70/100

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

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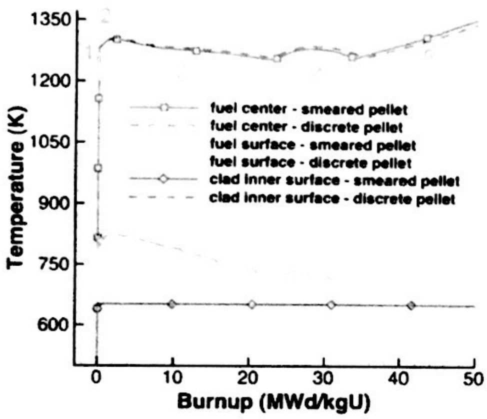
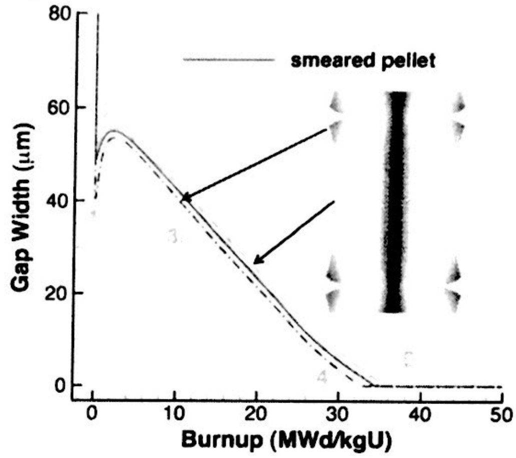
-9, 16/25

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. Start up of Reactor. Increase of temperature From Zero

-3 ,thermal expansion decreases gap

2. Fuel pellet Densification. Gaseous Swelling. gap size increased before Shrinking.

-1, Impact on T?

3. Fuel Pellet Solid Swelling. Fission gas release into gap. Cladding creep. Linear Decrease in gap size.

4. High burnup Swelling in Fuel pellet. transition to breakaway

-3, Break away what? Fission gas release causes T to increase before gap closure

5. Steady State operation of reactor. Linear increase in temp & No change in gap thickness

-2, T increases because fuel K decreases with burnup

-10, 20/30

Question 2 (30 points)

$a = 8\times10^{-4}$ (cm)
$\dot{F} = 2.0\times10^{13}$ (Fissions/(cm³·s))
$T = 900°C = 1173.15$ K

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)

$k_b = 8.6173303\times10^{-5}$ (eV/K)

$$D_1 = (7.6\times10^{-6})\exp\left(\frac{-3.03}{k_bT}\right) = (7.6\times10^{-6})e^{\left(\frac{-3.03}{(8.6173303\times10^{-5})(1173.15)}\right)}$$

$$\rightarrow D_1 = 7.31242478\times10^{-17}$$

$$D_2 = (1.41\times10^{-18})\exp\left(\frac{-1.19\text{ eV}}{k_bT}\right)(\dot{F})^{1/2} = (1.41\times10^{-18})\exp\left(\frac{-1.19}{(8.6173303\times10^{-5})(1173.15)}\right)(2.0\times10^{13})^{1/2} = 4.87043368\times10^{-17}$$

$$D_3 = (2.0\times10^{-30})\dot{F} = (2.0\times10^{-30})(2.0\times10^{13}) = 4.0\times10^{-17}$$

$$D = D_1 + D_2 + D_3 \longrightarrow \boxed{D = 8.9436\times10^{-17}}$$

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)

$Y = 0.3017$
$t = (3600)(24)(365)(2) = 63072000$ (sec)

$$N_{FG} = Y\dot{F}t = (0.3017)(2.0\times10^{13}[\text{Fissions}/(\text{cm}^3\cdot\text{s})])(63{,}072{,}000[\text{s}])\ 3.80576\times10^{20}$$

$$f = 6\sqrt{\frac{Dt}{\pi a^2}} - 3\frac{Dt}{a^2} = (6)\sqrt{\frac{(8.944e\text{-}17)(63072000)}{(\pi)(8\times10^{-4})^2}} - (3)\frac{(8.944e\text{-}17)(63{,}072{,}000)}{(8e\text{-}4)^2} = 0.29136 \text{ escaped}$$

-2, Wrong eqn

$$\rightarrow (N_{FG})(f) = (3.806\times10^{20}[\text{Fission gas atoms}/\text{cm}^3])(0.2737) = \boxed{1.08858\times10^{20}\ [\text{gas atoms}/\text{cm}^3]}$$

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)

$T = 2000°C = 2273.15$ K
$f = 10\%$

$$t = \frac{f^2a^2\pi}{36D} = \frac{(0.1)^2(8\times10^{-4})^2(\pi)}{(36)(8.9436\times10^{-17})} = 6244771.27 \text{ (seconds)}\left(\frac{1}{3600\times24}\right)$$

$$\boxed{t = 72.272 \text{ (Days)}}$$

-3, You need to recalculate D at new T

-5, How much gas was released?

