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G.Gorini, S.Conroy, G.Ericsson, L.Giacomelli, H.Henriksson,
A.Hjalmarsson, J. Källne, M.Tardocchi
and JET EFDA Contributors

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G.Gorini[1], S.Conroy[2], G.Ericsson[2], L.Giacomelli[1], H.Henriksson[2],
A.Hjalmarsson[2], J. Källne[2], M.Tardocchi[1]
and JET EFDA Contributors

EURATOM-UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 4XB, United Kingdom.
[1]INFM, Physics Department, Milano - Bicocca University,
and Plasma Physics Institute, EURATOM-ENEA-CNR Association, Milan, Italy
[2]Department of Neutron Research,Uppsala University,EURATOM-VR Association,Uppsala, Sweden
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ABSTRACT.

The DT experimental campaign on JET (1997) represented a major step forward for neutron emission spectroscopy (NES) diagnostics thanks to the high count rate measurements obtained with the magnetic proton recoil (MPR) neutron spectrometer in high fusion yield plasmas [1]. NES measurements were made on JET DT plasmas for different heating conditions including those generating energetic deuterons either directly through NB injection, or through ICRH acceleration using the (D)T minority scheme [2]. A multiple-component model has been developed for analysis of dt neutron spectra that is based on a simplified description of fuel ion velocity distributions for different heating conditions [3,4]. The same model is used here for projections of NES spectra from JET deuterium plasmas using the dt results as input. This is done on the basis of a system of two complementary NES instruments, the TOFOR (Time of Flight - Optimized Rate) [5] and MPRu (Magnetic Proton Recoil Upgrade) spectrometers that are presently proposed for installation on JET [6]. Both spectrometers would record neutron spectra in D plasmas but for different viewing lines. TOFOR would have a "vertical" view, i.e. at an angle of 90° relative to the toroidal magnetic field. This is the same viewing line used for some of the previous dd NES measurements on JET [7]. MPRu would have a "tangential" view, i.e. horizontal (on the equatorial plane) at an angle of 47° relative to the toroidal magnetic field and opposite to the beam injection direction. This is the same viewing line used for the 1997 dt measurements using the magnetic proton recoil (MPR) spectrometer.

Projections of dd neutron spectra under the assumptions above are used here for an assessment of the performance and requirements of NES as a diagnostic of energetic deuterons in JET.

1. MODELLING OF NEUTRON SPECTRA

The model neutron spectrum used for projections is the sum of two components. The first component (High Energy, HE) is due to energetic deuterons. These are strongly anisotropic and have different distributions for NBI and ICRH heating. In the ICRH case, a Maxwellian energy distribution is assumed but restricted to the pitch angle range 90°±10° ("RF" model distribution); its temperature (T_{HE}) is a free parameter in the fit. In the NBI case, a uniform energy distribution is assumed for 75 keV<E_d<150keV in the pitch angle range 60°±15° in the "counter" direction relative to the tangential NES view ("half box" model distribution). The second component (Bulk, B) is due to thermal deuterons plus what we refer to as "epithermal" deuterons. These are deuterons that are close to thermal, isotropic conditions, as is the case, for instance, of NBI deuterons after they are slowed down to a fraction of their initial energy. A single Maxwellian (temperature TB, free parameter) is assumed to model both thermal and epithermal deuterons.

NES spectra that best fit measured dt spectra for reference JET discharges are shown in Fig. 1-2. The model parameters (both input and output) are shown in Table 1, where $c_d = n_d/(n_H+n_d+n_t)$ is the relative deuteron concentration and A denotes the relative amplitude of the spectral components. To be noted is the double hump shape of the HE component (this is most easily explained for the ICRH case when viewed orthogonally [3]). HE components dominate on the high-energy side of the spectrum (above 14.4 and 14.6MeV in the ICRH and NBI case, respectively). Their detectability on the low energy side is hampered by background in the measured NES spectra.

From the intensity of the spectral components the relative density of the bulk and high energy deuterons is determined. The deuteron distribution is thus completely specified but for a global scale factor. Note that a 0-D model is assumed; i.e. all profile effects (such as the RF and NBI power deposition, particle diffusion, orbit size) are not considered for simplicity. The neutron spectrum is in any case representative of the plasma properties in the core plasma region.

