Chapter 37

Neutron Emission and Its Measurement Technique From Dense Plasma Focus (DPF) Device

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The plasma focus device is a strong source of neutrons and it also has suitable temperature to create fusion reaction and it gives information on plasma parameters. In this device the neutrons are produced in a time range of 50-500 ns. The normal detectors cannot be used for this purpose as their dead time is long and also, they are not suitable to measure the pulsed neutrons here we will discuss the pulsed neutron measurement techniques.

37.1. Introduction

A Dense Plasma Focus (DPF) device based high flux pulsed neutron source has been made operational at Pulsed Power Electro Magnetic Division (PP&EMD), BARC Facility, Vizag. The device (2.5 kJ) has mean neutron yield of $(2.5\pm0.5)\times10^{8}$ neutrons per pulse in 4πsr at ~180-200 kA peak discharge current for the deuterium gas at a pressure of 4 to 6 mbar and the typical duration of pulse/burst of 2.45 MeV neutrons is ~50ns. The pulsed neutrons are basically Z-pinch based D-D fusion neutrons. To measure these fast neutrons a highly sensitive activation detector is developed which consists of a moderator material, activation foil and GM tubes.

37.2 Dense Plasma Focus Device

The Plasma Focus device operates on two cylindrical electrodes. One end of the electrodes is closed and another end is open. These electrodes are separated by insulating material. By using the insulator, these electrodes can hold the required voltage. Another requirement of the insulator is to provide breakdown path and formation plasma sheath. A chamber encloses the electrode assembly and the chamber is filled with Deuterium gas at 4 to 6 mbar pressure. Other gases can be Neon and Argon or the mixture. The electrode at the center acts as anode, through which the high voltage is connected. A spark gap switch is used to connect the anode and capacitor. Other electrode is connected to ground. In this device, a sheath of plasma is developed when the capacitor discharges the electrical energy through spark gap switch to the electrodes in very less time i.e. in nano seconds. The J x B force makes sure that the sheath is evolving axially in the direction of electrodes. The sheath is further accelerated towards the other end of electrode assembly (open end).

At the top of anode this current flow ($J \times B$) in equal direction along all coaxial cathodes, starts compression and try to converge for formation of plasma diode. From plasma diode ions will travel upward and electrons will travel downward, ions travel up and catch deuterium gas as it is hitting the gas D-D fusion reaction will happen to produce neutrons. In every shot the plasma focus operates for very less time i.e. in the range of nano seconds to microseconds, hence this device can be operated in the repetitive regime.

37.3. Neutron Production Mechanism

When the chamber is filled with Deuterium, during the operation D-D reactions takes place in the device. Due to these reactions, neutrons of energy ~2.45 MeV are produced. In addition, protons (leaving behind ^{3}He and T) are produced.

deuterium-deuterium (D-D) fusion reactions can be explained as given below:

$$\mathrm{D} + \mathrm{D} \rightarrow \mathrm{P}\ (3.0\ \mathrm{MeV}) + \mathrm{T}\ (1.0\ \mathrm{MeV})$$

$$\mathrm{D} + \mathrm{D} \rightarrow \mathrm{He}^{3}\ (0.8\ \mathrm{MeV}) + \mathrm{n}\ (2.45\ \mathrm{MeV})$$

The probability of each reaction is fifty percent.

37.4. Neutron Measurement Technique

Neutron have no charge and low ionization effect. So, we can't detect in detectors based on ionization of gases. The problem of neutron detection is further complicated by fact that neutrons often occur together with gamma radiation, to which most neutron sensors have a similar response making the identification of neutrons more difficult.

37.4.1. Slow Neutron Detection

A. Boron detector

Neutron collide with Boron produces alpha particle which will produce ionization as result can be detected.

$$^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li + ^{4}_{2}He + 2.78 \text{ MeV}$$

Ionization chamber with Boron coated electrodes and proportional counter filled with Boron trifluoride vapor can be used to detect slow neutrons. The thermal neutron cross section is 3770 barns at lower energy it varies inversely to neutron velocity. Other materials like Li, N, and Cd may also use to detect neutrons.

B. He^3 Proportional Counter

Neutron absorption cross-section for He_3 (5330b) is higher than BF_3 neutron reacts with He_3, produces tritium and proton which ionize the proportional gas.

$$He^3 + {}_0n^1 \rightarrow {}_1H^1 + {}_1H^3 + 0.764 \text{ MeV}$$

The resulting charges are collected as measurable electrical pulses with amplitude proportional to the neutron energy. But this isotope is rarely found in nature but exists as a decay product of tritium, which is primarily produced in nuclear reactor. Due to the lower Q- reaction value of the He^3 (n, p) ${}_1H^3$ reaction makes gamma-ray discrimination more difficult than for a BF_3 counter.

37.4.2. Fast Neutron Detection:

A. Proton foil detection

Neutron can be detected by ionization produced by recoil protons, also paraffin at one end of chamber when neutron strike the paraffin foil it emits protons and protons will produce ionization inside the chamber.

