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The New MPRu Instrument for Neutron Emission Spectroscopy at JET

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ABSTRACT

The MPRu is an upgrade of the magnetic proton recoil (MPR) neutron spectrometer that has been used for 14MeV dt neutron measurements at JET during the DTE1 (1997) and TTE (2003) campaigns. In this contribution the principles of the MPR and its upgrade will be presented. The MPRu allows measurements of the full range of fusion relevant neutron energies, 1.5-18MeV, including the 14MeV dt neutrons, now with significantly reduced background, and also new high-quality measurements of the 2.5MeV dd neutron component. This improvement is made possible by the use of a new proton recoil detector in combination with custom-built transient recorder cards. The importance of these instrumental improvements for extending the use of the MPRu in diagnosis of D and DT plasmas will be discussed. Results from the first 2.5MeV measurements performed with the MPRu during JET high level commissioning in April 2006 are presented.

1. INTRODUCTION

The ultimate goal of fusion research is to produce fusion power; hence one of the most fundamental requirements of a fusion experiment is to accurately measure the fusion power and its dependent parameters, such as the ion density and velocity distribution. Fusion experiments normally operate with pure deuterium where the $d+d \rightarrow t+p$ and the $d+d \rightarrow {}^3He+n$ (2.5MeV) reactions take place with nearly the same probability. In more advanced experiments, such as JET and ITER, a mixture of deuterium and tritium is used; this is also the proposed fuel for a future reactor. In a 50:50 DT mixture the $d + t \rightarrow {}^4He + n$ (14MeV) reactions dominate the dd reactions.

The neutrons from the fusion reactions escape the plasma and carrying a wealth of information about the core fusion process and its fuel ions; Neutron Emission Spectroscopy (NES) can reveal this information, without perturbing the plasma. With NES one can determine the fusion power [1], the collective motion of the main plasma, the fuel ion densities, the ion velocity distributions and hence the effectives of the different heating modes, as well as the bulk fuel ion temperature [2]. In order to determine these parameters one needs a neutron spectrometer with high instrumental resolution, high count rate capability, high efficiency and immunity to background.

In 1996 a magnetic proton recoil (MPR) neutron spectrometer was installed at JET [3] to perform NES for 14-MeV neutrons and it has provided important information both during the tritium campaign DTE1 in 1997 as well as in the trace tritium experiment TTE in 2003. However, the MPR could not perform 2.5MeV neutron measurements due to insufficient background separation. To extend its operational range to include also the 2.5MeV spectrum as well as improving the 14-MeV neutron spectroscopy, thus contributing valuable information in both pure d as well as in mixed dt-operation, an MPR upgrade (MPRu) was completed in 2005 as part of the JET Enhanced Performance program JET-EP1. In this paper we present the principles of the MPRu and what consequences the upgrade will have on the diagnostic's performance. Some results from simulations of the MPRu will be presented as well as the first data from the high level commissioning at JET in April 2006.

2. THE MPR PRINCIPLE

The principle and components of the Magnetic Proton Recoil technique are illustrated in Fig.1. The fusion neutrons are collimated and scatter elastically on hydrogen nuclei (protons) in a thin plastic foil. The recoil protons emitted in the forward direction are allowed to enter the magnetic part of the spectrometer where they are momentum analyzed in the magnetic field and focused onto the focal plane. A focal plane detector composed of an array of plastic scintillators coupled to PM tubes register the spatial distribution of the protons. In the central detector channel, protons with an energy of 2450±20keV will be registered. This spatial distribution can be related back to the neutron energy at the foil through the spectrometer's response function.

