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** See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2002 (Proc. 19th IAEA Fusion Energy Conference, Lyon (2002).*

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INTRODUCTION

At present the number of large and compact neutron spectrometers is under development for application in fusion plasma experiments. Compact neutron spectrometers have a very high potential to be used in future fusion devices, and in ITER in particular, due to their ability to be placed inside narrow collimators of multi-channel neutron cameras providing the spatially resolved neutron spectrometry. Stilbene neutron detectors were successfully used for D-D neutron flux measurements on Tore-Supra and JT-60U [1,2] and neutron spectrometry and flux measurements on neutron generators. Results of measurements of DD and DT neutron spectra using compact stilbene neutron detector during 2003 Trace Tritium Experiments (TTE) at JET are presented in this paper.

1. EXPERIMENTAL ARRANGEMENT

1.1 STILBENE NEUTRON SPECTROMETER CHARACTERISTICS AND ARRANGEMENT AT JET

A stilbene is organic scintillator crystal ($C_{12}H_{14}$), which is widely used for fast neutron detection. The neutron flux and spectrum measurement is based on proton recoil detection in the stilbene crystal. Stilbene demonstrates very effective pulse shape discrimination property and could provide effective γ-ray suppression up to 10^{-3} that is strongly necessary for DD neutron spectrometry [1]. The neutron detection efficiency depends on the Stilbene crystal volume and are in the range $10^{-2} \div 10^{-1}$ for crystals with thickness 0.5÷6.3cm.

A stilbene neutron detector with crystal Ø30×30mm was specially developed for neutron measurements during the TTE campaign at JET. The detector efficiency and energy resolution were previously calibrated with a deuterium-tritium neutron generator. High performance for DT neutron measurements was demonstrated: neutron energy resolution – 300keV; detection efficiency – 3×10^{-2}. The stilbene detector was installed on a vertical line of sight from a distance ~ 20 meter far JET equatorial plain, behind a 2 meter collimator arranged in the torus hall roof (fig.1). Mainly perpendicular neutrons from the centre of JET plasma were measured in the present arrangement.

Stilbene detectors can be used for wide neutron energy range measurements allowing to measure DD and DT neutron flux simultaneously as it is shown in fig.2.

1.2. JET EXPERIMENTS WITH APPLICATION OF STILBENE NEUTRON SPECTROMETER

Installation of a stilbene spectrometer behind a perpendicular vertical collimator provided a useful information in a number of JET experiments during TTE campaign in 2003, including studies of:

1) fundamental tritium minority ion cyclotron resonance frequency (ICRF) heating at f = 23MHz in plasma configurations with B_t = 3.9T (resonance layer at R = 2.56m) and with 4.0T (resonance layer at R = 2.61m), I_p = 2.5 MA, $n_e = 2.3 \div 3.3\times10^{19}$ m^{-3}, T_e = 2.5÷4.5keV;

2) second harmonic tritium heating at B_t =3.7 T, I_p = 2MA, f = 37MHz.

2. RESULTS OF DT NEUTRON MEASUREMENTS

Perpendicular DT neutron spectra measured by stilbene neutron spectrometer during JET experiments with tritium gas puffing, tritium minority and second harmonic ICRH are shown in Figs.3 and 4. During second harmonic tritium ICRH with the same P_{ICRH} =4.5MW the full width at half maximum (FWHM) of measured perpendicular DT neutron spectra was higher (870±50keV) in the case of dipole (Pulse No: 61444) than $+90^{o}$ (Pulse No: 61445) wave phasing (630±50keV). Figure 4 illustrates that during tritium minority ICRH the FWHM of perpendicular DT neutron spectrum was higher (1270±60keV) in the case of higher P_{ICRH} = 1.4MW and resonance layer position at R = 2.61m (B_t = 4.0T, Pulse No: 61449) than (1140±60keV) in the case of lower PICRH = 1.2 MW and strongly shifted from the axis resonance layer position at R = 2.56 m (B_t = 3.9T, Pulse No: 61446). In all these experiments DT neutrons were produced in reactions of resonant, fast, strongly anisotropic tritons with relatively cold deuterons. In such a case the values of FWHM are determined by the perpendicular effective temperature of resonance tritons, T_T: FWHM = 178×SQRT((3×T_T + 2×T_D)/5) = 138×SQRT (T_T). Using this relation it was determined that the effective perpendicular triton temperatures T_T were equal to: 85keV (Pulse No: 61449), 68keV (Pulse No: 61446), 40keV (Pulse No: 61444) and 21keV (Pulse No: 61445).

Time window (300ms) of the stilbene detector data acquisition system was chosen for its spectrometry application to provide good statistics. An example of the stilbene detector application for DT and DD neutron flux measurements with this time resolution is shown in Fig.5 in comparison with data obtained by Si-diodes and fission chambers. Good agreement was found even with this long time window, which could be essentially diminished in future.