B. Photographic plate

Neutrons can be detected by photographing recoil protons tracks in a neutron proton scattering process in hydrogen and water vapor filled cloud chamber.

Fast Neutron Activation Analysis (FNAA) like ^{197}Au (n,n'γ) ^{97}Au^{m} and 89Y (n,n') ^{89m}Y were used to measure neutrons up to certain energy range (E_n=2.5-3 MeV) based on inelastic interaction of neutrons with activation material.

37.5. Pulsed Neutron Measurement

Although the neutron production time in plasma focus device is in the range of 50-500 nano seconds. Since the neutron counters like BF_3, ^{3}He or ^{6}Li- loaded detectors have comparatively longer dead times (a few 100s of micro seconds to a few milliseconds) which are not acceptable for pulsed neutron measurements.

37.5.1. Activation Method

Neutron can be detected by radioactive capture method. When neutron strike the activation foil it captures neutron with emission of beta/gamma radiation, as the neutron flux increases it is easier to detect as the relation is direct proportionality. A stable isotope captures the neutron and after capturing it becomes active. The absorbed energy is stored and later the decay of individual isotope gives the signature in the form of energy and frequency of released radiation. The released radiation is proportional to neutron flux.

The plasma focus generated (2.45 MeV) fast neutrons are slowed down in the moderator material, absorbed by the silver atoms, produce radioactive isotopes and emit either beta or beta-gamma which is subsequently recorded by GM-tubes and gives produced activity in terms of counts. From the calibration factor we can back calculate the neutron yield.

The following parameters decide the amount of radio activity by the foil:

1. Number of atoms that are reacting in the foil
2. Probability of foil absorbing the neutron
3. Incident neutron flux

The induced radioactivity can be calculated using the following relation:

$$A_0 = N \phi \sigma S$$

Where, A_0 is the activity induced in disintegration per second (dps) at the end of the reaction;

N is the number of target nuclei

ϕ is the neutron flux used to irradiate the sample

σ is the cross section of the neutron absorption reaction

S is the saturation term (accounts for decay time during irradiation)

37.5.2. Silver Activation Counter:

Silver Activation counter setup comprise of three GM tubes; all three tubes are connected in parallel mode to get better sensitivity. Each tube is wrapped with 250 micro meter thickness silver foil and surrounded by 75 mm thick moderator block as shown in Figure 37.1, separation of each GM tube 50 mm in the moderator block).

The generated 2.45 MeV fast neutrons from Dense Plasma Focus (DPF) Device, will thermalized while passing through 75 mm thickness moderator block of HDPE material. The moderated neutrons are captured by the silver foil and producing a radioactive isotope which then decays into beta. The 250 micro meter thickness silver foils are surrounding the GM-tubes permits the produced beta particles to pass though from all points of the 250 micro meter silver foil need to go through the remaining silver foil thickness and also the thin wall LND type GM tube to detect ultimately, i.e. creating a signal that is recognized by NIMBIN based electronics module, and is counted using a counter/timer, the experiment layout is shown in Figure 37.2.