3. THE MPRU UPGRADE

To access the 2.5MeV neutron spectrum and to develop even more detailed 14MeV spectroscopy, an instrumental upgrade to reduce the background and noise sensitivity and to improve the calibration and the control and monitoring system has been performed. To achieve these goals, several new hardware systems have been installed, the most important being a new focal plane detector. To reduce the background sensitivity of the scintillators, each of the 32 elements of the new hodoscope consists of a two-layered phoswich detector. The top layer facing the incoming protons is the 0.3mm thick fast plastic scintillator (BC404, 1.8ns decay time) in optical contact with the second thicker (2.5/3.2mm) slow scintillator (BC444, 180ns decay time). The distinctly different timing properties of the two layers makes Pulse Shape Discrimination (PSD) possible; 2.5MeV protons will be completely stopped within the fast layer, hence being distinguishable from penetrating electrons and gamma induced events, which predominantly give signals in both layers. Neutron induced background will in principle scale with the fast scintillator volume, reducing the intensity of the neutron interference in both 2.5MeV and 14MeV measurements. Each phoswich element has two PM-tubes attached via light guides (Fig.2), a configuration that increases the total light collection and gives more uniform longitudinal light collection efficiency. A more detailed description of the new hodoscope and its phoswich detectors is given in [4].

The PM-tubes collect the emitted scintillation light and transform it to electrical signals, which are summed and amplified before being registered by new, custom-built Transient Recorder Cards (TRCs) [5]. TRCs, with their waveforms storage capability, allows a detailed PSD, hence enhancing the background separation. The PSD technique of integrating the PM-tube voltage pulse over an early (Q_{fast}) and a late (Q_{slow}) time region has been adopted for this paper. The TRC modules also allow an event-by-event analysis including, e.g., base line restoration, noise reduction and pile-up rejection.

The ab initio energy calibration of the MPRu system requires good knowledge of the instrument's geometry. To improve the energy calibration of the instrument the relative distances between the different scintillators have been determined to 50μm precision using a UV LED based scanning system. By combining the results of the UV scans with the alignment and surveying of the fully assembled instrument using JET's digital photogrammetry [6], which gives the complete geometry of the MPRu installation in one common frame of reference, it was possible to determine the location of each scintillator relative to the magnetic field and the line-of-sight to a level of < 0.1 mm. This corresponds to a calibration accuracy of about 1keV at 14MeV.

The MPRu control and monitoring system has been upgraded with three new light sources. A custom built stable LED is used to monitor the short and medium term gain stability of the PM-tubes. To monitor the long term stability of the LED two YAP:Ce scintillators with embedded ^{241}Am ± sources are used as absolute references. In addition, a high repetition rate laser is also available.

4. MPRU EXPECTED PERFORMANCE

The MPR was upgraded to enable 2.5-MeV neutron spectroscopy as well as to improve the 14-MeV neutron spectroscopy. To simulate the performance of the new detector a GEANT4 [7] model was developed. Simulation results indicate that the MPRu system could reach a Signal-to-Background (S/B) ratio of 10:1 for the 2.5MeV measurements in D plasmas and 20000:1 for 14MeV measurements in DT plasmas. For D plasmas the simulations indicate that the background is dominated by penetrating gammas and Compton electrons, but PSD can separate these events from the 2.5MeV proton peak. A comparison between simulated results and the first preliminary data from the MPRu spectrometer can be seen in Fig.3, where the background separation can be seen in both cases.

The improved S/B will enable the MPRu to determine the ion temperature and fusion power also in D-operations where it was previously not feasible.

5. FIRST DATA

During the high level commissioning at JET in April 2006 the first 2.5MeV neutrons were detected with the upgraded instrument. For these measurements the MPRu was set to achieve high efficiency, providing data for the characterization of the instrument and tuning of operational working points. In order to accurately determine the background the MPRu was also operated with a zero B-field. Fig.4 show the first 2.5MeV data analyzed with a traditional short gate – long gate PSD technique; the proton peak is clearly separated from the bulk of the background events and there is an absence of a "proton" peak in the B = 0 data set. The data in Fig.4 also gives an indication of the experimental S/B situation, which seems to be in line with expectations. A detailed analysis has still to be done, but these first data indicate that the MPRu instrument works as anticipated.

