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NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

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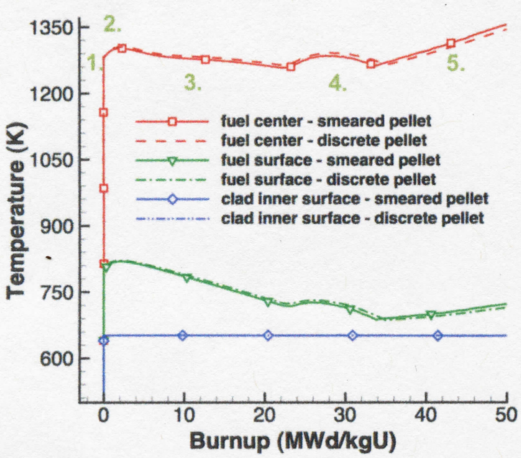
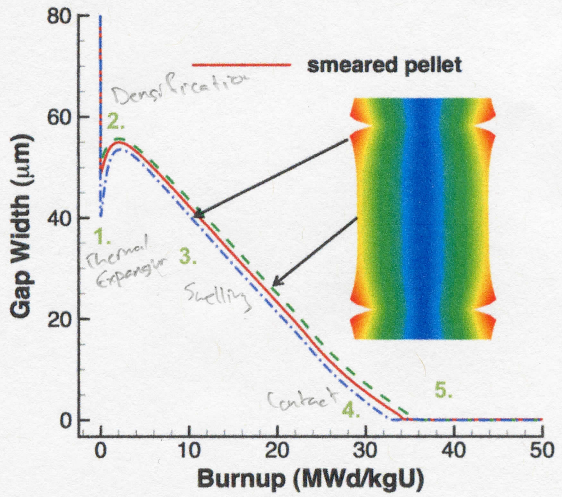
-3, 23/25

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. Initial Startup: Fuel heats up and thermally expands, closing some of the gap thickness.

2. Densification: Irradiation damage causes the fuel to shrink, increasing the gap thickness and somewhat raising fuel temperature because of decreased heat conduction through the gap.

3. Swelling: fission products cause fuel to expand, decreasing heat conduction through fuel, but increasing conduction through the gap as it closes.

✗ 4. Contact: Fuel closes the gap completely,

-3, fission gas release raises T before gap closure, then swelling causes it to decrease again

5. Fission products continue to build up and lower heat conduction in the fuel. This causes the temperature in the fuel to continue to rise.

Question 2 (30 points)

-4, 26/30

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)

$D = D_1 + D_2 + D_3$ $\quad k_b = 8.6173303\times10^{-5}\ \frac{eV}{K}$ (k) $\quad T = 1173\ K$

$D_1 = 7.6\times10^{-6}\exp\left(\frac{-3.03\ eV}{k_b T}\right) = 5.8613\times10^{-11}\ \frac{cm^2}{s}$ (T)

$D_2 = 1.41\times10^{-18}\exp\left(\frac{-1.19\ eV}{k_b T}\right)\sqrt{\dot{F}} = 2.6212\times10^{-4}\ \frac{cm^2}{s}$ (T, $\dot{F}$)

$D_3 = 2\times10^{-30}\dot{F} = 4\times10^{-17}\ \frac{cm^2}{s}$

-1, Math error, D = 8.94e-17 cm2/s

$\boxed{D = 2.62\times10^{-11}\ \frac{cm^2}{s}}$

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)

$t = 2\times365\times24\times3600 = 63072000\ s$ (T) $\quad a:$

$\tau = D\frac{t}{a^2}$ $\quad a = 0.0008\ cm$ $\quad \tau = 2583.2$ $\quad \pi^{-2} = 0.101$

$f = 1 - \frac{0.0662}{\tau}\left(1 - 0.93\exp(-\pi^2\tau)\right) = 0.99997$ (F)

gas released $= f y \dot{F} t = \boxed{3.806\times10^{20}\ \frac{atoms}{cm^3}}$

You used the wrong f eqtn due to error in D

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)

-3 Something is wrong, but you didn't show values so I can't tell what, t = 380 s

$f = 4\sqrt{\frac{Dt}{\pi a^2}} = 0.1 \Rightarrow \frac{f^2}{16} = \frac{Dt}{\pi a^2}$ $\quad \frac{f^2 a^2 \pi}{16 D} = t \Rightarrow \boxed{t = 47.96\ s}$

Amount of gas remaining in fuel: gas produced − gas released

$= (1-f) y \dot{F} t = 9.753\times10^{15}\ \frac{atoms}{cm^3}$

$0.1\times9.753\times10^{15} = \boxed{9.753\times10^{14}\ \frac{atoms\ released}{cm^3}}$

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)

$w\left(\frac{mg}{dm^2}\right) = 14.7 \times \delta(\mu m)$ $t = 365$ days

$\delta^* = 5.1\exp\left(\frac{-550}{T}\right) = 2.039\ \mu m$

$t^* = 6.62\times10^{-7}\exp\left(\frac{11949}{T}\right) = 295.01$ days

$K_L = 7.48\times10^6\exp\left(\frac{-12{,}500}{T}\right) = 0.0067\ \frac{\mu m}{day}$

$\delta = \delta^* + K_L(t - t^*) = 2.51\ \mu m$

$\boxed{w = 36.87\ \frac{mg}{dm^2}}$

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

$PBR = 1.56$ $\delta = 2.51\ \mu m$

$t_{clad} = 600\mu m$ $t_{Zr} = t_{clad} - \frac{\delta}{PBR}$

$\boxed{Zr\ \text{thickness} = 598.4\ \mu m \qquad \text{total thickness} = 600.94\mu m}$

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

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

$f = 0.15$

$\delta = 2.51\mu m$

$\rho_{oxide} = 5.68\ g/cm^3$

$f^o_{ZrO_2} = 0.26$

$M_H/M_O = 1/16 = 0.0625$

$t - \frac{\delta}{PBR} = 598.4\ \mu m$

$\rho_{metal} = 6.5\ g/cm^3$

$\boxed{C_H^{clad} = 7.12\ \text{wt. ppm}}$

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

-2, 13/15

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: Sudden temperature jump causes fuel to fracture.

-2, RIA increases Q while LOCA changes temperature BC

LOCA: More gradual temperature change causes fission gas release and relocation in fuel. Also gets breakaway oxidation and hydrogen pickup in cladding. (Also a phase change in cladding)

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

Both result in higher temperatures and thermal stresses in fuel. Both result in increased stress on cladding, leading to ballooning and cladding bursts and potential fuel dispersal.

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)

Cladding Coating:

Put a thin sleeve on exterior of cladding to prevent interaction between coolant and cladding such as oxidation and hydrogen pickup.

Meets primary goal of ATF program by improving reaction kinetics with steam.