Shehab Shousha

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Question (1) 10/12 - right process

Assumptions
a) Constant thermal conductivity $k(T) = k$ ✓
b) Assuming steady state ✓
c) Assuming symmetry in y, z direction ✓

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + Q = 0 \Rightarrow \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) = -Q$$

$$k\frac{\partial T}{\partial x} = -Qx + C_1$$

from boundary condition $\left.\frac{\partial T}{\partial x}\right|_{x=0} = 0 \Rightarrow 0 = 0 + C_1$

$\therefore C_1 = 0$ ✓

$$k\frac{\partial T}{\partial x} = -Qx$$

$$\therefore T(x) = -\frac{Qx^2}{2K} + C_2$$

from boundary conditions: $T(X) = T_1$

$$\therefore T_1 = -\frac{QX^2}{2K} + C_2 \Rightarrow \therefore C_2 = T_1 + \frac{QX^2}{2K}$$

$$\therefore T(x) = -\frac{QX^2}{2K} + T_1 - \frac{Qx^2}{2K}$$

$$T(x) = T_1 + \frac{Q}{2K}(X^2 + x^2)$$

Temp. drop accross fuel: $T_0 - T_F = \frac{Q}{2K}X_F^2$ (when X_F: fuel thickness)

16/16

Question (2)

1st without coating

$T_{CO} = 600K$, $Q = \cancel{280}$ $250 W/cm^3$

$LHR = \pi R_F^2 Q$

$= \pi (0.6)^2 * 250$

$= 90\pi \; W/cm$

$$T_{CI} = T_{CO} + \frac{LHR}{2\pi R_F} \frac{t_{clad}}{K_{clad}}$$

$$T_{CI} = 600 + \frac{90}{2*0.6} * \frac{0.05}{0.15}$$

$$T_{CI} = 600 + 25 = 625K$$ ✓

Gap

$$T_F = T_{CI} + \frac{90\pi}{2\pi R_F} \frac{t_g}{K_g}$$

$$T_F = 625 + \frac{90}{2*0.6} * \frac{0.005}{0.004} = 718.75K$$ ✓

$$T_0 = T_F + \frac{QR^2}{4K_F} = 718.75 + \frac{250 * 0.6^2}{4 * 0.05} = \boxed{1168.75K}$$ ✓

Question (2)

with Coating

$$T_{coating\,out} = 600\,K$$

$$T_{CO} = T_{coating} + \frac{q_0 \pi}{2\pi R_F} \frac{t_{coat}}{k_{coat}} = 600 + \frac{90}{2*0.6} * \frac{0.01}{0.015}$$

$$= 650\,K$$

$$T_{CI} = 650 + \frac{90}{2*0.6} * \frac{0.05}{0.15} = 675\,K$$

$$T_F = 675 + \frac{90}{2*0.6} * \frac{0.005}{0.004} = 768.75\,K$$

$$T_0 = 768.75 + \frac{250 * 0.6^2}{4 * 0.05} = \boxed{1218.75\,K}$$

Question (3)

13/14

a) $\phi = 5 * 10^{12} \frac{n}{cm^2 \cdot s}$

Heat gen. rate $= \frac{200 \text{ MeV}}{\text{fission}} * N_{U-235} * \sigma_f * \phi$

238 → 237.4

$N_{UN} = \frac{\rho N_{AV}}{M} = \frac{12.3 * 6.02 * 10^{23}}{238 + 14} = 2.94 * 10^{22} \frac{f.u}{cm^3}$

$N_U = N_{UN} = 2.94 * 10^{22} \frac{atoms}{cm^3}$

Approximately: 19.5% of them are U-235 ✓

$\therefore N_{U-235} = 2.94 * 10^{22} * \frac{19.5}{100} = 5.7 * 10^{21} \frac{atom}{cm^3}$

