*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-5.173 (2004)*

Performance of Neutron Measurements during Trace Tritium Experiments on JET

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INTRODUCTION

The introduction of trace amount (n_T/n_D<5%) of tritium into DD plasma provides a unique opportunity to study plasma effects as well as tritium transport under different conditions. Such kind of studies have been carried out at JET during DTE1 [1] and also successfully performed in the Trace Tritium Experimental campaign (TTE) in 2003 [2,3,4]. One of the main tools for these studies is the JET neutron diagnostics.

A comprehensive range of JET neutron diagnostics was deployed for TTE. The total (2.5 and 14 MeV) neutron emission from plasmas was determined using three pairs of fission chambers (U^{235} and U^{238}). A set of silicon diodes, Chemical Vapour Deposited (CVD) and Natural diamond (NDD) detectors was used to measure the 14 MeV neutron emission. The neutron emission profile monitor provided a simultaneous measurement of the line-integrated 2.5 MeV and 14 MeV neutron emissions, with temporal and spatial resolution. The absolute calibration of all detectors relied on a cross calibration with the neutron activation system.

NEUTRON YIELD MEASUREMENTS DURING TTE

At JET the instantaneous total neutron yield is measured with three sets of fission chambers arranged around the machine. Each set comprises a U^{235} and U^{238} chambers operating in pulse-counting and current mode [5]. Together, the two types of chambers allow reliable detection of the neutron emissions from 10^{10} to 10^{20} n/s.

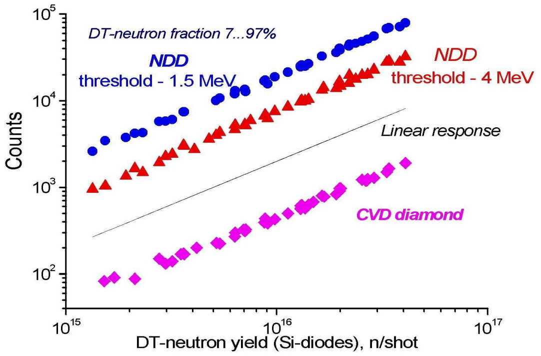

Fig. 1. NDD and CVD Diamond detectors response to Tritium JET shots ## 61084-61236

The utilization of $^{28}Si(n,p)$ and $^{28}Si(n,\alpha)$ threshold reactions in Silicon diodes for 14 MeV neutron flux measurements was pioneered at JET in 1987 [6] and since then it is one of the most satisfactory tools for this purpose. Four Si diodes with different surface area were installed in different locations at JET during TTE 2003 allowing the 14 MeV neutron rates from 10^{13} n/s up to 10^{18} n/s to be measured. The procedure to merge signals from all diodes has been implemented. DT neutron yield monitors based on diamond detectors were also operating in good compliance with the Silicon detectors. For the first time a CVD diamond detector [7] as a 14 MeV neutron monitor was successfully tested at JET during TTE, showing excellent correlation with Si diodes as well (fig. 1).

The absolute calibration of all neutron monitors mentioned above was derived from activation measurements [8]. The 14 MeV neutron yield was simultaneously measured using iron and silicon samples. The calibrations of Silicon diodes were then obtained by a comparison of these results with the counting recorded by the Silicon diodes (fig.2). For 2.5 MeV neutron fluence measurements, the counting of beta-delayed neutrons from fission events in ^{232}Th and gamma radiation from indium samples was usually used. Both measurements were in an excellent agreement (fig.3).

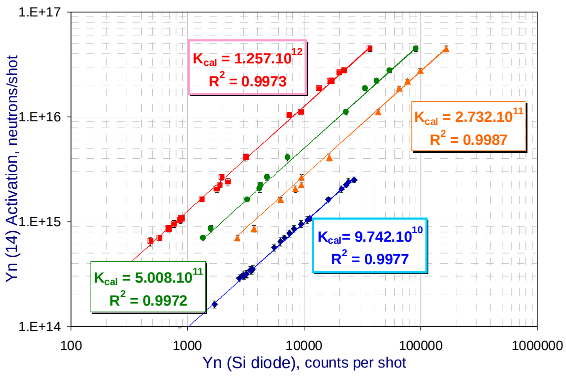

Fig. 2. Calibration factors for four different Silicon diodes (DT neutron monitors) derived from activation measurements.

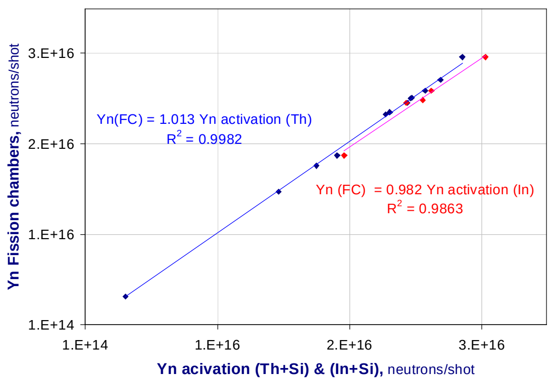

Fig. 3. Cross calibration of fission chambers against activation system for DD plasma: in red - Indium samples, in blue - Thorium samples.

