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NUCE497
HOMEWORK-5
SOLUTIONS

1)
a) Creep is the plastic deformation of a material under an applied stress which is less than yield stress. Such deformation occurs as a result of climb and glide of dislocations due to the absorption of point defects.
In thermal creep, climb and glide occurs with the diffusion and absorption of pre-existed defects in the microstructure with the help of temperature.
In irradiated creep, climb and glide occurs not only with the diffusion and absorption of the pre-existed defects but also with the defects induced by irradiation. In addition, diffusion coefficient of the irradiated materials is higher due to the fact that there is more available empty sites for the defects to move. Therefore, there is also diffusion compared to the non-irradiated material at the same temperature.

b) Vacancy and interstitial type loops form in zirconium which has an hcp crystal structure. Interstitial type loops form on prism (or pyramidal) planes while vacancy type loops form on basal planes.

c) Zirconium has anisotropic crystal structure and as it was mentioned in part (b), during the irradiation, vacancy and interstitial type loops form on basal and prism planes preferentially causing shrinkage of the crystal lattice along the center. Since cladding tubes are textured during the manufacturing, the shrinkage of the crystal lattice results in elongation of the cladding.

d) Material hardening is related to the dislocation motion. Irradiation of a material results the formation of dislocation loops. These loops act as a barrier for the dislocations and hinder their motion and hardening the material.

2- a) Time for oxide transition, t^*, can be determined with the following relation:

$$t^*[d] = 6.62\times10^{-7} \exp\left(\frac{11949}{T}\right) \quad \text{where } T = 325°C \text{ or } 598K$$

$$= 6.62\times10^{-7} \exp\left(\frac{11949}{598}\right)$$

$$\cong 314 \text{ days}$$

In order to find cladding thickness, we first need to find oxide thickness at t^* with the following relation:

$$\delta^*[\mu m] = 5.1 \exp\left[\frac{-550}{T}\right]$$

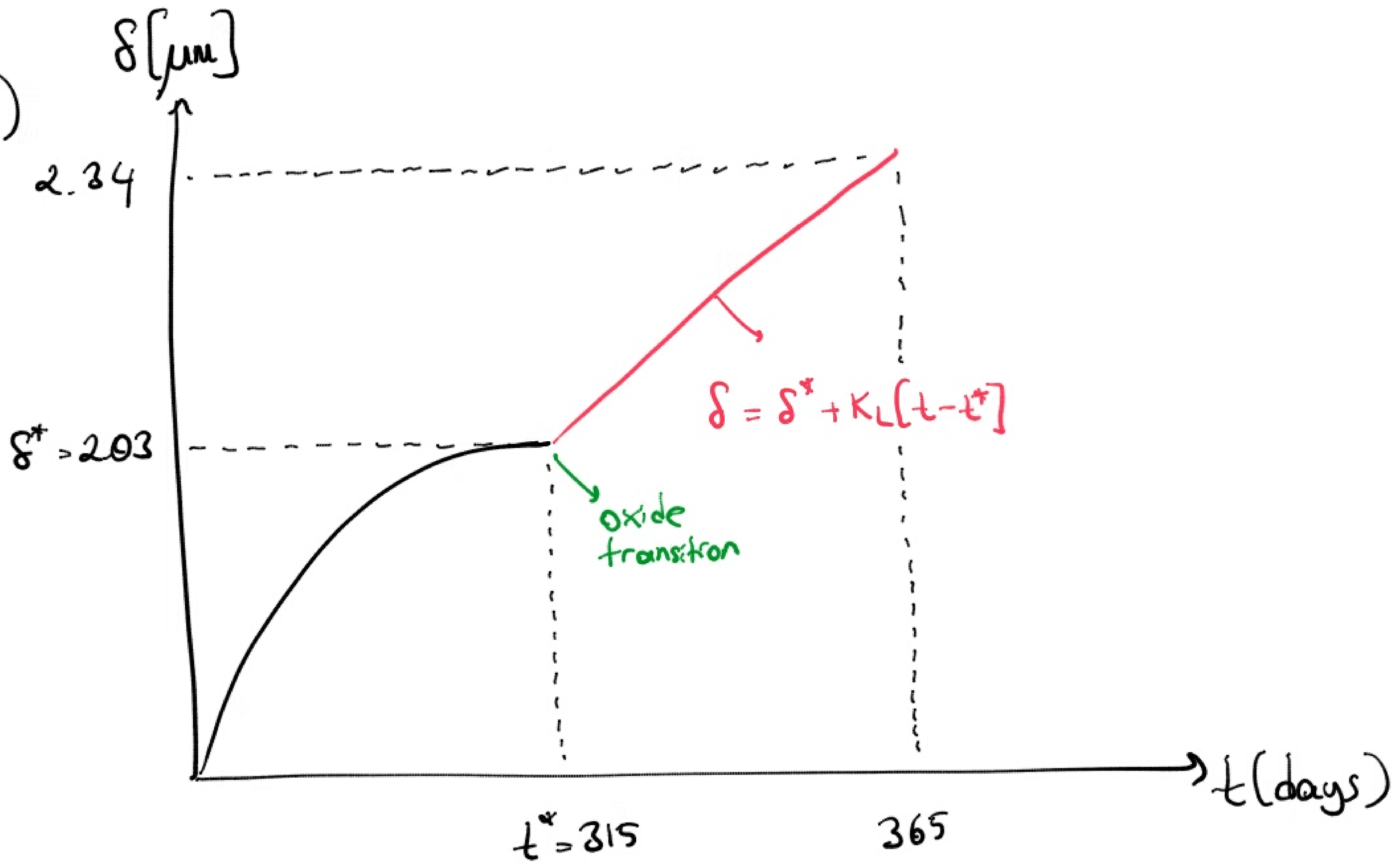
$$= 5.1 \exp\left[\frac{-550}{598}\right]$$

