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

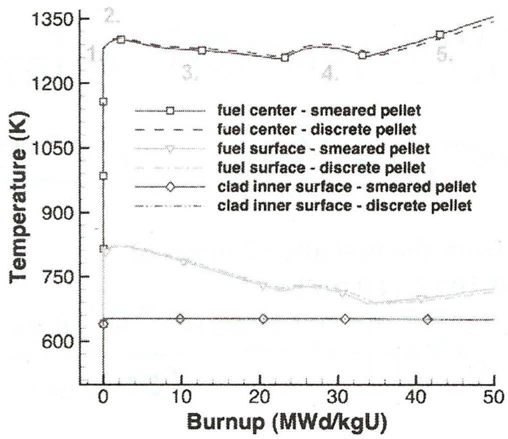
NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

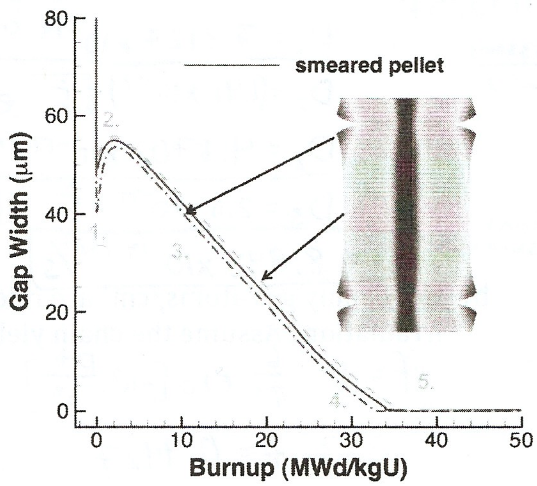
Name: Jacob Jayne

-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. During startup, the fuel temperature rises drastically, causing the pellet to thermally expand, thus reducing gap size drastically. Cladding is not changing. Plots show temp. increase & decrease in gap width

2. Due to densification, the gap width increases for a short period of time. Fuel pellets begin to fracture and the cladding is still not affected, shown by gap width growth. -1, T increases

3. The fuel expands again due to swelling, so gap decreases. The fission gases created within the pellet move to voids & grain boundaries. Plots show gap shrinkage. The cladding is still not affected.

4. Fission products continue to force the pellet to swell, further decreasing the gap size. Fuel & Cladding creep come into effect.

-2, T increases due to fission gas release before gap closure

5. End of life of fuel as the expansion of the pellets has completely closed the gap. Cladding corrosion has occured and so have fractures in the cladding. -2, T increases due to decrease in fuel k with burnup

Jacob Jayne

Question 2 (30 points)

-2, 28/30

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)

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

$T = 900°C = 1173.15K$

$\dot{F} = 2\times10^{13}\ \frac{fissions}{cm^3\cdot s}$

$$D = D_1 + D_2 + D_3 = 7.3127\times10^{-19}\ \frac{cm^2}{s} + 4.8702\times10^{-17}\ \frac{cm^2}{s} + 4\times10^{-17}\ cm^2/s$$

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

$$D_1 = 7.3127\times10^{-19}\ cm^2/s$$

$$D_2 = (1.41\times10^{-18})\sqrt{\dot{F}}\ \exp\left[-\frac{1.19}{k_bT}\right] = (1.41\times10^{-18})\sqrt{2\times10^{13}}\cdot\exp\left[\frac{-1.19}{(8.6173\times10^{-5}\frac{eV}{K})(1173.15K)}\right]$$

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

$$D_3 = 2.0\times10^{-30}\cdot\dot{F} = (2.0\times10^{-30})(2\times10^{13}\ \frac{fissions}{cm^3\ sec}) = 4\times10^{-17}\ cm^2/s$$

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

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)

$a = 0.0008\ cm$

$t = 63072000\ s$

$y = 0.3017$

$\dot{F} = 2\times10^{13}\ \frac{fissions}{cm^3\cdot s}$

$$f = 1 - \frac{6}{\pi^2}\exp\left[-\pi^2\frac{Dt}{a^2}\right] = 1 - \frac{6}{\pi^2}\exp\left[-\pi^2\frac{(8.943\times10^{-17}\frac{cm^2}{s})(63072000s)}{(0.0008\ cm)^2}\right]$$

$$f = 0.4427$$

-2, Wrong f equation, should check tau

$$N_{FG} = y\dot{F}t = (0.3017)(2\times10^{13}\ \frac{fissions}{cm^3\cdot s})(63072000s) = 3.8058\times10^{20}\ \frac{fission\ gas\ atoms}{cm^3}$$

↑ total produced

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

final answer → $\boxed{\#\text{gas atoms released after 2 years} = 1.685\times10^{20}\ \frac{gas\ atoms}{cm^3}}$

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)

$T = 2273.15K$

$f = 0.1$

$\dot{F} = 2\times10^{13}\ \frac{fissions}{cm^3\cdot s}$

$y = 0.3017$

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

$a = 0.0008\ cm$

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

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

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

$$D_2 = 1.4501\times10^{-14}\ cm^2/s$$

doesn't change from (a) → $D_3 = 4\times10^{-17}\ cm^2/s$

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

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

$\boxed{t = 379.93\ s}$

$$N_{FG} = 3.8058\times10^{20}\ \frac{atoms}{cm^3} - 1.685\times10^{20}\ \frac{atoms}{cm^3}$$

$$N_{FG} = 2.1208\times10^{20}\ \frac{atoms}{cm^3}$$

$\#\text{gas atoms released} = f\cdot N_{FG}$

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

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

Jacob Jayne

-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.

