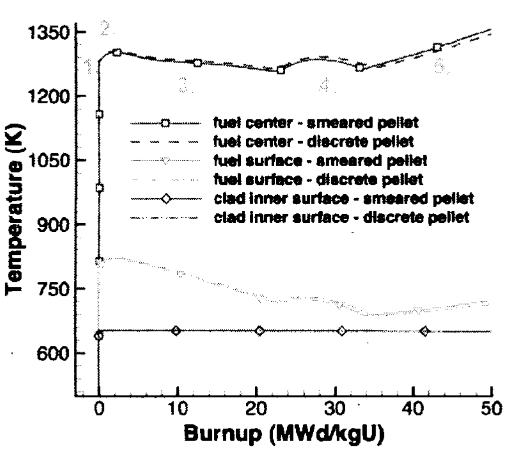
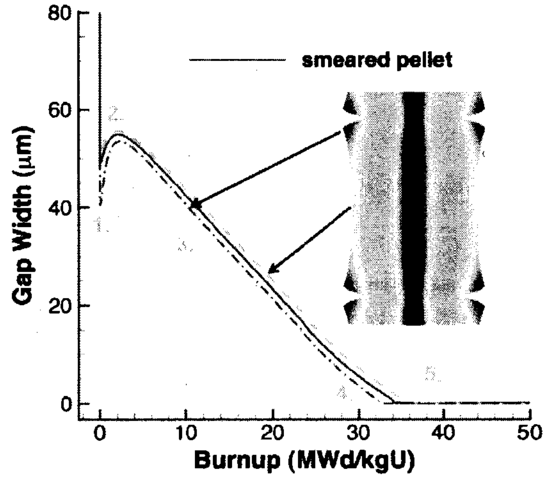
Your exam is very similar to four other students and I suspect cheating, 0/100

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

Name: -5, 20/25

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. The gap width decreases due to thermal expansion during startup. Fuel temperature rises drastically. Cladding not yet changing. Plots show rise in temperature and decrease in gap width.
2. Gap increases due to densification. Fuel pellets fracture. Cladding not yet affected. Shown by gap width growth.
   -1, Pellet fracture occurs due to thermal expansion (number 1)
3. Gap decreases as fuel begins to expand. Fission gas in pellets move to grain boundary and voids. Cladding still not affects. Plots show gap continuing to shrink.
4. Swelling due to fission products. Gap continues to shrink as fuel expands. Fuel and cladding creep.
   -2, T increaess due to fission gas release before gap closure
5. Fuel is at end of life. Expansion of pellets has reached the cladding. No gap. Cladding has corrosion and may fracture.

-2, Fuel k decreaes with burnup so T increases

-2, 28/30

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)

$K_b = 8.6173 \times 10^{-5}$ eV/K

$D = D_1 + D_2 + D_3$

$D_1 = (7.6\times10^{-6}) \exp\left[\frac{-3.03}{K_bT}\right] = 7.6\times10^{-6} \exp\left[\frac{-3.03}{8.6173\times10^{-5}(1173.15)}\right]$

$D_1 = 7.3127\times10^{-19}$ cm²/s

$D_2 = (1.41\times10^{-18})\sqrt{\dot{F}} \exp\left[\frac{-1.19}{K_bT}\right] = (1.41\times10^{-18})\sqrt{2\times10^{13}} \exp\left[\frac{-1.19}{k_bT}\right]$

$D_2 = 4.8702\times10^{-17}$ cm²/s

$D_3 = 2.0\times10^{-30} \cdot \dot{F} = (2.0\times10^{-30})(2\times10^{13}) = 4\times10^{-17}$ cm²/s

$D = D_1 + D_2 + D_3 = 7.3127\times10^{-19} + 4.8702\times10^{-17} + 4\times10^{-17}$

$\boxed{D = 8.943\times10^{-17}\ \text{cm}^2/\text{s}}$

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)

$2\text{yr}\left(\frac{365\text{d}}{\text{yr}}\right)\left(\frac{24\text{hr}}{\text{d}}\right)\left(\frac{3600\text{s}}{\text{hr}}\right) = 63072000$ s

$N_{FG} = y\dot{F}t = (0.3017)(2\times10^{13})(63072000)$

$N_{FG} = 3.8058\times10^{20}$ /cm³

-2, Wrong f equation, should check tau

$f = 1 - \frac{6}{\pi^2}\exp\left[\frac{\pi^2 Dt}{a^2}\right] = 1 - \frac{6}{\pi^2}\exp\left[\pi^2 \frac{(8.943\times10^{-17})(63072000)}{(2.0008\text{cm})^2}\right]$

$f = 0.4427$

$\boxed{\#\text{gas atoms/cm}^3 = f \cdot N_{FG} = (0.4427)(3.8058\times10^{20}) = 1.685\times10^{20}\ \text{atoms/cm}^3}$

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)

$D_1 = 7.6\times10^{-6}\exp\left[\frac{-3.03}{K_bT}\right] = 7.6\times10^{-6}\exp\left[\frac{-3.03}{8.6173\times10^{-5}(2273.15)}\right] = 1.4555\times10^{-12}\ \frac{\text{cm}^2}{\text{s}}$

