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► **To cite this version:**

José G. Moreno, Patricio Silva, Leopoldo Soto. Axial and radial measurements of the neutron emission from miniature plasma focus devices. 2004. hal-00001992

HAL Id: hal-00001992

<https://hal.science/hal-00001992>

Preprint submitted on 18 Nov 2004

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Axial and radial preliminary results of the neutron radiation from miniature plasma focus devices.

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Abstract. As first step of a program to design a repetitive pulsed neutron generator for applications two miniature plasma foci have been designed and constructed at the Comisión Chilena de Energía Nuclear. The devices operate at an energy level of the order of tens of joules (PF-50J, 160 nF capacitor bank, 20-35 kV, 32-100 J, ~150 ns time to peak current) and hundred of joules (PF-400J, 880 nF, 20-35 kV, 176-539 J, ~300 ns time to peak current). Neutron emission has been obtained in both devices operating in deuterium. An especial techniques was necessary to develop in order to detect neutron pulsed of 10^4 neutrons per shot. The maximum total neutron yield measured was of the order of 10^6 and 10^4 neutrons per shot in the PF-400J and PF-50J respectively. Axial and radial measurements of the neutron emission are presented and the anisotropy is evaluated in this work. The neutrons are measured by pairs of silver activation counters, ^3He detectors and scintillator-photomultiplier detectors.

Introduction.

The plasma focus (PF) is a dense transient plasma source of high temperature, when it operate with deuterium like filling gas it produces intense neutron pulses. These devices have been studied in a wide range of energies, MJ to kJ [1, 2]. In spite of the accumulated investigation in the area there is still open questions, particularly those related with the radiation emission mechanisms and with the transient processes that occurs at the time of maximum plasma compression; and also those related with the insulator preparation, impurities, mechanisms of electrical breakdown and formation of the current sheet. The motivations of to work at so low energy (tens to hundreds of joules) are: a) to open the possibilities of understanding the physics related to the plasma focus working at this limit of unexplored energy, b) to develop a repetitive and portable generator of pulsed neutron emission. A capacitor bank of tens to hundreds of joules has a smaller size in comparison with banks of kilojoules, from this way it would be easier to operate the device in a repetitive regime of Hz to kHz, due to the smaller transference of load in spark-gaps, thus diminishing its erosion. Also the power average would be smaller and it will make easy the system cooling if it is necessary. As it leaves from a program whose final mission is to develop and to construct a portable generator of pulsed neutron emission, we have designed and constructed two plasma focus devices of very low energy, tens of joules (PF-50J) and hundreds of joules (PF-400J). In this work we present the preliminary characterization of the axial and radial neutron radiation in both devices for a particular configuration and kind of electrodes.

Experimental details.

Originally, we have constructed a plasma focus of tens of joules (160nF, 65nH, 20-35kV, 32-98 joules, 30-50kA which are reached in 220ns) [3, 4]. In this device, the same plasma dynamics of bigger machines with energy several orders of upper magnitude [5],

was observed. Nevertheless it was not possible to observe the depression in the derivative current signal nor the peak in the voltage signal that characterizes a good plasma column compression (pinch of the focus). Probability, this is due to the change of plasma inductance that it does not produce an appreciable impedance variation in comparison with the capacitor bank impedance ($\sim 0.64\Omega$). Therefore, it was decided to improve the device (spark gap and connections) to diminish the total inductance of the generator. It was diminished the inductance to 38nH , so the impedance of the bank diminished to $\sim 0.5\Omega$ and the maximum available current increased in 28%. In parallel, maintaining the same disposition of geometry a greater capacitor (880nF) and identical inductance (38nH) was constructed. Table 1 summarizes the characteristics of both very low-energy plasma focus devices of our laboratory.

Dispositivo	C (nF)	L (nH)	Z (Ω)	V (kV)	E (J)	I(kA)	T/4 (ns)
PF-50J	160	~ 38	~ 0.5	20-35	32-98	40-70	~ 125
PF-400J	880	~ 38	~ 0.2	20-35	176-539	96-168	~ 300

Table 1. Main characteristics of low-energy plasma focus devices of the CCHEN. C: capacity, L: inductance, V: charge voltage, E: stored energy, I: maximum current, T/4 quarter period (nominal)

The dimensions used for anode and its insulator, in PF-50J and PF-400J, respectively, were: radius of the anode $r_a = 3\text{mm}$ and 6mm ; inner radius of the cathode $r_c = 11\text{mm}$ and 15.5mm ; overall length of the anode $z = 28.4\text{mm}$ and 28mm ; length of the

