Alex Chrystler NE591 Final Exam Apr 29 2021

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1 $a = 8\,\mu m \quad T = 1200\,K \quad \dot{F} = 2.0\times10^{14}\ \frac{\text{fissions}}{cm^3\ sec}$

$D = D_1 + D_2 + D_3$

$D_1 = (7.6\times10^{-6})\exp\left(\frac{-3.03}{K_B T}\right) = (7.6\times10^{-6})\exp\left(\frac{-3.03\ eV}{8.617\times10^{-5}\frac{eV}{K}\cdot 1200\ K}\right)$

$D_1 = 1.43\times10^{-18}\ \frac{cm^2}{s}$

$D_2 = (1.41\times10^{-18})\exp\left(\frac{-1.19}{K_B T}\right)\sqrt{\dot{F}} = (1.41\times10^{-18})\left(\exp\left(\frac{-1.19\ eV}{8.617\times10^{-5}\frac{eV}{K}\cdot 1200\,k}\right)\right)\left(\sqrt{2.0\times10^{14}}\right)$

$D_2 = 2.00\times10^{-16}\ \frac{cm^2}{s}$

$D_3 = 2.0\times10^{-30}\ \dot{F} = 2.0\times10^{-30}\ (2.0\times10^{14})$

$D_3 = 4\times10^{-16}\ \frac{cm^2}{s}$

$D = D_1 + D_2 + D_3 = (1.43\times10^{-18}) + (2.0\times10^{-16}) + (4\times10^{-16})$

$\boxed{D = 6.0143\times10^{-16}\ \frac{cm^2}{sec}}$

b) Gas production $= y\dot{F}t$

given $y = 0.3017$

$gas = (0.3017)\left(2\times10^{14}\ \frac{\text{fissions}}{cm^3\ sec}\right)(2\ years)\left(\frac{365.25\ days}{yr}\right)\left(\frac{24\ hrs}{day}\right)\left(\frac{3600\ sec}{hr}\right)$

$gas = \left(.3017\ \frac{atoms}{fiss}\right)\left(2\times10^{14}\ \frac{fiss}{cm^3\ sec}\right)(63115200\ sec)$

$\boxed{gas = 3.81\times10^{21}\ \frac{atoms}{cm^3}}$

c) $\tau > \pi^{-2}$

$\Rightarrow \quad f = 1 - \frac{6}{\pi^2}\exp\left(-\pi^2\frac{Dt}{a^2}\right) = 0.70$

$0.3 = \frac{6}{\pi^2}\left(\exp\left(-\pi^2\frac{Dt}{a^2}\right)\right)$

$$\ln\left[0.7\left(\frac{\pi^2}{6}\right)\right] = -\pi^2\frac{Dt}{a^2}$$

$$\frac{-a^2}{\pi^2 D}\ln\left[0.3\,\frac{\pi^2}{6}\right] = t = -\frac{(8\times10^{-4}\,cm)^2}{(\pi^2)(6.0143\times10^{-16}\,\frac{cm^2}{sec})}\ln\left[0.3\,\frac{\pi^2}{6}\right]$$

$$\boxed{t = 76149568 \text{ seconds} = 2.41 \text{ years}}$$

2) $t^*(days) = 6.62\times10^{-7}\exp\left(\frac{11949}{T}\right) = 295$ days $\Rightarrow$ have undergone transition

$T = 600$ K   thickness $= 600\,\mu m$ $t = 1\,yr$

$$\delta^* = 5.1\exp\left(\frac{-550}{T}\right) = 5.1\exp\left(\frac{-550}{600}\right) = 2.039\,\mu m$$

$$K_L = 7.48\times10^6\exp\left(\frac{-12500}{600}\right) = 0.0067\,\frac{\mu m}{days}$$

final thickness of oxide $= 2.039 + 0.0067(365-295) = \boxed{2.508\,\mu m}$

$LHR = 350\,\frac{W}{cm}$ $\sigma_m = 300$ MPa

b) $\varepsilon_{IRR} = C_0\,\phi_{fast}^{C_1}\,\sigma_m^{C_2}$ $C_0 = 2.846\times10^{-24}$ $C_1 = 0.85$ $C_2 = 1$

$$\phi_{fast} = LHR(3\times10^{11}) = (350)(3\times10^{11}) = 1.05\times10^{14}\,\frac{nt}{cm^2\,s}$$

$$\varepsilon_{IRR} = (2.846\times10^{-24})(1.05\times10^{14})^{0.85}(300)^1$$

$$\boxed{\varepsilon_{IRR} = 7.07\times10^{-10}\,\frac{1}{sec}}$$

$$t = (1\,yr)\left(\frac{365.25\text{ days}}{yr}\right)\left(\frac{24\text{ hrs}}{day}\right)\left(\frac{3600\text{ sec}}{day}\right) = 3.156\times10^7\text{ sec}$$

$$(\varepsilon_{IRR})(3.156\times10^7\,sec) = 0.022 = \boxed{2.2\%\text{ creep strain}}$$

