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# Status of the R&D activities to the design of an ITER core CXRS diagnostic system

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## HIGHLIGHTS

- The CXRS diagnostic for the core plasma of ITER will provide observation of the dedicated diagnostic beam (DNB) over a wide radial range, roughly $r/a = 0.7$ to 0.
- A high performance (étendue × transmission, dynamic range) is expected for the port plug system since the beam attenuation is large and the background light omnipresent.
- The design is particularly challenging in view of the ITER environment, especially with respect to the first mirror which faces the plasma.
- The current status of development is presented by detailing several sub-systems before a four years design phase under an FPA between F4E and the ITER core CXRS Consortium (IC3).

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## ABSTRACT

The CXRS (Charge-eXchange Recombination Spectroscopy) diagnostic for the core plasma of ITER will be designed to provide observation of the dedicated diagnostic beam (DNB) over a wide radial range, roughly from a normalised radius $r/a = 0.7$ to close to the plasma axis. The collected light will be transported through the Upper Port Plug #3 (UPP3) to a bundle of fibres and ultimately to a set of remote spectrometers. The design is particularly challenging in view of the ITER environment of particle, heat and neutron fluxes, temperature cycles, electromagnetic loads, vibrations, expected material degradation and fatigue, constraints against tritium penetration, integration in the plug and limited opportunities for maintenance. Moreover, a high performance (étendue × transmission, dynamic range) is expected for the port plug system since the beam attenuation is large and the background light omnipresent, especially in terms of bremsstrahlung, line radiation and reflections. The present contribution will give an overview of the current status and activities which deal with the core CXRS system, summarising the investigations which have taken place before entering the actual development and design phase.



## 1. Introduction

The core Charge-Exchange Recombination Spectroscopy diagnostic (CXRS) for ITER will be installed in an upper port plug (UPP 3) and shall observe the dedicated diagnostic beam (DNB) in the next sector in anti-clockwise direction. It is expected to measure and derive several physical quantities from the light emitted as a result of the interaction of the neutrals in the diagnostic beam with impurity ions in the plasma. It seemed appropriate to summarise the status of development reached before entering a four years design phase under the umbrella of a Framework Partnership Agreement (FPA) between

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the European Agency F4E and the ITER core CXRS Consortium (IC3).

The core CXRS diagnostic will be designed to provide observation of the DNB over a wide radial range, roughly from $r/a = 0.7$ to close to the plasma axis (with $r/a$ the radius normalised to the minor plasma radius $a$). The collected light will be transported by a bundle of fibres to a set of remote spectrometers. The design is particularly challenging in view of the ITER environment of particle, heat and neutron fluxes, temperature cycles, electromagnetic loads, vibrations, expected material degradation and fatigue, constraints against tritium penetration, integration in the plug and limited opportunities for maintenance [1,2].

The first mirror which is facing the plasma is obviously the most vulnerable component. It is subjected to simultaneous erosion and deposition of impurities which may reduce the specular reflectivity significantly. A high performance in terms of étendue × transmission or dynamic range is expected, though, since the beam attenuation is large and the background light omnipresent, especially from bremsstrahlung, line radiation and reflections. As a consequence, a shutter is foreseen to protect the mirror from the particle fluxes when no measurement is taking place.

Engineering studies were conducted on several concepts and on specific components like the above-mentioned shutter, retractable tubes, mirrors and mirror mounts, calibration systems, etc. They cover the optical design, electromagnetic, structural and thermal analysis of single components and assemblies and lead to preliminary performance assessments. Details are given in numerous separate, specialised contributions. The several functional elements of a possible diagnostic arrangement have reached different stages of development.

## 2. Spectral range

The core CXRS system is an active spectroscopic diagnostic which measures line emission of several highly ionised impurities in the plasma. The light emission is triggered by the capture of an electron from the neutral hydrogen atoms in the injected diagnostic beam. This charge exchange leaves the resulting H-like impurity ion in an excited state, which is stabilised by emitting light.

The physical quantities to be measured encompass the core He density, the concentration and/or the density and temperature profiles of several impurity ions and, to some extent, the plasma rotation. The detection limits (minimum density, time and spatial resolution) may be different for all these quantities and very much depend on the profile and available current density of the DNB. A summary of the requirements is given, for instance, in [3].