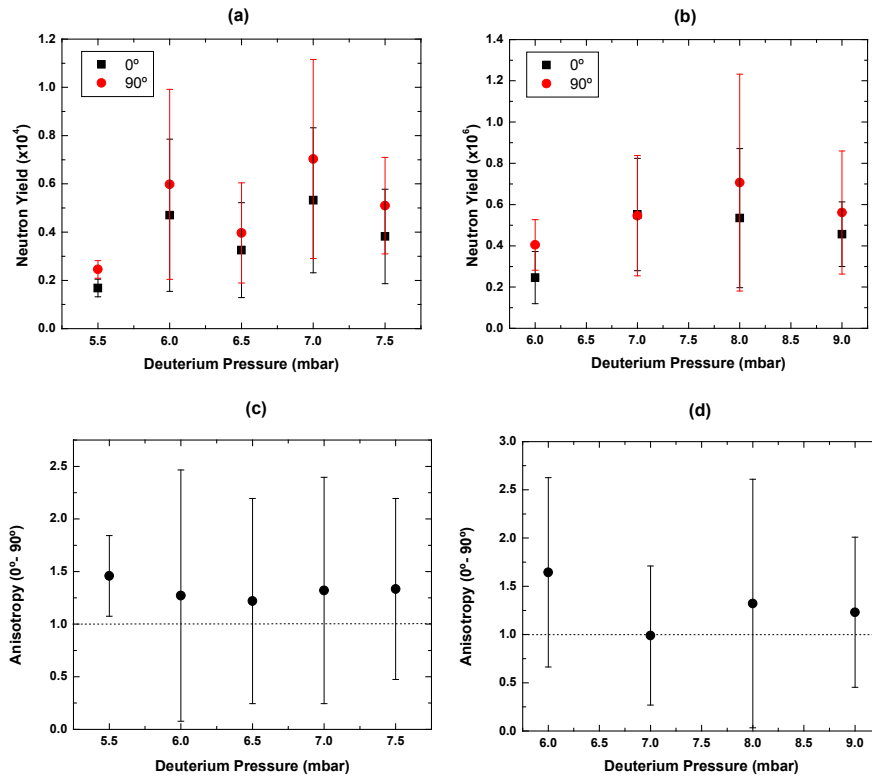


Figure 1. Graphic of neutron yield, Y_n , versus deuterium pressure for both devices, a) PF-50J y b) PF-400J. Dependence of axial (90°) and radial (0°) anisotropy in the neutron yield with pressure, c) PF-50J y d) PF-400J.

alumina insulator $l = 24.2\text{mm}$ and 21.5mm [6, 7]. The discharge chamber was filling with Deuterium at pressures of 5 to 9mbar, and a charging voltage of 30 kV. Voltage and derivative current signals was measured. The neutron yield was measured with activated silver (GMA and GMB) and ^3He (He3-206 and He3-209) detectors [8]. . The maximum total neutron yield measured was of the order of 10^6 and 10^4 neutrons per shot in the PF-400J and PF-50J respectively [6, 9]. Also the fast neutrons ($>1\text{MeV}$) and hard x-ray were directly measured with a scintillator-photomultiplier system (FM1 and FM2).

Figure 1 shows the neutron yield, Y_n , for two angular detector positions [0° (radial) and 90° (axial)]: activated silver detectors in the PF-400J case, and ^3He detectors in the PF-50J case. In general, for the different pressures the neutron emission at 90° is greater than at 0° , which indicates, that under the used experimental conditions in this work, an average anisotropy of 30% ($\pm 20\%$) was obtained.

Discussion and Conclusions.

An important point in the plasma focus devices characterization it is that related to the angular distribution of the neutron radiation. In fact, that is important because it will be able to explain the exact contribution of the thermonuclear fusion and beam-target mechanisms involved in the neutron generation of this kind of discharge. Figure 1 shows that the axial and radial neutron radiations are different, which could be due to a purely geometric reason (surroundings) or to the predominance of a beam-target process. In order to discard the surrounding influences, a calibration in situ using an Am-Be neutron source was placed in the pinch zone ($\sim 1\text{cm}$ on the anode) and the response factor of the detectors was determined, this response factor was used for the yield determination of yield, Y_n . So, the obtained results make think that the difference in the production in one and another direction showed in the figure 1, for both devices, could be due to the existence of one more probable direction of neutron emission the one that would be associate to a beam-target process. But in fact this is not exactly like this because in despite of the fact that the average values by pressure are greater than 1 (figs. 1c and 1d), also the errors associated to

