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4/21/17

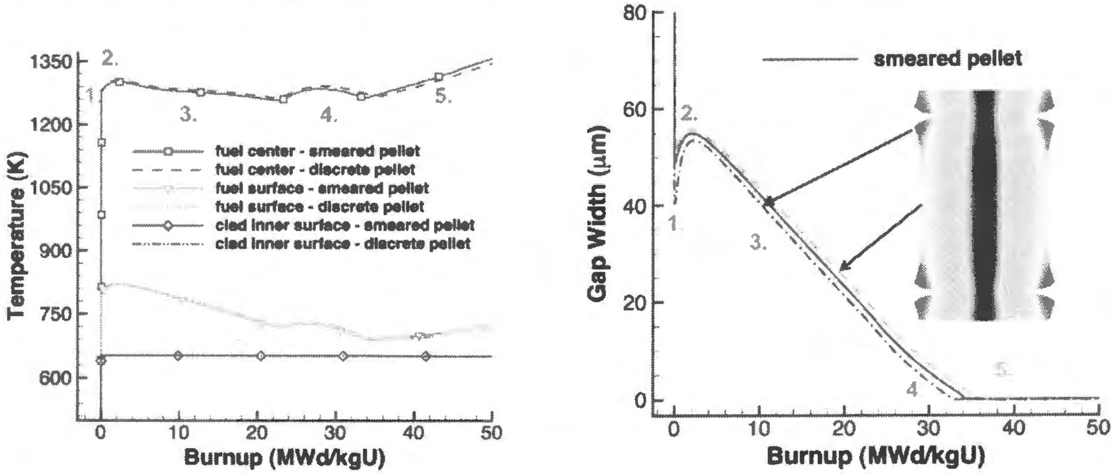
93/100

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

Name:

-2, 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. Clad + fuel Thermal expansion ⇒ Gap width ↓
fuel undergoes initial fracturing from high temp.
(sharp ↑ in initial temps + ↓ in Gap width)

2. Gap width ↑ due to Densification
fuel - point defects start to form / fission gas generation

3. Mid life fuel - Point defect diffusion + clustering,
fission gasses diffuse to grain boundaries
Bamboo-ing of pellet
clad - oxide layer forms.
fuel / clad irradiation creep + swelling ⇒ Gap width ↓ + T_{fuel} ↓

4. Gap width ↓ to ∅ ⇒ fuel + cladding
mechanical interaction

-2, Fission gas release causes T to go up before gap closure

5. fuel temp ↑ ⇒ - Potential clad failure due to PCMI
- cladding blistering / bubbling possibly
blocking coolant channel
• high burnup k_{fuel} ↓ = T_{fuel} ↑

-1, 29/30

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/(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)

$\boxed{T} = 900°C + 273.15 = \boxed{1173.15\,K}$ assume $\dot{F} = 2.0\times10^{13}\ \frac{fiss}{cm^3 \cdot s}$

$k_b = 8.617\times10^{-5}\ eV/K$

$D_1 = (7.6\,E\text{-}6)\exp\left(\frac{-3.03}{(k_b)(T)}\right) = \boxed{7.305\times10^{-19}}$

$D_2 = (1.41\,E\text{-}21)\exp\left(\frac{-1.19\,eV}{(k_b)(T)}\right)\sqrt{\dot{F}} = \boxed{4.868\times10^{-20}}$

$D_3 = (2.0\,E\text{-}36)(\dot{F}) = \boxed{4.0\times10^{-23}}$

$\boxed{D} = D_1 + D_2 + D_3 = \boxed{7.79\times10^{-19}}$ *

These equations are from an old slide with typos. 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)

PRODUCED: $\boxed{N_{fg\text{-}prod}} = y\dot{F}t = (0.3017)(2.0\times10^{13})\underbrace{(2\times365\times24\times3600)}_{t}$

