82/100

NucE 497 Fuel Performance Exam 2 covering modules 4 – 6

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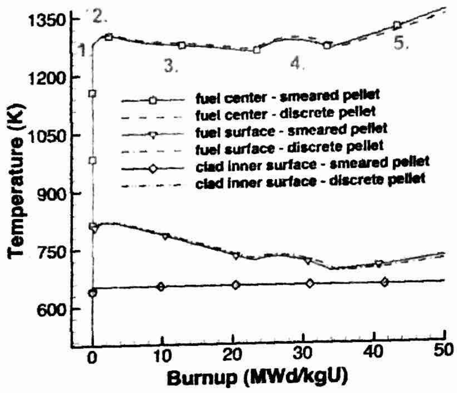
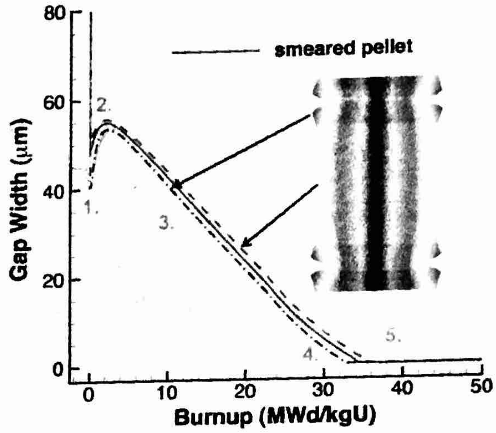
-2, 23/25

Question 1 (25 points):
The temperature and gap width of a fuel pellet, as predicted by a fuel performance code, is shown below. Using the plots as your guide, determine what is currently occurring within the cladding, gap, and pellet at each number. Note that the numbers are at the same burnups on the two plots.





For each number, describe what is occurring in the cladding, gap, and pellet. Also, describe what features in the plots indicated these behaviors.

1. The first step is thermal expansion. This is indicated by the rapid heating of the fuel pellet from graph 1 and the decrease in gap width from 80 μm to ~40 μm in graph 2

2. Next is the densification of the fuel. This is indicated on the second graph because the gap is increasing as the fuel shrinks. There is less effective heat transfer with the larger gap so the temperature continues to rise in graph 1

3. Fuel begins to swell in this position. The gap shrinks as the fuel expands as seen in graph 2. The fuel center temperature and surface temp decrease because of more effective heat transfer (graph 1)

4. The fuel continues to swell and the gap approaches zero. This is shown in graph two as the gap distance is very small. Even though the gap is decreasing there is fission gas release and bubble percolation that causes the temperature of the fuel to increase (graph 1)

5. The last step is the contact of the fuel and cladding. The gap is now zero (graph 2). While contact would provide the best heat transfer, cladding corrosion and continued fission gas release reduces the thermal conductivity causing an increase in temperature at this point (graph 1)

-2, increase in T is due to decrease in fuel conductivity with burnup

Question 2 (30 points) -12, 18/30

A fuel pellet with an average grain size of 8 microns is irradiated with a volumetric neutron flux of 2.0e13 fissions/(cm³ s). Assume the pellet is at a uniform temperature of 900 °C. → 1173 8.617E-5

a) What is the fission gas diffusion coefficient at this temperature? (5 pts)

$\dot{F} = 2.0E13$

$$D = D_1 + D_2 + D_3$$

$$= 2E\text{-}30 \cdot \dot{F} + 1.41E\text{-}17 e^{\left(\frac{-1.19}{k_B T}\right)} \sqrt{\dot{F}} + 7.6E\text{-}6 e^{\left(\frac{-3.03}{k_B T}\right)}$$

$$= 2E\text{-}30 \cdot (2.0E13) + 1.41E\text{-}17 e^{\left(\frac{-1.19}{8.6175E\text{-}5\,(1173)}\right)} \sqrt{2.0E13} + 7.6E\text{-}6 e^{\left(\frac{-3.03}{8.617E\text{-}5\ 1173}\right)}$$

$$= 4E\text{-}17 + 4.8642E\text{-}17 + 7.277E\text{-}19 = \boxed{8.93E\text{-}17 \ \frac{cm^2}{s}}$$

b) How many gas atoms/cm³ are released from the fuel after 2 years of irradiation? Assume the chain yield y = 0.3017. (10 pts)

