EUROPEAN FUSION DEVELOPMENT AGREEMENT

EFDA–JET–CP(06)03-13

G. Gorini, E. Andersson Sundén, L. Ballabio, S. Conroy, G. Ericsson, M. Gatu Johnson, L. Giacomelli, C. Hellesen, A. Hjalmarsson, J. Källne, A. Murari, F. Ognissanto, H. Sjöstrand, E. Ronchi, M. Tardocchi, M. Weiszflog and JET-EFDA Contributors

High-Energy Fuel Ion Diagnostics on ITER Derived from Neutron Emission Spectroscopy Measurements on JET DT Plasmas

High-Energy Fuel Ion Diagnostics on ITER Derived from Neutron Emission Spectroscopy Measurements on JET DT Plasmas

G. Gorini[1], E. Andersson Sundén[2], L. Ballabio[1], S. Conroy[2], G. Ericsson[2], M. Gatu Johnson[2], L. Giacomelli[2], C. Hellesen[2], A. Hjalmarsson[2], J. Källne[2], A. Murari[3], F. Ognissanto[1], H. Sjöstrand[2], E. Ronchi[2], M. Tardocchi[1], M. Weiszflog[2] and JET-EFDA Contributors*

[1]*Istituto di Fisica del Plasma, EURATOM-ENEA-CNR Association, Milan, Italy*
[2]*INF, Uppsala University, EURATOM-VR Association, Uppsala, Sweden*
[3]*EURATOM-ENEA-CNR Association, Padova, Italy*

**Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

Preprint of Paper to be submitted for publication in Proceedings of the
33rd EPS Conference,
(Rome, Italy 19-23 June 2006)

High-energy fuel ion (HEFI) populations are created in plasmas subjected to neutral beam (NB) injection and ion cyclotron resonance heating (ICRH). These heating schemes were tested at JET in the DTE1 and TTE campaigns and diagnosed with the help of neutron emission spectroscopy (NES) [1]. The JET experience can be transferred to burning plasma studies on ITER but for suitable rescaling including differences in plasma size and conditions, besides machine operating parameters. The main differences are that ITER NB will use 1 MeV tangential D beams (compared with 130 keV at oblique angle in JET) leading to d deposition into circulating orbits with a pitch angle about 30°. ICRH will use different heating schemes including some resonating with T or D as tested on JET [2] and shown to produce HEFI populations with pitch angle ≈90° and "tail" temperatures $T_{\perp} \geq 100$ keV depending on power density conditions. Other sources of HEFI populations of both d and t of up to 3 MeV are the α+d and α+t knock-on collisions, which give rise to a so-called alpha knock-on neutron (AKN) signature in the emission spectrum [3]. With ITER temperatures in the 20-keV range, the AKN would make about 10^{-3} of the total emission compared to 10^{-5} for JET [4].

NB, ICRH and AKN induced HEFI components have all been the object of NES measurements on JET and models have been worked out for the analysis/interpretation of the data and projection to ITER. A "bulk" (B) component mostly due to thermal fuel ions is also included [5]. Synergies between NB and ICRH have also been observed [6] but are not considered here. The relative intensities of the HEFI components depend on plasma and heating conditions and were often found to dominate at JET for both NB and ICRH in high performance discharges. This is different from high performance ITER H-mode, which is estimated to be 99% thermal, or, $Q_{th}/Q=0.99$. Lower performance and transient conditions would give higher HEFI fractions and lower Q_{th}/Q ratio; not to forget, the experiments with lower Q_{th}/Q will have to pave the way to reach and optimize high performance conditions. NES diagnostics benefit from optimal separation of the signatures in the neutron spectrum. This has been studied for the ITER conditions in new Monte Carlo calculations of the neutron emission spectrum for different heating scenarios. An example of NES simulation is shown in Figure 1. This refers to a model ITER situation with a radial NES sight line. The neutron emission is assumed to consist of three components: a bulk component accounting for nearly 99% of the neutron emission, a NB component representing 1% of the bulk emission, and the AKN emission at an intensity level (≈0.1%) representative of steady-state plasma conditions for a temperature of 20 keV, The AKN component is taken from [4] where it is found that the AKN emission is dominant over the bulk in the energy region E_n>15.5 MeV; the integrated AKN intensity above 15.5 MeV is about 1/5000 of the total emission. The shape of the NB component is calculated for tangential injection at 33° pitch angle and 1 MeV deuteron energy using the simplified NES models developed at JET (see, e.g., [5]). Its effect is to shift upward (E_n>16.0 MeV) the energy range where AKN is dominant. The integrated AKN intensity above 16.0 MeV is about 1/15000 of the total emission. Thus, the presence of NB component in the spectrum does not preclude the observability of the AKN in this case but raises more demanding requirements on NES diagnostics in terms, e.g., of energy range and sensitivity. Also it would be rather difficult to derive any useful information on the NB component in this case since it is dominated by either bulk or AKN neutrons over most of the energy range.

