Byrne 2E

1.8

a. What is the wavelength of a photon with an energy of 7.84×10^{-18} J?

b. Is this ionizing radiation? Explain...

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a. $E = h\nu = \frac{hc}{\lambda}$ where h = Planck's const $= 4.1357\times10^{-15}$ eV-s

$\therefore \lambda = \frac{hc}{E}$ c = speed of light $= 2.99792\times10^{10}$ cm/s

$$= \frac{(4.136\times10^{-15}\text{ eV-s})(2.998\times10^{8}\text{ m/s})}{(7.84\times10^{-18}\text{ J})\left(\frac{1\text{ eV}}{1.602\times10^{-19}\text{ J}}\right)}$$

$$= \boxed{2.534\times10^{-8}\text{ m}}$$

b. From a picture of the EM spectrum, a wavelength of 2.5×10^{-8} m falls in the high end of the UV range or in the low end of the x-ray range.

Note also that $E = (7.84\times10^{-18}\text{ J})\left(\frac{1\text{ eV}}{1.602\times10^{-19}\text{ J}}\right)$

$$E = 48.9\text{ eV}$$

Recall that we said that the minimum ionization energy is in the range of 4-25 eV. Thus, the given photon energy is just above this threshold

Yes, it can be considered as ionizing radiation!!!

(barely)

$\boxed{\text{Note}}$ Some people use ~100 eV as the cutoff. In this case, the answer is NO.

Either answer is OK if properly justified since an energy of 50 eV is just on the boundary. KeV photons are definitely ionizing whereas energies on the order of 50 eV are borderline at best...

Bayan 2E

1.18

Consider the nuclides: ${}^{64}_{32}Ge$, ${}^{20}_{8}O$, and ${}^{212}_{84}Po$. Classify each of these nuclides as neutron rich, neutron poor, or too heavy, identify an appropriate decay process that moves each of these radioactive nuclides closer to the island of stability and, finally, write out a possible decay equation for each of the processes chosen.

Let's treat each nuclide separately:

$\boxed{{}^{64}_{32}Ge}$

As Z increases, we expect that $N > Z$ for stability. Here this is not the case. Thus, Ge64 is <u>neutron poor</u>

Neutron poor nuclides tend to β^+ decay or electron capture (EC).

$\beta^+ \rightarrow \quad {}^{64}_{32}Ge \rightarrow {}^{64}_{31}Ga^- + \beta^+ + \nu \rightarrow$ $p \rightarrow n + \beta^+ + \nu$ conceptual

$EC \rightarrow \quad {}^{64}_{32}Ge \rightarrow {}^{64}_{31}Ga + \nu \rightarrow$ $p + e \rightarrow n + \nu$

$\boxed{{}^{20}_{8}O}$

For low Z, we expect $N \simeq Z$ for stability, but here $N > Z$. Thus O20 is <u>neutron rich</u>.

Neutron rich nuclide β^- decay

$\beta^- \rightarrow \quad {}^{20}_{8}O \rightarrow {}^{20}_{9}F^+ + e^- + \bar{\nu} \rightarrow$ $n \rightarrow p + e + \bar{\nu}$ conceptual

$\boxed{{}^{212}_{84}Po}$

There are no stable nuclides above bismuth ($Z = 83$). Many of the nuclides with $Z > 83$ decay via α emission because they are <u>too heavy</u>

$\alpha \rightarrow \quad {}^{212}_{84}Po \rightarrow {}^{208}_{82}Pb^{2-} + {}^{4}_{2}He^{2+}$

Lamarsh 3rd Ed

Multiplication Factor

$\boxed{4.1}$ given: bare sphere of ^{235}U

57.5 % of fission neutrons escape

$\eta = 2.31$ for system

→ what is the multiplication factor for this system

$$k = \frac{\text{\# fission neutrons}}{\text{\# of fission neuts in previous generation}}$$

$$\eta = \frac{\text{\# neuts emitted}}{\text{neut absorbed in fuel}}$$

also ultimate fate of neutron = $\left\{ \begin{array}{l} \text{absorption} \\ \text{leakage} \end{array} \right.$

∴ since 57.5 % leaks from the system, then 42.5 % must be absorbed in the ^{235}U

∴ neutron production rate = η * absorption rate in fuel

$= (2.31)(0.425)$

$= 0.98175$

∴ $K = \dfrac{0.98175}{1} = \boxed{0.98175}$ ans

$\boxed{k \approx 0.982}$

A typical conversion ratio in a PWR system is about 0.62. If the system has a thermal power of 2600 MW and a capacity factor of 0.88, estimate the mass of fissile plutonium produced per year of operation (use $\alpha = 0.17$ for U235).

