72/100

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

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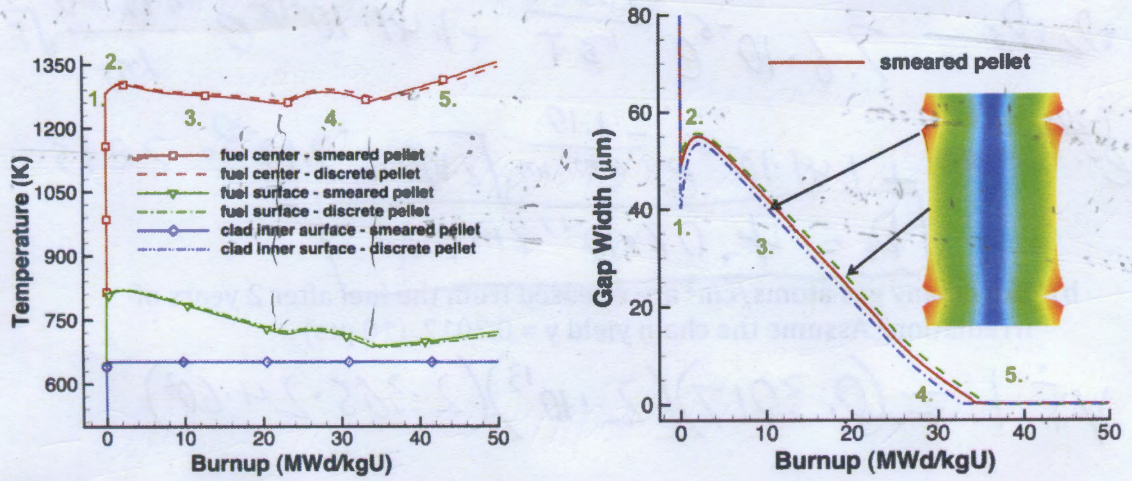
-10, 15/25

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. Thermal expansion occurs in the fuel.

-5, what features in the plots indicated these behaviors?

2. densification over powers the fuel, and gap rises, gradually build up of fission products in the gap

-1, no fission products in gap yet

3. swelling/thermal expansion has started to occur, bubble nucleation.

4. Fuel/cladding creep occurs (includes irradiation creep,) - small gap leads to better heat transfer temporarily, leading to the little drop.

-2, Fission gas release causes T increase before gap closure
Little drop caused by additional gap closure

5. Pellet/cladding interaction has occured due to thermal expansion/swelling; PCI,

- Inner surface of cladding doesn't change much at high burnup

-2, fuel k decreases with burnup, causing T to increase

Inner cladding not affected much by burnup

- Hydride formation/oxide delayed

-14, 16/30

Question 2 (30 points)

A fuel pellet with an average grain size of 8 microns is irradiated with a volumetric neutron flux of 2.0e13 fissions/(cm^3 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)

$a = 8\cdot10^{-6} m = 8\cdot10^{-4} cm$; $\dot{Q} = 2.0e^{13} \frac{fissions}{cm^3 s}$; $T = 900°C$

$$D = D_1 + D_2 + D_3 = 7.6\cdot10^{-6} e^{\frac{-3.03 eV}{k_B T}} + 1.41\cdot10^{-18} e^{\frac{-1.19 eV}{k_B T}} \sqrt{F} \cdot 2\cdot10^{-30} F$$

$$= 7.6\cdot10^{-6} e^{\left(\frac{-3.03}{8.617e^{-5}\cdot1173}\right)} + 1.41\cdot10^{-18} e^{\frac{-1.19}{8.617e^{-5}\cdot1173}} \sqrt{2\cdot10^{13}} + 2\cdot10^{-30}\cdot 2e13$$

$$\boxed{D_F = 4.07\cdot10^{-17}\ cm^2/sec}$$

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

b) How many gas atoms/cm^3 are released from the fuel after 2 years of irradiation? Assume the chain yield y = 0.3017. (10 pts)

$$N_{gas} = y\dot{F}t = (0.3017)(2\cdot10^{13})(2\cdot365\cdot24\cdot60^2)$$

-6, Gas RELEASED not produced

$$= 3.80576\cdot10^{20}$$

$$= \boxed{3.81\cdot10^{20}\ \frac{atoms}{cm^3}}$$

$D = 7.7585e^{-12}\ \frac{cm^2}{sec}$

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/cm^3 will have been released during this time? (15 pts)

$$f = 6\sqrt{\frac{Dt}{\pi a^2}} - 3\frac{Dt}{a^2} = 6\sqrt{\frac{4.07\cdot10^{-17}\cdot t}{\pi(8\cdot10^{-4})^2}} - 3\frac{4.07\cdot10^{-17}\cdot t}{(8\cdot10^{-4})^2}$$

$f = .10 \Rightarrow$ solve for $t \Rightarrow \boxed{t = 161.594\ days}$

-2, Used wrong diffusivity (use the one you calculated at high T)

-5, calculate gas atoms released during this time

-#d ⇒ displays the change in texture orientation due to arise in pressure.

