COMPACT ACTIVATION DETECTORS FOR MEASURING OF NEUTRON EMISSION ON PLASMA FOCUS INSTALLATIONS

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The paper presents the two compact simple systems for the measurement of the absolute neutron yield in the range 10^6–10^{12} neutrons/pulse and higher and spatial anisotropy of neutron radiation. The systems are destined for the registration of the short duration neutron radiation of the pulsed plasma installations, such as Plasma Focus (PF), z-pinches and others plasma installations. This paper also includes the results of the neutron emission measurements on different PF installations: "Tulip" (P.N. Lebedev Physical Institute, Moscow, Russia), the PF–1000 and PF–150 installations (Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland).
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1. INTRODUCTION

The neutron measurements are usually conducted on the every Plasma Focus installations. On the base of the results received by the neutron measurements on such installations the dependence of the neutron yield on the energy stored in capacitors (scaling law) was obtained. However, since the methods, used in those experiments for the neutron measurements, the absolute calibration of detectors, the background of low-velocity and moderate-energy neutrons were different, some degree of uncertainty can take place. Therefore it is necessary to carry out the neutron measurements on different installations with the same neutron measurement system (at most simple and mobile). In the paper we describe the devices for neutron measurements, which allow to measure of neutron yield with a good accuracy on different installations without the additional calibration.

2. THE SYSTEMS FOR THE NEUTRON MEASUREMENTS

Two compact simple systems for the measurement of the absolute neutron yield (10^6–10^{12} neutrons/pulse and higher) and spatial anisotropy of neutron radiation were developed in the Lebedev Physical Institute (Fig. 1). The systems are destined for the registration of short duration neutron radiation of the pulsed plasma installations.

These systems are minimally sensitive to background of low-velocity neutrons and have been calibrated as mobile instruments (in other words, the calibration parameters have to be unchanged when we place the neutron registration systems in different positions on different installations) [1–3].

The first system consists of minimal number of recording devices and compact interchangeable activation detectors with different dimensions of moderator containers. The electronic unit is built on the TTL standard; the AAA-accumulators are used in power supply of the electronic system.

The second system utilizes the same small activation detectors. The small optically isolated electronics package has 4-digit data output to LCD display and is screwed to the sensor of the detector. In the power supply of the electronic unit and the sensor the 9V accumulator is used.

Fig.1. Different detectors of the neutron registration systems. The size of containers with moderator: cylinders with diameter 3.5, 6.5, and 14 cm and length 12, 11, and 20 cm correspondingly

The developed neutron measurement systems utilize the halogenous Geiger–Muller counters of the CTC–5 and CTC–6 types as sensors (Russia) that is wrapped with indium or silver foils and placed in the containers filled with the neutron moderator. As it is known, for such relatively small moderator containers, the dimension of the moderator determines the sensitivity of the device—the larger moderator, the higher sensitivity. On the other hand, the larger the size of the moderator, the influence of background of low-velocity neutrons is heavier. (Low-velocity neutrons arise due to the scattering of fast neutrons in the material of the constructing elements of the installation, neutron shield packages, and walls.) Taking all that into account, we have determined the optimal size of the containers with moderator. The material of the moderator is plexiglas (or paraffin) covered with cadmium foil. Cadmium is used in order to reduce the influence of low-velocity neutrons on the results of measurements (the cadmium capture cross-section for thermal neutrons is very large one). The experiments conducted on the various installations have confirmed the correctness of the chosen parameters of the neutron detectors.

Rather low efficiency of the neutron detectors imposes severe conditions on the resolution time of the counter electronic circuit. In order to increase the efficiency of the neutron detectors it is desirable to reduce the miscounts of the recording system. With the purpose to reduce the miscounts, obviously, the resolution time of recording system is necessary to make as short as possible. For the given variant of the neutron detectors the resolution time of recording system was approximately equal to 120 µs that is only a little longer than the dead time of the sensors.

