EFDA–JET–CP(04)02-04

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Fusion Energy 2002 (Proc. 19th IAEA Fusion Energy Conference, Lyon (2002).

Preprint of Paper to be submitted for publication in Proceedings of the
23rd SOFT Conference,
(Venice, Italy, 20-24 September 2004)

ABSTRACT.

During the JET Trace Tritium campaign a few new neutron diagnostic systems were deployed under different plasma scenarios to provide information on the total neutron emission and its spatial and energy distribution. The 14MeV neutron yield was measured with a Chemical Vapour Deposited (CVD) diamond detector. Comparison with the JET 14MeV monitors (Si diodes) illustrates the good performance of the CVD device. Key information on the tritium transport and the behaviour of fast particles in the plasma was obtained from the spatially and temporally measurements of neutron emission from the Upgraded Neutron Profile Cameras which also provide an independent measure of the total neutron yield. Spatial asymmetries in the neutron emission were observed which is evidence for the influence of fast particles on the plasma. With regard to the energy distribution of the neutron emission, a spectrometer based on a liquid organic scintillator with n-γ Pulse Shape Discrimination (PSD) features was installed. The results demonstrate that such system can operate in real fusion experiments as compact broadband neutron ($1.5\mathrm{MeV}<E_n<20\mathrm{MeV}$) spectrometer with high energy resolution. A fast transient recorder has been successfully applied for Digital Pulse Shape Discrimination (DPSD) of neutron and gamma events acquired with an organic scintillator at high count rate operation (MHz range). The experience gained at JET indicates that these neutron measurement systems are suitable for large fusion devices such as JET-EP and ITER where fusion neutron diagnostics will play an increasingly important role.

1. INTRODUCTION

The Trace Tritium Experiment (TTE) was performed at JET in 2003 aimed at tritium transport studies, investigation of the fast particle influence on the plasma and new heating scenarios [1-3]. The TTE campaign was also devoted to the development and testing of new diagnostics for possible application on JET-EP and ITER [4]. Few new neutron detection systems were installed at JET and operated under different plasma scenarios in order to measure the 14 MeV neutron emission and its spatial and energy distributions.

2. NEUTRON YIELD - 14 MEV MONITORS

The monitors of the 14MeV neutron yield need to be resilient to nuclear radiation damage, particularly for ITER. At JET Si diodes are used for detection of DT yield but the neutron radiation damage limits the operation of these monitors to a total neutron fluence of 10^{12} n/cm^2, requiring a periodic replacement.

A Chemical Vapour Deposited (CVD) diamond detector (3mm^2 by 0.13mm) was for the first time installed at JET and operated during the whole TTE campaign, aiming to determine its reliability and stability in a tokamak environment [5]. This new DT monitor makes use of Carbon reactions and its advantages are high radiation hardness up to 10^{14}-10^{15} n/cm^2 and lower sensitivity to X-ray and gamma radiation.

The operation of the CVD monitor turned out to be quite satisfactory showing a linear response both in term of total DT yield and time dependent DT neutron rate (Fig.1). Measurements were carried out for JET DT yields in the range from $1 \cdot 10^{15}$ to $6 \cdot 10^{16}$ with a statistical uncertainty from 10% to 3%. Good agreement was found between the CVD detector and the JET Si diodes [6] showing the capability of this new class of detectors to withstand the tokamak environment and to operate satisfactorily.

3. NEUTRON SPATIAL DISTRIBUTION

The neutron emission profile diagnostic played a key role in many TTE experiments [7-9] This system was in operation during the 1997-DT1 [10] as well as during previous EFDA-JET campaigns. The neutron profile monitor consists of two fan shaped arrays of collimators, of which ten lines of sight cover the horizontal and another nine lines the vertical plasma cross section. Each line of sight comprises three detection systems: 1) a NE213 liquid scintillator (Φ 25mm by 10mm) with Pulse Shape Discrimination (PSD) electronics for simultaneous recording of the 2.5MeV, 14MeV neutron and gamma emission; 2) a BC418 plastic scintillator (Φ 15mm by 10mm), fairly insensitive to gammas with E_γ<10MeV, for the 14MeV neutron measurements only; 3) a CsI(Tl) detector (10×10×15mm) for measuring the gamma emission, within the energy range of 0.2 - 6MeV [11]. The neutron profile monitor also provides an independent measure of the total neutron yield where good agreement has been found with the JET Silicon 14MeV monitors [6].

