88/100

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NucE 497: Fuel Performance
Exam 2

Problem 1

-0, 25/25

① In the early life of the fuel, as the burnup starts to increase, the fuel temperature rises sharply when the reactor (→ fission chain reaction) starts. The gap size decreases very fast due to thermal expansion. The cladding temperature also increases due to heat conduction. The fuel volume increases → shrinks the gap.

② Densification happens, which decreases the fuel volume and thus increases the fuel temperature because the gap size increases.
The cladding temperature stays constant.

③. Swelling starts to happen, which, again, increases the fuel volume → lowers the fuel temperature and decreases the gap size. The gap size continues to decreases until contact between the cladding and the fuel. Fuel and cladding creep also happen.

④. The gap becomes very small. A lot of fission gas released and increase in the fuel temperature ← decrease in the fuel thermal conductivity.
Then contact with cladding (lower temperature)
→ Small decrease in fuel temperature.

(5) The fuel and the cladding are in contact with each other → PCMI and PCCI.

Fuel temperature continues to increase as fuel thermal conductivity decreases with burnup.

-7, 23/30

Question 2

$a = 8\ \mu m$

$\phi = 2.0 \times 10^{13}$ fissions/ $(cm^3 s)$

$T = 900^\circ C = 1173.15 K$.

a) Diffusion coefficient,

$D = D_1 + D_2 + D_3$

$D_1 = 7.6 \times 10^{-6} \exp\left(-\frac{3.03 eV}{K_B T}\right)$.

$D_2 = 1.41 \times 10^{-18} \exp\left(-\frac{1.19 eV}{K_B T}\right) \sqrt{\dot{F}}$.

$D_3 = 2.0 \times 10^{-30} \times \dot{F}$.

$\dot{F} = q\, \sigma_f\, N \phi$

Assuming $q = 0.042$

$\sigma_f = 5.5 \times 10^{-22}\ cm^2$.

$\phi = 2 \times 10^{13}\ f/(cm^3 s)$

$N = 2.44 \times 10^{22}$

$\hookrightarrow F = 1.1273 \times 10^{13}\ f/(cm^3 . s)$

$\rightarrow D = 5.9842 \times 10^{-17}\ cm^2 . s^{-1}$ with $T = 1173.15 K$

-0, Fdot = 2e13

b) # of gas atoms released :

$$\tau = \frac{Dt}{a^2} = \frac{5.9842 \times 10^{-17} \times 3600 \times 24 \times 365 \times 2}{(8 \times 10^{-4})^2}$$

$= 0.059$

-0, Fdot = 2e13

$\pi^{-2} = 0.1013 > \tau$

$$\rightarrow f = 4\sqrt{\frac{\tau}{\pi}} - \frac{3}{2}\tau = 0.1704$$

Total amount of fission gas produced:

$$N_{FG} = y\dot{F}t = 0.3017 \times 1.1273\times10^{13} \times 3600 \times 24 \times 365 \times 2$$
$$= 2.1451\times10^{20} \text{ fission gas atoms }/cm^3$$

$$N_{released} = f \times N_{FG} = 0.1704 \times 2.1451\times10^{20}$$
$$= 3.6553\times10^{19} \text{ atoms}/cm^3.$$

c) $f = 10\% = 0.1$

$T = 2000\,°C = 2273.15\,K$

$\rightarrow D = D_1 + D_2 + D_3$ @ $2273.15\,K$
$D = 1.4665\times10^{-12}\ cm^2.s^{-1}$.

Neglecting the 2nd term in f:

-2, Wrong equation

$$f = 4\sqrt{\frac{Dt}{a^2\pi}} \rightarrow t = \frac{a^2\pi}{D}\left(\frac{f}{4}\right)^2$$

$$t = \frac{8\times10^{-4} \times \pi \times 0.1^2}{1.4665\times10^{-12} \times 16} = 1.0711\times10^{6}\,s$$

-1, a should be squared

$$N_{released} = f \times N_{FG}$$
$$= 0.1 \times y\dot{F}t$$
$$= 0.1 \times 0.3017 \times 1.1273\times10^{13} \times 1.0711\times10^{6}$$
$$= 3.6429\times10^{17} \text{ atoms}/cm^3.$$

-4, No new gas is produced in post-irradiation annealing

Problem 3 -4, 26/30

T = 600 K

t = 1y

δ_0 = 0.6mm

a) $\delta(\mu m) = \frac{w(mg/dm^2)}{14.7}$

$[\delta^* = 5.1 \exp(-\frac{550}{600}) = 2.0392\ \mu m]$

$t^*(d) = 6.62 \times 10^{-7} \exp(\frac{11949}{600}) = 295\ d. < 365$

→ Transition occured.

$\delta(\mu m) = \delta^* + K_L(t - t^*)$.

