Neutron emission profiles and energy spectra measurements at JET

Giacomelli L, Conroy S, Belli F, Gorini G, Horton L, Joffrin E, Lerche E, Murari A, Popovichev S, Riva M, Syme B, JET EFDA Contributors

Neutron emission profiles and energy spectra measurements at JET

L. Giacomelli, S. Conroy, F. Belli, G. Gorini, L. Horton, E. Joffrin, E. Lerche, A. Murari, S. Popovichev, M. Riva, B. Syme, and JET EFDA Contributors

Citation: AIP Conference Proceedings **1612**, 113 (2014); doi: 10.1063/1.4894035
View online: http://dx.doi.org/10.1063/1.4894035
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1612?ver=pdfcov
Published by the AIP Publishing

Neutron Emission Profiles and Energy Spectra Measurements at JET

L. Giacomelli[1,2], S. Conroy[1,3], F. Belli[4], G. Gorini[2,5], L. Horton[1], E. Joffrin[1], E. Lerche[1], A. Murari[1], S. Popovichev[1], M. Riva[4], B. Syme[1] and JET EFDA Contributors*

[1] *JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK*
[2] *Department of Physics, Università degli Studi di Milano-Bicocca, Milano, Italy*
[3] *Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden*
[4] *Associazione EURATOM-ENEA sulla Fusione, Roma, Italy*
[5] *Istituto di Fisica del Plasma "Piero Caldirola", Milan, Italy*
** See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, USA*

Abstract. The Joint European Torus (JET, Culham, UK) is the largest tokamak in the world. It is devoted to nuclear fusion experiments of magnetic confined Deuterium (D) or Deuterium-Tritium (DT) plasmas. JET has been upgraded over the years and recently it has also become a test facility of the components designed for ITER, the next step fusion machine under construction in Cadarache (France). JET makes use of many different diagnostics to measure the physical quantities of interest in plasma experiments. Concerning D or DT plasmas neutron production, various types of detectors are implemented to provide information upon the neutron total yield, emission profile and energy spectrum. The neutron emission profile emitted from the JET plasma poloidal section is reconstructed using the neutron camera (KN3). In 2010 KN3 was equipped with a new digital data acquisition system capable of high rate neutron measurements (<0.5 MCps). A similar instrument will be implemented on ITER and it is currently in its design phase. Various types of neutron spectrometers with different view lines are also operational on JET. One of them is a new compact spectrometer (KM12) based on organic liquid scintillating material which was installed in 2010 and implements a similar digital data acquisition system as for KN3. This article illustrates the measurement results of KN3 neutron emission profiles and KM12 neutron energy spectra from the latest JET D experimental campaign C31.

Keywords: JET plasmas, neutron emission profile, neutron spectroscopy, MAXED unfolding.
PACS: 52.70.-m; 29.30.Hs.

INTRODUCTION

The Joint European Torus (JET, Culham, UK) [1] has recently celebrated the 30th year of operation. Over these years JET activity has been characterized by experimental campaigns for studying Deuterium (D) and Deuterium-Tritium (DT) plasmas. Periods of intervention are also planned to maintain the tokamak as well as to install new equipment and diagnostics. During the 2010 shutdown, the new ITER-like-wall (ILW) [2] made of Beryllium tiles was installed in the JET vacuum vessel to test it in view of ITER [3]. Also upgrades of existing diagnostic instrumentation and the installation of brand new one was carried out. Concerning neutron diagnostics, the upgrade of the data acquisition system of the plasma neutron emission profile monitor KN3 (i.e., neutron camera) and the installation of a brand new compact liquid scintillator neutron spectrometer (KM12) were performed.