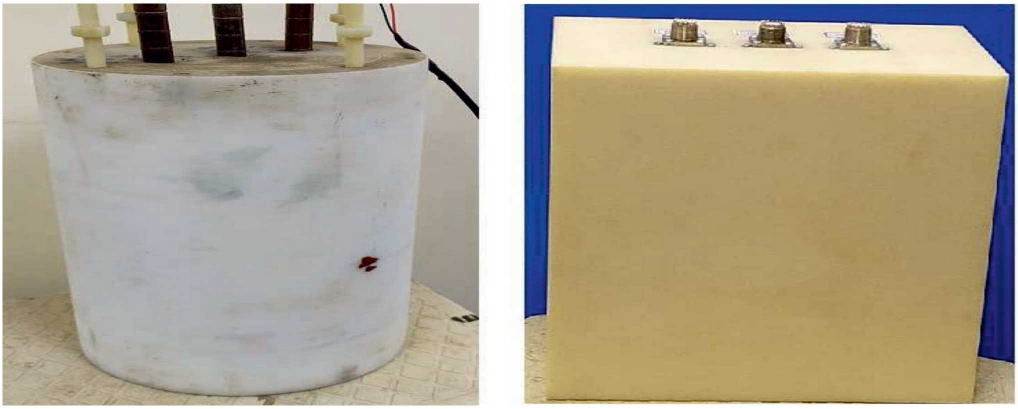

Figure 37.1. Moderator Geometry

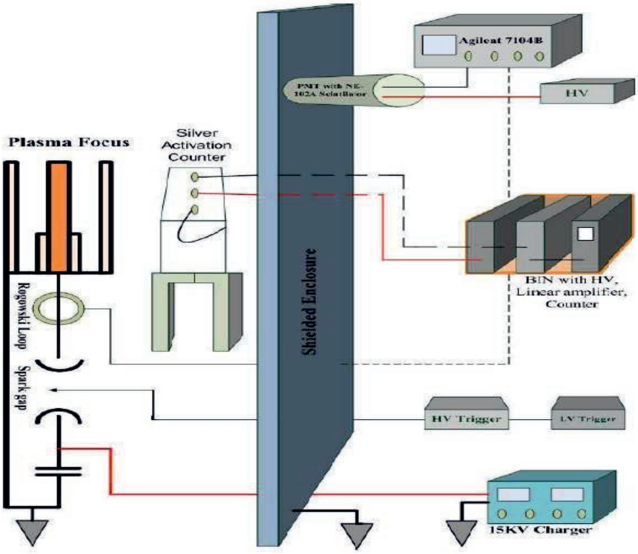

Figure 37.2. Final Layout for Experiment and Neutron Detection Set up.

The possible neutron capture reaction with the silver:

$$^{109}\text{Ag} + \text{n} \quad \underline{\sigma(n_{th},}\ \gamma) = 91.4\text{b} \rightarrow \text{Ag}^{110}\ \ 97.15\% \rightarrow \text{Cd}^{110} + \beta^- + \nu$$

$$(T_{1/2} = 24.6 \text{ Sec})$$

The state-of-the-art calibration technique is usually obtained with continuous neutron source. The calibration constant is 1 count = 2.5×10^8 Neutrons/Pulse in 99 Sec at a distance one meter from the source and accordingly cross calibrated the other new counter with many single DPF shots with corresponding background readings (false positive readings are generated in the detection system by natural background and electrical background noise).

37.5.3 Indium Activation Counter

The isotopes of Indium are ^{113}In (4.3%) and ^{115}In (95.7%). The thermal cross section of stable ^{113}In is comparatively low (σ =4barn). Due to its availability issues and low cross section with neutron activation to ^{114}In is rarely used. The activation analysis of ^{115}In with neutron gives three indium products, these are ^{116}In, ^{116m1}In and ^{116m2}In. Half-life of ^{116}In is approximately 13.9 Sec with cross section about 52 b. The half-life of ^{116m2}In is approximately 2 Sec and it has also low cross-section. The half-life of ^{116m1}In is 54 minutes (long half-life), gives essential activation products and ^{115}In has large thermal cross section (154 barns) for this specific reaction.

$$^{115}\text{In} + \text{n} \rightarrow {}^{116m1}\text{In} \quad ==> \quad \text{Sn}^{116} + \beta^- + \gamma$$

($\sigma = 154$ barn, $T_{1/2}$=54 min, E_β= 1 MeV, E_γ = 417 keV, 1097 keV and 1293 keV)

We need to form ^{116m1}In with neutron activation, which produces three different energy of gamma radiation, they are 417 keV, 1097 keV, and 1293 keV. Beta particle of 1 MeV is also released. The disintegration of ^{116m1}In is explained in Figure 37.3.

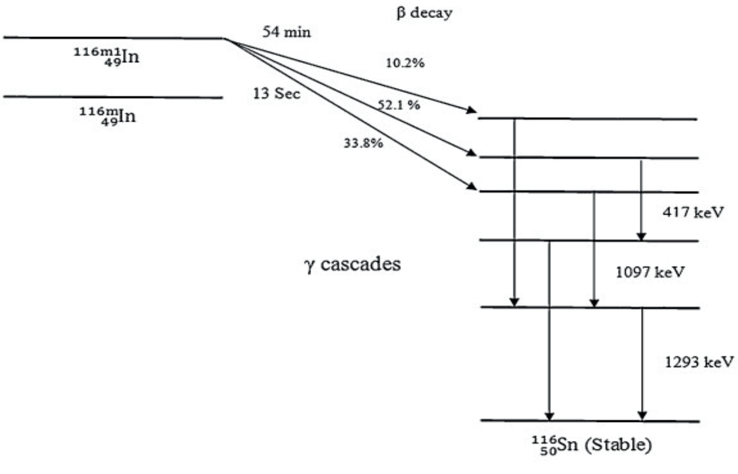

Figure 37.3. Decay scheme of ^{116m1}In.

For Indium there are three short half live isotopes (13.9 Sec, 2 Sec and 54 min) so, there will be background problems more while detecting the neutron.

37.6. Summary

Neutrons are difficult to detect as they are neutral particles and not affected by the presence of electric or magnetic fields. Thus, instead of measuring neutron directly, the byproducts of neutron reactions or their interactions are detected. Devices are used in this manner include glass, liquid or plastic scintillators, gas proportional counters and neutron activation detectors. Silver is used as activation material for suitable quantification of neutrons mainly when the neurons radiate in the form of pulses like DPF device. Other elements such as beryllium, yttrium and indium also used as activation material to measure neutron based on half-lives of their isotopes (induced by neutron) and initiation of the nuclear reaction.

References

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