90

1. (a) $T = 625\,K$, time 400 days, initial wall thickness = 500 μm

check if it is gone through transition

critical time $= t^*(d) = 6.62 \times 10^{-7} \exp\left(\frac{11949}{625}\right) \doteq 133$ days < 400 days

19/20

$\Rightarrow$ past transition time

$\Rightarrow$ use linear fit

$$\delta^*(\mu m) = 5.1 \times \exp\left(\frac{-550}{625}\right) \doteq 2.115393$$

$$K_L\left(\frac{\mu m}{d}\right) = 7.48 \times 10^6 \times \exp\left(\frac{-12500}{625}\right) \doteq 0.015417$$

$$\Rightarrow \boxed{\delta(\mu m) = \delta^* + K_L \times (400 - 133) \doteq 6.232\ \mu m} \rightarrow \text{oxide thickness}$$

(b)

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

As given, $PBR = 1.56$, $\rho_{Zr} = 6.5\ g/cm^3$, $\rho_{ZrO_2} = 5.68\ g/cm^3$, $f = 18\%$

$$\Rightarrow f^o_{ZrO_2} = \frac{2 \times 16}{2 \times 16 + 91} \doteq 0.26$$

$$C_H^{clad}\,[\text{wt.ppm}] = \frac{2 \times 18\% \times 6.232\,[\mu m] \times 5.68\,\cancel{g/cm^3} \times 0.26 \times \frac{1}{16}}{\left(500 - \frac{6.232\,[\mu m]}{1.56}\right) \times 6.5\,\cancel{g/cm^3}} \times 10^6$$

$$\doteq 63.721\ [\text{wt.ppm}]$$

looking for $t = 365$ dy in part b

2. Diffusion of the O and e⁻ is the rate-limiting step in the aqueous corrosion of Zr cladding.

4/4

e⁻ diffusion is "fast"

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3. Pilling - Bedworth ratio (PBR) is the ratio of volume of the oxide and volume of the oxidized metal.

4/4

$$PBR = \frac{V_{oxide}}{V_{metal}} = \frac{\frac{M_{oxide}}{\rho_{oxide}}}{\frac{M_{metal}}{\rho_{metal}}} = \frac{M_{oxide}\,\rho_{metal}}{M_{metal}\,\rho_{oxide}}$$

when

- $PBR < 1$ ⇒ the oxide layer is to thin to have protective effect eg. Mg
- $PBR > 2$ ⇒ the oxide layer is so thick that it starts to chip off ⇒ no protective effect eg. Iron
- $1 < PBR < 2$ ⇒ oxide coating has the passivating effect on the surface of the metal.

4. ① The hydrogen mostly form during the oxidation reaction between the water coolant and cladding surface. And, hydride usually easily to form at the place with lower temperature (∵ Soret effect)

② The soret effect says hydrogen prefer to move toward lower temperature place, - T solubility, Stresses in cladding

③ If the metal pickup the hydride,

⇒ Ⓐ Hydride embrittlement

② loss of fracture toughness

③ delay Hydride cracking

④ accelerated corrosion eg. IGSCC

⑤ accelerated irradiation growth.

