NUCL 402 Engineering of Nuclear power Systems

School of Nuclear Engineering, Purdue University

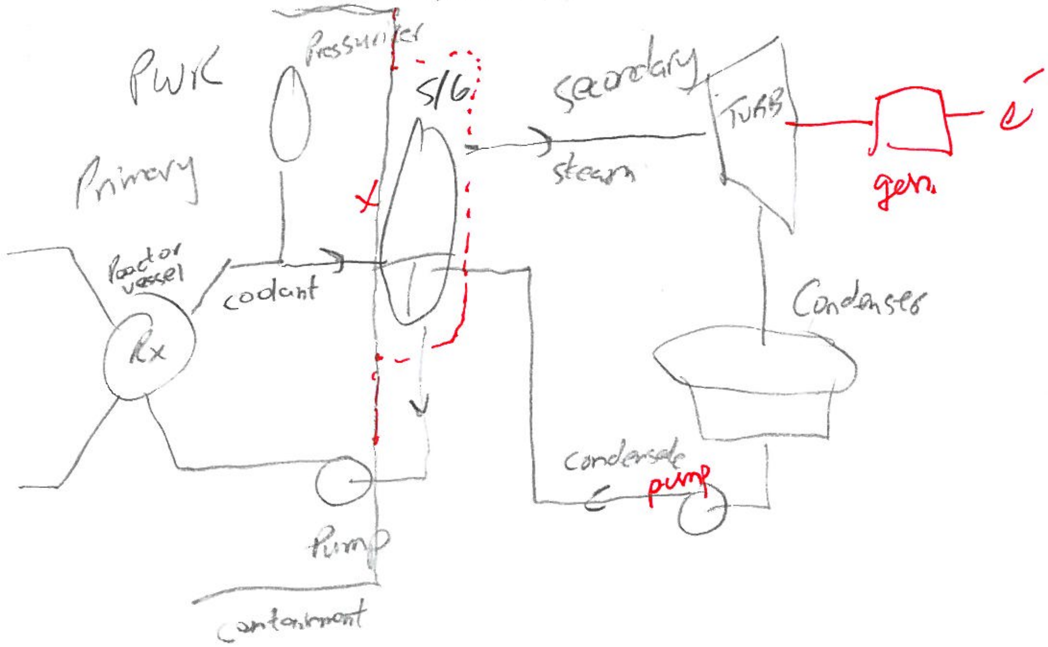
Test 1

NAME: Robert Jackson September 30, 2009

Instructions:

1. *Attempt all 5 questions- points for each questions are shown in bracket (Total points 90)*
2. *Closed book and closed notes- Calculator allowed.*
3. *All notations refer to class notes and textbook referred*
4. *Show relevant work in space provide*
5. *Time allowed 50 minute*

1. (a) Draw schematics PWR and BWR reactor flow loops that include reactor vessel, associated key piping and power generation systems. (7)



BWR on back

−1

(b) Compare the difference between PWR and BWR reactor vessel and its contents including, core fuel bundles, control rods and other associated components (8)

