

- a. What is the wavelength of a photon with an energy of  $7.84 \times 10^{-18} \text{ J}$ ?  
 b. Is this ionizing radiation? Explain...

a.  $E = h\nu = \frac{hc}{\lambda}$  where  $h = \text{Planck's const}$   
 $= 4.1357 \times 10^{-15} \text{ eV}\cdot\text{s}$

$\therefore \lambda = \frac{hc}{E}$   $c = \text{Speed of light}$   
 $= 2.99792 \times 10^{10} \text{ cm/s}$

$$= \frac{(4.136 \times 10^{-15} \text{ eV}\cdot\text{s})(2.998 \times 10^8 \text{ m/s})}{(7.84 \times 10^{-18} \text{ J}) \left( \frac{1 \text{ eV}}{1.602 \times 10^{-19} \text{ J}} \right)}$$

$$= \boxed{2.534 \times 10^{-8} \text{ m}}$$

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

Note also that  $E = (7.84 \times 10^{-18} \text{ J}) \left( \frac{1 \text{ eV}}{1.602 \times 10^{-19} \text{ J}} \right)$

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

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.

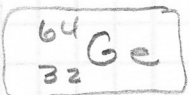
Yes, it can be considered as ionizing radiation!!!  
 (barely)

**Note** Some people use  $\sim 100 \text{ eV}$  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...

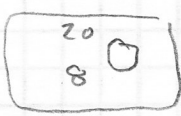
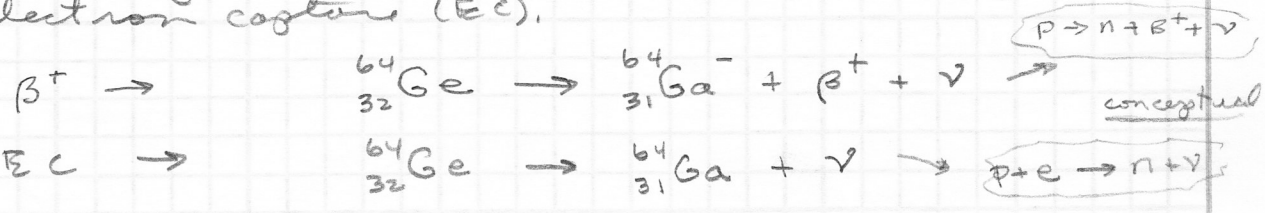
Consider the nuclides:  ${}^{64}_{32}\text{Ge}$ ,  ${}^{20}_8\text{O}$ , and  ${}^{212}_{84}\text{Po}$ . Classify each of these nuclides as neutron rich, neutron poor, or too heavy, identify an appropriate decay process that moves each of these radioactive nuclides closer to the island of stability and, finally, write out a possible decay equation for each of the processes chosen.

Let's treat each nuclide separately:



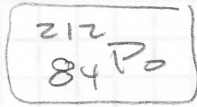
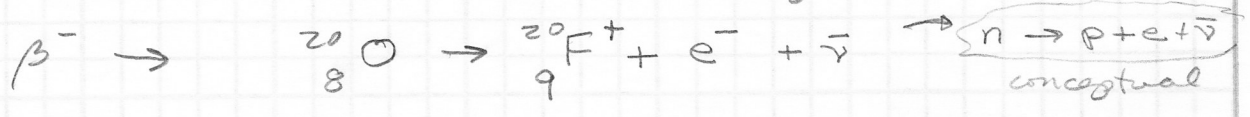
As  $Z$  increases, we expect that  $N > Z$  for stability. Here this is not the case. Thus,  $\text{Ge} 64$  is neutron poor.

Neutron poor nuclides tend to  $\beta^+$  decay or electron capture (EC).