CONCLUSION AND OUTLOOK

NES through the MPR instrument has proven to be a reliable and accurate tool for diagnosing the core fusion process during seven years of operation at JET. In DT†plasmas it has provided high quality data concerning the ion temperature, fusion power, alpha particle heating, etc. In preparation for the next step in fusion research, viz. ITER, the MPR has been upgrade to provide even more detailed information in DT plasmas as well as for the first time prove the MPR technique in pure D-operations. The first MPRu results from the JET high level commissioning in April 2006 show that the new instrument performs as projected and indicates that the predicted S/B level can be achieved for 2.5MeV measurements. The MPRu, together with the new TOFOR spectrometer [8], represents a significant step forward of the JET NES capability.

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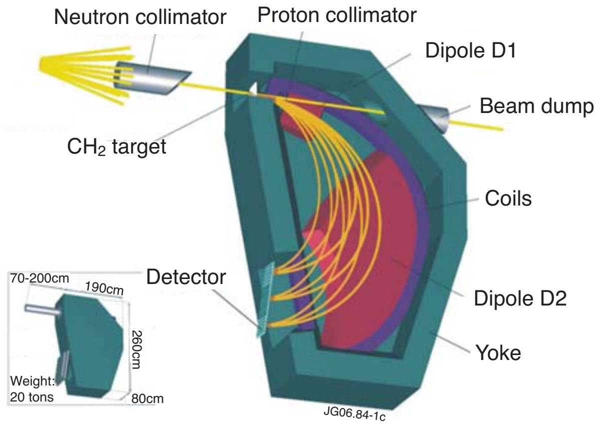

Figure 1: Schematic figure of the MPRu spectrometer, without its radiation shield.

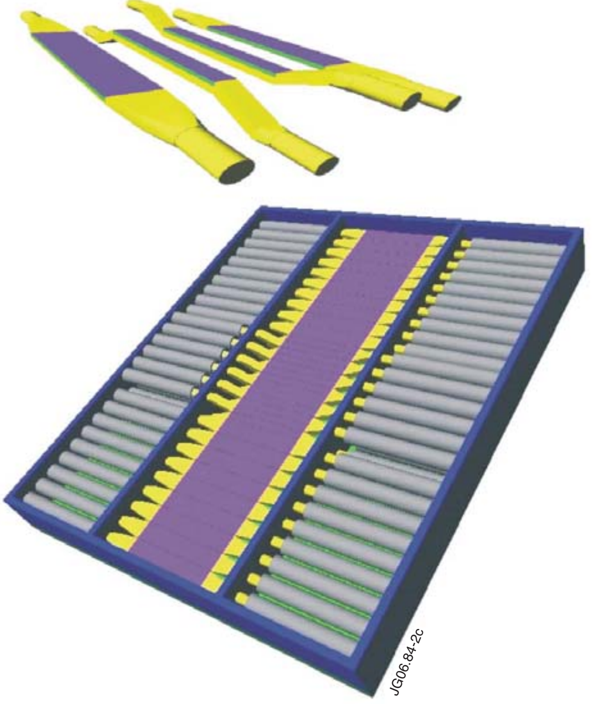

Figure 2: The MPRu hodoscope and its four different types of scintillators.

