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Active Beam Spectroscopy for ITER

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The latest status of 'Active Beam' related spectroscopy aspects as part of the ITER diagnostic scenario is presented. A key issue of the proposed scheme is the ultimate goal of achieving global data consistency. This implies that all particles involved, that is, intrinsic and seeded impurity ions well as helium ash ions and bulk plasma ions and also the plasma background data (e.g. magnetic and electric fields, electron density and temperature profiles) need to be addressed (cf [1]). A further sensible step in this direction is the decision of exploiting both a dedicated low-energy, low-power diagnostic beam (*DNB*, *2.2MW 100 keV/amu*) as well as the high-power, high-energy heating beams (*HNB*, *17MW 500keV/amu*) for maximum diagnostic information.

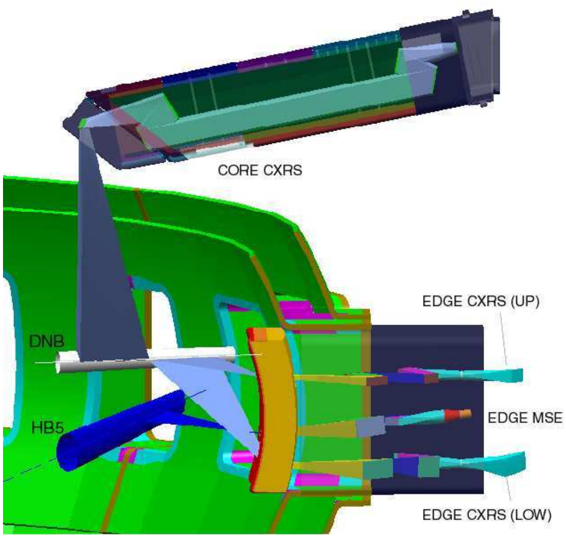


Fig.1 Layout of CXRS and BES on DNB

The feasibility study encompasses CXRS (*Charge Exchange Recombination Spectroscopy*) for the measurement of the main impurity ion densities (including helium ash), ion temperatures and toroidal and poloidal plasma rotation. *Beam Emission Spectroscopy* (BES) is proposed as indispensable cross-calibration tool for absolute local impurity density measurements [2] and also for the continuous monitoring of the neutral beam power deposition profile. Fluctuation measurements based on BES are considered for the plasma edge [3]. Finally, a full exploitation of the '*Motional Stark Effect*' pattern is proposed to deduce pitch angles, radial electric fields and total magnetic fields [4,5,6].

More recently [7], a further promising application has been proposed, that is a study of slowing-down alpha particles in the energy range of 0.1 to 0.6 MeV and 0.5 to 2.5 MeV respectively making use of *DNB* and *HNB*. An important asset of the proposed slowing-down scheme is the potential investigation of anisotropic features in the alpha velocity distribution function making use of top and equatorial observation periscopes (see Fig.1).

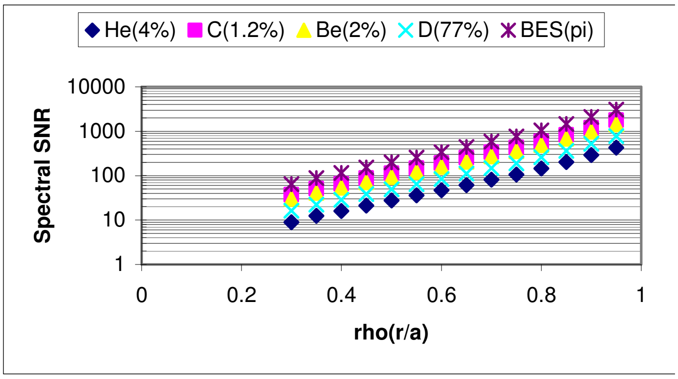
Calibration:

Absolute calibration of ion densities as deduced from CX spectra will be achieved by combining CXRS and BES. The use of neutral beam densities as deduced from BES (Beam

$$n_z = \frac{4\pi \cdot I_{CX}}{Q_{CX} \int\limits_{l.o.s} n_b ds} \qquad I_{bes}(E) = \frac{1}{4\pi} n_e \cdot Q_{BES} \cdot \int n_b(E) ds \qquad \frac{n_z}{n_e} = \frac{I_{CX} \cdot Q_{BES}}{I_{BES} \cdot Q_{CX}}$$

Emission Spectroscopy) avoids potential errors sources in beam attenuation calculations and reduces absolute density measurements to a line ratio measurement.