JET NEUTRON PROFILE MONITOR

The neutron profile monitor was the key diagnostic for the whole TTE campaign, with over 80% of the experiments relying on its profiles of 14 MeV neutrons to produce data from which thermal- and fast-ion transport parameters could be evaluated.

The diagnostic consists of two fan-shaped cameras of collimators with horizontal chord (channels 1 to10) and vertical chord (channels 11 to 19) views of the plasma (fig.4). Each channel is equipped with three detectors: 1) a NE213 liquid scintillator with Pulse Shape Discrimination electronics to measure 2.5 MeV, 14 MeV neutrons and gamma-rays simultaneously; 2) a Bicron plastic scintillator for 14 MeV neutron detection only; and 3) CsI(Tl) photodiodes for spatial gamma measurements with energies from 0.2 up to 6 MeV [9]. This system that has been used routinely in previous JET campaigns was fully recommissioned before TTE with particular emphasis on the 14 MeV neutron channels.

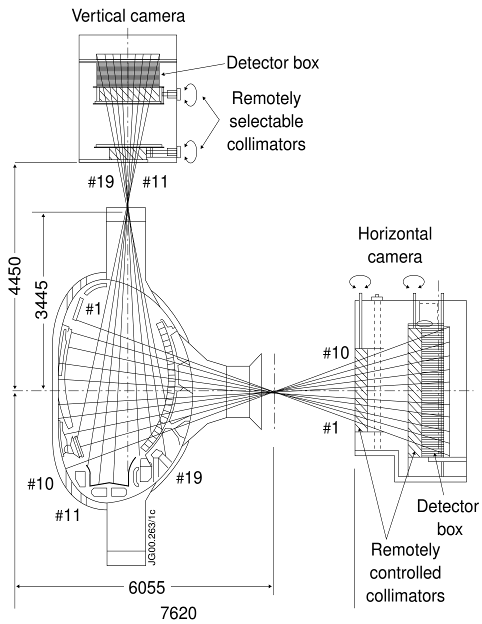

Fig. 4. Schematic view of JET neutron profile monitor

The profile monitor complements to activation system and neutrons flux monitors providing an independent estimate of the absolute neutron yield from the plasma. Fig 5 illustrates the comparison of total 14 MeV neutron yields derived from the silicon diodes and the neutron profile measurements, where a linear least squares fit indicates an agreement to within ~8%.

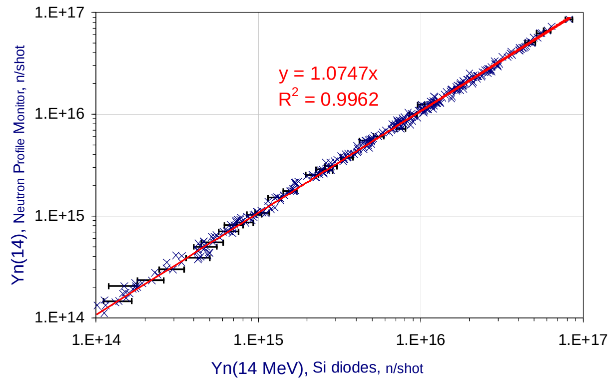

Fig.5 Comparison of 14 MeV neutron yield measured by Neutron Profile Monitor (Bicron detectors) and Si diodes (~450 TTE shots)

EXAMPLES OF NEUTRON PROFILE MEASUREMENTS DURING TTE

The spatial distribution of fast tritons heated by the ICRH system at the fundamental cyclotron frequency of tritium was measured showing energetic T tails of 80 to 120 keV [10]. The high-energy tritons reacting with the deuterium bulk plasma induce a neutron emission profile, which peaks off axis close to the T cyclotron layer as shown in figure 6, since the fast tritons tend to follow trapped orbits grazing the latter.

The presence of a current hole, a region of negligible current in the core of plasmas with strong reverse shear, is confirmed to have a detrimental influence on the fast ion confinement [11,12]. The current-hole effect on the fast particles distribution was investigated in experiments using NB injected tritons as test particles and monitoring their spatial and temporal evolution with the neutron cameras. An outward displacement of 14 MeV neutron profile maximum, comparable to current hole radius, was observed for the on-axis NB injected tritons with energy about 100 keV. A smaller shift in the opposite, inward, direction, was obtained for off-axis NB injections. Good agreement has been found with theoretical prediction (see figure 7) [13].

