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Influence of emission time on determination of energy distribution of D-D neutrons produced by plasma focus device

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Abstract - The energy distributions of DD-fusion neutrons emitted by the plasma focus devices at the Institute of Plasma Physics and Laser Microfusion, Warsaw were studied experimentally using time-of-flight (TOF) spectra of expanding neutrons. The analysis of TOF spectra was based on temporal Gaussian distribution of the neutron emission and on shifted-Maxwell velocity distribution of expanding neutrons. The evaluated TOF data were completed with responses of thermoluminescent dosimeters detecting moderated neutron inside a paraffin sphere.

For a long time the dense plasma focus devices are intreesting as intense sources of high energy X-rays, charged particles and nuclear fusion netrons [1]. As it turned out, great variety of particle interaction processes in created plasma contribute to the neutron prodution. In order to obtain complete information about the producting mechanisms, leading to the observed neutron yields from D-D reactions, numerous diagnostic techniques have to be simultaneously employed for a detailed observation of short-pulsed fusion processes ignited by z-pinches. For example, the time-integrated and time-resolved diagnostics such as nuclear activation and scintillation detectors as well as thermoluminescent dosimeters are generally used [2-3].

This contribution is focused on the determination of the yield and energy distribution of neutrons produced by a discharge of the Plasma-Focus Device PF-6 at IPPLM, Warsaw.

The time-of-fligt spectra of neutrons were measured with the use of probes composed of Ne102 scintillators and fast photo-multipliers. A Bonner Sphere (BS), containing set of thermoluminescent dosimeters at its centre [4], provided the time-integrated measurement of the neutron yield was employed. The evaluation of TLD responses was provided with the use of read-out at a heating ramp 3^0C/s from 50^0C to 240^0C followed by a reader annealing at 240^0C for 120 s in an N_2 atmosphere using a PC-aided Harshaw Model 3500 reader.

Fitting procedure

Simple analysing of TOF neutron spectra obtained in *z* direction of plasma pinch by the getting of second derivation in time shows that TOF consist of group of partial neutron fluxes [5]. In our calculation two-dimensional velocity and time source function, $f(V,t)$ of such fluxes is represented by a shifted-Maxwell velocity distribution affected by the temporal Gaussian distribution:

$$f(V,t) = 4\pi \left(\frac{m}{2\pi kT} \right)^{\frac{3}{2}} V^2 \exp\left\{ -\frac{m\left(V - V_{D-D} - V_{drift}\right)^2}{2kT} \right\} \exp\left\{ -\frac{\left(t - t_0\right)^2}{\tau} \right\} \qquad (1)$$

where $V_{D\text{-}D}$ stands for velocity of neutron with the energy E=2.45MeV and V_{drift} stands for the velocity of moving plasma pinch.

For computation purpose it is convenient to change the velocity scale, V into a reciprocal velocity scale, U (Eq.2). In such case, all neutrons originated on the straight line, l of the source function and satisfying condition (Eq.3) reach the scintillation detector at the distance, L at time, t_d.

$$U = \frac{1}{V} \qquad (2) \qquad\qquad t_d = t + LU \qquad (3)$$

The amplitude of the simulated TOF signal is obtained by integration of source function through the line, l:

$$S(t_d) = \int_l f(U,t)\,dl = \int f(U,t_d)\sqrt{1+L^2}\,dU \qquad (4)$$

Therefore, the final form of the equation describing the number of neutron, S that reaches the detector on the distance, L at the time, t_d is presented as follows:

$$S(t_d) = \int 4\pi \left(\frac{m}{2\pi kT} \right)^{\frac{3}{2}} \frac{1}{U^4} \exp\left\{ -\frac{m\left(\frac{1}{U} - V_{D-D} - V_{drift} \right)^2}{2kT} \right\} \exp\left\{ -\frac{\left(t_d - LU - t_0\right)^2}{\tau} \right\} \sqrt{1+L^2}\,dU \qquad (5)$$

Applying this procedure it is possible by picking up of initial parameters to deconvolute time resolved neutron spectra of the pulsed neutron source.

Results

On the Fig.1 the results of employing of the developed method to the measured at two different positions TOF spectra obtained on PF-6 are presented. Four distinct peaks are clearly distinguished. The parameters of these peaks are collected in a Table 1. Temperature of the neutron emission was difficult to evaluate by the fitting procedure because the emission time of the each peak cause considerably larger spreading of neutron spectra than due to expanding of the plasma and was set constant to all peaks.

