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Neutron and fast ion emission from PF-1000 facility equipped with new large electrodes

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Abstract A PF-1000 facility was operated for the first time at an energy level of up to 1 MJ. The maximal emission of 2×10^{11} neutrons/shot was registered. Relatively low emission anisotropy was observed. Fast ion beams were generated only from shots performed at a low filling pressure (1-2 Torr).

Key words fast ion beam • neutron emission anisotropy • neutron yield • plasma focus

Introduction

Corpuscular diagnostic techniques provide important information on nuclear reaction mechanisms leading to observed neutron emission, which is especially high (10^9–10^{12} neutrons/shot) from short-pulse plasma experiments i.e. Z-pinches and Plasma Focus experiments [1–3, 5, 14]. Nuclear reaction products, such as fast neutrons, protons, tritons and ^{3}He-ions, as well as primary energetic ions emitted from the plasma, deliver a lot of valuable data on energy and angular distribution of colliding ions, neutron emission sources and even on magnetic fields surrounding the hot plasma column [2, 7, 16]. Therefore, the corpuscular diagnostic methods have been readily applied within Z-pinch, Plasma-Focus, and other pulsed experiments since the very beginning of fusion research.

The question about neutron production mechanisms became the most intriguing one when it was observed that an extremely intensive X-ray emission and intensive bursts of 2.45 MeV neutrons are common and the most spectacular feature of these types of experiments [1–6, 11]. Taking into account that Z-pinch research is enjoying recently a renaissance [6, 8], one can expect that this question will be reconsidered both experimentally and theoretically. One should also point out that the problem of the neutron production mechanisms will be studied thoroughly within the PF-1000 experiment, and this paper is the first approach to this goal.

Experiment

The PF-1000 facility, constructed and operated at the Institute of Plasma Physics and Laser Microfusion (IPPLM), has recently been modernised and optimised [12–14]. The electrodes used for the previous experiments have recently been replaced by new ones of considerably

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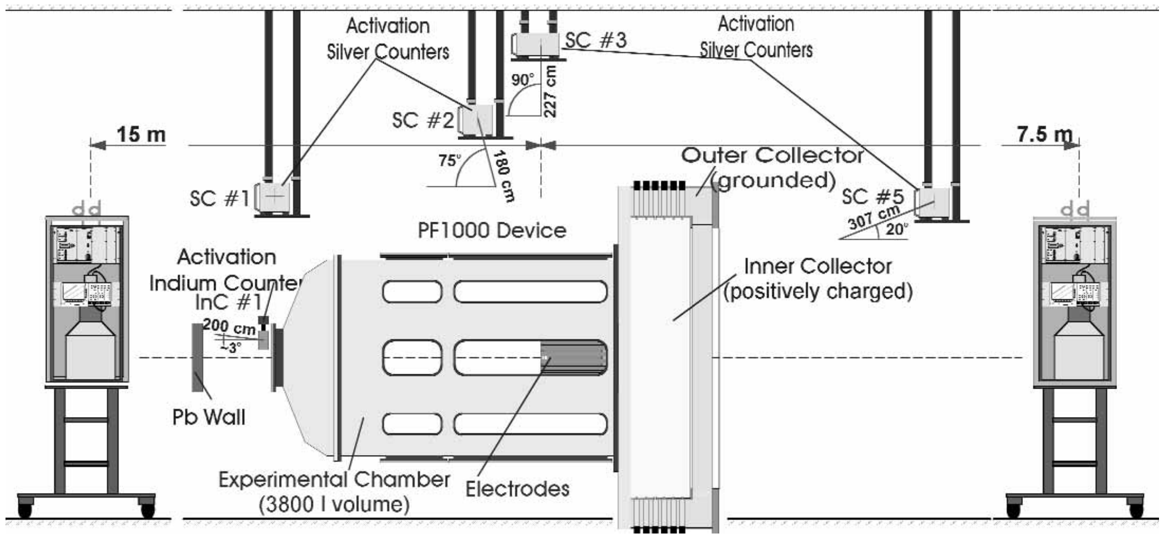