2. PROJECTION TO DEUTERIUM PLASMAS

The deuteron velocity distribution specified by the dt spectra is used as input to project NES spectra for dd reactions. A Monte Carlo code is available for this purpose. Strictly speaking, these are simulations of dd NES spectra from the same dt plasmas. However they can be assumed to represent certain features of dd spectra in a more general sense.

A two-component deuteron distribution yields three dd NES spectral components: i) Bulk-Bulk (B), ii) Bulk-HE (HE), iii) HE-HE (fast, F). These are reminiscent of the usual “thermal”, “beam-plasma”, and “beam-beam” components. Note however, that the Bulk component here includes an epithermal part accounting for a large fraction of “beam” deuterons. Hence the Fast component is always very small. Also, Bulk deuterons can have different effective temperatures depending on the reaction considered. The latter effect is disregarded here. The projection results are presented below for the two types of heating.

3. ICRH D-PLASMA

Most striking is the intensity of the HE component in the ICRH case (Fig. 3-4), accounting for about 75% of the dd neutrons (see Table 2), i.e., 5 times the relative HE intensity in the dt case. This is a very large extrapolation, which nevertheless indicates a clear trend: energetic deuterons are more easily detected in dd rather than in dt plasmas due to the stronger energy dependence of the dd fusion cross section compared to dt. Another noticeable difference compared to dt is the asymmetry of the HE component; this is due to the (backward/forward) asymmetry of the dd cross section. The projected spectra indicate that the energy bite required to detect ICRH dd NES spectra at 10^{-3} intensity would be 1.6-4.2 MeV for a 90° view. This is a very broad energy bite that will require special efforts to be met by NES diagnostics. A further requirement relates to the intensity of the HE component in D plasmas. As 2nd harmonic heating of (H)D-plasmas is not nearly as efficient as fundamental (D)T heating, much weaker HE deuteron components can be expected in D plasmas. This explains why previous low count rate NES measurements in D-plasmas did not detect strong non-thermal features with ICRH. High count rate capability and good background discrimination will be required for diagnosing energetic deuterons from ICRH in D plasmas.

4. NBI D-PLASMA

At 47° view (Fig.5), NBI deuterons give rise to a marked asymmetry in the NES dd spectrum. The HE intensity is enhanced over the dt case (though not as much as with ICRH). The HE component dominates above 2.6MeV. Note that it is the Fast component (at the 1% level) that dominates above 3MeV. This is a distinct feature that could be detected if statistics and energy bite allow for. The energy bite required to detect NBI dd NES spectra at 10^{-3} intensity would be 2.0-3.1MeV, i.e. not as demanding as in the ICRH case.

At 90° view (Fig.6), the strong asymmetry of the HE component is lost and the overall shape is triangular. The Fast component is not detectable in practice (it is out of range) and also the HE component is not very well separated from Bulk. The strong anisotropy of the HE component can be used to enhance its detectability by combining multiple NES measurements from different viewing lines, if these are available.

These projection are in qualitative agreement with previous NES measurements in D-plasmas [7]: in particular, observations with 90° view and 80 keV NBI are in qualitative agreement with the simulation of Fig.6.

CONCLUSIONS

Preliminary results indicate that, for the same fast deuteron content in D and DT plasmas, the high energy component in the 2.5-MeV neutron spectrum is strongly enhanced over that of the 14-MeV one reflecting the energy dependencies of the d+d-τ+n and d+t->α+n cross sections. This would make the task of detecting energetic deuterons relatively easier in D-plasmas compared to DT. Since the energetic components are anisotropic, much better separation can be achieved by a multiple viewing-line system; e.g., a tangential view is required in order to unambiguously detect the neutron emission from beam deuterons. On the other hand, isotropic components (epithermal) are featureless and generally undistinguishable from thermal.

The main requirements for NES diagnostics in D-plasmas are a large neutron energy bite (≈factor 2) and high signal/background ratio (s/b>>100). If these requirements can be met, a NES system installed on JET would provide unique information on energetic deuterons from ICRH, NBI or combinations of heating methods (including synergetic effects).