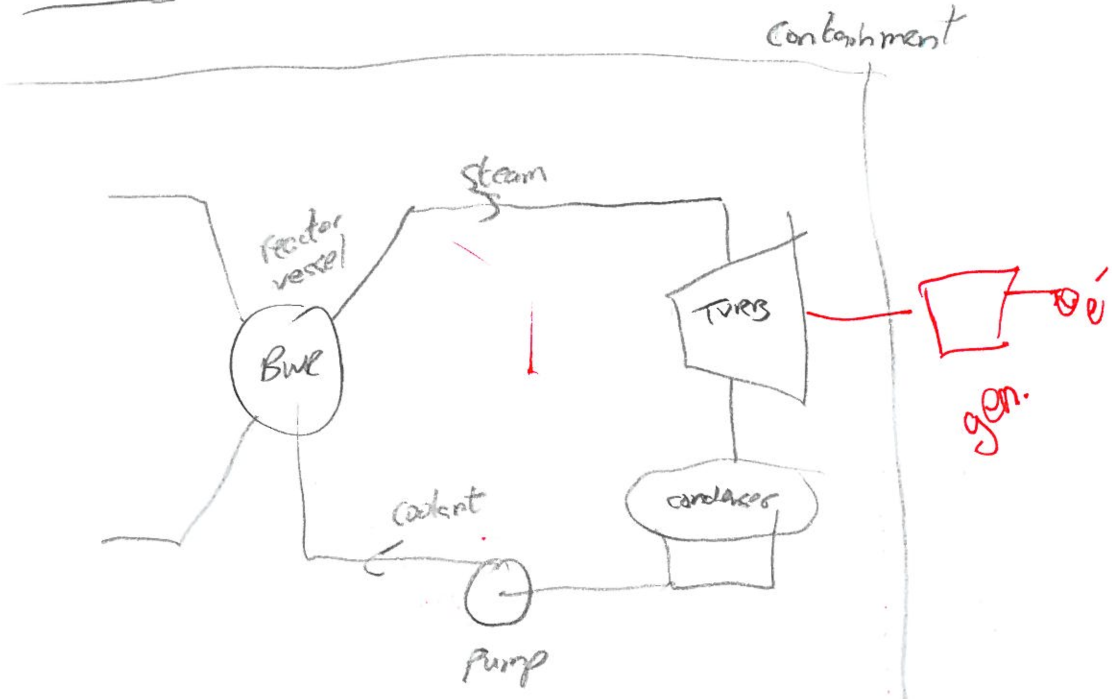
Both use UO_2 fuel. A BWR contains separators and dryers at the top as well as control rods. A PWR does not have separators or dryers, Both have pumps but the BWR has recirculation pumps interior and jet pumps for safety. Both have control rods. A BWR typically has more fuel bundles and rods but this is dependent on power density for both.

−4

BWR: control blades.
fuel bundles encased in metal sheet.

PWR: pressurizer
2ndary loop.

BWR


Containment
Steam
reactor vessel
BWR
TURB
gen.
coolant
condenser
Pump

2. (a) Explain the importance of delayed neutrons in reactor control.(5)
(b) In PWR operating at 3000MWt the average neutron lifetime is 10 msec. A reduction in power demand increases void in core resulting in 15 cent of negative reactivity and the response of the neutron density is given as

$$n = n_o\left[\frac{\beta}{\beta-\rho}e^{\lambda\rho t/(\beta-\rho)} - \frac{\rho}{\beta-\rho}e^{-(\beta-\rho)t/l}\right]$$

(i) Find reactor period, if $\beta = 0.0065$, $\lambda = 0.078\ s^{-1}$.
(ii) Find reactor power after five-reactor period.
(iii) What is the reactor period if there were no delayed neutrons? (15)

2.a. Delayed neutrons are .65% of all neutrons in the core. They are generated from the decay of neutron precursers. This decay is on the order of magnitude of seconds which provides a delay creating a longer reactor period thus give operators ample time to respond to power change.

i) $T = \frac{\beta - \rho}{\lambda\rho}$; $\rho = .15\beta = .15(.0065) = 9.75e^{-4}$

$\Rightarrow T = \frac{(.0065 - 9.75e^{-4})}{(.078)(9.75e^{-4})}\text{ sec} = \boxed{72.65\text{ sec}}$

ii) $P = P_0 e^{-t/T}$ Let $t = 5T \Rightarrow P = P_0 e^{-5}$

$\Rightarrow P = 3000\text{ MW}\, e^{-5} = \boxed{20.21\text{ MWt}}$

iii) No d.N. $\Rightarrow T = \frac{l_{eff}}{\rho} = \frac{10e^{-3}\text{ s}}{9.75e^{-4}} = \boxed{10.26\text{ sec}}$

-1

(-1)

