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NE 591 - EXAM 3

① $a = 8\,\mu m$; $\dot{F} = 2\times10^{14}$ fiss/(cm³·s) ; $T = 1200K$

$Vol = \frac{\pi a^3}{6} = 2.68\times10^{-10}\ cm^3$

$\dot{f} = 5.36\times10^{4}$ fiss/s

a) $D_1 = 7.6\times10^{-6}\, e^{-3.03eV/(8.617\times10^{-5})(1200)} = 1.428\times10^{-18}\ cm^2/s$

$D_2 = 1.41\times10^{-18}\, e^{-1.19eV/(8617\times10^{-5})(1200)}\sqrt{5.36\times10^{4}} = 3.28\times10^{-21}\ cm^2/s$

$D_3 = 2.0\times10^{-30}(5.36\times10^{4}) = 1.07\times10^{-25}\ cm^2/s$

$D = D_1 + D_2 + D_3 = 1.43\times10^{-18}\ cm^2/s$

b) $\tau = \frac{Dt}{a^2} = \frac{(6\times10^{-16})\overset{6.3\times10^{7}s}{(2\cdot365\cdot24\cdot60\cdot60)}}{(8\times10^{-4})^2} = 0.05913 < \pi^{-2} = 0.101$

$f = 4\sqrt{\frac{(1.43\times10^{-18})(6.3\times10^{7})}{\pi(8\times10^{-4})^2}} - \frac{3}{2}\frac{(1.43\times10^{-18})(6.3\times10^{7})}{(8\times10^{-4})^2} = 2.65\times10^{-2}$

total gas produced: $y\dot{F}t = 0.3017(2\times10^{14})(6.3\times10^{7}) = 3.8\times10^{21}$ at/cm³

total gas released: $(3.8\times10^{21})(2.65\times10^{-2}) = 1\times10^{20}$ at/cm³

c) $T = 2000K$, assuming $D = D_1$

$D = 7.6\times10^{-6}\, e^{-3.03eV/(8.617\times10^{-5})(2000)} = 1.76\times10^{-13}\ cm^2/s$

for $\tau > \pi^{-2}$, $f = -\frac{1}{1} + \frac{6}{\pi^2}\, e^{-\pi^2(1.76\times10^{-13})t/(8\times10^{-4})^2} = -0.3$

$e^{-2.71\times10^{-6}t} = \frac{(1-0.3)\pi^2}{6} = 1.15$

$t = \frac{\ln(1/1.15)}{-2.71\times10^{-6}} = \boxed{51572\,s}$

② $t^*(d) = 6.62 \times 10^{-7} \exp\left(\frac{11947}{600}\right) = 295$ days

$\delta^*(\mu m) = 5.1 \exp\left(\frac{-550}{600}\right) = 2.04\ \mu m$

$K_L = 7.28 \times 10^{6} \exp\left(\frac{-12500}{600}\right) = 6.52 \times 10^{-3}\ \mu m/d$

a) $\delta(\mu m) = 2.04 + 6.52\times10^{-3}(365-295) = \boxed{2.5\ \mu m}$ oxide thickness

b) $\sigma_m = 300$ MPa, LHR $= 350$ W/cm

$\dot{\epsilon}_{irr} = C_0 \Phi^{C_1} \sigma_m^{C_2}$, $\Phi = LHR(3\times10^{11}) = 1.05\times10^{14}$

$C_0 = 2.714\times10^{-24}$

$C_1 = 0.85$

$C_2 = 1$

$\dot{\epsilon}_{irr} = (2.714\times10^{-24})(1.05\times10^{14})^{0.81}(300) = 1.85\times10^{-10}\ s^{-1}$

$\epsilon_{irr} = (365)(24)(60)(60)(1.85\times10^{-10})$

$\epsilon_{irr} = 5.84\times10^{-3} = \boxed{0.58\%}$

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③ $\alpha_{Th} = 11\times10^{-6}$, $\beta = 0.0195$ FIMA, $T = 1800K$, $T_{ref} = 300K$

$\Delta\rho_0 = 0.01$; $\beta_D = 7$ MWD/KgU; $\rho_{UO_2} = 10.97$ g/cc

$\epsilon_{th} = (11\times10^{-6})(1800-300) = 0.0165$

$\beta_D = \frac{7}{950} = 7.4\times10^{-3}$ FIMA

$\epsilon_D = 0.01\left(e^{\frac{0.0195(\ln(0.01))}{1\ (7.4\times10^{-3})}} - 1\right) = -0.01$

$\epsilon_{sFP} = 5.577\times10^{-2}(10.97)(0.0195) = 0.01193$

$\epsilon_{GFP} = 1.96\times10^{-28}(10.97)(0.0195)(2800-1800)^{11.73} e^{-0.0162(2800-1800)} e^{-17.8(10.97)(0.0195)}$

$\epsilon_{GFP} = 0.01328$

total volume change

$$\epsilon_{TOT} = 0.0165 - 0.012 + 0.01193 + 0.01328 = 0.03171 = \boxed{3.17\%}$$

(4) → soluble oxides (Y, La and the rare earths)

→ Insoluble oxides (Zr, Ba and Sr)

→ Metals (Mo, Ru, Pd and Tc)

→ Volatiles (Br, Rb, Te, I and Cs)

→ Noble gases (Xe, Kr)

(5) st 1: gas atoms are produced in the fuel and diffuse towards grain boundaries,

st 2: gas bubbles nucleate on GBs, growing and interconnecting

st 3: gas travels through such interconnected bubbles to a free surface (leaves the fuel)

(6) Nabarro-Herring creep is based on bulk diffusion

Coble creep is based on grain boundary diffusion

(7) The models are based on the state of the microstructure instead of based on burnup. The material properties of fuel and cladding are determined from microstructure and property relationships that are functions of materials state variables and current fuel conditions. It is valuable because there is a potential to provide a more predictive fuel performance capability

(8) Low neutron cross section: almost no interaction with neutrons leaving them free for fission

Good thermal conductivity: important for cooling

Affordable cost

(9) When the fuel contains Zr, it difuses via Soret diffusion to the higher temperature region (center of the slug radially). Having different concentrations of Zr along the fuel, the melting temperature is affected and different phases are formed in the slug, with different elastic and thermal properties

(10) A Reactivity Initiated Accident is an accident caused by a large reactivity insertion in the core, that can be caused by the sudden removal of the control rods. When there is a large reactivity insertion, the temperature increases rapidly and that can cause many consequences in the fuel, ultimately causing fuel melting

(11) Hydrides respond to temperature and stress gradients, so their concentrations are not uniform; it moves toward lower temperatures causing a loss of ductility and leading to early failure.
They are formed on the cladding outer wall where there is corrosion