EXAM 2
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(1)

1. Beginning of life, the pellet is fresh, fission chain just started. Fuel expands due to thermal expansion, gap is small as we can see from plot 2. cladding also expands due to Temperature. Fuel centerline is not so high because gap is small an fuel thermal conductivity is still not so degraded.

2. Fuel pellet densify: pores left by sintering close. gap width increases. Fuel centerline T increases. cladding stays the same.

3. Fuel is swelling due to fission gas / solid products production. gap width decreases. centerline T decreases. Cladding by this burnup has some oxidation on the outer part and some hydride formation on the outer rim.

4. gap fully closes. We have pellet-cladding interaction (mechanical and chemical). Stress on the cladding, especially on the top and bottom of fuel pellets Ⅱ. Cladding deforms like a bamboo shape. Fuel centerline goes down because heat is transferred better to cladding.

5. at this burnup, all the material properties are degraded. Fuel thermal conductivity is low, fission products, cladding has oxidation and hydride formation. We are transitioning to HBS (high burnup structure) on the outer rim of the fuel. Fuel centerline goes up. gap still closed.

②

$a = 8\mu m = 8 \times 10^{-4}$ cm

$\dot{F} = 2e13 \dfrac{fission}{cm^3 s}$ →

I assumed you gave $\dot{F}$ because it is fission / cm³s instead of neutron / cm³s

-5, 25/30

$T = 900°C = 1173 K$

a)

$\begin{cases}
D_1 = 7.6 \times 10^{-6} \, exp\left(-3.03 / K_b T\right) \\[2mm]
D_2 = 1.41 \times 10^{-21} \, exp\left(1.19 / K_b T\right) \times \sqrt{\dot{F}} \\[2mm]
D_3 = 2 \times 10^{-36} \times \dot{F}
\end{cases}$

You used the equations from old slides that have typos,
D = 8.94e-17 cm2/s

$D = D_1 + D_2 + D_3$

plugging the values to MATLAB, $D = 8.1763 \times 10^{-10}$ cm²/s

-1, There is something wrong with your math

b)

$\tau < \tilde{\pi}^{-2}$

$f = 4\sqrt{\dfrac{\tau}{\tilde{\pi}}} - 3\tau$ ∴ $\tilde{\tau} = \dfrac{Dt}{a^2} = 8.0577 \times 10^{4}$

↓ fraction released

total produced $N_{fg} = y \dot{F} t$ ∴ $N_{fg} = 3.8058 \times 10^{20}$ atoms/cm³

total released = $f \times N_{fg}$

as $\tau \geqslant \tilde{\pi}^{-2}$, we need to use a different equation for f.

$f = 1 - \dfrac{0.0662}{\tilde{\tau}}\left(1 - 0.93 \exp(-\tilde{\pi}^2 \tau)\right)$ $\tau \geqslant \tilde{\pi}^{-2}$

plugging to MATLAB, $f = 1$.

$\boxed{N_{fgr} = 3.8058 \times 10^{20} \text{ atoms/cm}^3}$

c) Now we need to use "post annealing model".

$T = 2000°C = 2273 K$

$f = 0.10 \qquad t = ?$

ignoring the second term (only important for longer ts)

$$f = 6 \sqrt{\frac{Dt}{\pi a^2}}$$

$$\frac{f^2}{36} = \frac{Dt}{\pi a^2} \qquad \therefore \quad t = \frac{\pi a^2 f^2}{36 D}$$

$f = 0.1$

$a = 8 \times 10^{-4} \text{ cm}$

As there is no fission and no extra production of fission gas in the post annealing, we are using the diffusivity of Xe in the fuel.

$D = 8 \times 10^{-15} \text{ cm}^2/\text{s}$

-2, you need to recalculate D for T = 2273 K

solving for time:

$t = 6.9 \times 10^4 \text{ s} = 19.3925 \text{ h}$

assuming that we have the total produced along this 2 years inside the pellet,

released $= f \times$ produced $= \boxed{0.38 \times 10^{20} \text{ atoms} / \text{cm}^3}$

$\downarrow$

$N_{fg} = 3.8058 \times 10^{20} \text{ atoms}/\text{cm}^3$

from part b.

-2, Should be 0.1*(produced - released) = 0 in your case

③

a) T = 600K δ = 6 mmm

t = 1 year

We need to calculate the oxide thickness.

δ^* (μm) = 5.1 exp (-550/T)

t^* (d) = 6.62 × 10^{-7} exp (11949/T)

t^* = 295 d ,   so   we are post Transition.

