SOLUTIONS

Assignment #8 Physics 346

Due 4:30 PM **Friday** March 30, 2012

Use Phys 346 drop box located at entrance to Physics Dept. off main floor of AQ.

3

1. (a) A nuclear reactor produces 500 MW of electric power. Assuming 30% thermal efficiency in the steam turbines, estimate the number of kg of natural uranium required to fuel the nuclear reactor per day. Natural uranium contains 0.7% $^{235}_{92}U$ and 99.3% $^{238}_{92}U$ by mass. Assume 200 MeV per $^{235}_{92}U$ fission.

   (b) How many tons of coal would be required to achieve the same power output per day?

3

2. BC annual electricity consumption is approximately 54,000 GWh/year. Your goal is to calculate how many wind turbines you would need to replace all of this power. Assume an average wind speed of 8 m/s, a turbine blade length of 36 m and an overall efficiency of 30%.

   (a) What is the power output of each turbine?

   (b) Assume that the minimum spacing between turbines is 5 times the turbine diameter. What is the total land area covered by the turbines?

   (c) How does your answer in (b) change if the average wind speed drops by a factor of 2?

3. Questions from your text:
   Ch 12 Problems #4,5,8 2, 2, 3
   Ch 14 Problem #4 3

16

Homework #8 Phys346 2012

① (a) $500\,MW \times 24\frac{hr}{day} \times \frac{3600 s}{h} = \boxed{4.320\times10^{13}\,J}$

Heat required $= \frac{4.320\times10^{13} J}{.3} = \underline{1.440\times10^{14}}\,J/day$

Heat per fission $= 200\,MeV \times 1.6\times10^{-19}\frac{J}{eV} \times \frac{10^6 eV}{MeV}$

$= 3.200\times10^{-11}\,J$

# of fissions $= \frac{1.440\times10^{14}\,J/day}{3.200\times10^{-11}\,J/fission} = 4.500\times10^{24}\,\frac{fissions}{day}$

Mass $^{235}U \stackrel{\#}{=}$ # of fissions $\times \left(\frac{1\,mol}{6.022\times10^{23}\,fissions}\right)\left(\frac{.235\,kg}{mol}\right)$

$\boxed{= 1.756\,kg}$

$\cancel{\frac{m^{238}}{m^{235}} = .993}$ $\quad \frac{m^{235}}{m^{total}} = \frac{.007}{1}$

$\therefore M^{total} = \frac{m^{235}}{.007} = \underline{251\,kg/day}$

(b) Energy content of coal $= 28 \times10^6\,J/kg$

$\therefore$ total mass per day $=$

$\frac{(1.44\times10^{14}\,J/day)}{(28\times10^6\,J/kg)} = \boxed{5.14\times10^6\,\frac{kg}{day}}$

1

(2) Total power required = 54,000 GWh / year

(a) $= \left(54{,}000 \times 10^9 \frac{\text{Wh}}{\text{year}}\right)\left(\frac{1 \text{ year}}{24 \times 365 \text{ h}}\right) = 6.164 \times 10^9 \text{ W}$

Power per turbine $= \eta \frac{1}{2} \rho v^3 A$

$= (0.3) \frac{1}{2} \left(1.3 \frac{\text{kg}}{\text{m}^3}\right)\left(8 \frac{\text{m}}{\text{s}}\right)^3 \left(\pi (36 \text{ m})^2\right)$

$= \underline{4.06 \times 10^5 \text{ W}}$

N = Number of turbines $= \frac{6.164 \times 10^9 \text{ W}}{4.06 \times 10^5 \text{ W}} = \boxed{15182}$

Each turbine occupies land area $(5D)^2$

$\therefore$ Total land area $= N (5D)^2$

$= (15182)(5 \times 72 \text{ m})^2$

$= 1.97 \times 10^9 \text{ m}^2$

$\boxed{= 1.97 \times 10^3 \text{ km}^2}$

= square w/ sides of $\underline{44 \text{ km}}$

(b) Because wind power varies as v^3, a decrease by $\frac{1}{2}$ drops the power by $\frac{1}{8}$

This increases land area by 8X

12.4

$\mu_b = 0.31\ cm^2/g$ $\rho_b = 3.0\ g/cm^3$

$\mu_m = 0.068\ cm^2/g$ $\rho_m = 1.3\ g/cm^3$

Bone $I_b = I_0 e^{-\mu_b \rho_b x_b}$ $x_b = 2\ cm$

Muscle $I_m = I_0 e^{-\mu_m \rho_m x_m}$ $x_m = 4\ cm$

Ratio $\frac{\text{Bone}}{\text{Muscle}} = \frac{e^{-\mu_b \rho_b x_b}}{e^{-\mu_m \rho_m x_m}}$

$$= \frac{e^{-(.31)(3.0)(2)}}{e^{-(.068)(1.3)(4)}}$$

$$\boxed{= \underline{0.22}}$$

i.e. $\sim \frac{1}{5}$ of the intensity compared with muscle.