CONCLUSIONS

Neutron flux time evolution and neutron spectra measurements with a stilbene detector have been performed during TTE JET campaign. Fast triton energy for ICRH heated plasma has been evaluated from the neutron spectra.

With the current detector settings in JET roof laboratory, a stilbene neutron spectrometer could be used for analysis without deadtime correction and pulse shape discrimination for shots with neutron yields up to $Y_n < 4\times10^{16}$ n/shot.

The use of a stilbene detector for fusion neutron measurements at JET gave an indication on the major future requirements of the method: more modern approaches to the fast neutron measurements (advanced PMT, PMT gain stabilisation, listing ADC) and the development of digital pulse shape discrimination system with fast ADC.

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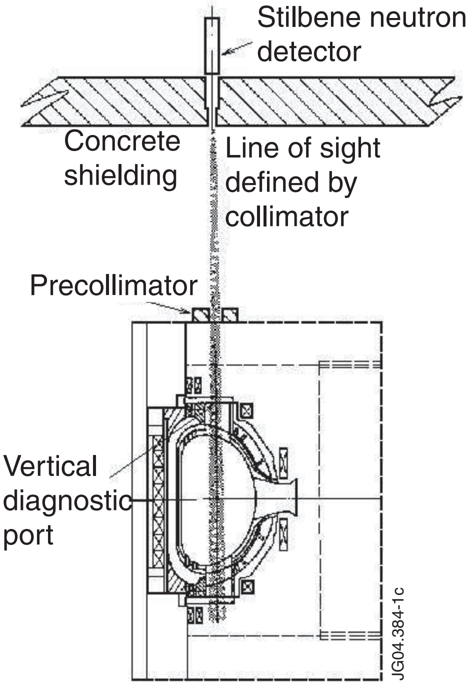


Figure 1: Stilbene neutron detector installation at the JET roof laboratory.

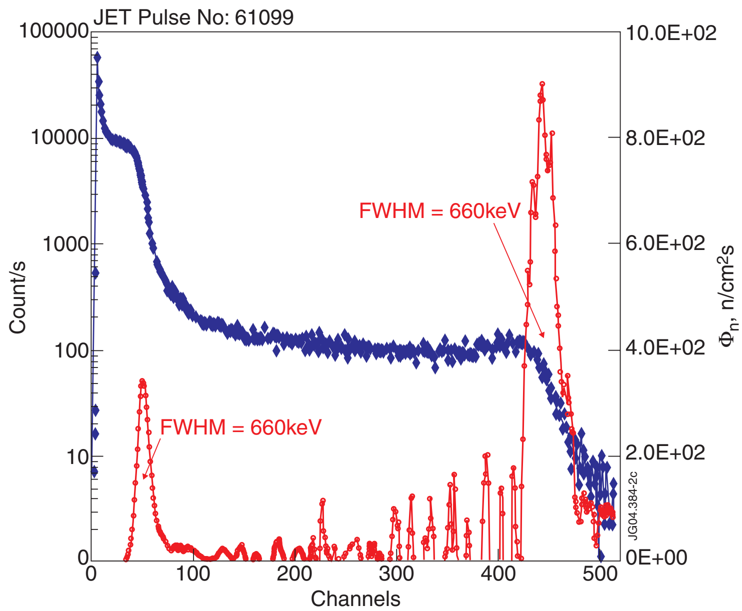
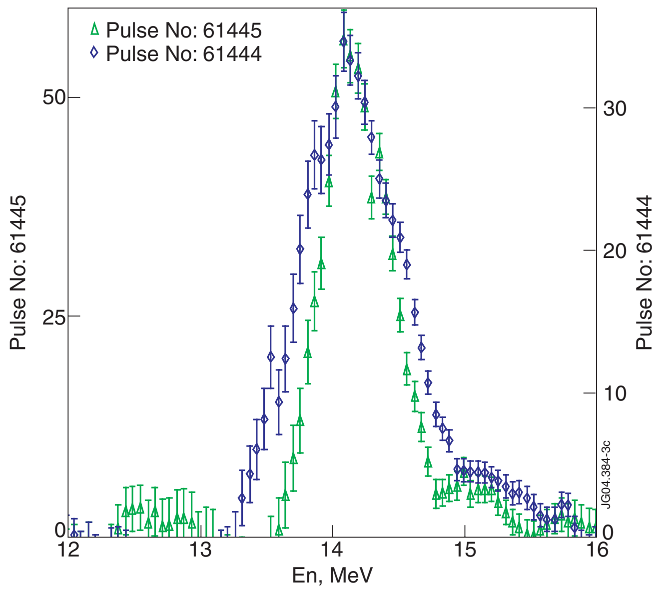


Figure 2: Simultaneous measurements of DD and DT neutrons during JET Pulse No: 61099. Pulse height raw data is in blue, the unfolded energy spectrum is in red.



