Question 1

A sample of leather from a tomb is burned to obtain 0.20 g of carbon. The measured activity of the sample is 0.017 Bq. How old is the sample? In the environment, about one carbon atom in 7.7×10^{11} is ^{14}C. The half-life of ^{14}C is 5730 a. *(2 points)*

Question 2

^{226}Ra undergoes alpha decay with a half-life of 1600 years. Consider a 100 g sample of pure ^{226}Ra. What is the initial power output of this sample? *(4 points)*

Given, the masses in amu:
$M_{Ra} = 226.025402$, $M_{Rn} = 222.017570$, $M_{He} = 4.002603$

Question 3

To determine the sodium concentration in a material, an investigator irradiates and measures 100 mg of the sample material. The reaction of interest is $^{23}Na(n,\gamma)^{24}Na$. The neutron flux during irradiation is known to be 5.10^{16} $m^{-2}s^{-1}$. The irradiation lasts 0.5 hours, the sample is left alone for 36 hours after irradiation, and is then measured during 1.5 hours.

a) In the measured gamma-ray spectrum, the 1368 keV peak coming from ^{24}Na has an area of 1300 counts in a clean spectrum with negligible numbers of counts in the baseline. ^{24}Na emits such photons with 100% probability when it decays. The distance between the sample and the detector was 10 cm, the detector radius is 3.5 cm, and the intrinsic efficiency of the detector for gamma-rays of this energy is 15%. The dead time during the measurement is negligible, and the probability of the gamma-rays being emitted by the source is 100%.

   How many ^{24}Na decays took place during the measurement? (Also specify the uncertainty in this number due to counting statistics). *(2 points)* 26.

b) The half life of ^{24}Na is 14.96 hours. What must have been the number of ^{24}Na atoms present at the end of the irradiation (with its relative uncertainty)? *(2 points)*

c) The neutron capture cross section for $^{23}Na(n,\gamma)^{24}Na$ is 0.43 b. The isotopic abundance of ^{23}Na is 100%. The atomic mass is 22.99. What was the sodium concentration in the sample, and its relative uncertainty? *(2 points)*

d) What kind of standardisation did we apply like this? *(1 point)*
   NAA?

Question 4

Name and explain 4 labeling methods for radioactive tracers. *(4 points)*

Question 5

a) ^{100}Mo (100% abundance) is irradiated on a 19 MeV cyclotron with a 300 μA proton beam for 3 h. The two main nuclear reactions occurring are $^{100}Mo(p,2n)^{99m}Tc$ (σ=2201 mb) and $^{100}Mo(p,2n)^{99g}Tc$ (σ=5313 mb). The half-life of ^{99m}Tc is 6 h, the one of ^{99g}Tc is 213000 a. The size of the target foil is 1.2 cm^3 with a Mo density of 10.2 g/cm^3. The surface area of the beam is 1 cm^2. The elemental charge is $1.609 \cdot 10^{-19}$ C.

How much ^{99m}Tc is produced at the end of irradiation? *(2 points)*

b) The amount of ^{99g}Tc produced in question 5a) is 816866 Bq. Calculate the specific activity of ^{99m}Tc at the end of irradiation and after 1 day waiting time. If you have not managed to solve 5a), assume an activity of 1 GBq for ^{99m}Tc at end of irradiation. *(2 points)*

c) ^{99m}Tc is usually obtained in hospitals from a $^{99}Mo/^{99m}Tc$ generator. Describe the principles of an isotope generator. What is the mathematical relationship between the activity of the mother and the activity of the daughter? *(3 points)*

d) Name 2 production routes for ^{99}Mo. *(2 points)*

e) *Where is* ^{99m}Tc used in medicine? Give 2 specific examples. *(2 points)*

Useful constants

Avogadro's number (N_A) = 6.022137×10^{23}/mol
mass of proton = 1.007276 amu
mass of neutron = 1.008664 amu
mass of electron = 5.485799×10^{-4} amu
speed of light (c) = 3.0×10^{8} m/s
6.022137×10^{23} amu = 1g
1 J = 1 kg•m^2/s^2
1 eV = 1.602×10^{-19} J
1 Mev = 10^6 eV

Exam problem 1 - INAA

To determine the sodium concentration in a material, an investigator irradiates and measures 100 mg of the sample material.
The reaction of interest is Na-23(n,gamma)Na-24.
The neutron flux during irradiation is known to be 5.10^{16} m^{-2}s^{-1}. The irradiation laststst 0.5 hours, the sample is left alone for 36 hours after irradiation, and is then measured during 1.5 hours.