3. In the "Sm poisoning" write Pm and Sm and Xe rate equation and obtain expression for steady state reactivity due to Sm poisoning. Show a graph of reactivity change due to Sm with startup, shutdown and restart of the reactor. (20)

$$^{149}Nd \xrightarrow[1.7hr]{\beta} {}^{149}Pm \xrightarrow[53hr]{\beta} {}^{149}Sm(stable)$$

$$\gamma_{Pm} = 0.01071,$$

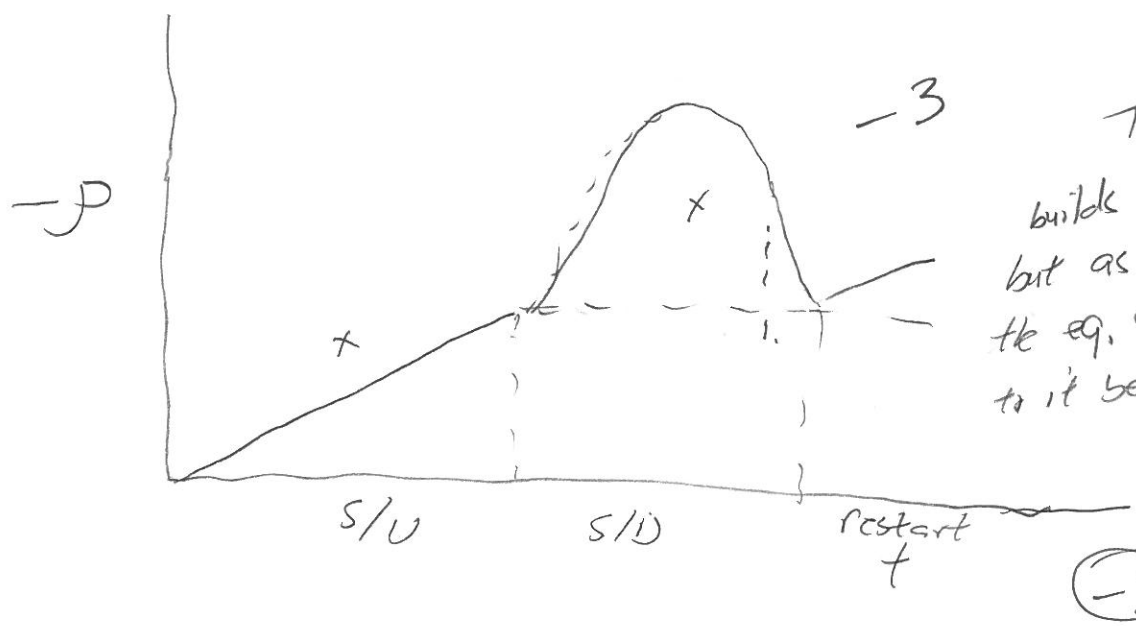
$$\frac{dX}{dt} = \lambda_i I + \gamma_x \Sigma_f \phi - \lambda_x X - \sigma_{a,x} \phi X$$

$$\frac{dP}{dt} = \lambda_{Nd} N_d + \gamma_{Pm} \Sigma_f \phi - \lambda_p P - \sigma_{a,p} \phi P$$

$$\frac{dS}{dt} = \lambda_p P + \gamma_s \Sigma_f \phi - \sigma_{a,s} \phi S \quad (\text{no decay})$$

at equilibrium $\frac{dS}{dt} = 0$

$$\Rightarrow S = \frac{\lambda_p P + \gamma_s \Sigma_f \phi}{\sigma_{a,s} \phi}$$



The Sumarium concentrato builds and decays during S/D but as $t \to \infty$ it only reaches the eq. concentration at S/D due to it being stable.