$= \delta^* + 7.48 \times 10^6 \exp(-\frac{12500}{600})(365 - 295)$

$= 2.5083\ \mu m$

↳ ~~$\delta_{tot} = \delta + \delta_0 = 0.6 \times 10^3 + 2.5083\ \mu m = 602.8\ \mu m$~~

↳ $W = 14.7 \times 2.5083 = 36.87201\ mg/dm^2$

b) $\delta_{tot} = \delta + \delta_0 = 0.6 \times 10^3 + 2.5083\ \mu m$
$= 602.8\ \mu m$

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

c) $\delta_O = 1.47\ g/cm^3$

$W = 2.5083 \times 14.7 = 36.87201\ mg/dm^2$

$N_O = 36.87 \times 10^{-3} \times NA/16 = 1.3877 \times 10^{21}$

$f = 15\% \longrightarrow 0.15 \times 2 \times 1.3877 \times 10^{21}$
$= 4.1631 \times 10^{20}$ atoms of H/dm^2

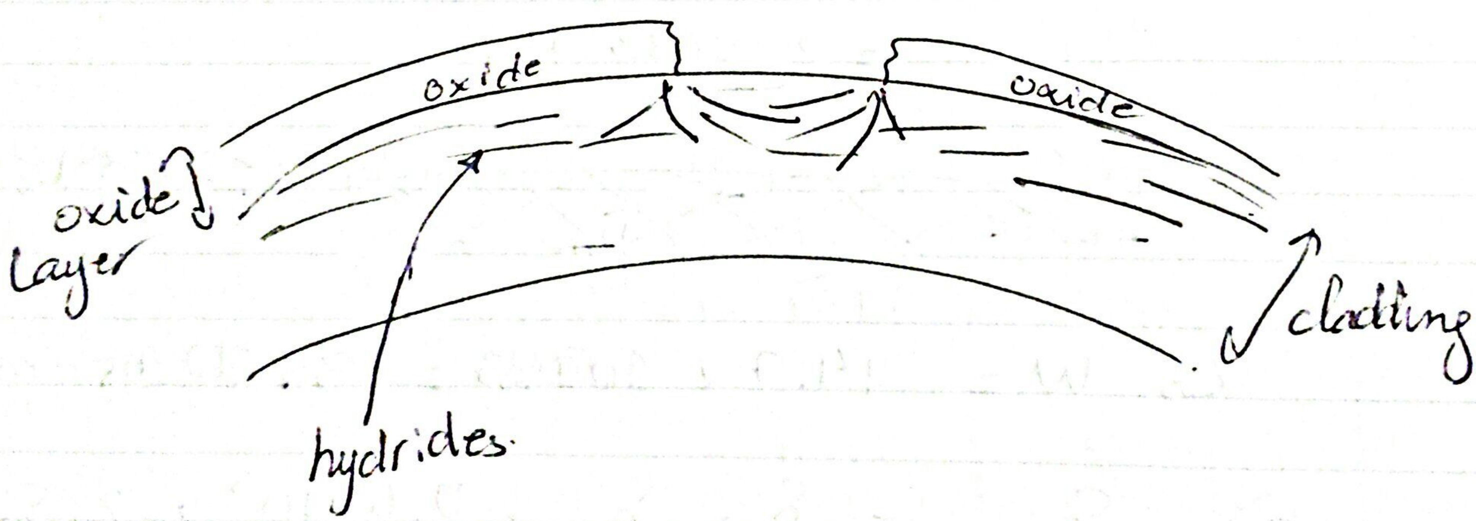
Uncorroded thickness $= 600 - \dfrac{2.5083}{PBR \leftarrow 1.56}$

$= 598.4$

total mass of Zr $= 6.5 \times 5.984 = 38.9\,g$.

$\hookrightarrow C^{H} = \dfrac{4.1631 \times 10^{20}}{6.022 \times 10^{23} \times 38.9} = 1.777 \times 10^{-5}$
$= 17$ wt. ppm

d)



Problem 4 -1, 14/15

a) In a RIA, the fuel temperature goes up sharply, which increases its volume due to thermal expansion.
The cladding temperature increases slowly but significantly because of PCMI, which decreases the yield stress.
Ballooning can happen and can block the coolant channel and thus cause fuel melting.
It can also break because of the brittle region formed by the hydride blister, and let fuel escape.

-1, There isn't a pulse in a LOCA, that is in a RIA

In a LOCA, the cladding starts to balloon and can break if the pulse is rapid. It can change from alpha to beta phases (high temperature), which makes it more ductile. A higher oxidation rate and heat production, along with a rapid hydrogen pickup can also happen in a LOCA.
The fuel has more fission gas release since the temperature goes up. It can even melt. The burnup increases the probability of failure when it is high.

b) In both cases, fuel can break (fragmentation), which can cause fuel dispersal. The cladding can balloon and even break. Both temperatures of the fuel and the cladding increase significantly (rapid Temperature changes).
Also, the coolant channel can be blocked, increasing even more the fuel temperature.

c) A potential accident tolerant fuel concept is the use of high uranium density fuels like metal uranium, uranium silicide and uranium nitride.
Usinge these fuels allows to have a highe ~~fudel~~ thermal conductivity and a better efficiency because of the higher fissile density.