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NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

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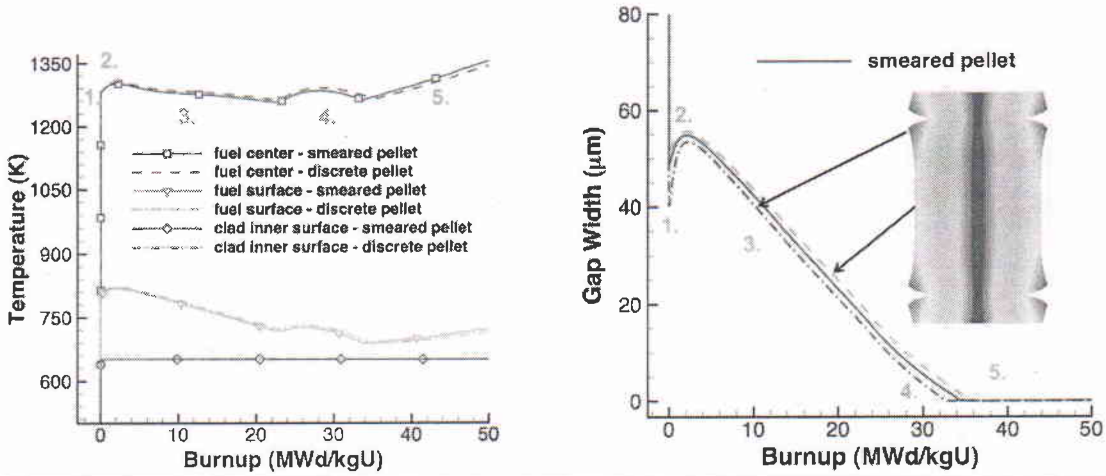
Question 1 (25 points):

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. - rapid increase in temperature and decrease in gap width indicate thermal expansion in the fuel and cladding

2. - increase in gap width (and corresponding increase in fuel temperature) at low burnup indicates densification (loss of initial porosity in the fuel), the cladding is unaffected

3. - solid and gaseous fission products build up in the fuel, causing it to swell and decrease the gap width, decreasing the fuel temperature, the cladding is unaffected

4. - the fuel size increases enough for it to contact the cladding, closing the gap, heat transfer is enhanced, the competing processes of swelling, contact, and fission gas contamination of the gap affect temperature in complex ways leading up to this time

5. - following gap closure, fuel thermal conductivity continues to decrease with burnup, raising fuel temperature, PCMI induces additional stresses on the fuel and cladding

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Question 2 (30 points)

fission rate density

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. $= 1173\ K$

$\dot{F} = 2.0 \times 10^{13} \frac{1}{cm^3\, s}$

a) What is the fission gas diffusion coefficient at this temperature? (5 pts)

$$D = 7.6 \times 10^{-6} \exp\left(\frac{-3.03\ eV}{} \Big| \frac{K}{8.617 \times 10^{-5}\ eV} \Big| \frac{}{1173\ K}\right)$$

$$+ 1.41 \times 10^{-21} \exp\left(\frac{-1.19\ eV}{} \Big| \frac{K}{8.617 \times 10^{-5}\ eV} \Big| \frac{}{1173\ K}\right) \sqrt{2.0 \times 10^{13}}$$

$$+ 2.0 \times 10^{-36} \left(2.0 \times 10^{13}\right)$$

$$= \boxed{7.764 \times 10^{-19} \frac{cm^2}{s}}$$

-0, you used eqns from old slides with typos

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)

- in-pile release $\quad \tau = \frac{Dt}{a^2} = \frac{7.764 \times 10^{-19}\ cm^2}{s} \Big| \frac{2\ y}{} \Big| \frac{365\ d}{1\ y} \Big| \frac{24\ hr}{1\ d} \Big| \frac{3600\ s}{1\ hr} \Big| \left(\frac{}{8\ \mu m}\right)^2 \Big| \left(\frac{10^4\ \mu m}{cm}\right)^2$

$= 7.65 \times 10^{-5} < \pi^{-2} \rightarrow$ short time problem

- release fraction $\quad f = 4\sqrt{\frac{Dt}{\pi a^2}} - \frac{3}{2}\frac{Dt}{a^2} = 0.0196$

- atoms per cm³ produced $\quad N_{fg} = y\dot{F}t = \frac{0.3017}{} \Big| \frac{2.0 \times 10^{13}}{cm^3\ s} \Big| 2 \Big| 365 \Big| 24 \Big| 3600\ s$

$= 3.806 \times 10^{20} \frac{atom}{cm^3}$

- released $\quad f N_{fg} = \boxed{7.459 \times 10^{18} \frac{atom}{cm^3}}$

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)

$T = 2273\ K$

- gas remaining in pellets $\quad N_{fg}(1-f) = 3.731 \times 10^{20} \frac{atom}{cm^3}$

- post irradiation annealing, recalculating diffusivity at 2273 K $\rightarrow D = 1.453 \times 10^{-12} \frac{cm^2}{s}$

- using the first term of the short time equation

$$f = 6\sqrt{\frac{Dt}{\pi a^2}} \quad \text{or} \quad t = \frac{\pi a^2 f^2}{36 D} = \frac{\pi}{} \Big| \left(8 \times 10^{-4}\ cm\right)^2 \Big| \left(0.1\right)^2 \Big| \frac{}{36} \Big| \frac{s}{1.453 \times 10^{-12}\ cm^2}$$