-3

4. (a) Define (i) Rontgen, (ii) rem and (iii) build-up factor (5)
(b) Calculate absorbed dose rate in mrad/h at a distance 5m from a point source of 35 mCi emitting gamma ray of energy 1Mev. The mass-energy coefficient for soft tissue is 0.003 m^2/kg at 1 MeV. What is the thickness of lead shielding required reducing this dose rate by 25%? Use linear attenuation coefficient for lead at 1Mev as 70 m^{-1} and neglect buildup factor. (15)

a.) 1) Rontgen – The unit of measure defined by ionizing radiation required to create 1 standard electric charge in 1 cc/kg of dry air.

2) rem – a unit of measure of absorbed dose equivalent to biological damage done. Rem = rad × Q where Q is the factor of biological damage for different types of radiation.
Q for γ = 1 ⇒ rad = rem

3.) build-up factor – a factor that takes into account dose by scattered radiation sources. −1

b) $\dot{X} = .0659\, I E\left(\frac{\mu}{\rho}\right)$

units I [$\gamma/cm^2 s$]
E [mev]
$\frac{\mu}{\rho}$ [cm^2/g]

−3

Conversions

⇒ $.003 \frac{m^2}{kg} = .03\ cm^2/g$

$5m = 500\ cm$

$35e^{-3} Ci \left| \frac{3.7\times10^{10}\ DPS}{Ci} \right. = 1.295e^{9}\ DPS$

$A = 4\pi r^2 = 3.142e^{6}\ cm^2$

⇒ $\dot{X} = .0659 \frac{1}{A} E\left(\frac{\mu}{\rho}\right)$ X

$\dot{X} = \frac{(.0659)(1.295e^{9})(1)(.03)}{(3.142e^{6})}$ rad/hr

$\dot{X} = \boxed{814.8\ mrad/hr}$ X

−5

cont'd

5. (a) Calculate the and fill effective half life for the followings (5):

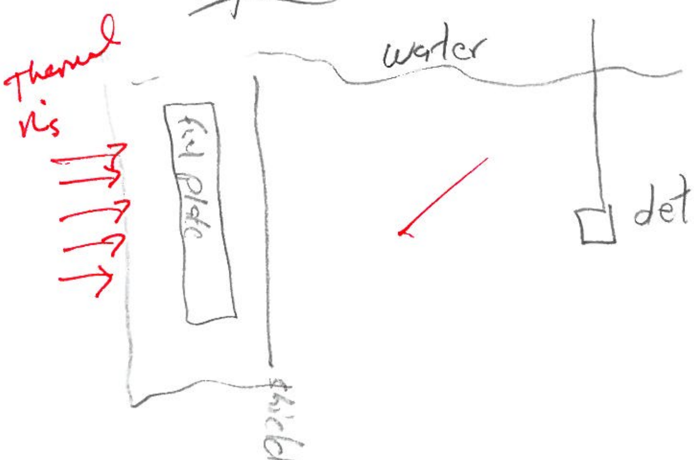
Radionuclides	Physical Half-Life(Tr)	Biological Half-Life(Tb)	Effective Half-Life (Te)
Rubidium-87	1.8×10^{13}	60	60
Technetium-99m	0.25	20	.247
Iodine-131	8	138	7.56
Cesium-137	1.1×10^{4}	70	70
Gold-198	2.7	120	2.64
Mercury-203	45.8	14.5	11.01
Radon-222	3.83	None (Inert Gas)	3.83
Uranium-235	2.6×10^{11}	300	300

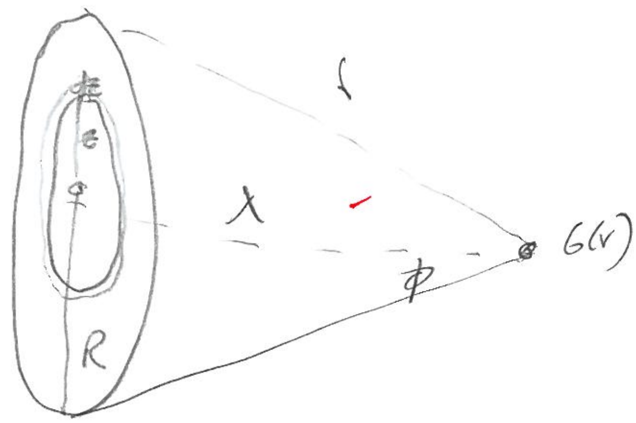
* Equation wasn't given but I used $\frac{T_P T_B}{T_P + T_B}$ If that isn't right I would choose the shortest $t_{1/2}$ as given by those that are very long.

