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Cross-validation of JET fast deuterium results from TOFOR and NPA

M. Gatu Johnson[1], M. Cecconello[1], C. Hellesen[1], E. Andersson Sundén[1], S. Conroy[1], G. Ericsson[1], G. Gorini[2], E.Ronchi[1], M. Tardocchi[2], M. Weiszflog[1] and JET-EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1] Department of Physics and Astronomy, Uppsala University, Box 525, SE-75120 Uppsala, Sweden (EURATOM-VR Association)

[2] Physics Department, Milano-Bicocca University, and Istituto di Fisica del Plasma del CNR, Milan, Italy (EURATOM-ENEA-CNR Association)

1. Introduction

The neutron time-of-flight spectrometer TOFOR [1] and the low- and high-energy Neutral Particle Analyzers (NPA) KR2 [2] and KF1 [3] are instruments capable of indirectly diagnosing fast deuterium ions at JET. The diagnostics rely on different physical processes: neutron emission from fusion reactions and neutrals emission by charge exchange. Modeling has been developed to derive the Energy Distribution Functions (EDFs) of fast deuterons based on the measured data. This work presents the first cross-validation of EDFs obtained independently from TOFOR and KF1 (with overlapping energy ranges). The validation of TOFOR and NPA measurements is important to form a solid basis for the fast ion diagnostic techniques to provide reliable information in the ITER relevant energy region E_d<1 MeV.

2. Instrument description

TOFOR has a vertical line of sight through the plasma in octant 8 centered at R = 2.88 m and is optimized for the observation of 2.5 MeV neutrons, with no upper limit on detectable neutron energies. A population of highly energetic deuterons results in a broad neutron energy spectrum: for example, the neutron energy spectrum generated by ICRH driven deuterons with an energy of 1.5 MeV would span the range $1.5 < E_n < 4.8$ MeV. TOFOR has been successfully used to diagnose deuterium ions with energies $E_d < 3.5$ MeV [4]. KF1, sitting on top of octant 4, is also characterized by a vertical line of sight, located at R = 3.14 m, with a narrow field of view crossing the neutral beams injected from the octant 4 NBI. With this geometry, the neutral fluxes observed with KF1 include a two-component population: the isotropic bulk population with a temperature equal to the parallel (bulk) temperature and an anisotropic population with a much higher temperature resulting from the ICRH accelerated ions. The largest contribution to the anisotropic population comes from energetic deuterons

* See the Appendix of F. Romanelli et al., Fusion Energy Conference 2008 (Proc. 22nd Int. FEC Geneva, 2008) IAEA, (2008)

with banana orbit tips on the NPA line of sight and in the ICRH resonance layer. For this study, deuterium atoms were measured in the energy range $0.3 < E_d < 1.1$ MeV. KR2 is also located in octant 4, with a radial view of the plasma intercepting the octant 4 NBI beams and is used to measure deuterons in the region 125-375 keV.

3. Experiment

The plasmas considered in this study are deuterium plasmas with deuterium neutral beam injection heated by Ion Cyclotron Resonance Heating (ICRH) of the 2nd harmonic. The main pulse studied is 69247, with the RF resonance layer R_{RF} located at 3.0 m. The position of R_{RF} is crucial: Pulses 69249 (R_{RF} = 3.4 m) and 69250 (R_{RF} = 2.7 m) were also considered, but with the resonance layer lying outside the field of view of one or both instruments, the count rates were so low that no reliable information on the fast deuterium EDF could be obtained.

