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NucE 497
exam #2

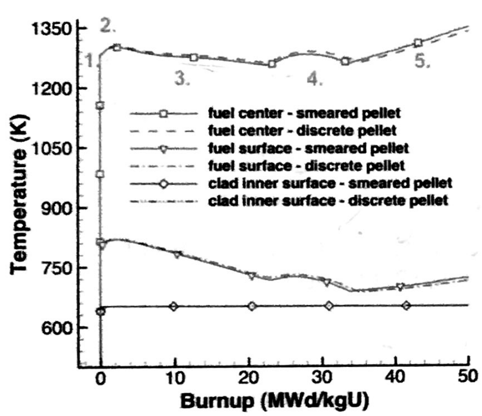
79/100

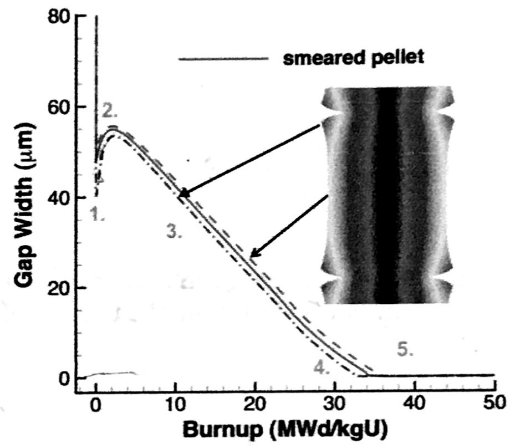
*NucE 497 Fuel Performance Exam 2 covering modules 4 – 6*

*Name:*

-4, 21/25

**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. Center line temp of fuel rapidly increases at start up and the gap closes due to thermal expansion

2. fuel begins to shrink due to densification causing the cladding gap to increase and fuel temp decreases

3. the fuel begins to swell from creation of vacancies and interstitials causing the Gap to close and temp decreases slightly

4. fuel is still swelling but the gap is getting very close to zero and tem increases

-2 Fission gas release raises temperature before gap closure

5. fuel and cladding are touching and more dislocations continue to form. In the cladding you experience oxidation and hydriding, the fuel also is releasing fission gases.

-2 fuel k goes down with burnup so T increases

**Question 2 (30 points)**

-14, 16/30

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)

$D = D_1 + D_2 + D_3$ $\quad \dot{F} = 2.0\times10^{13}$ $\quad k_b = 8.617\times10^{-5}$

$D_1 = 7.6\times10^{-6} e^{\frac{-3.03}{k_bT}}$ $\quad D_1 = 7.6\times10^{-6} e^{\frac{-3.03}{8.617\times10^{-5}\times1173}} = 7.27\times10^{-19}$ $\quad T = 1173\,°K$

$D_2 = 1.41\times10^{-18} e^{\frac{-1.19}{k_bT}}\sqrt{\dot{F}}$ $\quad D_2 = 4.86\times10^{-17}$

$D_3 = 2.0\times10^{-30}\dot{F}$ $\quad D_3 = 4\times10^{-17}$

$\boxed{D_1 + D_2 + D_3 = 8.93\times10^{-17}\ cm^2/s}$

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)

1 year = 3.154×10⁷ seconds

$N_{FG} = y\dot{F}t$ $\quad t = 2\times3.154\times10^{7}$

$N_{FG} = .3017\times2.0\times10^{13}\times2\times3.154\times10^{7}$

$\boxed{3.806\times10^{20}\ atoms/cm^3}$

-6, Gas released NOT gas prodiced

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)

$f = 10\%$ $\quad a = 8\times10^{-6}$

$D = 8.93\times10^{-17}$

$f = 4\sqrt{\frac{Dt}{\pi a^2}}$ $\quad t = \pi\times(8\times10^{-4})^2\times.1^2 / 16\times8.93\times10^{-17}$ $\quad t = 2\ years$

-4, D should be at T = 2273 K

$\boxed{t = 62542589\ sec = 723\ days}$

$N_{FG} = y\dot{F}t$

$\boxed{N_{FG} = .3017\times2\times10^{13}\times62542589 = 3.77\times10^{-19}\ atoms/cm^3}$

-4, Irradiation induced annealing, so no new gas is produced

**Problem 3 (30 points)**

-0, 30/30

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)

$t_o = .6mm \quad T = 600k \quad T = 1 year$

Critical time for transition $= 6.62 \times 10^{-7} \exp\left(\frac{11949}{T}\right) = 275 days$