$= \boxed{3.806\times10^{20}\ \frac{atoms}{cm^3}}$

RELEASE (IN PILE): $f = 4\sqrt{\frac{Dt}{\pi a^2}} - \frac{3Dt}{2a^2} = 4\sqrt{\frac{(7.79E\text{-}19)(t)}{\pi(0.0008)^2}} - \frac{3(7.79E\text{-}19)t}{2(0.0008)^2}$

$a = 8\,\mu m = 0.0008\,cm$ $\boxed{f = 0.0197}$

-1, calculate tau to know which equation to use

RELEASED: $\boxed{N_{fg\text{-}rel}} = fN_{\text{-}prod} = (0.0197)(3.806\times10^{20}) = \boxed{7.498\times10^{18}\ \frac{atoms}{cm^3}}$ *

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)

$\boxed{T} = 2000°C + 273.15 = \boxed{2273.15\,K}$

Trapped fg: $\boxed{N_{fg\,TR}} = N_{fg\,prod} - N_{fg\,rel} = 3.806E20 - 7.498E18 = \boxed{3.731\times10^{20}\ \frac{atm}{cm^3}}$

D for 2273.15K: (using eqN from part A w/ T=2273.15K and $\dot{F}=0$)

$\Rightarrow D_1 = (7.6E\text{-}6)\exp\left(\frac{-3.03}{(k_b)(T)}\right) = \boxed{1.455\times10^{-12}}$

$D_2 = D_3 = \emptyset$ since $\dot{F} = \emptyset$

time OUT of pile f release: $f = 6\sqrt{\frac{Dt}{\pi a^2}} - \cancel{3\frac{Dt}{a^2}}$ Not significant for short time periods

f=0.1

$\Rightarrow \boxed{t} = \frac{\left(\frac{f}{6}\right)^2\pi a^2}{D} = \frac{\left(\frac{0.1}{6}\right)^2\pi(0.0008)^2}{(1.455\times10^{-12})} = \boxed{383.85\,sec}$ *

AMT RELEASED: $\boxed{N_{fg\,rel}} = fN_{fg\,TR} = 0.1\left(3.731\times10^{20}\ \frac{atm}{cm^3}\right) = \boxed{3.731\times10^{19}\ \frac{atoms}{cm^3}}$ *

$T = 600K$
$t = 365$ days
$\delta_0 = 0.6mm = 600 \mu m$

-4, 26/30

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)

Transition thickness : $\boxed{\delta^*} = 5.1 \exp(-550/T) = \boxed{2.039 \mu m}$

Trans. time : $\boxed{t^*} = 6.62 \times 10^{-7} \exp(11949/T) = \boxed{295.01 \text{ days}}$

$\boxed{K_L} = (7.48 \times 10^6) \exp(-12500/T) = \boxed{0.0067}$

Post Trans thickns : $\delta = \delta^* + K_L(t - t^*) = 2.039 \mu m + 0.0067(365 - 295.01)$

$\boxed{\delta = 2.508 \mu m}$

EST. Weight $\boxed{w} = \delta(14.7) = 2.508(14.7) = \boxed{36.87 \, mg/dm^2}$ *