The corresponding spectral range, which forms the basis of the optical design, can be roughly split in the visible in

a λ460 nm band (He, Be) – around 468 nm which enables observation of He II, Be IV;
a λ520 nm band (C, Ne, Ar, Kr) – around 527 nm, for Ne IV, Be II, Ne X and Ar XVII/XVI; and
a λ656 nm band (Balmer) with $H_\alpha$, $D_\alpha$, $T_\alpha$ at 656 nm.

The system is thus designed for the visible spectral range with the blue region, from 450 nm up, the most difficult to achieve but also the most important one. The design will be based on recent physics and instrumental developments as found in [3–6].

## 3. Functional assemblies and analysis

A possible arrangement of the CXRS port plug UPP 3 is depicted in Fig. 1.

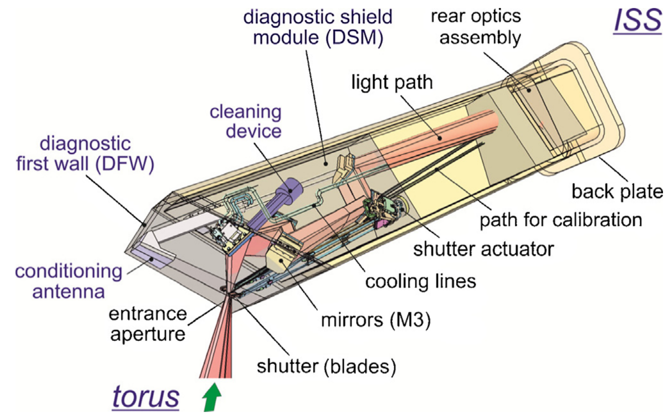


**Fig. 1.** View of a possible setup in the upper port plug No. 3.

The whole setup is embedded in the port plug container which also hosts other diagnostic systems. In the present case, it is a wall conditioning antenna with its feeding lines. Similarly, the Diagnostic First Wall (DFW), the Diagnostic Shield Module (DSM) at the front and the volume for a rear assembly at the back are given parts of the generic port plug.

Several building blocks or sub-systems of the CXRS diagnostic can readily be identified on the picture. The list comprises, according to a functional breakdown: the entrance aperture and optical duct, the front mirror assembly, the first mirror (M1) protection shutter, the M1 cleaning device (not part of the current FPA), the rear mirror assembly, the calibration system and, behind the vacuum windows, the external components like the light transport system made of glass fibres, the spectrometers and sensors, the data-acquisition system. Alternatively, the imaging and light transport system in the port plug can be split from another point of view, i.e. according to the demanding environmental requirements, in a first mirror M1 and a catadioptric chain of subsequent optical elements, composed mostly if not exclusively of mirrors M2. . .Mx.

The thermal, thermo-mechanical, full structural and electromagnetic analysis of several components of the last but one option can be found in [7–13].

### 3.1. The optical duct

The optical duct is obviously an indispensable penetration through the diagnostic first wall, which influences the actual positioning of the water channels which ensure the active cooling. The exact shape will depend on the optical design but it is likely that the entrance hole (most probably the entrance pupil of the optics) must and can be kept with a diameter $D$ between Ø25 mm and Ø45 mm. The current target is to withdraw the first mirror by a distance $L$ such that $L/D \geq 5$. Experimental investigations are pursued, some of which are reported on in [13]. A long conical duct – the longer the better – with an integrated system of baffles can be mandatory, both to reduce stray light and the effect of impinging particles, sputtering and deposition [14]. Similarly, the length of the duct and the layout of the baffles can significantly improve the heat flux incident on the first mirror; a recent detailed analysis in the case of purely radiative loads can be found in [15]: the flux density can be reduced from an impinging order of magnitude of 200 kW/m$^2$ to about 400 W/m$^2$ depending on the assumed emissivity of the duct walls and on their temperature, that is on the efficiency of the local active cooling. Note that this dramatic reduction applies only to the radiative case and is also dependent on the temperature which can be assumed for M1 as well, so it very much depends on the actual design. The estimation was performed for a large mirror option as shown in Fig. 2.