FAST DEUTERONS AND NEUTRONS
IN PLASMA FOCUS DISCHARGE

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Abstract

Recently the D-D reaction in the PF-1000 device at IPPLM Warsaw was studied with ten scintillation detectors placed at the distances between 7 and 85 m from the neutron source in both axial directions. The deuterons producing the neutrons have the energies in the range of 10 - 300 keV. The energy distribution of deuterons was calculated supposing both the axial motion of deuterons and the dense and hot spherical structure at the heel of the umbrella shape of the current sheath as a neutron source. A small part of neutrons, minimally 20% with energies in axial direction between 2.35-2.55 MeV, could be produced by the deuterons with isotropic distribution of velocities.

1. Experimental and diagnostic setup

The measurements were performed on the PF 1000 facility [1], which operated at the electrical energy of 500 kJ, the voltage of 27 kV, and the maximum current at about 1.8 MA.

The radiation in the range from visible to hard X-ray was measured with temporal, spatial, and energy resolution. We used the diagnostics similar to that described in [1]. We employed one soft X-ray microchannel-plate (MCP) detector, split into 4 quadrants. A PIN-silicon diode detected XUV-rays in the window of 200 to 300 eV and in the range above 600 eV. Four optical framing cameras imaged the intensity of bremstrahlung at the visible spectral window. A thin plastic scintillation detector, covered with a 10 μm thick Al foil filter, recorded soft X-rays (SXR) of energy above 5 keV. Plastic scintillation probes of 5 cm

thickness, equipped with fast photomultipliers detected the hard X-ray radiation (HXR) above a few hundred keV and neutron emission. The probes were situated downstream (at distances of 6.8 m, 16.3 m, 58.4 m and 84.2 m), upstream (at distances of 6.8 m, 16.3 m, 30.4 m, 44.2 m. 58.4 m and 84,2 m) and side-on (at distance of 6.8 m) and they were shielded from the scattered noise. For the neutron yield measurement, indium and silver activation counters were used.

2. Experimental results and discussion

The presented results were obtained from the detail analysis of signals recorded mainly in the shot No. 6540 with the total neutron yield amounting $7x10^{10}$. The time of production and energy distribution of neutrons were calculated using Monte-Carlo simulations and the time-of-flight method (K. Rezac in this proceedings).

In Fig. 1 we can see the energy distribution of neutrons simulated from the signals recorded in all axial detectors. Dominant part of deuterons producing neutrons had dominant axial component of their velocity downstream (above 2.45 MeV).

In Fig. 2 one can see the signals of scintillation detectors registered in distances 6.84 m downstream, upstream and side-on and the dominance of the fast deuteron velocities downstream, especially in the second neutron pulse.
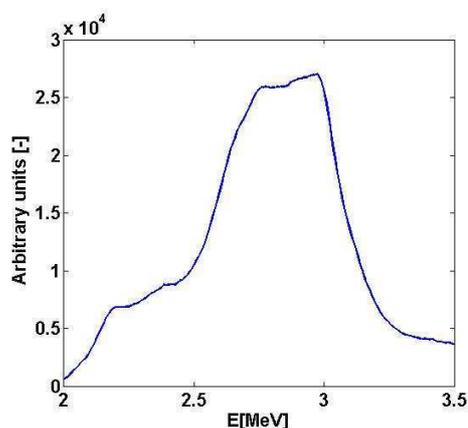

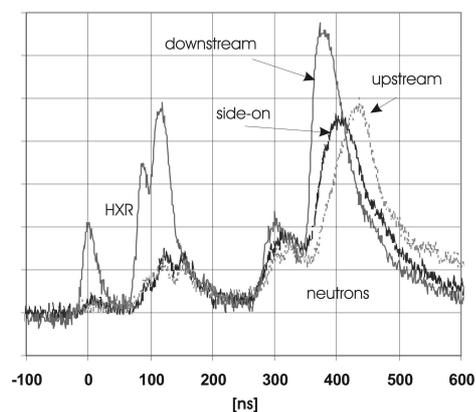Fig. 1: Shot 6540. Energy distribution of neutrons in the direction downstream

Fig. 2: Shot 6540. Signals of scintillation detectors registered at 6.84 m downstream, side-on and upstream