Signal-to-Noise Estimates



Fig,2 Expected spectral SNR ratio of the main plasma ions versus normalized minor radius. The present set assumes an offset DNB with a height of 600mm above the toroidal mid-plane. Discussions are underway for a 'tilted' DNB which would reach the magnetic axis.

The main experimental challenge for the feasibility of a CXRS diagnostic on ITER is the detection of a very weak CX signal in the presence of an enormous level of continuum background radiation. Both items are due to the high density and dimensions of ITER. The main route taken is the optimisation of the optical detection system and allocating for each radial channel one high-throughput spectrometer [9].The proposed DNB can be operated in a pulsed mode with a maximum of 22 A neutral at 100keV/amu. In principle, high-power, pulsed neutral beams in burst mode, which are currently proposed [10], would offer an alternative route, but have not yet reached suitable potential bench-marking performance levels.

V. Global Data Consistency

The concept of integrated data evaluation procedures plays a pivotal role for a feasible and successful application of active beam diagnostics on ITER. The issue of measuring the helium ash content and part of the slowing-down velocity function is strongly interwoven with the ability of assessing at the same time all complementary ion densities (including bulk ions) and ion temperatures and plasma rotation. The consistency of diamagnetic energy data with spectroscopic reconstructions from electron and ion pressure profiles, or the consistency of measured thermo-nuclear neutron rates with modelled predictions from measured ion temperature and deuteron/triton density profiles belong to standard prediction packages e.g. TRANSP, CHEAP used for example at JET. Each of these reconstructions require a high degree of data accuracy and local resolution which cannot be provided by any other non-active, and hence non-localised, diagnostic method.

VI. Magnetic Field Measurements (MSE on HNB and DNB)

Since the main MSE features are described elsewhere [4,5] we report here only on some new aspects referring to the use of the DNB for MSE. The main idea is to treat both beams as potential diagnostic tools with complementary roles. In the case of ITER the main concerns are presently the optical qualities of the observation periscope with its labyrinth mirror system and its effect on the polarisation and reflectivity [12,13]. Another concern is spatial resolution required for accurate current density profiles. The equatorial ports for the

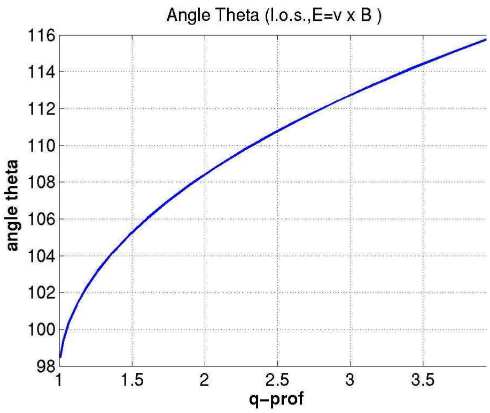


Fig2. Change of angle Theta across q-profile for lower equatorial periscope (MSE on DNB)

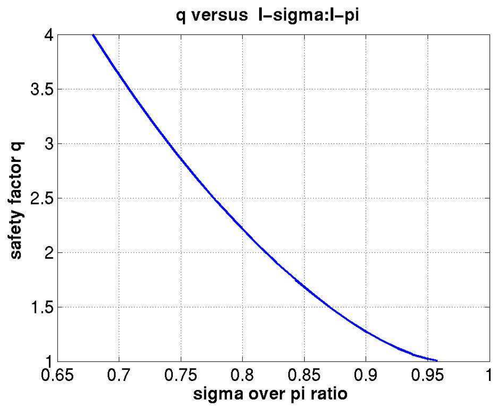


Fig3. Safety factor q versus intensity ratio of σ&π multiplets for lower equatorial port.

DNB promise excellent spatial resolution ($\delta r<a/20$). The predicted change of the angle between Lorentz field vector and line of sight across the DNB path allows the deduction of q(r) from the ratio of σ/π-intensities In order to optimise the MSE measurements we propose to exploit all the information available in the emission spectrum. Through a complete interpretation of the spectral and polarisation characteristics we expect to be able to improve on the accuracy achievable by not relying solely on one technique.

VII. Slowing-Down Fusion Alphas

The high-power, high-energy ITER D^0 heating beam (17MW, 500keV/amu) can be used as probe beam for diagnosing slowing-down fusion alphas with a birth energy of 3.5MeV. The actual energy window accessible by CXRS is determined by the width of the effective emission rate curve versus collision energy. The observed CX slowing-down spectrum is the projection in velocity space of alphas with components in the direction of observation (cf.[11]). The corresponding alpha energy covers a range between **0.5 MeV and 2.5 MeV** .