10/12

③

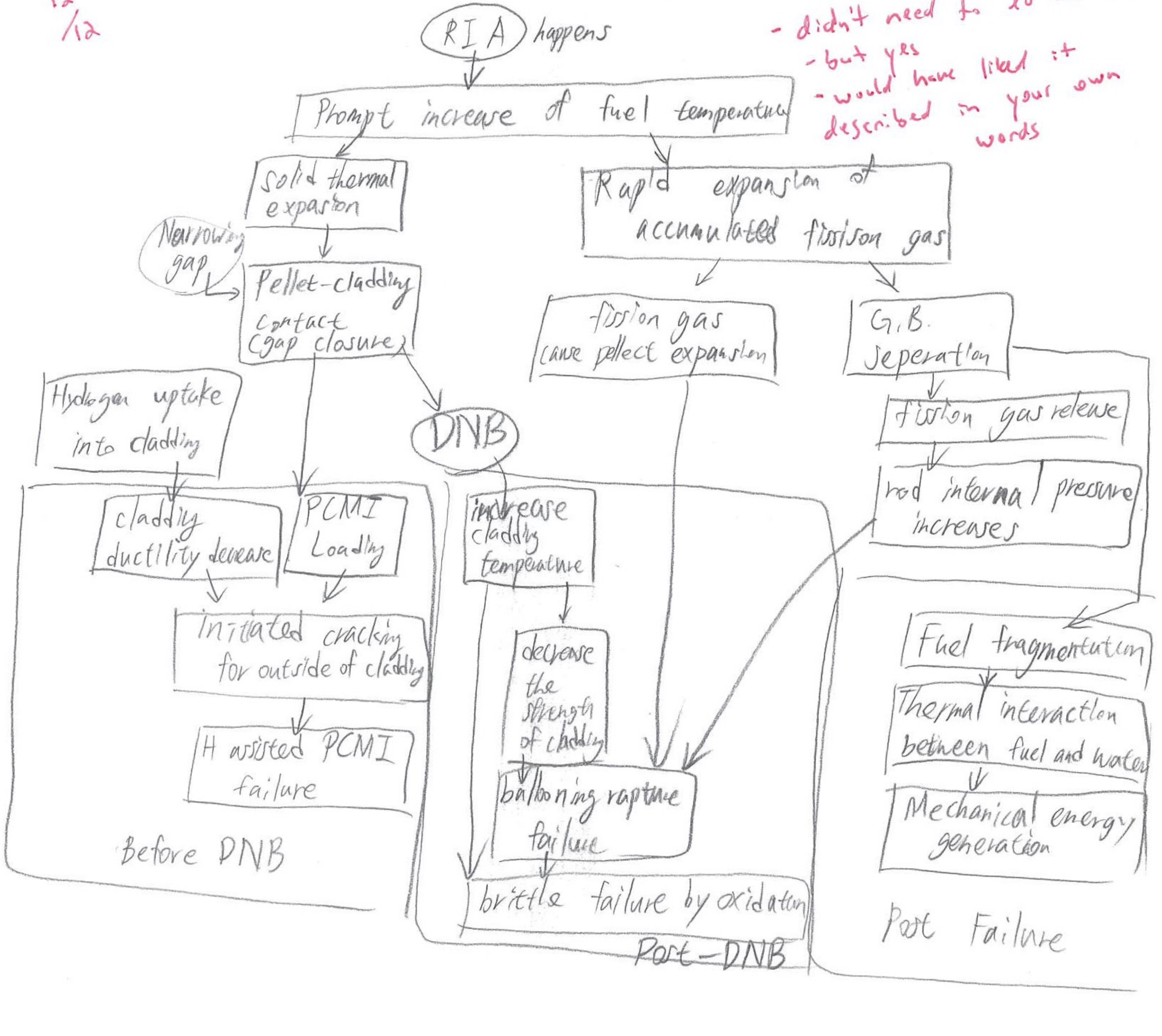
5. ① RIA is reactivity insertion (initiated) accident, which means the rapidly changed reactivity can cause fuel power ↑, temperature ↑ ⇒ generates a lot steam / pressure pulse ④

② The typical RIA in PWR : Control Rod ejection accident (CREA)
BWR : Control Rod drop accident (CRDA)

③ RIA can be described easily with a flow chart

12/12

- didn't need to do all this!
- but yes
- would have liked it described in your own words



6. LOCA is the loss of coolant Accident.

⇒ Temp ↑ ∵ radio active decay increse but cooling decrease

6/10

The main difference between RIA and LOCA is LOCA can evolve to RIA, but RIA doesnot Loss Coolant ⇒ not Zr + Steam reaction

- different effects in LOCA.
  - slower, more oxidation, plasticity, etc.

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7. eg ① Improve the reaction kinetic with steam
② fission product retention

4/6

ATF option : Ti_3SiC_2, Cr for Cladding coating
SiC, FeCrAl for Alternative cladding
dope Cr, SiC, BeO in UO_2

8. When Zr is exposed to high temperature steam,

5/6 it will have steam oxidation effect and also interact directly with steam $Zr_{(s)} + 2H_2O_{(g)} \rightarrow ZrO_{2(s)} + 2H_2 + 586\ kJ/mol$

⇒ release more heat and could have high risk of hydrogen exploration and hydrogen embrittlement.

- phase changes, breakaway oxidation

4/4 9. (eg) Change the cladding material to Fe-Cr, Fe-Cr-Al or SiC

10.

Limit Phenomenon (eg) 1. Cladding oxidation and hydrogen pickup

- wanted a small description also

4/6 2. Power to melt

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11. CRUD is Chalk River Unidentified Deposite, which is an accumulation of the corrosion products, ions, and oxides.

4/6

The impact is mainly at the water chemistry and making higher chance for corrosion of cladding.

- low K_{th}, increases fuel/cladding temp
- radiation source by activating corrosion species

12.

Water chemistry controls : eg ① pH value

② Impurities (eg. Cl , F)

ok ...

4/6

For ① , we need to maintain the environment to be slightly alkaline by adding (eg) LiOH , H_3BO_3 to make it less corrosive.

② , we need to purify the water frequently to make sure the environment doesnot content too much Cl and F

⇒ less corrosive.

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13. MOX fuel has
- shorter fuel rod
- smaller fuel diameter
- Stainless steel cladding
- higher heating rate
- Larger gas plenum
- Sodium coolant

6/9

- what are physical phenomena that occur?
  - restructuring, high FP inventory, JOG, etc.