Problem 1. 2-1

What target isotope must be used for forming the compound nucleus $^{24}_{11}\text{Na}$ when the incident projectile is:

(a) a neutron

(b) a proton

(c) an alpha particle?

Solution

Part (a)

A neutron will increase the mass number, A, by one, but leave the element number, Z, unchanged. Therefore, the answer is a lighter isotope of Neon: $^{23}_{11}\text{Na}$

Part (b)

Capturing a proton increases both the mass number and element number by one: $^{23}_{10}\text{Ne}$

Part (c)

Capturing an α particle increases the mass number by four and the element number by two: $^{20}_{8}\text{O}$

Problem 2. 2-4

A fission product of very considerable importance in thermal reactor operation is ^{135}Xe, which has an enormous thermal absorption cross section of $2 * 10^6 b$. This nuclide can be produced either directly as a fission product or by beta decay of ^{135}I, as indicated by the radioactive chains below: Write the rate equations describing the concentration of ^{135}I and ^{135}Xe in a nuclear reactor. Then assuming a constant production rate of these isotopes from fission and transmutation rate by neutron capture, determine the steady-state or saturated concentration of ^{135}Xe.

Solution

Holy hell that was really hard! Like, just typing it!

Problem 3. 2-6

Boron is a common material used to shield against thermal neutrons. Estimate the thickness of boron required to attenuate an incident thermal neutron beam to 0.1% of its intensity. (Use the thermal cross section data in Appendix A.)

Solution

From *Duderstadt* Appendix A, $\Sigma_t = 104cm^{-1}$ for Boron.

$$\begin{aligned} \left(\frac{1}{e}\right)^n &= \frac{1}{1000} \\ e^{-n} &= 1000^{-1} \\ e^n &= 1000 \\ n &= ln(1000) \end{aligned}$$

Dividing this by the macroscopic cross section Σ_t gives:

$$\begin{aligned} \frac{n}{\Sigma_t} &= \frac{ln(1000)}{\Sigma_t} \\ &= 0.0664cm \end{aligned}$$

Problem 4. 2-8

A free neutron is unstable against beta decay with a half-life of 11.7m. Determine the relative probability that a neutron will undergo beta-decay before being absorbed in an infinite medium. Estimate this probability for a thermal neutron in H_2O.

Solution

We know that:

$$\begin{aligned} P_{absorption}\left(x\right) &= \Sigma_a \int_0^x e^{-\Sigma_a x} dx \\ &= \sigma_a N \int_0^x e^{-\sigma_a x} dx \end{aligned}$$

Assume that the incident particle is a thermal neutron with speed $\dot{x} = 2.2 * 10^5 cm/s$. In this case, the neutron should travel a distance of $\dot{x}\lambda$ before decaying:

$$\begin{aligned} &= \sigma_a N \int_0^{\dot{x}\lambda} e^{-\sigma_a x} dx \\ &= 1 - e^{-\sigma_a N \dot{x}\lambda} \end{aligned}$$

The probability of decaying instead of being absorbed (assuming that these are the only two interaction modes:

$$\begin{aligned} 1 &= P_{absorption} + P_{decay} \\ P_{decay} &= 1 - P_{absorption} \\ &= e^{-\sigma_a N \dot{x}\lambda} \end{aligned}$$

Substituting our speed $\dot{x} = 2.2 * 10^5 cm/s$, half life $\lambda = 11.7m = 702s$, and $\sigma_a N = 0.022$ for a thermal neutron in H_2O:

$$= 2.11 * 10^{-1475594}$$

To any reasonable approximation this may be treated as equal to zero.

Problem 5. 2-10

How many mean free paths thick must a shield be designed in order to attenuate an incident neutron beam by a factor of 1000?

Solution

We know that for every mean free path, Σ, travelled, the incident beam attenuates by a factor of $\frac{1}{e}$. Therefore:

$$\begin{aligned}\left(\frac{1}{e}\right)^n &= \frac{1}{1000} \\ e^{-n} &= 1000^{-1} \\ e^n &= 1000 \\ n &= ln(1000) \\ &= 6.91\end{aligned}$$