EFDA-JET-CP(05)02-17

L.Bertalot, S.Conroy, A.Murari, M.Reginatto, H.Schuhmacher, A.Zimbal
and JET EFDA contributors

Neutron Energy Measurements of Trace Tritium Plasmas with NE213 Compact Spectrometer at JET

Neutron Energy Measurements of Trace Tritium Plasmas with NE213 Compact Spectrometer at JET

L.Bertalot[1], S.Conroy[2], A.Murari[3], M.Reginatto[4], H.Schuhmacher[4], A.Zimbal[4]
and JET EFDA contributors*

[1]*Associazione EURATOM-ENEA Fusione, v. E. Fermi 45, I-00044 Frascati, Italy*
[2]*Department of Neutron Research, Uppsala University, BOX 525, SE-75120 Uppsala, Sweden*
[3]*Consorzio RFX Assoc. EURATOM-ENEA Fusione, Corso Stati Uniti 4, I-35127 Padova, Italy*
[4]*Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany*
** See annex of J. Pamela et al, "Overview of JET Results ",*
(Proc.20 th IAEA Fusion Energy Conference, Vilamoura, Portugal (2004).

Preprint of Paper to be submitted for publication in Proceedings of the
EPS Conference,
(Tarragona, Spain 27th June - 1st July 2005)

“This document is intended for publication in the open literature. It is made available on the understanding that it may not be further circulated and extracts or references may not be published prior to publication of the original when applicable, or without the consent of the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.”

“Enquiries about Copyright and reproduction should be addressed to the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.”

INTRODUCTION

Neutrons in a tokamak plasma are mainly produced via thermal fusion reactions and reactions between accelerated ions and the thermal plasma, due to the application of auxiliary plasma heating systems like Neutral Beam Injection (NBI) and Ion Cyclotron Resonance Frequency (ICRF). Properties of the energy distribution functions of thermal and high energy ions can be determined by measuring the spectral distribution of the neutron fluence [1-4]. During the 2003 JET Trace Tritium Experimental (TTE) campaign [5,6] a compact broadband neutron spectrometer was operated to acquire pulse height spectra of the neutron emission from different TTE plasma scenarios with NBI, ICRF and combined NBI+ICRF heating schemes. Experimental neutron spectra have been determined with newly developed data analysis techniques and unfolding codes finding satisfactory agreement with theoretical spectra calculated by means of the Monte Carlo neutron kinematics code FPS [7] which takes into account the various parameters of the investigated plasma scenarios.

1. INSTRUMENTATION AND DATA ANALYSIS

The development and improvement of plasma measuring techniques are among the objectives of the EFDA JET programme. Within this frame, the diagnostic capabilities of a compact broadband neutron spectrometer have been successfully assessed in a real fusion experiment such as JET providing useful information for the determination of the various contributions to the neutron emission taking place with different heating schemes.

The compact neutron spectrometer is based on the NE213 liquid scintillator which has neutron/gamma discrimination properties and is well suited for high energy resolution spectrometry in mixed n/γ fields [8]. Particular features are: its compactness, detailed knowledge of the detector response function and photomultiplier gain control. The device was fully characterized for neutron detection ($1.5\text{MeV} < E_n < 20\text{MeV}$) at the Physikalisch-Technische Bundesanstalt accelerator facility. The detector was installed in the JET roof laboratory, viewing vertically at the plasma (major radius $R = 2.95$m) through a collimator in the biological shield achieving energy resolutions of $\Delta E/E < 4$ % at $E_n = 2.5$MeV and of $\Delta E/E < 2$ % at $E_n = 14$ MeV [9].

By taking into account the various measured parameters of the investigated plasma scenarios and heating diagnostics, an evaluation of theoretical neutron spectra has been carried out with the FPS Monte Carlo code. This code provides spectra of the different neutron emission components, due respectively to thermal and to high energy ions-plasma bulk reactions. Neutral beam accelerated ions are slowed down in the plasma bulk whereas the ICRF heating accelerate ions perpendicularly to the magnetic field to energies up to the MeV range. The ICRF heating can be approximated with a two maxwellian distribution with perpendicular and parallel temperatures representing the ion energy distribution in the plasma [1-4].

