Exam 3: NE533: Nuclear Fuel Performance
Show your work. Point values are indicative of the depth of expected response. Check units.

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1. A ZIRLO cladding tube is in reactor at 625 K for 400 days. The initial wall thickness is 500 μm.
   a) Estimate the oxide thickness after this time? (8 pts)
   b) Assuming the hydrogen pickup fraction is 18%, what is the weight PPM of hydrogen in the cladding after one year? Assume PBR = 1.56, ρ_{Zr} = 6.5 g/cc, ρ_{ZrO2} = 5.68 g/cc. (8 pts)

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1 a) $T_i = 500\ \mu m \quad t = 400d \quad T = 625°k$

$t^* = 6.62e{-7}\, e^\wedge(11949/625) = 133\ d$

$\delta^* = 5.1\, e^\wedge(-550/625) = 2.115$

$K_L = 7.48 \cdot 10^6\, e^\wedge\left(\frac{-12500}{625}\right) = 0.0154$

$\delta = 2.115 + 0.0154\,(400-133) = \boxed{6.231\ \mu m}$

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b) $\delta = 6.231\ \mu m \quad f = .018 \quad t_c = 0.05\ cm$

$$C_H = \frac{2(0.18)(6.231)(5.68)(0.26)\left(\frac{1}{16}\right)}{\left(500 - \frac{6.231}{1.56}\right)(6.5)} \times 10^6$$

$\boxed{C_H = 64.2\ wt.\ ppm}$

2. Determine the total change in the fuel volume given: $\alpha_{th}=11\text{x}10^{-6}$, fission rate = $3.5\text{x}10^{13}$ fiss/cm^3-s, T=1200 K, T_{ref}=300 K, $\Delta\rho_0$=0.01, B_D=5 MWD/kgU, $\rho(UO2)$=10.97 g/cc, t=85 days. (16 pts)

(2)

$$\varepsilon_{tot} = \sum \varepsilon_i$$

$$\varepsilon_{th} = \alpha \Delta T = 11\cdot 10^{-6} \cdot (1200-300) = 9.9 \cdot 10^{-3}$$

$$\varepsilon_d = \Delta\rho_0 \left[e^\wedge\left(\frac{\beta \ln(0.01)}{C_D B_0} \right) - 1 \right]$$

$$B_0 = \frac{5}{950} = 5.3\cdot 10^{-3}\ \text{F:ma}$$

$$\beta = \frac{3.5\cdot 10^{13} \cdot 7.344000}{2.415\cdot 10^{22}}$$

$$\beta = 0.0105$$

$$C_D = \underline{7.235}\ \cancel{-0.0086(T(c)-25)}$$

$$= 1$$

$$\varepsilon_d \approx -0.01$$

$$\varepsilon_{SFP} = 5.577\cdot 10^{-2} \rho\beta = 0.00642$$

$$\varepsilon_{GFP} = 1.98\cdot 10^{-28} \underbrace{\rho\beta(2800-T)^{11.73}}_{4.42\cdot 10^{36}} \underbrace{e^{-0.0162(2800-T)}}_{5.5346\cdot 10^{-12}} \underbrace{e^{-17.8\beta\rho}}_{0.1287}$$

$$\varepsilon_{GFP} = 6.238\cdot 10^{-5}$$

$$\varepsilon_{tot} = 0.00638 \simeq 0.64\%$$

3. What is the total creep in a zirconium cladding given a von mises stress of 200 MPa, a temperature of 600 K, a LHR of 150 W/cm, and a time of 1.5 years? Use nominal values from lectures. (12 pts)