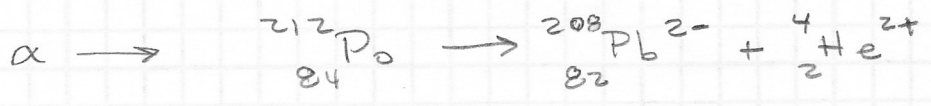


For low  $Z$ , we expect  $N \leq Z$  for stability, but here  $N > Z$ . Thus  $\text{O} 20$  is neutron rich.

Neutron rich nuclides  $\beta^-$  decay



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



4.11

given: bare sphere of  $^{235}\text{U}$   
 57.5% of fission neutrons escape  
 $\eta = 2.31$  for system

→ what is the multiplication factor for this system

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

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

also ultimate fate of neutron = { absorption, leakage

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

$$\therefore \text{neutron production rate} = \eta \times \text{absorption rate in fuel}$$

$$= (2.31)(0.425)$$

$$= 0.98175$$

$$\therefore k = \frac{0.98175}{1} = \boxed{0.98175} \quad \underline{\text{ans}}$$

$$k \approx \boxed{0.982}$$

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  $2.70 \times 10^{21}$  fissions are required to produce 1 MWD of energy.

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

$$\begin{aligned} \text{Consumption rate of U235} &= (1 + \alpha) \text{ fission rate} \left( \frac{\text{units}}{\text{fiss}} \right) \left( \frac{\text{fiss}}{\text{mwo}} \right) (\text{mw}) \left( \frac{\text{days}}{\text{year}} \right) \\ &= (1 + 0.17) (2.70 \times 10^{21}) (2600) (365) (0.88) \\ &= 2.638 \times 10^{27} \text{ atoms of U235 per year} \end{aligned}$$

Now, the definition of conversion ratio is

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

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

$$\begin{aligned} \therefore \text{mass of fissile Pu produced per year} &= \left( 1.636 \times 10^{27} \frac{\text{atoms of Pu}}{\text{yr}} \right) \left( \frac{239 \text{ g of Pu}}{0.6022 \times 10^{24} \text{ atoms of Pu}} \right) \\ &= 6.492 \times 10^5 \text{ g of Pu} \\ &= \boxed{649.2 \text{ kg of Pu}} \end{aligned}$$

→ 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 approximate reduction in the consumption of the U235).

(Note) an average  $\alpha$  over the cycle may be  $\sim 0.20 - 0.30$  and using a correct value here would give a better result



11.6

Explain why the turbine room in a BWR is <sup>not</sup> inhabitable during normal operation.

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



However, N-16 is radioactive with a 7.1 sec half life 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 half life, the radiation levels drop to a low (manageable) 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"...

11.2

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

- Estimate the thermal power rejected through the condenser to the cooling water.
- 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)?

$$\textcircled{a} \quad P_e = \eta P_{Th} \quad \therefore P_{Th} = \frac{P_e}{\eta}$$

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

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

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

- Energy gained by a flowing liquid is given by

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

$$\textcircled{\text{units}} \quad W = \frac{J}{s} = \left( \frac{kg}{s} \right) \left( \frac{J}{kg \cdot C} \right) (C) \quad \textcircled{\text{etc}}$$

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

$$\dot{m} = \frac{2030 \times 10^6 \text{ J/s}}{4180 \frac{J}{kg \cdot C} (12 C)} = \boxed{40,470 \text{ kg/s}} = \boxed{145.7 \times 10^6 \text{ kg/hr}}$$

4.15 given:  $P_e = 470 \text{ MWe}$  (electrical output)  
 $\eta = 32.5\%$  (efficiency)

60% of power from U235  
 40% " " Pu239

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

Thermal Power =  $P_e / \eta = \frac{470}{.325} = 1446 \text{ MWth}$

→ also from class notes, we have  $2.70 \times 10^{21} \text{ fission/day}$  (assuming 200 MeV/fiss)