The two nuclear reactions give an important contribution to activation of indium or silver foil. Correspondingly [4, 5]:

$$In^{115} + n \rightarrow In^{116} \Rightarrow Sn^{116} + \beta^-$$

σ_{act} = 52 Barn, $T_{1/2}$ = 13 s,

E_β = 3.29 MeV

$$In^{115} + n \rightarrow In^{116m} \Rightarrow Sn^{116} + \beta^- + g$$

σ_{act} = 155 Barn, $T_{1/2}$ = 54.2 min,

E_β = 1 MeV; 0.87 MeV; 0.60 MeV

and

$$Ag^{107} + n \rightarrow Ag^{108} \Rightarrow Cd^{108} + \beta^- + g$$

σ_{act} = 45 Barn, $T_{1/2}$ = 2.3 min,

E_β = 1.77 MeV; 1.15 MeV

$$Ag^{109} + n \rightarrow Ag^{110} \Rightarrow Cd^{110} + \beta^- + g$$

σ_{act} = 113 Barn, $T_{1/2}$ = 24.2 s,

E_β = 2.24 MeV; 2.82 MeV

The neutron measurement systems were calibrated with Po–Be, Pu–Be, and Americium–241/Beryllium sources. The procedure of calibration of the neutrons counters with indium foils is given in [2]. The influence of the low-velocity and moderate-energy neutrons background to experimental results have been tested by the independent measurements of the neutron yield [6].

The recorded neutron output is

$$N + \Delta N - \bar{N}_{ph}^{\Delta t} = I \left(\frac{\Omega}{4\pi}\right)[\varepsilon' T' \left(1 - e^{t_1/T'}\right) e^{-t} \ldots$$
$$+ \varepsilon'' T'' \left(1 - e^{-t_1/T''}\right) e^{-t_2/T''} \left(1 - e^{-\Delta t/T''}\right).$$

The single and double primes indicate the parameters of reactions, which we have written for two indium isomers or silver isotopes (In^{116} and In^{116m} or Ag^{108} and Ag^{110}).

N—the recorded number of pulses;

ΔN —the errors of the recording system;

I—the intensity of the neutron source;

ε —the effectiveness of detector;

Δt —the measurement time;

t_1—the irradiation time;

t_2—the time interval between the irradiation end and the counter beginning;

$\bar{N}_{ph}^{\Delta t}$ —the average number of background pulses for Δt ;

Ω —solid angle at which the detector is visible from the location of the pulsed neutron source;

$T = \frac{T_{1/2}}{\ln 2}$ —the relaxation time of a radioactivity;

$T_{1/2}$ —the half-life of corresponding foil isotope.

CALIBRATION CONDITIONS

$$t_1 >> T', T''; \; t_2 \simeq 0; \; \Delta t = 1 \text{ s}$$
$$\varepsilon \equiv \varepsilon' + \varepsilon'' = N + \Delta N - \bar{N}_{ph}^{\Delta t} / I(\Omega/4\pi). \qquad (2)$$

REAL NEUTRON MEASUREMENTS

For In foil:

$$N + \Delta N - \bar{N}_{ph}^{\Delta t}$$
$$= I_1 \left(\frac{\Omega}{4\pi}\right)\varepsilon\left[0.251\left(1 - e^{-\Delta t/T'}\right) + 0.749\left(1 - e^{-\Delta t/T''}\right) \ldots\right.$$

where $T' = 20.34$ s, $T'' = 4683$ s, I_1 is the neutron yield for shot.

For Ag foil:

$$N + \Delta N - \bar{N}_{ph}^{\Delta t}$$
$$¿ I_1 \left(\frac{\Omega}{4\pi}\right)\varepsilon\left[0.249\left(1 - e^{-\Delta t/T'}\right) + 0.715\left(1 - e^{-\Delta t/T''}\right) \ldots\right.$$

where $T' = 199$ s, $T'' = 35$ s.

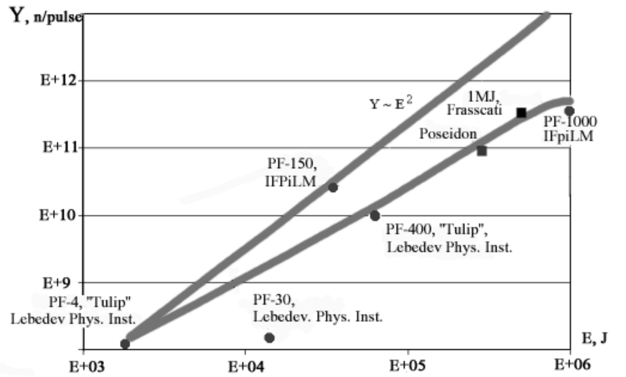

Fig.2. The maximum neutron yield on the different Plasma Focus installations. ●— measurements with these diagnostic systems; ■*—data from the literature*

3. RESULTS AND DISCUSSIONS

The results of the neutron measurements are presented in Figures 2–3. In Fig. 2 one can see that the character of the neutron emission of two installations (PF–4 and PF–150) is close to the E^2 law, the neutron emission on others PF installations are significantly lower. The reasons of such low yield could be:

- the shape and dimensions of the electrodes are not optimum;

• a restriction of the ion component of the current that could be arise in the near anode area on the big PF installations [7];
• the loss of the current due to the pinch rotation [8];
• the splitting of the pinch into filaments [9];
• the secondary breakdowns near the insulator,
and others.