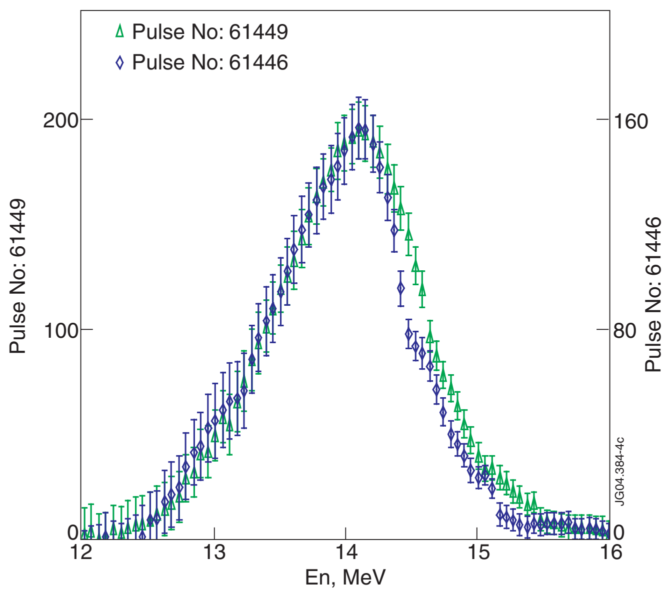
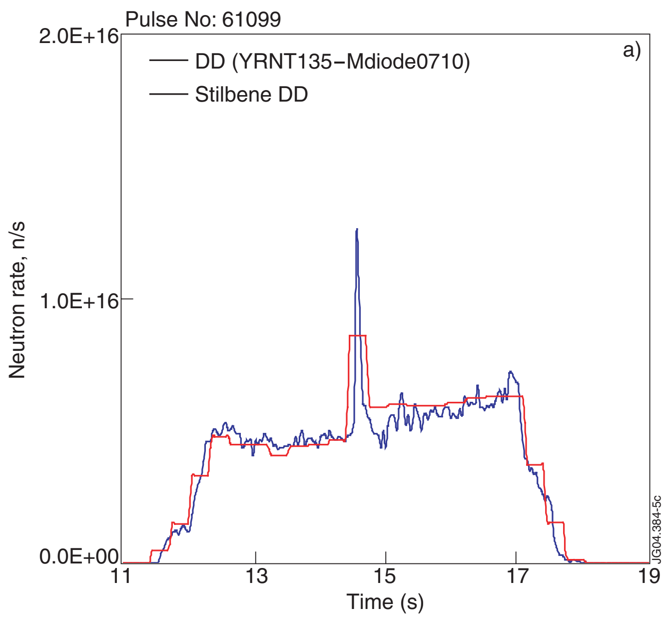


Figure 3: Neutron spectra measured during JET T-puff shots with ICRH ($2\omega_T$), P_{ICRH} = 4.5MW with dipole (Pulse No: 61444 (blue)) and +90^o (Pulse No: 61445 (green)) wave phasing.

Figure 4: Neutron spectra measured during JET T-puff shots with tritium minority ICRH (ω_T) at P_{ICRH} = 1.2MW, B_t = 3.9T (Pulse No: 61446 (blue) and P_{ICRH} = 1.4MW, B_t = 4.0T (Pulse No: 61449 (green))



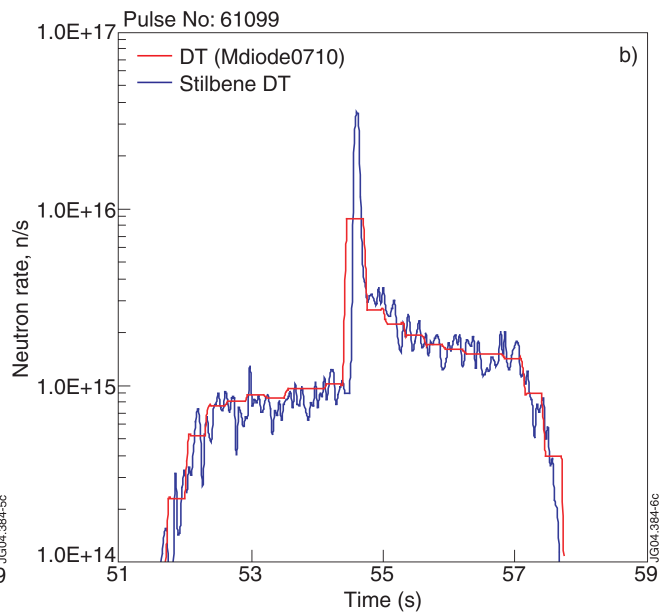


Figure 5. 2.5MeV (a) and 14MeV (b) neutron flux evolution measured with the stilbene detector (red) and with basic JET neutron diagnostics (blue). DT neutron flux was measured with Si-diodes. DD neutron flux was founded as a difference between fission chamber and Si-diodes data [4].