95/100

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

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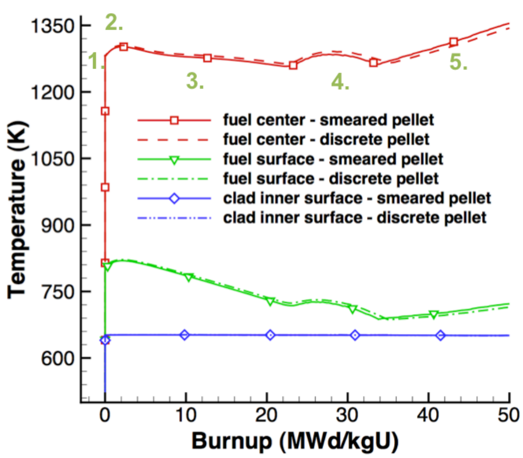
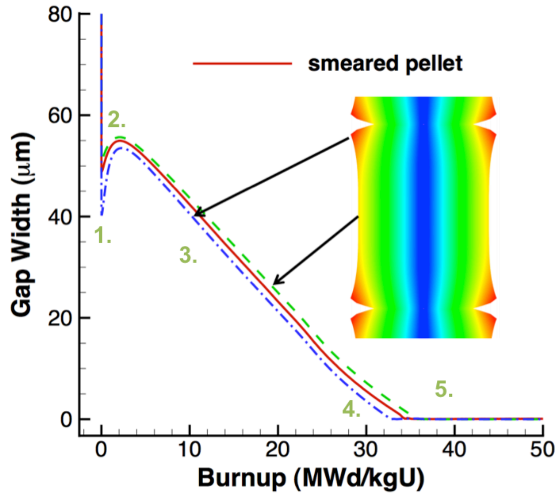
-0, 25/25

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. From starting up the reactor, the temperature is increasing rapidly due to the new fissions. At this time, the gap is closing rapidly as well. This is due to the initial thermal expansion of the fuel. The cladding expands as well, but only a little bit.

2. At number 2 is where densification is occuring in the fuel. When this happens, the gap will increase. Due to the gap increase, thermal conductivity goes down and the temperature will increase once more.

3. At this point, swelling is taking place due to the fission. The fuel is filling up with fission gasses and these vacancies and interstials are making the fuel swell up. The temperature of the fuel is decreaseing due to the closing up the gap width, but the temperature is not decrasing at a fast rate because fission gases decrease thermal conductivity.

4. At number four is where the swelling gets to the point where we get PCMI. The fuel swells until it touches the inner cladding surface. This is is why the gap goes to zero. There is fission gas release as well. The cladding is now under mechanical stress and it is creeping because of the irradiation.

5. At number five, the fuel is still in contact with the cladding, but we also have PCCI. There is a chemical bond between the two. We have higher and higher burnup and the thermal conductivity is suffering because of this. The temperature of the fuel will increase because of this.

Question 2 (30 points) -5, 25/30

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)

$D = D_1 + D_2 + D_3$

$D_1 = 7.6 \times 10^{-6} e^{-\frac{3.03\ eV}{k_b T}}$

$T = 1173\ (K)$

$k_b = 8.617\ 3303\ e^{-5}\ (eV/K)$

$D_1 = 7.285\ 447 \times 10^{-19}\ (cm^2/s)$

$D_2 = 1.41 \times 10^{-21}\ e^{\frac{-1.19\ eV}{k_b T}} \sqrt{\dot{F}}$

$D_2 = 4.863\ 107 \times 10^{-20}\ cm^2/s$

$D_3 = 2.0 \times 10^{-36} \cdot \dot{F}$

$D_3 = 4.0 \times 10^{-23}\ (cm^2/s)$

$\boxed{D = 7.77 \times 10^{-19}\ (cm^2/s)}$

You used old slides that had a typo
(-0) D = 8.94e-17 cm2/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)

$8\mu m = 8e^{-4}\ cm$

$N_{PRODUCED} = y \dot{F} t = (0.3017)(2.0 \times 10^{13})[(3600)(24)(365)(2)]$

$N_{PRODUCED} = 3.805\ 764 \times 10^{20}\ (atoms/cc)$

$N_{RELEASED} = f\ N_{PRODUCED}$; where $f = 4\sqrt{\frac{DA}{\pi a^2}} - \left(\frac{3}{2}\right)\frac{DA}{a^2}$

$\tau\ in < \frac{1}{\pi^2}$

6.125×10^{-8}

$f = 0.0196\ 331\ 745$

$N_{RELEASED} = 7.47192 \times 10^{18}\ (atoms/cc)$

$\boxed{N_{RELEASED} = 7.47 \times 10^{18}\ (atoms/cc)}$

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)

$N_{LEFT} = N_{PRO} - N_{REL} = 3.805\ 764 \times 10^{20}\ (atom/cc) - 7.47192 \times 10^{18}\ (atom/cc)$

$N_{LEFT} = 3.7310448 \times 10^{20}\ (atoms/cc)$ still left inside!

$D = 1.4541 \times 10^{-12}\ cm^2/s$

MATLAB...

10% released

$(0.10) N_{LEFT} = f\ N_{LEFT}$

$\therefore f = 0.10 = 1 - \frac{6}{\pi^2} e^{-\pi^2 \frac{DA}{a^2}}$

$\tau > \frac{1}{\pi^2}$

$\tau = 143.3$

-2, this function is for high release fractions, 10% is a low fraction

$\boxed{t = 17496.384\ (s)} \approx 4.86\ (hrs.)$

-3, How many gas atoms were released during this time?