5 (b) Define point water kernel G(R) with a figure and explain how it is used in neutron attenuation analysis. What is the neutron flux at a distance 20 cm from plane neutron source strength of 10^9 neutrons /sec with an iron shield of thickness 5cm. (10)

Assume a point water kernel $G(r) = \frac{Ae^{-\Sigma_{RW} r}}{4\pi r^2}$, with $A = 0.12$, $\Sigma_{RW} = 0.103$ cm^{-1} . Use For iron $\Sigma_R = 0.168$ cm^{-1}

Figures





The point water kernel G(r) is defined by the distance r through water where a point source isotropically emits 1 n/cm² s (ϕ)

It is used in NAA because once G(r) is defined

$\phi(x) = S\,G(r)$ where S is the source strength

If a shield is installed $\phi(x) = S\,G(r)\,e^{-\Sigma_R t}$ where t is thickness

$$G(r) = \frac{(.12)e^{-(.103)(20)}}{4\pi(20)^2} = 3.043e^{-6}$$

$$\Rightarrow \phi(x) = S\,G(r)\,e^{-\Sigma t} = \left[(10^9)(3.043e^{-6})e^{-(.168)(5)}\right] \text{n/cm}^2\text{ s}$$

$$\Rightarrow \phi(x) = \boxed{1313.5 \text{ n/cm}^2\text{ s}}$$

76/90

Nov. 30
Christianity exam.

NUCL 402 Engineering of Nuclear power Systems

School of Nuclear Engineering, Purdue University

Test 2 October 30, 2009

NAME: Robert Jackson

Instructions:

1. *Attempt all 4 questions- points for each questions are shown*
2. *Closed book and closed notes- Calculator allowed.*
3. *All notations refer to class notes and textbook referred*
4. *Show relevant work in space provide*
5. *Time allowed 50 minute*

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1. (14) (a) List the required/desired properties of fuel material for LWR. Discuss all fuel materials studied and how they fair with these required/desired properties. (b) For UO_2 : give the values for melting point (^oC), thermal conductivity from room temperature to 1000 ^oC (W/m^oC) and its crystal structure.

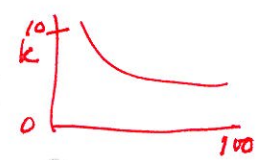
1. High thermal conductivity
2. Resistance to radiation
3. Chemical stability with coolant
4. High melting point with no phase change
5. Low termal expansion coefficient
6. Permits economic fabrication
7. High fissile materials with low absorption

Fuel materials

U metal → 1 good
→ 2 3 4 bad

ceramics of U, Pu, Th
→ 1 bad
→ 2 3 4 5 good

b) $T_m = 1842\,^oC$, thermal cond $= 2\ W/m^oC$



Structure α = orthohombic β = tetragonal γ = ~~BCC~~ FCC

-4

2. **(a)** (8) Give principles of GNEP program

(b) (10) Give governing equations for separation factor for gaseous diffusion and gas centrifuge with variable defined

(c) (10) Give schematic of PUREX process

* The major idea is to prevent proliferation while controlling the recycling process allowing the safe distribution of nuclear fuel for safe energy purposes.

A) a) Fuel recycling center – to re-process fuel and create actinide fuel rods for APR.

b) APR – burnup atinides in an advanced reactor.

c) Advanced Fuel Research Facility – continuous improvement and research on cycle.

