88/100

1.

-5, 20/25

-3, In 1-4, how do these changes impact T?

① Thermal expansion

high temperature causes fuel and cladding to expand.
Due to the expansions, the size of the gap decreases

② Densification

Shrinking of porosity left after sintering, the fuel pellets decrease their volume.
so the gap between cladding and fuel increases.

③ swelling.

Due to fission gas release, the pellets start to increase their volume.

Fission gas bubble formation, not gas release

therefore, the gap between the cladding and fuel decreases.

④ PCMI

due to the expansion of both fuel and cladding, the pellets are directly interacting with the cladding. (there is no gap between fuel and cladding)

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

⑤ still PCMI

However, the thermal conductivity of the fuel is dependent on both temperature and burnup, the overal fuel temperature keeps increasing.
the cladding is possibly under (ballooning or burst)

↳ however code cannot show these scenarios.

2.

a)

$D = D_1 + D_2 + D_3$

-6, 24/30

$$D_1 = 7.6\times10^{-6} \times e^{-\frac{3.03}{k_b T}}$$

where $k_b = 8.617\times10^{-5}\ \frac{eV}{k}$

$T = 900 + 273.15$

$$D_1 = 7.305\times10^{-19}\ [cm^2/s]$$

$$D_2 = 1.41\times10^{-21}\, e^{-\frac{1.19}{k_b T}} \times \sqrt{\dot{F}}$$

$$= 1.41\times10^{-21} \times 7.72\times10^{-6} \times \sqrt{2\times10^{13}}$$

$$= 4.868\times10^{-20}\ [cm^2/s]$$

$$D_3 = 2\times10^{-36} \times \dot{F}$$

$$= 2\times10^{-36} \times 2\times10^{13} = 4\times10^{-23}\ [cm^2/s]$$

$$D = 7.305\times10^{-19} + 4.868\times10^{-20} + 4\times10^{-23}$$

$$= \boxed{7.792\times10^{-19}\ [cm^2/s]}$$

-0, You used eqns from old slides that had typos,
D = 8.94e-17 cm2/s

b)

$$N_U = N_a \rho_U / M_U = \frac{6.022\times10^{23} \times 9.65}{238} = 2.442\times10^{22}\ [\text{atom } U/cm^3]$$

$$\dot{F} = 2\times10^{13}\ [\text{fission}/cm^3\, s]$$

$$N_{FG} = y\dot{F}t = 0.3017 \times 2\times10^{13} \times 2\times365\times24\times3600$$

$$= 3.806\times10^{20}\ [\text{fission gas atom}/cm^3]$$

time range: $\tau = Dt/a^2 = (7.792\times10^{-19})\times(2\times365\times3600\times24)/0.0008^2 = 7.679\times10^{-5} < \pi^{-2}$

In pile

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

$$= 4\sqrt{\frac{7.792\times10^{-19}\times(2\times365\times24\times3600)}{\pi\times0.0008^2}} - \frac{3}{2}\,\frac{7.792\times10^{-19}\times24\times3600\times365\times2}{0.0008^2}$$

$f = 0.01978 - 1.152\times10^{-4} = 0.01966$

$\text{gas released}/cm^3 = N_{FG}\times f = 0.01966\times 3.806\times10^{20}$

$= \boxed{7.483\times10^{18}\ [\text{atoms released}/cm^3]}$

c) Since this is out pile,

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

-3, You need to recalculate D at 2273 K

$$\frac{f^2/36 \times \pi \times a^2}{D} = t = \frac{0.1^2\times\pi\times0.0008^2}{36\times7.792\times10^{-19}} = 716767660\ \text{sec}$$

$$f = 6\sqrt{\frac{Dt}{\pi a^2}} - 3\frac{Dt}{a^2}$$

$$= 6\times\sqrt{\frac{(7.792\times10^{-19})(2\times365\times24\times3600)}{\pi\, 0.0008^2}} - 3\,\frac{(7.792\times10^{-19})(2\times365\times24\times3600)}{0.0008^2}$$

$= \boxed{}$

$\text{gas released}/cm^2 = N_{FG}\times\boxed{}$

$= 3.806\times10^{20}\times\boxed{}$

-3, Should be f*(Produced - released)

3

a)

-0, 30/30

$$t^* = 6.62\times10^{-7} \exp\left(\frac{11949}{600}\right)$$

$$= 295\,[d]$$

$$\delta^* = 5.1 \exp\left(\frac{-550}{600}\right)$$

$$= 2.039\ \mu m$$

since it passes the transition,

$$\delta = \delta^* + k_L(365 - t^*)$$

$$k_L = 7.48\times10^{6} \exp\left(\frac{-12500}{600}\right)$$

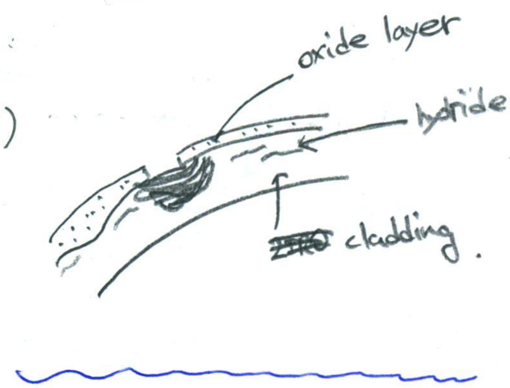
$$= 0.0067\left[\frac{\mu m}{d}\right]$$

$$\delta = 2.039 + 0.0067(365 - 295)$$

$$= 2.508\ \mu m$$ ← oxidation thickness

$$\delta = \frac{w}{14.7} \Rightarrow 2.508\times14.7 = \omega = \boxed{36.868\ [mg/dm^2]}$$

d)



b)

Initial wall = 600 μm

$$\text{uncorroded after 1yr} = 600 - \frac{2.508}{1.56} = 598.39\ \mu m$$

$$\text{ZIRLO + oxidation} = 598.39 + 2.508 = 600.9\ \mu m$$

c)

$$N_O = 0.036868\times6.0233\times10^{23}/16 = 1.387\times10^{21}\ \text{atoms O}/dm^2$$

$$N_H = 0.15\times2\times N_O = 4.161\times10^{20}\ \text{atoms H}/dm^2$$

$$W_H = \frac{4.161\times10^{20}}{0.602\times10^{24}} = 6.913\times10^{-4}\ g$$

$$C_H = \frac{6.913\times10^{-4}}{6.5\left(600 - \frac{2.508}{1.56}\right)(10\times10\times10^{-4})} = 1.777\times10^{-5} = \boxed{17.77\ [wt.\ ppm]}$$

4

-1, 14/15

a) In RIA, fuel expands in ~~milliseconds~~ and hit ~~the cladding~~. Due to PCMI, the clading starts to crack / break. However in LOCA, the coolant pressure drops while temperature of the fuel rod increases. Due to rapid hydrogen pickup, the dadding becomes brittle. ~~the fuel is under thermal stress with transient induced fission gas release~~. Also the fuel starts relocation in LOCA.

b)

Both RIA and LOCA causes the cladding ballooning and burst. Also, due to the high temperature of the fuel, both RIA and LOCA causes fission gas releasing.

c)

- Advanced steel:

Since this material has very high ductility, it takes longer times the cladding to burst from RIA and LOCA accidents

-1, Primary benefit is less oxidation

- addictives w/ UO_2

(SiC, BeO, etc)

with high thermal conductivity, it reduce fission gas release.