In order to enhance the sensitivity of NES measurements to the NB component a counter-tangential sight line (147° pitch angle) was considered (see Fig.2). The NB component is dominant in the energy range 15 MeV < E_n < 17 MeV and can be easily distinguished from the other components even though it represents only 1% of the total neutron emission. Above 17 MeV the AKN is still visible although its intensity is below 10^{-4}. This is a low value but still higher than the JET observations [4] suggesting that the measurement may still be feasible if a high sensitivity spectrometer is used.

ICRH will use different heating schemes on ITER and here we consider first the case of triton HEFI populations with pitch angle ≈90° and a “tail” temperature $T_{\perp}$=100 keV. The NES spectrum for this case is shown in Fig.3 for a radial sight line. The observability of the AKN is only slightly worse when compared with the effect of a 1% NB component for the same sight line (Fig.1). This is because the ICRH driven HEFI populations extend to higher energies and their spectrum can overlap with the AKN over a broader energy rangewhen viewed radially. The effect is dramatically reduced in the case of a tangential sight line (shown in Fig.4 for the case of deuteron population with 1% relative intensity, $T_{\perp}$=100 keV and 33° pitch angle) due to the strong anisotropy of the ICRH driven HEFI. In order to strongly limit the observability of the AKN in this case the relative intensity of the ICRH component must be increased to 10% and the “tail” temperature to $T_{\perp}$=300 keV as shown in Fig.5.

A first survey of NES conditions for different sight lines and HEFI populations has shown that the AKN, NB and ICRH signatures can be distinguished under most conditions, especially because of the strong anisotropy of the NB and ICRH components. It is also found that a radial view provides the best conditions for diagnostics of the ICRH components; a counter-tangential view (i.e. counter to the NB direction) would be most sensitive to the NB induced component; and an oblique view in the co-tangential direction is ideal for diagnostics of the AKN induced component. The AKN can be diagnosed in most cases with limitations due to the NB component in the case of counter-tangential view and ICRH in the case of a radial view but only if the ICRH-driven tail temperature exceeds 200 keV.

An interesting aspect in this context is the dual-sight line measurements now planned with the new JET instrumentation. JET is equipped with a time-of-flight neutron spectrometer [7] viewing the plasma vertically/radially and a magnetic proton recoil spectrometer [1] viewing the plasma horizontally/tangentially with a 47° pitch angle relative to the magnetic axis. Both spectrometers can be used for detection of 2.5 MeV neutrons from the dd reaction and are expected to provide new insight into high power fusion experiments on JET. A similar sight line arrangement can be considered for ITER and would provide a full separation of all HEFI components under most conditions.

REFERENCES

[1]. L. Giacomelli et al, Nucl. Fusion **45** (2005) 1191.

[2]. D. Start et al, Nucl. Fusion **39** (1999) 321.

[3]. L. Ballabio, G.Gorini, J.Källne, Phys Rev E **55** (1997) 3358.

[4]. J. Källne et al, Phys Rev Lett **85** (2000) 1246.

[5]. H. Henriksson et al, Plasma Phys. Control. Fusion **47** (2005) 1763.

[6]. H. Henriksson et al, Nucl. Fusion **46** (2006) 244.

[7]. A. Hjalmarsson et al, Res. Sci. Instr. **74** (2003) 1750.

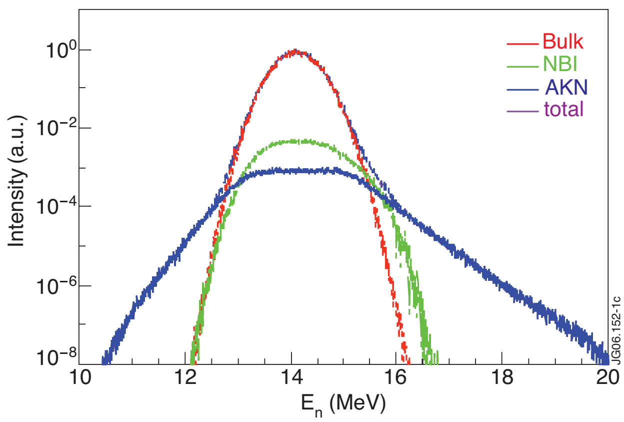

Figure 1: NES spectrum for an ITER radial sight line. The spectrum is assumed to be the sum of a “bulk” component (see text) and two more components from NB injection (NBI) and AKN emission.

