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79/100

NucE 497 Fuel Performance Exam 1 covering modules 1 - 3

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

-6, 24/30

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-235 is the fissile isotope.

Unenriched uranium fuel only has 0.711% Uranium-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)**

$Q = E_f N_f^{235} \sigma_f^{235} \phi_{th}$

$N_f^{Si_2} = \frac{\rho N_A g}{M}$, $M = 3(235(1-0.03) + 238(0.03)) + 28(2)$
$= 761.27$ g/mol

$N_f^{Si_2} = \frac{(1.31)(6.022\times10^{23})(0.03)}{761.27} = 2.68\times10^{20} \frac{1}{cm^3} = N_f^{Si_5}$

$2.68\times10^{20} = \frac{(7.5)(6.022\times10^{23})g}{M} \Rightarrow g = \frac{2.68\times10^{20} M}{(7.5)(6.022\times10^{23})}$

-3, M is molar mass of U (238)

where $M = 3[235(1-0.03) + 238(0.03)] + 5(28)$
$= 845.27 \frac{g}{mol}$

$g = \frac{(2.68\times10^{20})(845.27)}{(7.5)(6.022\times10^{23})} \times 100 = \boxed{5.016\ \%}$

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

U_3Si_5 would rank lower than U_3Si_2 since you would have to enrich U_3Si_5 by 5% to achieve the same energy release rate.

-3, thermal conductivity?

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Question 2:

-1, 34/35

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).

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

$K_{Zr} = 0.17$

$T_{co} = \frac{LHR}{2\pi R_f h_{cool}} + T_{cool} = \frac{250}{2\pi(0.45)(2.5)} + 580 = 615.37\,K$

$T_{ci} = \frac{LHR\, t_c}{2\pi R_f K_c} + T_{co} = \frac{250(0.06\,cm)}{2\pi(0.45)(0.17)} + 615.37 = 646.58\,K$

$h_{gap} = \frac{K_{gap}}{t_G}$; $K_{He} = 16\times10^{-6} T_i^{0.79} = 2.66\times10^{-3}$

$K_{Xe} = 0.7\times10^{-6} T_i^{0.79} = 1.16\times10^{-4}$

$K_{gap} = K_{He}^{1.95} K_{Xe}^{0.05}$

$K_{gap} = 2.27\times10^{-3}$

$h_{gap} = \frac{2.27\times10^{-3}}{80\times10^{-4}} = 0.2837$

$T_s = \frac{LHR}{2\pi R_f h_{gap}} + T_{ci}$

$= \frac{250}{2\pi(0.45)(0.2837)} + 646.58$

$= \boxed{958.25\,K}$

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)

$\sigma^* = \frac{\alpha E(T_0 - T_s)}{4(1-\nu)}$, $T_0 = \frac{LHR}{4\pi K} + T_s = \frac{250}{4\pi(0.2)} + 958.25 = 1057.7\,K$

$\sigma^* = \frac{(7.5\times10^{-6})(246.7\times10^9)[1057.7-958.25]}{4(1-0.25)} = 61.16\,MPa$

Max stress => hoop $\quad \eta = \frac{r}{R_f} \Rightarrow r = R_f \Rightarrow \eta = 1$

$\sigma_{\theta\theta} = -\sigma^*(1-3\eta^2) = -(61.16\,MPa)(1-3) = \boxed{122.32\,MPa}$

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

Assuming all values stay the same aside for the K value, we would expect to see the stress be higher if the pellet was UO_2. This is because the K value for UO_2 is much smaller, this will then result in T_0 being a higher value, resulting in an increase in stress.

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

Steady State

-1, There are several more assumptions

Axisymmetric

T is constant in Z

Thermal conductivity K is independent of T

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-14, 21/35

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)

$$\bar{\sigma}_\theta = \frac{pR}{\delta}, \quad \bar{\sigma}_z = \frac{pR}{2\delta}, \quad \bar{\sigma}_r = -\frac{1}{2}p$$

-5, Small strains, isotropic, stress is constant through radius

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

$$\bar{\sigma}_\theta = \frac{(6\,MPa)(5.6\,mm)}{(0.6\,mm)} = \boxed{56\,MPa}$$

$$\bar{\sigma}_r = -\frac{1}{2}(6\,MPa) = \boxed{-3\,MPa}$$

$$\bar{\sigma}_z = \frac{(6\,MPa)(5.6\,mm)}{2\,(0.6\,mm)} = \boxed{28\,MPa}$$

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)

$$\sigma_{\theta\theta}(r) = p\,\frac{(R_o/r)^2+1}{(R_o/R_i)^2-1}, \text{ where } R_o = 5.9\,mm \text{ and } r_{max} = R_i = 5.3\,mm$$

-4, test stress at multiple radii and see if it changes

$$= (6\,MPa)\left[\frac{(5.9/5.3)^2+1}{(5.9/5.3)^2-1}\right] = \boxed{56.16\,MPa}$$

$$\%error = \frac{56.16-56}{56.16} \times 100 = \boxed{0.285\%}$$

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)

-2 No stress tensor
-1 Didn't actually calculate strains
-2 No strain tensor

$$\begin{bmatrix} \sigma_{rr} \\ \sigma_{zz} \\ \sigma_{\theta\theta} \end{bmatrix} = \frac{1}{70\,GPa} \begin{bmatrix} 1 & -0.41 & -0.41 \\ -0.41 & 1 & -0.41 \\ -0.41 & -0.41 & 1 \end{bmatrix} \begin{bmatrix} \varepsilon_{rr} \\ \varepsilon_{zz} \\ \varepsilon_{\theta\theta} \end{bmatrix}$$