-1

B) Diffusion

$\frac{M_H v_H^2}{2} = \frac{M_L v_L^2}{2}$ -1

$\alpha^* = \sqrt{\frac{m_L}{m_H}}$ from KE (theoretical) $\qquad \alpha = \frac{a/(1-a)}{b/(1-b)}$

$m_L \leftarrow$ light stream

$m_H \leftarrow$ heavy stream

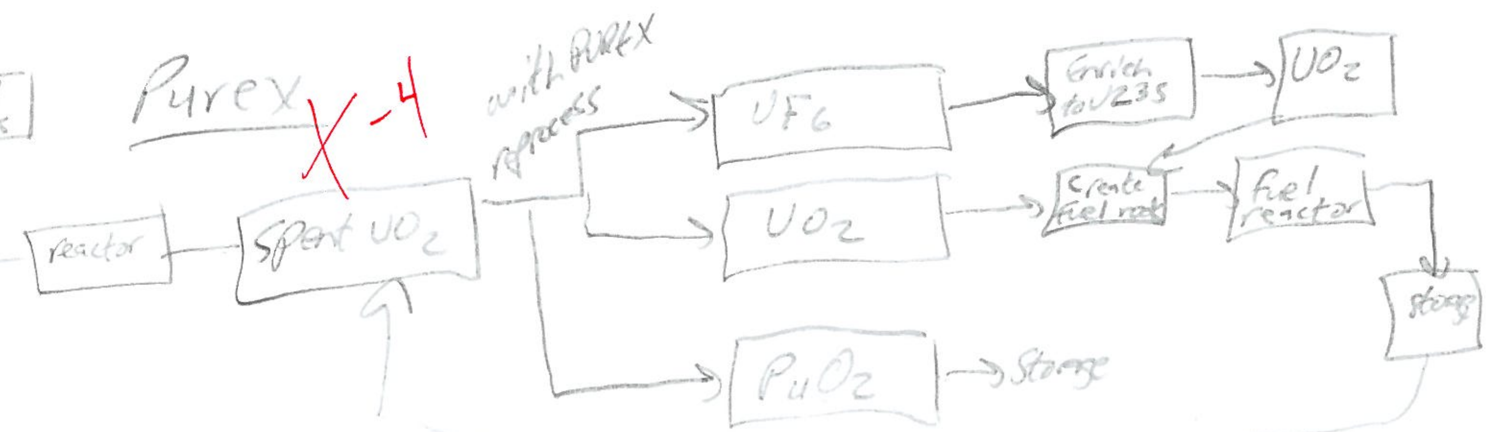
a + b are assays or weight fractions of processed and unprocessed U-235.

Gas Centrifuge $\quad \alpha = \exp\left[(m_H - m_L)\, v^2/2RT\right]$ T = Temp

m_L ; m_H from above $\quad v$ = speed. R – ideal gas constant

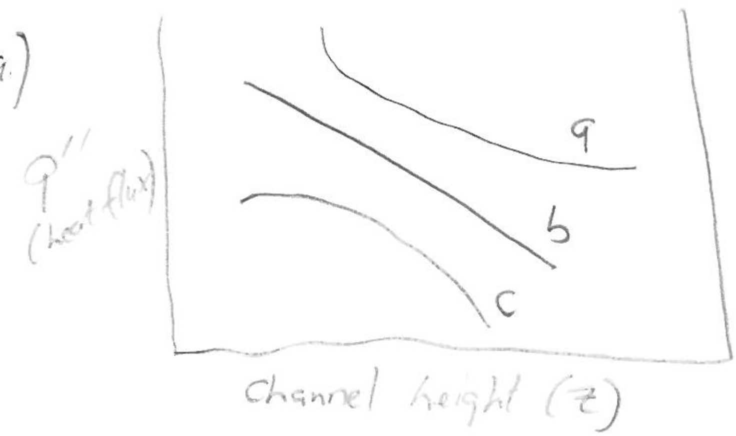
Purex

X -4



3. (a) (8)Explain DNBR and MCPR with a figure and give their importance in LWR safety or operation.
(b) (10) Calculate the volumetric thermal source strength in a reactor core. Core neutron flux is 10^{16} n/s cm^2 with effective microscopic cross section for fissionable fuel of 380 barns and density of fissionable fuel 2.5 x10^{21} nuclei/ cm^3