1a) In the measured gamma-ray spectrum, the 1368 keV peak coming from Na-24 has an area of 1300 counts in a clean spectrum with negligible numbers of counts in the baseline. Na-24 emits such photons with 100 % probability when it decays. The distance between the sample and the detector was 10 cm, the detector radius is 3.5 cm, and the intrinsic efficiency of the detector for gamma-rays of this energy is 15 %. The dead time during the measurement is negligible, and the probability of the gamma-rays being emitted by the source is 100%.
How many Na-24 decays took place during the measurement? (Also specify the uncertainty in this number due to counting statistics).

answer:

The geometric efficiency of the detector is to be calculated with $\eta_g = \frac{\Omega}{4\pi} = \frac{1}{2}(1 - \frac{d}{\sqrt{d^2 + a^2}})$,
the answer is 0.0281. The total efficiency of the detector is then 0.15 x 0.0281 = 0.00421.
The observed number of counts was 1300, the uncertainty due to counting statistics is √1300 = 36.
The number of Na-24 decays must have been
(1300 ± 36) / 0.00421 = 308743 ± 8563 = (3.09 ± 0.09) x 10^5 = 3.09 x 10^5 ± 3%

1b) The half life of Na-24 is 14.96 hours. What must have been the number of Na-24 atoms present at the end of the irradiation (with its uncertainty)?

answer: use $\Delta N\left(t_{ir}, t_d, t_m\right) = \frac{RN_0}{\lambda}\left(1 - e^{-\lambda t_{ir}}\right)e^{-\lambda t_d}\left(1 - e^{-\lambda t_m}\right) = N\left(t_{ir}\right)e^{-\lambda t_d}\left(1 - e^{-\lambda t_m}\right)$
We know ΔN = 308743 ± 8563.
$\lambda = \ln(2)/t_{½} = 0.0463\ h^{-1}$.
$e^{-\lambda t_d}\left(1 - e^{-\lambda t_m}\right) = 0.01266$
so $N\left(t_{ir}\right) = \Delta N\left(t_{ir}, t_d, t_m\right) \Big/ e^{-\lambda t_d}\left(1 - e^{-\lambda t_m}\right)$ = (3.09 x 10^5 ± 3%)/0.01266 = 2.44 x 10^7 ± 3%.

1c) The neutron capture cross section for Na-23(n,gamma)Na-24 is 0.43 b. The isotopic abundance of Na-23 is 100%. The atomic mass is 22.99. What was the sodium concentration in the sample?

answer:
Use
$N\left(t_{ir}\right) = \frac{RN_0}{\lambda}\left(1 - e^{-\lambda t_{ir}}\right)$ meaning than $N_0 = \frac{N\left(t_{ir}\right)\lambda}{R\left(1 - e^{-\lambda t_{ir}}\right)}$

and

$R = \Phi_0 \sigma_0$ =5x10^{16} x 0.43 x 10^{-28} = 2.15 x 10^{-12} s^{-1}

λ must now be expressed in s^{-1}: 1.287x10^{-5}, because so is the neutron acitavtion rate *R*.
so for N_0 we get (2.44 x 10^7 ± 3%) x 1.287x10^{-5}/ (2.15 x 10^{-12} x (1 - exp(-0.0463 x 0.5))) = 6.38x10^{15} ± 3%.
The mass of that many Na-23 atoms is 22.99 x 6.38x10^{15} / 6x10^{23} = 2.45 x 10^{-7} g ± 3%.
The mass of the sample was 100 mg, so the sodium concentration was 2.45 x 10^{-6} g/g ± 3%

1d) What kind of standardisation did we apply like this?
Absolute standardization.