During the measurements Pulse Height Spectra (PHS) of the light output in terms of equivalent electron energies (E_e) are acquired [8]. The discretized neutron spectrum j_i is related to the measured number of counts N_k in channel k of the PHS by $N_k + e_k = \Sigma R_{ki}\varphi_i$, where R_{ki} is the response matrix of the detector, i.e. the relationship between neutron energy and light output, and e_k is a term that allows for experimental uncertainty. We first unfolded the measured PHS data using the code MAXED [10] with a constant default spectrum as input, for a first step of exploratory data analysis. We then evaluated the neutron spectrum using Bayesian methods. To do this, we introduced a parametrized model of the neutron spectrum made up of different components estimated with the FPS code (i.e. thermal, NBI, ICRF) and defined parameters for the unknown fractions. We folded each of the components with the response functions and generated a set of model PHS to be compared with the measured PHS. We then determined the parameters using Bayesian parameter estimation [11].

2. NEUTRON ENERGY SPECTRA

We report the results (see table 1) of the analysis performed within time intervals where plasma conditions were stationary. Beam-beam as well as impurities-plasma reactions play a minor role and have been neglected.

2.1. 2.5 MEV NEUTRONS WITH NBI HEATING ONLY.

Plasma discharge 61039 is a low temperature plasma scenario with 3 MW total power injected of only deuterium NBI heating.

Comparison of the measured PHS with the PHS that results from folding the evaluated neutron spectrum with the response function is shown in fig.1, finding good agreement. The neutron spectrum is reported in fig.2 with a thermal contribution less than 1% and the beam-plasma one > 99%. Shot 61206 is a discharge with higher level of NBI power and the contributions to the neutron emission for the thermal and beam plasma components are 26 % and 74 %, respectively.

2.2. 2.5 MEV NEUTRONS WITH COMBINED NBI+ICRF HEATING.

The discharge 61112 is a typical “low temperature ELMy H-mode” plasma scenario [12] with combined heating schemes, i.e. deuteron neutral beams plus ICRF heating tuned on the proton minority, ICRF-(H)D. The plasma has been heated with 3.5MW of NBI (as in 61039) and with 6MW RF polychromatic mode which has a large resonant region between 2.8m and 3.05m of the major radius *R*.

A recent study [13] has been carried out to investigate if the ICRF-(H)D scenario can affect the deuteron distribution function. Analysis based on the PION code indicates that such ICRF scenarios can produce an accelerated deuteron component which contributes to the total neutron emission besides the other beam-plasma and plasma-plasma (i.e. thermal) reactions. There is good agreement between the measured PHS and the PHS that results from folding the evaluated neutron spectrum with the response functions (fig.3). The small disagreement for E_e > 0.9MeV is caused by the presence of 14MeV neutrons which have not been taken into account in the analysis. The ICRF fraction is ~ 9% (as determined by the median of its probability density) and the thermal and beam plasma fractions are ~ 17% and ~ 73% (fig.4), whereas for the ICRF low power Pulse No: 61118 the thermal (~40%) and NBI (~59%) components are dominant. The probability density of the ICRF fraction parameter of Pulse No: 61112 has a long tail, and a fraction ~15% is not excluded by the data. Due to the limited statistics of the PHS, the analysis is somewhat insensitive to the precise ICRF temperature, and here we have assumed a ICRF deuteron suprathermal population with a perpendicular tail temperature of 20keV based on the initial exploratory data analysis done with the MAXED unfolding code.

2.3. 14 MEV NEUTRONS WITH RF HEATING ONLY.

New heating schemes have been performed during TTE, such as the ICRF minority tritium heating (T)D experiments [14] where the whole neutron emission is only due to the 14MeV neutrons induced by reactions of high energy ICRF accelerated tritons with thermal deuterons.

