# Problem 1 [Poston Prob. 1.1]

Identify the decay products of the following nuclides given their mode of decay:

${}^{90}_{38}\mathrm{Sr}(\beta)$, ${}^{238}_{92}\mathrm{U}(\alpha)$, ${}^{147}_{61}\mathrm{Pm}(\beta)$, ${}^{78}_{35}\mathrm{Br}(\beta^+)$, ${}^{79}_{36}\mathrm{Kr}(\mathrm{EC})$, ${}^{222}_{86}\mathrm{Rn}(\alpha)$, ${}^{99m}_{43}\mathrm{Tc}(\gamma)$, ${}^{252}_{98}\mathrm{Cf}(\mathrm{SF})$

# Problem 2 [Poston Prob. 1.10]

${}^{131}$I has a radioactive half-life of 8 days and a liver excretion half-time of 55 min. Plot the effective decay rate fir 1 mCi of labeled material in the liver.

# Problem 3 [Poston Prob. 1.11]

${}^{64}$Cu decays by positron ($\beta^+$), internal conversion and electrons ($\beta^-$). Identify the decay products and the amounts accumulating over the life ($7T_{1/2}$) of the source.
Cu ($T_{1/2}$=12.8 h)
Branching ratios are: $\beta^-$ 38%, $\beta^+$ 19%, CE 43%.

# Problem 4 [Poston Prob. 1.13]

A geiger counter has a background count of 60 cpm. It is placed in a uniform $\gamma$ radiation field. If the detection efficiency os 3%, calculate the minimum intensity required for a net count rate of five times the background.

# Problem 5 [Poston Prob. 1.16]

Determine the relative intensities of the

a) 1.29 and 1.098 MeV $\gamma$-ray emissions in the decay of ${}^{59}$Fe,

b) the 0.177 et 0.284 $MeV$ lines of ${}^{131}$I.

# Problem 6 [Poston Prob. 1.17]

Matural antimony consists of ${}^{121}$Sb (57.25%, $\sigma_{n\gamma} = 6b$) et ${}^{123}$Sb (42.75%, $\sigma_{n\gamma} = 4b$). Neutron activation produces ${}^{122}$Sb ($T_{1/2}$= 2.8 days) and ${}^{124}$Sb ($T_{1/2}$= 60 days).

Calculate the activities produced if a 5-g sample of antimony is exposed in a neutron flus of 1013 n/cm$^2$-ses for

a) 2 hours

b) 2 days

c) 1 year

Determine in cas case how lont the sourcewould have to cool down in each case for the $^{122}$Sb activity to constitute less that 10% of the total activity.

## Problem 7 [Poston Prob. 1.2]

A given accelerator produces neutrons by the (d,n) reaction on beryllium. If the beam current is 50 milliamps and the conversion efficiency is 1%, calculate the neutron production rate.

## Problem 8 [Poston Prob. 1.3]

A certain $^{238}$Pu source has an activity of 50 millicuries. If all the alpha particles are self absorbed in the source material, calculate the heat production (alpha energy = 5.5 MeV)

## Problem 9 [Poston Prob. 1.4]

In the previous question, estiate the amount of helium generated in the source in one year. If the source capsule has internal dimensions of 5 mm diameter by 2 mm thick and 5% void space, calculate the helium pressure after one year.

## Problem 10 [Poston Prob. 1.5]

A 10 MBq $^{60}$Co source consists of a thin wire 2 mm in length. Calculate the gamma-ray intensity at 30 cm and 2 m distance from that source.

## Problem 11 [Poston Prob. 1.6]

Calculate the mass needed to produce an activity of 10 mCi of the following nuclides: $^{226}$Ra, $^{131}$I, $^{65}$Zn, $^{24}$Na

## Problem 12 [Poston Prob. 1.7]

Calculate the amount of $^{99m}$Tc ($T_{1/2}$=6 hours) that is present in a 50 mCi $^{99}Mo$ ($T_{1/2}$=67 heures) a) 6 hours, b) 12 hours, c) 30 hr, d) 67 hours, e) 150 hours after the molybdenum source was freshly prepared.

## Problem 13 [Poston Prob. 1.8]

A 100-mg silver foil is irradiated in a neutron fuls of $10^{13}$neutrons/(cm$^2$.sec). $^{109}$Ag has an abundance of 48.17% and cross sections of 4b and 88b, respectively, to produce $^{110}$Ag ($T_{1/2}$=253 days) and $^{110m}$Ag ($T_{1/2}$=24sec). Calculate the activity of this foil after 5-min exposure and after 3-min and 3-hr cooling times.

## Problem 14 [Turner Prob. 3.12]

(a) Calculate the energy released by the alpha decay of $^{222}_{86}Rn$
(b) Calculate the energy of the alpha particle
(c) What is the energy of the recoil polonium atom?