KN3 implements two different sets of detectors implemented along 10 horizontal and 9 vertical lines of sight. For neutron measurements, NE213 liquid scintillators are chosen the diagnosis of 2.45 MeV neutron emission from D plasmas while thin plastic scintillation detectors are usually used for DT 14 MeV neutrons. In addition, CsI gamma scintillators can be inserted in the lines of sight if the plasma gamma emission profile is of major interest. The upgrade of the KN3 concerned the installation of a brand new digital acquisition system (14 bit and 0.2 Gsample/s) [4] in parallel to the old analogue system, which makes use of pulse shape discrimination units [5]. A similar digital acquisition system is implemented in KM12 which response function was measured at the Physicalisch-Technische Bundesanstalt (PTB Braunschweig) [6][7].

Fusion Reactor Diagnostics
AIP Conf. Proc. 1612, 113-116 (2014); doi: 10.1063/1.4894035
2014 AIP Publishing LLC 978-0-7354-1248-4/$30.00

KN3 NEUTRON EMISSION PROFILES AND KM12 NEUTRON ENERGY SPECTRA

Two D plasma discharges were selected and analyzed in terms of KN3 and KM12 data from the ongoing JET D experimental campaign C31. The first discharge is from experiments aiming at the optimization of Ion Resonance Cyclotron Heating (ICRH) in H-mode. This is obtained by selecting the most efficient position for gas puffing to improve the frequency coupling of ICRH. The results presented here concern JET shot 84747 where 5.9 MW ICRH were injected into the D plasma at the end of 14.6 MW Neutral Beam Injection (NBI) steady phase. The toroidal magnetic field was $B_t = 2.7$ T while the plasma current $I_p = 2.5$ MA. The second discharge, JET 84806 is part of the experiments which goal is to develop hybrid plasmas to lower triangularity and optimizing pumping and fuelling to access lower density. JET shot 84806 featured 25 MW NBI auxiliary heating with $B_t = 2.3$ T and $I_p = 2.0$ MA. This shot provided the record neutron rate in JET ILW of $1.8 \cdot 10^{16}$ n/s.

The KN3 and KM12 detectors are sensitive to both neutron (n) and gamma (γ) radiations which produce signals of different pulse shapes [8]. The Short/Long gate method is used for n/γ discrimination [9]. A step further in this type of analysis has been conceived to identify the n and γ contributions into the overlapping region at low energies as shown in Fig. 1 [10]. The technique consists in a tomographic analysis of the Short/Long vs. Energy distribution (Fig. 1(b)). For arbitrary energy ranges (i.e., 5 keVee), the corresponding Short/Long distribution is compared to a model obtained as sum of two Rayleigh distribution functions and background level (Double Rayleigh in Fig. 1(a)). The comparison is obtained minimizing Cash statistics *C* [11]. This analysis allows for an accurate determination of the n/γ separation line, i.e., the minimum of the Double Rayleigh model (magenta line in Fig. 1(a)), and a detailed identification of the events in the overlapping region of the Short/Long distribution. The n and γ pulse height spectra (phs) are then determined with an improved accuracy at low energies.

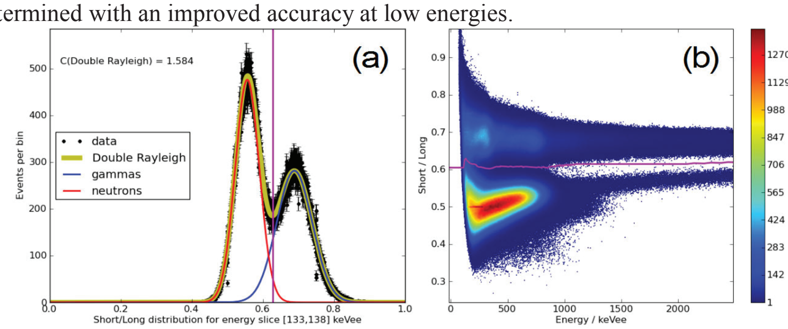

FIGURE 1. In (a), the KM12 Short/Long distribution corresponding to the energy interval 133-138 keVee sliced from (b) and compared to the Double Rayleigh model in terms of Cash statistics *C*. The magenta line represents the n/γ discrimination line while the red and blue lines corresponds to the n (left) and γ (right) events in this energy interval. In (b), a magnification of the Short/Long vs. Energy distribution for KM12 with the n/γ discrimination line (magenta).

