79.5/100

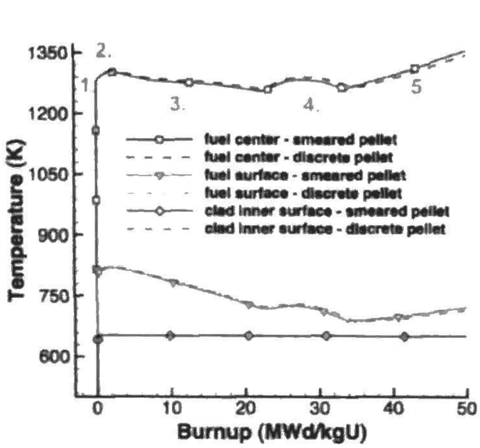
NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

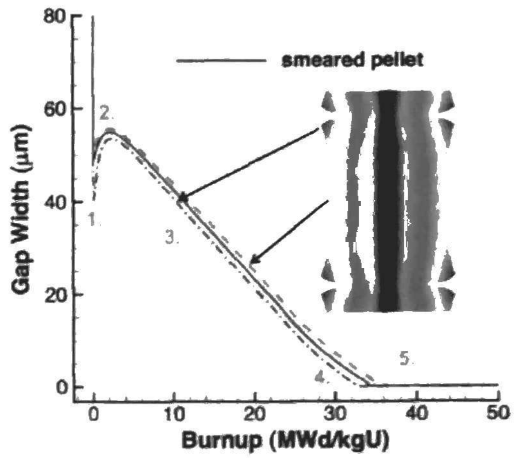
Name: Lyle Grove

-6, 19/25

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.

-4, Describe how these changes impact on T

1. Fuel: initial thermal expansion
   Gap: decreased due to thermal expansion, creep
   Cladding: thermal creep
2. Fuel: densification due to elimination of initial porosity
   Gap: increasing in size as fuel shrinks
   Cladding: thermal & irradiation creep
3. Fuel: Swelling due to fission products
   Gap: decreasing as fuel swells, cladding creeps
   Clad: hydride formation, creep
4. Fuel: Creep due to temperature/irradiation, fission gas release, decreased k
   Gap: decreasing as fuel
   Clad: same as 3
5. Fuel: creep continues, swelling continues, more gas release
   Gap: vanishes, fuel in contact w/ cladding
   Clad: contacts fuel, fracture possible

-2, T increaes because fuel k decreases with burnup

Question 2 (30 points) -4, 26/30

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)

$\dot{F} = g\sigma_F N \phi = 0.03(1.028e^{21})(5.50e^{-22})(2.0e^{13})$
$= 3.3924e^{11}$

-0, Fdot = 2.0e13

$D_1 = 7.6e^{-6} \exp\left[\frac{-3.03}{k_b T}\right] = 7.6e^{-6} \exp\left[\frac{-3.03}{8.617e^{-5}(1173)}\right]$
$= 7.28e^{-19} \ cm^2/s$

$D_2 = 1.41e^{-18} \exp\left[\frac{-1.19}{k_b T}\right]\sqrt{\dot{F}} = 1.41e^{-18} \exp\left[\frac{-1.19}{k_b(1173)}\right]\sqrt{5.39e^{11}} = 5.12e^{-18}$

$D_3 = 2.0e^{-30}\dot{F} = 6.785e^{-19}$

$D = D_1 + D_2 + D_3 = 6.5265e^{-18} \ cm^2/s$

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)

$N_{gas} = y\dot{F}t = 0.3017(3.3924e^{11})(1.752e^{4}(3600)) = 6.455e^{18} \frac{1}{cm^3}$

-0, Fdot = 2e13

$N_{release} = f N_{gas}$

-1, Check tau to see which eqn to use

$f = 4\sqrt{\frac{Dt}{\pi a^2}} - \frac{3}{2}\frac{Dt}{a^2} = 4\sqrt{\frac{6.5265e^{-18}(6.307e^{7})}{\pi(8e^{-4})^2}} - \frac{3}{2}\left[\frac{6.52e^{-18}(6.3e^{7})}{(8e^{-4})^2}\right]$

$f = 0.056268$

$N_r = (0.056268)(6.455e^{18}) = 3.632e^{17} \frac{1}{cm^3}$

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)

$D_1 = 7.6e^{-6} \exp\left[\frac{-3.03}{k_b(2273)}\right] = 1.453e^{-12} \ \frac{cm^2}{s}$