## Problem 15 [Turner Prob. 3.15]

The Q value for alpha decay of $^{239}_{94}$Pu is 5.25 MeV. Given the masses of the $^{239}Pu$ and $^{4}He$ atoms, 239.052174 AMU and 4.002603 AMU, calculate the mass of the $^{235}_{92}$U atom in AMU.

## Problem 16 [Turner Prob. 3.17]

(a) Calculate the energy released in the beta decay of $^{32}_{15}P$.
(b) If a beta particle has 650 keV, how much energy does the antineutrino have?

## Problem 17 [Turner Prob. 3.20]

A $^{108}_{49}$In source emits a 633 keV gamma photon and a 606 keV internal conversion electron from the K shell. What is the binding energy of the electron in the K shell?

## Problem 18 [Turner Prob. 3.24]

Nuclide A decays into nuclide B by $\beta^+$ emission (24%) or by electron capture (76%). The major radiations, energies (in MeV), and frequencies per disintegration are:

$\beta^+$: 1.62 max (16%), 0.98 max (8%)

$\gamma$: 1.51 (47%), 0.64(55%), 0.511(48%,$\gamma^\pm$)

Daughter X rays

$e^-$: 0.614

(a) Draw the nuclear decay scheme, labeling type of decay, percentages and energies
(b) What leads to the emission of the daughter X rays?

## Problem 19 [Turner Prob. 3.27]

A parent nuclide decays by beta-particle emission into stable daughter. The major radiations, energies (in MeV), and frequencies per disintegration are:

$\beta^-$: 3.92 max (7%), 3.10 max (8%), 1.60 max (88%)

$\gamma$: 2.32 (34%), 1.50(54%), 0.820(49%)

$e^-$: 0.818,0.805

(a) Draw the nuclear decay scheme.
(b) What is the maximum energy that the antineutrino can receive in this decay?
(c) What is the value of the internal conversion coefficient?
(d) Estimate the L-shell electron binding energy of the daughter nuclide.
(e) Would daughter X rays be expected also? Why or why not?

## Problem 20 [Turner Prob. 3.29]

Refer to the decay scheme of $^{137}_{55}$Cs. The binding energies of the K- and L-shell electrons of the daughter $^{137}_{56}$Ba atom are 38 keV and 6 keV.

(a) What are the energies of the internal conversion electrons ejected from these shells?
(b) What is the wavelength of the $K_\alpha$ X ray emitted when an L-shell electron makes a transition to the K-shell?
(c) What is the value of the internal conversion coefficient?

## Problem 21 [Turner Problem 3.3]

What minimum energy would an alpha particle need in order to react witn a $^{238}U$ nucleus?

## Problem 22 [Turner Prob. 3.30]

(a) Calculate the Q value for the K orbital electron capture by the $^{37}_{18}$Ar nucleus, neglecting the electron binding energy.
(b) Repeat (a), including the binding energy, 3.20 keV, of the K-shell electron in argon.
(c) What becomes of the energy released as a result of this reaction?

## Problem 23 [Turner Prob. 3.31]

What is the maximum possible positron energy in the decay of $^{35}_{18}$Ar?

## Problem 24 [Turner Prob. 3.36]

The isotope $^{126}_{53}$I can decay by EC, $\beta^-$ and $\beta^+$ transitions.

(a) Calculate the Q values for the three modes of decay to the ground states of the daughter nuclei.
(b) Draw the decay scheme.
(c) What kind of radiation can one expect from a $^{126}$I source?

## Problem 25 [Turner Prob. 3.5]

Calculate the total binding energy of the alpha particle.

## Problem 26 [Turner Prob. 3.8]

Calculate the binding energy per nucleon for the nuclide $^{40}_{19}K$

## Problem 27 [Turner Prob. 4-10]

How many grams of $^{32}P$ are there in a 5 $mCi$ source?

## Problem 28 [Turner Prob. 4-12]

An encapsulated $^{210}$Po radioisotope was used as a heat source, in which an implanted thermocouple junction converts heat into electricity with an efficiency of 15% to power a small transmitter for an early space probe.
(a) How many curies of $^{210}$Po are needed at launch time if the transmitter is to be supplied with 100 W of electricity 1 year after launch.
(b) Calculate the number of grams of $^{210}$Po needed.
(c) If the transmitter shuts off when the electrical power to it falls below 1 W, how long can it be expected to operate after launch?

## Problem 29 [Turner Prob. 4-13]

The Cassini spacecraft went into oribit about the planet Saturn in July 2004 after a nearly seven-year journey from Earth. On-board electrical systems were powered by heat from three

radioisotope thermoelectric generators, which together utilized a total of 32.7 kg of $^{238}$Pu, encapsulated as $PuO_2$. The isotope has a half-life of 86.4 years and emits an alpha particle with an average energy of 5.49 MeV. The daughter $^{234}$U has a half-life of $2.47\times10^5$ years.
(a) Calculate the specific thermal power generation rate of $^{238}$pu in W/g.
(b) How much total thermal power is generated in the spacecraft?

