = 8.617\times10^{-5}\frac{eV}{K}$, $900\,^\circ C + 273 = 1173K$

$D_1 = 7.6\times10^{-6}\, e^{\frac{-3.03\, eV}{k_b T}} = 7.6\times10^{-6}\, e^{\frac{-3.03\, eV}{(8.617\times10^{-5}\frac{eV}{K})(1173K)}} = \boxed{7.28\times10^{-19}}$

$D_2 = 1.41\times10^{-18}\exp\left[-1.19\,eV/k_bT\right]\sqrt{\dot F} = 1.41\times10^{-18}\exp\left[\frac{-1.19\,eV}{8.617\times10^{-5}\frac{eV}{K}(1173)K}\right]\sqrt{\dot F} = 1.09\times10^{-23}\sqrt{\dot F} = 6.35\times10^{-18}$

$\dot F = \rho\sigma_F N\phi = 3.39\times10^{11}$

-0, Fdot = 2e13

$D_3 = 2.0\times10^{-30}\dot F = 6.78\times10^{-19}$

$D = 7.28\times10^{-19} + 6.35\times10^{-18} + 6.78\times10^{-19} = \boxed{7.76\times10^{-18}\frac{cm^2}{s}}$

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)

$N_{release} = f N_{gas}$ where, $N_{gas} = y\dot F t = (0.3017)(3.39\times10^{11})(2\times365\times24\times3600) = 6.451\times10^{18}\frac{1}{cm^3}$

$f = 4\sqrt{\frac{Dt}{\pi a^2}} - \frac{3}{2}\frac{Dt}{a^2} = 4\sqrt{\frac{7.76\times10^{-18}(6.3072\times10^{7})}{\pi(8\times10^{-4})^2}} - \frac{3}{2}\frac{(7.76\times10^{-18})(6.3072\times10^{7})}{(8\times10^{-4})^2}$

-0, Fdot = 2e13

$f = 0.0624 - 0.001147 = 0.061253$ -1, Check tau to determine which equation?

$N_{release} = (0.061253)(6.451\times10^{18}) = \boxed{3.95\times10^{17}\frac{1}{cm^3}}$

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)

$D_1 = 7.6\times10^{-6}\exp\left(-3.03/k_b(2273)\right) = 1.45\times10^{-12}$

$D_2 = 1.41\times10^{-18}\exp\left(\frac{-1.19}{(k_b\, 2273)}\right)\sqrt{\dot F} = 8.21\times10^{-13}$

-1, Math error

$D_3 = 2\times10^{-30}\dot F = 6.79\times10^{-19}$

$D = 2.27\times10^{-12}\frac{cm^2}{s}$

$f = 6\sqrt{\frac{Dt}{\pi a^2}} - \cancel{\frac{3Dt}{a^2}}^{0,\,t<<} \Rightarrow t = \left(\frac{f}{6}\right)^2\frac{\pi a^2}{D} = \left(\frac{0.1}{6}\right)^2\left(\frac{\pi(8\times10^{-4})^2}{2.27\times10^{-12}}\right)$

$\boxed{t = 246.04\ s}$

$N_{release} = fy\dot F t = (0.1)(0.3017)(3.39\times10^{11})(246.04) = \boxed{2.52\times10^{12}\frac{1}{cm^3}}$

-4, No more gas is produced in post irradiation annealing. Should be fraction of gas remaining from previous irradiation

Problem 3 (30 points)

-9, 21/30

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/dm^2 after this time? (10 pts)

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

$$K_L = 7.48\times10^6 \exp\left[\frac{-12500}{T}\right] = 7.48\times10^6 \exp\left[\frac{-12500}{600}\right] = 0.0067$$

$$\delta^* = 5.1 \exp\left[\frac{-550}{T}\right] = 5.1 \exp\left[\frac{-550}{600}\right] = 2.039\ \mu m$$

$$t^* = 6.62\times10^{-7} \exp\left[\frac{11949}{T}\right] = 6.62\times10^{-7} \exp\left[\frac{11949}{600}\right] = 295.01\ \text{days}$$

$$\delta = (2.039) + (0.0067)(365 - 295) = 2.508\ \mu m$$

$$\delta = \frac{W}{14.7} \Rightarrow W = \delta(14.7) = 2.508(14.7) = 36.87\ \frac{mg}{dm^2}$$

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

$$t_g = t_g^0 + \delta = \underbrace{0.6\,mm}_{600\,\mu m} + 2.508\,\mu m = \boxed{602.508\ \mu m}$$

