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# Improved Charge Exchange Spectroscopy on JET for Ion Temperature and Rotation Velocity Profiles

# The TOFOR Neutron Spectrometer and its First Use at JET

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**ABSTRACT.**
The JET edge charge exchange recombination spectroscopy diagnostic has recently been enhanced to extend its spatial coverage and improve its time resolution. Two identical periscopes have been installed on opposite ports so that they have perfectly symmetrical views of the edge plasma. This matched viewing geometry allows both the poloidal and toroidal components of the impurity ion rotation velocity can be accurately resolved. These measurements play a crucial role in the understanding of the physics of edge phenomena such as Edge Transport Barrier formation and ELMs. The diagnostic also has a more central view of the plasma with a third periscope that faces up towards the top of the vessel. This is a new configuration for the diagnostic and allows the poloidal rotation velocity profile to be measured further in towards the plasma core than previously possible. The new upward facing, core plasma viewing arrangement provides the advantage that the spatial evolution of the Internal Transport Barrier can be tracked from its formation. An additional spectrometer-detector system doubles the total number of CXRS lines of sight that are analysed and improves time resolution from 50ms to 10ms.

## 1. INTRODUCTION
JET's edge Charge eXchange Recombination Spectroscopy (CXRS) diagnostic has been used since the early 1990's [1, 2] to provide detailed measurements of both the edge and core ion temperature, Ti, toroidal rotation velocity, $\nu_\phi$ and poloidal rotation velocity, $\nu_\theta$, of impurity ions on JET. These parameters have been essential to both the edge physics studies on JET such as, the LH transition, the H-mode edge pedestal and ELMs [3, 5] and the core physics studies of internal transport barriers [7, 8]. The most recent diagnostic system consisted of two periscopes with unmatched views of the JET Octant 4 neutral beams. A lower periscope with a high spatial resolution was used to view the edge plasma while an upper periscope with lower spatial resolution had an extended view towards the core plasma. Light was coupled from both periscopes to a single spectrometer-CCD camera system. A mirror was used to switch between the core and edge plasma view, allowing either edge of core CXRS measurements to be made using the same detector with a minimum time resolution of 50ms. This paper describes recent enhancements to the edge CXRS system's viewing periscopes and spectrometer-detector analysing systems. These changes have increased the spatial coverage of both the edge and core plasma view and improved URL: http://www.Second.institution.edu/~Charlie.Author the time resolution of the CXRS measurements.

## 2. VIEWING GEOMETRY
Two identical periscopes are used to view the the outer edge of the JET plasma using collection and fibre optics to couple the plasma light to spectrometers. The geometrical arrangement of the heating neutral beams and the periscope lines of sight for the edge plasma view are shown in figure 1(a) and 1(b). The diameters of edge view lines of sight are about 7.8mm at the intersection with the neutral beam. However, each viewing line of sight crosses a range of flux surfaces as it intersects the neutral

beam volume, which degrades the space resolution of the diagnostic to as much as 40mm for the innermost chords. The collection optics are installed in vertically opposite, 9cm diameter ports in the top and bottom of JET's mechanical structure. The periscope optical heads consist of two telecentric quartz lenses and a ate plate containing an array of  fibre optics. The optics are housed in a probe assembly that is held in place in springs in a collar behind the windows. The port and hence the optical head diameter, act as constraints to fix the amount of demagnification that can be built into the viewing system. The  fibre diameter together with the magnification set the line of sight spot size in the plasma. The whole assembly operates at the JET wall temperature of 200$^{o}$C. The lens system design minimises the effect of aberrations for the extreme off-axis position used for these edge measurements. Image distortion in the lens is considered in setting the positions of the fibre optics. The charge exchange emission light is imaged by the lens system onto thirty five, 600 micrometer, quartz fibres mounted in a linear array within each periscope and the collection optics fill the f number (f/2.5) of the  fibres. The plasma light is transferred 120 m away from the tokamak to a low-radiation area, where the spectrometer systems are located. Light is coupled to two separate McPherson spectrometer systems for full edge plasma coverage.