Tritium transport features were investigated in different plasma scenarios [7]. Figure 2 shows the large increase of the DT neutron emission profile after a tritium gas puff in the “hybrid scenario” plasma Pulse No: 61161 where the neutron emission centre follows the magnetic axis.

Within the experiments on new heating schemes and fast particle physics, clear evidence of spatial asymmetries in the neutron emission was observed in the vertical camera measurements. In the Tritium fundamental RF heating scenario [8] (a possible ITER heating scheme) the 14MeV neutron emission axis is not located along the magnetic axis but it is shifted towards the high field side near the T cyclotron resonance layer, located at R=2.55m (Fig.3).

Off- and On- axis tritium beams in strong reverse shear plasmas were used as fast probe particles for studying the effect of current holes on the confinement of fast particles. An outward or inward displacement of the neutron emission from the magnetic axis was also detected for On- and Off-axis beam injection respectively, indicating the effect of orbit distortion due to the low poloidal field in such plasmas in [9].

4. NEUTRON ENERGY DISTRIBUTION

Compact broadband neutron spectrometers based on scintillators with Pulse Shape Discrimination (PSD) features have been considered as possible diagnostic systems for large devices such as ITER [12].

Measurements with NE213 liquid scintillators were successfully carried out at JET during the 2002 DD campaigns and during TTE, aiming to determine the energy resolution at 2.5MeV and 14MeV neutron energy of such a compact spectrometer in a real fusion experiment [13]. One NE213 spectrometer had been fully characterized for neutron (1.5MeV < E_n < 20MeV) detection at the

Physikalisch-Technische Bundesanstalt accelerator facility [14]. A detailed knowledge of the detector response function was determined using MonteCarlo programs based on measured photon and monoenergetic neutron data. New methods of data analysis based on Bayesian methods, L-curve techniques and Maximum Entropy unfolding have been developed. Pulse height spectra were acquired from different plasma heating scenarios (Ohmic, Neutral beam and RF heating). During the 2002 campaign peaks with width of ~ 110keV at E_n = 2.5MeV (corresponding to a $\Delta E/E < 4\%$) have been resolved in neutron unfolded spectra of ohmic DD plasmas. From TTE-DT ohmic plasmas peak widths of ~ 250keV at E_n = 14MeV (DE/E <2%) have been resolved. These values therefore provide an indication of the upper limits of the energy resolution.

Table 1 reports the NE213 peak widths (FWHM) of TTE ohmic plasmas spectra simultaneously acquired at 2.5MeV and 14MeV energy. The expected widths from independent ion temperature data performed with the Charge-exchange diagnostic are also reported for comparison, finding quite satisfactory agreement.

By considering these FWHM values one obtains as upper estimate of the ion temperature respectively 2.4keV and 2.2keV which lie in the range of the CX ion temperature measurement.

5. DPSD TECHNIQUE

The advent of A/D fast transient recorders allows the direct digitization of detector signals and the unique possibility of post-experiment data reprocessing. At ENEA-Frascati a Digital Pulse Shape Discrimination (DPSD) system was developed for high count rate operation and n/γ discrimination with organic scintillators [15]. The system is based on a fast digitizer (12-bit, 200MHz sampling rate and 256 Msamples on-board memory). Various data recording modes are possible and dedicated software programs have been developed for data treatment and analysis. An NE213 scintillator was installed in the JET roof lab and connected to the DPSD hardware. Measurements were carried out during TTE with satisfactory performance of the DPSD system: total count rates up to MHz level were detected as well neutron and gamma pulse height spectra were acquired (up to 300kHz) under different plasma scenarios [16].

CONCLUSIONS

New neutron diagnostics were deployed at JET during the 2003 TTE aiming to validate these new systems as candidate diagnostics for ITER and JET-EP. As a DT neutron yield monitor the CVD diamond detector can be reliably applied. Data from the upgraded neutron profile monitor have shown spatial asymmetries in the neutron emission during different plasma scenarios. The importance of this diagnostic system, particularly of the vertical camera, has demonstrated its essential role in plasma phenomena studies for ITER and its potential for ITER itself. It has also been clearly demonstrated that liquid organic scintillators (NE213) can operate in a real fusion experiment as compact broadband neutron spectrometers with high energy resolution. A digital pulse shape discrimination system has been successfully applied to a NE213 scintillator for neutron emission counting as well for simultaneous neutron and gamma pulse height spectroscopy at high count rate regime.

