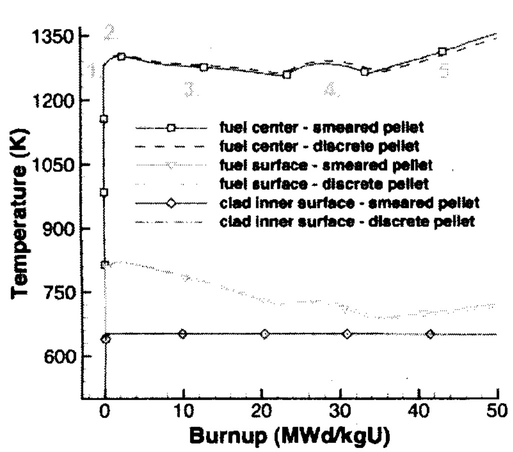
Your exam is very similar to four other students and I suspect cheating, 0/100

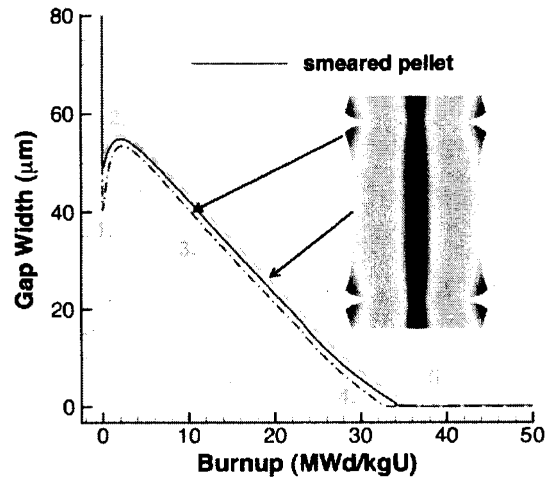
*NucE 497 Fuel Performance Exam 2 covering modules 4 – 6*

*Name:* Eric Burkhardt

-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. Thermal expansion occurs during startup, which causes the gap width to decrease. Fuel temperature rises drastically. Cladding doesn't change here. The plots show a rise in temp and decrease in gap width.

2. The gap width increases here due to densification. The cladding still is not affected as seen by the width still above 0. The fuel pellets fracture.
-1, pellets fracture due to thermal expansion (number 1)

3. The gap decreases due to the expanding fuel. The fission gas in the pellets move to grain boundary and voids. The cladding still isn't affected. The plot shows that the gap width continues to shrink.

4. At this stage, there is swelling due to fission products. The gap continues to shrink while the fuel expands. The fuel and cladding begin to creep.
-2, T increaess due to fission gas release before gap closure

5. The fuel has reached the end of its life. Expansion of the pellets has reached the cladding, so there is no gap. The cladding has corrosion and may fracture.
-2, Fuel k decreases with burnup so T increaes

-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)

$D = D_1 + D_2 + D_3$

$D_1 = (7.6\times10^{-6})\exp\left[\frac{-3.03}{k_BT}\right] = 7.6\times10^{-6}\exp\left[\frac{-3.03}{8.6173\times10^{-5}(1173.15)}\right] = 7.31\times10^{-19}\ cm^2/s$

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

$D_2 = 4.8702\times10^{-17}\ cm^2/s$

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

$D = D_1 + D_2 + D_3 = 7.3127\times10^{-19} + 4.87\times10^{-17} + 4\times10^{-17} = \boxed{8.943\times10^{-17}\ cm^2/s}$

$k_B = 8.6173\times10^{-5}\ eV/K$

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)

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

-2, Wrong f equation, should check tau

$N_{FG} = y\dot F t = (0.3017)(2\times10^{13})(63072000) = 3.8058\times10^{20}/cm^3$

$f = 1 - \frac{6}{\pi}\exp\left[\frac{\pi^2 Dt}{a^2}\right] = 1 - \frac{6}{\pi^2}\exp\left[\pi^2\frac{(8.943\times10^{-12})(63072000)}{(0.0008\,cm)^2}\right]$

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

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)

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

$D_2 = (1.41\times10^{-15})\sqrt{\dot F}\exp\left(\frac{-1.19}{k_BT}\right) = 1.41\times10^{-18}\sqrt{2\times10^{13}}\exp\left[\frac{-1.19}{(8.6173\times10^{-5})(2273.15)}\right]$