$D_2 = 1.41e^{-18} \exp\left[\frac{-1.19}{k_b(2273)}\right]\sqrt{3.3924e^{11}} = 8.213e^{-13}$

$D_3 = 2e^{-30}\dot{F} = 6.785e^{-19}$

-1, No fissioning so D = D1

$D = 2.2743e^{-12} \ cm^2/s$

-2, In post irradiation annealing, no new gas is produced

$\cancel{\frac{Dt}{a^2}} \to 0$, assume t ≪

$f = 6\sqrt{\frac{Dt}{\pi a^2}} - \cancel{3\frac{Dt}{a^2}}$

$t = \left(\frac{f}{6}\right)^2\left(\frac{\pi a^2}{D}\right) = \left(\frac{0.1}{6}\right)^2\left(\frac{\pi(8e^{-4})^2}{2.27e^{-12}}\right) = 2.46e^{2} \ s$

$N_r = f y \dot{F} t = 0.3017(3.3924e^{11})(2.46e^{2})(0.1) = 2.518e^{12} \frac{1}{cm^3}$

Problem 3 (30 points) -8, 22/30

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)

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

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

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

$$t^* = 6.62\times10^{-7} \exp\frac{11949}{T} = 6.62\times10^{-7} \exp\frac{11949}{600} = 295 \ d$$

$$k_L = 7.48\times10^{6} \exp\frac{-12500}{T} = 7.48\times10^{6} \exp\frac{-12500}{600} = 6.7\times10^{-3} \ \frac{\mu m}{d}$$

✓ $$\delta = 2.039 \ \mu m + 6.7\times10^{-3}\frac{\mu m}{d}(365\ d - 295\ d) = 2.508 \ \mu m$$

$$w = \delta(14.7) = 2.508 \ \mu m (14.7) = 36.87 \ \frac{mg}{dm^2}$$

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

$$t_g = t_g^0 + \delta = 0.6 \ mm + 2.508 \ \mu m = 0.60251 \ mm$$

-2, metal lost = oxide thickness/1.56

-2, thickness is lost not gained

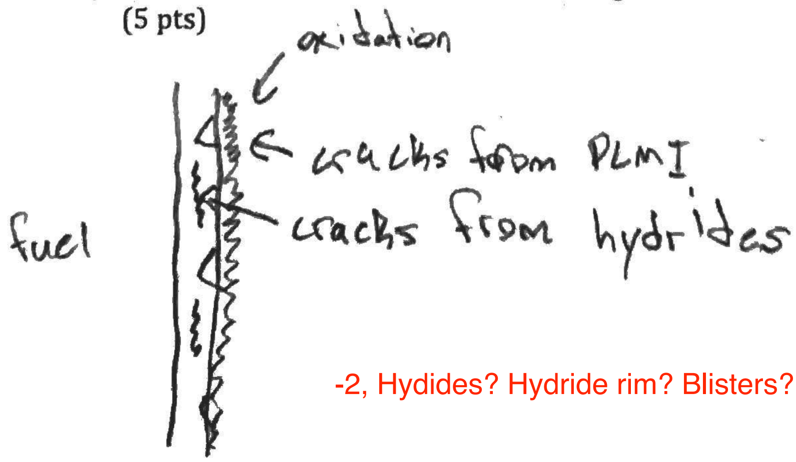
c) Assuming the hydrogen pickup fraction is 15%, what is the weight PPM of hydrogen in the cladding after one year? (10 pts)

$$C_H^{clad} = \frac{2f\,\delta\,\rho_{ox}\,f^0_{ZrO_2}\left(\frac{M_H}{M_O}\right)}{\left[t - \frac{\delta}{PBR}\right]\rho_{met}} \times 10^6 = \frac{2(0.15)(2.508)(5.68)(0.26)(\frac{1}{16})10^6}{\left[365 - \left(\frac{2.508}{1.56}\right)\right]6.5}$$

$$C_H^{clad} = 297 \ wt.ppm$$

-2, t is thickness not time

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



-2, Hydides? Hydride rim? Blisters?

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 causes the cladding to alpha → beta transition, and oxidation breaks away causing rapid hydrogen pick up; while in a RIA the cladding can only balloon or bust. In regards to fuel, RIA can cause fuel melting or crumbling.

-3, RIA is much faster, increases heat generation. LOCA changes surface temperature of the fuel

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

Both cause significant thermal stresses & can result in cladding burst/ballooning

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 potental concept is improving fuel properties, this will lower operating temperatures and raise melting temps ∴ when in a LOCA the change in temp needed for melting is significantly increased.

-2.5, What will you do to the fuel to change its properties