Active Beam Spectroscopy

M.G. von Hellermann[1], E.Delabie[1], R.J.E.Jaspers[1], W.Biel[2], O.Marchuk[2], H.P.Summers[3], A.Whiteford[3], C.Giroud[4], N.C.Hawkes[4], K.D.Zastrow[4]

[1]*FOM-Institute for Plasma Physics Rijnhuizen**, *Association EURATOM-FOM, member of Trilateral Euregio Cluster, PO Box 1207, 3430 BE Nieuwegein, The Netherlands*
[2]*Institut für Plasmaphysik, Forschungszentrum Jülich GmbH, Association EURATOM-FZJ, member of Trilateral Euregio Cluster, 52425 Jülich, Germany*
[3]*Strathclyde University,Dept. Appl. Physics, Glasgow,UK*
[4]*UKAEA Culham Laboratory Euratom Association, Abingdon OX14 3EA, UK*

Abstract. Charge eXchange Recombination Spectroscopy (CXRS) plays a pivotal role in the diagnostics of hot fusion plasmas and is implemented currently in most of the operating devices. In the present report the main features of CXRS are summarized and supporting software packages encompassing "Spectral Analysis Code CXSFIT", "Charge Exchange Analysis Package CHEAP", and finally "Forward Prediction of Spectral Features" are described.

Beam Emission Spectroscopy (BES) is proposed as indispensable cross-calibration tool for absolute local impurity density measurements and also for the continuous monitoring of the neutral beam power deposition profile. Finally, a full exploitation of the 'Motional Stark Effect' pattern is proposed to deduce local pitch angles, total magnetic fields and possibly radial electric fields.

For the proposed active beam spectroscopy diagnostic on ITER comprehensive performance studies have been carried out. Estimates of expected spectral signal-to-noise ratios are based on atomic modelling of neutral beam stopping and emissivities for CXRS, BES and background continuum radiation as well as extrapolations from present CXRS diagnostic systems on JET, Tore Supra, TEXTOR and ASDEX-UG.

Supplementary to thermal features a further promising application of CXRS has been proposed recently for ITER, that is a study of slowing-down alpha particles in the energy range up to 2 MeV making use of the 100 keV/amu DNB (Diagnostic Neutral Beam) and the 500 keV/amu HNB (Heating Neutral Beam). Synthetic Fast Ion Slowing-Down spectra are evaluated in terms of source rates and slowing-down parameters

Keywords: Active beam spectroscopy, diagnostics of hot fusion plasmas, CXRS, MSE, BES.
PACS: 52.25Vy, 52.55Fa, 52.55Pi, 52.70Kz

INTRODUCTION

Active Beam Diagnostics have developed over the last three decades [1-14] into a mature diagnostic tool for fusion plasmas. A comprehensive package of active beam based spectroscopy tools for ITER has been recently submitted and evaluated. The feasibility study encompasses CXRS (*Charge Exchange Recombination*

* www.fom.rijnh.nl

CP988, *Burning Plasma Diagnostics*, edited by F. P. Orsitto, G. Gorini, E. Sindoni, and M. Tardocchi

Spectroscopy) for the measurement of the main impurity ion densities (including helium ash), ion temperatures and toroidal as well as poloidal plasma rotation. *Beam Emission Spectroscopy* is proposed as indispensable cross-calibration tool for absolute local impurity density measurements [21] and also for the continuous monitoring of the neutral beam power deposition profile. Finally, a full exploitation of the '*Motional Stark Effect*' pattern is proposed to deduce local pitch angles, total magnetic fields and possibly radial electric fields.

More recently, a further promising application has been proposed, that is a study of slowing-down alpha particles in the energy range of 0.1 to 0.7 MeV and 1.6 to 2.4 MeV respectively making use of the *3.6MW 100 keV/amu* H^0 *DNB (Diagnostic Neutral Beam)* and the *17MW 500keV/amu* D^0 *HNB (Heating Neutral Beam)*. 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.

Performance studies and estimates of expected spectral signal-to-noise ratios are based on atomic modelling of neutral beam stopping and emissivities for CXRS, BES and background continuum radiation as well as extrapolations from present CXRS diagnostic systems. Single high-étendue and high-resolution spectrometers for each radial channel are proposed for thermal CXRS and BES/MSE and high-étendue broad-band spectrometers for CXRS on slowing-down features.