In the case of NB heating, a two-component NES model (“bulk”, B, and “high energy”, HE) has proven to work well for DT. The same model was assumed here for NES simulations in D-plasmas. A conversion from our empirical B/HE ratio into the conventional ratio of thermal and beam-plasma components, as simulated, for instance, by the TRANSP code, is presently being investigated.

ACKNOWLEDGEMENTS

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Discharge (#)	Viewing Angle (°)	Heating Type	A_B (%)	A_{HE} (%)	$c^d{}_B$ (%)	$c^d{}_{HE}$ (%)	T_B (keV)	T_{HE} (keV)	$T_{TRITIUM}$ (keV)
42769	47°	ICRH	63±0.8	37±0.6	17.3	0.7	8.0±0.2	109.4±3.7	8.0±0.2
43134	47°	NBI	73±2.3	27±1.6	83.6	6.4	15.4±0.7		15.4±0.7

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Table 1: NES spectra parameters for the reference JET DT plasma discharges

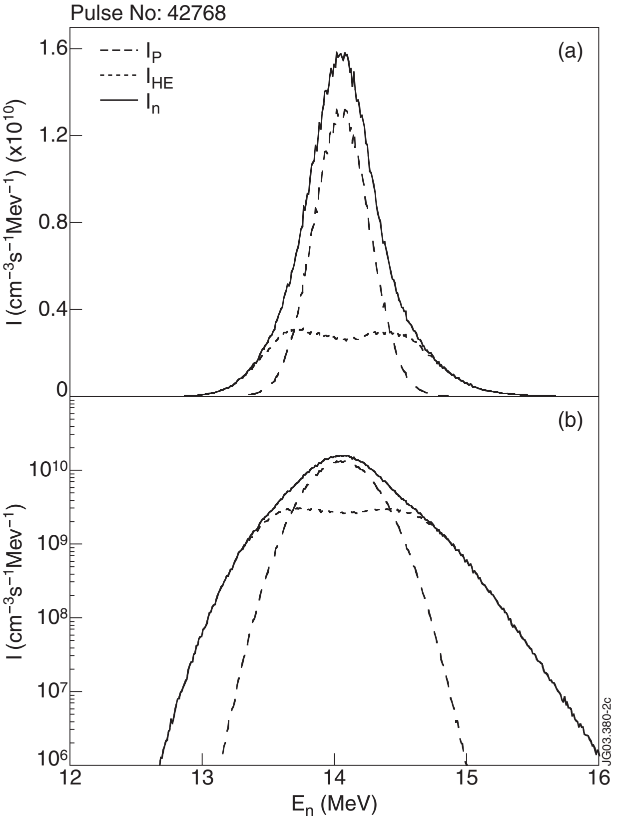

Figure 1: NES spectra fitted to the NES data of JET Pulse No: 42769 (ICRH discharge) plotted on (a) linear and (b) log scale. The full line (In) is the sum of Bulk (IB) and High Energy (IHE) components.

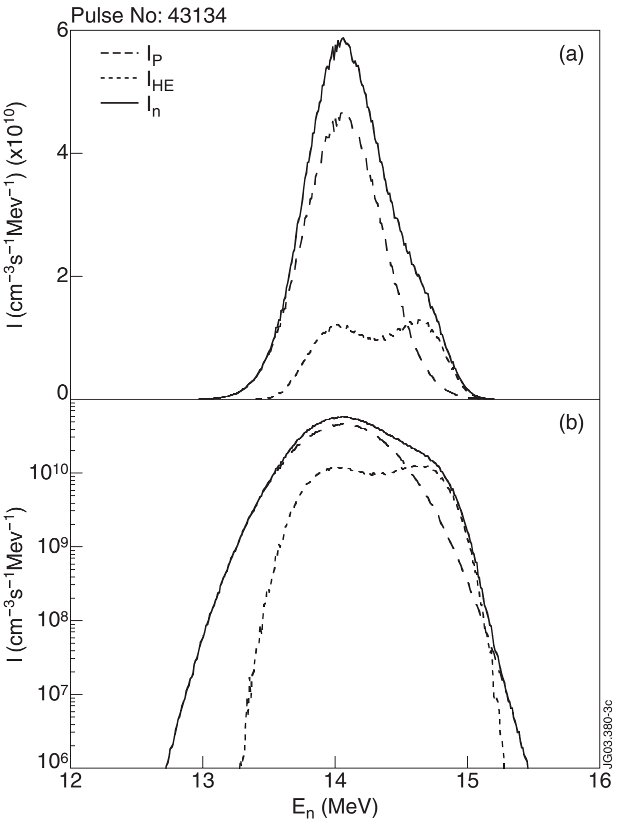

Figure 2: Same as Fig. 1 but for JET Pulse No: 43134.

