1.) Fuel volume change?

$\alpha_{th} = 11\times10^{-6}$ $\quad T = 1500K$

$\dot{F} = 4\times10^{14} \frac{f}{cc\cdot s}$ $\quad T_{ref} = 300K$

$\Delta\rho_0 = 0.01$ $\quad B_D = 5\ \frac{MWD}{kgU}$

$\rho = 10.97\ g/cc$

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

$t = 20$ dys

$N_U = 10.97\ g/cc \cdot \frac{1\,mol}{270\,g} \cdot \frac{6.022\times10^{23}}{1\,mol} = 2.45\times10^{22}\ U/cc$

$B = FIMA = \frac{\dot{F}t}{N_U} = \frac{(4\times10^{14})(20\times24\times3600)}{2.45\times10^{22}} = 0.028\ FIMA$

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

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

$C_D = 1 \quad T > 750°C$

$B_D = \frac{5}{950} = 0.0053\ FIMA$

$B > B_D \rightarrow \epsilon_D = -0.01$

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

$\epsilon_{GFP} = (1.96\times10^{-28})\rho B\,(2800-T)^{11.73}\exp(-0.0162(2800-T))\exp(-17.8\rho B)$

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

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

c) Post-annealing FGR

$t = 40$ days $\quad a = 10\ \mu m \quad T = 1500\ K$

$$D_{Xe} = ? = 7.6\times10^{-6}\exp\left(-\frac{3}{k_B T}\right)\ cm^2/s$$

$$= 6.83\times10^{-16}\ cm^2/s$$

$$\tau = \frac{D\times t}{a^2} = \frac{(6.83\times10^{-16})(40\times24\times3600)}{(10\times10^{-4})^2} = 0.0022 < \pi^{-2} = 0.101$$

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

$$= 6\sqrt{\frac{\tau}{\pi}} - 3\tau = \underline{0.15}$$

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3) In-pile FGR

$t = 2$ hrs $\quad a = 10\ \mu m \quad T = 1500\ K \quad \dot{f} = 5\times10^{14}\ \frac{fiss}{cc\cdot s}$

$$D = D_1 + D_2 + D_3 = 7.6\times10^{-6}\exp\left(\frac{-3}{kT}\right) + 1.41\times10^{-18}\exp\left(\frac{-1.2}{kT}\right)\sqrt{\dot{f}} + 2\times10^{-30}\dot{f}$$

$$= 6.83\times10^{-16} + 2.93\times10^{-15} + 1\times10^{-15}$$

$$= 4.56\times10^{-15}\ cm^2/s$$

$$\tau = \frac{(4.56\times10^{-15})(2\times3600)}{(10\times10^{-4})^2} = 3.28\times10^{-5} < \pi^{-2} \qquad f = 4\sqrt{\frac{\tau}{\pi}} - \frac{3}{2}\tau$$

$$\underline{f = 0.013}$$

total gas released $= f\times(y\dot{f}t) \qquad y = \text{yield} \approx 0.3$

4) Zr creep rate

$\dot{\epsilon}_{tot} = \dot{\epsilon}_{ss} + \dot{\epsilon}_{ir}$

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

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

$\sigma_m = 150$ MPa

$T = 600K$ $\quad t = 1yr$

LHR $= 250$ W/cm

PR/A

$A_0 = 3.14 \times 10^{24}$

$G = 4.85 \times 10^{10} - 2.0185\,T$

$n = 5$

$Q = 2.7$ eV

$C_0 = 2.714 \times 10^{-24}$ $\quad C_1 = 0.85$ $\quad C_2 = 1$

$\dot{\epsilon}_{ss} = 3.14 \times 10^{24} \left(\frac{150}{42500} \right)^5 \exp\left(\frac{-2.7}{kT} \right)$

$= 5.3 \times 10^{-12}$

$G = 4.85 \times 10^{10} - 2.0185(600)$

$= 42.5$ GPa

$\Phi = \text{LHR} \times 3 \times 10^{4}$

$= 7.5 \times 10^{13}$

$\dot{\epsilon}_{ir} = 2.714 \times 10^{-24} (7.5 \times 10^{13})^{0.85} (150)^{1}$

$= 2.53 \times 10^{-10}$

$\dot{\epsilon}_{tot} = 2.58 \times 10^{-10}$

$\epsilon_{tot} = \dot{\epsilon}_{tot}\, t$

$= 2.58 \times 10^{-10} (1 \times 365 \times 24 \times 3600)$

$= 0.0081$