1.) a.) Max stress?

Max = σ_θ, $\eta = 1$

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

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

$\boxed{90}$

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

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

$$\sigma^* = 169\text{ MPa}$$

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

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

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

b.) cracks?

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

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

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

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

2.) a.) all stresses?
– thin wall –

$R = 0.54$ cm

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

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

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

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

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

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

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

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

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

b.) – thick wall –

$r = 0.56$ cm $\quad r_i = R$

Some are R_o/r

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

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

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

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

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

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

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

Some are R_o/R:

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

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

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c.) Max strain?

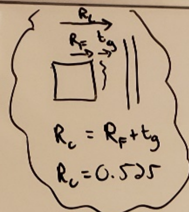
$$\varepsilon_\theta = \frac{1}{E}\left(\sigma_\theta - \nu(\sigma_r + \sigma_z)\right)$$

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

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

right eqn

3.) Gap thickness change?



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

$\Rightarrow T_{cI} = \dfrac{LHR \cdot t_c}{2\pi R_f k_c} + T_{cg}$

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

$T_{cI} = 587\ K$ ✓

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

$T_0 - T_s$: $\Delta T_F = \dfrac{225}{4\pi(0.05)} = 358\ K$

not equal

$\Rightarrow \Delta t_F = R_F \alpha_F \Delta T_F \rightarrow \overline{T}_F - T_{ref}$

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

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

$\overline{T}_c - T_{ref}$

$\Rightarrow \Delta T_c = 587 - 300$

$\Delta T_c = 287\ K$

$\overline{R}_c = R_F + t_g + \dfrac{t_c}{2}$

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

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

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

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

- right equations, but misunderstood concepts

4.) # of gas atoms released?

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assume spherical grain

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

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

- didn't need this, I asked for per volume

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

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

$\dot{F} = 73700$

$= 7.37e4$

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

prod. $= 0.3107(7.37e4)(6.307e7)$

prod. $= 1.44e12$

- I told you the fission rate

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

$\tau = 0.19$ ✓

$\tau > \pi^{-2}$ ✓

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

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

$f = 0.705$ ✓

$\Rightarrow$ release $=$ prod(f) ✓

release $= 0.705(1.44e12)$

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

- overlooked info in the problem statement

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

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Dislocation pile-up = yes, but I wanted more here

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

6/6

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

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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 ✓

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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

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10.) 0D defect: vacancy ✓

3D defect: Void ✓

4/4

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

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- migration allows for a reduction in GB length

12.) U^{+4} ✓ 4/4

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