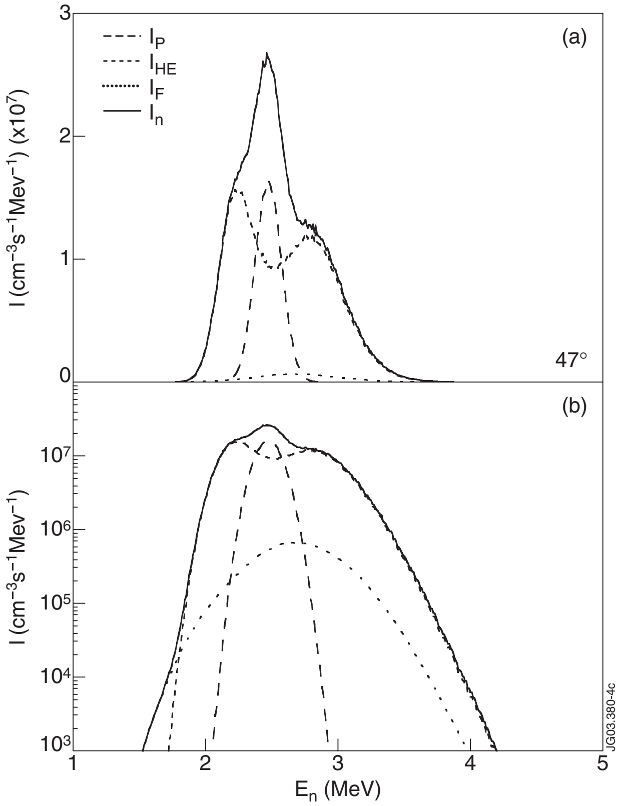

Figure 3: NES spectra for the same conditions as Fig.1 (ICRH discharge) but for the dd reaction, plotted on (a) linear and (b) log scale. The full line (In) is the sum of Bulk (IB), High Energy (IHE) and Fast (IF) components.

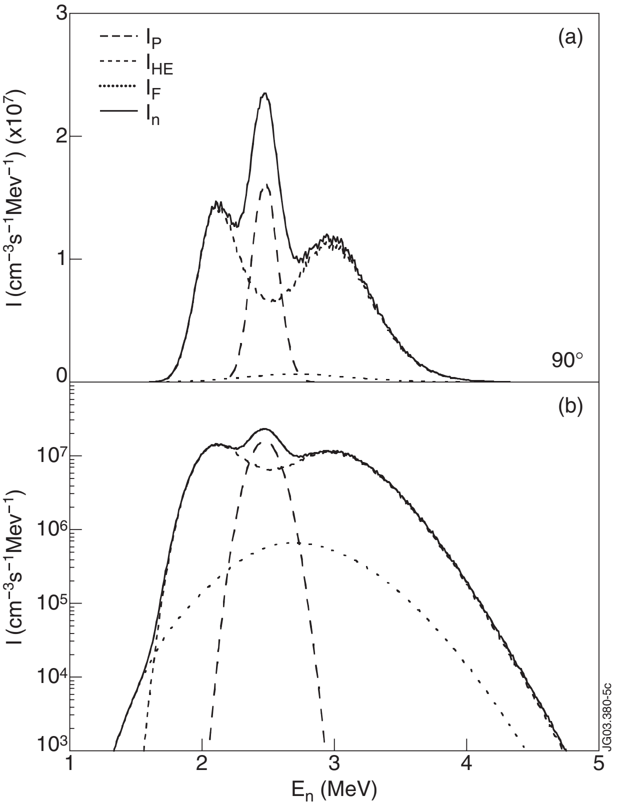

Figure 4: Same as Fig.3 but for a 90° viewing angle (vertical view).