From the Lecture Notes, about 2.70×10^{21} fissions are required to produce 1 MWD of energy.

Thus, for the current system, the consumption rate of U235 is given as

units $\left(\frac{abs}{fis}\right)\left(\frac{fiss}{MWD}\right)(MW)\left(\frac{days}{year}\right)$

$$\text{consumption rate of U235} = (1+\alpha)\text{ fission rate}$$
$$= (1+0.17)(2.70\times10^{21})(2600)(365)(0.88)$$
$$= 2.638 \times 10^{27} \text{ atom of U235 per year}$$

Now, the definition of conversion ratio is

$$CR = \frac{\text{fissile atoms produced}}{\text{fissile atom destroyed}}$$

$$\therefore \text{fissile atoms produced per year} = (0.62)(2.638\times10^{27}\text{ atoms/yr})$$
$$= 1.636 \times 10^{27}\text{ atoms/yr}$$

$$\therefore \text{mass of fissile Pu produced per year} = \left(1.636\times10^{27}\ \frac{\text{at of Pu}}{\text{yr}}\right)\left(\frac{239\text{ g of Pu}}{0.6022\times10^{24}\text{ at of Pu}}\right)$$
$$= 6.492\times10^{5}\text{ g of Pu}$$
$$= \boxed{649.2\text{ kg of Pu}}$$

→ Note that this is only an approximate result because we assumed that all the fission was U235 and that the fissile Pu is solely Pu239.

Also note that, in practice, a lot of this Pu gets consumed during operation (with an appropriate reduction in the consumption of the U235).

Note: an average α over the cycle may be ~ 0.20 – 0.30 and using a correct value ~~here~~ would give a better result

Shultis + Faw 2E

11.6

Explain why the turbine room in a BWR is ^not inhabitable during normal operation.

All water-moderated/cooled reactors produce N-16 via an n,p reaction with the O16 in the water

$$ {}^{16}_{8}O + {}^{1}_{0}n \rightarrow {}^{16}_{7}N^{-} + {}^{1}_{1}p^{+} $$

However, N-16 is radioactive with a 7.1 sec halflife and it emits two high energy gammas (6.1 MeV and 7.1 MeV).

Thus, even with some shielding, because of the direct cycle associated with a BWR, the Turbine room will be a high radiation area during operation.

With a 7.1 s halflife, the radiation levels drops to a low (managable) level shortly after the power level goes to zero.

Note that PWRs, with their intermediate steam generator, do not have this issue..

PWRs have an "indirect cycle"...

Shultis + Faw 2E

11.2

A 1000 MWe nuclear plant has a thermal conversion efficiency of 33%.

a. Estimate the thermal power rejected through the condenser to the cooling water.

b. What is the required coolant flow rate (kg/s) if the temperature rise of the cooling water is 12 C (use 4180 J/kg-C as the specific heat of water)?

(a) $P_e = \eta P_{Th}$ $\therefore$ $P_{Th} = \frac{P_e}{\eta}$

$$P_{Th} = \frac{1000 \text{ MWe}}{0.33} = 3030 \text{ MWt}$$

Since about $\frac{1}{3}$ of this is converted to electricity, we can assume that most of the remainder is rejected to the environment within the condenser

$$\therefore P_{loss} = P_{Th} - P_e = \boxed{2030 \text{ MW}_t}$$

(b) Energy gained by a flowing liquid is given by

$$Q = \dot{m} C_p \Delta T$$

units $W = \frac{J}{s} = \left(\frac{kg}{s}\right)\left(\frac{J}{kg\text{-}C}\right)(°C)$ o.k.

$$\therefore \dot{m} = \frac{Q}{C_p \Delta T}$$

$$\dot{m} = \frac{2030 \times 10^6 \text{ J/s}}{4180 \frac{J}{kg\text{-}C}(12 C)} = \boxed{40,470 \text{ kg/s}}$$

$$= \boxed{145.7 \times 10^6 \text{ kg/hr}}$$

$\boxed{4.15}$ given: $P_e = 470\ MW_e$ (electrical output)