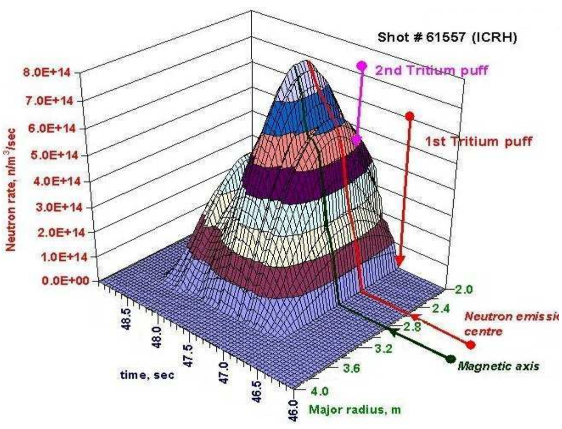

Fig.6. 14 MeV neutron profile with ICRH Tritium fundamental heating showing that the neutron emission centre is shifted toward the high field side with respect to the magnetic axis.

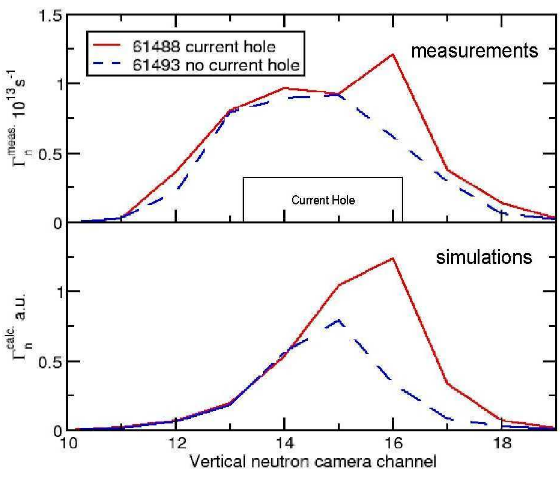

Fig.7. Comparison of calculated and measured profiles for the vertical 14 MeV neutron camera for on-axis tritium beams. DT neutron profiles during on-axis tritium beam blip indicate an outward displacement of neutron emission (measured on the top, calculated on the bottom).

NB current drive is proposed as a mechanism for q-profile control in ITER. The radial distribution of NB injected fast ions, which is related to the profile of the driven current, can be assessed using the neutron emission profile in cases where the thermal neutron yield is negligible. Dedicated experiments were carried out using tritium beams injected into deuterium plasmas to provide a basis for the validation of NB fast ion models. On-axis and off-axis beams were injected into plasmas with high and low power deuterium NB heating and different toroidal magnetic field strengths (i.e. varying q95). The measured 14MeV-neutron emission shows hollow or peaked profiles corresponding to off-axis or on-axis beam injection respectively (see figure 8). An agreement with simulations was achieved at high q95, but not at low field, suggesting a fast ion radial redistribution in the latter case.

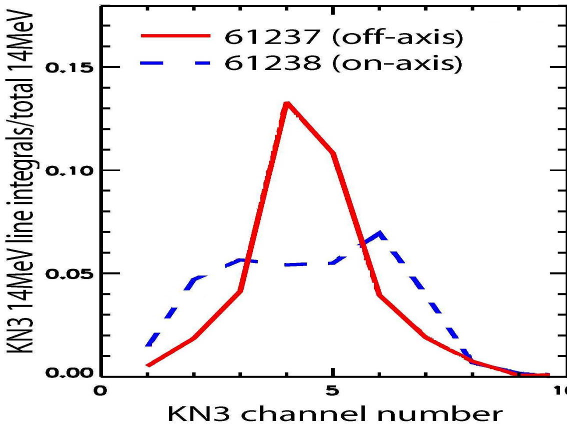

Fig. 8. Differences in shape and emissivity centres between on- and off- axis Tritium beam blips.

SUMMARY

A very comprehensive set of neutron diagnostics was available and successfully operated at JET during Trace Tritium experiments in 2003. Data obtained by means of JET neutron diagnostics, and in particular by the profile monitor, provided essential information for the investigation of fast particle physics. In particular the vertical camera played a key role in these studies highlighting the importance of such a diagnostic tool in studying issues for ITER, and its potential for ITER itself.

Amongst the important results, which illustrate the capabilities of the neutron profile diagnostic, the following was demonstrated:

- vertical neutron emission profiles from fast tritons clearly show off-axis peaking in plasma discharges with strong negative shear, in agreement with theoretical analysis;
- the off-axis peaking at the resonance position of fast tritons produced by Ion Cyclotron RF heating of tritium minority is clearly seen on the neutron profiles;
- the vertical profile of Neutral beam fast tritons injected into low q plasmas shows clear signs of continual radial redistribution even between sawteeth.

The work was performed under the European Fusion Development Agreement, and partly funded by the UK Engineering and Physical Sciences Research Council and EURATOM.

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