PHY3004W Laboratory
Neutron radiation from ^{241}Am-Be

Unlike gamma ray sources, there are no practical isotope sources of neutrons. Neutrons are usually obtained from fission (spontaneous or induced), radioisotopic (α, n) or (γ, n) reactions, or reactions using accelerated charged particles.

An americium-beryllium radioisotopic source produces neutrons by the (α, n) reaction. Americium-241 produces energetic α-particles ($\sim$5.5 MeV) via the decay[1]:

$$^{241}\text{Am} \rightarrow {}^{237}\text{Np} + \alpha \ (t_{1/2} = 433 \text{ years}).$$

An α-particle may slow down within the source and capture with ^{9}Be to produce ^{12}C, a neutron and a 4.44 MeV γ-ray associated with the first excited state of ^{12}C:

$$^{9}\text{Be} + \alpha \rightarrow {}^{13}\text{C}^{*} \rightarrow {}^{12}\text{C} + \text{n} + \gamma(4.44 \text{ MeV}).$$

The energy spectrum of the neutrons produced by the ^{241}Am-Be source range from thermal energies (0.025 eV) up to $\sim$ 11 MeV. Figure 1 shows a typical energy spectrum for neutrons produced by an ^{241}Am-Be source [2].

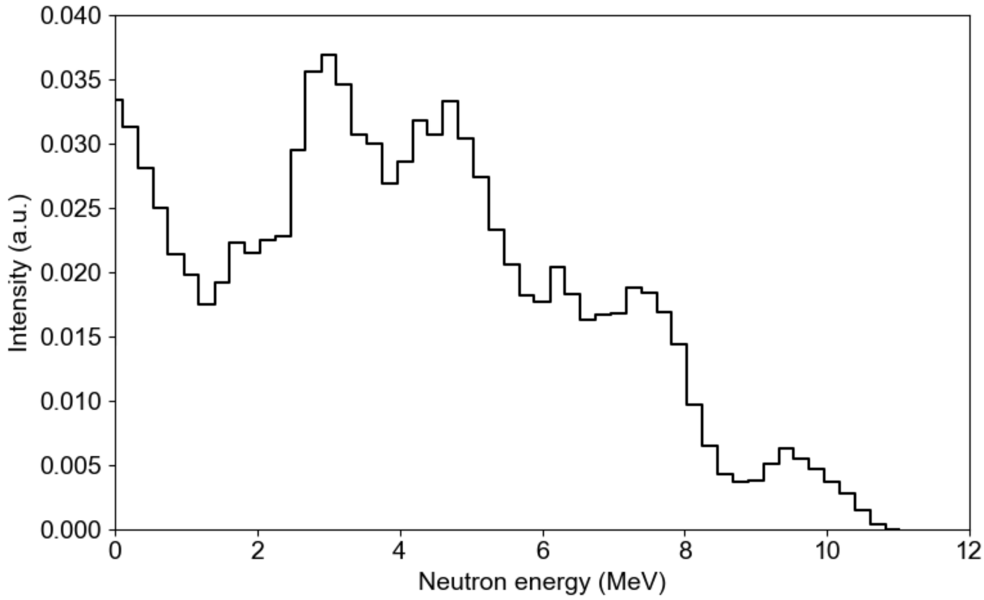

Figure 1: Neutron energy spectrum for a typical ^{241}Am-Be source.

Within the Department of Physics, University of Cape Town, two ^{241}Am-Be sources exist: one permanently installed within the n-lab, a fast neutron research laboratory, with an ^{241}Am activity of 220 GBq (6 Ci) and approximate neutron emission rate of 10^{7} s^{-1}; and a second used for teaching and research with an ^{241}Am activity of 2.2 GBq (0.06 Ci) and approximate neutron emission rate of 10^{5} s^{-1}.

Due to their uncharged nature, neutrons are highly penetrating and, through nuclear reactions with matter, produce ionising radiation, such as gamma rays, protons and α-particles. To minimise the radiation risk associated with the neutron source(s) they are typically stored within a large volume of hydrogenous shielding material, such as water (H_2O) or high-density polyethylene ($(C_2H_4)_n$). These sources should not be handled without direct supervision.

[1] Basunia, M.S., *Nuclear Data Sheets* 107:3323 (2006).

[2] International Standards Organisation (ISO), *Neutron reference radiations field - Part 1: characteristics and methods of production*, ISO 8529-1:2021(E) (2021)

Neutron reactions

Neutrons readily pass through most materials since they carry no charge and interact only with atomic nuclei. In principle it is known how likely a neutron is to interact with a certain isotope, and how likely a certain reaction type is to occur, which is defined by the reaction cross section. For the simple case of a beam of neutrons passing through matter, they will be exponentially attenuated according to $I(x) = I_0 \exp(-x/\lambda_p)$ where x is the thickness of the material and λ_p is the neutron mean free path, which is related to the density of the material and the total reaction cross section. The total reaction cross section is the sum of the individual cross sections associated with the different reaction types. The reaction cross section varies with incident neutron energy and is characteristic for each nuclide.

When a neutron interacts with matter via elastic scattering, the neutron collides with a nucleus and subsequently undergoes a change in energy and momentum. The difference in energy is transferred to the nucleus as it recoils, conserving kinetic energy and momentum of the two-body system. Low energy and low mass scattering tends to be relatively isotropic, and becomes more anisotropic with the increase of energy and/or mass. The fraction of energy retained by the neutron after an elastic scatter from a target nucleus, with atomic mass A, is given by:

$$\alpha = \frac{(A-1)^2}{(A+1)^2},$$

which indicates that a neutron will transfer more kinetic energy to low mass nuclei (e.g. hydrogen) compared to high mass nuclei (e.g. lead). This is relevant when considering which materials to use as a radiation shield where neutrons are present. Elastic collisions tend to be very probable, and often serve to bring the neutrons into thermal equilibrium with the surrounding matter after several scatters before being captured by the surrounding nuclei. The slowing down of neutrons to thermal energies is known as “moderation”and is an important process in nuclear physics and engineering.

Inelastic scattering is a threshold reaction where the neutron is briefly captured, leaving the compound nucleus in an unstable, excited state. De-excitation occurs through the re-emission of the neutron and (at least) one high-energy gamma ray. As such these reactions can only occur when the incident neutron energy sufficiently is above the first energy level of the nucleus. The total energy and momentum of the system are conserved. For nuclei with high atomic mass inelastic scattering reactions are more efficient at removing energy from the incident neutron.

Other types of reactions where the incident neutron is absorbed or captured by the target nucleus are: radiative capture; secondary particle emission; and fission. In the case of radiative capture, the incoming neutron is absorbed by the target nucleus. The now excited nucleus (plus one neutron) decays to the ground state via gamma ray emission. Secondary particle emission reactions occur when the compound nucleus is sufficiently excited that it ejects one or more secondary particles, typically in the form of neutrons, protons, deuterons and alpha particles. In fission reactions it is energetically favourable for the target nucleus to split into two (or more) nuclei and several free neutrons, with the release of a large amount of energy in the form of electromagnetic radiation (gamma rays) and kinetic energy of the reaction products. Fission reactions can be spontaneous in some cases, or induced by neutron capture.