$$\delta^* \cong 2.03 \, \mu m \text{ thick after } 315 \text{ days.}$$

$$t_{clad}^{final} = 600\mu m - \frac{2.03}{1.56} \cong 599 \, \mu m.$$

PBR

b)



c) Total weight gain can be calculated from the oxide thickness as follows:

$$\delta = \delta^* + K_L[t - t^*] \quad \text{where}$$

$\delta^* = 2.03\ \mu m$

$K_L = 6.25 \times 10^{-3}$

$t = 365\ d$

$t^* = 315\ d$

$$= 2.03 + 6.25\times10^{-3}[365-315]$$

$$\delta = 2.34\ \mu m$$

$$w\ [mg/dm^2] = \delta \times 14.7 = 34.4\ mg/dm^2$$

d) Change in mass of the cladding, Δm, can be calculated as follows:

$$\boxed{w} = \frac{\boxed{\Delta m}}{\boxed{S}}$$

Δm → unknown

w → 34.4 mg/dm²

S → surface area $= \pi D L = \pi . [2\times 4.75\times10^{-2}][2.5\times10]$

$S = 7.46\ dm^2$

$$\Delta m = (34.4)(7.46)$$

$$\boxed{\Delta m = 256.6\ mg}$$

3) a) $$C_H^{clad}[\text{wt.ppm}] = \frac{m_H}{m_{Zr}} = 2f\,\frac{m_O}{m_{Zr}} = \frac{2f \times \delta \times \rho_{oxide} \times f^{O}_{ZrO_2} \times m_H/m_O}{\left(t - \frac{\delta}{PBR}\right) \times \rho_{metal}} \times 10^6$$

f : Hydrogen pickup fraction $= 0.15$

δ : Oxide thickness $= 100\ \mu m$

ρ_{oxide} : Oxide density $= 5.68\ g/cm^3$

$f^{O}_{ZrO_2}$: Fraction of oxygen in ZrO_2 $= \frac{m_{O_2}}{m_{ZrO_2}} = \frac{32}{91+32} = 0.26$

$\frac{m_H}{m_O} = \frac{\text{molecular mass of } H}{\text{" " " } O} = \frac{1}{16}$

PBR : Pilling - Bedworth Ratio $= 1.56$

ρ_{metal} : Density of Zr metal $= 6.5\ g/cm^3$

$$C_H^{clad} = \frac{2(0.15)(100)(5.68)(0.26)\cdot\left(1/16\right)}{\left(600 - \frac{100}{1.56}\right)6.5} \times 10^6$$

$$C_H^{clad} = 795 \text{ wt. ppm}$$

Total H content in the cladding $\longrightarrow$ $C_H^{total} = 795 + 20 = 815$ wt.ppm.

b) From Slide 15 of Lecture 33, the amount of hydride precipitate during cooling can be obtained with:

$$TSS_p = 30853.3 \exp\left[-\frac{25249.6}{RT}\right]$$ where $R = 8.314\ J/mol\text{-}K$, $T = 325 + 273 = 598\ K$

