Derek Buckley

88/100

NucE 497 Fuel Performance Exam 1 covering modules 1 - 3

-3, 27/30

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)**

U_{235} is fissile element

unenriched uranium is .7 % 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)**

$M_{U_3Si_2} = 3\times(.03(235 + (1-.03)238) + 2\times 28 = 769.73\ \text{g/mol}$

$N_{f_{U_3Si_2}} = \dfrac{\rho N_A}{M_{U_3Si_2}} = \dfrac{.03\times 6.022\times10^{23}\times 7.5}{768.73}$

$N_{f_{U_3Si_2}} = 1.759\times10^{20}$

-3, Use U densities

$1.759\times10^{20} = \text{enr}_{U_3Si_5}\times7.5\times6.022\times10^{23}/(3(238)+5\times28)$

$1.759\times10^{20} = 4.515\times10^{24}/854$

$\boxed{\text{enr} = .0331 = 3.31\%}$

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

It is worse fuel because it has to be enriched more which costs more money also its thermal conductivity is less than U_3Si_2 so you would get less effective heat transfer.

$k_{He} = 16\times10^{-6} \times 646.56^{.79} = .002657$ $k_{gap} = .002657^{.95} \times 1.162\times10^{-4\,.05}$

$k_{Xe} = .7\times10^{-6}\, 646.56^{.79} = 1.162\times10^{-4}$ $k_{gap} = .00227$

$.06cm$ $h_{gap} = \frac{.00227}{.008cm} = .284$

$.45cm$ $.008cm$

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)

$T_{co} = \frac{250}{2\pi\,.45cm \times 2.5} + 580 = 615.36\,°k$ $T_s = \frac{250}{2\pi \times .45 \times .284} + 646.56$

$T_{ci} = \frac{250 \times .06cm}{2\pi \times .45cm \times .17} + 615.36 = 646.56\,°k$ $\boxed{T_s = 957.89\,°k}$

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)

$\eta = \frac{r}{R_f}$

at max stress $\eta = 1$ $\sigma_{\theta\theta\,max} = 122.696\ MPa$

$T_0 = \frac{250}{4\pi \times 2} + 957.89 = 1057.36$

$\sigma^* = \frac{7.5\times10^{-6} \times 246.7\times10^{9}(957.89 - 1057.36)}{4(1-.25)} = 61.348MPa$

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

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

c) Would you expect this stress to be higher or lower if the pellet was UO₂? Why? (5 points) ther thermal condctivity of UO_2 is much higer so you would get a bigger temperature gradient which would lead to more thermal expansion leading to a higher thermal stress.

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

Static body

-1, Several more assumptions were made

gravity is neligible

Problem is axisymmetric

isotropic material responce

-8, 27/35

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) Stress is constant throughout the cladding

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

$\sigma_{\theta\theta} = \frac{6 \times .56}{.06} = 56 \text{ MPa}$ $\sigma_z = 28 \text{ MPa}$ $\sigma_r = -3 \text{ MPa}$

-4, Calculate stress at multiple radii to test approximation

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)

$\frac{59.15 - 56}{59.15} \times 100 = 5.3\%$ difference from thick wall to thin wall

thin wall is not conservative because it is an average stress not max stress.

thick wall $\sigma_{\theta\theta} = 6 \times \frac{(6.2/5.6)^2 + 1}{(6.2/5.6)^2 - 1} = 59.15 \text{ MPa}$

-4, No tensors

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)

$\sigma_{\theta\theta} = 56 \text{ MPa}$ $\sigma_z = 28 \text{ MPa}$ $\sigma_r = -3 \text{ MPa}$

$\varepsilon_{rr} = \frac{1}{70 \times 10^3}(-3 - .41(56 + 28)) = -5.34 \times 10^{-4}$

$\varepsilon_{\theta\theta} = \frac{1}{70 \times 10^3}(56 - .41(-3 + 28)) = 6.535 \times 10^{-4}$

$\varepsilon_{zz} = \frac{1}{70 \times 10^3}(28 - .41(56 - 3)) = 8.96 \times 10^{-5}$

$\varepsilon_{rr} = \frac{1}{E}(\sigma_{rr} - \nu(\sigma_{\theta\theta} + \sigma_{zz}))$ $\varepsilon_{zz} = \frac{1}{E}(\sigma_{zz} - \nu(\sigma_{\theta\theta} + \sigma_{rr}))$

$\varepsilon_{\theta\theta} = \frac{1}{E}(\sigma_{\theta\theta} - \nu(\sigma_{rr} + \sigma_{zz}))$