With this method, KN3 and KM12 data for JET shots 84747 and 84806 were analyzed. Fig.s 2 and 3 show the n phs and count rates measured along the KN3 different sight lines during the steady NBI and ICRH phase of shot 84747 (49.50-50.86 s).

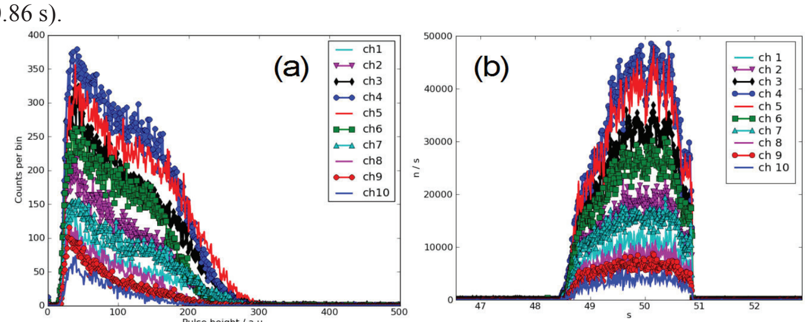

FIGURE 2. The n phs (a) and count rates (b) measured along the KN3 horizontal lines of sight during shot 84747.

The KN3 horizontal central (chs 4 and 5) and vertical (chs 15 and 16) channels are the ones viewing the hottest core of the plasma which feature the highest neutron emissivity for the D ions nuclear fusion cross section. KN3 digital acquisition system was able to reach 70 kCps in ch 15 which is well below its capability of 0.5 MCps [4]. A similar analysis was carried out for JET shot 84806 during the steady NBI phase (45.75-48.30 s).

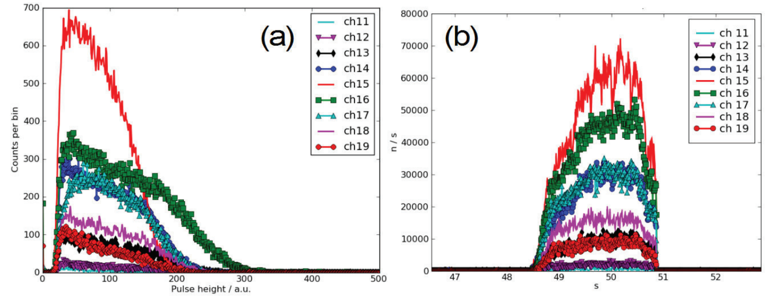

FIGURE 3. As in Fig. 2 but for the KN3 vertical lines of sight.

From the measured KN3 phs, information on the plasma n and γ emission profile can be obtained (Fig. 4). Fig.4(a) shows the trend of measured n and γ events for shot 84747. The D plasma n emission is peaked in the core corresponding to KN3 central horizontal and vertical channels. The measured γ profile is flat in KN3 horizontal camera since it views the inner ILW through the plasma while it is structured for KN3 vertical camera. Here the central channels receive the γ emission from the tungsten divertor region while the edge channels see mostly the ILW lower part [5]. The higher γ fraction measured by KN3 vertical edge channels can be explained as the effect of background induced by scattered neutrons in KN3 shielding: Detailed calculations are planned to verify this hypothesis. For shot 84806 (Fig. 4(b)) the measured n and γ profiles follow a similar trend as for shot 84747 but with an abrupt interruption for KN3 vertical chs 17-19 because of a pc fault during the data acquisition.