$\therefore$ Image shows bone as <u>dark</u> regions

Ch 12-5. Calculate the dose the plant receives due to radiation fall out

$$D = \frac{E}{m}$$

we know $m = 200g$, but what is E?

$$E = \underset{\text{activity}}{A} \cdot \underset{\text{time}}{t} \cdot \underset{\text{energy / decay}}{\Delta E}$$

$$= 3700\ Bq \cdot 1d \cdot 24 h/d \cdot 3600 s/h \cdot 0.10 MeV \cdot 1.6 \times 10^{-13} J/MeV$$

$$\boxed{= 5.11 \times 10^{-6} J}$$

$$\therefore \quad D = \frac{5.11 \times 10^{-6} J}{0.2 kg} = \boxed{2.6 \times 10^{-5}\ Gy.}$$

2-8. A worker is exposed to radiation for 5s.

γ-rays dose rate 0.9×10^{-4} Gy/hr
1.25×10^{-7} Gy / 5s

fast neutrons dose rate 1.1×10^{-4} Gy/hr
1.52×10^{-7} Gy / 5s

thermal neutrons dose rate 0.8×10^{-4} Gy/hr.
1.11×10^{-7} Gy / 5s

The dose received is $D = \frac{dD}{dt} \cdot \Delta t$

where $\frac{dD}{dt}$ is the dose rate

and Δt is the time exposed.

The equivalent dose is given by

$$H_T = \sum W_R D_R.$$

where $W_R(\gamma\text{-rays}) = \boxed{1}$.
$W_R(\text{fast neutrons}) = \boxed{20}$
$W_R(\text{thermal neutrons}) \boxed{=5}$.

The equivalent dose rate

$$\frac{dH_T}{dt} = \sum W_R \frac{dD_R}{dt} = \left[(1 \times 0.9 \times 10^{-4}) + (20 \times 1.1 \times 10^{-4}) + 5(0.8 \times 10^{-4})\right] \text{ Sv/hr}$$

$$= 26.9 \times 10^{-4} \text{ Sv/hr}$$

$$= 2.7 \text{ mSv/hr}.$$

and $H_T = 2.7 \text{ mSv/hr} \cdot {}^{1\,hr}/_{3600\,s} \cdot 5\,s = 3.7 \times 10^{-3}$ mSv

this is $\frac{3.7 \times 10^{-3}}{20} = 0.018\%$ of the allowed dose of 20 mSv

(Students will get a different answer if they use Table 12-5

14-4 a. Each windmill would have

$R = 73$ m radius of circle swept out

$f = 17$ rpm rate of rotation

$P = 5$ MW power output

The power generated is given by

$$P = \tfrac{1}{2}\, \eta\, \rho\, \pi \cdot R^2 \cdot v^3 \cdot \tfrac{1}{2} \quad \text{energy captured}$$

$$\therefore\ v^3 = \frac{2 \cdot 2\, P}{\eta \rho \cdot \pi R^2} = \frac{4 \times 5 \times 10^6\, W}{0.9 \cdot 1.3 kg/m^3 \cdot \pi \cdot (73 m)^2}$$

$$= 1021\ m^3/s^3.$$

$$\therefore\ \boxed{v = 10\ m/s.}$$ is the windspeed required.

b. $$\text{capacity factor} = \frac{\text{Energy produced}}{\text{Total capacity}}$$

$$= \frac{17 \times 10^6\, kW \cdot h}{5000\, kW \cdot 365 d \cdot 24 h/d}$$

$$\boxed{= 0.39.}$$

c. energy generated by burning 31,000 bbl oil at 35% efficiency

$$0.35 \times 31{,}000\ bbl \cdot 5500 \times 10^6\, J/bbl \cdot 1\, kWh / 3.6 \times 10^6\, J$$

$$\boxed{= 1.65 \times 10^7\ kWh}$$, as claimed.