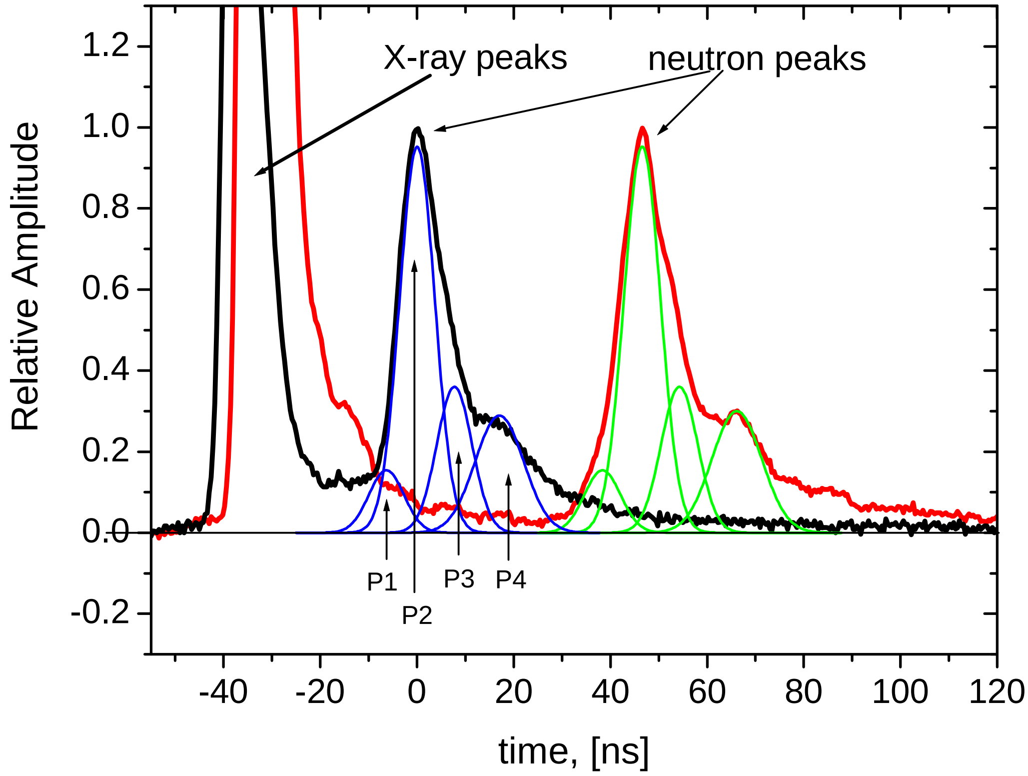

Fig. 1 Time-of-flight spectra measured at two different positions (black line - L_1=0.994m, red line - L_2=2.1m); deconvoluted partial fluxes of neutrons.

Table 1

T=1KeV	**Peak 1**	**Peak 2**	**Peak 3**	**Peak 4**
E_n, [MeV]	3.2	2.95	2.95	2.65
t_0, [ns]	-46.5	-41.8	-34.1	-27.1
t_{FWHM}, [ns]	8.3	8.3	8.3	11.6

The energy distribution of evaluated time profile is presented on Fig.2. Time-integrated measurement of the neutron yield provided by thermoluminescent dosimeters give value $Y_n=10^8$ neutrons in this pulse.

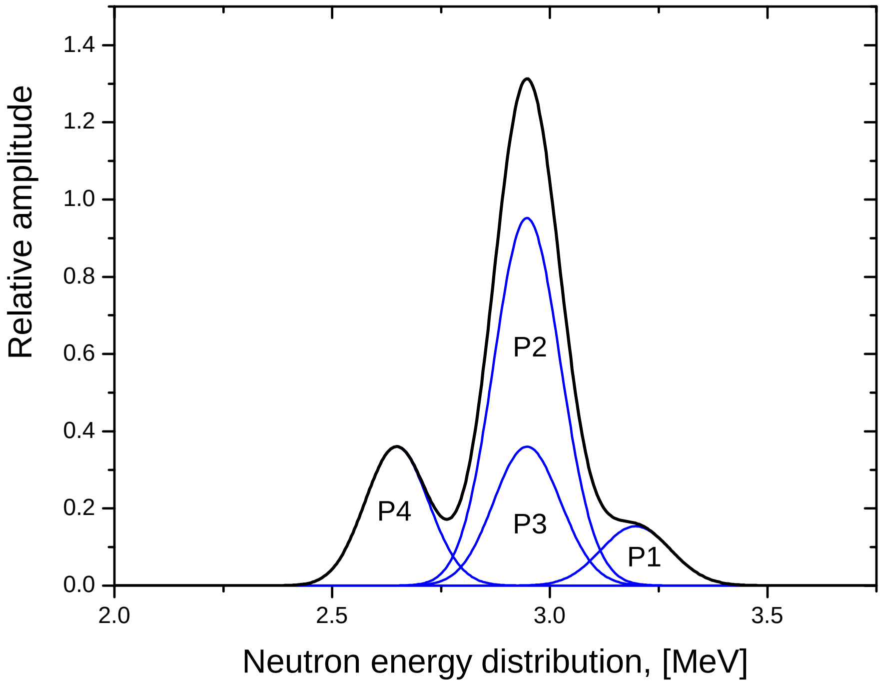

Fig. 2 Reconstructed energy distribution of the measured neutron TOF spectra.

Conclusions

In order to obtain information about the interaction processes in created by z-pinch plasma evaluation of the observed TOF neutron spectra is needed. It was demonstrated that analysis of TOF spectra by fitting procedure based on temporal Gaussian distribution of the neutron emission and on shifted-Maxwell velocity distribution of expanding neutrons seems to be resonable.

Acknowledgment

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