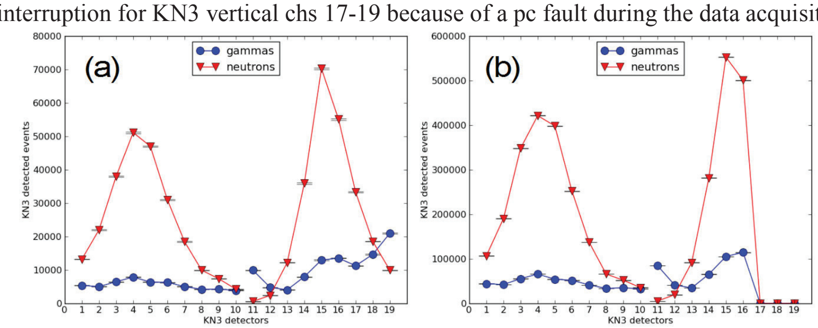

FIGURE 4. The KN3 measured n and γ profiles for JET shots 84747 (a) and 84806 (b).

Concerning KM12 measurements, the measured n phs was unfolded with MAXED code [12] to obtain the corresponding n energy spectrum. A sensitivity analysis of the code's input parameters was set up [13] to select their optimal combinations for the analysis. Fig.s 5 and 6 show the measured n phs, the MAXED unfolded n energy spectra and the n count rates reached during the steady auxiliary heating phases of the shots as for KN3.

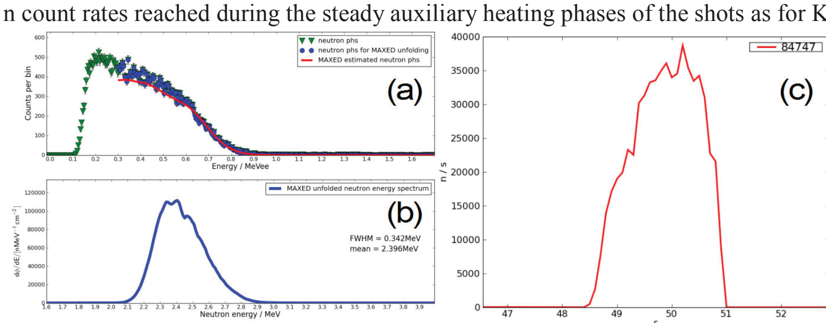

FIGURE 5. KM12 measured n phs (a), MAXED unfolded n energy spectrum (b) and n count rate for shot 84747.

The n energy spectra show similar values of full width at half maximum (FWHM) from which the D plasma effective temperature can be calculated as T_{eff} = (FWHM/82.5)^2 with FWHM and T_{eff} expressed in keV [14]. It results in T_{eff} = 17.2 keV and 18.4 keV for shots 84747 and 84806, respectively. The shape of the neutron spectra is different, with the one corresponding to shot 84747 asymmetric which relates to the application of ICRH heating and to the KM12 line of sight being it horizontal-tangential along the equatorial plane of the machine [15]. The n count rate KM12 reached in shot 84747 was about 39 kCps while, for shot 84608, it was larger than 0.2 MCps.

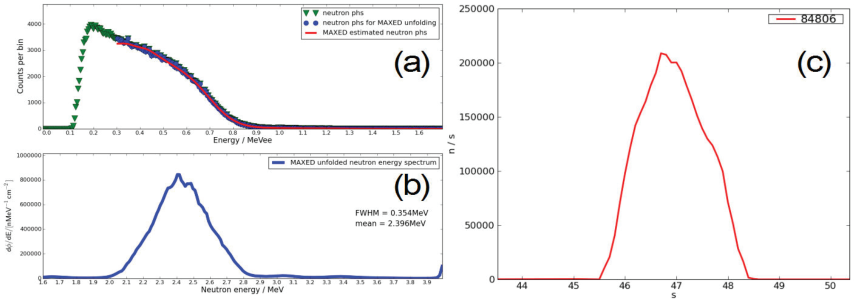

FIGURE 6. As Fig. 5 but for shot 84806.