-2, ZIRLO lost is oxide thickness / 1.56

-2, ZIRLO loses thickness, not gains

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

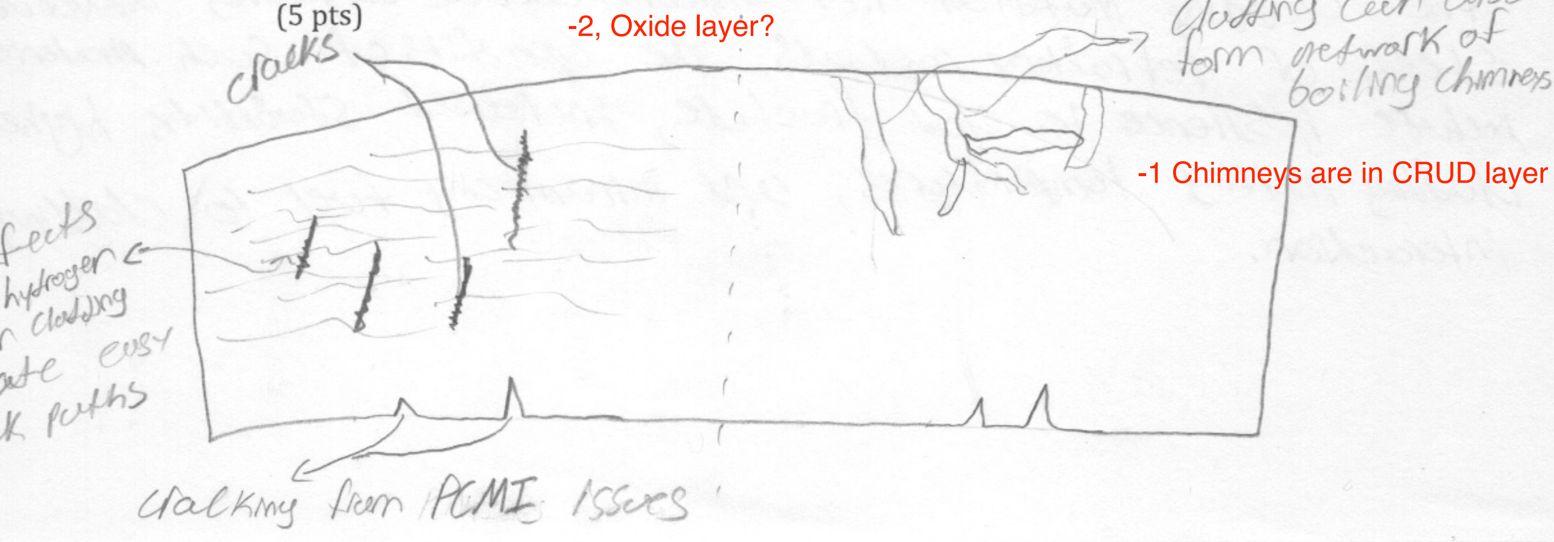
$$C_H^{clad} = \frac{2f\,\delta\,\rho_{oxide}\,f^0_{ZrO_2}\left(\frac{M_H}{M_O}\right)}{\left(t - \frac{\delta}{PBR}\right)\times \rho_{metal}}\times10^6 = \frac{2(0.15)(2.508)(5.68)(0.26)\left(\frac{1}{16}\right)}{\left(365 - \frac{2.508}{1.56}\right)(6.5)}\times10^6$$

$$C_H^{clad} = \boxed{29.4\ \text{wt. ppm}}$$

-2, t is the thickness, not the time

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

-2, Oxide layer?



-1 Chimneys are in CRUD layer

Problem 4 (15 points)

-6, 9/15

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)

The primary difference in the cladding is that in LOCA you have alpha to beta transition as clad temp increases. Also for a LOCA relocation occurs in the fuel whereas in RIA fuel dispersal occures.

-2, RIA is much faster
-2, RIA increases Q while LOCA increases coolant T

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

Some of the similarities include the cladding swelling and bursting, the fuel breaking into pieces, fission gas release. Both cause thermal stresses on fuel and cladding.

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)

Some potential accident tolerant fuel concepts are to change the cladding material i.e., silicon carbide composite, advanced steel, or refractory metals. The benefits of such materials include resilience to clad fracture, increased stability, higher cladding melting temperatures, and minimizing fuel to cladding interaction.

-2, Primary cladding benefit is reduced oxidation kinetics