NE 591

Final Exam

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Problem 1

(a) volumetric fission rate $= 2 \times 10^{14} \ \frac{fiss}{cm^3 \cdot s}$

grain size, $a = 8 \times 10^{-4}$ cm

Assuming spherical grains

$$V = \frac{4}{3}\pi r^3 = \frac{\pi}{6} a^3$$

$$= 2.68 \times 10^{-10} \ cm^3$$

$\therefore$ fission rate, $\dot{f} = (2 \times 10^{14}) \times (2.68 \times 10^{-10})$

$$= 53600$$

$$D_1 = 7.6 \times 10^{-6} \, e^{-\frac{3.03}{k_B T}}$$

$$= 7.6 \times 10^{-6} \exp\left(-\frac{3.03}{8.617 \times 10^{-5} \times 1200}\right)$$

$$= 1.43 \times 10^{-18}$$

$$D_2 = 1.41 \times 10^{-18} \exp\left(-\frac{1.19}{k_B T}\right) \sqrt{\dot{f}}$$

$$= 3.28 \times 10^{-21}$$

$D_3 = 2 \times 10^{-30} \dot{f}$

$= 1.07 \times 10^{-25}$

$D_{tot} = D_1 + D_2 + D_3$

$= 1.43 \times 10^{-18} \ \frac{cm^2}{s}$

(b)

gas production $= y \dot{f} t$

$= 0.3017 \times 53600 \times 2 \times 3.15 \times 10^7$

$= 1.02 \times 10^{12}$

$\tau = \frac{Dt}{a^2}$

$= \frac{1.43 \times 10^{-18} \times 2 \times 3.15 \times 10^7}{(8 \times 10^{-4})^2}$

$\therefore \tau = 8 \times 10^{-9} < \pi^{-2}$

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

$$= 0.0002$$

$$= 0.02\%$$

$$\cancel{N_{FG} = \dot{f} V}$$

gas atoms released $= (0.02\%)\,\dot{f}$

$$= (0.02\%)(53600)$$

$$= 11 \ \frac{\text{atoms}}{cm^3}$$

(c) $T = 2000\,K$

$$f = 1 - \frac{6}{\pi^2} e^{-\pi^2 \frac{Dt}{a^2}}$$

$\Rightarrow 0.3 = 1 - 0.61 \exp(2.2 \times 10^{-11}\, t)$

$\Rightarrow \exp(2.2 \times 10^{-11}\, t) = \dfrac{1 - 0.3}{0.61}$

$\Rightarrow t = \dfrac{\ln\left(\frac{0.7}{0.61}\right)}{2.2 \times 10^{-11}}$

$= 6.26 \times 10^{9}$ seconds

Problem 2

(a) $T = 600\ K$

$$t^*_{(d)} = 6.62 \times 10^{-7} \exp\left(\frac{11949}{600}\right)$$

$$= 295 \text{ days}$$

$\therefore$ Transition occurred after 1 year.

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

$$= 2.04\ \mu m$$

$$K_L\left(\frac{\mu m}{d}\right) = 7.48 \times 10^6 \exp\left(\frac{-12500}{T}\right)$$

$$= 0.0067$$

$$\delta = \delta^* + K_L(t - t^*)$$

$$= 2.04 + 0.0067(365 - 295)$$

$$= 2.509$$

(b)

$$C_0 = 2.846 \times 10^{-24}$$

$$C_1 = 0.85$$

$$C_2 = 1$$

Irradiation creep, $\dot{\varepsilon}_{is} = C_0 \, \Phi^{C_1} \, \sigma_m^{C_2}$

