NE 533 : Spring 2003

Nuclear Fuel Performance

Exam 3 Solutions

2) $\epsilon_{tot} : \epsilon_{th} + \epsilon_{D} + \epsilon_{SFP} + \epsilon_{GFP}$

$\alpha_{th} = 10 \times 10^{-6}\ 1/K \qquad \dot{f} = 8 \times 10^{13}\ f/cm^2\text{-}s \qquad T_f : 1400\ K \qquad T_f^{ref} : 300\ K$

$\Delta\rho_0 : 0.01 \qquad \beta_D : 5\ \frac{MWd}{kgU} \qquad \rho(UO_2) : 10.97\ g/cc \qquad t : 200\ dy$

$\beta : ? = \frac{\dot{f} \cdot t}{N_u} \qquad N_u : 10.97\ \frac{1\ mol}{270}\ \frac{6.022 \times 10^{23}}{1\ mol} = 2.45 \times 10^{22}\ U/cc$

$\beta = \frac{(8 \times 10^{13})(200 \times 24 \times 3600)}{2.45 \times 10^{20}} = 0.0564\ FIMA$

$\epsilon_{th} = \Delta T \alpha = (1400 - 300)(10 \times 10^{-6}) = 0.011$

$\epsilon_D : \Delta\rho_0 \left[\exp\left(\frac{\beta \ln 0.01}{C_0 \beta_D} \right) - 1 \right] \qquad \beta_D : \frac{5\ \frac{MWd}{kgU}}{950} = 0.005\ FIMA$

$\beta > \beta_D \rightarrow \epsilon_D : -0.01$

$\epsilon_{SFP} : 5.577 \times 10^{-2} \rho\beta = 5.577 \times 10^{-2}(10.97)(0.0564)$

$= 0.0345$

$\epsilon_{GFP} = 1.96 \times 10^{-28} \rho\beta (2800 - T)^{11.73} \exp(-0.0162(2800 - T)) \exp(-17.8\rho\beta)$

$\rho = 10.97 \qquad \beta = 0.0564 \qquad T = 1400$

$\epsilon_{GFP} = (1.21 \times 10^{-28})(9.02 \times 10^{36})(1.413 \times 10^{-10})(1.649 \times 10^{-5})$

$\epsilon_{GFP} = 2.26 \times 10^{-6}$

$\epsilon_{tot} : 0.011 + 0.01 + 0.0345 + 2.26 \times 10^{-6}$

$\boxed{\epsilon_{tot} : 0.0355 \rightarrow 3.5\%}$

2) $\sigma_m = 250$ MPa $\qquad$ LHR $= 150$ W/cm

$T = 650$ K $\qquad$ $t = 70$ days

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

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

$G = 4.5519 \times 10^{10} - 2.2185 \times 10^{7}\, T$

$G = 28098$ MPa

$Q = 2.8$ eV $\qquad$ $n = 5$

$$\dot{\epsilon}_{ss} = 3.14 \times 10^{24} \left(\frac{250}{28098}\right)^5 \exp\left(\frac{-2.8}{kT}\right)$$

$$= 3.415 \times 10^{-8}$$

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

$C_0 = 1.6524 \times 10^{-24}$

$C_1 = 0.85$

$C_2 = 1$

$$\dot{\epsilon}_{ir} = 1.6524 \times 10^{-24} \left(4.5 \times 10^{13}\right)^{0.85} (250)^1$$

$\Phi = 3 \times 10^{11}$ LHR

$= 4.5 \times 10^{13}$ n/cm²-s

$$\dot{\epsilon}_{ir} = 1.665 \times 10^{-10}$$

$$\dot{\epsilon}_{tot} = \dot{\epsilon}_{ss} + \dot{\epsilon}_{ir} = 3.432 \times 10^{-8} \text{ 1/s}$$

$$\epsilon_{tot} = \dot{\epsilon}_{tot} \times t = (3.432 \times 10^{-8})(70 \times 24 \times 3600)$$

$$\boxed{= 0.208}$$

3) $T = 1600\ K \qquad t = 30\ hrs$

$a_1 = 10 \times 10^{-4}\ cm \qquad a_2 = 25 \times 10^{-4}\ cm$

$D = 7.6\times10^{-6} \exp\left(\frac{-3}{kT}\right) = 2.70 \times 10^{-15}\ cm^2/s$

$\tau_1 = \frac{D \times t}{a_1^2} = \frac{(2.70\times10^{-15})(30\times3600)}{(10\times10^{-4})^2} = 2.91\times10^{-4}$

$\pi^{-2} = 0.101$

$\tau_1 < \pi^{-2}$

$\tau_2 = \frac{D \times t}{a_2^{\ 2}} = \frac{(2.70\times10^{-15})(30\times3600)}{(25\times10^{-4})^2} = 4.66\times10^{-5}$

$\tau_2 < \pi^{-2}$

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

$f_1 = 6\sqrt{\frac{\tau}{\pi}} - 3\tau = 0.057$

$f_2 = 6\sqrt{\frac{\tau}{\pi}} - 3\tau = 0.023$

~2.5x as much released in smaller grain pellet

4) Stage 1: fission gas atoms are produced inside the grains, form intragranular bubbles, resolve + diffuse to the grain boundaries.

Stage 2: intergranular fission gas bubbles nucleate and grow as more fission gas arrives at the grain boundaries, Fission gas bubbles decorate the grain faces and start to interconnect, forming pathways to triple junctions,

Stage 3: Networks connecting triple junctions interconnect and fission gas is transported to a connected free surface.

5) Higher retained fission gas, higher thermal conductivity, higher porosity, sub-micron grain sizes, brittle, etc.

6) - soluble oxides: go into fluorite lattice, act as phonon Scatterers, increase lattice constant, change U charge State

- insoluble oxides: form oxide precipitates, scatter phonons, can be sink for defects

- metallic : form metal precipitates that increase the thermal conductivity

- fission gases: form fission gas bubbles which cause swelling and degradation in K_{th}

- volatile gases: form fission gas bubbles, participate in SCC

7) neutron transparent, low T void swelling resistance, cheap, etc.

8) • corrosive environment: volatile fission products diffuse to the pellet/clad interface and react w/ the Zr cladding

- susceptible material: all Zr alloys are susceptible to SCC, changes in composition can affect the degree/severity

- sufficient stress: stress is imposed both by the swelling fuel which comes into contact w/ the cladding and by the internal pressure in the cladding tube

- sufficient time: SCC occurs after the fuel has come into contact w/ the cladding and fission products have been transported to the pellet/clad interface.

9) generation of fission products, changes in the O/M ratio, bubble and void generation, formation of HBS, etc.

10) vacancies cluster on the basal plane and interstitials cluster along the pyramidal planes. this leads to an increase in 'a' and a shrinkage in 'c', leading to anisotropic irradiation growth

11) 1) Coolant pressure is greater than gap pressure, Zr cladding creeps down. 2) Partial contact from creep down + fuel swelling leads to mixed axial elongation. 3) full contact from fuel swelling leads to cladding radial expansion and axial shrinkage

12) lattice constant, Young's modulus, thermal conductivity, etc.

13) Material: changing compositions, adding dopants, add liner, etc.

Operational: modifying practices to ensure greater safety margins