Basic Features of Active Beam Spectroscopy

The following section gives a very brief summary of the main features of Active Beam Aided Spectroscopy which is a synonym for the following two reactions between plasma ions, plasma electrons and impurity or bulk ions. We show here as an example the reaction for plama ions i.e. the bulk plasma deuterons:

CXRS: $D^{+1}(T) + D^0(E) \rightarrow D^*(T) + D^+(E)$

$$I_{CXRS}. = \frac{1}{4\pi} n_d \cdot Q_{CXRS} \cdot \int n_b ds \qquad (1)$$

Here n_d is the local deuteron density, Q_{CXRS} the effective atomic emission rate [9-11] and the line of sight integration extends across the beam path (cf. Fig.3)

and **BES**: $D(E) + e \rightarrow D^*(E) + e$

$$I_{BES}. = \frac{1}{4\pi} n_e \cdot Q_{BES} \cdot \int n_b ds \qquad (2)$$

The local neutral beam strength is determined by the beam stopping processes (c.f. [9-11]), that is ionization by electrons and ions and by charge exchange losses.

$$n_b. = n_b(0) \cdot \exp\left[- \int_{beampath} n_e \sum_{z=1}^{z=18} c_z \cdot \sigma_{stop,z} \right] \qquad (3)$$

Combining BES and CXRS and making use of multiple instruments linked to the same viewing chords allows the replacement of the exponential beam stopping calculation by local beam densities derived from BES. This method avoids not only the exponential error propagation along the beam path but takes also care of uncertainties in absolute calibration of the optical observation system shared by BES and CXRS we obtain therefore:

$$\frac{n_z}{n_e} = \frac{I_{CXRS}}{I_{BES}} \cdot \frac{Q_{BES}}{Q_{CXRS}} \tag{4}$$

There are two caveats. The atomic emission rates Q_{CXRS} and Q_{BES} do depend on the collision energy, i.e. beam energy, electron density n_e, plasma temperature T_i and also impurity ion composition n_Z. So the apparent simplicity of eqn. 4 hides in truth an iterative process. However, both the beam-stopping calculation as well for the ratio of Q_{BES}/Q_{CXRS}, the iteration usually takes only a few steps and converges rapidly. The second caveat is the wavelength variation of the calibration factor for the case the CXRS spectrum not being at the same wavelength as the Balmer-Alpha Spectrum. In this case we use the underlying bremsstrahlung as cross-reference:

$$\frac{n_z}{n_e} = \frac{I_{CXRS}}{I_{BES}} \cdot \frac{Q_{BES}}{Q_{CXRS}} \cdot \frac{I_{cont}(\lambda_{BES})}{I_{cont}(\lambda_{CXRS})} \cdot \frac{\lambda_{CXRS}}{\lambda_{BES}} \cdot \frac{g_{ff}(\lambda_{CXRS})}{g_{ff}(\lambda_{BES})} \tag{5}$$

To illustrate the two examples of beam induced spectra we show an historical first spectrum at JET in 1988 which shows nicely the dramatic changeover from passive background spectrum to the beam induced CXRS D_α spectrum representing the bulk plasma ions (deuterons) and the Doppler shifted Beam Spectrum.

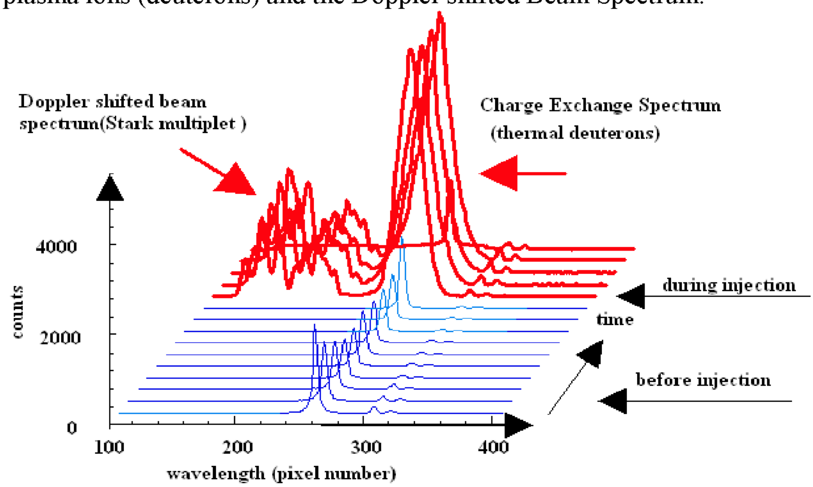


FIGURE 1. Beam induced Balmer Alpha Spectra as measured on JET in 1988. The Doppler shifted beam spectrum represents the MSE pattern of high energy beam neutrals with energies E, E/2 and E/3 respectively travelling across the magnetic field (cf. [6])