$\therefore$ Heat gen. rate $= 200 * 10^6 * 1.6 * 10^{-19} J * 5.7 * 10^{21} cm^{-3} * 570 * 10^{-24} cm^2 * 5 * 10^{12} \left(\frac{1}{cm^2 s}\right)$

$\approx \boxed{520 \frac{W}{cm^3}}$ ✓

(b) if UO_2 instead of UN

mass → 238(1-x) + 235x

$N_{U-235} = 5.7 * 10^{21} \frac{atom}{cm^3}$, $N_{U-235} \approx N_U *$ enrichment ✓

$\therefore N_U = \frac{5.7 * 10^{21}}{\text{enrichment}}$, $\therefore N_{UO_2} = N_U = \frac{5.7 * 10^{21}}{\text{enrichment}}$ ✓

$\therefore \frac{\rho_{UO_2} N_{AV}}{M_{UO_2}} = \frac{5.7 * 10^{21}}{\text{enrichment}} \Rightarrow \frac{10.97 * 6.02 * 10^{23}}{238 + 16 * 2} = \frac{5.7 * 10^{21}}{\text{enrich}}$

$\therefore$ $\boxed{\text{enrichment} \approx 23.3\%}$ ✓

Question (4) $LHR^{\circ} = 350 \, W/cm$, $\gamma = 1.3$, $Z_o = \frac{3.5m}{2} = 1.75m$

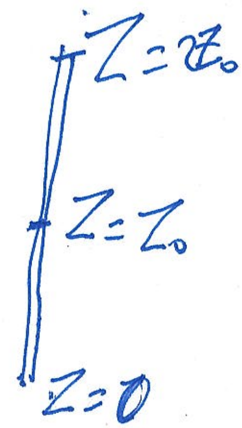
12/12

(a) $LHR(z=1.4m) = LHR^{\circ} \cos\left[\frac{\pi}{2\gamma}\left(\frac{z}{z_o} - 1\right)\right]$

$= 350 \cos\left[1.2(0.8-1)\right]$

$= 350 * 0.97$

$\approx \boxed{340 \, W/cm}$



(b) $C_p = 4200 \, J/kg\text{-}K$, $\dot{m} = 0.22 \, \frac{kg}{s \cdot rod}$

$$\Delta T_{cool} = \frac{1}{1.2} \frac{Z_o \, LHR^{\circ}}{\dot{m} C_p} \left\{ \underset{0.932}{\sin(1.2)} + \underset{0.932}{\sin\left[1.2\left(\frac{2z_o}{z_o} - 1\right)\right]} \right\}$$

$[T_{out} - T_{in}]$

$$= \frac{1}{1.2} * \frac{1.75 \, m * 350 * 10^2 \, W/m}{0.22 * 4200 \, W} \left[0.932 + 0.932\right]$$

$\approx \boxed{103 \, K}$

Question (5) $dt = 0.5$, $t_0 = 0$, $y_0 = 4$ 12/12

$$\frac{dy}{dt} = t e^{-2t}$$

$$y(t+dt) = y(t) + dt\, y'(t+dt)$$

$\Rightarrow \boxed{y_0 = 4}$

$$\Rightarrow y_{0.5} = 4 + 0.5\, y'(0.5) = 4 + 0.5 * [0.5\, e^{-1}]$$

$$= \boxed{4.092}$$

$$\Rightarrow y_1 = 4.092 + 0.5\, y'(1) = 4.092 + 0.5\,[1 * e^{-2}] = \boxed{4.16}$$

$$\Rightarrow y_{1.5} = 4.16 + 0.5\, y'(1.5) = 4.16 + 0.5\,[1.5\, e^{-3}]$$

$$= \boxed{4.197}$$

Question (6) 4/4

Fertile: Isotope that can be transformed into a fissile isotope by absorbing neutrons.

