EUROPEAN FUSION DEVELOPMENT AGREEMENT

EFDA–JET–CP(06)03-26

E. Andersson Sundén, S. Conroy, G. Ericsson, M. Gatu Johnson, L. Giacomelli, C. Hellesen, A. Hjalmarsson, J. Källne, E. Ronchi, H. Sjöstrand, M. Weiszflog, G. Gorini, M. Tardocchi, A. Murari, S. Popovichev, J. Sousa, R.C. Pereira, A. Combo, N. Cruz and JET EFDA contributors

Neutron Emission Spectroscopy Diagnosis of JET D plasmas with the new MPRu Instrument

Neutron Emission Spectroscopy Diagnosis of JET D plasmas with the new MPRu Instrument

E. Andersson Sundén[1], S. Conroy[1], G. Ericsson[1], M. Gatu Johnson[1], L. Giacomelli[1], C. Hellesen[1], A. Hjalmarsson[1], J. Källne[1], E. Ronchi[1], H. Sjöstrand[1], M. Weiszflog[1], G. Gorini[2], M. Tardocchi[2], A. Murari[3], S. Popovichev[4], J. Sousa[5], R.C. Pereira[5], A. Combo[5], N. Cruz[5] and JET EFDA contributors*

[1] INF, Uppsala University, EURATOM-VR Association, Uppsala, Sweden
[2] Istituto di Fisica del Plasma, EURATOM-ENEA-CNR Association, Milan, Italy
[3] EURATOM-ENEA-CNR Association, Padova, Italy
[4] Association EURATOM-UKAEA, Culham Science Centre, Abingdon, OXON OX14 3DB, UK
[5] Associação EURATOM/IST, Centro de Fusão Nuclear, Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
** See annex of J. Pamela et al, "Overview of JET Results ", (Proc. 20th IAEA Fusion Energy Conference, Vilamoura, Portugal (2004).*

Preprint of Paper to be submitted for publication in Proceedings of the
33rd EPS Conference,
(Rome, Italy 19-23 June 2006)

ABSTRACT.

From 2006, two new neutron spectrometers at JET will make it possible to perform advanced Neutron Emission Spectroscopy (NES) diagnosis of most plasmas produced in either Deuterium (D) or mixed Deuterium-Tritium (DT). One of the spectrometers, MPRu, is an upgrade of the Magnetic Proton Recoil (MPR) neutron spectrometer. While providing improved measurements of the 14MeV neutron emission in DT plasmas, the MPRu will also allow diagnosis of the 2.5MeV neutrons in D operations, thereby extending the use of this technique to the full range of fusion relevant energies. In particular, NES diagnosis of JET D plasmas can now be performed with two spectrometers with complementary capabilities and functions.

In this contribution the principles of the MPR and its upgrade will be presented. MPRu offers a significant enhancement in the immunity to extraneous background and the importance of this improvement for extending its use to NES diagnosis of D plasmas will be discussed. To achieve these enhanced capabilities a new High Immunity to Background (HIB) detector system has been designed and built, based on pulse-shape discriminating phoswich scintillators and read out by fast Transient Recorder data acquisition electronics. The characteristics of the HIB detector will be illustrated in perspective of their relevance for diagnostic performance. Examples of results will be taken from the TTE campaign and the MPRu test and commissioning phase; results from the first use of the instrument to observe the 2.5MeV emission from D plasmas from the campaigns planned for early 2006 will also be presented. Of special interest is the complementary use of the MPRu, with its high calibration accuracy, and the new TOFOR with its data of high statistical accuracy. A particular aspect is the use of spectrometers with quasi-orthogonal sight lines to the plasma. In this context, the MPRu together with TOFOR will allow the first quantitative test of using the non-isotropy in the neutron emission to enhance the diagnostic capability of NES. The NES results with the MPRu on JET will be projected to ITER conditions, where the diagnostic capabilities will increase in proportion to the fusion power.