A single periscope is installed in a lower port on the opposite side of the torus, to view the other set of neutral beams, from the core to the outer edge of the JET plasma. The geometrical arrangement of the heating neutral beams and the periscope lines of sight for the core plasma view are shown in figure 1(c) and (d). The diameter of each viewing line is about 50mm at the intersection with the neutral beam and can degrade to as much as 100mm for the innermost lines of sight as they cross a range of flux surfaces which intersect the neutral beam volume. The optical head of the periscopes consist of three lenses, a prism and a plate containing an array of  fifteen  fibre optics. The optics are housed in a probe assembly, which is also held in place with springs in a collar behind the window in a similar way to the edge viewing system. The core viewing periscope is also installed through a 9cm diameter port-hole and the periscope's tubular housing provides suffi cient shielding to the periscope window from coating during beryllium evaporation.

## 3. SPECTROMETER AND CCD DETECTORS

JET's edge CXRS diagnostic uses two spectrometer-CCD detector systems. The first is a coupled spectrometer system comprising a pre-filter spectrometer and an analyser spectrometer and is described in detail in [1, 2]. Eight matched  fibres from each of the edge viewing periscopes are coupled to the double spectrometer system. To accommodate sixteen fibres the entrance slit of the pre-filter spectrometer is arranged in four rows and four columns, coupled using input optics. The analysing spectrometer of this system is a 1.33m Czerny-Turner instrument (McPherson model 209) that accepts light up to f/9.

Six  fibres from the core viewing periscope are vertically stacked on a  fibre plate that is connected to the spectrometer via input optics to second input slit of the analyser spectrometer. A mirror is used to switch the incoming light between either the edge or core view.

The output spectra (either edge or core view) of the analyser spectrometer are imaged on to a CCD with a 22μm 385×578 pixel, thinned and back illuminated EEV chip which is phosphor coated to extend the short wavelenth sensitivity below 500 nm [2]. The CCD is controlled and read out by a low noise camera system [2] that also provides Peltier cooling to maintain the chip at $200^{o}$K to reduce charge build up from the dark current. This system provides measurements of $T_i$, $v_\theta$ and $v_{phi}$ at eight edge radial positions and $T_i$ and $v_\theta$ measurements at six core plasma radii. The minimum time resolution of this systems remains at 50ms.

Twelve fibre optics, six each from the upper and lower edge viewing periscopes, are coupled to a 0.5m Czerny-Turner instrument (McPherson model 205) that accepts light up to f/4. The spectrometer is fitted with a 2160 lines.$mm^{-1}$, 128×154 mm grating. The twelve 0.6 mm diameter fibres are vertically stacked in a fibre plate that is directly coupled to the 20 mm high entrance slit. The 20mm high image from the spectrometer is demagnified 3× on to an XCAM CCD camera chip using a standard f/1.2 50 mm camera lens. The XCAM CCD is an E2V CCd57-20 detector and has 512×512 pixels in the active area and each pixel measures $13\mu m^2$. The CCD is thinned and back-illuminated to give a high quantum efficiency in of 87% at 500nm. With on chip binning the minimum exposure time with plasma operation will be 10ms. The edgemost fibres from the edge viewing periscopes are coupled to this system due to its higher quantum efficiency and it provides measurements of $T_i$, $v_\theta$ and $v_{phi}$ at six radial positions.

Data from each CCD is digitised in the camera and transferred to the memory of a Personal Computer (PC). Each of the CCD detectors uses dedicated data acquisition software written for the JET computer system. The PCs are controlled automatically by file transfer protocol commands from a central JET UNIX data acquisition computer over Ethernet connections. Data from each JET discharge is acquired on the PC and is automatically archived on the main JET data storage system.