$T = 600K$

$t = 365 d$

a) What is the oxide weight gain in mg/dm² after this time? (10 pts)

$$t^* = (6.62\times10^{-7})\exp\left[\frac{11949}{T}\right] = (6.62\times10^{-7})\exp\left[\frac{11949}{600}\right] = 295.007 \text{ days}$$

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

$$\delta = \delta^* + K_L(t - t^*) = 2.0392\ \mu m + 0.0067\ \mu m(365d - 295.007d) = 2.5082\ \mu m$$

$$K_L = (7.48\times10^6)\exp\left[-12500/T\right] = (7.48\times10^6)\exp\left[-12500/600\right] = 0.0067\ \mu m/d$$

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

$$\boxed{W = 36.871\ mg/dm^2}$$

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

$$t_f = t_i + \delta = 0.6\ mm + 2.5082\times10^{-3}\ mm =$$

$$\boxed{t_f = 0.6025\ mm}$$

-2, metal lost = oxide thickness/1.56

-2, thickness lost not gained

$N_a = 6.022\times10^{23}$

$M_O = 16$

$M_H = 1$

$\rho_{Zr} = 6.5$

$PBR = 1.56$

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

$$N_O = \frac{wN_A}{M_O} = \frac{(36.871\times10^{-3}\ g/dm^2)(6.022\times10^{23})}{16} = 1.3877\times10^{21}\ \frac{\text{atoms O}}{dm^2}$$

$$N_{HZr} = 2fN_O = 2(0.15)(1.3877\times10^{21}\ \frac{\text{atoms O}}{dm^2}) = 4.1631\times10^{20}\ \frac{\text{atoms H}}{dm^2}$$

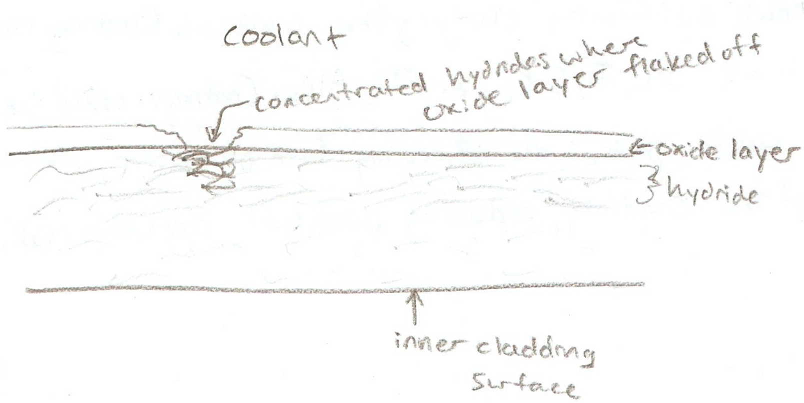
$$W_H = \frac{(N_{HZr})(M_H)}{N_A} = \frac{(4.1631\times10^{20})(1)}{6.022\times10^{23}} = 6.913\times10^{-4}\ g$$

$$C_H = \frac{W_H}{W_{Zr}} = \frac{W_H}{\rho_{Zr}V_{Zr}} = \frac{W_H}{\rho_{Zr}(t_{Zr}A_{Zr})} = \frac{W_H}{\rho_{Zr}(t - \frac{\delta_{ZrO_2}}{PBR})A_{Zr}} = \frac{6.913\times10^{-4}\ g}{(6.5)(600 - 2.5082/1.56)(10\cdot10\cdot10^{-4})} = 1.77733\times10^{-5}$$

$$\boxed{C_H = 17.7733\ \text{wt. ppm}}$$

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

Hydrides move toward the outer surface of the cladding because it is cooler temp. there, and also areas w/ more stress.



Hydrides are squigly lines.

Jacob Jayne

-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)

The primary difference between LOCA & RIA in regards to the fuel is that in RIA, the fuel expands to touch the cladding in milliseconds, where in LOCA, the fuel breaks apart into pieces and relocates. In regards to the cladding, in RIA, the cladding experiences PCMI (cracking) at low temperatures, while, in LOCA the cladding balloons outward. The fuel temperature also rises very quickly in RIA, where in LOCA, it rises fast, but not as fast, due to decay heat.

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

One similarity is that under certain conditions, the cladding in both can balloon and burst. Another is that they both have a greater impact on high burnup fuel. Fuel temperature increases in both. The increase in temperature of the fuel could lead to cracking & breaking apart of the pellets. There is also a rapid release of fission gas in both cases. In both, the cladding is put under stress, which could break due to oxidation embrittlement & 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)

A potential ATF concept is to add coatings outside of the zircaloy cladding. Coatings on the outer layer of the cladding would protect the zircaloy from steam, without significantly changing the material. Coating materials include things such as SiC, Ti, SiC$_2$, or Ti$_3$AlC$_2$. Coatings could be implemented rapidly. A coating would protect the zircaloy from oxidation, which would maintain the ductility of the cladding, reducing potential accident risk.

-1, Less oxidation means less H production