Problem 3 (30 points)

-4, 26/30

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)

$T = 600K$; $T = 1$ year $= 365$ days, $t_c = 0.06$ cm

$W = [\text{Oxide thickness}]\, 14.7$; $t^* = 6.62 \cdot 10^{-7} \exp\left[\frac{11\,949}{T}\right] = 295$ days

$\delta^* = 5.1 \exp\left[\frac{-550}{T}\right] = 2.03923\ \mu m$

$K_L = 7.48 \cdot 10^{6} \exp\left[\frac{-12500}{T}\right] = 0.0067 \Rightarrow \delta = \delta^* - K_L(t - t^*)$

$\delta = 2.03923 + 0.0067[365 - 295] = 2.5084\ \mu m \Rightarrow \boxed{W = 36.87 \frac{mg}{dm^2}}$

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

$PBR = 1.56 = \frac{\delta_{ZrO_2}}{\delta_{Zr}} = 2.50816\ \mu m\ [ZrO_2]$ → $1.6078\ \mu m = \delta_{Zr}$

$\frac{\delta_{ZrO_2}}{\delta_{Zr}} \Rightarrow \delta_{Zr} = \frac{\delta_{ZrO_2}}{1.56}$ → $\delta_{ZrO_2} = 2.50816\ \mu m$

Notes $\Rightarrow \delta_{ZrO_2} = \frac{W}{14.7} = \frac{36.87}{14.7} = 2.50816\ \mu m$ →

-2, Subtract lost ZIRLO form wall thickness
600 - 1.6078 = 598.4 microns

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

$\delta_{ZrO_2} = 2.508\ \mu m \rightarrow W = 36.87 \frac{mg}{dm^2}$; $N_O = \frac{w N_{Av}}{M_O} = \frac{(0.03687)(6.022 \cdot 10^{23})}{16} = 1.388 \cdot 10^{21}$ O atoms

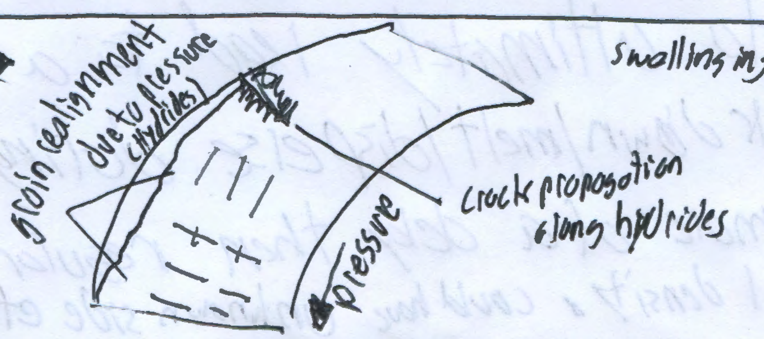
$N_H = 2N_O = 2.77539 \cdot 10^{21} \Rightarrow N_{H-Zr} = f N_H = 4.163 \cdot 10^{20}$ hydrogen atoms/dm² ($f = 15\%$)

$wH = \frac{N_H M_H}{N_a} = \frac{4.163 \cdot 10^{20} \cdot 1}{6.022 \cdot 10^{23}} = 0.000691$ g of H

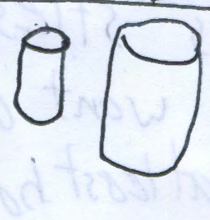
d) Draw a section of the cladding, showing the various microstructure changes (5 pts)

$C_H = \frac{W_H}{W_{Zr}} = \frac{W_H}{\rho_{Zr}\left[t - \frac{\delta_{ZrO}}{PBR}\right] A} = \frac{0.000691}{6.5\left[600 - \frac{2.5081}{1.56}\right](10 \cdot 10 \cdot 10^{-4})} = 1.777 \cdot 10^{-5} = \boxed{17.77 \text{ Wt. ppm H}}$

~~Thermal expansion~~ →
changes | expansion, densif.
creep, swell,
~~Densification~~ →



swelling ing →



• Increase volume
decrease density

-2, Oxide layer?

-0, 15/15

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 a quick accident caused by control rod/blade leading to: Fuel breaking, ~~cladding burst, fuel dispersion~~ [~~Ballooning/Burst; PCMI~~]) Fission occurs

while a LOCA is less rapid and leads to ~~Temperature increase~~, Decrease in coolant pressure, ~~Ballooning of cladding, bursting, with the~~ has cycles due to ECCS -SCRAM and decay heat (source of heat) ~~(Big difference of Being slower, Decreases coolant pressure, relocation and fission gas in fuel~~

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

-Both lead to temperature rises, potential ballooning / Bursts ~~fuel~~ and fuel fragment release / dispersion

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)

-additives to UO_2 such as Si, BeO, that could help lead to higher thermal conductivities, lower fuel temp, reduces fission product release, and lowers stress to ultimately lead to a fuel that ~~also~~ wont break down/melt/disperse during an accident or at least have more of a delay then regular UO_2.

-neg. reduced fuel density, could have unknown side effects.