CONCLUSIONS AND OUTLOOK

KN3 and KM12 measurement results in high power JET D shots demonstrate the good diagnostic capability of both instruments equipped with the new digital acquisition systems. With the improved n/γ discrimination technique [10], KN3 measured n and γ emission profiles and KM12 n energy spectra were determined to extract information of the D plasma position and T_{eff}. Further developments in KN3 data analysis concern the implementation of the energy scales in the n and γ phs and the determination of the efficiency and attenuation coefficients to reconstruct the plasma emission profile. With this information, the comparison of the count rate along the different KN3 lines of sight would allow for the investigation of plasma edge instabilities [16] and of the plasma positioning control in view of DEMO [17][18]. For KM12, new multi component analysis method of the n phs need be designed to achieve information upon the characteristics of the various D ion populations produced during the plasma discharge.

ACKNOWLEDGMENTS

The authors are grateful to colleagues of ENEA Frascati (Italy) and PTB Braunschweig (Germany) laboratories for the precious work and fruitful collaboration and to D. Simpson, P. Blanchard, M. Beldishevski and P. Heesterman for their support at JET. This work was supported by EURATOM and carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

REFERENCES

1. http://www.efda.org/jet/.
2. https://www.efda.org/jet/jet-iter/iter-like-wall-project/.
3. http://www.iter.org/.
4. M. Riva, B. Esposito, D. Marocco, F. Belli, B. Syme, Fusion Engineering and Design **86** (2011) 1191.
5. J. M. Adams, O. N. Jarvis, G. J. Sadler, D. B. Syme, and N. Watkins, Nucl. Instrum. Methods Phys. Res. A **329** (1993) 277.
6. F. Belli, S. Conroy, B. Esposito, L. Giacomelli, V. Kiptily, A. Lücke, D. Marocco, M. Riva, H. Schuhmacher, B. Syme, K. Tittelmeier, A. Zimbal, IEEE TRANSACTIONS ON NUCLEAR SCIENCE **59** 5 (2012) 2512.
7. F. Gagnon-Moisan, M. Reginatto and A. Zimbal, 2nd INTERNATIONAL WORKSHOP ON FAST NEUTRON DETECTORS AND APPLICATIONS, 6-11 Nov. 2011, EIN GEDI, ISRAEL, http://iopscience.iop.org/1748-0221/7/03/C03023/pdf/1748-0221_7_03_C03023.pdf.
8. L. Giacomelli, A. Zimbal, K. Tittelmeier, H. Schuhmacher, G. Tardini, R. Neu, Rev. Sci. Instrum. **82** (2011) 123504.
9. L. Giacomelli, A. Zimbal, M. Reginatto, and K. Tittelmeier, Rev. Sci. Instrum. **82** (2011) 013505.
10. L. Giacomelli, S. Conroy, G. Gorini, H. Lorne, A. Murari, S. Popovichev, D. B. Syme, to be submitted to Rev. Sci. Instrum..
11. W. Cash, The Astrophysical Journal **228** (1979) 939.
12. M. Reginatto, P. Goldhagen, S. Neumann, Nucl. Instrum. Methods Phys. Res. A **476**, Issues 1-2 (2002) 242-246.
13. L. Giacomelli and M. Reginatto, in preparation.
14. G. Lehner and F. Pohl, Z. Phys. **207** (1967) 83-104.
15. L. Giacomelli, S. Conroy, G. Ericsson, G. Gorini, H. Henriksson, A. Hjalmarsson, J. Källne, and M. Tardocchi, Eur. Phys. J. D **33** (2005) 235-241.
16. H. Weisen and L. Giacomelli, private communication.
17. http://ec.europa.eu/research/energy/euratom/index_en.cfm?pg=fusion&section=tech-prep-demo.
18. T. N. Todd, D. B. Syme, A. Hjalmarsson and L. Giacomelli, private communication.