Here, $\sigma_m = 300$ MPa

$$\bar{\Phi} = LHR \left(3 \times 10^{11}\right)$$

$$= (350)\left(3 \times 10^{11}\right)$$

$$= 1.05 \times 10^{14}$$

$$\therefore \dot{\varepsilon}_{is} = 2.846 \times 10^{-24} \left(1.05 \times 10^{14}\right)^{0.85} (300)$$

$$= 7.07 \times 10^{-10} \ s^{-1}$$

Problem 3

$$\varepsilon_{tot} = \varepsilon_{th} + \varepsilon_{D} + \varepsilon_{sfp} + \varepsilon_{gfp}$$

$$\varepsilon_{th} = \alpha (T - T_{ref})$$

$$= 11 \times 10^{-6} (1800 - 300)$$

$$= 0.0165$$

$$\varepsilon_{D} = \Delta\varphi_0 \left[\exp\left(\frac{\beta \ln 0.01}{C_D \beta_D} \right) - 1 \right]$$

$$= 0.01 \left[\exp\left(\frac{0.0195 \ln 0.01}{C_D \beta_D} \right) - 1 \right]$$

$$\beta_D = \frac{7}{950} = 0.0074$$

$$C_D = 1 \quad [\because T \geq 750^\circ C]$$

$$\therefore \varepsilon_{D} = -0.01$$

$$\varepsilon_{sfp} = 5.577 \times 10^{-2} \rho\beta$$

$$= 5.577 \times 10^{-2} \times 10.97 \times 0.0195$$

$$= 0.012$$

$$\varepsilon_{gfp} = 1.96 \times 10^{-28} \rho\beta (2800 - 1800)^{11.73}$$

$$\times \exp(-0.0162 \times (2800 - 1800))$$

$$\times \exp(-17.8 \rho\beta)$$

$$= 0.0133$$

$$\therefore \varepsilon_{tot} = \varepsilon_{ta} + \varepsilon_{D} + \varepsilon_{sfp} + \varepsilon_{gfp}$$

$$= 0.0165 - 0.01 + 0.012 + 0.0133$$

$$= 0.0318$$

Problem 4

1. Soluble oxides
   (Y, La, rare earths)

2. Insoluble oxides
   (Zr, Ba, Sr)

3. Metals
   (Mo, Ru, Pd, Tc)

4. Volatiles
   (Br, Rb, Te, I, Cs)

5. Noble ~~ga~~ gases
   (Xe, Kr)

Problem 5

Stage 1

Gas atoms are produced throughout the fuel due to fission and diffuse towards grain boundaries.

Stage 2

Nucleation of gas bubbles on grain boundaries, growth and interconnection.

Stage 3

Gas travels through interconnected bubbles to the free surface

Problem 6

Nabarro-Herring creep, where atomic diffusion causes grains to elongate the grains along the stress axis, is based on bulk diffusion.

Two types of thermal creep are:

1. Nabarro-Herring creep
2. Coble creep

Problem 7

In microstructure-based fuel performance modeling-structural properties are connected to the microstructure variables. In this way, mechanistic materials modes are based on the ~~sa~~ state of the evolving microstructure rather than burnup. A series of ~~state~~ variables define the ~~states~~ state of microstructure and the evolution of those states change the fuel conditions. So, the material / fuel properties are determined from microstructure properties.

This modeling is valuable because it can provide better insight, more accurate properties and better prediction of mechanisms and behaviors.