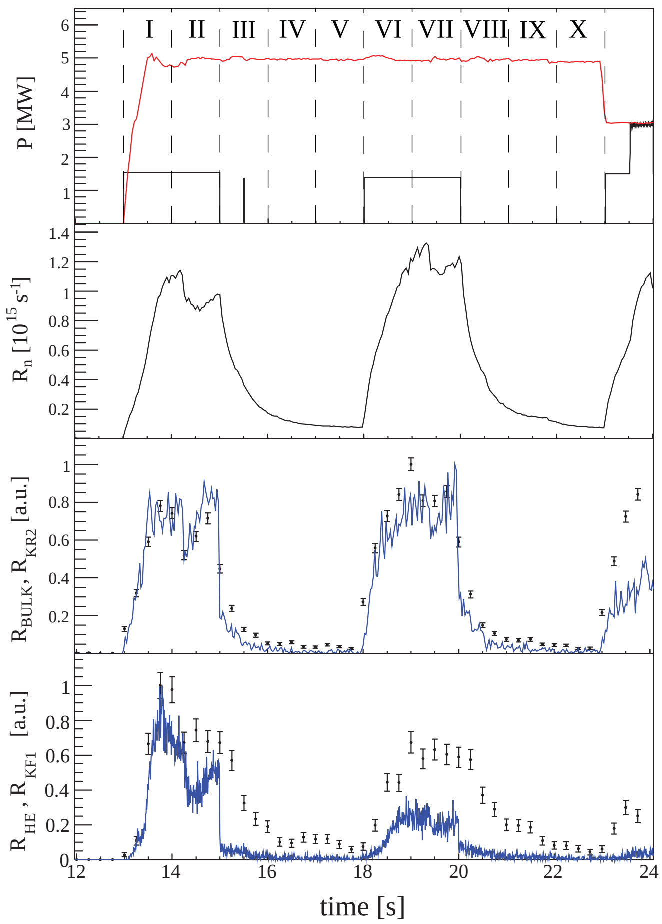

Figure 1: *Plasma parameters for JET pulse 69247. Top panel: NBI (black) and RF (red) heating power; also indicated are the 1 s regions of study (roman numerals). Second panel: total neutron rate (fission chambers). Third panel: normalized count rate for the low energy NPA (KR2) and the bulk region of the TOFOR spectrum. Bottom panel: normalized count rate for the high energy NPA (KF1) and the high-energy region of the TOFOR spectrum.*

Relevant plasma parameters for pulse 69247 are illustrated in figure 1. The count rates from KR2 ($0.1 < E_d < 0.4$ MeV) and the bulk region of the TOFOR spectrum (dominated by $E_d < 0.3$ MeV) follow each other (and the total neutron emission from the fission chambers) quite well. The count rates from KF1 ($0.3 < E_d < 1.1$ MeV) and the high-energy region of the TOFOR spectrum ($E_d > 0.3$ MeV) however do not follow each other as closely. The rapid drop in KF1 count rates after the Neutral Beam Injection (NBI) is switched off is well understood since the NBI from octant 4 provides the necessary source of neutrals with which the fast deuterons can charge exchange. The data shown in the bottom panel have been normalized to their maximum values: it is not clear therefore if the disagreement between TOFOR and KF1 in time periods VI and VII is true or a consequence of the chosen normalization. It is clear however that the use of different PINIs from octant 4 (normal for I and II, tangential for VI and VII) affects KF1 significantly. Finally, it should be noted that the third NBI blip (at t=23 s) is from the octant 8 beam bank. This explains why the TOFOR count rates follow the KN1 rate in this region, while the NPA count rates are proportionally significantly lower.

4. The deuteron energy distribution function

The deuteron EDF is derived from the flight time spectrum measured by TOFOR through the Bayesian method described in [5]. To determine the absolute level of fast deuterons, the deuteron density is required: in this work, it has been assumed that $n_d = 0.7\ n_e$, where the electron density was obtained from the far-infrared interferometer (KG1) (LIDAR was not available for this pulse). An additional parameter necessary for the correct estimation of the number of fast deuterons is the neutron emitting volume in the TOFOR field of view [6]. The EDF of the energetic neutral D measured by KF1 has been calculated over 1 s time intervals from 53 to 63 s using the model described in [7]. Inputs to this model are the ion temperature, the electron density profile, the effective charge Z_{eff}, the relative concentrations of Be/C and He/C and the plasma elongation (time averaged in 1 s intervals). However, Z_{eff} and ion temperatures were not measured in the analyzed pulse. The former was assumed to be equal to 2 (assuming Z_{eff} = 4 did not modify the EDF significantly), while the second was set to $T_i = 0.8\ T_e$. The electron density profile from KG1 was used. The uncertainty in the EDF is determined by standard propagation technique of the uncertainty in the neutral counts (assumed to be governed by a Poisson distribution), in the neutron background noise, in instrumental uncertainties and in the uncertainties in the input plasma parameters.