## RESULTS

The enhanced edge CXRS diagnostic is now successfully taking data and examples of typical C VI, 529.1nm spectra are shown in figure 2 (a) and (b). Calibration and further commissioning of each of the diagnostic systems is currently taking place in preparation for plasma operation of JET beginning in April 2006.

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## REFERENCES


[1]. Hawkes N and Peacock N. Takizuka, Review of Scientific Instruments **63**(10) October 1992, 5164-5166.

[2]. Hawkes N.C, Review of Scientific Instruments **68**(5) May 1997, 2051-2059.

[3]. Hawkes N.C, Plasma Physics and Controlled Fusion **38** (1996) 1261-1266.

[4]. Righi E, Bartlett D.V, Christiansen J.P, Conway G.D, Cordey J.G, Eriksson L-G, De Esch HPL, Fishpool G.M, Gowers C.W, de Haas J.C.M, Harbour P.J, Hawkes N.C, Jacquinot J, Jones T.T.C, Kerner W, King Q.A, Lowry C.G, Monk R.D, Nielsen P, Rimini F.G, Saibene G, Sartori R, Schunke B, Sips A.C.C, Smith R.J, Stamp M.F, Start D.F.H, Thomsen K, Tubbing B.J.D, Zornig N, Nuclear Fusion **39** (3) (1999) 309-3197.

[5]. Andrew Y, Hawkes N.C, O'Mullane M.G, Sartori R, Beurskens M.N.A, Coffey I, Joffrin E, Loarte A, McDonald D.C, Prentice R, Saibene G, Suttrop W and Zastrow K-D, Plasma Physics and Controlled Fusion **46** (2004) 337-347.

[6]. Saibene G, Lomas P.J, Sartori R, Loarte A, Stober J, Andrew Y, Arshad S.A, Conway G.D, de la Luna E, Gunther K, Ingesson L.C, Kempenaars M.A.H, Korotkov A, Koslowski H.R, Lonroth J.S, McDonald D.C, Meigs A, Monier-Garbet P, Parail V, Perez C.P, Rimini F.G, Sharapov S and Thomas P.R, Nuclear Fusion **45** (2005) 297-317.

[7]. Crombe K, Andrew Y, Brix M, Giroud C, Hacquin S, Hawkes N.C, Murari A, Nave F..F, Ongena J, Parail V, Van Oost G, Voitsekhovitch and Zastrow K-D, Physical Review Letters **95**, 15003 (2005).

[8]. Tala T, Andrew Y, Corrigan G, Crombe K, Heading D, Parail V, Salmi A, Strabd P and Weiland J, presented at the EPS Tarragona (2005).