Fig. 1. Positions of neutron activation counters in relation to the PF-1000 discharge chamber.

larger dimensions. The outer electrode is 400 mm in diameter and the inner one is 230 mm in diameter. Both the electrodes are about 600 mm in length. These new large electrodes seem to be better matched to transmit electrical energy (up to 1 MJ stored in the condenser battery) to plasma discharges. This paper reports on neutron emission, which was registered in the first series of shots performed with an electrode assembly. The total neutron yield (in every single shot), and the neutron emission angular distribution, were measured with four silver activation counters placed around the main discharge chamber of the PF-1000 facility as shown in Fig. 1. Those counters were specially designed and manufactured for the PF-1000 experiment purposes. After their fixing, they were calibrated using an Am-Be neutron source of precisely defined activity equal to 1.5×10^7 neutrons/sec 4π. In order to perform time-resolved measurements of the hard X-ray radiation and fast neutrons also scintillation probes were used. For the experiment described, these probes were located ~15 m from the electrode outlet. For future experiments the probes will be moved to a distance of a few dozen meters in order to measure neutron energy spectra by means of the time-of-flight method.

In the experiments performed recently the emission of fast ions (mainly energetic deuterons) was measured by means of a miniature pinhole camera which was placed on the electrode axis, at a distance of 40 cm from the electrode outlet as shown in Fig. 2. This camera was equipped with a solid-state nuclear track detectors of the CR-39 or PM-355 type, which enabled to register the ions penetrating through the hole. Aforementioned track detectors were earlier precisely calibrated by means of monoenergetic ions (protons, deuterons, ^{4}He-ions, etc.) provided by particle accelerators [9, 10, 15].

Experimental results

Experimental data and neutron yields registered in a series of discharges, which were performed with the modernised PF-1000 facility, are presented in Table 1. Table 1

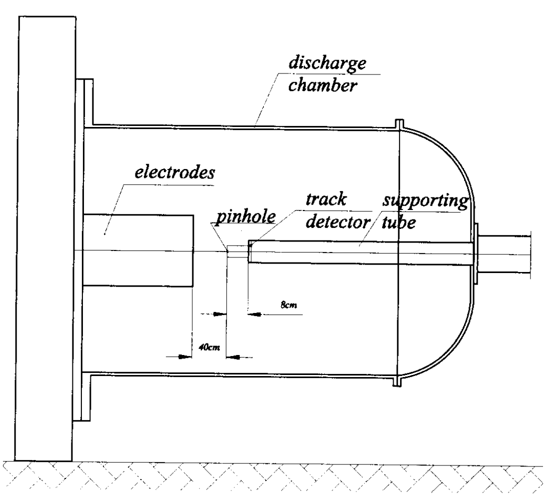

Fig. 2. Schematic diagram of the equipment used for ion beam measurement within the PF-1000 experiment.

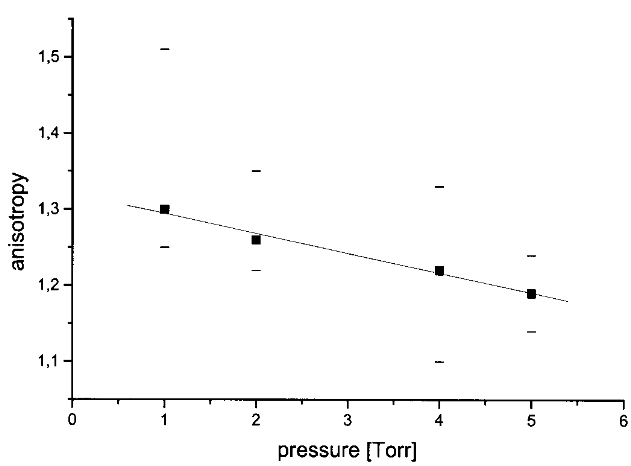

Fig. 3. Anisotropy ($Y_n(25°)/Y_n(90°)$) of the neutron emission as a function of the initial deuterium filling pressure.