$\delta^* = 5.1 e^{\frac{-550}{600}} = 2.039 \, um$

$k_L = 7.48 \times 10^6 e^{-12500/T} = .00067$

$\delta = \delta^* + k_L(t - t^*) = 2.039 + .00067(365 - 275) =$

$\boxed{\delta = 2.508 um \times 14.7 = 36.86 mg/dm^2}$

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

$thickness = t_0 - \frac{2.508}{1.56} = 600um - \frac{2.508}{1.56} um$

$\boxed{thickness = 598.39 um}$

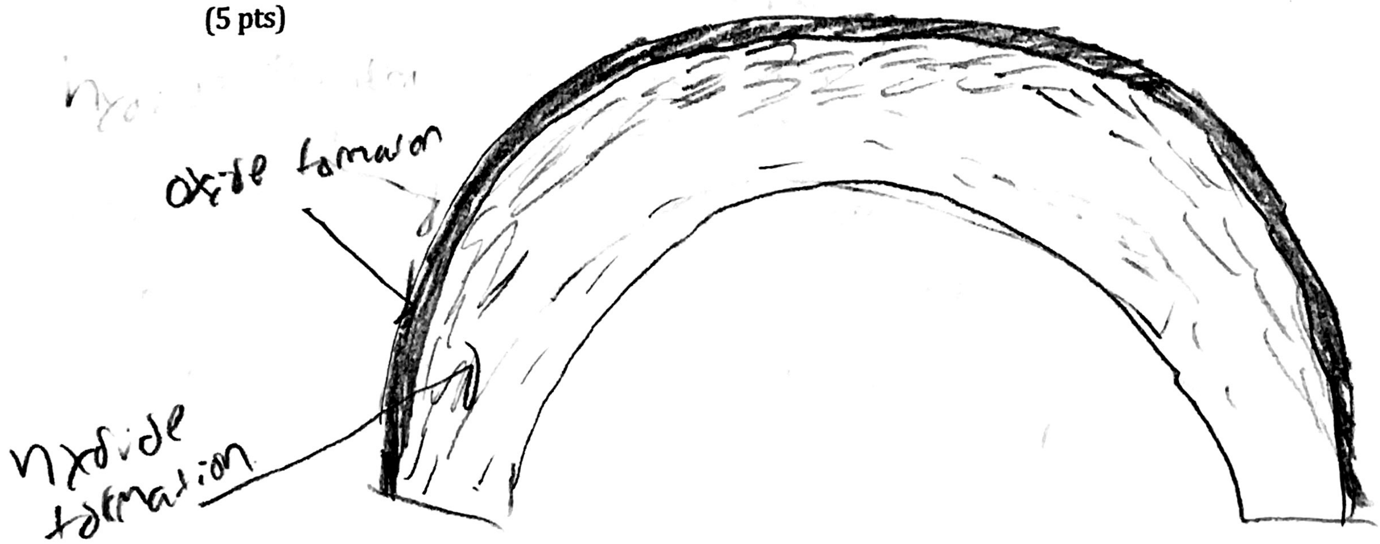
c) Assuming the hydrogen pickup fraction is 15%, what is the weight PPM of hydrogen in the cladding after one year? (10 pts)

$C_H = \frac{2 f n_o}{n_{zr}} = \frac{2 f \times \delta \times \rho_{oxide} \times f_{ZrO_2} \times M_H / M_O}{\left(t - \frac{\delta}{PBR}\right) \times \rho_{metal}} \times 10^6 =$

$C_H = 10^6 \times \frac{2(.15)(2.508)(5.68)(.26)\left(\frac{1}{16}\right)}{\left(600 - \frac{2.508}{1.56}\right) 6.5}$

$\boxed{C_H = 17.85 \, wt \, ppm}$

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



-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)

RIA is much more Rapid than a LOCA accident. In RIA the reactivity causes the fuel to rapidly swell and burst through the cladding while in LOCA the slow rise in fuel temp will cause the fuel to melt. Also LOCA causes rapid oxidation and hydrogen pickup while RIA does not.

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

In both the fuel temp and cladding pressure increase.

-1, Ballooning, both can result in fuel release or melting

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 potential accident tolerant fuel concept is to switch out Zirconium cladding for an advanced steel cladding. The steel is much stronger and ductile and also is more corrosion resistant. This properties make it a more safe option and can be implemented in current reactors.