

$$\textcircled{1} r_{\text{pu}} = 4.5 \text{ mm} \quad \dot{q} = 250 \text{ W/cm}$$

Jess Williams

$$a) \quad k = 0.1 \text{ W/cm} \cdot \text{K} \quad E = 290 \text{ GPa} \quad \nu = 0.3 \quad \alpha = 8.2 \times 10^{-6} / \text{K}$$

$$\sigma_{rr}(\eta) = -\sigma(1-\eta^2) \quad \eta = \frac{r}{r_f} \checkmark$$

$$\sigma_{\theta\theta}(\eta) = -\sigma(1-3\eta^2)$$

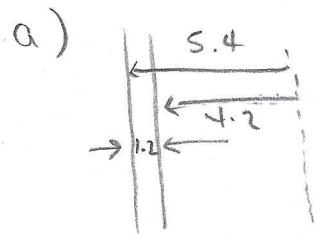
$$\sigma_{zz}(\eta) = -2\sigma(1-2\eta^2) \checkmark$$

- Starting on the right track...

4/14

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② $p = 50 \text{ MPa}$ $r_{\text{rad}} = 5.4 \text{ mm}$ $t_{\text{clad}} = 1.2 \text{ mm}$



Using thin wall cylinder approximation,
Can simplify to force balance

hoop $\bar{\sigma}_\theta = \frac{pR}{t_{\text{clad}}} = \frac{50 \text{ MPa} \cdot 5.4 \text{ mm}}{1.2 \text{ mm}} = \boxed{225 \text{ MPa} = \bar{\sigma}_\theta}$

$\bar{\sigma}_z = \frac{pR}{2t_{\text{clad}}} = \frac{50 \text{ MPa} \cdot 5.4 \text{ mm}}{2 \cdot 1.2 \text{ mm}} = \boxed{112.5 \text{ MPa} = \bar{\sigma}_z}$

inside wall

$\bar{\sigma}_r = -\frac{1}{2}p = -\frac{1}{2}(50 \text{ MPa}) = \boxed{-25 \text{ MPa} = \bar{\sigma}_r}$

b) $= 5.6 \text{ mm}$ assuming Thick walled

$R = 5.4$ $r_i = 4.2$ $R_o = 6.0$

$R_i = 5.4 \text{ mm} - 1.2 \text{ mm} = 4.2 \text{ mm}$

$\sigma_{rr}(r) = -p \frac{(R_o/r)^2 - 1}{(R_o/R_i)^2 - 1} = -50 \text{ MPa} \frac{(5.4/5.6)^2 - 1}{(5.4/4.2)^2 - 1}$
 $\boxed{\sigma_{rr}(5.6 \text{ mm}) = 5.37 \text{ MPa}}$

$\sigma_{\theta\theta}(r) = p \frac{(R_o/r)^2 + 1}{(R_o/R_i)^2 - 1} = 50 \text{ MPa} \frac{(5.4/5.6)^2 + 1}{(5.4/4.2)^2 - 1}$
 $\boxed{\sigma_{\theta\theta}(5.6 \text{ mm}) = 147.75 \text{ MPa}}$

$\sigma_{zz}(r) = p \frac{1}{(R_o/R_i)^2 - 1} = 50 \frac{1}{(5.4/4.2)^2 - 1}$

$\boxed{\sigma_{zz}(5.6 \text{ mm}) = 76.56 \text{ MPa}}$

- wrong radius, but
correct implementation

$$\textcircled{2}c) E = 180 \text{ GPa} \quad \nu = 0.28$$

$$G = \frac{E}{2(1+\nu)} = \frac{180 \text{ GPa}}{2(1.28)} = 70.31 \text{ GPa}$$

$$G \epsilon_{\max} = \sigma_{rr} + \sigma_{\theta\theta} + \sigma_{zz}$$

$$\epsilon_{\max} = \frac{\sigma_{rr} + \sigma_{\theta\theta} + \sigma_{zz}}{G} = \frac{5.37 + 147.75 + 76.56}{70.31 \times 10^3 \frac{\text{MPa}}{\text{MPa}}}$$

$$\epsilon_{\max} = 0.003$$

$$\epsilon_o = \frac{1}{E} \left(\sigma_o - \nu(\sigma_r + \sigma_z) \right)$$

$$\textcircled{3} R_f = 0.52 \text{ cm}$$

$$t_{\text{gap}} = 0.005 \text{ cm}$$

$$LH\eta = 225 \text{ W/cm}$$

$$T_{\text{ref}} = 300 \text{ K}$$

$$T_{\text{co}} = 550 \text{ K}$$

$$t_{\text{cded}} = 0.08 \text{ cm}$$

$$\alpha_c = 4.5 \times 10^{-6} \frac{1}{\text{K}}$$

$$\alpha_f = 15 \times 10^{-6} \frac{1}{\text{K}}$$

$$k_{\text{fuel}} = 0.05 \text{ W/cm K}$$

$$k_{\text{gap}} = 0.003 \text{ W/cm K}$$

$$k_{\text{cded}} = 0.15 \text{ W/cm K}$$

$$1.2 / 1.4$$

$$\bar{R}_c = R_f + t_{\text{gap}} + t_{\text{cded}} / 2 =$$

$$= 0.52 + 0.005 + 0.04 = 0.565 \text{ cm}$$

$$\Delta R_c = \bar{R}_c \alpha_c \Delta T = (0.565 \text{ cm}) (4.5 \times 10^{-6} \frac{1}{\text{K}}) (550 \text{ K} - 300 \text{ K})$$

$$= 6.35 \times 10^{-4} \text{ cm}$$

$$\bar{T}_c = (T_s + T_{\text{center}}) / 2 \quad T_{\text{center}} = \frac{225}{4\pi} \cdot 0.05 + T_s$$

$$\Delta R_f = R_f \alpha_f (\bar{T}_f - 300 \text{ K})$$

$$\Delta \delta_{\text{gap}} = \bar{R}_c \alpha_c (\bar{T}_c - T_{\text{ref}}) - \bar{R}_f \alpha_f (\bar{T}_f - T_{\text{ref}})$$

- on the way, and correct implementation

⑤ Strain hardening is when a material is permanently changed after a load. This happens when a material undergoes plastic deformation and retains permanent strain after unloading. *yes but wanted dislocation interaction*

⑥ melting temperature, thermal conductivity, chemical reactions between fuel + inner surface of clad

⑦ Predict temperature profile + volumetric change in fuel

6/6 predict temperature profile + stress in clad

6/6 predict gap heat transport + mechanical interaction between fuel + clad

⑧ Diffusion of gas atoms to grain boundaries

9/9 Growth + interconnection of grain boundary bubbles
transport gas atoms through bubbles to surface

⑨ HBS can lead to a densely porous structure, which degrades the material conductivity + reduces grain boundary size. *Can increase thermal conductivity*

⑩ 0D: Vacancies
4/4 3D: Voids

⑪ Fuel densification: change in free energy from decrease in surface area of pores + bounding surface free energy

6/6 grain growth: reduction of grain boundary energy, temperature gradients, elastic energy gradients, dislocation energy gradients

(2) U^{4+} ✓ is the most stable for UO_2 -
possible: U^{3+} , U^{4+} , U^{5+} , U^{6+} $\frac{4}{4}$