The experience gained at JET indicates that these new neutron diagnostic systems operate reliably contributing with essential information to the operation and physics of DT plasmas. However further R&D activity is necessary for a complete assessment of the diagnostic capabilities of such systems within the prospective of their use on JET-EP and ITER where fusion neutron diagnostics will play an increasingly important role.

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	NE213	CX T_{ion} = (2.0 ± 0.2) keV
FWHM $_{2.5\ MeV}$	(128± 10) keV	(117 ± 6) keV
FWHM $_{14\ MeV}$	(260± 100) keV	(250 ± 12) keV

Table 1:
NE213 measured widths (FWHM) and expected widths (FWHM) from independent Charge-exchange (CX) ion temperature data

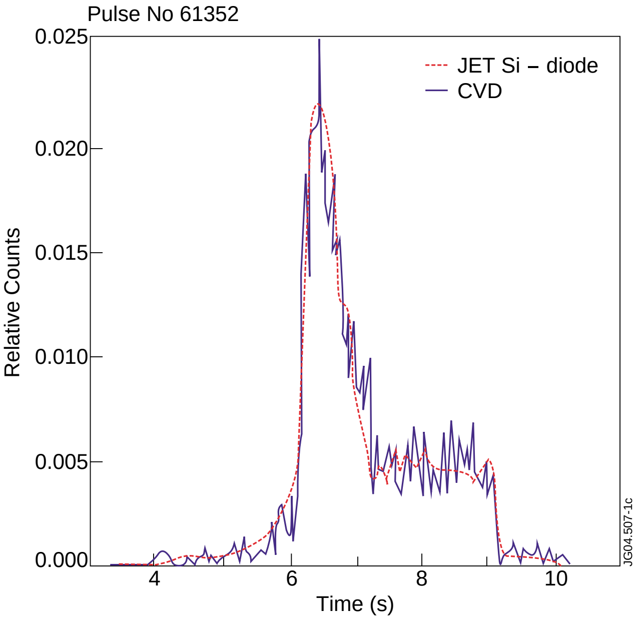

Figure 1: 14MeV - Time traces of CVD Diamond detector and JET Silicon diodes.