$= 192.18$ wt.ppm

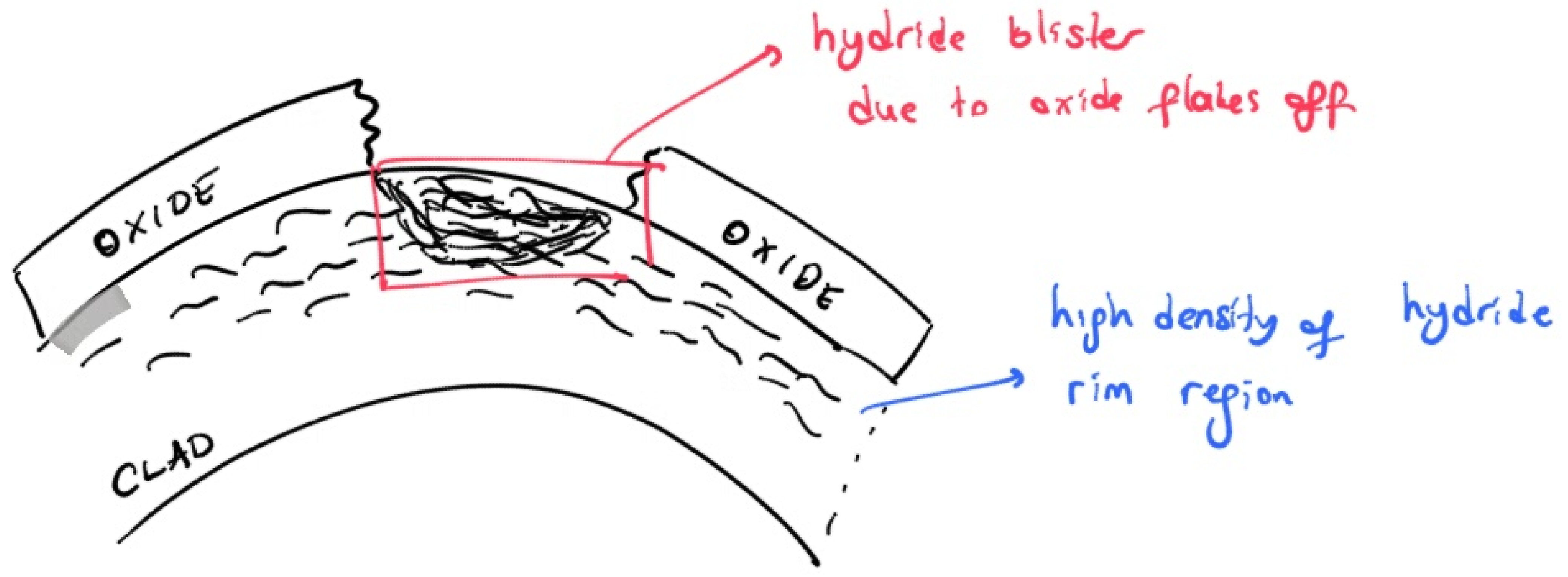
Then, $f_{precipitate} = \frac{192.18}{815} = 0.24$ or $24\ \%$

c) $$TSS_D = 111955 \exp\left[-\frac{35580}{RT}\right]$$ where $TSS_D = 815$ wt. ppm, $R = 8.314\ J/K\,mol$

$$815 = 111955 \exp\left[-\frac{35580}{8.314T}\right]$$

$$-4.923 = -\frac{4279.53}{T} \longrightarrow T = 869\ K \text{ or } 596\ °C$$

d)



Q-4)

a) CRUD forms on the cladding because of the corrosion of reactor components that the coolant water going through such as reactor internals, pipelines etc. These corrosion products are carried on and then ending up getting stuck to the cladding. They form on the cladding due to small regions of coolant boiling where small bubbles exist. CRUD deposits build up, accumulate and precipitate under the bubbles.

b)

1- Reduced heat transport: Due to their low thermal conductivity, CRUD reduces heat transport.

2- Increased radioactivity of the fuel rod: The corrosive products that are in the coolant can be activated as a result of neutron interaction and form radionuclides. If these products form CRUD, they will increase the overall radioactivity

3- CRUD induced power shift (CIPS): CRUD can be surrounded by boron. Then it absorbs more neutrons and change the power distribution.

4- CRUD induced localized corrosion (CILC): Due to poor heat transfer, CRUD can cause hot spots and cause localized corrosion.

c) 1- Addition of filters to the fuel assembly to block the junks and particles carried out from different part of the reactor.

2- Changing the core loading pattern to flatten peaking factors to reduce subcooled boiling and therefore minimize CILC risk.