Table 1. Experimental data from a series of shots performed with the modernised PF-1000 machine.

Shot No.	U_0 [kV]	W_0 [kJ]	p_0 [Torr]	I_{max} [kA]	Yn(25°)×10^{10}	Yn(90°)×10^{10}	Anisotropy
01/19/09	27.25	500.0	1	1020	2.74	1.82	1.51
02/19/09	27.25	500.0	1	927	2.31	1.83	1.26
03/19/09	27.25	500.0	1	952	2.81	2.09	1.34
05/19/09	27.25	500.0	1	768	0.98	0.76	1.30
10/19/09	31.06	650.0	1	1129	4.01	3.14	1.28
10/19/09	31.06	650.0	1	1285	2.52	2.01	1.25
01/21/09	29.00	566.5	2	1101	3.11	2.33	1.33
05/21/09	30.00	606.3	2	1265	6.30	4.89	1.29
06/21/09	30.00	606.3	2	1306	3.03	2.38	1.27
09/21/09	31.00	647.4	2	1258	9.98	7.40	1.35
01/22/09	31.00	647.4	2	1346	9.69	7.92	1.22
04/22/09	35.00	825.3	2	1646	6.58	5.19	1.14
08/22/09	35.00	825.3	4	1505	5.70	5.25	1.08
09/22/09	36.00	873.1	4	1761	6.38	5.26	1.21
01/27/09	35.00	825.3	4	1673	6.72	5.52	1.22
01/27/09	36.00	873.1	5	1992	3.21	2.63	1.22
02/27/09	37.00	922.3	5	2156	13.10	11.80	1.18
03/27/09	38.00	972.3	5	2020	19.00	16.40	1.17
04/27/09	38.50	998.6	5	2101	20.00	16.20	1.23
05/27/09	40.00	1078.0	5	1992	20.60	18.00	1.14

contains only the most important operational parameters: the initial charging voltage (U_0), the electrical energy stored in the condenser battery (W_0), the D_2 filling pressure (p_0), the maximum current amplitude (I_{max}), and a coefficient describing the neutron emission anisotropy defined in this work as ($Y_n(25°)/Y_n(90°)$). The neutron emission was investigated as a function of the initial charging voltage for several values of the D_2 filling pressure. The preliminary results obtained so far show that there is the optimum value of the charging voltage for each chosen initial pressure. At a constant D_2 – filling pressure the neutron yield increases initially with an increase of the charging voltage, but there appears certain saturation effect. When a maximum is achieved, at a further increase in the voltage the neutron emission decreases. One can see (Table 1) that the highest neutron yield registered so far was about 2×10^{11} neutrons/shot, but it is expected that still higher neutron yields will be attained in next series of shots after appropriate conditioning of the insulator and electrode surfaces. Fig. 3 shows that an averaged coefficient of the neutron emission anisotropy decreases monotonically with an increase in the initial filling pressure. Relatively low values of this coefficient, even for the discharge pressure of 1 Torr, are interesting results. One could assume that energetic deuterons considerably contribute to the total neutron emission, especially in discharges at a low filling pressure. This supposition was confirmed by the measurements of fast ions emitted along the electrode axis. Ion beams were

