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## **STUDY NEUTRON EMISSION IN PLASMA FOCUS DEVICE BY SILVER ACTIVATION METHOD**

**Abstract.** Dense Plasma Focus machine may be suitable for fusion first wall studies and its related material researches. As is well-known plasma focus devices are sources of high energy ions, electrons, x-rays and neutrons and intense bursts of fast plasma streams. In this paper, experimental measurements of neutron emission and hard x-ray emission from the plasma focus device are presented. The measurement of neutron and hard x-ray emission is studied using silver activation counter detector with two different dimensions Pb shielding and two scintillator photomultiplier detector systems. The research paper reported that the experimentally detected neutron emission in the radial direction where focus occurs also evaluated neutron fluency at different distances. The results show that neutron emission with different intensities and pulse width. Silver detector registered neutrons in the range  $10^6$ - $10^7$  n/shot in the radial direction. The maximum neutron yield is  $1.7 \times 10^7$  neutrons per shot.

**Key words:** neutron yield, plasma focus, X-ray, shielding, silver foil, photo multiplier tube.

### **Introduction**

The dense plasma focus or simply the plasma focus is a device that can induce nuclear reactions using electromagnetic force generated between electrodes. The phenomenon of "plasma focus" was discovered independently in the middle of the twentieth century by N.V. Filippov (USSR) [1] and J. Mather (J. Mather, USA) [2] in the studies conducted under the program of controlled thermonuclear fusion. Plasma focus attracted the attention of researchers when the working chamber was filled isotope of hydrogen–deuterium, the intensity of accelerated (fast) ionic and electronic particles inside the chamber generates a powerful short pulse of fast neutrons and X-rays.

It is well known that neutron is an uncharged particle and does not interact directly with the electrons of matter and hence it is difficult to detect it directly. Therefore to detect neutrons it is necessary to use indirect methods such as recoil technique or nuclear reactions. The foil activation technique is also used for detecting neutron [3]. In this technique the neutron is allowed to be absorbed by the nucleus to form a compound nucleus. The measure of particles emitted from the compound nucleus such as beta or gamma radiation. The method of foil

activation by neutrons is one of the best methods to measure neutron flux [5,6].

The Neutron activation method and silver activation detectors are widely used in measurements of neutron yield and neutron flux parameters in plasma focus. In practice, it is the only method that allows measurements of neutron field parameters in a wide energy range (from thermal to 20 MeV) [9]. The activation method is widely used as a diagnostic technique for neutron yield registered in pulsed thermonuclear sources. In early plasma focus (PF) research papers [4-7], activation of Silver foil has been used and the so-called silver activated Geiger counter is the most known and accuracy detector. In PF devices, depending on the filling gas, neutrons from D–D reactions are produced with typical energies of 2.45MeV. Silver activation detectors are usually converted fast neutrons to thermal neutrons. Nonetheless, activation by fast neutrons could be used as the Indium or Beryllium counters when neutron intensity is high enough, typically higher than  $10^8$  n per source pulse [8].

The use of plasma focus in thermonuclear reactors was considered in [4,6]. The present-day level of understanding of these processes opens new perspectives for creation of a fusion reactor based on the new data. Therefore, it is necessary to study the

possibility of creating an alternative type of thermonuclear reactor at the plasma focus installations and to conduct experiments on existing installations. Experimentally measurements of the neutron yield and use it modern technology an essential and important part of our research. In this paper, the problem is posed experimentally to measure neutron yield by activation method.

**Method of investigation**

The experiment was carried out plasma focus PF-4 which cylindrical coaxial electrodes: anode and cathode (length of anode and cathode 33 mm and 38 mm respectively). The insulator used is a 31 mm long ceramic. The energy storage system of the PF-4 includes a capacitor bank of capacitance 20 μF with a working voltage of 10–20 kV and 2.6–280 nH [7, 9]. High voltage is switched using a controllable discharger (air-filled). The results in this work were obtained by charging the capacitor bank at 14-18 kV. To study the characteristics of neutron emission we used activation detectors which were previously calibrated with an Am–Be source and a photomultiplier tube (PMT) with a plastic scintillator.

A typical neutron activation detector consists of a block of a hydrogen-containing fast neutron moderator, inside which a silver foil is placed. The silver foil is wrapped around the Geiger counter, which registers β- activity induced by slow neutrons. This type of sensor has a relatively large “dead time” (~100 μs). Let the detector be irradiated with fast (2.5 MeV) neutrons from a constant source of intensity I (neutron/s), located at the point from which the detector is visible at a solid angle Ω. After the

irradiation process, the activity of the wrapped foil  $A(t_2)$  will be equal to [7,10]:

$$A(t_2) = n\bar{V}\Sigma(\bar{V})d(1 - e^{-t_1/T}) \tag{1}$$

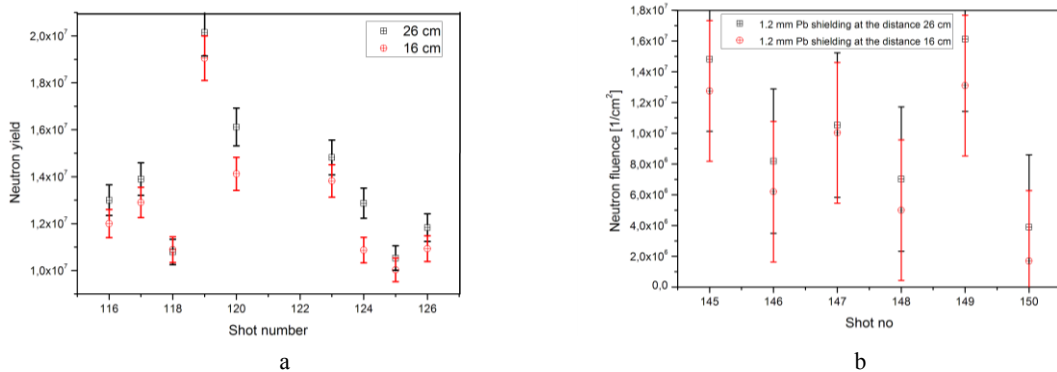
Then the expression (1) can be rewritten:

$$N = I \left( \frac{\Omega}{4\pi} \right) \varepsilon T \left( 1 - e^{-t_1/T} \right) e^{-t_2/T} \left( 1 - e^{-\Delta t/T} \right) \tag{2}$$

where  $\psi$  is the coefficient of proportionality characterizing the efficiency of registration of β particles by the Geiger counter,  $T$  is the radioactivity relaxation time,  $\Sigma$  is the activation cross-section,  $d$  is the activated plate thickness ( $\Sigma d \ll 1$ ),  $\varepsilon$  is the detector efficiency,  $t_1$  is the radiation time of the foil,  $t_2$  is the time interval between the end of irradiation and start of counting,  $\Delta t$  is the measurement time,  $I$  is the intensity of the neutron source,  $\Omega$  is a solid angle at which the detector is visible from the point where the pulsed neutron source is formed,  $N$  is the number of pulses,  $Y$  is the neutron yield.

**Results and Discussion**

To measure the neutron flux in the radial direction silver activation detectors were located at distances at 16 cm and 26 cm. The centers of the detectors were placed at the same height and were shielded by the lead sheet of thickness 1.2 mm and 2.5 mm to avoid activation by hard x-rays. We evaluated the angular differential neutron yields at the distances of 16 cm and 26 cm from the electrode where compression of plasma occurs. The comparison of the neutron yields is shown in Fig. 1.

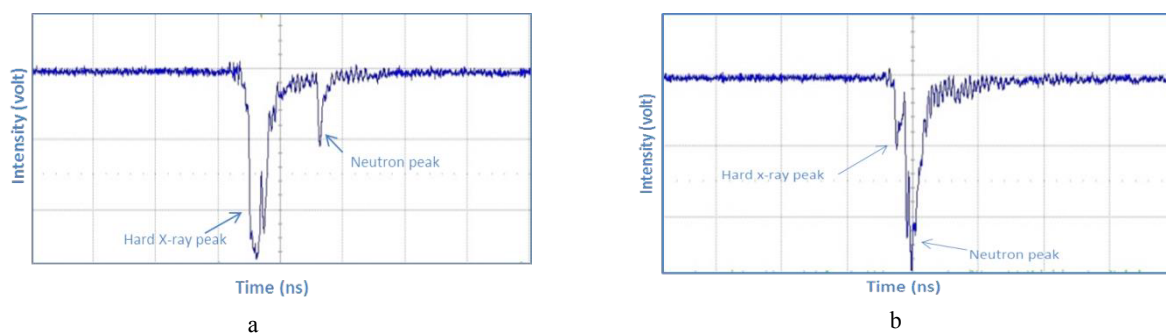


**Figure 1** – Neutron yield and neutron fluence in the radial direction at the distance of 16 cm and 26 cm: *a* – without shielding, *b* – with shielding

The maximum neutron yield  $Y$  in the present case roughly matches the scaling law  $Y \sim I^4$  ( $I$  in kA) proposed by early researchers [7]. To evaluate the dependence of the neutron emission on the filling gas pressure, the neutron signals (PMT) and neutron counts (by SAC) were recorded by varying the filling gas pressure from 2 to 10 Torr. The neutron emission reduces dramatically with variation in pressure in the

experimental device. This might be explained by the fact that with an increase in pressure, the role of the beam mechanism in the neutron production decreases.

Two scintillator-photomultiplier systems have been used for hard X-ray and neutron measurement. The temporal evolution in neutron and X-ray pulse with respect to the  $dI/dt$  dip was obtained using PMT (Fig. 2).