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

$\boxed{\text{Wall thickness}} = \delta_0 + \delta = 600 \mu m + 2.508 \mu m$

$= \boxed{602.508 \mu m}$

-2, metal lost = oxide thickness/1.56
-2, Thickness is lost, not gained

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

$f = 0.15$

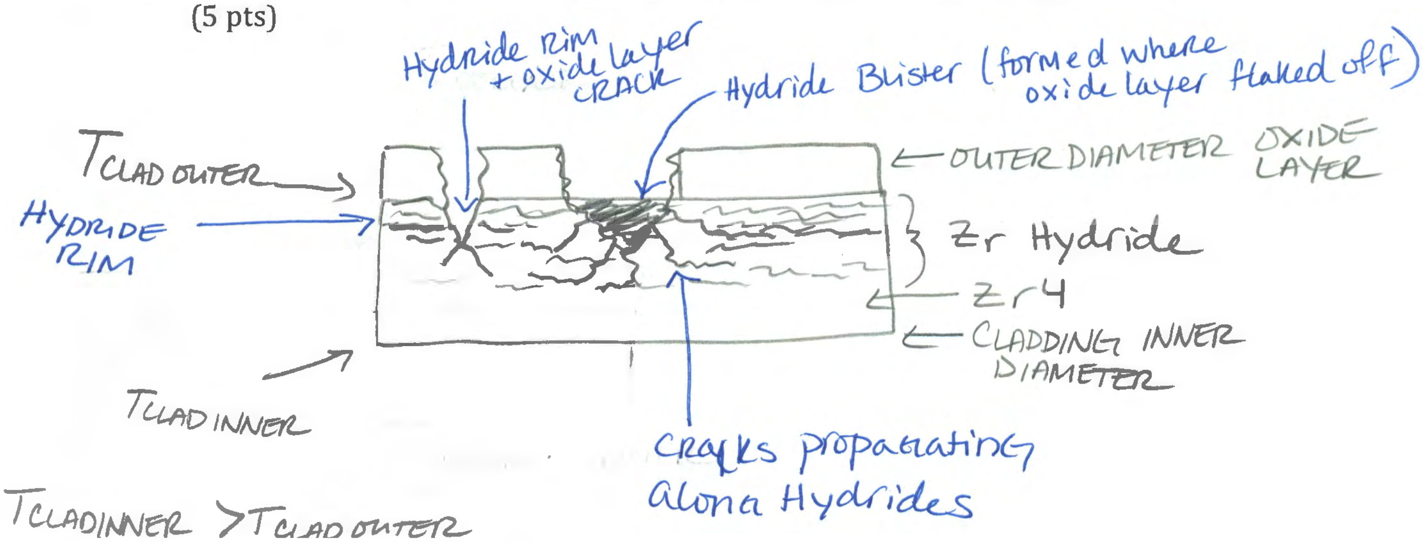
$\rho_{oxide} = 5.68 \, g/cm^3$, $\rho_{zr} = 6.5 \, g/cm^3$, $f^{o}_{ZrO_2} = 0.26$, PBR $= 1.56$

$M_H = 1$, $M_O = 16$, $t_{clad} = 600 \mu m$, $\delta = 2.508 \mu m$

$$\boxed{C_H^{CLAD}} = \frac{2 f \delta \rho_{ox} f^{o}_{ZrO_2} (M_H/M_O)(10^6)}{\left(t_{clad} - \frac{\delta}{PBR}\right)\rho_{ZR}} = \frac{(2)(0.15)(2.508)(5.68)(0.26)(1/16)(10^6)}{\left(600 - \frac{2.508}{1.56}\right)(6.5)}$$

$= \boxed{17.85 \text{ wt. ppm}}$ *

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



-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 - large Rapid insertion of reactivity
  - ⇒ fuel expands then hits the cladding
    - ↳ if cladding is BRITTLE it breaks due to PCMI
    - ↳ if cladding is DUCTILE it ballons due to PCMI
  - → faster rise in temp of fuel/clad than LOCA (typially)

- LOCA - Loss of coolant ⇒ Oxygen in coolant ↑
  - ⇒ Hydrogen embrittlement ↑

Coolant Pressure ↓ ⇒ Departure from Nucleate boiling may occur (CRITICAL HEAT flux) + Tclad ↑↑ / Tfuel ↑↑

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

→ ↑ fuel temp could result in the fuel exceedin melting point

- Both result in Rise in fuel temp + clad temp
- Both can result in cladding failure + subsequent fuel/fission product release into the coolant

↳ Possible clad failure due to PCMI or balloning for Both

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)

- Silicon Carbide composite (SiC) cladding w/ Zircaloy end caps instead of traditional cladding.

→ SiC has low neutron cross section, no high temp creep, + low activation. It can meet the ATF goal because it can provide increased degredation resistance up to ~1800°C.

⇒ less degredation during accident scenarios which allows for more time before catastrophic behavior occurs during design basis accident (DBA).