The neutron emission can exhibit a strong forward directed anisotropy. Anisotropy factors Y_0/Y_{90} and Y_0/Y_{180} in the range between 1 and 2 were measured (Y_0, Y_{90}, and

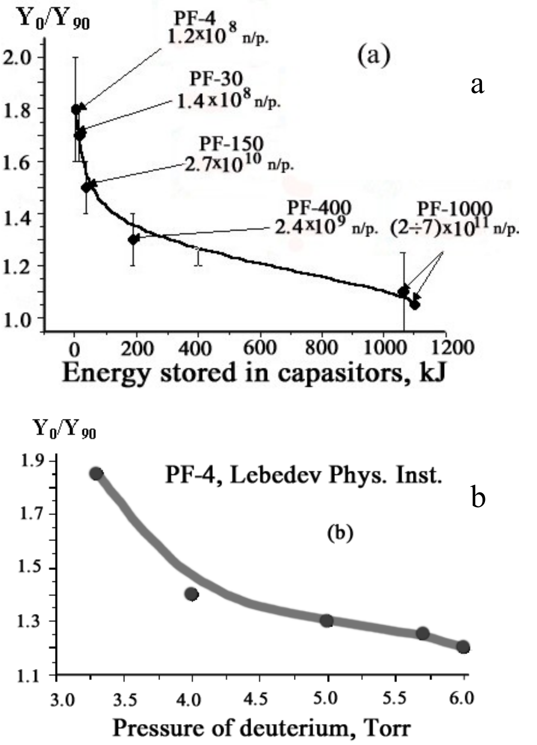

Fig.3. Spatial neutron anisotropy measured with these neutron activation counters systems

Y_{180}—correspondingly neutron yields at the angles 0º, 90º , and 180º to the Z-axis of PF).

The figures show that anisotropy factor decreases with the increase of gas pressure in PF chamber. We also observed that anisotropy is higher in shots with high neutron yield (especially for the factor Y_0/Y_{180}). The high spatial anisotropy is an indication of the dominant role of axially directed ion beams in the neutron generation process. Fig. 3(a) shows that the role of the accelerating mechanism of the neutron production on the large installations is less than one on the small PF devices. The accelerating mechanism, as it seen from the Fig. 3(b), is suppressed by the increase of the pressure of the operating gas.

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МАЛОГАБАРИТНЫЕ АКТИВАЦИОННЫЕ ДЕТЕКТОРЫ ДЛЯ ИЗМЕРЕНИЯ НЕЙТРОННОЙ ЭМИССИИ НА УСТАНОВКАХ ТИПА «ПЛАЗМЕННЫЙ ФОКУС»

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В работе представлены две простые малогабаритные системы для измерения абсолютного нейтронного выхода в области 10^6–10^{12} нейтронов/импульс и выше и пространственной анизотропии нейтронного излучения. Системы предназначены для регистрации короткого по длительности нейтронного излучения импульсных плазменных установок, таких как Плазменный фокус (ПФ), z-пинчи и других. В работе также приведены результаты по измерению нейтронной эмиссии на различных ПФ установках: «Тюльпан» (Физический институт им. П.Н. Лебедева, Москва, Россия), PF–1000 и PF–150 (Институт физики плазмы и лазерного микросинтеза, Варшава, Польша).

МАЛОГАБАРИТНІ АКТИВАЦІЙНІ ДЕТЕКТОРИ ДЛЯ ВИМІРУ НЕЙТРОННОЇ ЕМІСІЇ НА УСТАНОВКАХ ТИПУ «ПЛАЗМОВИЙ ФОКУС»

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У роботі представлені дві прості малогабаритні системи для виміру абсолютного нейтронного виходу в області 10^6–10^{12} нейтронів/імпульс і вище і просторової анізотропії нейтронного випромінювання. Системи призначені для реєстрації короткого по тривалості нейтронного випромінювання імпульсних плазмових установок, таких як Плазмовий фокус (ПФ), z-пінчи й інших. У роботі також приведені результати по виміру нейтронної емісії на різних ПФ установках: «Тюльпан» (Фізичний інститут ім. П.Н. Лебедєва, Москва, Росія), PF–1000 і PF–150 (Інститут фізики плазми і лазерного мікросинтезу, Варшава, Польща).