1) UN $\epsilon = 19\%$ $\rho = 12.3\ g/cc$ $\sigma = 587\ b$ $\phi = 2\times10^{13}\ n/cm^2 s$

$Q = ? = N_u^{235} E_f \phi \sigma_f$

$M(UN) = 0.19 \times 235 + 0.81 \times 238 + 14 =$
$251.43\ g/mol$

$N_u = 12.3\ g/cc \cdot \frac{1\ mol}{251.43\ g} \cdot \frac{6.022\times10^{23}\ mole}{1\ mol} \cdot \frac{14}{1\ mole\ (UN)} \times 0.19 = 5.597\times10^{21}$

$Q = (200\times10^6\ eV)(1.602\times10^{-19}\ J/eV)(5.597\times10^{21}\ U\text{-}235)(2\times10^{13}\ n/cm^2 s)(587\times10^{-24}\ cm^2)$

$\underline{Q = 2105\ W/cc}$ - bit too high for realism

b) $N^{U\text{-}235}(UN) = N^{U\text{-}235}(UO_2)$ $M(UO_2) = 235x + 238(1-x) + 32$
$= 270 - 3\epsilon$

$5.597\times10^{21} = 10.97 \cdot \frac{1}{270-3\epsilon} \cdot 6.022\times10^{23} \cdot \frac{1U}{1UO_2} \times \epsilon$

$8.472\times10^{-4} = \frac{\epsilon}{270-3\epsilon}$ $0.2288 - 2.54\times10^{-3}\epsilon = \epsilon$

$\boxed{\epsilon = 22.8\%}$

2) $T(r=0.2)$

cladding midpoint

$K_c = 0.18 \ \frac{W}{cm\text{-}K}$

$K_f = 0.04 \ W/cm\text{-}K$

$h_{cool} = 1.5 \ \frac{W}{cm^2\text{-}K}$

$T_{cool} = 500 \ K$

$Q = 350 \ W/cc$

$R_F = 0.4 cm$

$t_g = 30 \mu m$

$t_c = 0.05 \ cm$

$$LHR = \pi R_F^2 Q = \pi (0.4)^2 (350) = 175.93$$

$$\frac{LHR}{2\pi R_F} = 70$$

$$T_{co} - T_{cool} = \frac{LHR}{2\pi R_F} \frac{1}{h_{cool}} = 70 \frac{1}{1.5} = 46.67 \ K \qquad \underline{T_{co} = 546.67 \ K}$$

$$T_{ci} - T_{co} = \frac{LHR}{2\pi R_F} \frac{t_c}{K_c} = 70 \frac{0.05}{0.18} = 19.44 \qquad \underline{T_{ci} = 566.1 \ K}$$

$$K_g = 16 \times 10^{-6} T^{0.79} \rightarrow T \sim T_{ci} \rightarrow K_g = 16 \times 10^{-6} (566.1)^{0.79}$$

$$K_g = 0.00239$$

$$T_s - T_{ci} = \frac{LHR}{2\pi R_F} \frac{t_g}{k_g} = 70 \frac{0.003}{0.00239} = 87.76 \ K \qquad T_s = 653.9 \ K$$

$$T(r) - T_s = \frac{Q}{4K}(R^2 - r^2) = \frac{350}{4(0.04)}(0.4^2 - 0.2^2) = 262 \ K$$

$$T(r=0.2) = \underline{916.4 \ K}$$

$$T_{clad} = \frac{T_{co} + T_{ci}}{2} = \frac{566.1 + 546.67}{2} = \underline{556.4 \ K}$$

· linear T in cladding

2 - cont.

oxide layer

$$\Delta T_{ox} = \frac{LHR}{2\pi R_f}\,\frac{t_{ox}}{k_{ox}} = 70\,\frac{0.005}{0.015} \cdot 23.3\ K$$

$\rightarrow$ increase by 23.3 K

$$T_0 - T_s = \frac{LHR}{4\pi k_f} = \frac{175.9}{4\pi(0.04)}$$

$$T_0 = 1004\ K$$

$$\underline{T_0 + \text{oxide} = 1023\ K}$$

3) $L = 3.6\ m$ $\quad z_0 = 1.8\ m$ $\quad LHR^\circ = 250\ W/cm$ $\quad \gamma = 1.1$