Due to the limited statistics in the pulse height spectrum (fig.5), details of the spectral shape can not be unambiguously resolved. By assuming a Gaussian shape the evaluation corresponding to Pulse No: 61280 indicates a full width half maximum of 1850keV corresponding to a high energy equivalent perpendicular temperature of 120keV. The 61280 neutron spectrum is shown in fig.6 and the comparison of the measured and evaluated pulse height spectra in fig.5, finding again good agreement. The results of the present neutron spectra analysis are summarized in table 1.

CONCLUSIONS

The diagnostic capabilities of a compact NE213 broadband neutron spectrometer in a real fusion experiment have been assessed by performing neutron energy measurements at JET. A method has been developed which allows to quantitatively determine the contribution of the various neutron production mechanisms taking place in different plasma scenarios with various heating schemes. Further analysis will be carried out on more plasma discharges for a more detailed investigation of the fast particle interactions with the plasma and on the analysis of uncertainties.

R&D activity is in progress on compact neutron spectrometers aiming at high counting rates operation with new developed digital acquisition systems [15] and at a complete assessment of the diagnostic capabilities for burning plasma diagnostic at JET-EP and ITER [16, 17].

ACKNOWLEDGEMENTS

The authors wish to thank for their assistance and discussions J.M.Adams, B.Esposito, T.Johnson, H.Klein, P.Lamalle, M.Mayoral, S.Popovichev, M.Santala. This work was performed under the European Fusion Development Agreement.

REFERENCES

[1]. O.N. Jarvis, Nucl. Instrum. Methods Phys. Res. A 476 (2002) 474

[2] . B.Wolle, Physics Report **312**, 1-2 (1999)

[3] . W. W.Heidbrink and G. Sadler, Nucl. Fusion **34** (1994) 535

[4]. N.P.Hawkes et al., Nucl. Instrum. Methods Phys. Res. A 476 (2002) 490

[5]. K-D. Zastrow et al., Plasma Phys. Controlled Fusion **46** (2004) B255

[6]. D. Stork et al., “Overview of Transport, Fast Particle and Heating and Current Drive Physics using Tritium in JET plasmas”, submitted to Nuclear Fusion

[7]. P. van Belle, G. Sadler in: P.E.Stott et al. (Eds), Course and Workshop on Basic and Advanced Diagnostic techniques for Fusion Plasma, Varenna, Vol III, CEC, Brussels EUR10797, 1986, pg 767

[8]. H. Klein and S. Neumann, Nucl. Instrum. Methods Phys. Res. A 476 (2002) 132

[9]. A. Zimbal et al., Rev. Sci.Instrum. **75** (2004) 3553

[10]. M. Reginatto, P. Goldhagen and S. Neumann, Nucl. Instr. and Meth. A 476 (2002) 242

[11]. D. S. Sivia, “Data Analysis - A Bayesian Tutorial” (Clarendon Press, Oxford, 1996).

[12]. G Bonheure et al., Paper/poster P1.083, these proceedings

[13]. M.Mayoral and T. Johnson, “ ICRF effect on deuteron in the combined Heating ELMy H-modes: PION Analysis”, EFDA JET -TF DT meeting 17/11/2004, Culham Research Center, UK

[14]. P.U. Lamalle et al., “Expanding the operating space of ICRF on JET with a view to ITER” to be submitted to Nuclear Fusion

[15]. B. Esposito et al., Rev. Sci.Instrum. **75** (2004) 3550

[16]. L. Bertalot et al., “ITER relevant develpments of neutron diagnostics during JET Trace Tritium Experiment”, to appear in Fus. Eng. and Design (2005)