-9, 21/30

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)

$\delta^* = 5.1 e^{(-550/T)} = (5.1)\exp(-550/600) = 2.039233\ \mu m$

$t^*(d) = (6.62\times10^{-7}) e^{(11949/T)} = (6.62\times10^{-7})\exp(11949/600) = 295.0072$ days

$R_L(\mu m/d) = (7.48\times10^{6}) e^{(-12500/T)} = (7.48\times10^{6})\exp(-12500/600) = 0.0067\ \mu m/day$

$\delta(\mu m) = \delta^* + R_L(t - t^*) = (2.039) + (0.0067)(365 - 295.0072) = 2.508212\ \mu m$

$\delta = \frac{W}{14.7} \Rightarrow W = 14.7\delta = (14.7)(2.5082) \Rightarrow \boxed{W = 36.8707\ (mg/dm^2)}$

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

$\delta_{ZIRLO} = \delta + 0.6mm = 2.508212(\mu m) + 0.6(mm)$

$\hookrightarrow 0.002508212 + 0.6$

-2, Metal lost = oxide thickness/1.56
-2, ZIRLO thickness is lost, not gained

$\Rightarrow \boxed{\delta_{ZIRLO} = 0.602508212(mm)}$

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

-5, Use equation and plug in values

$N_O = \frac{W N_a}{M_O} = \frac{(0.03687)(6.022e23)}{16} = 1.3877\times10^{21}\ (atoms/dm^2)$

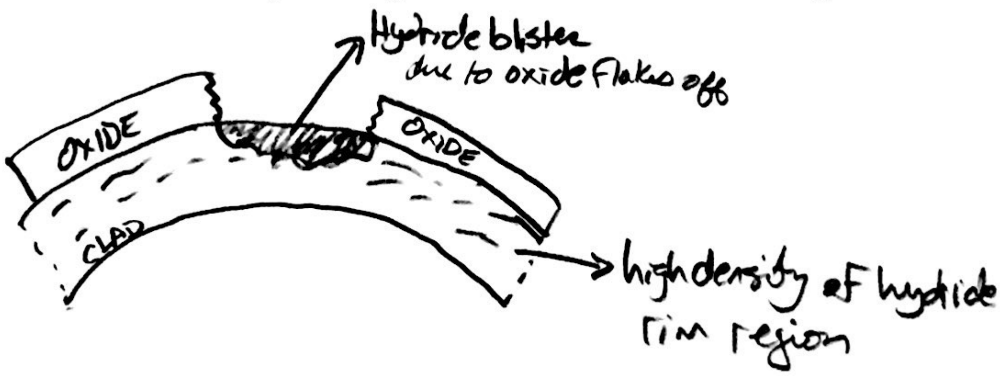
$N_H = 2N_O = 2.7754\times10^{21}\ (atoms/dm^2)$

$N_{H\text{-}Zr} = f N_H = (0.15)(2.775e21) = 4.1632\times10^{20}$

$W_H = \frac{N_{H\text{-}Zr} M_H}{N_a} = \frac{(4.163e20)(1)}{6.022e23}$

$\Rightarrow \boxed{W_H = 0.69133\ (mg)}$

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



Problem 4 (15 points)

-2, 13/15

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)

LOCA: • Relocation in Fuel

• Decrease in Coolant pressure
• Undergoes α & β transition

RIA: • Higher pressure
• Fuel breaks into pieces
• Faster accident
• PCMI @ high burnup

-2, RIA has increase heat production and LOCA has increased cladding temperature

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

• Hydrogen pickup
• Fission gas increase
• Ballooning & bursting
• Fuel temp & pressure rise in cladding

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)

Add cladding Coatings & sleeves. the coatings protect the Zircaloy From Steam w/out significant changes to the material could have a rapid implimentation time. Sleeves protect the inside of the cladding From Oxidation & interactions w/ the Fuel