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64/100

NucE 497 Fuel Performance Exam 1 covering modules 1 - 3 -8, 22/30

Question 1:

U_3Si_5 is a uranium silicide fuel being considered for use in light water reactors. It has a thermal conductivity of 12.5 W/(m K) and a density of Uranium metal of 7.5 g of U/cm³. Answer the following questions $k = 12.5 \frac{W}{m \cdot k}$ $\rho = 7.5 g\ U/cm^3$

a) What is the fissile isotope in U_3Si_5? What would be the enrichment of this isotope in the natural (unenriched) form of the fuel? (7 points) $q = ?$

$N = 2Z - (43 \pm 2)$ U-235

$N = 2(92) - [41, 42, 43, 44, 45]$ 0.7%

U-231; U-235

b) What enrichment would be required for U_3Si_5 to have the same energy release rate of U_3Si_2 enriched to 3% with a neutron flux of 3.2e13 n/(cm² s)? You can assume that U_{235} has a negligible impact on the total molar mass of U in the fuel (15 points) $\phi_{th} = 3.2 \times 10^{13}\ n/cm^2 \cdot s$ $q = 0.03$ $M_U = 238$

$M_{U_3Si_2} : 3(238) + 2 * 28 = 770\ g/mol$ $Q = E N \sigma \phi_{th}$

$$N_{U235} = \frac{0.03(6.022 \times 10^{23})(7.5\ g/cm^3)}{770\ g/mol} = 1.75 \times 10^{20}\ atoms/cm^3$$

$$Q = (3 \times 10^{-11}\ J/fission)(1.75 \times 10^{20}\ atoms/cm^3)(5.5 \times 10^{-22}\ cm^2)(3.2 \times 10^{13}\ n/cm^2 \cdot s)$$

$$Q = 92.4\ W/cm^3$$

$M_{U_3Si_5} = 3(238) + 5 \times 28 = 854\ g/mol$

-5, Use ratio of U densities

$$1.75 \times 10^{20}\ atoms/cm^3 = \frac{q(6.022 \times 10^{23})(7.5\ g/cm^3)}{854\ g/mol}$$

$\boxed{q = 0.033 = 3.3\%}$

c) How would you rank U_3Si_5 as a potential fuel compared to U_3Si_2? Why? (8 points)

-3, thermal conductivity?

U_3Si_2 is preferred because it has a lower enrichment percentage.

$R_F = 0.45cm$ $T_{cool} = 580K$

$h_{gap} = \frac{k_{gap}}{t_c}$ $\delta_g = 80\mu m = 0.008cm$ He .5 Xe

x_c? $t_c = 0.06cm$ $h_{cool} = 2.5 \, W/cm^2 \cdot K$

$Q = 250 \frac{W}{cm}$

Question 2: -12, 23/35

Consider a fuel rod with a pellet radius of 4.5 mm, an 80 micron gap, and a zircaloy cladding thickness of 0.6 mm. It is experiencing a linear heat rate of 250 W/cm with a coolant temperature of 580 K. The gap is filled with He and 5% Xe and the coolant conductance is 2.5 W/(cm² K). 0.00340116

a) What is the surface temperature of the fuel rod? (15 points)

Coolant: $\frac{250 \frac{W}{cm}}{2(2.5 \frac{W}{cm^2 \cdot K})}(0.45cm) + 580K = 602.5K$

-1, TCO = 615.4 K

$k_{gap} = \left[(16\times10^{-6})(605)^{.79}\right]^{.95}\left[(0.7\times10^{-6})(608)^{.79}\right]^{.05}$

$h_{gap} = \frac{0.0021565 \; W/cm \cdot k}{0.06cm}$

Clad: $\frac{250 W/cm}{2(0.17 W/cm \cdot k)}(0.45cm)(0.008cm) + 602.5k = 605.147$ -2, Mistake in Eqn

-2 Should be 80 microns

Fuel: $T_m = \frac{250 W/cm}{?\boxed{(0.03 W/cm \cdot k)}}(0.45cm)^2 + 2169.9K$

Gap: $T_s = \frac{250 W/cm}{2(0.03594)}(0.45cm) + 605K = 2169.9K$

h_{gap}

-1, Mistake in Eqn

$\boxed{T_m = 2591.775K}$

b) Assume the pellet is made from Uranium Nitride. What is the maximum stress experienced by the pellet, given that uranium nitride has E = 246.7 GPa, ν = 0.25, and α = 7.5e-6 1/K? (10 points)