1. INTRODUCTION

Neutrons are produced in high temperature fusion energy experiments such as JET through the reactions $d + d \rightarrow {}^3He + n$ (2.5MeV) and $d + t \rightarrow \alpha + n$ (14.0) where the neutron energy is given in parentheses. Neutron Emission Spectroscopy (NES) is a valuable tool in fusion energy research, since the neutrons leave the fusion plasma undisturbed and thus give information from the very centre of the plasma. NES can give information on the state of the fuel ions such as ion temperature, plasma rotational speed and fusion power [1].

2. THE UPGRADED MAGNETIC PROTON RECOIL SPECTROMETER

The upgraded Magnetic Proton Recoil (MPRu) neutron spectrometer [2] is in operation at JET since April 2006. The instrument is depicted in Figure 1. In the MPRu a collimated flux of neutrons from the JET tokamak impinge on a thin plastic foil. Some neutrons scatter elastically on the hydrogen nuclei (protons) of the foil. Recoil protons scattered in the forward direction are momentum analysed in the spectrometer's electromagnet and registered in the focal plane by an array of phoswich plastic scintillators.

The phoswich scintillators consist of two layers, each with its characteristic decay-time: a thin (0.3mm) layer with a fast light-pulse decay time (1.8ns) facing the incoming protons followed by a thick layer (2.2 – 3.2mm) with a slow decay time (180ns). These thicknesses were chosen to accomodate the range in plastic of 2.5MeV and 14MeV protons, which are about 0.1 mm and 2.2mm, respectively.

Each scintillator has two Photo Multiplier (PM) tubes connected to give efficient collection of the scintillation light. The summed PM tube voltage signals for each detector are processed and saved, event-by-event, by custom built Trancient Recorder digital electronics cards [3]. The time of each event is also stored. The main data provided by the MPRu are thus time-stamped signal proton wave forms, from which time-resolved proton position histograms can be built.

3. DATA ANALYSIS

The acquisition of the full PM tube wave forms makes it possible to perform advanced Pulse Shape Discrimination (PSD) analysis, including base line restoration, pile-up rejection and separation of signal and background events. The latter task is here accomplished by a standard long and short gate analysis (Q_{long}, Q_{short}). Q_{short} corresponds to the integrated charge over the early part of the PM tube wave form dominated by signal from the thin layer of the scintillator. Q_{long} is the integration of the late part of the wave form dominated by signal (if any) from the thick layer. Separation of proton signal from background can then be achieved as exemplified in Figure 2 where the proton "island" around $Q_{short} \simeq 150$ (encircled) is well separated from the background and noise region (at $Q_{short} \leq 110$) [4].

For the present analysis, efficient separation of signal protons from background is achieved by selecting events for $Q_{long} \leq Q_{cut}$ in the (Q_{long}, Q_{short}) distribution, as indicated in Figure 2. The values of $Q_{tot} = Q_{long} + Q_{short}$ for such a selection is shown in Figure 3 (upper panel). This can be compared to the situation of the original MPR when no PSD selection was possible, as shown in the lower panel of Figure 3. The improvement in signal to background ratio, from about 1≤10 for the original MPR to about 10:1 in MPRu, is clearly visible.

To estimate the level of background in the proton peak region, data were collected with the spectrometer's electomagnet turned off (B = 0). In Figure 3 the background data (red curve) is normalised to the signal + background data (black curve) for $Q_{tot} \leq 200$. By subtracting the normalised background from the proton data in the indicated region the number of protons for each specific detector channel (and time interval) can be determined.