$D_2 = (1.41\times10^{-18})\sqrt{\dot{F}}\exp\left[\frac{-1.19}{K_bT}\right] = 1.41\times10^{-18}\sqrt{2\times10^{13}}\exp\left[\frac{-1.19}{(8.6173\times10^{-5})(2273.15)}\right]$

$= 1.4501\times10^{-14}$ cm²/s

$D_3 = 2.0\times10^{-30}\dot{F} = 2.0\times10^{-30}(2\times10^{13}) = 4\times10^{-17}$ cm²/s

$D = D_1 + D_2 + D_3 = 1.47004\times10^{-12}$ cm²/s

$f = 6\sqrt{\frac{Dt}{\pi a^2}} \Rightarrow t = \left(\frac{f}{6}\right)^2\left(\frac{\pi a^2}{D}\right) = \left(\frac{0.1}{6}\right)^2\left(\frac{\pi(0.0008)^2}{1.47004\times10^{-12}}\right)$

$\boxed{t = 379.935}$

$N_{FG} = 3.8058\times10^{20} - 1.685\times10^{20} = 2.1208\times10^{20}$ /cm³

$\#\text{gas atoms/cm}^3 = (0.1)(2.1208\times10^{20})$

$\boxed{\#\text{gas atoms/cm}^3 = 2.1208\times10^{19}\ \text{atoms/cm}^3}$

-6, 24/30

Problem 3 (30 points)

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)

$t^* = 6.62 \times 10^{-7} \exp\left[\frac{11949}{T}\right] = 6.62 \times 10^{-7} \exp\left[\frac{11949}{600}\right] = 295.007$ days

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

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

$k_L = 7.48 \times 10^6 \exp[-12500/T] = 7.48 \times 10^6 \exp[-12500/600] = 0.0067$

$\delta = 2.039\ \mu m + 0.0067(365 - 295.007) = 2.508\ \mu m$

$\delta = \frac{w(mg/dm^2)}{14.7} \Rightarrow w(mg/dm^2) = \delta \cdot 14.7 = 2.5082\ \mu m (14.7)$

$\boxed{w = 36.867\ mg/dm^2}$

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

$t_{hf} = t_{hi} + \delta = 0.6 + 2.5082 \times 10^{-3} = 0.6025082$ mm

$\boxed{t_{hf} = 602.5082\ \mu m}$

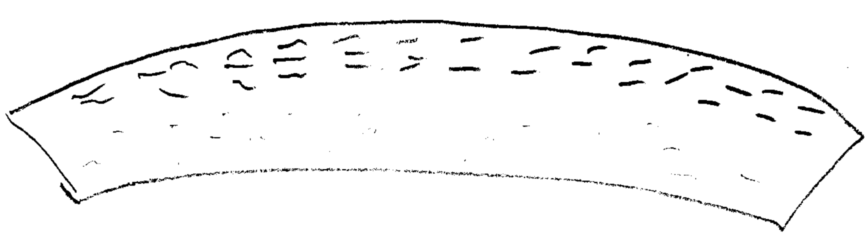
-2, metal lost = oxide thickness/1.56
-2, thickness lost not gained

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

Part c on next page.

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

Coolant



Fuel

Hydrides move to the cooler areas of the cladding and areas with more stress.

-2, Oxide layer?

c) $N_o = \frac{w N_A}{M_o} = \frac{36.8707 \times 10^{-3} (6.022 \times 10^{23})}{16}$

$N_o = 1.3877 \times 10^{21} \frac{\text{oxygen atoms}}{dm^2}$

$N_H = 2 N_o = 2.7754 \times 10^{24} \frac{\text{hydrogen atoms}}{dm^2}$

$N_{HZr} = 2 f N_o = 2(0.15)(1.3877 \times 10^{21}) = 4.1632 \times 10^{20} \frac{\text{hydrogen atoms}}{dm^2}$

$w_H = \frac{N_{HZr} M_H}{N_A} = \frac{(4.16 \times 10^{20})(1)}{6.022 \times 10^{23}}$

$w_H = 6.91 \times 10^{-4} g$

$C_H = \frac{W_H}{W_{Zr}} = \frac{w_H}{\rho_{Zr} V_{Zr}} = \frac{w_H}{\rho_{Zr}(t_{Zr} A_{Zr})} = \frac{w_H}{\rho_{Zr}\left(t - \frac{\delta_{ZrO_2}}{PBR}\right) A} = \frac{6.91 \times 10^{-4}}{6.5\left(600 - \frac{2.5057}{1.56}\right)(10.1 \cdot 10^{-4})}$

$C_H = 1.7726 \times 10^{-5}$

$\boxed{C_H = 17.726 \text{ wt. ppm}}$

Problem 4 (15 points)

-0, 15/15

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)

Fuel temperature rises much faster during a RIA than LOCA. Changes due to rapid positive reactivity insertion in RIA, while changes are due to decay heat in LOCA.

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

Fuel temperature increases. This may lead to fuel breaking apart or melting. Cladding put under stress and may break due to oxidation and hydrides and pellet-cladding interactions

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 concept is to change the thermal conductivity of the fuel. Additives such as SiC or BeO can increase thermal conductivity. This will lower fuel temperature and will allow fuel to remain safe for longer periods of time after an accident.