1.) a.) Max stress?

$$\Delta T = \frac{LHR}{4\pi K}$$

Max $= \sigma_\theta,\ \eta = 1$

$$\Delta T = \frac{250}{4\pi(0.1)} = 199\,K$$

$$\sigma^* = \frac{\alpha E \Delta T}{4(1-\nu)}$$

$$\sigma^* = \frac{(8.2e\text{-}6)(290e3)(199)}{4(1-0.3)}$$

$$\sigma^* = 169\,MPa$$

$$\Rightarrow \sigma_\theta = -\sigma^*(1-3\eta^2)$$

$$\sigma_\theta = -169(1-3(1^2))$$

$$\boxed{\sigma_\theta = 338\,MPa}$$

b.) cracks?

$$\sigma_{fr} = 120\,MPa$$

$$\eta = \sqrt{\frac{\left(1+\frac{\sigma_{fr}}{\sigma^*}\right)}{3}}$$

$$\eta = \sqrt{\frac{\left(1+\frac{120}{169}\right)}{3}}$$

$$\boxed{\eta = 0.755}$$

2.) a.) all stresses?
– thin wall –

$R = 0.54\,cm$

$$\Rightarrow \sigma_\theta = \frac{PR}{\delta}$$

$$\sigma_\theta = \frac{50(0.54)}{0.12}$$

$$\boxed{\sigma_\theta = 225\,MPa}$$

$$\Rightarrow \sigma_z = \frac{1}{2}\sigma_\theta$$

$$\sigma_z = \frac{1}{2}(225)$$

$$\boxed{\sigma_z = 112.5\,MPa}$$

$$\Rightarrow \sigma_r = \frac{-P}{2}$$

$$\sigma_r = \frac{-50}{2}$$

$$\boxed{\sigma_r = -25\,MPa}$$

b.) – thick wall –

$r = 0.56\,cm \qquad r_i = R$

$$\Rightarrow \sigma_r = \frac{-P\left(\frac{r}{R}\right)^2 - 1}{\left(\frac{r}{R}\right)^2 - 1}$$

$$\sigma_r = \frac{50\left(\frac{0.56}{0.54}\right)^2 - 1}{\left(\frac{0.56}{0.54}\right)^2 - 1}$$

$$\boxed{\sigma_r = -699.5\,MPa}$$

$$\Rightarrow \sigma_\theta = \frac{P\left(\frac{r}{R}\right)^2 + 1}{\left(\frac{r}{R}\right)^2 - 1}$$

$$\sigma_\theta = \frac{50\left(\frac{0.56}{0.54}\right)^2 + 1}{\left(\frac{0.56}{0.54}\right)^2 - 1}$$

$$\boxed{\sigma_\theta = 726\,MPa}$$

$$\Rightarrow \sigma_z = \frac{P}{\left(\frac{r}{R}\right)^2 - 1}$$

$$\sigma_z = \frac{50}{\left(\frac{0.56}{0.54}\right)^2 - 1}$$

$$\boxed{\sigma_z = 662.7\,MPa}$$

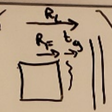
c.) Max strain?

$$\varepsilon_\theta = \frac{1}{E}\left(\sigma_\theta - \nu(\sigma_r + \sigma_z)\right)$$

$$\varepsilon_\theta = \frac{1}{180e3}\left(726 - 0.28\,[662.7 - 699.5]\right)$$

$$\boxed{\varepsilon_\theta = 0.004}$$

3.) Gap thickness change?



$R_c = R_F + t_g$

$R_c = 0.525$

$$\Delta t_c = R_c \alpha_c \Delta T_c$$

$$\Rightarrow T_{CI} = \frac{LHR \cdot t_c}{2\pi R_f k_c} + T_{co}$$

$$T_{CI} = \frac{(225)(0.08)}{2\pi(0.52)(0.15)} + 550$$

$$T_{CI} = 587\ K$$

$$\Rightarrow \Delta T_c = 587 - 300$$

$$\Delta T_c = 287\ K$$

$$\Rightarrow \Delta t_c = (0.525)(4.5e\text{-}6)(287)$$

$$\Delta t_c = 6.78e\text{-}4$$

$$\Delta T_F = \frac{LHR}{4\pi K}$$

$$\Delta T_F = \frac{225}{4\pi(0.05)} = 358\ K$$

$$\Rightarrow \Delta t_f = R_F \alpha_F \Delta T_F$$

$$\Delta t_f = (0.52)(1.5e\text{-}6)(358)$$

$$\Delta t_f = 2.79e\text{-}4$$

$$\Rightarrow \Delta t_g = 0.005 + 6.78e\text{-}4 - 2.79e\text{-}4$$

$$\boxed{\Delta t_g = 0.0054\ \text{cm}}$$

4.) # of gas atoms released?

assume spherical grain

$$V = \frac{\pi}{6} a^3 = \frac{\pi}{6}(8e\text{-}4)^3$$

$$V = 2.68e\text{-}10\ \text{cm}^3$$

$$\Rightarrow \dot{F} = N \phi \sigma_f V$$

$$\dot{F} = (2.5e22)(2e13)(550e\text{-}24)(2.68e\text{-}10)$$

$$\dot{F} = 73700$$

$$= 7.37e4$$

$$\Rightarrow \text{prod.} = y \dot{F} t$$

$$\text{prod.} = 0.3107(7.37e4)(6.307e7)$$

$$\text{prod.} = 1.44e12$$

$$\Rightarrow \tau = \frac{Dt}{a^2} = \frac{(2e\text{-}15)(6.307e7)}{(8e\text{-}4)^2}$$

$$\tau = 0.19$$

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

$$\Rightarrow f = 1 - \frac{0.0662}{\tau}\left(1 - 0.93e^{(-\pi^2 \tau)}\right)$$

$$f = 1 - \frac{0.0662}{0.19}\left(1 - 0.93e^{-\pi^2(0.19)}\right)$$

$$f = 0.705$$

$$\Rightarrow \text{release} = \text{prod}(f)$$

$$\text{release} = 0.705(1.44e12)$$

$$\boxed{\text{release} = 1.02e12\ X_e\ \text{atoms}}$$

5.) The use of permanent deformation to increase material strength

Dislocation pile-up

6.)
1. Melting Temp
2. Thermal Conductivity
3. Chemical reactions at cladding interface

7.)
1. Fuel
   - temp. profile
   - volumetric change
2. Cladding
   - temp profile
   - stress
3. Gap
   - heat transport
   - fuel-clad mechanical interaction
   - gap pressure

8.) Stage 1: gas atoms are produced in the fuel due to fission and diffuse towards grain boundaries

Stage 2: gas bubbles nucleate on grain boundaries, growing and interconnecting

Stage 3: gas travels through interconnected bubbles to a free surface

9.) Fission gas is retained, not released

A densely porous structure is formed due to grains subdividing

Intrinsic thermal cond. increases but material cond. decreases

10.) 0D defect: vacancy

3D defect: Void

11.) Densification - driving force is change in free energy from the decrease in pore surface area and lowering of surface free energy

Grain Growth - driving force is grain boundary migration

12.) U^{+4}

Possible: U^{+3}, U^{+4}, U^{+5}, U^{+6}