δ^* = 2.0392

δ (μm) = δ^* + K_L (t - t^*)

K_L = 7.48 × 10^6 exp (- 12500 /T)   ($\frac{\mu m}{d}$)

K_L = 0.0067 μm/d

δ (μm) = 2.5082

weight gain

w (mg/ dm^2) = δ (μm) × 14.7

$\boxed{W \ (mg/ dm^2) \ = \ 36.8707}$

b) The remaining Thickness should consider the volume expansion.

$$\delta_{remain} = \delta_{initial} - \frac{\delta_{oxide}}{PBR}$$

$$PBR = 1.56$$

$$\boxed{\delta_{remain} = 5.9984 \ mm}$$

-0, Math error, should be 5.984 microns

c) $\quad f_H = 15\%$

$$C_H^{clad} \ [wt\cdot ppm] = \frac{2 f \delta_{oxide} \ f_{ZrO_2}^0 \ \frac{M_H}{M_0} \ 10^6}{\left(t - \frac{\delta}{PBR}\right) \rho_{metal}}$$
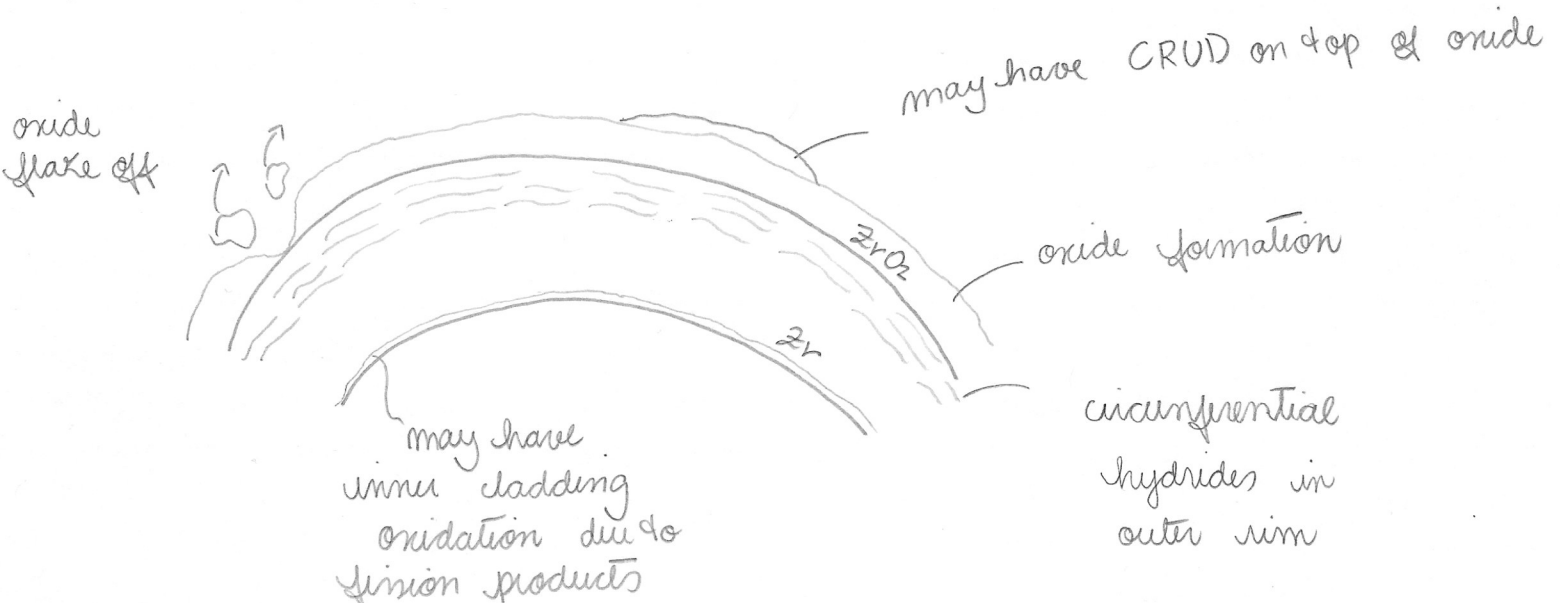
plugging The values:

-2, Eqn right, but you got the wrong answer. Should be 17.87 wt ppm

$$C_H^{clad} \ [wt\cdot ppm] = 794.9282$$

assuming no initial H content.

d)

oxide
flake off

may have CRUD on top of oxide

ZrO_2

oxide formation

Zr

may have
inner cladding
oxidation due to
fission products

circumferential
hydrides in
outer rim

(4)

a) RIA: There is a rapid insertion of reactivity, so the fuel rapidly heats up (which can cause fracture). The fuel heats the coolant, which evaporates. The fuel temperature increases more.

LOCA: We loose coolant first, then the fuel temperature increases due to the loss of coolant.

b) In both accidents we have the fuel temperature going up and loss of coolant at some point. The pressure inside the rod goes up and due to pellet-clad interaction, the cladding can balloon and rupture.

c) SiC as cladding.

The primary goal is to give time to the operator before something worst happens. As SiC does not react with H like Zr, it will be safer and meet the goal.