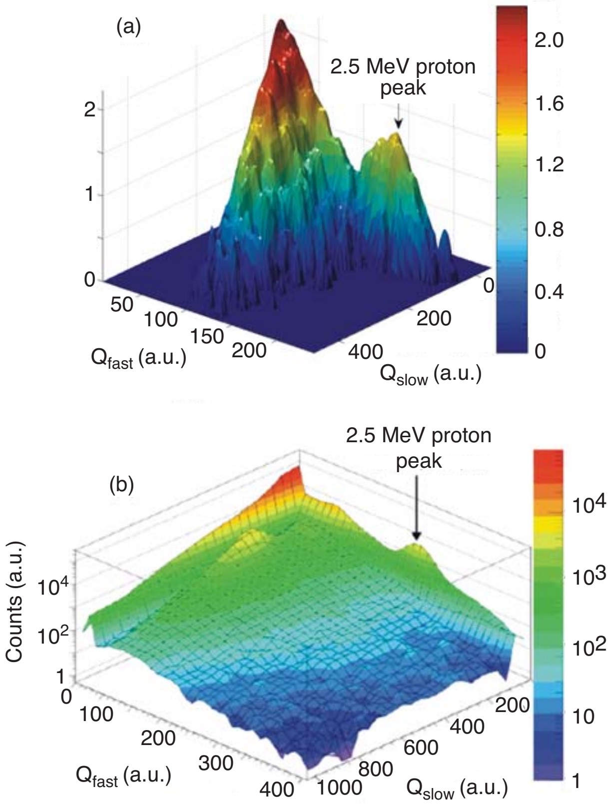

Figure 3: Comparison between (a) experimental data for a central hodoscope channel and (b) simulated data for a central phoswich scintillator. A standard two-gate PSD technique has been used. Q_{fast} and Q_{slow} are the integrations of the PM-tube voltage pulse over an early respectively a late time region.

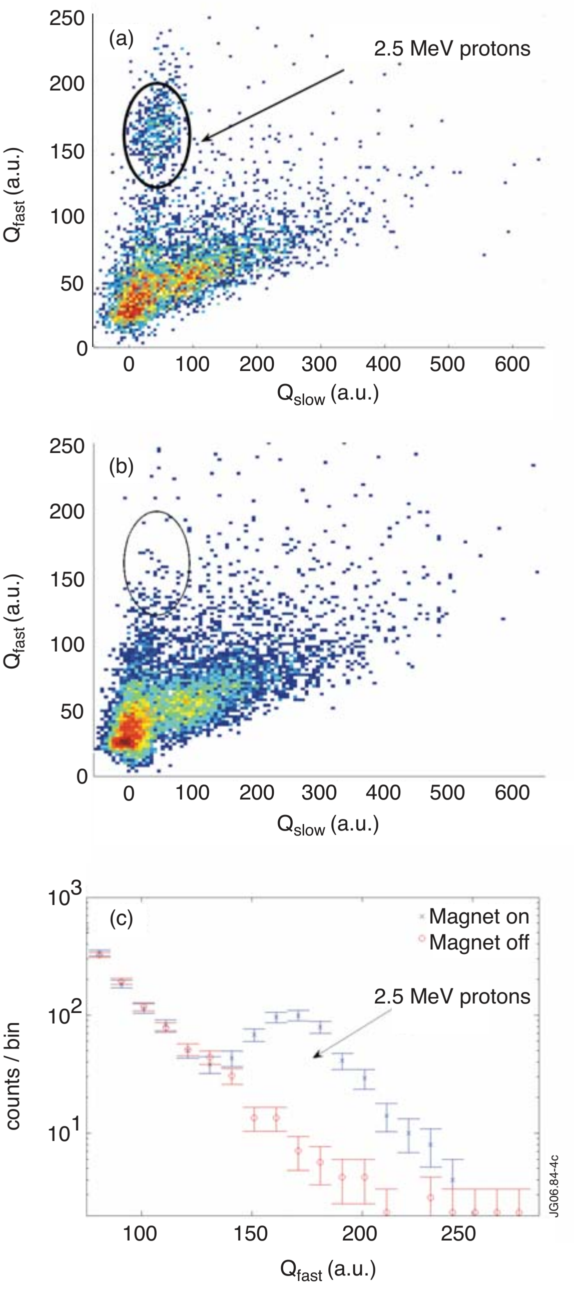

Figure 4: (a) Proton data for a central hodoscope channel, acquired during the high level commissioning at JET. The recoil proton peak is indicated. (b) Background data collected with a 0T B-field, with slightly better statistics than in (a). (c) The signal and the normalised background data in the 0-200 Q_{slow} region projected on to the Q_{fast} axes.