① $r_{pel} = 4.5$ mm $\dot{q} = 250$ W/cm Jess Williams

a) $k = 0.1$ W/cm·K $E = 290$ GPa $\nu = 0.3$ $\alpha = 8.2e{-6}/K$

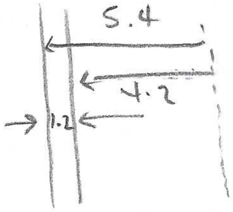
$$\sigma_{rr}(\eta) = -\sigma(1-\eta^2) \qquad \eta = \frac{r}{R_F}$$

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

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

② $p = 50$ MPa $r_{rod} = 5.4$ mm $t_{clad} = 1.2$ mm

a)



Using thin wall cylinder approximation, can simplify to force balance

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

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

inside wall

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

b) $= 5.6$ mm assuming thick walled

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

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

$\boxed{\sigma_{rr}(5.6 \text{ mm}) = 5.37 \text{ MPa}}$

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

$\boxed{\sigma_{\theta\theta}(5.6 \text{mm}) = 147.75 \text{ MPa}}$

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

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

② c) $E = 180\ GPa \quad \nu = 0.28$

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

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

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

$$\varepsilon_{max} = 0.003$$

(3) $R_f = 0.52$ cm　　$T_{co} = 550$ K　　$k_{fuel} = 0.05$ W/cm K

$t_{gap} = 0.005$ cm　　$t_{clad} = 0.08$ cm　　$k_{gap} = 0.003$ W/cm K

LHR $= 225$ W/cm　　$\alpha_c = 4.5 \times 10^{-6} \frac{1}{K}$　　$k_{clad} = 0.15$ W/cmK

$T_{ref} = 300$ K　　$\alpha_f = 15 \times 10^{-6} \frac{1}{K}$

$$\overline{R_c} = R_f + t_{gap} + t_{clad}/2 =$$
$$= 0.52 + 0.005 + 0.04 = 0.565 \text{ cm}$$

$$\Delta R_c = \overline{R_c}\,\alpha_c\,\Delta T = (0.565 \text{ cm})(4.5e{-6}\tfrac{1}{K})(550K - 300K)$$
$$= 6.35 \times 10^{-4} \text{ cm}$$

$$\overline{T_f} = (T_s + T_{center})/2 \qquad T_{center} = \frac{225}{4\pi \cdot 0.05} + T_s$$

$$\Delta R_f = R_f\,\alpha_f\,(\overline{T_f} - 300K)$$

$$\Delta \delta_{gap} = \overline{R_c}\,\alpha_c(\overline{T_c} - T_{ref}) - \overline{R_f}\,\alpha_f(\overline{T_f} - T_{fab})$$

(5) Strain hardening is when a material is permenently changed after a load. This happens when a material undergoes plastic deformation and retains permenent strain after unloading.

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

(7) Predict temperature profile + volumetric change in fuel
predict temperature profile + stress in clad
predict gap heat transport + mechanical interaction between fuel + clad

(8) Diffusion of gas atoms to grain boundaries
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.

(10) 0D: Vacancies
3D: Voids

(11) Fuel densification: change in free energy from decrease in surface area of pores + lowing surface free energy
grain growth: reduction of grain boundary energy, temperature gradients, elastic energy gradients, dislocation energy gradients

(12) U^{4+} is the most stable for UO_2.
possible: U^{3+}, U^{4+}, U^{5+}, U^{6+}