87/100

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-1, 24/25

Problem 1

(1) Thermal expansion is occurring at startup, increasing the fuel volume and partially closing the gap. This improves heat transfer from the fuel to cladding.

(2) The effects of densification between to show: the fuel shrinks in size widening the gap. The heat transport rate is hurt by this

(3) Fission products buildup in the fuel causing the fuel to swell. This increases the fuel volume, which decreases the gap size. -1, impact on T?

(4) The effects of fission products escaping into the fuel hurt the thermal conductivity. Less heat escapes the fuel, so its temperature rises. Eventually, the fuel has come into contact with the cladding (between 4 and 5)

(5) The fuel has expanded to the point where it comes into contact with the cladding and the thermal conductivity through the (now nonexistent) gap is as high as it can be. The loss of thermal conductivity of the fuel that occurs with burnup, lowers the rate at which heat is transported form the fuel to the cladding and across the fuel. The fuel center temperature increases at a faster rate than the fuel surface temperature as a result of this.

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Exam II

2)

-3, 27/30

(a) $D_1 = 7.6 \times 10^{-6} \exp(-3.03\ eV / k_b T)$

$D_1 = 7.6e{-6} \exp(-3.03/((8.617e{-5}\ eV/K)(1173K)))$

$D_1 = 7.28 \times 10^{-19}$ cm^2/s

$\dot{F} = 2.0e13$ fission $/(cm^3 \cdot s)$

$D_2 = 1.41e{-18} \exp(-1.01/k_b T)\sqrt{\dot{F}}$

$D_2 = 6.45e{-23}$ cm^2/s -1, math error

$D_3 = 2.0 \times 10^{-30} \dot{F} = 4e{-17} = D_3$ $[cm^2/s]$

$D = D_1 + D_2 + D_3 \rightarrow \boxed{D = 4.07 \times 10^{-17}\ cm^2/s}$

(b) $N_{gas} = y\dot{F}t = (0.3017)(2.0 \times 10^{13})(2 \cdot 365 \cdot 24 \cdot 3600)$ [fissions/cm³·s] [Seconds]

$N_{gas} = 3.81 \times 10^{20}$ atoms/cm³

$\tau = Dt/a^2 = \frac{(4.07 \times 10^{-17})(2 \cdot 365 \cdot 24 \cdot 3600)}{(8e{-4})^2} = 0.101 \ll \frac{1}{\pi^2}$

$f = 4\sqrt{\frac{Dt}{\pi a^2}} - \frac{3}{2}\frac{Dt}{a^2} = 0.137 = f$

$N_{release} = f N_{gas} = 0.137(3.81 \times 10^{20})$

$$\boxed{N_{release} = 5.21 \times 10^{19}\ \text{atoms}/cm^3}$$

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2) continued $T = 2273 K$

(c) $D_1 = 7.6e{-6} \exp(-3.03/k_b T) = 1.45 \times 10^{-12}\ cm^2/s$

$D_2 = 0$ since $\dot{F} = 0$ and $D_3 = 0$ too

$\boxed{D = 1.45 \times 10^{-12}\ cm^2/s}$

-2, wrong eqn

$f \cong 4\sqrt{\frac{Dt}{\pi a^2}}$ (short time)

$\rightarrow \left(\frac{1}{4} f\right)^2 = \frac{Dt}{\pi a^2} \rightarrow \frac{1}{D}\pi a^2 \left(\frac{1}{16} f^2\right) = t$

$t = \frac{1}{1.45 \times 10^{-12}} (\pi) a^2 \frac{1}{16} f^2 = \boxed{867 \text{ seconds}}$

$N_{anneal} = N f = (N_{gas} - N_{release})(0.1)$ gas left in fuel

$\boxed{N_{anneal} = 3.29 \times 10^{19}\ \text{atoms}/cm^3}$

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Exam II

-9, 21/30

3) $T = 600K$

(a) $t^* = 6.62 \times 10^{-7} \exp\left(\frac{11949}{T}\right)$

$t^* = 29.5$ days

$\delta^* = 5.1 \exp\left(-\frac{550}{T}\right) = 2.04\ \mu m = \delta^*$

$K_L = 7.48 \times 10^6 \exp\left[-\frac{12500}{T}\right] = \boxed{0.0067 = K_L}$

$\delta = \delta^* + K_L(t - t^*) \rightarrow \delta = 2.508\ \mu m$

$w = 14.7\ \delta = \boxed{36.87\ mg/dm^2 = W}$

(b) $\delta_{total} = \delta_{Zr} + \delta_{oxide} \rightarrow \delta_{Zr} = \delta_{total} - \delta_{oxide}$

-2, thickness not number of atoms
-2, Metal lost = d_oxide/1.56

assume $S = 1 dm \rightarrow N_0 = \frac{wN_A}{M_O} = 1.388 \times 10^{21}$ atoms

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3) assume $S = 1 dm^2$

(c) $N_O = \frac{W N_A}{M_O} = \frac{(0.03687 g) N_A}{16} = 1.388 \times 10^{21}$ atoms O / dm^2

$N_H = 2 N_O = 2.78 \times 10^{21}$ H atoms / dm^2

$N_{H-Zr} = 2 f N_O = 2(0.15) N_O = 4.16 \times 10^{20}$

$W_H = \frac{N_{H-Zr} M_H}{N_A} = \frac{(4.16 \times 10^{20})(1)}{N_A} = 6.913 \times 10^{-4}$ g

$C_H = \frac{W_H}{W_{Zr}} = \frac{W_H}{\rho_{Zr} V_{Zr}} = \frac{W_H}{\rho_{Zr}\left(t - \frac{\delta_{ZrO_2}}{PBR}\right) S} = \frac{6.913 \times 10^{-4}}{6.5\left(600 - \frac{2.508}{1.56}\right)(10cm \cdot 10cm) 10^{-4} cm/\mu m}$

$\boxed{C_H = 17.75 \text{ ppm.wt}}$

-5, part d?

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Problem 4

-0, 15/15

(a) The primary difference between a loss of coolant accident (LOCA) and a reactivity insertion accident (RIA) is that LOCA occurs over a large time frame than RIA. Typically a RIA is caused by the removal of a control rod, while a LOCA is caused by a loss of coolant flow with the control rods being fully inserted as part of the emergency system. The coolant still flows properly in a RIA (unless a catastrophic problem such as cladding ballooning occurs), while it does not in a LOCA.

In a RIA, the power jumps at a rapid rate as a result of a large increase of fission rate and the fuel temperature rises quickly. A LOCA is when there is a partial or full loss of coolant flow. This means that the temperature of the fuel and cladding cannot transport heat away at a quick enough rate and the fuel temperature will rise but at a slower rate than in a RIA. Also, in a RIA hydride formation is not a concern because it will not be significant in such a short time frame, while hydrogen pick is a concern in a LOCA.

In short, in a RIA accident, the power rises, and the temperature rises quickly as a result. In a LOCA accident, the power does not rise, but the temperature does not transport away fast enough. The heat in a LOCA is caused by decay heat, while in a RIA the heat is caused by an increase in fission rate.

(b) In both events, the fuel temperature and cladding temperature will rise. The fuel will expand as a result of its increased temperature and will come into contact with the cladding. Many fuel and cladding problems may occur, such as fission gas release from the increase temperature. This will raise the inner cladding pressure. Cladding ballooning may occur, depending on how badly the material properties of the cladding are affected. A significant amount of oxidation may also occur in both events.

(c) A potential accident tolerant fuel concept is a cladding coating with a high enough thermal conductivity. The purpose of this coating is to protect the cladding from steam to prevent a rapid growth of oxidation.