DD FUSION PRODUCTS MEASUREMENTS ON T-10 TOKAMAK

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For measurements of fluxes and energy spectra of charged fusion products (CFP) from DD reaction in T-10 Tokamak (R_0 = 150 cm, a_L = 32 cm) the silicon diode (SD) was used located close to bottom plasma edge [1]. The detector surface was covered with a thin light absorbent film from tungsten and aluminum which practically does not distort energy distribution of the detected CFP (1 MeV tritons and 3 MeV protons). The SD was placed in the body made from tungsten alloy (80% of W) for it protection from hard X-rays (Fig. 1). CFP come into detector after the collimator with effective aperture $\Delta\alpha_{det} = \pm 7°$. To measure the fusion yield, a set of ten neutron monitors was used based on helium and boron counters.

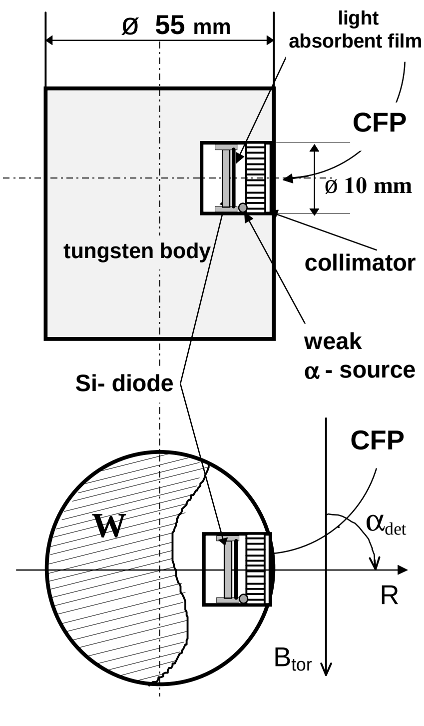

Fig. 1. Schematic view of the CFP detection unit.

The measurements have been performed in the regimes with B_{tor} = 2.2÷3.0 T, I_p = 200÷360 kA, $\langle n_e \rangle = (2÷5)\cdot 10^{13}$ cm^{-3}, total neutron yield - up to $8\cdot 10^9$ per shot.

Temporal behavior of proton and triton signals was in good correlation with neutron emission and demonstrated the cooling and heating of ions at low and high electron density during ECRH.

The neutron sawtooth oscillations were first observed in the T-10 whiles only weak indication of sawtooth was presented on CFP signals because of poor statistics (Fig. 2).

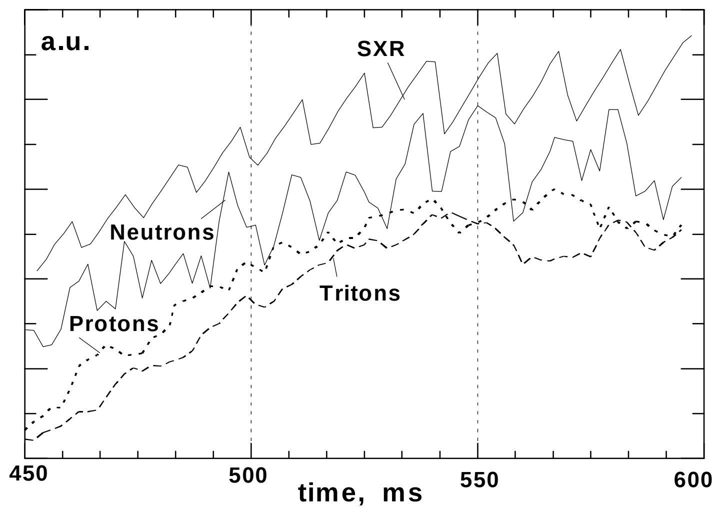

Fig. 2. Sawtooth oscillations on SXR, neutrons, protons and tritons signals.