Problem 8

1. Low neutron cross section

2. Good thermal conductivity

3. Corrosion resistance in 300°c water

Problem

~~The hydrogen atoms for~~

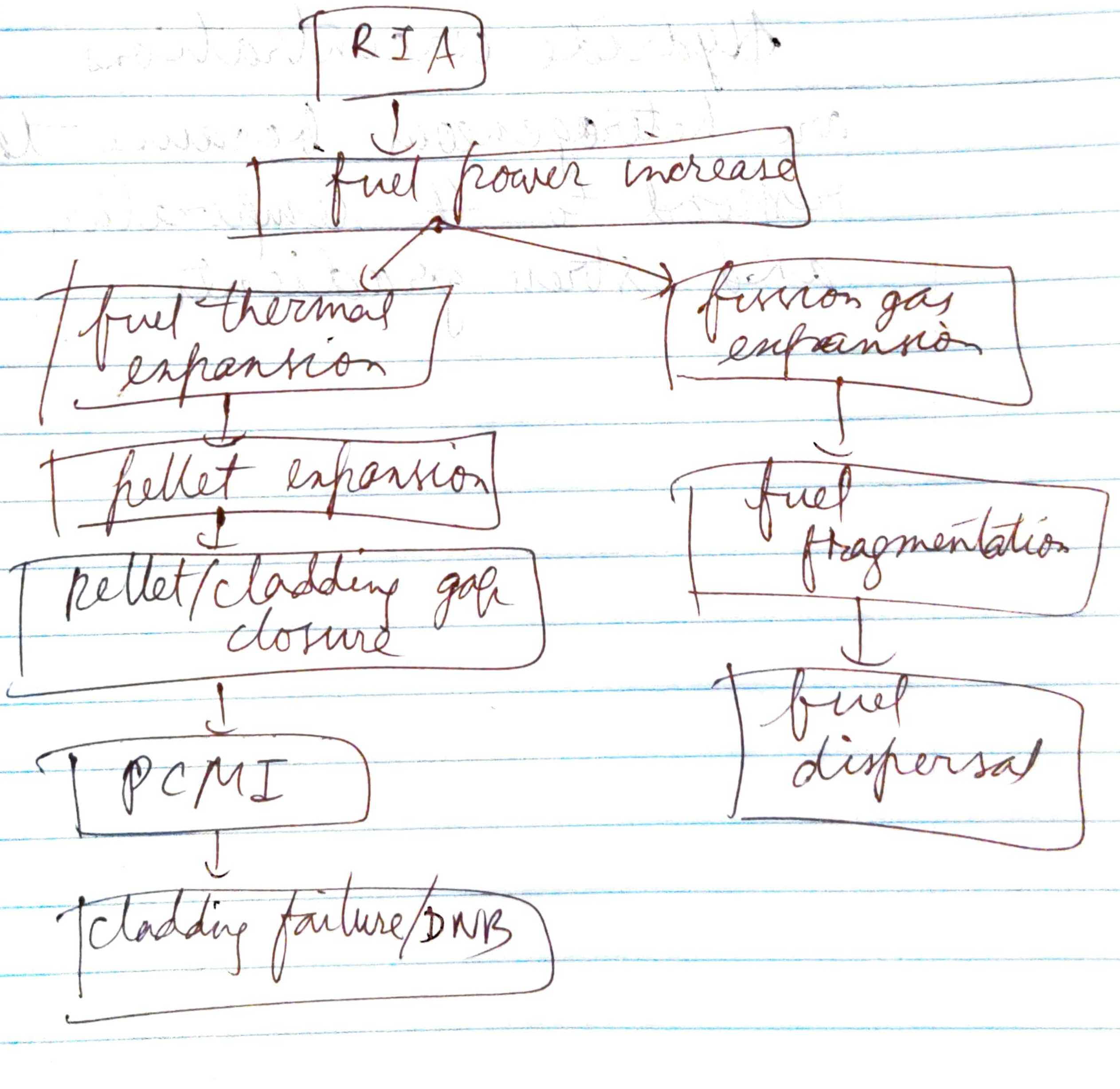
Metallic fuel redistributes via Soret diffusion and it diffuses up the temperature gradient. This leads to distinct zones of varying properties. Metallic fuels observe constituent redistribution radially, in addition to axially ~~xx~~ varying microstructure.

The different zones can have different phases as well. Different density and phases of metallic fuel provide different thermal/elastic properties. The content of U also changes along with the metal. All these together make the fuel properties heterogeneous and thus it affects fuel performance.

Problem 10

RIA = Reactivity Initiated Accident

RIA means large and rapid insertion of reactivity in the reactor core.



Problem 11

The hydrogen atoms produced by oxidation can enter the cladding via diffusion and form hydrides.

Hydride concentrations are heterogeneous because they respond to ~~th~~ temperature and stress gradients.