$= 1.4501\times10^{-14}\ cm^2/s$

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

$D = D_1 + D_2 + D_3 = 1.47004\times10^{-12}\ cm^2/s$

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

time for 10% of the gas to be released was solved for using MatLab

$f = 0.1,\ a = 0.0008$

$\boxed{t = 401.1\,s}$

$N_{FG} = 3.8058\times10^{20} - 1.685\times10^{20} = 2.1208\times10^{20}\ /cm^3$

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

$= 2.1208\times10^{19}\ atoms/cm^3$

-4, 26/30

**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)

See attached sheet

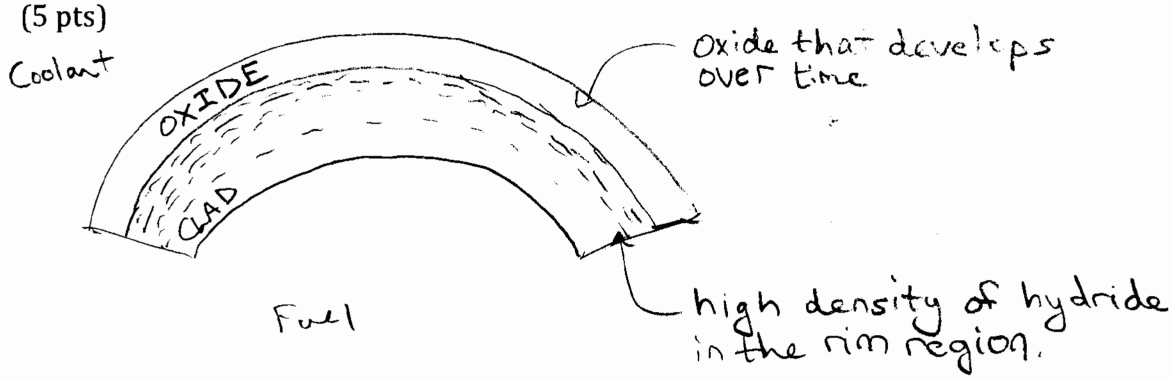
b) What is the ZIRLO wall thickness after this time? (5 pts)

See attached sheet

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

See attached sheet

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



Problem 3

$T = 600K$ for 1 year

-4, 26/30

a) $t^* = 6.62\times10^{-7}\exp\left[\frac{11949}{T}\right] = 295.0072$ days

$\delta^* = 5.1\exp\left[\frac{-550}{600}\right] = 2.0392\ \mu m$

$\delta[\mu m] = \delta^* + K_L(t - t^*)$

$K_L = 7.48\times10^6 \cdot \exp(-12500/T) = 0.0067$

$t = 365$ days

$\delta[\mu m] = 2.5082\ \mu m$

$\delta[\mu m] = \frac{w[mg/dm^2]}{14.7} \rightarrow w = \delta \cdot 14.7 = \boxed{36.8707\left[\frac{mg}{dm^2}\right]}$

b) $th_i = 0.6$ mm $\rightarrow$ initial thickness

$th_f = th_i + \delta = 0.6 + 2.5082\times10^{-3} = \boxed{0.6025082\ mm}$

↳ Final thickness after 1 year

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

c) $w = 36.8707\left[mg/dm^2\right]$, $\delta_{ZrO_2} = 2.5082\ \mu m$, $f = 0.15$

$N_O = \frac{w N_{av}}{M_O} = \frac{36.8707\times10^{-3} \cdot 0.6022\times10^{24}}{16} \Rightarrow N_O = 1.3877\times10^{21}\ \frac{\text{oxygen atom}}{dm^2}$

$N_H = 2N_O = 2\cdot1.3877\times10^{21} = 2.7754\times10^{21}\ \frac{\text{Hydrogen atoms}}{dm^2}$

$N_{H-Zr} = 2f\cdot N_O = 2\cdot0.15\cdot1.3877\times10^{21} = 4.1632\times10^{20}\ \frac{\text{hydrogen atom}}{dm^2}$

$w_H = \frac{N_{H-Zr} M_H}{N_{av}}$

$M_H = 1$ g/mol

$w_H = \frac{4.16\times10^{20}}{0.6022\times10^{24}} = 6.91\times10^{-4}$ g of H in cladding

$c_H = \frac{w_H}{w_{Zr}} = \frac{w_H}{\rho_{Zr}V_{Zr}} = \frac{w_H}{\rho_{Zr}(t_Z A)} = \frac{w_H}{\rho_{Zr}\left(t - \frac{\delta_{ZrO_2}}{PBR}\right)A} = \frac{6.91\times10^{-4}}{6.5\left(600 - \frac{2.5082}{1.56}\right)\cdot(10\cdot10\cdot10^{-4})}$

$C_H = 1.7726\times10^{-5} = \boxed{17.726\ wt\ ppm}$

**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)

One primary difference between a LOCA and RIA is that fuel temperature rises much faster in a RIA than a LOCA. Another is that the changes in the reactor in RIA are due to a rapid transient with large reactivity change, while in LOCA changes are from decay heat. A LOCA also trips the emergency shutdown system and SCRAMS the reactor.

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

Similarities in RIA and LOCA include:

1) Fuel temperature increases
2) Fuel breaking apart or melting
3) Cladding put under stress which could break from 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 accident tolerant fuel concept is to use different types of fuels. There is microencapsulated fuel, which has a high thermal conductivity, is resistant to melting, and has excellent fission product retention. The primary goal of the accident tolerant fuel program is to enhance tolerance to loss of active core cooling. This can help meet that goal through its melting resistance and fission product retention.