4. RESULTS

Using the procedure described above, data from a number of JET pulses (pulses 66454 - 66470) with very similar conditions were summed and analysed to provide proton position histograms. The selected pulses were divided into two time phases: an early phase (47 – 50s), dominated by Neutral Beam

(NB) heating and a late phase (50 – 56s), with mixed Radio Frequency (RF) and NB heating. In Figure 4 preliminary proton position histograms are presented for each phase. The number of proton events in the two distributions is quite similar, but the shapes differ significantly. The NB dominated data (blue) has a peaked fairly broad distribution, reflecting the neutron-producing reactions that occur as the injected high-energy neutral fuel ions slow down in the plasma. The data of the mixed RF+NB heating phase exhibit a flat even broader distribution with distrinct high- and low-energy wings. Such features are a typical spectral signature of RF heating effects. To allow a more elaborate analysis in terms of neutron spectral components, new spectrometer response functions must be calculated for the MPRu; this work is in progress.

CONCLUSIONS

The first preliminary analysis of data from the upgraded Magnetic Proton Recoil neutron spectrometer shows that the instrument is now capable of meausering 2.5MeV neutron spectra of good quality (in addition to improved 14MeV measurements).

The aim of the upgrade project in 2.5MeV operations, to improve the signal-to-background ratio of the focal plane detector by a factor 100 compared to the original MPR, has been met. The first preliminary proton position histograms have been extracted, showing clear spectral differences between the neutron emmision from NB and RF dominated plasmas. Based on these preliminary results we estimate that the MPRu has a sensitivity to measure weak spectral components on the percent level of the main 2.5MeV emission peak (counting statistics permitting).

ACKNOWLEDGMENTS

This work has been performed under the European Fusion Development Agreement (EFDA) and the Association EURATOM-VR with support from Swedish Research council (VR), Uppsala University and JET-EFDA.

REFERENCES

[1]. L. Giacomelli et al., Advanced neutron diagnostics for JET and ITER fusion experiments, Nuclear Fusion **45**, 1191 (2005)

[2]. G. Ericsson et al., Upgrade of the Magnetic Proton Recoil (MPRu) spectrometer for 1.5-18MeV neutrons for JET and the next step, Proceedings of Intl. Workshop on Fast Neutron Detectors and Applications, University of Cape Town, South Africa (2006)

[3]. A. Combo et al., A PCI transient recorder for the magnetic proton recoil neutron spectrometer at JET, Fusion Eng. Des. **71**, 101 (2004)

[4]. H. Sjöstrand et al., The new MPRu instrument for neutron emission spectroscopy at JET, Proceedings of 16th Workshop on High Temperature Plasma Diagnostics, Williamsburg, Virginia, USA (2006)

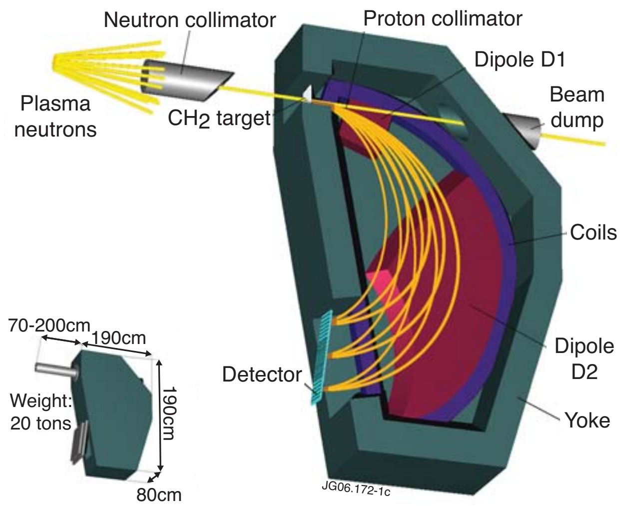

Figure 1: Schematic overview of the MPRu spectrometer.