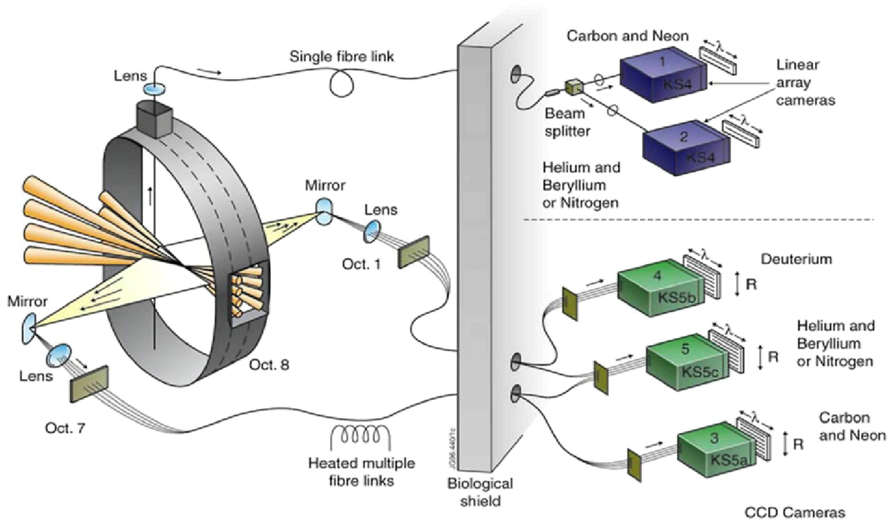


FIGURE 2. The CXRS diagnostic on JET. Several multi-chord periscopes aimed at the JET heating neutral beams are used for the radial profile reconstruction of the main low-Z ions as well as bulk ion CX spectra.

The JET diagnostic evolved in the course of time from an originally single chord diagnostic into a comprehensive instrumentation with several periscopes and accompanying spectroscopic instruments (Fig.2). This example illustrates the multiplicity of instruments required for a self-consistent evaluation of spectroscopic data based on atomic modelling of beam target interactions in a fusion plasma and its ionic species.

Supporting Software Packages

A successful quantitative exploitation of observed CX spectra on fusion devices depends on a number of key ingredients such as a powerful, well focused diagnostic neutral beam, perfect instrumentation, established calibration and alignment procedures, but more importantly, *suitable analysis tools* based on advanced atomic modelling of spectral features, the parameterization of its components, and finally *the efficient and reliable extraction of meaningful physics parameters*. An extensive collection of CXRS software packages have been developed since the mid-eighties, in particular at JET, which are presented in the following section as an illustration. In the current preparation phase for ITER, it is the ultimate goal to share those tools with the participating partners.

a) Spectral Analysis Codes

An efficient tool for the extraction of physics parameters such as local ion temperature, plasma rotation, intensity and continuum radiation level is a challenging task for the routine application of CXRS. The main basis for the development of this tool is an advanced atomic modelling [9-11] of the

emission rates and modelling of the beam target interaction, which allows subsequently the parameterization of complex features [15], and finally the link to physical meaningful plasma data. Following the earlier developments at JET a recent update and review of the spectral analysis code "KS4FIT" has led to modernized and more efficient, platform independent software packages (e.g. the IDL based, ADAS supported version "CXSFIT" [16]).
A typical performance criterion for a suitable spectral code is the availability of physics results in between subsequent plasma pulses. Stretching this point even more, once analysis tools can be used for the creation of substantial data bases, the next step towards real-time neural-network based spectral analysis is very close [17]. Several advanced code features based on the JET experience allow a great flexibility in the treatment of standard and non-standard cases. Each plasma scenario is typically characterized by its combination of active and passive spectral features, as a result a comprehensive collection of representative examples have been developed at JET. Moreover, a pulse number linked documentation of all code settings allows the replay of already analysed spectra at any time.

b) Charge Exchange Analysis Package (CHEAP)

A key issue for the self-consistent evaluation of active CX spectra is a comprehensive modelling of the beam target interaction, this approach requires in the presence of several impurity ions the monitoring of all CX spectra representing the main low-Z impurity ions, such as He^{+2}, Be^{+4}, C^{+6}, N^{+7}, Ne^{+10} or Ar^{+18}. The latter is a typical representative for a medium-Z seeded plasma to induce radiation cooling at the plasma edge. The CHEAP concept is based on a number of key principles such as:

1) *Assumption of flux symmetry of main plasma data (ion and electron temperature and densities, plasma rotation)*
2) *Mapping of all plasma data on a common magnetic flux surface grid*
3) *Mapping of beam-path on magnetic flux surface coordinates*
5) *Monitoring of the main low-Z impurity ions*
6) *Absolute calibration of spectroscopic instruments*
7) *Use of BES as a complementary measurement for local beam densities*
8) *Analytical presentation of neutral beam profile*
9) *Analytical presentation of Beam-Target interaction and its anisotropic Slowing-down distribution function*
10) *Starting from initial estimates for the impurity composition, local atom emission rates are calculated. New ion densities are derived from absolute photon fluxes and the process is then iterated until convergence is achieved*

c) Simulation of Active and Passive Spectral Features

An import step in the preparation of the ITER CXRS diagnostic has been the development of suitable tools for the simulation of CX spectra, or the forward prediction of active and passive spectral features [15]. This tool package is based on the one hand on advanced atomic modelling and on the other hand on the extrapolation from established CXRS diagnostic systems on JET, TEXTOR, Tore Supra and ASDEX-UG. The universal simulation package which encompasses existing and future planned diagnostics (EAST, SST, W7-X and ITER) allows not only a minute prediction of spectral feature, but more importantly, the optimization of key ingredients for the CXRS and BES performance that is:

1) *Specification of neutral beam*
2) *Optimization of periscope optics*
3) *Optimization of spectral instruments*

A schematic presentation of the simulation is shown in the following figure:

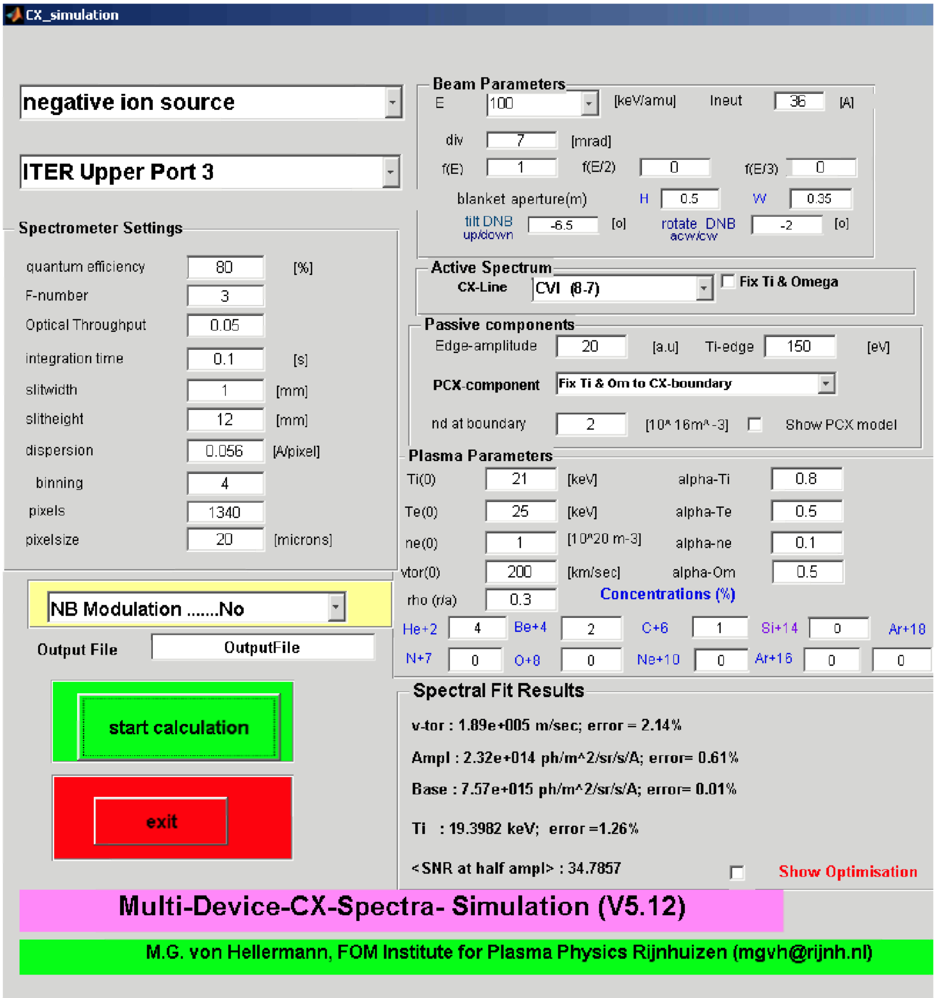
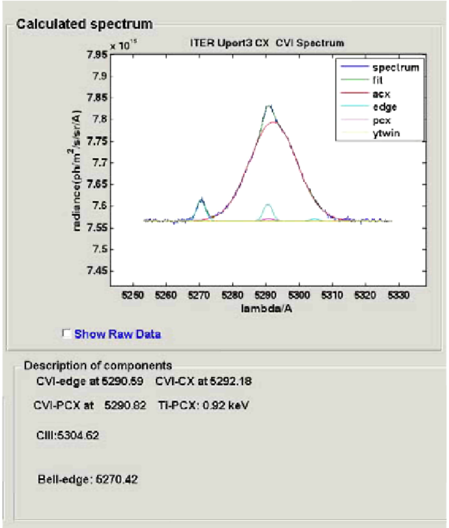


FIGURE 3. The Matlab Simulation Package "**CX_simulation**" input panels contains several input modules for a) neutral beam type, b) device selection, c) beam parameters, d) CX transition, e) plasma parameters and f) instrumentation. The presented example is ITER CXRS diagnostic, using a negative ion DNB, the ITER U-port-3 for the case of the CVI spectrum and its passive background features. Noise levels represent the photon noise from active and passive signals. A least-square routine is finally applied to retrieve from the noisy spectrum the original plasma parameters and associated fit-errors.



