

⑩ Zircaloy Clad fuel rod w/ $P = 20 \text{ MPa}$
 $R_c = 5.4 \text{ mm} = 0.54 \text{ cm}$ & $t_{clad} = 0.8 \text{ mm} = 0.08 \text{ cm}$

(a) Calc stress components assuming thin walled approx

$$\frac{R_i + R_o}{2} = 0.54 \quad t_c = R_o - R_i$$

2 unknowns → solve
↓
 $R_o = t_c + R_i$

$$\frac{t_c + R_i + R_o}{2} = 0.54$$

$$\frac{0.08 \text{ cm} + 2R_i}{2} = 0.54 \Rightarrow R_i = 0.5 \text{ cm}$$
$$R_o = 0.58 \text{ cm}$$

$$\sigma_\theta = \frac{P R_c}{8} = \frac{(20 \text{ MPa})(0.54 \text{ cm})}{0.08 \text{ cm}}$$

$$(\sigma_\theta = 135 \text{ MPa})$$

$$\sigma_r = -\frac{P}{2} = -10 \text{ MPa}$$

$$\sigma_z = \frac{P R_c}{28} = \frac{\sigma_\theta}{2} = 67.5 \text{ MPa}$$

12 cont. See excel tab for 12
W/ thermal exp

$$\Delta \delta_{gap} = \bar{R}_c \alpha_c (\bar{T}_c - T_{c\text{ Ref}}) - \bar{R}_F \alpha_F (\bar{T}_F - T_{F\text{ Ref}})$$

$$\begin{aligned}\bar{R}_c &= R_F + t_{gap} + \frac{t_c}{2} \\ &= 0.5 \text{ cm} + 0.02 \text{ cm} + \underline{0.52 \text{ cm}} / 2\end{aligned}$$

letting $t_c \approx R_i = 0.5 + 0.02 = 0.52 \text{ cm}$

$$R_c = 0.78 \text{ cm}$$

assume $T_{ci} = \bar{T}_c$

$$\begin{aligned}\Delta \bar{R}_c &= (0.78 \text{ cm})(4.5 \times 10^{-6} \text{ K}^{-1})(450 \text{ K} - 300 \text{ K}) \\ &= 5.27 \times 10^{-4} \text{ cm}\end{aligned}$$

$$\Delta \bar{R}_F = R_F \alpha_F (\bar{T}_F - T_{F\text{ Ref}})$$

$$\bar{T}_F = \frac{T_0 + T_S}{2}$$

$$T_S = - \left[\frac{LHR}{4\pi k_F} - T_0 \right] = 501.73 \text{ K}$$

so

$$\bar{T}_F = 760.35 \text{ K}$$

$$\Delta R_F = 3.45 \times 10^{-3} \text{ cm}$$

$$\text{so } \Delta \delta_{gap} = +2.93 \times 10^{-3} \text{ cm}$$

do only 1 iteration for gap thickness

(12) $R_F = 0.5 \text{ cm}, t_{gap} = 0.02 \text{ cm}; T_{C1} = 450 \text{ K}$
 $k_F = 0.05 \text{ W/cm}\cdot\text{K}; k_{gap} = 0.04 \text{ W/cm}\cdot\text{K}$

$$R_C = 0.15 \text{ W/cm}\cdot\text{K}; LHR = 325 \text{ W/cm}$$

$$\alpha_C = 4.5 \times 10^{-6} \text{ K}^{-1}; \alpha_F = 15 \times 10^{-6} \text{ K}^{-1}$$

$$T_F^{\text{Ref}} = T_C^{\text{Ref}} = 300 \text{ K}$$

centerline T, T_0^F (w/o thermal exp)

$$T_{Fuel} - T_{C1} = \frac{(LHR)t_{gap}}{2\pi R_{Fuel} k_{gap}} = \frac{2T - \bar{T}}{2\pi R_{Fuel} k_{gap}}$$

$$= \frac{(325 \text{ W/cm})(0.02 \text{ cm})}{2\pi (0.5 \text{ cm})(0.04 \text{ W/cm}\cdot\text{K})}$$

$$= 51.73 \text{ K}$$

$$T_{Fuel} = 51.73 \text{ K} + 450 = 501.73$$

$$T_0 = T_{Fuel} + \frac{LHR}{4\pi R_{Fuel}} = 501.73 + \frac{325}{4\pi (0.05)}$$

$$= 501.73 + \frac{325 \text{ W/cm}}{4\pi (0.05 \text{ W/cm})}$$

w/o thermal exp

$$T_0 = 1018.98 \text{ K}$$

$$t_{gap}^{new} = t_0 + \Delta \delta_{gap} = 1.71 \times 10^{-2} \text{ cm}$$

$$R_F^{new} = \Delta R_r + R_F^0 = 0.503 \text{ cm}$$

Resolve for T_0

$$T_F = \frac{(LHR) t_{gap}^{new}}{2\pi R_F k_{gap}} + T_{C1} = 493.85 \text{ K}$$

$$T_0 = T_F + \frac{LHR}{4\pi k_F} = 1011.21 \text{ K}$$

(B) $R_F = 0.55\text{cm}; N = 0.25, E = 210 \text{ GPa} = 2.1 \times 10^5 \text{ MPa}$
 $LHR = 200 \text{ W/cm}; \alpha_F = 10.5 \times 10^{-6} \text{ K}^{-1} \quad \sigma_{fract} = 120 \text{ MPa}$
 $k_F = 0.05 \frac{\text{W}}{\text{cm} \cdot \text{K}}$

$$\eta = \frac{r}{R_F} \quad \& \quad \sigma^* = \frac{\alpha E (T_0 - T_s)}{4(1-N)}$$

$$T_0 - T_s = \frac{(LHR)}{4\pi k_F} = \frac{(200 \text{ W/cm})}{4\pi (0.05 \text{ W/cm} \cdot \text{K})} = 318.31 \text{ K}$$

$$\sigma^* = \frac{(\alpha \times 10^{-6} \text{ K}^{-1})(E)(T_0 - T_s)}{4(1-N)} = \frac{(10.5 \times 10^{-6} \text{ K}^{-1})(2.1 \times 10^5 \text{ MPa})(318.31 \text{ K})}{4(1-0.25)} = 2.34 \times 10^2 \text{ MPa}$$

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

Letting $\sigma_{\theta\theta} = \sigma_{fract}$ & solving for r

$$120 \text{ MPa} = -(2.34 \times 10^2 \text{ MPa}) (1 - 3(r^2/R_F^2))$$

$$-5.13 \times 10^{-1} = 1 - 3[r^2/0.3025 \text{ cm}^2]$$

$$-1.513 = -3 r^2 / 0.3025 \text{ cm}^2$$

$$0.504 = r^2 / 0.3025 \text{ cm}^2$$

$$0.153 \text{ cm}^2 = r^2 \rightarrow r = 0.391 \text{ cm}$$