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66/100

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

$k = 125$ W/mK

$\rho_u = 7.5 g/cm^3$

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)

The fissile isotope in U_3Si_5 is Uranium 235. The enrichment of U-235 in natural uranium 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/(cm² s)? You can assume that U_{235} has a negligible impact on the total molar mass of U in the fuel (15 points)

U_3Si_5

$3(238)+5(28) = 854$

$\varphi = 3.2 \cdot 10^{13}$

$N_u = \rho_{U_3Si_5} N_a$

$N_u = \frac{\rho_{U_3Si_2} N_a}{M_u} = \frac{11.31(6.022 \cdot 10^{23})}{238}$ ← assuming M_{U-235} is negligible

~~$N_{u235} = 3q N_a = 0.03 N_a$~~

-5, Use U density

$E_f = \frac{Q}{N_f \sigma_f \varphi_{th}}$

$N_{u235} = \frac{3q N_a \rho_{U_3Si_2}}{M_{U_3Si_2}}$

$\frac{3q_1 N_a \rho_{U_3Si_5}}{M_{U_3Si_5}} = \frac{3q_2 N_a \rho_{U_3Si_2}}{M_{U_3Si_2}}$

$q_1 = \frac{M_{U_3Si_5}}{\rho_{U_3Si_5}} \cdot \left[q_2 \frac{\rho_{U_3Si_2}}{M_{U_3Si_2}} \right] = \frac{854}{\rho_{U_3Si_5}} (0.03) \frac{11.31}{769.73}$

$q_1 = \frac{0.3764}{\rho_{U_3Si_5}}$

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

As a safety precaution, it is desired to obtain max energy or most efficient without too much enrichment [or having to go to a higher enrichment to obtain same energy density].

-3 Thermal conductivity?

U_3Si_5 has a lower fuel potential compared to U_3Si_2

-10, 25/35

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).

$LHR = 250$

$T_{cool} = 580K$

$h_{cool} = 2.5$

$R_f = 0.45cm$

$t_c = 0.06cm$

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

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

$$T_{co} = 615.36K$$

-2, Surface temp = Ts = surface of pellet

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)

$r = R_f$

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

$$= -\frac{\alpha E(T_o - T_s)}{4(1-\nu)}(1-3)$$

$$= -\frac{7.5 \cdot 10^{-6}(246.7)\left(\frac{250}{4\pi(13.52)}\right)(1-3)}{4(1-0.25)}$$

max stress

$$\sigma_{\theta\theta} = 1.81 \cdot 10^{-3}$$

$= 646.57$

$$T_o - T_s = \frac{250}{4\pi(13.52)}$$

-3, k = 0.2 W/cmK

c) Would you expect this stress to be higher or lower if the pellet was UO_2? Why? (5 points) If pellet was UO_2, stress would be higher because of the comparatively low thermal conductivity.

$$\frac{1}{k_{UO_2}} > \frac{1}{k_{UN}}$$

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

assumed $\eta = \frac{r}{R_f} = 1$ b/c assumed $r = R_f$ for max stress

-5, Axisymmetry, steady state, constant k, no shear, no gravity, etc

-16, 19/35

$P = 6$ MPa $r = 5.6$ mm
$t_c = 0.6$ mm

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)

Stress is constant through wall of cylinder

-2, Small strain, isotropic

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

$$\bar{\sigma}_\theta = \frac{pR}{\delta} = \frac{6(5.6)}{0.6} = 56 \text{ MPa}$$

$$\sigma_z = \frac{pR}{2\delta} = \frac{6(5.6)}{2(0.6)} = 28 \text{ MPa}$$

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

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) ~~Assuming fuel cladding~~

-8 Use thick walled equations at two radii and check how close they are

$$\sigma_{wall} = 2\pi R \delta \bar{\sigma}_z = 2(\pi)(5.1\text{e-}3)(0.6 \cdot 10^{-3})(28) = 59112 \text{ Pa}$$

$$F_{stress} = 2\delta\bar{\sigma}_\theta = 2(0.006)(56) = 0.00672 \text{ MPa}$$

useful for the sake of caution.

The thin walled cylinder approx. would NOT be conservative if used to estimate if cladding would fail. Yield stress of cladding is far greater than any of the stresses approximated.

0.56 cm

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

$$\varepsilon_{rr} = \frac{2r}{5} = \frac{2}{5}(0.56) = 0.224$$

$$\varepsilon_{\theta\theta} = \frac{r}{5} = \frac{0.56\text{cm}}{5} = 0.112$$

$$C_{11} = \frac{70(1-0.41)}{(1+0.41)(1-2(0.41))} = 162.726 \text{ GPa}$$

$$C_{12} = \frac{70(0.41)}{(1+0.41)(1-2(0.41))} = 113.08 \text{ GPa}$$

$$\varepsilon = \begin{bmatrix} 0.224 & 0 \\ 0 & 0.112 \end{bmatrix} \qquad \sigma = \begin{bmatrix} 49.115 & 0 \\ 0 & 43.56 \end{bmatrix}$$

-2, Tensors missing zz component
-4, use stress from part b and calculate the strain

$$\sigma_{rr} = 0.224(162.726) + 0.112(113.08) = 49.115$$

$$\sigma_{\theta\theta} = 0.112(162.726) + 0.224(113.08) = 43.555$$