3 $\alpha_{th} = 11\times10^{-6}$ $B = 0.0195$ FIMA $T = 1800$ K $T_{ref} = 300$ K $\Delta\rho_0 = 0.01$

$B_D = 7 \frac{MWD}{kgU}$ $\rho(UO_2) = 10.97 \frac{g}{cc}$ $C_D = 1$ since $T > 750\,°C$

$$\varepsilon_{th} = \alpha_{th}\Delta T = (11\times10^{-6})(1800-300) = 0.0165$$

$$\varepsilon_D = \Delta\rho_0\left(\exp\left(\frac{B\ \ln 0.01}{C_D\ B_D}\right)-1\right) = 0.01\left(\exp\left(\frac{0.0195\ \ln 0.01}{1\ (7/950)}\right)-1\right) = -0.01$$

$$\varepsilon_{SFP} = 5.577\times10^{-2}\rho B = 5.577\times10^{-12}(10.97)(0.0195) = 0.012$$

$$\varepsilon_{GFP} = (1.96\times10^{-28})(10.97)(0.0195)(2800-1800)^{11.73}\exp\left[-0.0162(2800-1800)\right]\exp\left[-17.8(10.97)(0.019\right.$$

$$\varepsilon_{GFP} = (6493776)\exp\left[-0.0162(1000)\right]\exp\left[-17.8(10.97)(0.0195)\right]$$

$$\varepsilon_{GFP} = 0.013$$

$$\varepsilon_{tot} = 0.0165 - 0.01 + 0.012 + 0.013 = 0.0315 = \boxed{3.15\%\text{ change in fuel volume}}$$

4 5 types of Fission products:

- Soluble Oxides
- Insoluble Oxides
- Metals
- Volatiles
- Noble Gasses

5 3 stages of Fission gas release:

1. Gas atoms produced throughout fuel due to fission, diffuse towards grain boundaries
   - Intragranular bubbles form w/in grains
   - Gas atoms that don't get trapped w/in bubbles migrate towards grain boundaries
2. Gas bubbles nucleate on grain boundaries, growing & connecting
3. Gas travels through connected bubbles to a free surface

6 Two types of thermal creep:

1) Nabarro-Herring Creeb, caused by Bulk Diffusion

2) Grain Boundary Diffusion

7 Microstructure based fuel performance modeling predicts behavior of fuels on a much smaller length scale than current models; It aims to predict, on these scales, how fuel will behave outside the realm of experiments that have already been performed such that it can inform larger length-scale models with accurate values such as average grain sizes, U defect concentrations, Dissolved fission products, etc. It is valuable as it wouldn't depend on enperical fits to experimental data to properly model fuel performance simulations.

8) Three benefits of using Zr cladding:

1) Resistive to corrosion by water at 300 C

2) Good thermal conductivity

3) Affordable cost due to high availability

9 Metallic fuel undergoes redistribution due to alloyed Zr diffusing up a temperature gradient via Soret diffusion, and having varying solubilities in each U phase. This leads to distinct zones of Zr in rings in a fuel pellet. There are also different elastic & thermal properties in each phase & Zr content

10) A RIA is a "Reactivity Inserted Accident," and during these, fuel temperature tends to quickly rise. This could cause a centerline fuel melt, or other failure of rods, leading to more severe issues when molten fuel could breach cladding and interact with coolant, boiling it and increasing steam pressure, etc.

11 Hydrides can form at locations where the cladding has undergone oxidation, where the hydrogen atoms produced by the oxidation can enter the cladding. They precipitate circumferentially under reactor conditions, but in used fuel, after drying, they can reprecipitate w/ a radial orientation.

The concentration of hydrides can be heterogeneous due to their responding to temperature and stress gradients. Like Zr alloyed in U fuel, hydride diffuse up temperature gradients via Soret diffusion, and also towards areas w/ tensile stress, resulting in non-homogeneous concentrations.