## Problem 30 [Turner Prob. 4-14]

A 0.2 g sample of $^{85}$Kr gas, which decays into stable $^{85}$Rb, is accidentally broken and escapes inside a sealed warehouse measuring $40 \times 30$ m. What is the specific activity of the air inside?

## Problem 31 [Turner Prob. 4-15]

A 6.2 mg sample of $^{90}$Sr is in secular equilibrium with its daughter $^{90}$Y.
(a) How many Bq of $^{90}$Sr are present? (b) How many Bq of $^{90}$Y are present? (c) What is the mass of $^{90}$Y present? (d) What will be the activity of the $^{90}Y$ be after 100 years?

## Problem 32 [Turner Prob. 4-17]

Consider the following $\beta^-$ nuclide decay chain with the half-lives indicated:

$$^{210}_{82}Pb \xrightarrow[22y]{\beta^-} {}^{210}_{83}Bi \xrightarrow[5.0d]{\beta^-} {}^{210}_{84}Po$$

A sample contains 30 MBq of $^{210}$Pb and 15 MBq $^{210}$Bi at time t=0.
(a) Calculate the activity of $^{210}$Bi at time t=10d.
(b) If the sample was originally pure $^{210}$Pb, then how old is it at time t=0?

## Problem 33 [Turner Prob. 4-19]

$^{59}$Fe has a half-life of 45.33 d.
(a) What is the mean life of a $^{59}$Fe atom?
(b) What is the specific activity of a $^{59}$Fe.
(c) How many atoms are there in a 10 $mCi$ source of $^{59}$Fe?

## Problem 34 [Turner Prob. 4-20]

At tome t=0 a sample consists of 2 $Ci$ of $^{90}$Sr and 8 $Ci$ of $^{90}$Y.
(a) What will be the activity of $^{90}$Y be in the sample after 100 h?
(b) At what time will the $^{90}$Y activity be equal to 3 $Ci$?

## Problem 35 **[Turner Prob. 4-21]**

$^{136}$Cs decays into $^{136}$Ba as follows:

$$^{136}Cs \xrightarrow[13.7d]{\beta^-} {}^{136m}Ba \xrightarrow[0.4s]{\gamma} {}^{136}Ba$$

(a) Calculate the decay constant of $^{136}$Cs.
(b) Calculate the specific activity of $^{136}$Cs
(c) Starting with a pure $10^{10}$ Bq sample of $^{136}$Cs at time t=0, how many atoms of $^{136m}$Ba decay between time $t_1$=13.7d (exactly) and time $t_2$=13.7d+5s?

## Problem 36 **[Turner Prob. 4-24]**

A 40 mg sample of pure $^{226}$Ra is encapsulated.
(a) How long will it take for the activity of $^{222}$Rn to build up to 10 $mCi$?
(b) What will be the activity of $^{222}$Rn after 2 years?
(c) What will be the activity of $^{222}$Rn after 1000 years?
(d) What is the ratio of the specific activity $^{222}$Rn to that of $^{226}$Ra?

## Problem 37 **[Turner Prob. 4-28]**

The average mass of potassium in the human body is about 140 g. Estimate the average activity of $^{40}$K in the body.

## Problem 38 **[Turner Prob. 4.3]**

The activity of a radioisotope is found to decrease by 30% in one week. What are the values ot its:
(a)decay constant
(b)half-life
(c)mean life?

## Problem 39 **[Turner Prob. 4.5]**

The isotpe $^{132}$I decays by $\beta^-$ emission into stable $^{132}$Xe with a half-life of 2.3 h.
(a)How long it will take for $\frac{7}{8}$ of the original $^{132}$I atoms to decay?
(b)How long it will take for a sample of $^{132}$I to lose 95% of its activity?

## Problem 40 **[Turner Prob. 4-6]**

A very old specimen of wood contained $10^{12}$ atoms of $^{14}C$ in 1986.
(a) How many $^{14}C$ atoms did it contain in the year 9474 BC?
(b) How many $^{14}C$ atoms did it contain in 1986 BC?

## Problem 41 **[Turner Prob. 4-7]**

A radioactive sample consists of a mixture of $^{35}S$ and $^{32}P$. Initially, 5% of the activity is due to the $^{35}S$ and 95% to the $^{32}P$. At what subsequent time will the activities of the two nuclides in the sample be equal?

## Problem 42 **[June 2013]**

In an experiment designed to measure the total neutron cross section of 10 MeV with lead, the neutron flux after passing a 1 cm thick rod is found to be 84.5% of its initial value. If the atomic weight of lead is 207.21 g/mol and its density is 11.3 g/cm$^3$

a) Calculate the total effective cross-section (in barns)

b) Calculate also the macroscopic cross section