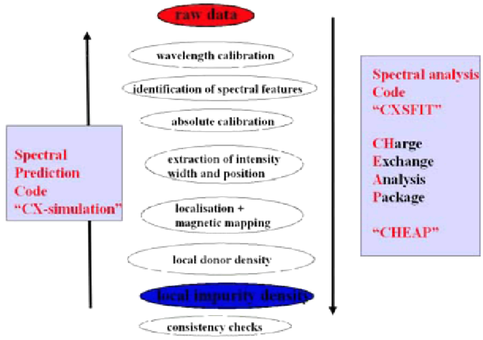


FIGURE 4. Simulated CVI CX spectrum and its passive background components comprising: CVI – PCX (passive CX), CVI-edge, BeII and CIII respectively.

FIGURE 5. Schematic presentation of supporting software packages. Spectral prediction code : "CX_simulation", extraction of spectral features : "CXSFIT" , self-consistent reconstruction of ion densities: "CHEAP".

Active Beam Spectroscopy for ITER

The CX simulation package as describes in the previous section has enabled a detailed performance study for the future ITER CXRS system [18-25].The proposed system comprises CXRS (Charge Exchange Recombination Spectroscopy) and BES (Beam Emission Spectroscopy), which will exploit a Diagnostic Neutral Beam injected radially into the plasma:

A 'Core CXRS' system (EU) which covers dominantly the inner half of the confined plasma, and an 'Edge CXRS' system (RF) which ensures a high radial resolution in the outer half of the plasma. The Core system utilises an upper port periscope (U-port-3), and two periscopes located in an equatorial port (E-port-3) are envisaged for the Edge CX system. The equatorial port is shared with a dedicated MSE (Motional Stark Effect) system for the measurement of magnetic field pitch angles making use of the Heating Neutral Beams. A complementary MSE approach is proposed for the exploitation of intensity line ratios as measured by the BES data from upper and equatorial ports.

Obviously, the main players in the predicted ITER CXRS performance are the achievable values for the required DNB specifications, the optical transmission of the observation periscopes and the optical throughput of the spectroscopic instrumentation. A serious challenge is the maintenance of the "First Mirror" and its durability during ITER operation (cf. [27]), a similar challenging task is the performance of the proposed DNB (100keV/amu, 36A, 7mrad) which stretches today's technology in terms of neutral beam current, beam divergence and duty cycle. The following performance studies are developed for a standard ITER plasma scenario-2 with a flat electron density profile ($10^{20}m^{-3}$) an electron temperature of 25keV, ion temperature of 21keV, v_{tor}=200km/s and a magnetic field of 5.3 Tesla.

Ongoing discussions suggest a beryllium and tungsten-only impurity composition. In this case, the main ion temperature monitor will be the BeIV CX spectrum at 465nm. Alternatively, a low-level of Neon (0.1%) may serve as a CXRS temperature indicator. The main goal for the ITER CXRS, the measurement of core helium ash densities, will even benefit from enhanced levels of beryllium providing twice the same ion temperature information in the same spectrum (cf.[31]).

For MSE, a complementary scheme to the proposed HNB based MSE polarization measurement, is the use of line intensity ratios in the DNB induced MSE spectrum. ITER relevant pilot experiments presently performed on TEXTOR are presented on this conference [26]. Figs.8 and 9 show the predicted MSE spectrum and the error analysis for the MSE evaluation, where the pitch angle is derived from the intensity ratio I_π/I_σ as measured by the Upper-port-periscope and the expected error levels across the radial profile for pitch angle, Lorentz field and MSE amplitudes. For a dt-plasma the CX feature comprises both d and t, and therefore the local fuel density ratio d/t may be derived from the combined CXRS/BES spectrum.

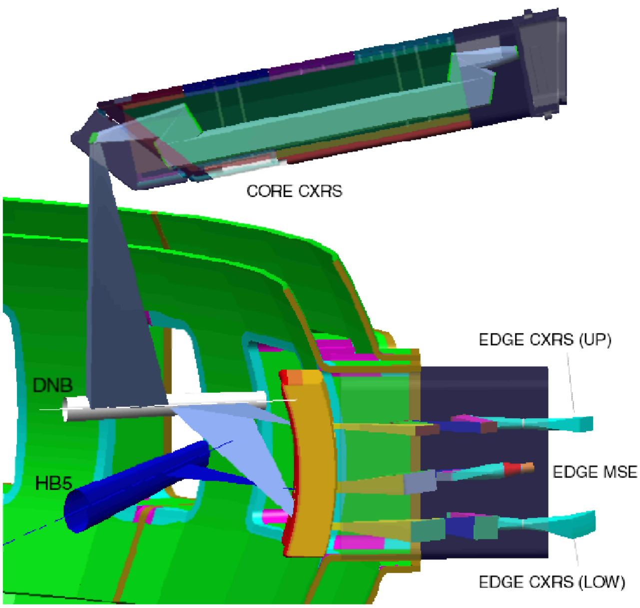


FIGURE 6 ITER Core and Edge CXRS periscopes. The DNB is injected approximately radially (angle of 7°) it reaches the magnetic axis at R=6.2m, z=0.6m. The periscopes consist of optical labyrinths in order to avoid a direct neutron streaming from blanket to the end of periscope. A crucial part is the "First Mirror" (c.f. [26,27]) close to the blanket aperture which will be mounted on a heat-exchange system at the end of an extractable tube to allow replacements in case of irreversible damages.