$$N_{FG} = 0.3017 \cdot 2E13 \cdot 2(365)(24)(3600) =$$

$$\boxed{N_{FG} = 3.806E20 \ \frac{atoms}{cm^3}}$$

-6, Gas RELEASED not gas produced

c) After 2 years of irradiation, the pellet is removed from the reactor and from its cladding, venting all released gas. It is then moved to a furnace and annealed at 2000 °C. Estimate how long before 10% of the gas trapped in the pellet is released. How many gas atoms/cm³ will have been released during this time? (15 pts)

$$f = 6\sqrt{\frac{Dt}{\pi a^2}} \qquad f = .1 \quad a = 8E\text{-}6\,(m) \qquad D = 8.93E\text{-}17$$

-4, Calculate new D at T = 2273 K

$$\left(\frac{f}{6}\right)^2 \cdot \frac{\pi a^2}{D} = t = \left(\frac{.1}{6}\right)^2 \frac{\pi (8E\text{-}6)^2}{8.93E\text{-}17} = 1737.29 \text{ hrs}$$

$$\boxed{= 72.39 \text{ days}}$$

$$N_{FG} = y \dot{F} t$$

$$.3017 \cdot 2E13 \cdot (1737.29)(3600) = \boxed{3.774E19 \ \frac{atoms}{cm^3}}$$

-2, No new gas is produced, just release what is left from part b

-0, 30/30

Problem 3 (30 points)

A ZIRLO cladding tube is in reactor at 600 K for one year. The initial wall thickness is 0.6 mm.

a) What is the oxide weight gain in mg/dm² after this time? (10 pts)

$t^* = 6.62E-7\, e^{\frac{11949}{600}} = 295.007$ days $K_L = 7.48E\, e^{\frac{-12500}{600}} = .0067$

$\delta^* = 5.1 e^{\frac{-550}{600}} = 2.0392$

$\delta = \delta^* + K_L(t - t^*) = 2.0392 + .0067\,(365 - 295.007)$

$\delta = 2.508\ \mu m$ $\delta \cdot 14.7 = W = \boxed{36.87\ \frac{mg}{dm^2}}$

b) What is the ZIRLO wall thickness after this time? (5 pts)

$t_{clad} = 600\,\mu m - \frac{2.508}{1.56} = \boxed{598.4\ \mu m}$

c) Assuming the hydrogen pickup fraction is 15%, what is the weight PPM of hydrogen in the cladding after one year? (10 pts)

$f^{O}_{ZrO_2} = \frac{32}{91+32} = .26$

$C_H^{clad} = \frac{2 \cdot f \cdot \delta \cdot \rho \cdot f^{O}_{ZrO_2} \cdot M_H / M_O}{(t - \frac{\delta}{PBR})\, \rho_{metal}} = \frac{2 \cdot (.15)(2.508) \cdot (.26) \cdot (5.68) \cdot (1/16)}{598.4\,(6.5)}$

$= (1.785E{-5}) \cdot 10^6 = \boxed{17.85\ \text{wt. ppm}}$

d) Draw a section of the cladding, showing the various microstructure changes (5 pts)

-4, 11/15

Problem 4 (15 points)

a) What are the primary differences between a loss of coolant accident and a reactivity insertion accident, regarding the fuel and cladding behavior? (5 pts)

In a loss of coolant accident the cladding undergoes, alpha/beta transition, break away oxidation, and rapid hydrogen pickup. For rod insertion this is not the case because the cladding does not deal with the plastic deformation but cracks from the fuel rod expanding rapidly. For LOCA fuel, undergoes thermal stresses but is not subject to the fuel breaking into pieces and fuel dispersal that is present in RIA

-3, RIA much faster, RIA increases heat generation, LOCA decreases heat removal

b) What are similarities between the fuel and cladding behavior in a RIA and a LOCA? (5 pts)

The cladding for both of these accidents are subject to ballooning and eventual bursting from the temperature and pressure change in the core. In both the fuel undergoes thermal stresses and fission gas release

-1, Fuel fracture

c) List a potential accident tolerant fuel concept and describe how it could meet the primary goal of the accident tolerant fuel program. (5 pts)

One way which the accident tolerant fuel program can meet their goals is with a coating or sleeve over the ziraloy. The coating would help the outside be protected from steam and the sleeve would help slow the oxidation effects of the cladding