PROJECTED NEUTRON EMISSION SPECTROSCOPY DIAGNOSIS OF JET DEUTERIUM PLASMAS

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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 such as NB injection or ICRH using, e.g., 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 MPR spectrometer.

Projections of dd neutron spectra under the assumptions above are used here for an assessment of the performance and requirements of NES in JET D-plasmas. 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,

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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<150 keV 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 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 T_B, free parameter) is assumed to model both thermal and epithermal deuterons.

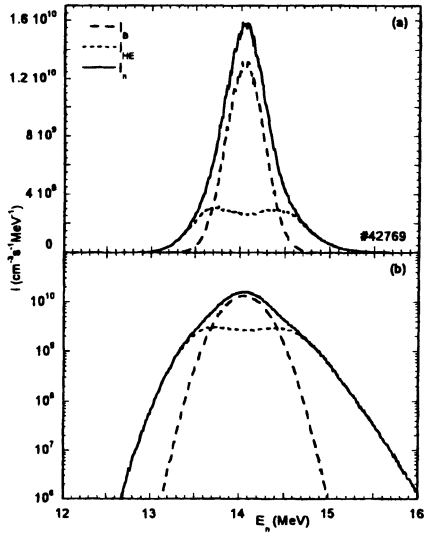
NES spectra fitted to measured DT spectra for reference JET discharges are shown in Fig. 1-2. The model parameters (both input and output) are shown in Table 1. To be noted is the double hump shape of the HE component. HE components dominate on the high-energy side of the spectrum (above 14.4 and 14.6 MeV in the ICRH and NBI case, respectively); their detectability on the low energy side is hampered by background. 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.

The deuteron velocity distributions specified by the DT spectra are used as input to project NES spectra for dd reactions using a Monte Carlo code. 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 projection results have different features depending on the type of heating. In the ICRH case, 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. High count rate capability and good background discrimination will be required for diagnosing energetic deuterons from ICRH in D plasmas.

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

discharge (#)	heating type	A_B (%)	A_{HE} (%)	c^d_B (%)	c^d_{HE} (%)	T_B (keV)	T_{HE} (keV)
42769	ICRH	63±0.8	37±0.6	17.3	0.7	8.0±0.2	109.4±3.7
43134	NBI	73±2.3	27±1.6	83.6	6.4	15.4±0.7	



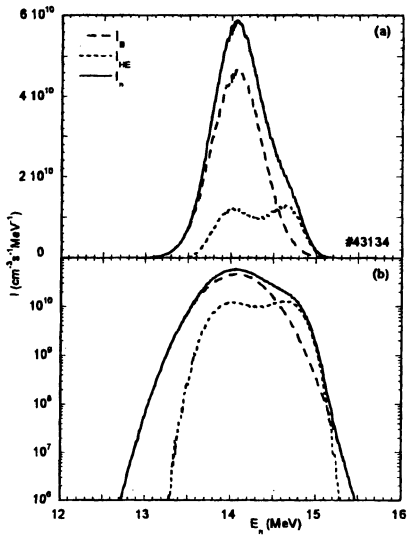
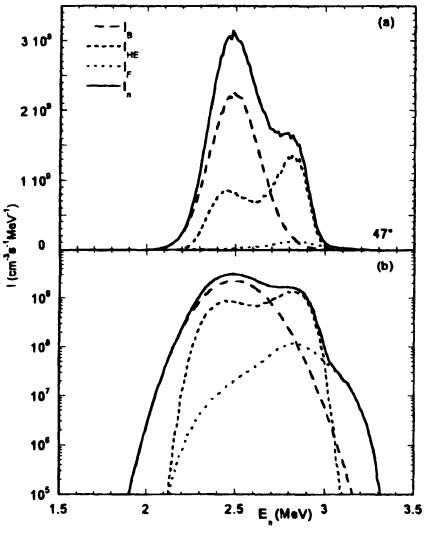


Figure 1. NES spectra fitted to the NES data of JET discharge # 42769 (ICRH discharge) plotted on (a) linear and (b) log scale. The full line (I_n) is the sum of Bulk (I_B) and High Energy (I_{HE}) components, see text.
Figure 2. Same as Fig. 1 but for JET discharge # 43134 (NBI discharge).



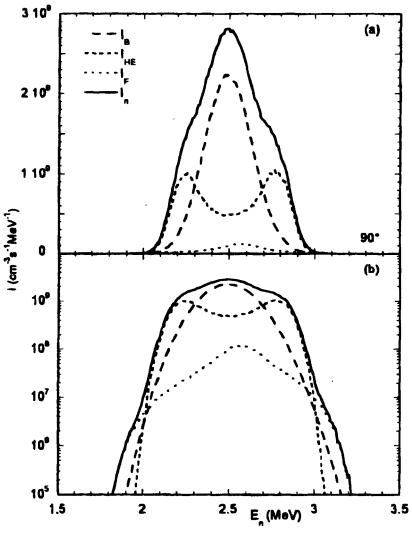


Figure 3. NES spectra for the same conditions as Fig.2 (NBI discharge) but for the dd reaction, plotted on (a) linear and (b) log scale. The full line (I_n) is the sum of Bulk (I_B), High Energy (I_{HE}) and Fast (I_F) components.
Figure 4. Same as Fig.3 but for a 90° viewing angle.

In the case of NBI heating, HE neutrons give rise to a marked asymmetry in the NES dd spectrum at 47° view (Fig.3). The HE component is enhanced over the DT case and dominates above 2.6 MeV. Note that it is the Fast component (at the 1% level) that dominates above 3 MeV. 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 2.0-3.1 MeV, i.e. not as demanding as in the ICRH case.

At 90° view (Fig.4), 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.4.

In conclusion, 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 enhanced over that of the 14-MeV one reflecting the energy dependencies of the $d+d \rightarrow {}^3He+n$ and $d+t \rightarrow \alpha+n$ 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. 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.

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