5. Experimental results, discussion and conclusions

Figure 2 shows the EDFs for TOFOR and KF1 for the ten one-second time intervals indicated in figure 1. From left to right, the first two panels are during NBI beam blip, the middle panel right after beam blip and the last two panels during periods of RF heating only. No normalization is performed; the absolute level of fast deuterium is derived independently from the two diagnostics, using the assumptions described above. The development of the EDF over time can be seen to follow the heating applied, with a build-up of a population of highly energetic deuterons during the first second of NBI injection, a stable high-energy population during the second, a decline period after the beam is switched off followed by a decreased but significant presence of high-energy deuterons during the RF-only phase. The KF1 data during the RF only phase (IV,V,IX,X) are on the limit of statistical significance.

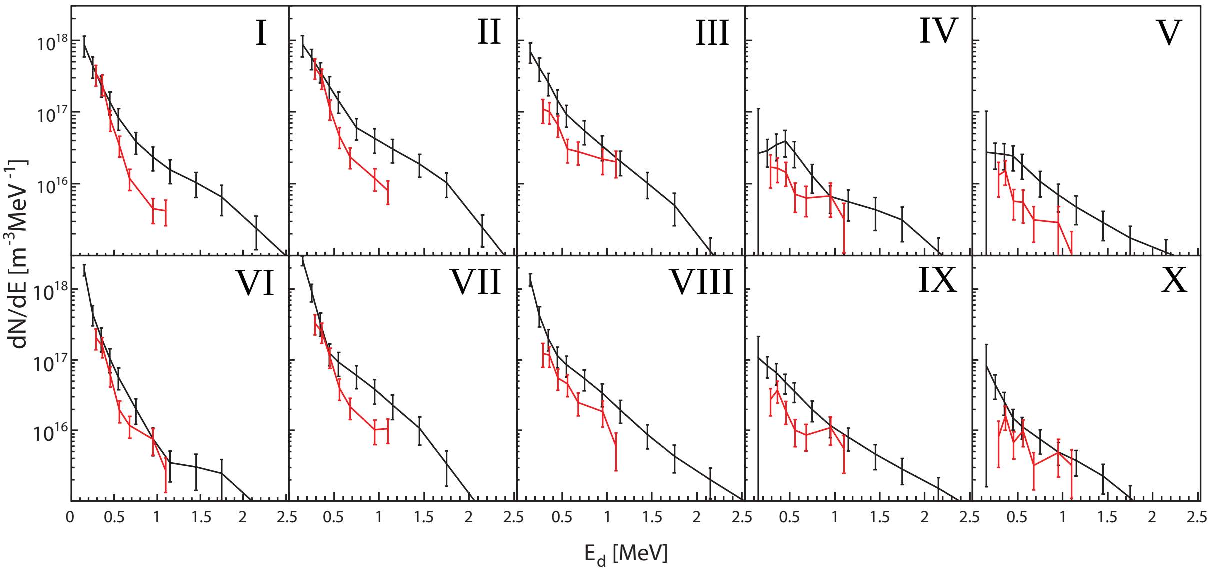

Figure 2. *Deuteron energy distributions derived from measured TOFOR (black) and KF1 (red) data using the modeling described in the text, for time period I-X of JET pulse 69247 indicated in figure 1.*

As can be seen in figure 2, the agreement between the EDFs derived from TOFOR and NPA data is good both in the presence of combined NBI and ICRH as well as during the phase of IRCH heating only. In general, the amplitude of the EDF from KF1 is consistently lower than the one derived from TOFOR: this discrepancy can be reduced by assuming a more parabolic profile for the electron density compared to the very flat one obtained from KG1. In addition to the small difference in the EDF absolute values, further differences can be seen in particular towards high deuterium energies in periods I, II and VII. This will be investigated further in a dedicated upcoming experiment at JET, where the effect of the line-of-sight and the NBI PINI selection on the derived distributions will be studied in detail.

6. References

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