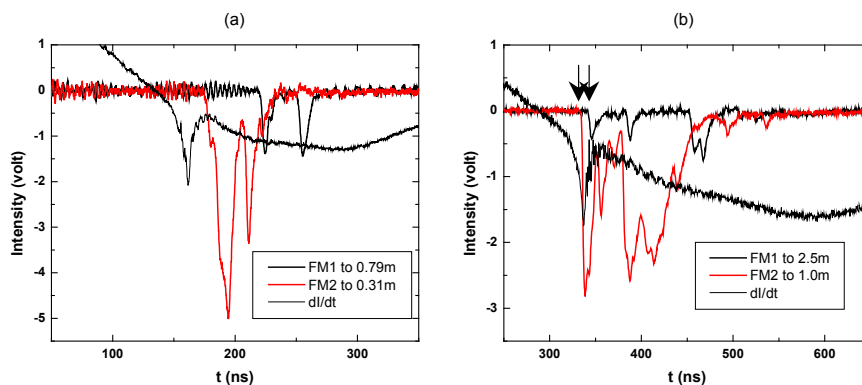


Figure 2. Characteristic signals of the scintillation system and the derivative current. a) In the PF-50J the scintillation system signals only show pulses associated with neutrons, instead b) in the PF-400J it is possible to observe neutrons and hard X-rays ($\sim 100\text{keV}$), which are shown by arrows.

the measures are considerable, which forces to think to improve the statistic increasing the number of measurements.

It is possible to use the time of flight (TOF) complementary method for to estimate the neutron average energy, because if the neutrons are mainly thermonuclear, the energy distribution should be around 2,45 MeV. This was made putting radially two scintillation detectors (scintillator + photomultiplier), separated by a distance of 0.48m for the PF-50J and 1.5m for the PF-400J, obtaining characteristic signals like ones showed in the figure 2.

In the figure 2 is observed the signals of the two scintillation systems (FM1 and FM2), and different pulses exist which are associated to the both X-rays and neutrons. In this figure, the pulsed X-rays are indicated by means of arrows (fig 2b). The existence of these two kind of radiation in a same shot allows to correlate the different pulses more easily because the temporal location of the X-ray pulse can be determined easily (in general it is very close to the deep of dI/dt). Thus, by means of the obtained temporal difference between both peaks due to the neutrons, and considering the spatial separation of the detectors, it is possible to consider the energy and eventually to determine the spectrum of them. But this is not direct because it must consider that the temporal measurement has two "components", the first one, and perhaps the most difficult one to obtain, is due to the time of neutron emission during the pinch compression phase, and the second one is that directly related with time of flight due to the neutron energy. In this case, for the used experimental conditions and for the analyzed data set, an neutron energy range between 2 and 3,1 MeV could be found for the PF-400J device, with an estimated mean value of $(2,42 \pm 0,39)$ MeV. For the PF-50J device the energy ranged between 0,3 to 4,1 MeV, with a mean value of $(2,29 \pm 1,28)$ MeV, which shows a great dispersion, mainly because the pulse correlation was much more difficult to determine due to an emission of minor intensity.

With the obtained results during this investigation it was not possible to conclude the kind of process that has more influence in the neutron radiation, however advances in the characterization of our devices has been obtained. In addition it is possible to suggest a tendency in the neutron radiation at very low energy and open the possibility to improve the measurement methods and radiation detection. At lower energy range operating conditions, the development and use of sensible and more efficient detectors is needed.

The next step consider to obtain the characterization of angular neutron emission and anisotropy, performing measurements in several angles. In the reference [10] it is reported time integrated measurements of the neutron emission from -90^0 to 90^0 including 9 angles of view in two plasma focus devices. The neutron flux was measured with CR-39 nuclear track detectors covered with polyethylene. The results are consistent with an angular uniform plateau (isotropic emission) plus a shape peaked in the direction of the axis of the discharge (anisotropic emission). Using this analysis the authors obtain an interesting result, the 70% of the total neutron emission is isotropic and only the 30% is anisotropic, because to the axial emission is concentrated only in a small solid angle, thus its contribution to the total emission is lower in comparison to the isotropic emission. The value usually reported, as the ratio between only to point of measured, axial and radial, may be misleading.

Acknowledgments.

This work has been financed by project FONDECYT N° 1040231 and project CCHEN 562. This work also is part of a bilateral agreement between the National Commission of Atomic Energy (CNEA, Argentina) and the Chilean Commission of Nuclear Energy, (CCHEN, Chile).

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