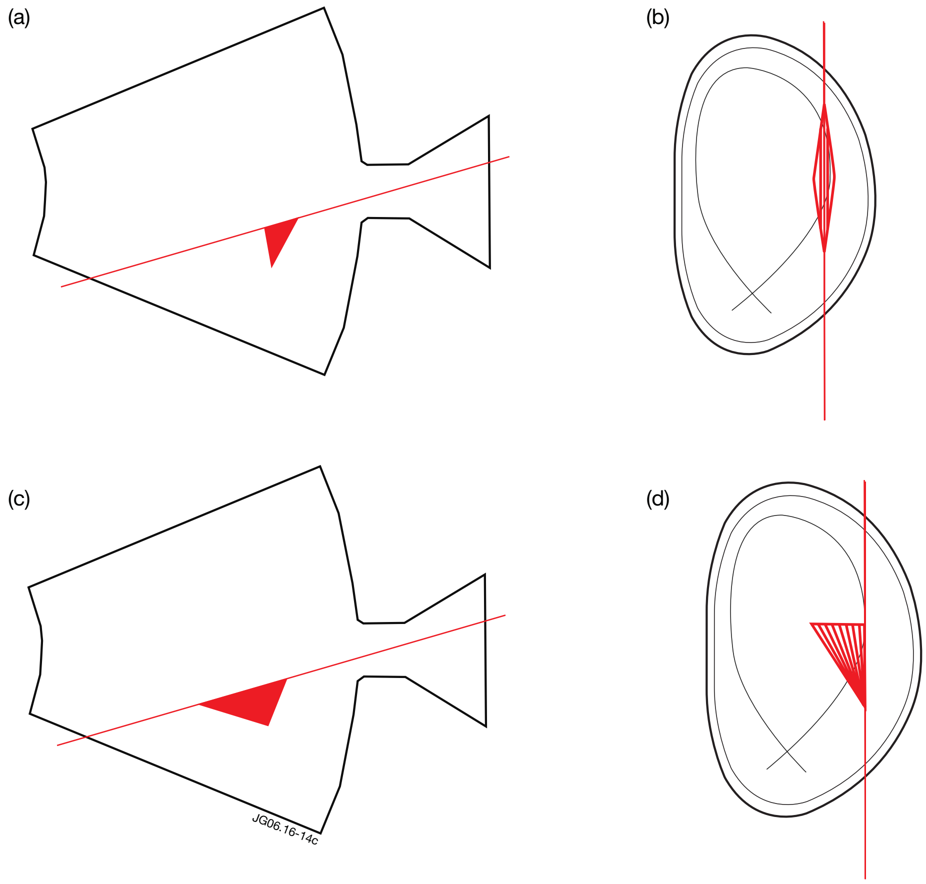


*Figure 1: Layout of viewing lines of sight and neutral beams for JET's edge CXRS diagnostic. (a) Plan view of neutral beams and edge lines of sight and (b) Poloidal section. (c) Plan view of neutral beams and core lines of sight and (d) Poloidal section. The viewing lines of sight have both poloidal and toroidal components.*

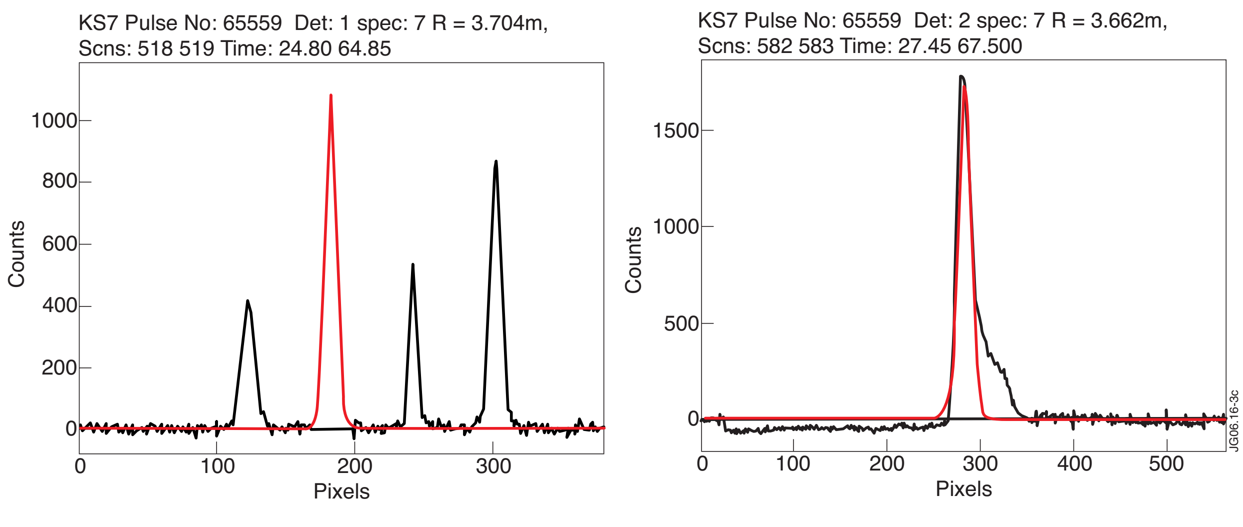


*Figure 2:Example charge exchange spectra from C VI, n=8-7 529.1nm for (a) Edge plasma view using McPherson 209, (b) Edge plasma using McPherson 205.*