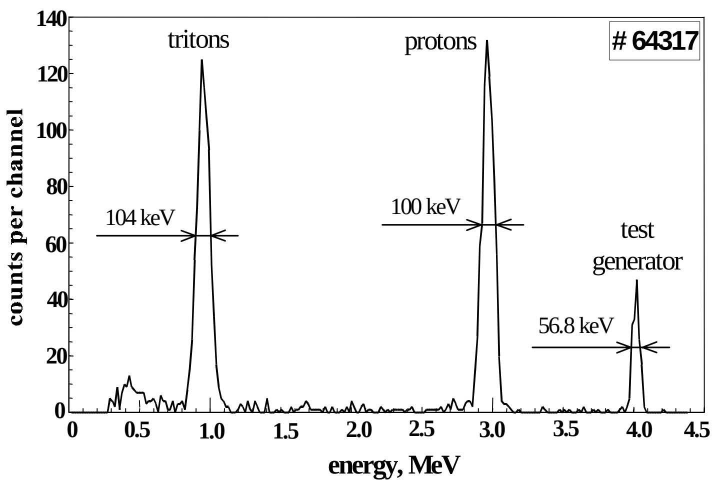

Fig. 3. Fusion products energy spectra measured during 0.1 s in the regime: B_{tor} =2.6 T, I_p = 250 kA, $<n_e>$ = 5.4·10^{13}

The main goal of experiments was to measure the ion temperature T_i from Doppler broadening of CFP spectra and estimation of ion temperature profile.

Figure 3 presents the CFP energy spectra measured during 0.1 s at the steady-state phase of the T-10 shot. Energy scale of amplitude analyzer equals 17 keV / channel. The broadening of test generator line (56.8 keV) characterizes the input of electronics noise to the spectrometer energy resolution. It was taken into account as well as the SD own resolution (~10 keV) to obtain the value of ion temperature according to

$$FWHM[keV]=91.3\cdot(T_i\ [keV]\ )^{1/2}.$$

For this particular shot the value of T_i was estimated as 0.81±0.07 keV.

To assess the spatial distribution $T_i(r)$, the "detector-DD source" geometry was changed by two techniques: a) the rotation of detector, and b) the displacement of plasma along major radius.

In the case (a) the measurements of CFP flux were made at a few detector orientation α_{det} relative to toroidal field B_{tor} (Fig. 4), namely at α_{det}=90°, 77°, 65° and 40°. The data for additional angles of α_{det}=103° and 115° were obtained by means of inversion of plasma

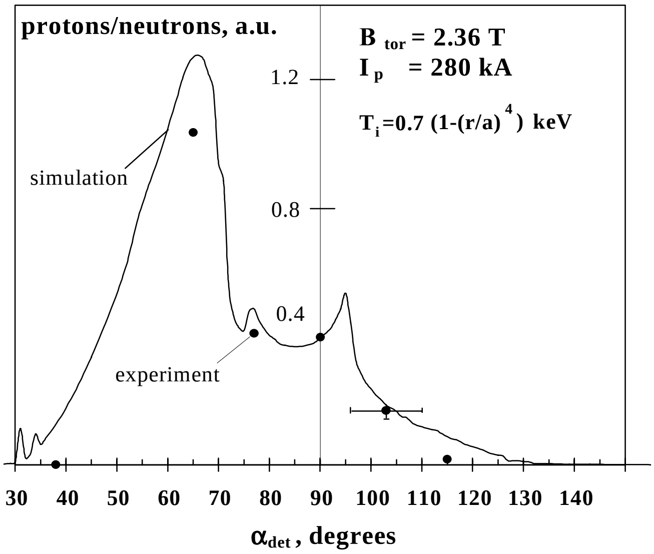

Fig. 4. 3 MeV protons flux versus detector orientation angle. Experimental points and calculated curve are fitted at α_{det} = 90°.

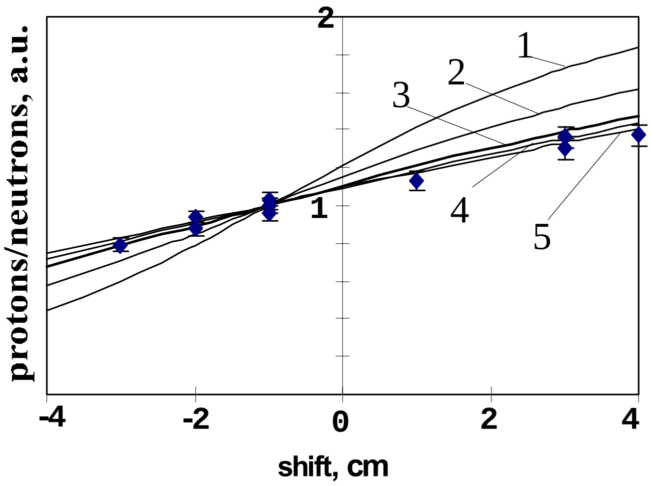

Fig. 5. 3 MeV protons flux versus plasma radial shift : points - experimental results, solid lines - numerical simulation for different profiles $T_i(r)$:

1- $T_i(r) \sim (1 - x^2)^2$, **2-** $T_i(r) \sim (1 - x^2)$, **3-** $T_i(r) \sim (1 - x^4)$, **4-** $T_i(r) \sim (1 - x^4)^2$, **5-** $T_i(r) \sim (1 - x^4)^{1/2}$, where $x = r/a_L$. Measured points and calculated curves are fitted at shift = -1 cm.

current direction with detector angle α_{det} =77° and 65° respectively. The localized, "banana" and passing particles are detected depending on the angle α_{det}.

In the case (b) the detector was permanently oriented perpendicular to the toroidal field and, hence, it measured mainly localized CFP. The plasma radial shift (for example, inward) results in the detector "sight line" which depends on magnetic configuration only will see another (outward) DD source region. The steeper $T_i(r)$ the more strong dependence of measured CFP flux on the plasma shift. First this idea was realized on PLT [2]. Fig. 5 presents the results obtained.

For the interpretation of the experimental data the orbits of measured CFP were calculated taking into account the magnetic field ripples. The results of calculations are also shown in Figs. 4 and 5. Several $T_i(r)$ profiles were used for these simulations while the central temperature $T_i(0)$ was fixed. The best agreement between the experimental data and results of simulations was achieved for $T_i(r)$ profile with rather flat peak, like $(1-(r/a_L)^4)^k$, where k = 0.5÷2.

A new method is proposed to measure angular distribution of CFP by means of an only spectrometric detector. For this purpose several collimators oriented at different angles may be installed in front of the detector. Thus it will measure 3 MeV protons with selected pitch angles simultaneously. To distinguish them every collimator is provided with an individual proton moderator. Then the additional shifted peaks of protons should appear according to slowdown of particles. This approach is more beneficial than the use of several separate detectors and spectrometric circuits.

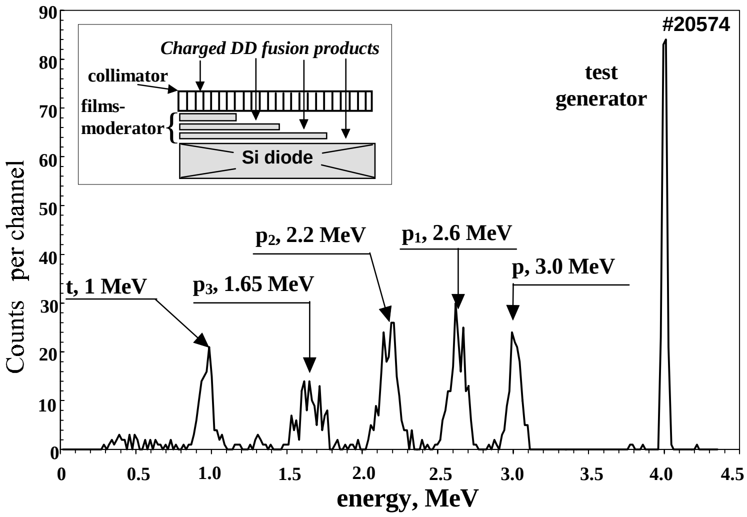

Fig. 6. Charged fusion products energy spectra measured with Al-moderators during 0.1 s in the regime: B_{tor} =2.65 T, I_p = 290 kA, $<n_e> = 4.3{\cdot}10^{13}$ cm^{-3}.

To test this idea experimentally the detector surface was partially covered with Al films with thickness of 20, 40 and 60 μm. The collimator was single for all films. The measured energy spectra are shown in Fig. 6. The new peak locations are in good agreement with the calculated energy loss of 3 MeV protons in the films.

Acknowledgments

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References

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[2] W.W. Heidbrink, J. Lovberg, J.D. Strachan, and R.E. Bell: Nucl. Fusion **27**(1), 129, 1987.