NPA Homework solutions 2

05/12/12

1)

$M(^2H) = 2.014102\ u$

$= 1876.14\ MeV/c^2$

$^1H + {}^1H \rightarrow {}^2He$ does not occur because pp is not a bound state

thus pp fusion can only occur with associated β^+ decay via weak interaction and because of this small cross section the fusion process must "wait" for this bottle neck before further fusion can proceed.

Each of the 3 reaction give rise to ν_e which emerge from the sun imediately and can be detected on earth.

Both β decay steps give rise to continuous ν_e spectra with different characteristic endpoint.
The ε process gives rise to a monochromatic ν_e peak.

2)

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Assume all energy from p^+ decay eventually appears as energy i.e. pion decays too. Total energy from 1 decay is then simply p^+ rest mass = 938 MeV ①

Average human weighs 70 kg, (although I'm extra average, 78 kg)

Half this mass is from protons (other half = neutrons) = 35 kg p^+

$0.001\,kg = N_A$ protons ~~∴ 35 kg =~~

$\therefore$ body contain $\frac{35 \times N_A}{0.001} = 2\times10^{28}$ ~~p~~ protons $= N_0$

Let p^+ have lifetime τ, then $N(t) = N_0 e^{-t/\tau}$

So number of decays $= N_0 - N(t)$ ①

$= N_0 (1 - e^{-t/\tau})$

Max dose $= 5\,Gy = 5\,J/kg = \frac{5}{1.6\times10^{-19}}\,eV/kg = \frac{3\times10^{13}}{~~6\times10^{12}~~}$ MeV/

$= \frac{2\times10^{15}}{~~4\times10^{14}~~}$ MeV for 70 kg human ①

Each decay produces 938 MeV energy, so limit is

$\frac{2\times10^{15}}{938} = 2\times10^{12}$ decays

①

So, $\frac{2\times10^{12}}{~~4\times10^{11}~~} = 2\times10^{28}(1 - e^{-t/\tau})$ with $t = 1$ year

now rearrange for τ: $\frac{2\times10^{12}}{2\times10^{28}} = 1 - e^{-1/\tau} = ~~2\times10^{-17}~~\ 1\times10^{-16}$

$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \cdots$

~~1 - 2×10^-17~~ $e^{-1/\tau} = 1 - 10^{-16}$ ①

take 1st 2 terms of expansion ~~1/τ = ln(1-10^-16)~~

$1 - e^{-1/\tau} \approx \frac{1}{\tau} = 10^{-16}$ $\therefore$ $\tau > 10^{16}$ years ①

Perhaps we should have considered a 4 kg baby not 70 kg adult?

3)
X-rays: cheap to produce, and can penetrate deep within body, but delivered dose of radiation varies exponentially with depth, so healthy tissue close to surface of body receives largest dose. Requires more complex equipment to modulate the dose using collimators and/or multiple beams from different angles.

Electrons: cheap to produce, but cannot penetrate deep within the body

Protons: very expensive to produce controlled beam of protons, but beam energy can be tuned to deliver large dose at the depth of the tumor location, and minimize received dose to healthy tissue, i.e. highly localized. Good for use against tumors in inaccessible sites, e.g. eyes.

4) Brachytherapy is the use of sealed radioactive sources which are placed inside the body either next to, or inside the target tissue (tumor). This increases the local dose to the tumor compared to other therapies. Relatively long half-life radionuclides can be used compared to the use of unsealed sources which chemically bind to tumor sites (which should have very short half lives). The nuclide used should have stable daughters for long-term brachytherapy, be solid and non-soluble, not produce liquid/gaseous decay products, and be cheap to produce.