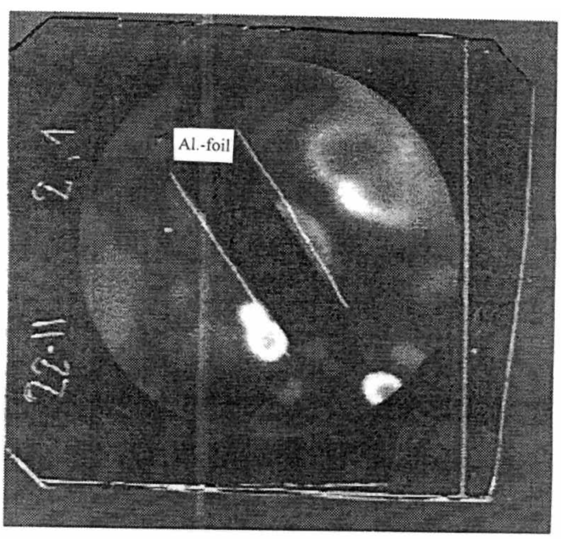

Fig. 4. Ion pinhole picture from a single discharge performed within PF-1000 facility at p_0 (D_2) = 1 Torr, U_0= 30 kV, W_0 = 600 kJ.

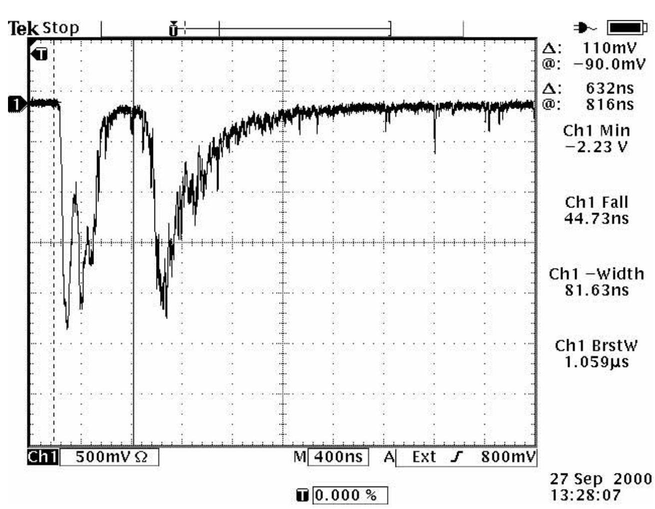

Fig. 5. Typical signals registered with the scintillation probe.

registered with a pinhole camera only in PF shots performed at a low D_2 filling pressure as shown in Fig. 4. The ion pinhole picture, as taken with the camera equipped with a CR-39 track detector, reveals a quite complex structure of fast ion beams emitted from different sources formed inside the plasma column. The ion picture scanned with an optical microscope showed ion crater densities of the order of $(1–6)\times10^6$ craters/cm^2 (up to the saturation level). Taking into account calibration characteristics of the detector used [9, 10, 15] one can conclude that the registered ions had energies ranging from 100 keV to 1.5 MeV. The application of an Al-foil of 5 μm in thickness, which was placed on the detector sample inside the ion camera (Fig. 4), showed that the registered ions had energies below 1.5 MeV. It should be noted that ion track densities that were obtained behind the foil were one or two orders of magnitude lower than those registered without the foil-filter. Fig. 5 shows typical signals from the scintillation probe which was located on the electrode axis at a distance of 15 m from the electrode outlet. The first peak corresponds to the hard X-ray radiation and the second one was induced by 2.45 MeV neutrons.

Conclusions

The most important results of the experimental studies described in this paper can be summarised as follows:

1. For the first time the neutron yield and neutron emission anisotropy have been measured for PF shots performed at about 1 MJ discharge energy.
2. Neutron yield of the order of 2×10^{11} neutrons/shot was registered in the series of shots carried out within the PF-1000 facility equipped with new (large) electrodes.
3. Angular distribution of the neutron emission is more isotropic in the PF-1000 facility than that observed in other PF experiments.
4. Noticeable fast ion emission was observed only in the discharges carried out at a relatively low filling pressure p_0 (1–2) Torrs.
5. Ion pinhole pictures, as taken with the ion pinhole camera, reveal a complex structure of ion emitting sources.

In conclusion, the results obtained so far show that there is a considerable difference in the anisotropy factors for PF shots performed up to 1 MJ. On the other hand, it would of interest to carry out analogous measurements for neutron optimised discharges at higher initial filling pressures.

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