∴ fission rate in U235 =  $(2.70 \times 10^{21}) (.60) (1446) \frac{\text{fiss}}{\text{day}} \times \frac{365 \text{ day}}{\text{yr}}$   
 $= 8.55 \times 10^{26} \frac{\text{fiss}}{\text{yr}} \times \frac{235 \text{ g of U235}}{6.022 \times 10^{23} \text{ atoms of U235}} \times \frac{1 \text{ kg}}{10^3 \text{ g}}$   
 $= \boxed{333.7 \text{ kg/yr}}$  ans

consumption rate in U235 =  $(1 + \alpha)(\text{fission rate})$   
 $= (1.169)(333.7 \text{ kg/yr})$   
 $= \boxed{390.0 \text{ kg/yr}}$  ans

$\alpha_{\text{U235}} = .169$   
 from Table 3.4 p. 82

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

from above, we have

fission rate in Pu239 =  $(2.70 \times 10^{21}) (.40) (1446) (365) \left(\frac{239}{6.022 \times 10^{23}}\right) (10^{-3})$   
 $= \boxed{226.2 \text{ kg/yr}}$  ans

consumption rate in Pu239 =  $(1 + \alpha)(\text{fission rate})$   
 $= (1.362)(226.2)$   
 $= \boxed{308.1 \text{ kg/yr}}$  ans

$\alpha_{\text{Pu239}} = .362$   
 from Table 3.4 p. 82

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

42-381 50 SHEETS EYE-EASE® 8 SQUARE  
 42-382 100 SHEETS EYE-EASE® 8 SQUARE  
 42-383 200 SHEETS EYE-EASE® 8 SQUARE  
 42-392 100 RECYCLED WHITE 8 SQUARE  
 42-393 200 RECYCLED WHITE 8 SQUARE  
 Made in U.S.A.



Mass Balance for Fossil Fuel Plant

Given:  $P = 1000 \text{ MWe}$   
 $\eta = 38\%$   
 capacity factor = 0.70

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

$$P_{th} = \frac{1000 \text{ MWe}}{0.38} = 2632 \text{ MW}_{th}$$

$$\begin{aligned} \text{Energy produced in one year} &= 2632 \times 10^6 \frac{\text{J}}{\text{s}} \times \left( \frac{3600 \text{ s}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{365 \text{ d}}{\text{yr}} \times 0.70 \right) \\ &= 5.810 \times 10^{16} \text{ J} \quad \text{per yr} \end{aligned}$$

only operates 70% of time

$$\begin{aligned} \text{convert to BTU/year} &= 5.810 \times 10^{16} \text{ J} \times \frac{1 \text{ BTU}}{1055 \text{ J}} \\ &= 5.507 \times 10^{13} \text{ BTU} \quad \text{per yr} \end{aligned}$$

$$\begin{aligned} \text{amt of coal needed} &= 5.507 \times 10^{13} \text{ BTU} \times \frac{1 \text{ lbm}}{13000 \text{ BTU}} \times \frac{1 \text{ Ton}}{2000 \text{ lbm}} \\ &= 2.12 \times 10^6 \frac{\text{tons}}{\text{yr}} \quad \leftarrow \text{short Tons} \end{aligned}$$

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

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

c) If coal contains 1.5 w/o sulfur and this is released as  $\text{SO}_2$ , how much  $\text{SO}_2$  does the plant produce per year.

$$\text{amt of sulfur} = 2.12 \times 10^6 \times 0.015 = 3.18 \times 10^4 \text{ ton/yr}$$

$$\text{amt of } \text{SO}_2 = 3.18 \times 10^4 \frac{\text{ton of S}}{\text{yr}} \times \frac{64.06 \text{ Ton } \text{SO}_2}{32.06 \text{ Ton S}}$$

$$= 6.35 \times 10^4 \frac{\text{Ton } \text{SO}_2}{\text{year}}$$

$$M_s = 32.064$$

$$M_o = 15.9994$$

$$M_{\text{SO}_2} = 64.063$$