Quiz 1 Close Book Exam at 14:30-16:00 on April 2, 2001 (Room 32-109)

1-1: Compute the activities in Ci for 1 milli-gram of pure: a) Na-24 ($T_{1/2}$ = 14.8 h); and b) Ra-226 ($T_{1/2}$ = 1620 y).

Solution:

The activity A is given by:

A (in Ci) = N λ

= [(6.02x10^{23}/mole)(10^{-3}g)/ (M_A g/mole)] [0.693/$T_{1/2}$ in sec] /(3.7x10^{10} Bq/Ci)

A = 1.13x10^{10} / (M_A) ($T_{1/2}$)

a) For Na-24; A = 1.13x10^{10} / (24) (14.8x3600) = 8.8 x10^{3} Ci

b) For Ra-226; A = 1.13x10^{10} / (226) (1620x365x24x3600) = 2.3 x10^{-3} Ci

1-2: Tc-99m (half-life = 6.00 hours) is usually used for a medical diagnostic purpose. Tc-99m is generated as the daughter product of Mo-99 (half-life = 66.0 hours) following its beta transformation. If 0.01 mCi Tc-99m is needed for a medical diagnostic purpose at the hospital, and if 132 hours elapse between shipment of the Tc-generator (= Mo-99) and the use of Tc-99m in the test, how many Bq of Mo-99 must be ordered in the shipment?

Solution:

Since Tc-99m is shorter-lived than Mo-99, for simplicity we can assume it will reach the transient equilibrium after 132 hours. In transient equilibrium,

$A_{Tc}/A_{Mo} = \lambda_{Tc} / (\lambda_{Tc}-\lambda_{Mo}) = T_{Mo} / (T_{Mo} - T_{Tc})$.

This means that we need the activity of Mo-99 at the hospital should be:

$A_{Mo} = A_{Tc} (T_{Mo} - T_{Tc}) / T_{Mo}$

$= (0.01 \text{ mCi})(66.0-6.00)/66.0$

$= 0.0091 \text{ mCi}$

$= 3.36\text{x}10^5 \text{ Bq}$

In this case, before shipment, we at least need:

$A_{Mo} (0)= A_{Mo} \exp (+\lambda t) = A_{Mo} \exp (0.693/66)(132) = 4 A_{Mo}$

$A_{Mo} (0)= 4 \text{ x } 3.36\text{x}10^5 \text{ Bq} = 1.34\text{x}10^6 \text{ Bq}$

1-3: Find the uncollided and observed flux through a 10 cm Al shield. The photon source is a point isotropic with 1 MeV energy is located at the contact of shield. The source strength is $3\text{x}10^{10}$ photons per second. Assume that the mass attenuation factor of Al for 1 MeV photon is 0.0614 cm^2/g, the specific weight of Al is 2.7 g/cm^3, and the exposure buildup factor is simply estimated by $B = 1+ \mu x$.

Solution:

The uncollided photon flux at 10 cm away is given by:

$\Phi_u(r) = S_o \exp(-\mu r) / 4\pi r^2$

$= (3\text{x}10^{10} \text{ photons per second}) \exp(-(0.0614 \text{ cm}^2/\text{g})(2.7 \text{ g/cm}^3)(10\text{cm})) / 4\pi(10^2)$

$= 2.39\text{x}10^7 \exp(-1.657)$

$= 4.56 \text{ x}10^6 \text{ photons/sec.cm}^2$

The observed flux is given by:

$\Phi(r) = \Phi_u(r)\, B$

$= \Phi_u(r)\,(1+ \mu x)$

$= (4.56 \times 10^6 \text{ photons/sec.cm}^2)(1+1.657)$

$= 1.21 \times 10^7 \text{ photons/sec.cm}^2$

1-4: N-24 is produced in a Liquid Metal Reactor by neutron activation of Na-23 reactor coolant. Considering the neutron flux level of 1×10^{14} n/cm^2.sec, find the specific activity of Na-24 in the coolant (Ci/gm) during reactor operation. Assume the average radiative capture X-section of Na-23 ($\sigma_{n\gamma}$) is 0.53 b. The half-life of Na-24 is 15 hours.

Solution:

The production rate of Na-24 in the reactor coolant is given by:

$dN_{24}/dt = \Sigma_{n\gamma}\phi - \lambda_{24}N_{24} = N_{23}\sigma_{n\gamma}\phi - \lambda_{24}N_{24}$

In an equilibrium state, $dN_{24}/dt = 0$. Hence, the number nuclide of Na-24 in the reactor coolant in an equilibrium state is given by:

$N_{24}(t=\infty) = N_{23}\sigma_{n\gamma}\phi \,/\, \lambda_{24}$

In this case, the activity of Na-24 in one gram of reactor coolant in an equilibrium state is given by

$A_{24}(t=\infty) = \lambda_{24}N_{24}(t=\infty)$

$= N_{23}\sigma_{n\gamma}\phi$

$= [(6.02\times10^{23}/mole)/(23 grams/mole)][(0.53\times10^{-24}\ cm^2)][1\times10^{14}\ n/cm^2.sec]$

$= 1.38\times10^{12}$ Bq/g

= 37.2 Ci/g

1-5: Calculate the equilibrium concentration of Rn-222 ($T_{1/2}$ = 3.82 days) in a sealed room (V= 4mX10mX20m = 800 m^3) when 1 Ci of Ra-226 ($T_{1/2}$ = 1,620 years) is stored. Find the ventilation exhaust rate (m^3/hour) in order to keep the concentration of Rn-222 under 4×10^{-6} Ci/m^3.

Solution:

Equilibrium concentration

$$C = \frac{1Ci}{800\times10^6 ml} = 1.25\times10^{-3}(\mu Ci/ml)$$

The production rate of Rn-222 in the reactor coolant is given by:

$dN_{222}/dt = \lambda_{226}N_{226} - \lambda_{222}N_{222} - RN_{222}$

where R = room ventilation exhaust rate (volumes/hour).

In an equilibrium state, $dN_{222}/dt = 0$. Hence, the number nuclide of Rn-222 in the room is given by:

$N_{222}(t=\infty) = \lambda_{226}N_{226} / (\lambda_{222} + R)$

In this case, the activity concentration of Rn-222 in the room in an equilibrium state is given by

$C_{222}(t=\infty) = A_{222}(t=\infty)/V$

$= \lambda_{222} N_{222}(t=\infty)/V$

$= \lambda_{222} A_{226} / (\lambda_{222} + R) V$

$= \lambda_{222} A_{226} / R V$: Assuming $\lambda_{222} << R$

($\lambda_{222} = 0.693/(3.82 \text{ days})(24 \text{ hours/day}) = 7.56\text{x}10^{-3} \text{ hr}^{-1}$)

Hence, the ventilation rate RV, (m^3/hour) becomes:

$RV = \lambda_{222} A_{226} / C_{222}(t=\infty)$

$= (7.56\text{x}10^{-3} \text{ hr}^{-1}) (1 \text{ Ci}) / (4\text{X}10^{-6} \text{ Ci/m}^3)$

$= 1.9\text{x}10^3 \text{ m}^3\text{/hour}$