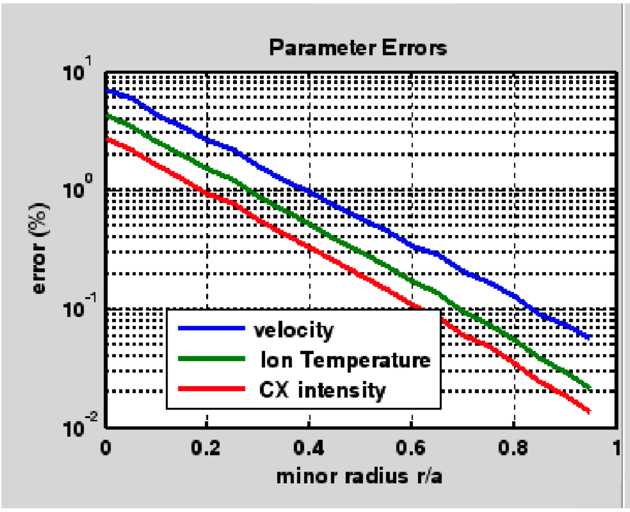


FIGURE 7. Performance analysis for ITER based on evaluation of predicted CVI spectra ($c(C^{+6})$=1%, $n_e=10^{20}m^{-3}$, $T_i(0)$=21keV), $T_e(0)$=25keV, v_{tor}=200km/s). Integration time 0.1sec. In the case of a tungsten and beryllium scenario for ITER, alternative CXRS ion temperature monitors such as low level Ne^{+10} will be used.

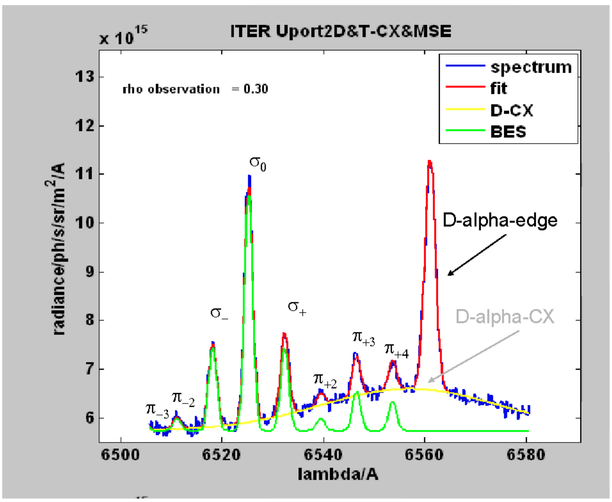


FIGURE 8. **"MSE_Simulation"** Predicted MSE (**E_L=v_{DNB} x B**) and D-alpha-CX spectrum for ITER U-port-3 for a magnetic field of 5.2Tesla. The local pitch angle and safety factor q is derived from MSE intensity ratio I_π/I_σ , the local field from the Lorentz split. The huge offset represents the underlying continuum. Both continuum and edge lines will be subtracted in the case of neutral beam modulation or use of a passive viewing lines not directed at the beam.

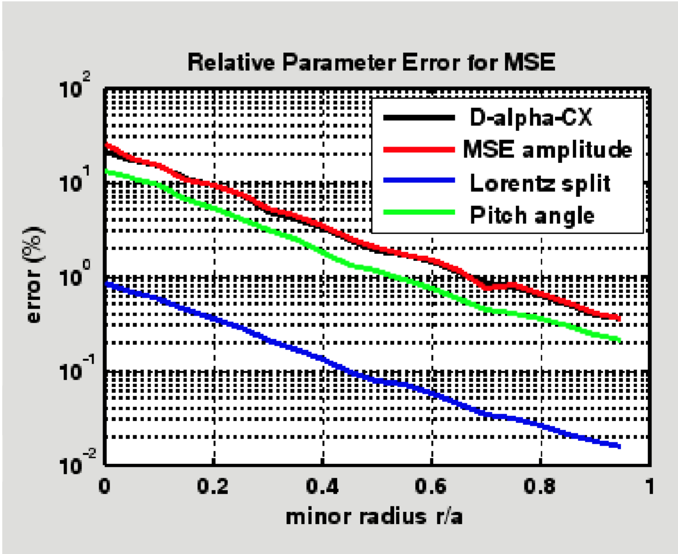


FIGURE 9. Error analysis of DNB induced Balmer Alpha spectrum (ITER U-port 3, τ=0.1s, slit-width =0.1mm). The most accurate parameter extracted from the spectrum is the Lorentz split representing the local total magnetic field. The pitch angle is used for the deduction of the q-profile, the MSE amplitude represents the local DNB density and finally the CX amplitude represents the bulk ion deuteron density. In the presence of d and t the local isotope ratio d/t may be deduced from the respective CX intensities.