We can discuss the energy distribution of deuterons supposing the existence of the axial deuteron velocity component only. The number of deuterons is strongly influenced with the cross-section of D-D reaction. The neutrons with energies in the range of 2.55 – 3.2 MeV are

produced with deuterons of 10 - 300 keV energies moving downstream and the neutrons with energies 2.0-2.35 MeV with deuterons of 10 - 250 keV energies moving upstream. We can estimate the mean free path of D-D reaction λ_{DD} for the cross-section $\sigma(E_D)$ [2] using the equation $\lambda_{DD} = 1/n_i\sigma(E_D)$, where E_D is energy of deuterons and n_i is the deuteron density of the target (neutron source). Then we can calculate the energy distribution of fast deuterons for the probability of D-D reaction $p_{DD} = l/\lambda_{DD}$ (l is the length of the target) knowing the neutron energy distribution function and the dimension and the density of the target.
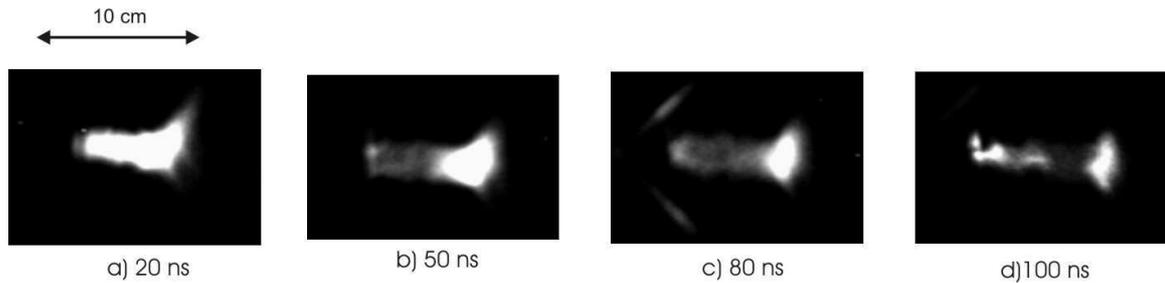

Fig. 3: Shot 5071. XUV frames of the dense and hot structure at the heal of the current sheath

The time of neutron production corresponded to the formation of the dense like spherical structure imaged in Fig. 3 and described in [1,3,4]. We can calculate, if this dense and hot structure may be the spatial source of the neutrons. Visible and XUV frames showed the evolution of the stagnated plasma. During $0 - 70$ ns the cylindrical structure of the hot and dense plasma was transformed into spherical. This locality with intense radiation had temperature above 10 eV (threshold of the sensitivity of the soft X-rays MCP) and electron and ion density above 10^{25} m^{-3} [4,5]. Its left boundary moved axially from the anode with the velocity of 10^6 m/s, which corresponds to 10 keV deuteron energy (Figs. 4 a,b,c). The structure was located at the heel of the umbrella shape of the current-sheath and it lasted for life-time up to 150-200 ns. Using $n_i = 2\times10^{25}$ m^{-3} and $l = 2$ cm we obtained the dependence presented in Fig. 4. In this figure we can see, that the number of fast deuterons monotonically increases with decreasing deuteron energy downstream as E^3 and upstream as E^4. The deuterons with energy below 10 keV do not take part at the D-D reaction (in this case their number should overcome the real number of particles in the pinched column 3×10^{20}). The neutrons in the energy range of 2.35-2.55 were generated by the fast deuterons with important radial velocity component.
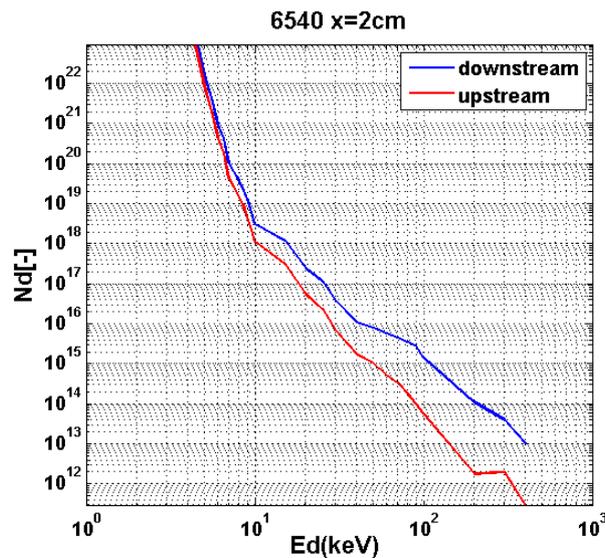
Fig. 4: Shot 6540. Energy distribution of fast deuterons downstream (up) and upstream (down)

3. Conclusions

In this paper we estimated the distribution of velocities of fast deuterons from energy distribution of fusion deuterons in typical shot at the plasma focus device PF 1000. 70% of deuterons had dominant component downstream and 10% upstream both in energy range of 10-300 keV. Minimally 10% of detected neutrons can have a dominant component of radial velocity. The number of fast deuterons monotonically increased with decreasing deuteron energy and the neutrons are produced only by deuterons with energy above 10 keV.

Acknowledgements

References

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[2] http://www.fusionnow.org/dolan.html, chapter 2, p 28.

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