Discharge (#)	Viewing Angle (°)	Heating Type	A_B (%)	A_{HE} (%)	$c^d{}_B$ (%)	$c^d{}_{HE}$ (%)	T_B (keV)	T_{HE} (keV)
42769	47°	ICRH	23.8	73	96	4	8	109.4
42769	90°	ICRH	20.5	76	96	4	8	109.4
43134	47°	NBI	56.4	40.5	93	7	15.4	
43134	90°	NBI	56.2	40.3	93	7	15.4	

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Table 2: Spectra parameters for dd NES simulation

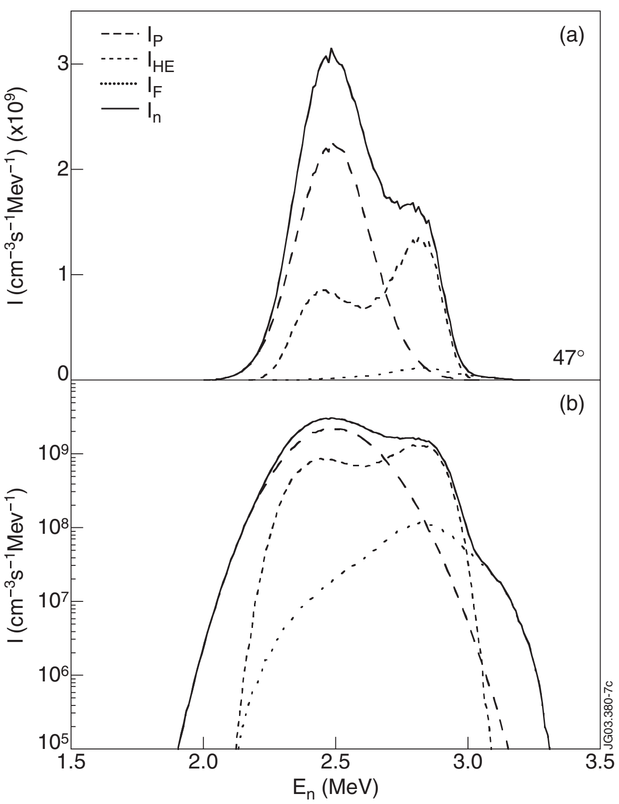

Figure 5: Same as Fig.3 but for the same conditions as Fig.2 (NBI discharge).

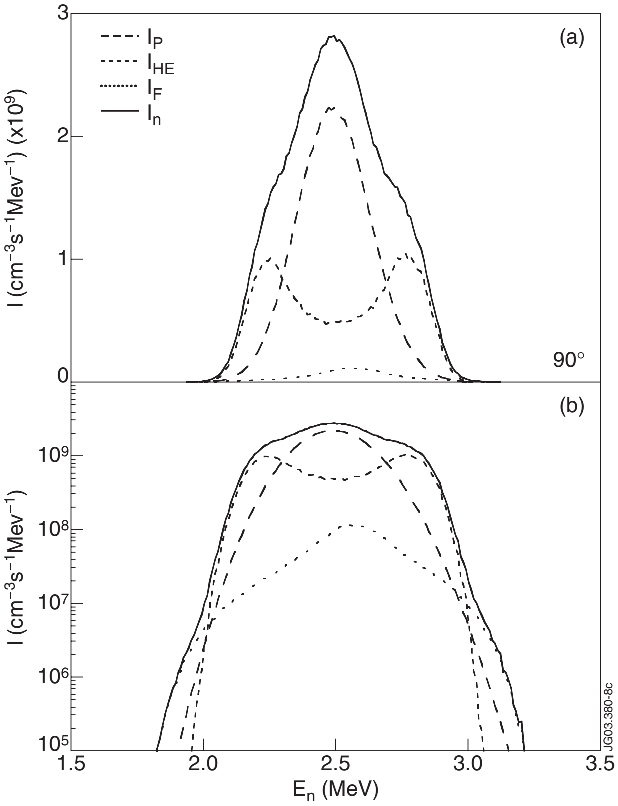

Figure 6: Same as Fig.4 but for a 90° viewing angle (vertical view).