Post-Annealing Fission Gas Release

$t = 20$ hrs $\quad D_{Xe} = (6.02\times10^{-4})\exp\left(-\frac{3}{k_B T}\right)$ cm²/s

Grain size $= 10\ \mu m = 10E{-4}$ cm $\quad T = 1200$ K

which f? $\quad t = 20$ hrs $\rightarrow$ 72000 s $\quad D_{Xe} = 1.51\times10^{-16}$ cm²/s

$$\tau = \frac{Dt}{a^2} = \frac{(1.51\times10^{-16})(72000)}{(10\times10^{-4})^2} = 1.09\times10^{-5}$$

$\tau < \pi^{-2}$

$\pi^{-2} = 0.101$

$\rightarrow$ short time!

$$f = 6\sqrt{\frac{Dt}{\pi a^2}} - 3\frac{Dt}{a^2}$$

$$f = 6\sqrt{\frac{(1.51\times10^{-16})\,72000}{\pi(10\times10^{-4})^2}} - 3\frac{(1.51\times10^{-16})(72000)}{(10\times10^{-4})^2}$$

$$f = 0.011 - 3.26\times10^{-5} = 0.011$$

In-pile fission gas release

$t = 20$ hrs $\quad D_{xe} = (6.02\times10^{-4})\exp\left(-\frac{3}{k_B T}\right)$ cm²/s

L

Grain size = 10 μm = 10E-4 cm $\quad D_{xe} = 1.51\times10^{-16}$ cm²/s

$t = 20$ hrs $\rightarrow \tau < \pi^{-2}$

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

$$f = 4\sqrt{\frac{(1.51\times10^{-16})(72000)}{\pi(10\times10^{-4})^2}} - \frac{3}{2}\frac{(1.51\times10^{-16})(72000)}{(10\times10^{-4})^2}$$

$$f = 0.0074 - 1.63\times10^{-5} = \underline{0.00738}$$

Total gas atoms released? ignoring decay

gas production $= y\dot{F}t \qquad y = 0.3017$

$\dot{F} = N_u^{235}\phi\sigma_f V \qquad \sigma_f = 550$ barns $\quad \phi = 4\times10^{13}\ \frac{n}{cm^2\text{-}s}$

$N_u^{235} = 2.5\times10^{22}$ atoms/cc

$V \rightarrow$ assume spherical grain $\rightarrow \frac{4}{3}\pi r^3 \rightarrow \frac{\pi}{6}d^3 = \frac{\pi}{6}(10\times10^{-4})^3 = 5.24\times10^{-10}$ cm³

$\dot{F} = (2.5\times10^{22})(4\times10^{13})(550\times10^{-24})(5.24\times10^{-10}) = 2.88\times10^5$ fiss/sec

Total gas $= (0.3017)(2.88\times10^5$ fiss/sec$)(72000) = 6.26\times10^9$ Xe

gas released $= (0.00738)(6.26\times10^9) = \underline{4.62\times10^7 \text{ Xe atoms}}$

Zircaloy cladding creep w/ $\sigma_m = 240$ MPa, $T = 550$ K
$t = 2$ yrs   LHR = 250 W/cm

$A_0 = 4\times10^{24}\ s^{-1}$ $G = 4.1\times10^{10} - 2.3\times10^{7}T$ Pa

$n = 5$ $Q = 2.7\times10^{5}$ J/mol $C_0 = 2.714\times10^{-24}$

$C_1 = 0.85$

$C_2 = 1$

$$\dot{\epsilon}_{ss} = A_0\left(\frac{\sigma_m}{G}\right)^n \exp\left(\frac{-Q}{RT}\right)$$

$$\dot{\epsilon}_{ss} = \left(4\times10^{24}\right)\left(\frac{240}{28350}\right)^5 \exp\left(\frac{-2.7\times10^5}{8.314\times550}\right)$$