$t = \boxed{384.38\ s} \quad \rightarrow$ recalculating $\tau < \pi^{-2}$

- released $\quad 0.1\left[N_{fg}(1-f)\right] = \boxed{3.731 \times 10^{19} \frac{atom}{cm^3}}$

Problem 3 (30 points) -1, 29/30

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)

- the transition time is $t^* = 6.62 \times 10^{-7} \exp\left(\frac{11949}{T}\right) = 295.007$ days
- the transition thickness is $\delta^* = 5.1 \exp\left(\frac{-550}{T}\right) = 2.039\,\mu m$

$K_L = 7.48 \times 10^6 \exp\left(\frac{-12500}{T}\right) = 0.0067 \frac{\mu m}{day}$

- the oxide thickness is $\delta = \delta^* + K_L(\underbrace{t}_{365\ day} - t^*) = 2.508\,\mu m$
- the weight gain per area is $w = 14.7\,\delta = \boxed{36.87 \frac{mg}{dm^2}}$

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

- the amount of ZIRLO in the oxide layer is $\delta_0 = \frac{\delta}{\underbrace{PBR}_{1.56}} = 1.608\,\mu m$
- the uncorroded ZIRLO is $0.6 \times 10^3 - 1.608 = 598.392\,\mu m$
- the total ZIRLO thickness with the oxide layer is $598.392 + \delta = \boxed{600.9\,\mu m}$

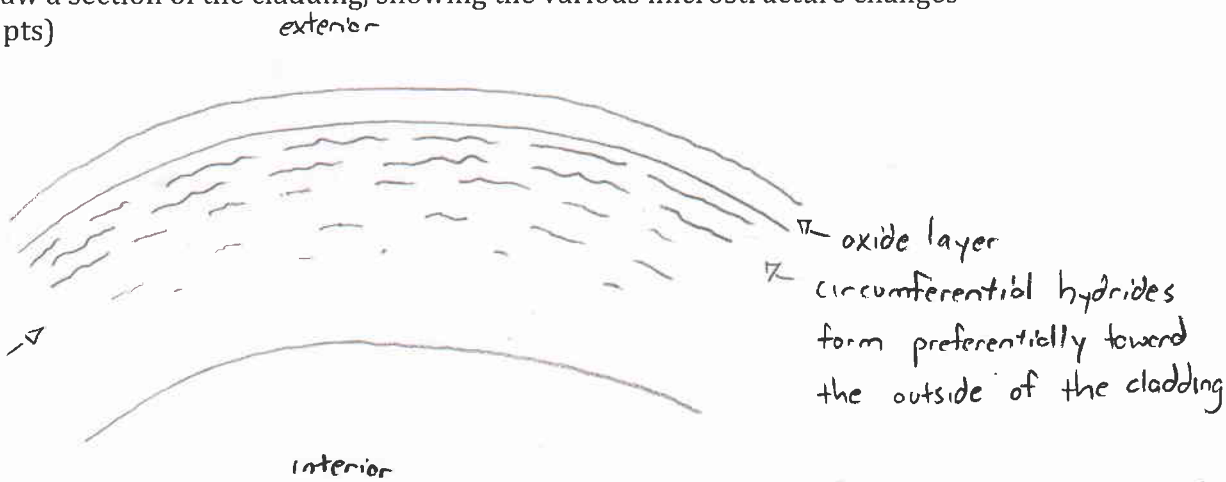
c) Assuming the hydrogen pickup fraction is 15%, what is the weight PPM of hydrogen in the cladding after one year? (10 pts)

$$C_H^{clad} = \frac{2 f\, \delta\, \rho_{oxide}\, f^o_{ZrO_2} \frac{M_H}{M_O} \times 10^6}{\left(t - \frac{\delta}{PBR}\right) \rho_{metal}} = \boxed{8.927 \text{ wt. ppm}}$$

-1, I think you forgot the CH = 17.87 wt.ppm

$$C_H^{clad} = \frac{2 \cdot 0.15 \cdot 2.508\,\mu m \cdot 5.68\,g/cm^3 \cdot 0.26 \cdot 1\,g/mol \cdot 10^6 \cdot cm^3 \cdot mol}{\left(600\,\mu m - \frac{2.508\,\mu m}{1.56}\right) \cdot 6.5\,g \cdot 32\,g}$$

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



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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 changes the source condition due to positive reactivity insertion (heat generation rate) within the fuel over a short period of time and deposits energy in the fuel, the fuel heats up and the heat must be conducted through the cladding
- LOCA changes the boundary condition (flowrate of the coolant) cooling the rod and occurs over longer times, the reactor is shut down but decay heat is not being removed so the fuel and cladding heat up, pressure decrease outside cladding increases risk of ballooning and burst

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

- the fuel and cladding heat up in both
- thermal stresses in the fuel and cladding can cause failure
- both can lead to PCMI and ballooning / burst behaviors
- behaviors are burnup dependent

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)

- advanced steel FeCrAl cladding
- more corrosion resistant in high temperature water and steam, producing less hydrogen in the event of an accident condition due to breakaway oxidation, thereby giving more coping time for operators to combat the casualty before an explosion hazard is created