$LHR\,(z = 2.1)$

$$LHR(z) = LHR^\circ \cos\left(\frac{\pi}{2\gamma}\left(\frac{z}{z_0} - 1\right)\right) = 250 \cos\left(\frac{\pi}{2 \cdot 1.1}\left(\frac{2.1}{1.8} - 1\right)\right)$$

$$= \underline{243\ W/cm}$$

$$T_{cool}^{out} = T_{cool}(z = 3.6)$$

$$T_{cool}^{out} - T_{cool}^{in} = \frac{2\gamma}{\pi}\,\frac{z_0\,LHR^\circ}{\dot{m}\,c_p}\left[\sin\left(\frac{\pi}{2\gamma}\right) + \sin\left(\frac{\pi}{2\gamma}\left(\frac{z}{z_0} - 1\right)\right)\right]$$

$$= \frac{2.2}{\pi}\,\frac{180 \times 250}{4200\,(0.2)}\left[\sin\left(\frac{\pi}{2.2}\right) + \sin\left(\frac{\pi}{2.2}\left(\frac{3.6}{1.8} - 1\right)\right)\right]$$

$$= 37.51\ [0.989 + 0.989]$$

$$\Delta T = 74.2\ K \qquad \underline{T_{cool}^{out} = 574.2\ K}$$

4) $\frac{K_{eff}}{K_{ox}} = 1 - p^{2/3}$ $K_{ox} = \frac{1}{A + BT}$ $T = 1200$

$FIMA = 0.05$

K_o nominal $\rightarrow$ $FIMA = 0$

$A = 3.8 + 200 \times FIMA \rightarrow A = 3.8$

$B = 0.0217$

$$K_{ox} = \frac{1}{3.8 + 0.0217(1200)} = 0.0335$$

K_{ox} @ $FIMA = 0.05$

$A = 3.8 + 200 \times 0.05 = 13.8$

$$K_{ox} = \frac{1}{13.8 + 0.0217(1200)} = 0.0251$$

$K_{eff} = K_{ox}(FIMA = 0.05)$

$$\frac{0.0251}{0.0335} = 1 - p^{2/3}$$

$p = 0.1255$

$= \underline{12.6\% \text{ porosity}}$

5) natural uranium is only 0.7% U-235. In order to have high power, thus high heating rates, we need a higher U-235 number density. By enriching, we increase the relative amount of fissile material. UF_6 is utilized as a gaseous product in the enrichment process. Centrifugal enrichment involves a feed of UF_6 into a rapidly rotating cylinder. The mass difference between U-235 and U-238 leads U-238 to preferentially accumulate at the periphery, resulting in an enriched UF_6 gas at the center. The gas is removed from the center and the process is repeated.

6) The CHF is the flux at which heat transfer via boiling is at a maximum, beyond which heat transfer is no longer effective. The DNB is literally when nucleate boiling is no longer the mode of boiling heat transfer. Film boiling begins to predominate. The DNB ratio is the ratio of the CHF to the heat flux in the hottest channel and is used as an operational limit.

7) Low melting point, poor compatibility w/ water, anisotropic thermal expansion and irradiation growth, etc.

8) The ratio of the fuel volume inside the cladding to the theoretical maximum volume inside the fuel cladding. The space is filled w/ a 'bond' material, e.g. He. This allows for thermal expansion and fission gas swelling of the fuel.

9) Point defects, fission products, bubbles, grain boundaries, precipitates, etc.

10) Mo, Cs, Nd, La, Ru, Zr, etc.

Double hump distribution of fission products w/ one peak at A~90 and the other at A~135

11) Cladding is the primary containment, it prevents fission product release to the coolant, prevents interaction of the fuel w/ the coolant, and holds the fuel in place.

12) Fuel + cladding + gap + coolant

13) Heat transfer out of the fuel + into the coolant

Operating during nominal conditions w/o failures

Behavior during accident scenarios