(3) $\sigma_m = 200$ MPa $T = 600$ K LHR = 150

$t = 1.5$ yr $Q = 2.7 \cdot 10^5$ $n = 5$ $R = 8.314$

$A_0 = 3.14 \cdot 10^{24}\ s^{-1}$ $G = 4.1 \cdot 10^{10} - 2.3 \cdot 10^{7} T = 2.9200$ MPa

$$\dot\varepsilon_{ss} = A_0 \left(\frac{\sigma_m}{G}\right)^n e^{\wedge}\left(\frac{-Q}{RT}\right) = 1.48 \cdot 10^{-10}\ s^{-1}$$

$$\dot\varepsilon_{Irr} = C_0 \phi^{C_1} \sigma_m^{C_2} \quad \phi = 3 \cdot 10^{11} \cdot 150$$

$$\dot\varepsilon_{Irr} = 2.87 \cdot 10^{-10}\ s^{-1}$$

$$\varepsilon_{tot} = (2.87 + 1.48) \cdot 10^{-10} \cdot 365 \cdot 1.5 \cdot 24 \cdot 3600$$

$$\varepsilon_{tot} = 0.007 \Rightarrow 0.7\%$$

(2.87+1.48)*10^-10=4.35*10^-10
1.5*365*24*3600=47304000
47304000*4.35*10^-10=0.020577
etot=2.06%
My mistake.

4. What are the five types of fission products that form in the fuel? (5 pts)

    a. Soluble oxides
    b. Insoluble oxides
    c. Metals
    d. Volatiles
    e. Noble Gases

5. Describe the concept of microstructure-based fuel performance modeling and why it is potentially beneficial. (6 pts)

    Examination of the microstructural behavior such as grain growth change in thermal conductivity, intragranular porosity, Precipitated fission products, etc. Is being conducted to produce mechanistic models of the behavior of the fuel over the course of a fuel cycle to create more accurate prediction capabilities.

    The potential benefits are many, but a reduction of the necessary experimentation is a large one.

6. List three benefits of using Zr cladding. (6 pts)

    a. Resistance to void swelling
    b. Good thermal conductivity
    c. Available in large quantities

7. Why does metallic fuel undergo constituent redistribution? (5 pts)

    Redistribution occurs in metallic fuel more than oxide fuel because the metallic fuel will undergo phase changes which substantially disturbs the constituent.

8. What are some of the key differences in MOX fuel compared to LWR fuel? Emphasize differences on in-reactor behavior/performance/environment. (8 pts)

    a. Higher power density
    b. Higher neutron flux intensity
    c. Higher burnup

9. What are the four conditions that must be met for SCC? Briefly describe how each is met in PCI. (8 pts)
    a. Four Conditions
        i. Corrosive environment
        ii. Susceptible material
        iii. Sufficient stress
        iv. Sufficient time

b. Pellet-clad interaction (PCI)
    i. Fission products, combined with the high temperature and pressure produced inside the cladding creates the corrosive environment.
    ii.
    iii. Thermal transport provides substantial stress.
    iv. Fuel cycles last for extended periods.

10. What leads to the possibility of oxide fuel pulverization/fragmentation in the HBS? How are scientists addressing this topic? (6 pts)
    a. HBS?
    b. During LOCA, trapped gas in bubbles heats up and becomes over pressurized; cracking initiates at these over pressurized bubbles
    c. How?
        i. Current efforts are focused on developing a physics-based criterion for pulverization in BISON that accounts for microstructure.

11. What are the performance/behavior differences between a RIA and a LOCA? Provide an example of a RIA. (8 pts)
    a. Reactivity Initiated Accident (RIA)
        i. A Ria will cause higher power due to increased reactivity
    b. Loss Of Coolant Accident (LOCA)
        i. A LOCA will decrease power due to doppler absorption from the higher fuel temperatures due to the lack of coolant
    c. Example
        i. Control rod ejection accident causing an increase in reactivity.

12. What are two of the pathways to make the fuel/cladding system more accident tolerant? Provide an ATF option being considered that targets one of these pathways. (6 pts)

    a. two of the pathways
        i. The time required for the water to boil away
        ii. The time required for the fuel to melt
    b. option being considered
        i. Alternate fuels

13. Provide two examples of limiting phenomena governing LWR operation. (4 pts)

    a. Cladding elongation
    b. Cladding oxidation