$\eta = 32.5\ \%$ (efficiency)

60% of power from U235
40% " Pu239

ⓐ How many kg of U235 would be fissioned and consumed per year?

thermal Power $= P_e/\eta = \frac{470}{.325} = 1446\ MW_{th}$

→ also from class notes, we have

$$\text{fission rate} = 2.70 \times 10^{21}\, P \frac{\text{fission}}{\text{day}}$$ (P in MW_{th}) (assuming 200 MeV/fiss)

∴ fission rate in U235 $= (2.70\times10^{21})(.60)(1446)\frac{\text{fiss}}{\text{day}} * \frac{365\ \text{day}}{\text{yr}}$

$= 8.55\times10^{26}\frac{\text{fiss}}{\text{yr}} * \frac{235\ \text{g of U235}}{6.022\times10^{23}\ \text{at of U235}} * \frac{1\ \text{kg}}{10^3\ \text{g}}$

$= \boxed{333.7\ \text{kg/yr}}$ ans

consumption rate in U235 $= (1+\alpha)(\text{fission rate})$ $\boxed{\alpha_{U235} \simeq .169}$ from Table 3.4 p.82

$= (1.169)(333.7\ \text{kg/yr})$

$= \boxed{390.0\ \text{kg/yr}}$ ans

ⓑ How many kg of Pu239 would be fissioned and consumed per year?

from above, we have

fission rate in Pu239 $= (2.70\times10^{21})(.40)(1446)(365)\left(\frac{239.}{6.022\times10^{23}}\right)(10^{-3})$

$= \boxed{226.2\ \text{kg/yr}}$ ans

consumption rate in Pu239 $= (1+\alpha)(\text{fission rate})$ $\boxed{\alpha_{Pu239} \simeq .362}$ from Table 3.4 p.82

$= (1.362)(226.2)$

$= \boxed{308.1\ \text{kg/yr}}$ ans

$\sigma_a = \sigma_c + \sigma_f$
$= \sigma_f\left(1 + \frac{\sigma_c}{\sigma_f}\right)$
$= \sigma_f(1+\alpha)$

Mass Balance for Fossil Fuel Plant

Given: $P = 1000\ MW_e$

$\eta = 38\%$

capacity factor = 0.70

(a) How many Tons of 13,000 BTU/lbm of coal does the plant consume in one year?

$$P_{th} = \frac{1000\ MW_e}{0.38} = \boxed{2632\ MW_{th}}$$

Energy produced in one year $= 2632 \times 10^6 \frac{J}{s} \times \left(\frac{3600\ s}{hr} \times \frac{24\ hr}{day} \times \frac{365\ d}{yr} \times .70\right)$

only operates 70% of Time

$= \boxed{5.810 \times 10^{16}\ J}$ per yr

convert to BTU/year $= 5.810 \times 10^{16}\ J * \frac{1\ BTU}{1055\ J}$

$= \boxed{5.507 \times 10^{13}\ BTU}$ per yr

amt of coal needed $= 5.507 \times 10^{13}\ BTU \times \frac{1\ lbm}{13\,000\ BTU} \times \frac{1\ Ton}{2000\ lbm}$

$= \boxed{2.12 \times 10^6\ \frac{tons}{yr}}$ ← short Tons

(b) If average coal car carries 100 Tons of coal, how many cars, on average, are needed per day

$$2.12 \times 10^6 \frac{tons}{yr} \times \frac{1\ car}{100\ Tons} \times \frac{1\ yr}{365\ d} = \boxed{58\ \frac{cars}{day}}$$

(c) If coal contains 1.5 w/o sulfur and this is released as SO_2, how much SO_2 does the plant produce per year.

amt of sulfur $= 2.12 \times 10^6 \times .015 = 3.18 \times 10^4$ Ton/yr

amt of SO_2 $= 3.18 \times 10^4 \frac{\text{ton of S}}{yr} * \frac{64.06\ \text{Ton}\ SO_2}{32.06\ \text{Ton S}}$

$= \boxed{6.35 \times 10^4\ \frac{\text{Ton}\ SO_2}{year}}$

$M_S = 32.064$

$M_O = 15.9994$

$M_{SO_2} = 64.063$