Fissile: Isotope that can undergo fission with neutrons of any energy (even thermal energies)

Fissionable: Isotope that can undergo fission only with neutrons of a minimum threshold energy

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Question (7) We don't use pure metallic U because: 4/4

(1) ~~the~~ Phase changes

(2) swelling during thermal cycling

(3) Anisotropic thermal expansion & Anisotropic irradiation growth

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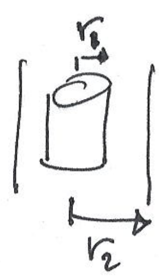
Question (8) Smear density is the ratio between the fuel volume and the total internal volume of fuel element 4/4

$$\text{smear density} = \frac{\pi r_1^2 h}{\pi r_2^2 h} = \frac{r_1^2}{r_2^2}$$



It is important to have a gap to accomodate fuel swelling & fission gas release

Question (9)

6/8

⇒ We need to enrich U to increase the percentage of U-235 isotope [which is the fissile isotope] ✓

⇒ Natural U has only 0.7% of U-235 ✓

⇒ We need U-235 bec. it undergoes fission with thermal neutrons

⇒ In enrichment process, UF_6 is utilized ✓
(Uranium hexafluoride) gaseous form

In Centrifuge

- opposite. heavy goes to outside

Lighter gas with more U-235 goes to the outside and can be extracted

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Question (10)

① Finite ~~element~~ difference : simple and fast ✓
(using discrete points) but can't be applied for heterogeneous structure

6/6

② Finite volume : ✓

~~③ Finite difference~~

③ Finite element : ✓

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Question (11)

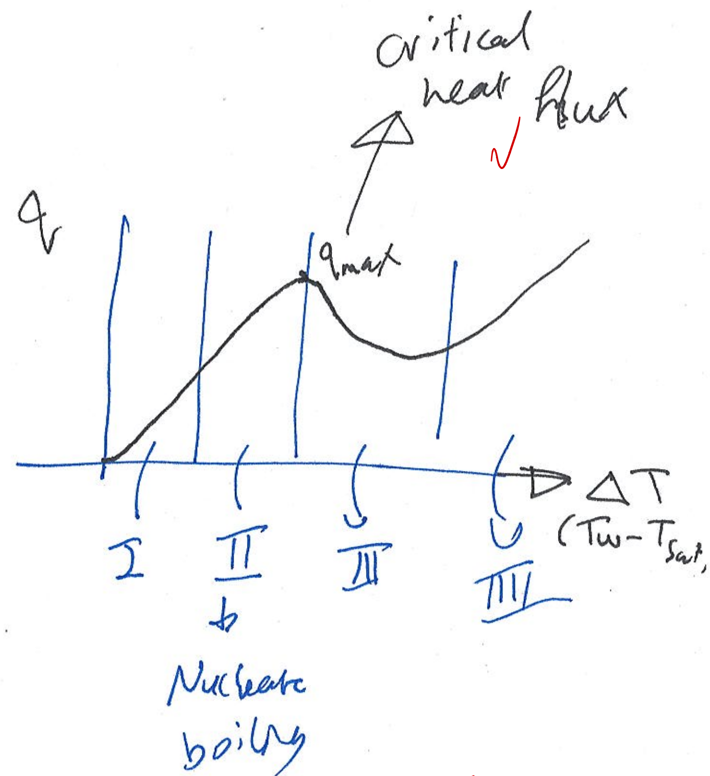
8/8

Departure from Nucleate boiling

$$DNBR = \frac{\text{Critical heat flux}}{q(z)}$$

$DNBR > 1$

The margin allowed is typically $1.15 \rightarrow 1.3$ ✓



✓

Critical heat flux:
is the max heat flux that can be achieved before a vapor film is created and then heat flux decreases ✓

Question (12)

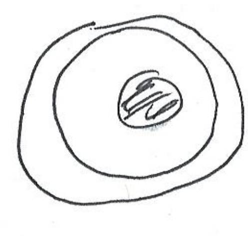
TRISO : UC or UCO ✓ 3/5

Carbide fuel

-pyC layer

+ buffer

with SiC coating ✓



In High temp. gas cooled reactor (HTGR)