a)



a: q_{crit}/q'' ✓
CHFR b: predicted q_{crit} ✓
✓ c: operating q'' ✓

DNBR = departure from nucleate boiling ratio ≥ 1.3 in PWR to prevent clad damage

MCPR = min critical power ratio ≥ 1.2 BWR to prevent clad damage.

b) $q''' = G_f \sigma_f N_f \phi$

$$= \frac{200\,MeV}{fission} \cdot \frac{380\,b}{b} \cdot 1e^{-24}\,cm \cdot \frac{2.5e^{21}}{cm^3} \cdot \frac{10^{16}}{s\,cm^2} \cdot \frac{1.602e^{-19}\,J}{eV}$$

$q''' = \boxed{.30438\ mW/cm^3}$ ✓

4. (40) A bare cylindrical fuel rod is cooled by the liquid sodium at 550°C. The fuel properties are: Radius: R = 5 mm, Density: ρ = 10,000 kg/m^2, Heat Capacity: c_p = 300 J/kg°C, Thermal Conductivity: k = 2 W/m°C
The operating conditions are: Linear Heat Rate: q' = 50,000 W/m, Heat Transfer Coefficient (between fuel surface and liquid) : h = 100, 000 W/m^2 °C

a. Calculate the resistance between the fuel and the coolant. Use the bulk fuel temperature definition.
b. Calculate the fuel bulk and surface temperatures.
c. What is thermal time constant of the fuel? (Hint: Use RC circuit equivalence)
d. If the reactor is shut down at t = 0 sec., how long does it take for the temperature difference between fuel and coolant to be reduced by a factor of 10. (Hint: Write transient conduction equations in non-dimensional form. Note power is zero).

$R_f = .01989 \ m°C/W$
$R_m = 3.18309e^{-4} \ m°C/N$

a.) $R_{Total} = R_f + R_m = \frac{1}{8\pi k} + \frac{1}{2\pi r h}$

$R_T = \frac{1 \ [m°C]}{8\pi (2W)} + \frac{1}{2\pi (5mm)} \left| \frac{1000 \ mm}{m} \right| \frac{m^2 \ C}{100,000 \ W}$

$R_T = \boxed{.0202 \ m°C/W}$ ✓

$T_{fo} = q' R_m + T_m$

b.) $T_{fo} = \frac{q'}{2\pi r h} + T_{Na} = 50,000 \frac{W}{m} \left| \frac{3.18309e^{-4} \ m°C}{W} \right. + 550°C = \boxed{565.915°C}$ ✓

$\overline{T_f} = R_f q' + T_{fo}$

$\overline{T_f} = \frac{q'}{8\pi k} + T_{fo} = \boxed{1560.63°C}$ ✓

c.) $\tau = MCR_T$ ✓ $= \rho A C R_T = \rho \pi R^2 C R_T$

$= \frac{10,000 \ kg}{m^3} \left| \pi \right| \frac{(5 \ mm)^2}{(1000 \ mm)^2} \left| m^2 \right| \frac{300 \ J}{kg \ °C} \left| \frac{.0202 \ m°C}{J} \right| S$

90/100

$\tau = \boxed{4.76 \ sec}$ ✓

d.) $\theta = \theta_0 e^{-t/\tau}$ ✓ $\Rightarrow -\ln\left(\frac{\theta}{\theta_0}\right)\tau = t$ let $\theta = \frac{1}{10}\theta_0$

$\Rightarrow -\ln(.1)\tau = t = \boxed{10.96 \ sec}$ ✓

(4.76 sec)