$G = \left(4.1\times10^{10} - 2.3\times10^{7}(550)\right) = 28350$ MPa

$\dot{\epsilon}_{ss} = 3.95\times10^{-12}\ s^{-1}$

$$\dot{\epsilon}_{ir} = C_0\,\Phi^{C_1}\,\sigma_m^{C_2}$$

$\Phi = 3\times10^{11}$ LHR $= 7.5\times10^{13}$ n/cm²·s

$$= \left(2.714\times10^{-24}\right)\left(7.5\times10^{13}\right)^{0.85}(240)^1$$

$\dot{\epsilon}_{ir} = 4.05\times10^{-10}\ s^{-1}$

$\dot{\epsilon}_{tot} = \dot{\epsilon}_{ss} + \dot{\epsilon}_{ir} = 4.09\times10^{-10}\ s^{-1}$

@ $t = 2$ yrs $= 6.307\times10^{7}$ s $\epsilon_{tot} = 0.026$ 2.6%

Estimate oxide thickness

$T = 600\ K \qquad t = 300$ days

→ has gone through linear transition?

$$t^*(d) = 6.62\times10^{-7} \exp\left(\frac{11949}{T}\right) \rightarrow 295 \text{ days} \rightarrow \text{Yes}$$

→ oxide thickness @ transition?

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

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

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

$$\delta = 2.04 + (0.0067)(300 - 295) = \underline{2.07\ \mu m}$$

Total change in fuel volume

$$\epsilon_{tot} = \epsilon_{th} + \epsilon_D + \epsilon_{SFP} + \epsilon_{GFP}$$

$\alpha_{TH} = 11\times10^{-6}$ $\quad \dot{F} = 4\times10^{14}\ f/cm^3\text{-}s$ $\quad T = 1500\ K$ $\quad T_{ref} = 300K$

$\Delta\rho_0 = 0.01$ $\quad B_D = 5\ MWD/kg\,U$ $\quad t = 20$ days $\quad \rho(UO_2) = 10.97\ g/cc$

B @ $t = 20$ days $\quad N_U = 10.97\ g/cc\ \frac{1\,mol}{270\,g}\ \frac{6.022\times10^{23}}{1\,mol} = 2.45\times10^{22}\ U/cc$

$$B = FIMA = \frac{\dot{F}t}{N_U} = \frac{(4\times10^{14})(1728000)}{2.45\times10^{22}} = 0.028\ FIMA$$

$$\epsilon_{th} = (11\times10^{-6})(1500-300) = 0.0132$$

$$\epsilon_D = \Delta\rho_0\left(\exp\left(\frac{B\ln 0.01}{C_D B_D}\right)-1\right) \rightarrow$$

$C_D = 1\ (T<750°C)$

$B_D = 5\ \frac{MWD}{kg\,U}\ \frac{1}{950} = 0.0053\ FIMA$

$$\epsilon_D = 0.01\left(\exp\left(\frac{0.028\ln 0.01}{1\times0.0053}\right)-1\right) = -0.01$$

$$\epsilon_{SFP} = 5.577\times10^{-2}\rho B = (5.577\times10^{-2})(10.97)(0.028) = 0.0171$$

$$\epsilon_{GFP} = (1.96\times10^{-28})\rho B(2800-T)^{11.3}\exp(-0.0162(2800-T))\exp(-17.8\rho B)$$

$$\epsilon_{GFP} = 2.8\times10^{-5}$$

$$\epsilon = 0.0132 - 0.01 + 0.0171 + 2.8\times10^{-5} = \boxed{0.0203}$$

Given a fission rate of $\dot{F} = 3 \times 10^{16}$ fiss/sec and $T = 1250$ K, what is the D_{Xe}?

$$D_1 + D_2 + D_3$$

$$D_1 = 7.6 \times 10^{-4} \exp\left(-\frac{3.03}{k_B T}\right)$$

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

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

$D_1 = 4.62 \times 10^{-18}$ cm²/s

$D_2 = 3.89 \times 10^{-15}$ cm²/s

$D_3 = 6 \times 10^{-14}$ cm²/s

$$\underline{D = 6.39 \times 10^{-14} \text{ cm}^2/\text{s}}$$