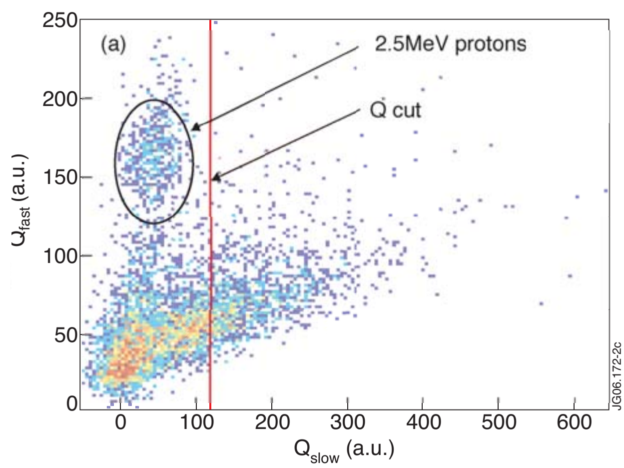

Figure 2: Example of signal and background separation using PSD for a central MPRu detector channel. Events are plotted in the Q_{long} and Q_{short} parameter space (see text). The proton signal "island" is encircled. A cut Q_{long} = 100 used in the analysis is indicated (see text).

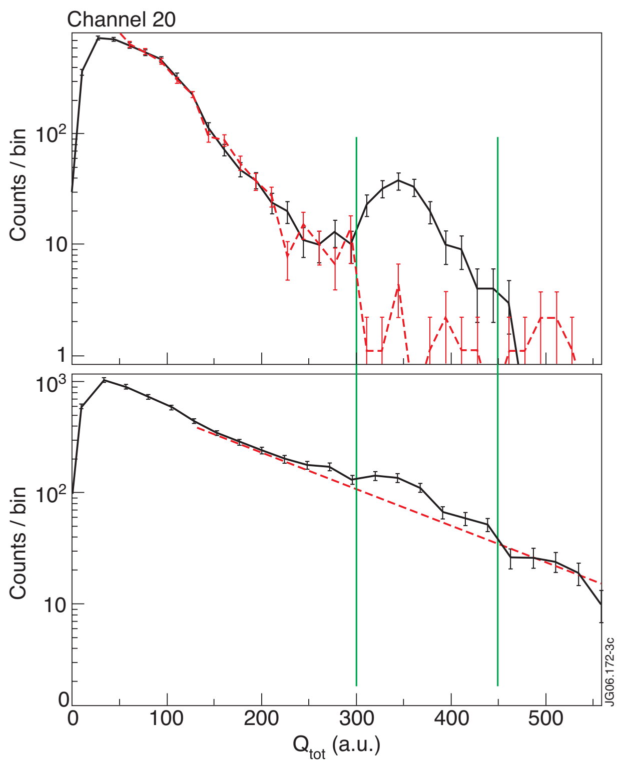

Figure 3: Q_{tot} distributions (log) for a central detector channel. The upper panel shows data selected with a condition $Q_{long} < Q_{cut}$ as indicated in Figure 1. The lower panel shows data without any cut. Data taken with the electromagnet turned on in black and data taken with the electromagnet turned off (B=0) in red. The B=0 data is normalised (see text). The proton signal region is indicated by vertical (green) lines.

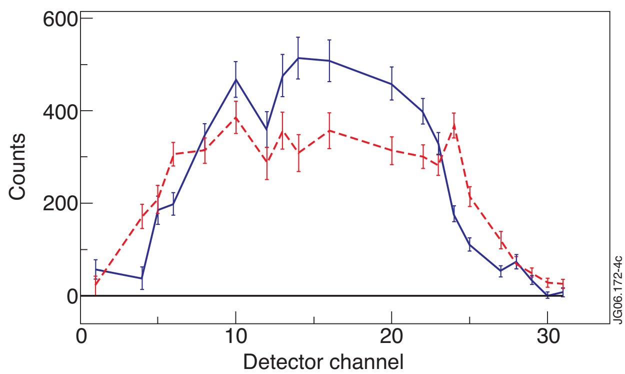

Figure 4: Preliminary proton position histograms. The histogram in blue is for the NB dominated early phase of the selected JET pulses. The histogram in red is for the mixed RF+NB heated late phase.