Non Thermal Slowing-Down Features

The use of CXRS has been proposed in several papers as a promising option for the diagnosis of fast ion distributions (cf. [8,13,28,29,31]). Two cases are considered, alpha slowing down spectra and beam fast ion spectra [13,28]. For ITER the potential use of the proposed CXRS diagnostic in connection with the 100 keV/amu DNB and the 500 keV/amu HNB is briefly summarized here. In this paper we present as an illustration the isotropic case of slowing-down 3.5 MeV alpha particles as predicted for ITER. The source rate profile is based on nuclear reaction rates [30]. The alpha velocity distribution function depends on source rate, critical velocity and slowing-down time. Each parameter can, in principle, be extracted from the comparison of modelled and observed spectrum.

$$S_{alpha} = n_d \cdot n_t \cdot \sigma v_{dt}(T_i) \tag{6}$$

$$g_{alpha}(v) = \frac{S_{alpha} \cdot \tau_s}{v_{crit}^3 + v^3} \tag{7}$$

$$v_{crit}^3 = \frac{3}{4}\sqrt{\pi}\left(\frac{2T_e}{m_e}\right)^{3/2} \sum_j \frac{n_j}{n_e} Z_j^2 \frac{m_e}{m_j} \tag{8}$$

$$\tau_s = \frac{3v_e^3 m_e m}{16\sqrt{\pi}e^4 Z^2 n_e \ln\Lambda} \tag{9}$$

Finally, the observed spectrum which is the result of a 3-dim integration in velocity space representing the convolution between collision velocity dependent emission rate and the slowing-down function is given by [13]:

$$f_{obs}(v_z) = \int_0^\infty v'^2\, dv' \int_0^\pi d\theta' \sin\theta' \int_0^{2\pi} d\varphi'\, g_{slow}(v',\theta',\varphi') Q_{cx}(v_r)\delta(v_z - v'\cos\theta') \tag{10}$$

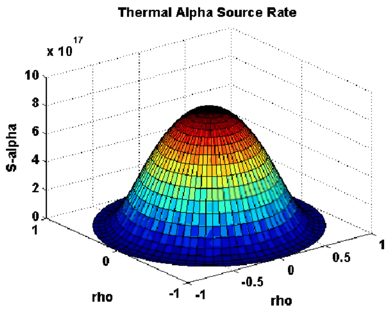


FIGURE 10 Alpha Source Rate profile for ITER based on d-t nuclear rates [30]

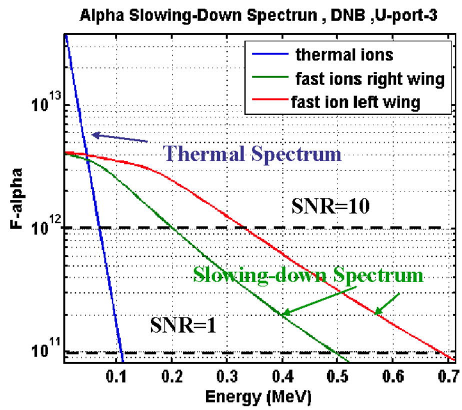


FIGURE 11 Predicted HeII CX spectrum in logarithmic scale for the Maxwellian thermal feature (blue) and the slowing-down alpha feature (red) for the case of an ITER standard plasma. The x-axis scales as $\Delta\lambda^2$, or energy. The SNR values refer to dedicated broad-band instrumentation (2nm/mm, and integration time of 0.1s). For the higher energy range up to 2MeV the use of the MSE periscope in E-port-3 aimed at the 500keV/amu HNB is proposed [31].

ACKNOWLEDGMENTS

The authors are indebted to the support by the CXRS teams of JET, Tore Supra, TEXTOR and ASDEX-UG as well as the international members of the ITPA expert group on Beam Aided Diagnostics

REFERENCES

1. R.C Isler, *Phys.Rev.Lett.* **38**, 1359(1977)
2. V.V Afrosimov., Y.S.Gordeev, A.N. Zinoviev, A.A Korotkov., *JETP Lett.***28**, 501(1979)
3. R.C.Isler, L.E Murray., *Appl. Phys. Lett.* **42**, 355(1983)