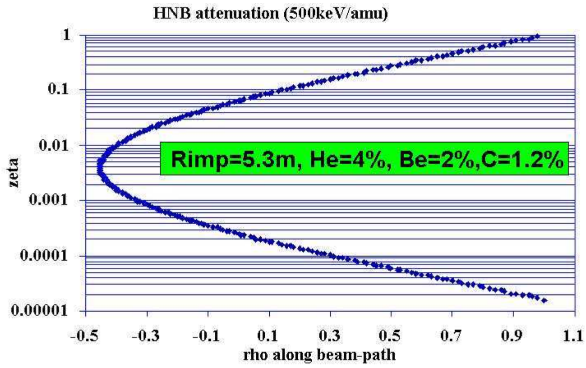


Fig.4 Beam attenuation for HNB

The feasibility depends to a great degree on the ability of assessing accurately the continuum level since the expected spectrum covers a wide spectral range from which the continuum needs to be subtracted. The extraction of the actual alpha velocity distribution function relies on the accurate atomic modelling of the CX process [8] leading to precise synthetic spectra.

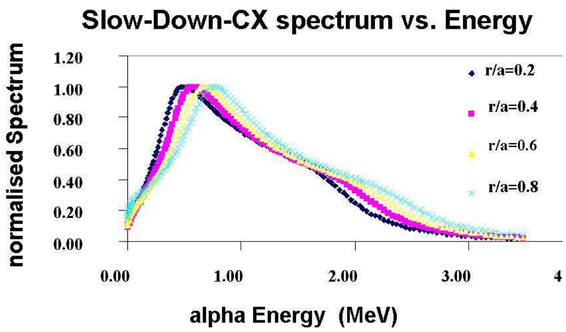


Fig.5a Predicted CX spectrum for 4 lines of sights on the HNB versus alpha energy.

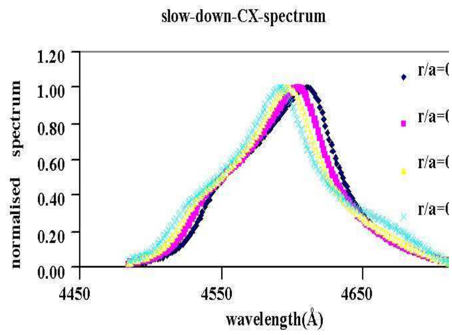


Fig.5b Predicted CX spectrum for 4 lines of sights on the HNB versus wavelength.

VIII. Concluding remarks: A key issue for the viability of the proposed active beam spectroscopy package is the survival probability of the first mirror in its periscopes. Studies of metallic mirrors and deposition and sputtering processes in today's experiments addressing reflection values and polarisation characteristics have given first results [12,13].

IX.References:

[1] M.von Hellermann et al., 1st Int. Workshop on ITER Diagnostics, Varenna, Sept.1995, Pl. Press N.Y.
[2] M.von Hellermann et al., Proc.Adv.Diagn. Magn.& Inert. Fus., Varenna 2001,205-208 Pl. Press N.Y
[3] G.M.Mc Kee et al. Rev. Sci.Instr. 70, 913(1999)
[4] N.C.Hawkes et al. Plasma Physics Contr. Fus.,**44**,1105(2002)
[5] P.Lotte et al. . Proc. 4'th ITPA Topic Group Meeting on Diagnostics**,** 17-21 February, Padova 2003
[6] M. von Hellermann et al. 29th EPS Conf.on Contr. Fusion and Plasma Physics, Montreux, June 2002
[7] M. von Hellermann et al, 4'th ITPA Topical Meeting on Diagnostics, Padova, Italy, 2003
[8] ADAS Data Base used in Fusion Community, see: http://adas.phys.strath.ac.uk/
[9] S.Tugarinov et al. Proc.Adv.Diagn. for Magn.& Inert. Fus., Varenna 2001,253-256 Plenum Press N.Y
[10] J.Park , G.Wurden., US ITER Forum at University of Maryland, May 2003
[11] M. von Hellermann et al. Plasma Physics &Contr.Fus.,**35**,799(1993)
[12] K.Vukolov, V.Voitsenya, 4'th ITPA Topical Meeting on Diagnostics, Padova, Italy, 2003
[13] A.Malaquias et al. This conference