[17]. A.Murari et al., Invited Talk I5.0001 these proceedings

Shot number	*Acquisition time start/end (s)*	*NBI/ICRF power (MW)*	*RF tail temperature (keV)*	*Fraction of neutron fluence(%)*		
				Thermal	*NBI*	*ICRF*
61039 DD	*55/65*	*3/−−*	*−−*	*<1*	*99*	*−−*
61206 DD	*60/63*	*8/−−*	*−−*	*26*	*74*	*−−*
61112 DD	*59/62*	*2/6*	*20*	*17*	*73*	*9*
61118 DD	*57/60*	*10/2*	*5*	*40*	*59*	*<1*
61280 DD	*46.5/49*	*−−/1.5*	*120*	*−−*	*−−*	*100*

Table 1. Shots investigated and observed contributions to the neutron emission

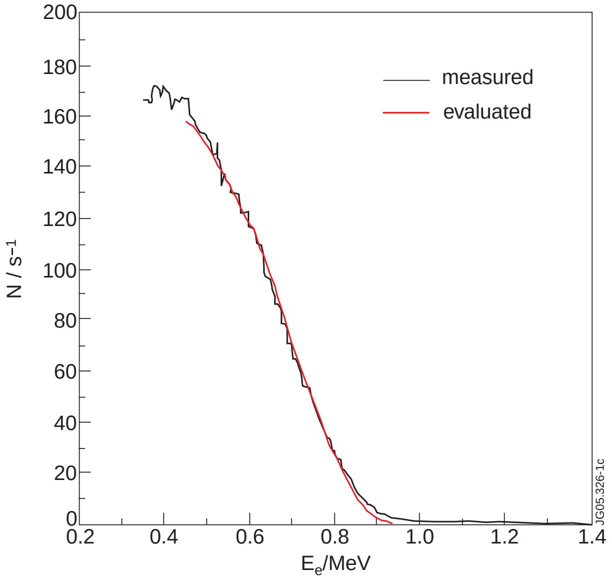

Figure 1: Pulse No: 61039 Measured and evaluated PHS

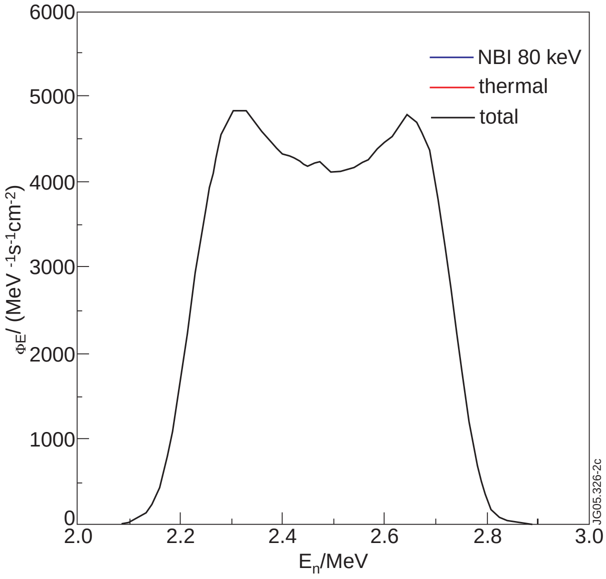

Figure 2: Pulse No: 61039 neutron spectrum

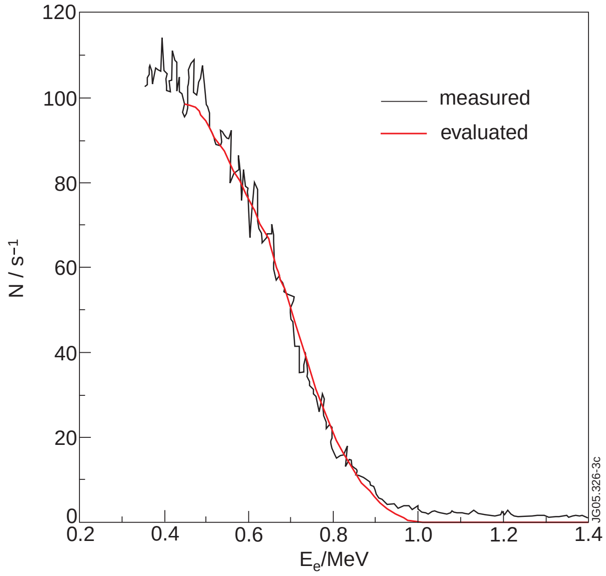

Figure 3: Pulse No: 61112 Measured and evaluated PHS

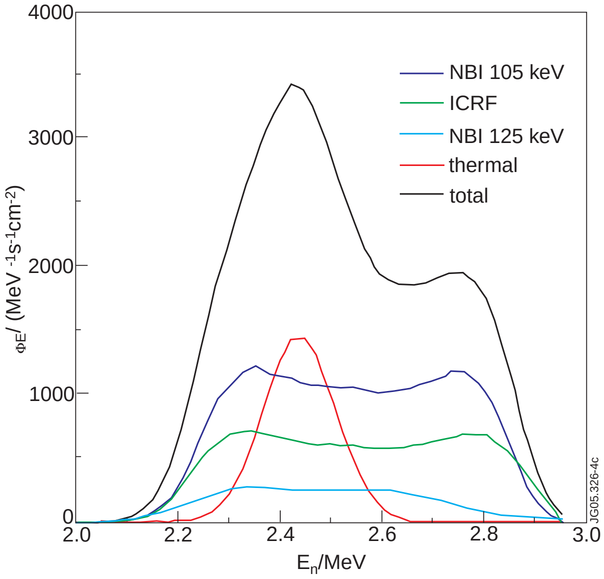

Figure 4: Pulse No: Shot 61112 neutron spectrum

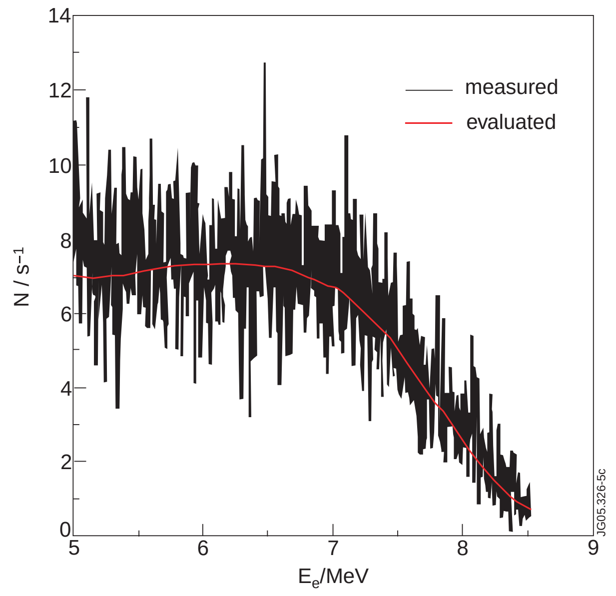

Figure 5: Pulse No: 61280 Measured and theoretical PHS

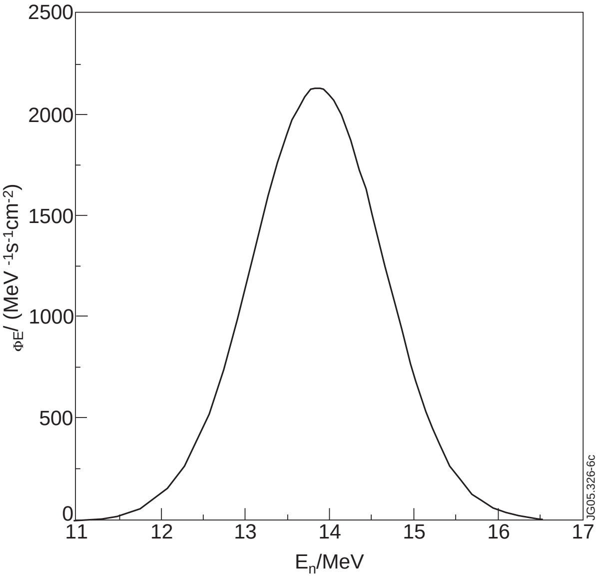

Figure 6: Pulse No: Shot 61280 neutron spectrum