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84/100

NucE 497 Fuel Performance Exam 1 covering modules 1 - 3

-5, 25/30

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/cm^3. 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)

U^{235} The natural enrichment is 0.7%

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/(cm^2 s)? You can assume that U_{235} has a negligible impact on the total molar mass of U in the fuel (15 points)

$$M_{u_{Si_2}} = 3\cdot(235(.03) + 238(1-.03)) + 2\cdot(28) = 769.73$$

$$M_u = 3(238(1-q)) + 5\cdot 28 =$$

-5, Just use U densities

$$N_{u_{Si_2}} = \frac{(7.5)(6.022E23)(.03)}{769.73} = 1.76E20$$

$$q = \frac{1.76E20\,(854)}{7.5(6.022E23)}$$

$$Q = \cancel{E_f} N_{f_{Si_2}} \cancel{\sigma_f} \cancel{\phi_{th}} = \cancel{E_f} N_{f_{Si_5}} \cancel{\sigma_f} \cancel{\phi_{th}}$$

$$\boxed{q = .03327}$$

$$1.76E20 = \frac{(7.5)(6.022E23)\,q}{3(238)+5\cdot 28} \Rightarrow \frac{1.76E20}{7.5(6.022E23)} = \frac{q}{714+5\cdot 28}$$

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

It would rank lower than U_3Si_2 because it needs a higher enrichment and also the thermal conductivity is lower which results in worse heat transfer

$k_{He} = 16e^{-6} (646.5668)^{.79} = .00265$

$k_{xe} = .7e{-6}(646.5668)^{.79} = 1.1677e{-4}$

$k_{gap} = .00265^{.95} (1.1677e{-4})^{.05}$

$k_{gap} = .002266$

$h_{gap} = \frac{k_{gap}}{t_g} = .2833$

LHR = 250 W/cm

$r_f = .45cm$

$t_g = .008cm$

$t_c = .06cm$

$T_{co} - 580 = \frac{250}{2\pi(.45)2.5} \Rightarrow T_{co}$

$T_{co} = 615.36$

$T_{c1} - 615.36 = \frac{250(.06)}{2\pi(.45)(.17)}$

$T_{c1} = 646.5668$

-1, 34/35

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).

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

$$T_s - 646.5668 = \frac{250}{2\pi(.45)(.2833)}$$

$$\boxed{T_s = 958.67\,°K}$$

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)

$k_{UN} = .2 \ \frac{W}{cm\,K}$

$\eta = 1$

$$\sigma^* = \frac{7.5e{-6}(246.7E9)(1058.141 - 958.67)}{4(1-.25)}$$

$$T_0 - 958.67 = \frac{250}{4\pi(.2)}$$

$$T_0 = 1058.141\,°K$$

$$\sigma^* = 61.3 \text{ MPa}$$

$$\sigma_{\theta\theta} = -\sigma^*(1-3\eta^2) = -61.3 \text{ MPa} \cdot (-2) = \boxed{122.69 \text{ MPa}}$$

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

It would be higher because the lower thermal conductivity which would make a higher temperature gradient resulting in a higher stress

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

1) Static body
2) Gravity negligible
3) Problem is axisymmetric
4) Isotropic material response

-1, there are several more assumptions

-11, 24/35

Question 3:
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)

The stress is constant through the wall of the cylinder

-2, Isotropic, small strain

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

$$\sigma_\theta = \frac{6\,MPa\,(5.6mm)}{.6mm} = \boxed{56\,MPa} \qquad \sigma_r = -\tfrac{1}{2}(6) = \boxed{-3\,MPa}$$

$$\sigma_z = \frac{6\,MPa\,(5.6)}{2(.6)} = \boxed{28\,MPa}$$

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)

-4, Compute stress at two radii and see if they vary, Outer radius is at 5.9 mm

$$\sigma_{\theta\theta}(r) = -p\frac{\left(\frac{R_o}{r}\right)^2+1}{\left(\frac{R_o}{R_i}\right)^2-1} = -6MPa\,\frac{\left(\frac{6.2}{5.6}\right)^2+1}{\left(\frac{6.2}{5.6}\right)^2+1} = 59.15$$

$r=R_{max}$

$$100 \cdot \frac{59.15-56}{59.15} = \boxed{\sim 5.3\%\ \text{difference}}$$

The thin wall approximation is non-conservative because it is assuming an average stress rather than stress variance

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)

$$\epsilon_{\theta\theta} = \frac{1}{\underset{E}{70\,GPA}}\left(\overset{\sigma_\theta}{56MPa} - \underset{\nu}{.41}(\overset{\sigma_z}{28} + \overset{\sigma_r}{-3\,MPa})\right) = \boxed{6.53E-4}$$

$$\epsilon_{rr} = \frac{1}{70}\left(-3 - .41(28+56)\right) = \boxed{5.348E-4}$$

-1, Should be minus

$$\epsilon_{zz} = \frac{1}{70}\left(28 - .41(56-3)\right) = \boxed{8.957E-5}$$

$\boxed{\sigma_\theta = 56\,MPa}$

$\boxed{\sigma_z = 28\,MPa}$ $\boxed{\sigma_r = -3\,MPa}$

-4, Write stress and strain in tensor form