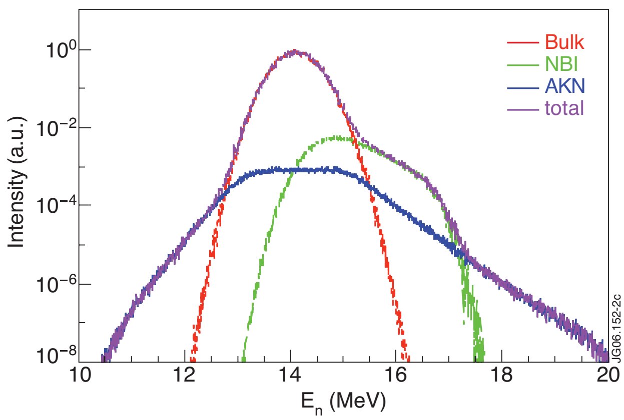

Figure 2: Same as Figure 1 but for countertangential sight line.

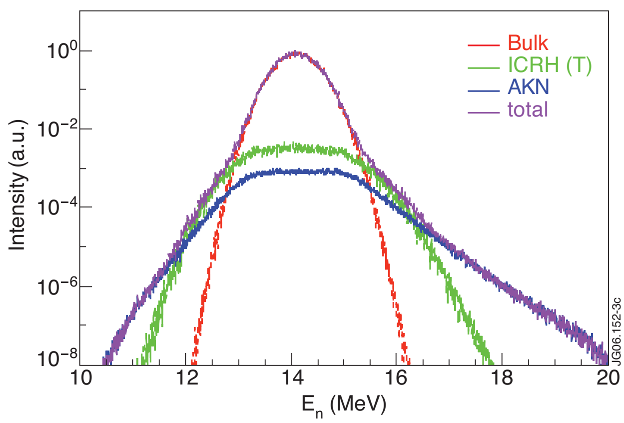

Figure 3: NES spectrum for an ITER radial sight line. The spectrum is assumed to be the sum of a “bulk” component, a component due to ICRH giving a triton tail (see text), and the AKN emission.

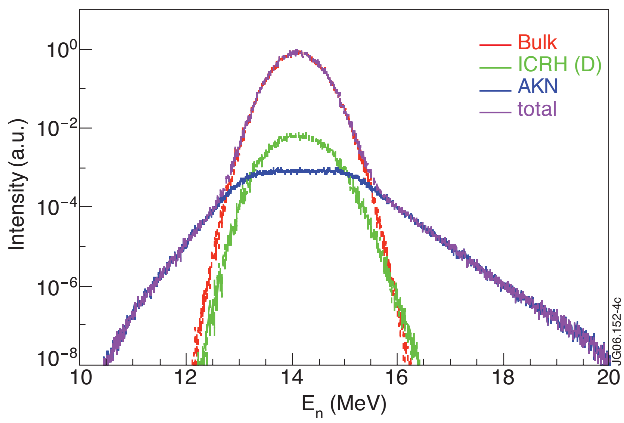

Figure 4: Same as Figure 3 but for a deuteron tail driven by ICRH (see text) and a tangential sight line.

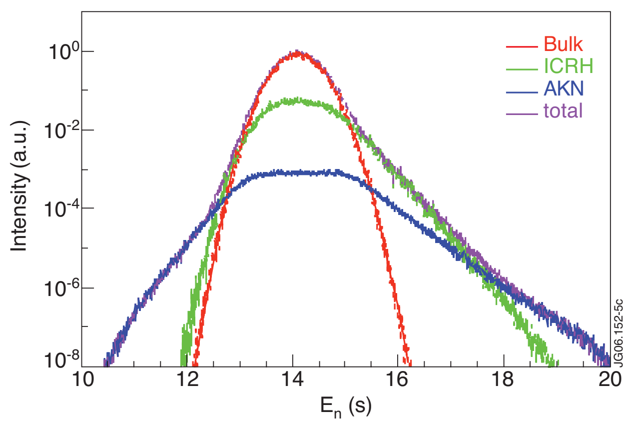

Figure 5: Same as Figure 4 but for a deuteron tail with T=300 keV giving a NES component of 10% relative intensity.