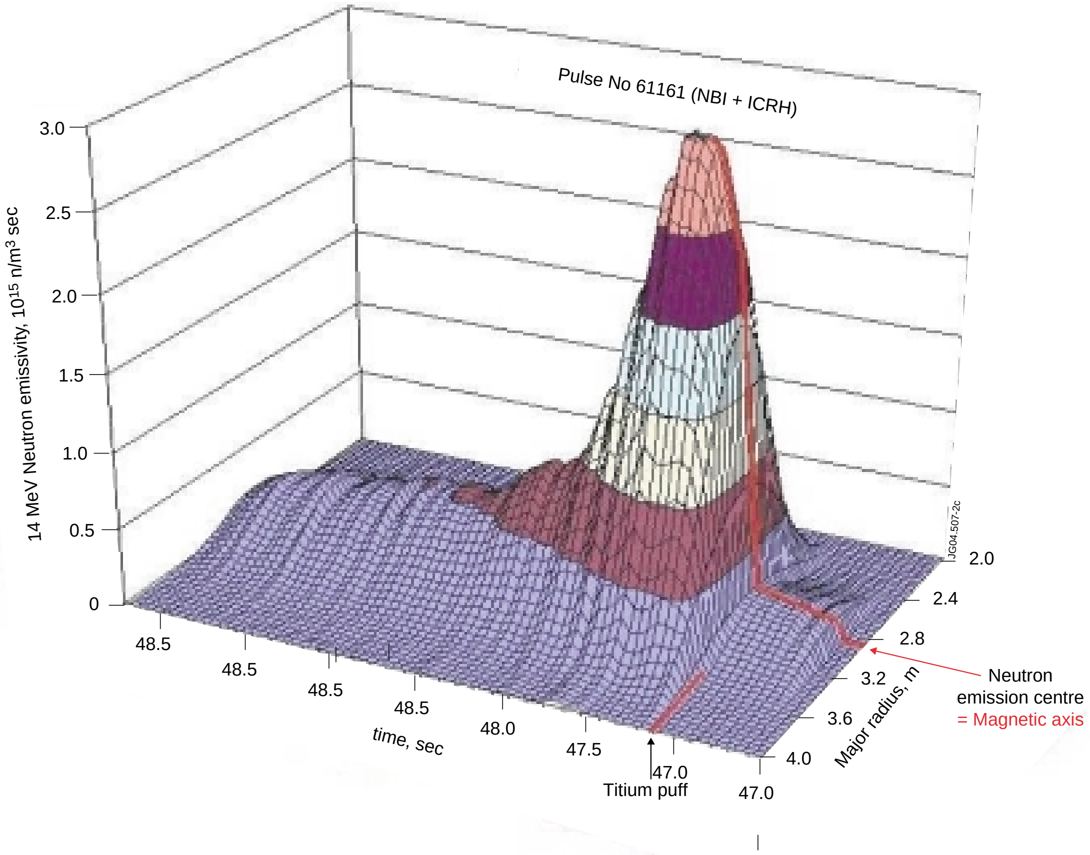

Figure 2: Time evolution of the 14 MeV neutron profile of the “hybrid scenario” plasma discharge 61161.

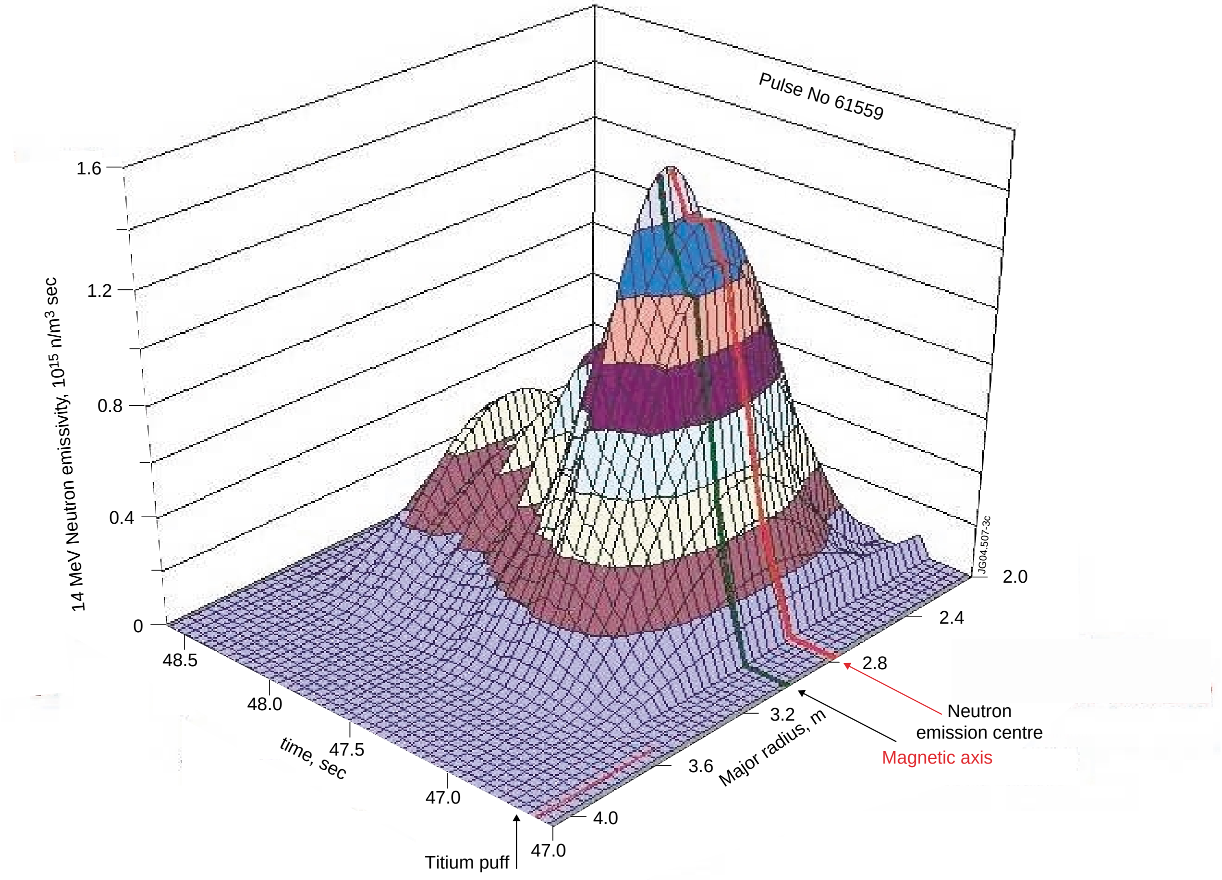

Figure 3: 14MeV neutron profile measured during ICRH Tritium fundamental heating showing that the neutron emission centre is shifted to the high field side with respect to the magnetic axis.