**Figure 2** – Typical neutron signal obtained by PMT:

- a* – weak neutron and strong hard X-ray signals without lead sheet;
- b* – strong neutron and weak hard X-ray signal capture with lead sheet

The PMT was placed at distances 1.5 and 1.9 meters away from the tip of the central electrode in its radial direction. It is noted that both PMT signals give two distinct pulses as shown in Fig.2. The first pulse in both PMT signals appears at the same time, while the second pulses appear with a time difference of around 100 ns. From this observation, one can conclude that the first pulse is due to hard X-ray emission, as it appears at the same time in both signals. The generation of this hard X-ray is due to the bombardment of the anode surface by an energetic electron beam [11-12]. The second pulse is thought to be a result of emission of an energetic particle as it took time to reach the PMT. Since the particles penetrated the plasma focus chamber wall, it must be due to neutron emission. To make the results more precise, both detectors had shielding (Pb filters) of thickness 1.2 mm and 2.5 mm in front of the PMT and their signals were monitored. The shielding considerably reduced the first pulse leaving the second pulse almost the same. The shielding of thickness 1.2 mm can significantly attenuate hard X-rays, but the attenuation is insignificant for the neutron (Fig.2c). In some of the PMT signals, it is observed that the neutron pulse is very intense in amplitude with a small pulse of hard X-ray, while in some cases, the opposite result is obtained, i.e. a

small neutron pulse with an intense hard X-ray pulse (Fig.2a and 2b).

## Conclusion

The neutron emission has been studied using a PF-4 device operating in the deuterium medium by using PMT and a silver foil detector. The results show two pulses of neutron emission with different intensities and pulse width. Depending on the relative proportion of ion and electron currents or time of their existence the PF device will emit more intense hard X-ray or more intense neutron pulse. The neutron emission is found to be strongly dependent on the operating pressure and it was the highest at around 7,5-8 Torr. The corresponding pinching time is observed near the maximum of discharge current and thus transfers the maximum energy into the plasma. Therefore, the neutron emission is the highest at this pressure. The maximum neutron yield of  $1,7 \times 10^7$  neutrons per shot has been achieved for the silver detector. These experiments detected neutrons in the range  $10^6$ - $10^7$  n/shot in the radial direction. The measurement of neutron fluency ( $2 \cdot 10^6$ - $1,7 \cdot 10^7$  n/cm<sup>2</sup>) at different distances from the pinch in the radial direction shows that the DD neutrons are mainly emitted in the axial direction. In

our case, the registered particles were  $6.4 \times 10^6 - 1.4 \times 10^7$  neutrons per shot and velocity 2,625-8,75 cm/ $\mu$ s. The obtained results can use experimental study basic problems for all fusion facilities.

### References

- 1 J. Mather. "Investigation of the high-energy acceleration mode in the coaxial gun", *Physics of Fluids* 7, (1964).
- 2 N. Filippov, T. Filippova, V. Vinogradov. "Dense high-temperature plasma in a non-cylindrical z – pinch compression", *Plasma*, (1962).
- 3 N.V. Filippov, T.I. Filippova, I.V. Khutoretskaya, V.V. Milton, V.P. Vinogradov. "Megajoule Scale Plasma Focus as Efficient X-ray Source", *Physics Letters A*, 211 (1996).
- 4 J.M. Koh, R.S. Rawat, A. Patran, T. Zhang, D. Wong, S.V. Springham, T.L. Tan, S. Lee and P. Lee "Optimization of the high pressure operation regime for enhanced neutron yield in a plasma focus device" *Plasma Sources Science and Technology*, (2003)
- 5 R.K. Cherdizov et al. "Experimental research of neutron yield and spectrum from deuterium gas-puff z-pinch on the GIT-12 generator at current above 2 MA", *Phys.: Conf. Ser.* 830 (2017).
- 6 N. Talukdar, N.K. Neog, and T.K. Borthakura. "Study on neutron emission from 2.2 kJ plasma focus device", *Physics of Plasmas*, (2014).
- 7 O.N. Krokhin, V.Ya. Nikulin, M. Scholz, I.V. Volobuev. "The Measurements of Neutron Emission on Plasma Focus Installations with Energy Ranging from 4 to 1000 kJ", *Proc. of 20th Symp. on Plasma Physics and Technology*, (2002).
- 8 Ariel Tarifeno-saldiva, Roberto E. Mayer, Cristian Pavez and Leopoldo Soto. "Methodology for the use of proportional counters in pulsed fast neutron yield measurements" (2011).
- 9 A.M. Zhukeshov, B.M. Ibraev, Sh.G. Giniyatova, B.M. Useinov, V.Ya. Nikulin, A.T. Gabdulina, A.U. Amrenova "Parameters calculation and design of vacuum camera for «Plasma Focus» facility", *International Journal of Mathematics and Physics*, 1 (2016).
- 10 O.N. Krokhin, V.Ya. Nikulin, I.V. Volobuev. "Compact activation detectors for measuring of absolute neutron yield generated by powerful pulsed plasma installations", *Czech. J. Phys.*, 54 (2004).
- 11 I. Murata, I. Tsuda, R. Nakamura, S. Nakayama, M. Matsumoto H. Miyamaru. "Neutron and gamma-ray source-term characterization of Am-Be sources in osaka university", *Progress in Nuclear Science and Technology*, 4 (2014).
- 12 A. Zhukeshov, A. Amrenova, A. Gabdulina, Z. Moldabekov "Calculation and Analysis of Electrophysical Processes in a High-Power Plasma Accelerator with an Intrinsic Magnetic Field", *Technical physics*, 62 N.3(2019).