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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/dm^2 after this time? (10 pts)

$T = 600\,(K)$

$\delta_0 = 0.6\,(mm)$

$t^*(d) = 6.62 \times 10^{-7} e^{\left(\frac{11949}{T}\right)}$

$t^* = 295.0071871\ (days) \rightarrow$ transition

$\delta^* = (5.1)e^{\frac{-550}{T}}$

$\delta^* = 2.039\,233\,237\,(\mu m)$

$\delta(\mu m) = \delta^* + k_L\,(t - t^*)$; $\left\{ k_L = (7.48\times10^6)e^{\left(\frac{-12500}{T}\right)} \right.$

$\delta = 2.508\,212\,175\,(\mu m)$

$\delta \cdot (14.7) : W = 36.870\,718\,98\,\left(\frac{mg}{dm^2}\right) \Longrightarrow \boxed{W \doteq 36.87\,\left(\frac{mg}{dm^2}\right)}$

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

$PBR = 1.56$

$\left(\frac{\delta}{PBR}\right) = (\text{ZIRLO thickness lost})$; where $\left\{ \begin{array}{l} \delta = 2.508\,212\,175\,(\mu m) \\ PBR = 1.56 \end{array} \right.$

$\delta_{ZIRLO,LOST} = 1.607\,828\,317\,(\mu m)$ lost!

$0.6(mm) - \delta_{ZIRLO,LOST} = 0.6(mm) - 0.0016078283(mm) = 0.598\,392(mm)$

$\boxed{(\text{ZIRLO Left}) \doteq 0.598\,(mm)}$

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

$f_H = 0.15$

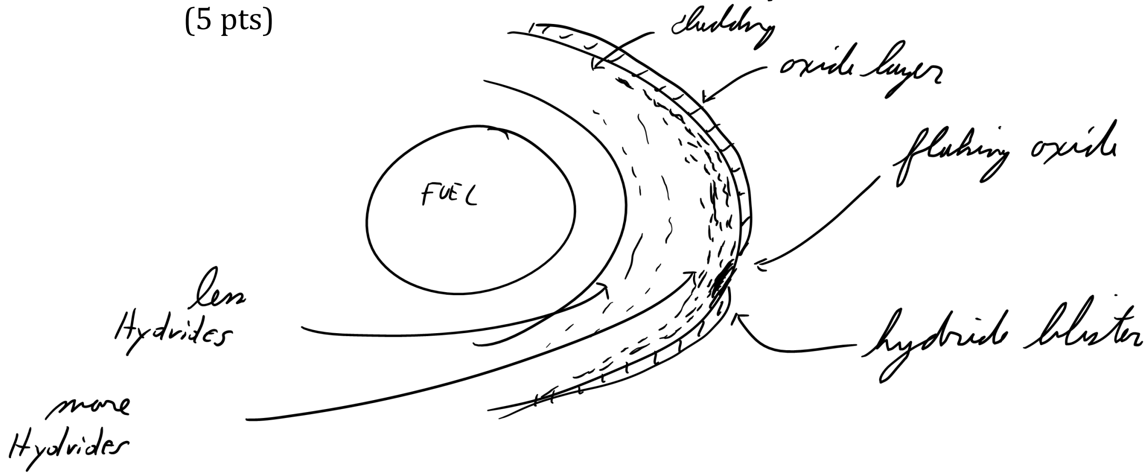
assume initial H content is zero...

$$C_H^{clad} = \frac{2f\,\rho_{OXIDE} + f\,\delta_{ZrO_2} + \frac{M_H}{M_O}}{\left(t - \frac{\delta}{PBR}\right)\rho_{metal}} \times 10^6$$

$$C_H^{clad} = \frac{2(0.15)\left(5.68\,\frac{g}{cc}\right)\left(0.2597\right) + \left(\frac{1.00794\,g/mol}{15.9994\,g/mol}\right)}{\left(600 - \frac{2.508212\,\mu m}{1.56}\right)\left(6.5\,\frac{g}{cc}\right)} \times 10^6 \Longrightarrow C_H^{clad} = 17.997$$

$\boxed{C_H^{clad} \doteq 18.0\,(wt.\,ppm)}$

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



Problem 4 (15 points)

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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 largest difference between a LOCA and a RIA is the timescale. A RIA is immediate within milliseconds, whereas as LOCA may happen over minutes, hours, days, etc.

With LOCA, the fuel has high thermal stresses, and the fuel breaks. This also releases the fission gases trapped inside. The cladding starts to have break away oxidation, rapid hydrogen pickup, ballooning, and possibly burst. This ballooning can compound the problem by blocking coolant channels.

With RIA, there is a large reactivity insertion, a huge temperature and power increase (before Doppler Broadening kicks in), and the fuel hits the cladding (where it may burst if not ductile enough).

With high BU, RIA is not as dangerous because of the lower availability of enthalpy.

With high BU, LOCA is more dangerous because the fuel and cladding are more brittle and are more fragile.

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

Both may have ballooning of the cladding, the fuel will crack and release fission gasses, and the cladding may break.

Both are design basis accidents

Both have high thermal stresses.

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 is that of a cladding coating, and this is one of the ones proposed that could be implemented in the short term.

If designed properly, this could reduce the amound of crud and oxidation of the cladding. This would prevent our cladding from breakaway oxidation and eventually failure. With little oxidation, the efficiency of the reactor would increase due to the increase in thermal conductivity.