-5 Wrong conductivity, equation wrong

$$\sigma^* = \frac{\alpha E (T_0 - T_s)}{4(1-\nu)} \qquad \sigma_{\theta\theta}(\eta) = -\sigma^*(1-3\eta^2)$$

$$\sigma^* = \frac{(7.5\times10^{-6}\frac{1}{K})(246.7GPa)(2591.775K - 2169.9K)}{4(1-0.25)} = 0.26GPa$$

$$\sigma_{\theta\theta}(\eta) = -0.26(1-3(1)^2) = \boxed{0.52GPa}$$

c) Would you expect this stress to be higher or lower if the pellet was UO_2? Why? (5 points)

Higher because UO_2 has poor thermal conductivity which would produce a larger temperature difference.

d) What assumptions were made in your calculations for a) and b)? (5 points)

- Steady state
- axisymmetric
- T constant in Z
- k independent of T

-1, there are several more assumptions

$P = 6\,MPa$

$r = 5.6mm = 0.56cm$

-16, 19/35

Question 3: $t_c = 0.6mm = 0.06cm$

Consider the stress state in a zircaloy fuel rod pressurized to 6 MPa with an average radius of 5.6 mm and a cladding thickness of 0.6 mm.

a) What assumptions are made in the thin walled cylinder approximation for the stress state? (5 points)

- Gravity negligible
- Static body
- Axisymmetric
- Stress constant throughout

b) Calculate all three components of the stress using the thin walled cylinder approximation. (10 points)

$\bar{\sigma}_\theta = \frac{PR}{\delta}$ $\qquad$ $\bar{\sigma}_z = \frac{PR}{2\delta}$ $\qquad$ $\bar{\sigma}_r = -\frac{1}{2}P$

$\sigma_\theta = \frac{(6MPa)(0.56cm)}{0.06cm}$ $\qquad$ $\bar{\sigma}_z = \frac{(6MPa)(0.56cm)}{2(0.06cm)}$ $\qquad$ $\bar{\sigma}_r = -\frac{1}{2}(6MPa)$

$\boxed{\bar{\sigma}_\theta = 56MPa}$ $\qquad$ $\boxed{\bar{\sigma}_z = 28MPa}$ $\qquad$ $\boxed{\bar{\sigma}_r = -3MPa}$

c) Quantify how accurate the thin walled cylinder approximation is for the cladding. Would the thin walled cylinder approximation be conservative if used to estimate if the cladding would fail? (10 points)

Thin wall approx. would not be very accurate. Thick wall would take into account the thermal stress due to temperature gradient

-10, Calculate stress using thick wall equation at two radii and see if they are the same, then compare to part b

d) Write the stress and strain tensors for the stress state in the thin walled cylinder, with E = 70 GPa and ν = 0.41. (10 points)

$r = 0.56cm$

$u_{rr} = 2r/5$

$u_r/r = r/5$

$$\begin{bmatrix} \sigma_{rr} \\ \sigma_{\theta\theta} \end{bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu \\ \nu & 1-\nu \end{bmatrix} \begin{bmatrix} u_{r,r} \\ u_r/r \end{bmatrix}$$

$$\epsilon = \begin{bmatrix} u_{rr} & 0 \\ 0 & u_r/r \end{bmatrix}$$

$$\epsilon = \begin{bmatrix} 0.224 & 0 \\ 0 & 0.112 \end{bmatrix}$$

$$C_{11} = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} = \frac{70(1-0.41)}{(1.41)(1-2(.41))} = 162.73GPa$$

$$C_{12} = \frac{E\nu}{(1+\nu)(1-2\nu)} = \frac{70(0.41)}{(1.41)(1-2(.41))} = 113.08GPa$$

$\epsilon_{rr} = 0.224$

$\epsilon_{\theta\theta} = 0.112$

$\sigma_{rr} = (0.224)(162.73GPa) + (0.112)(113.08GPa) = \boxed{51.72GPa}$

$\sigma_{\theta\theta} = (0.112)(162.73GPa) + (0.224)(113.08GPa) = \boxed{43.56GPa}$

-2, stress and strain missing zz component

-4, Calculate strains from stress from part b