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78.5/100

NucE 497 Fuel Performance Exam 1 covering modules 1 - 3

-6.5, 23.5/30

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

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)

Uranium its natural enrichment is .7%

-3.5, What is fissile isotope?

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)

3.2×10^{13}

$N_U = \frac{\rho_U N_A q}{M_U}$

$N_{U_3Si_2} = U_3Si_5$

7.5

$\frac{\rho_U N_A q}{M_U} = \frac{\rho_U N_A q}{M_U} \rightarrow \frac{q_{Si_2}}{M_{U_{Si_2}}} = \frac{q_{Si_5}}{M_{Si_5}}$

-3, Use U densities

$\frac{q}{M_{U_{Si_5}}} = \frac{.03}{M_{U_{Si_2}}} \rightarrow q = \frac{.03(3 \cdot 238 + 5 \cdot 28)}{3 \cdot 238 + (2 \cdot 28)}$

3.327% enrichment

$q = 0.03327$

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

U_3Si_5 is likely a worse fuel then U_3Si_2 because to get the same energy out of the fuel a much higher enrichment. Its thermal conductance is lower as it is composed of less Uranium

$k_c = .7$

$h_{gap} = \frac{k_{gap}}{t_G}$

Question 2:

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).

-1, 34/35

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

$T_{c6} = \frac{LHR}{2\pi R_f h_{cool}} + T_{cool} = \frac{250}{(2.5)2\pi(.45)} + 580 = 615\ K$

$T_{c1} = \frac{LHR\, t_c}{2\pi R_f k_c} + 615 = \frac{250(.06)}{2\pi(.45)(.7)} + 615 = 646\ K$

$T_s = \frac{LHR}{2\pi R_f h_{gap}} + T_{c1} = \frac{250}{2\pi(.45)(\ )} + 615 = 958\ K$

$k_{gap} = \frac{k_{gas}}{t_g}$ $\quad h_{gap} = \frac{0.00227}{.008}$

$k_{He} = 0.000265$

$k_{Xe} = 0.000116$

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)

$T_o - T_s = \frac{LHR}{4\pi k} = \frac{250}{4\pi(.2)} + 958 = 1058$

$\sigma^* = \frac{\alpha E (T_o - T_s)}{4(1-\nu)} = \frac{7.5 \times 10^{-6}(246.7)(1058-958)}{4(1-.25)} = 6.3\ MPa$

$\sigma_{\theta\theta} = -\sigma^*(1-3\nu^2) = 2\sigma^* = \boxed{12.6\ MPa}$

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

Yes

Higher temperature difference increase σ^* which increases hoop stress

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

Neglect gravity

Static body

not assymetric

Isotropic material

-1, several more assumptions were made

Question 3: -14, 21/35

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)

Stress is constant across the hoop

-2, small strain and isotropic

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

$\sigma_\theta = \frac{PR}{\delta}$ $\sigma_z = \frac{PR}{2\delta}$ $\sigma_r = -\frac{1}{2}P$

$\sigma_\theta = \frac{6(5.6)}{.6} = 56$ $\sigma_z = \frac{6(5.6)}{2(.6)} = 28$ $\sigma_r = -3$ MPa

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)

Non Conservativ

Thin wall is non conservative because it assumes average stress at all points, where thick wall accounts for stress concentration

max at $R = R_i$

$\sigma_{\theta\theta}(r) = P\frac{(R_o/R_i)^2+1}{(R_o/R_i)^2-1} = 59.15$ this is about 5.3% larger.

-4, Check stress at multiple radii to see if it is constant

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)

$\epsilon_{rr} = \frac{1}{E}(\sigma_{rr} - \nu(\sigma_{\theta\theta} + \sigma_{zz})) = \frac{1}{70\times10^3}(-3 - .41(56+28)) = -5.348\times10^{-4}$

$\epsilon_{\theta\theta} = \frac{1}{E}(\sigma_{\theta\theta} - \nu(\sigma_{rr}+\sigma_{zz})) = \frac{1}{70\times10^3}(56 - .4$ $= 8.45\times10^{-5}$

$\epsilon_{zz} = \frac{1}{E}(\sigma_{zz} - \nu(\sigma_{\theta\theta}+\sigma_{rr}))$ $= 8.457\times10^{-5}$

-4, no tensors

-4, last two strains are incorrect

$\epsilon_\theta = 6.53\times10^{-5}$

$\sigma_\theta = 56$ $\sigma_r = -3$

$\sigma_z = 28$