4. R.J Fonck., R.J.Goldston, R Kaita., D.Post, *Appl. Phys. Lett.* **42**,239(1983)
5 R.J Groebner., N.H Brooks., K.H Burrell., L Rottler., *Appl.Phys. Lett.* **43**,920(1983)
6. A. Boileau, M.G. von Hellermann, W. Mandl, H.P. Summers, H.Weisen, A. Zinoviev, *J.Phys.B:At.Mol.Opt.Phys.*,**22**, L145(1989)
7. A.Boileau, M.G. von Hellermann, L.D Horton., J. Spence, H.P Summers. *Plasma Phys. Contr. Fusion* **31**,779(1989)
8. M.G. von Hellermann, W.Mandl, H.P.Summers, A.Boileau, R. Hoekstra, F.J. de Heer, J.Frieling, *Plasma Physics and Controlled Fusion,* **33**, 1805 (1991
9. H.P. Summers, P. Thomas, R. Giannella, M.G. von Hellermann, W.Dickson, K. Lawson, W. Mandl, P. Briden *Z.f.Phys.D suppl.* **21**,17(1991) and http://adas.phys.strath.ac.uk
10 . H.P.Summers et al. *Physica Scripta* **T92**,80(2001)
11. H.P.Summers , M.G. von Hellermann, Atomic and Plasma Material Interaction Processes in Controlled Thermonuclear Fusion, Ed. Janev, *'Elsevier Science Publishers* ',1993, 87-117
12. M.G. von Hellermann, H.P.Summers , Atomic and Plasma Material Interaction Processes in Controlled Thermonuclear Fusion, Ed. Janev, *'Elsevier Science Publishers* ',1993, 135-164
13. M.G. von Hellermann, W.G.F.Core, J.Frieling, L.D.Horton, R.W.T. König, W.Mandl, H.P.Summers, *Plasma Phys. Contr. Fusion,* **35**,799, 1993
14. R C Isler *Plasma Phys. Control. Fusion* **36** No 2 (February 1994) 171-208
15. M.G. von Hellermann, W.Biel, G.Bertschinger, C.Jupen, M.O'Mullane, H.Summers, A.Whiteford, *Physica Scripta*, T120, 2005
16. A.Whiteford, M.G. von Hellermann, L.D.Horton, K-D Zastrow, "CSFIT User Manual", May 2007, refer to allan@phys.strath.ac.uk
17. J.Svensson, M.G. von Hellermann, R. König, *Plasma Physics and Controlled Fusion*, **41**, 315(1999)
18. M.G. von Hellermann, W.G.F. Core, A.Howman, C.Jupen, R.W.T.König, M.F. Stamp, H.P.Summers, P.R.Thomas, K-D. Zastrow, 1st International Workshop on ITER Diagnostics, Varenna, Sept. 1995, Diagnostics for Experimental Fusion Reactors I, *Plenum Press N.Y.* 1996, Ed. P.E.Stott et al., page 321
19. R.W.T. König, H. Anderson, P.Breger, W.G.F.Core, J.P.Feist, N.Hawkes, M.G. von Hellermann, A.C Howman, A.C.Maas, P.D.Morgan, M.F.Stamp, H.P.Summers, J.Svensson, M.Tunklev, P.R.Thomas, K-D. Zastrow, 2nd International Workshop on ITER Diagnostics, Varenna, Sept. 1997, Diagnostic for Experimental Fusion Reactors 2, Ed. P.Stott et al., *Plenum Press, N.Y.* 1998, page 371
20. D.M. Thomas, K.H.Burrell, M.R.Wade, R.T.Snider, 2nd International Workshop on ITER Diagnostics, Varenna, Sept. 1997, Diagnostic for Experimental Fusion Reactors 2, Ed. P.Stott et al., *Plenum Press, N.Y.* 1998, page 361
21. M.G. von Hellermann et al. Proc.Adv.Diag.for Magn. & Inert. Fus. Varenna 2001,205-208, *Plenum Publ. N.Y.*
22. M.G. von Hellermann et al. Proc. 4'th ITPA Topic Group Meeting on Diagnostics, Padova ,17-21 February, 2003
23. S.Tugarinov et al. *RF Meeting on ITER/BPX Relevant Diagnostic Developments*, St. Petersburg,15 July 2003
24. M.G. von Hellermann, EFDA contract 01.649 "Active Charge Exchange Recombination Spectroscopy (CXRS) and Beam Emission Spectroscopy (BES + MSE) with Diagnostic Neutral Beam (DNB)", December 2003, not publicly available (contact mgvh@rijnh.nl)
25. M.G. von Hellermann, R.Jaspers, W.Biel, O.Neubauer, N.Hawkes, Y. Kaschuck,V.Serov, S.Tugarinov, D.Thomas, W.Vliegenthart, *21st IAEA Conference on Fusion Energy*, Chengdu 2006, IT/PI-26
26. R.J.E. Jaspers, M.G. von Hellermann, E. Delabie, J.E. Boom, A.J.H. Donné et al, *this conference*
27. D.V.Orlinski, V.S.Voitsenya, K.Yu.Vukolov, *Plasma Devices and Operations*, **15**, 33-75, 127-146(2007)
28. W W Heidbrink, Y Luo, K H Burrell, R W Harvey, R I Pinsker and E Ruskov *Plasma Phys. Control. Fusion* **49** No 9 (September 2007) 1457-1475
29. H.Bindslev, S.K.Nielsen, L.Porte, J.Hoekzema, S.B. Korshholm et al. *Phys. Rev. Lett.* **97**, 205005 (2006)
30. H.S. Bosch, G.M. Hale, *Nuclear Fusion*, **32**, 611(1992)
31. M.G. von Hellermann, *12th ITPA Topical Meeting on ITER diagnostics*, Princeton, March 2007