# RESULTS ON JET PLASMA AND IMPURITY BEHAVIOUR BASED ON MEASUREMENTS OF RADIAL PROFILES IN THE SOFT X-RAY REGION

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## Abstract

First measurements of spatial profiles of the emission lines of different nickel ionisation stages were carried out at JET by means of the spatial scan double crystal monochromator. These profiles are compared with results of transport simulations, by which the calculated ionisation balance is verified. The measurements, furthermore, give the emission shells presently used for ion temperature measurements using X-ray line profiles.

## 1. Introduction

The measurements of the spatial and temporal distributions of impurities in magnetically confined high temperature plasmas are important for the investigations of impurity behaviour and radiation power losses. For electron temperatures of several keV the line radiation is emitted predominantly in the soft X-ray region. Therefore X-ray spectroscopy over a wide wavelength range (from about 0.1 nm to 2.5 nm) with continuous spatial scanning across the minor plasma radius is important both for studying the emission shells to understand the ionisation equilibrium and the impurity transport and for emission layer measurements in diagnostics like ion temperature measurements from X-ray line Doppler profiles.

For this purpose a double crystal monochromator [1], capable of continuous spatial scanning of X-ray spectral lines across the plasma minor radius, has recently come into operation at JET. The double crystal system allows effective shielding against neutrons and hard X-rays from the plasma.

## 2. The spatially scanning double crystal monochromator

A scheme (not to scale) of this double crystal monochromator is shown in Fig. 1. The two plane crystals simultaneously have to fulfill the Bragg condition $n\lambda = 2d \cdot sin\ \Theta$ (with $\lambda$ the wavelength, 2d the lattice constant, $\Theta$ the Bragg angle and n an integer) within a relatively small angular margin. The crystal reflectivity has to be high and constant across the crystal surface to obtain high photon throughput of the monochromator [2]. The spectral resolution of the device is determined by the angular acceptance of the X-ray collimator and the rocking curve width of crystal 2.

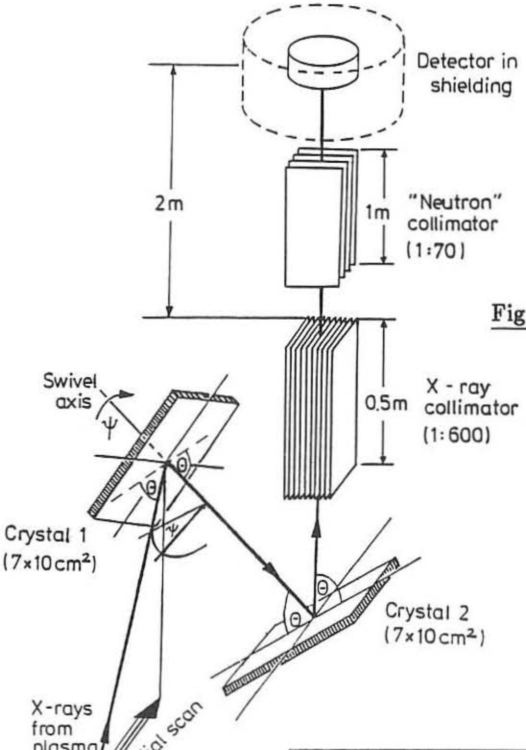

Fig. 1 Schematic of the spatial scan double crystal monochromator

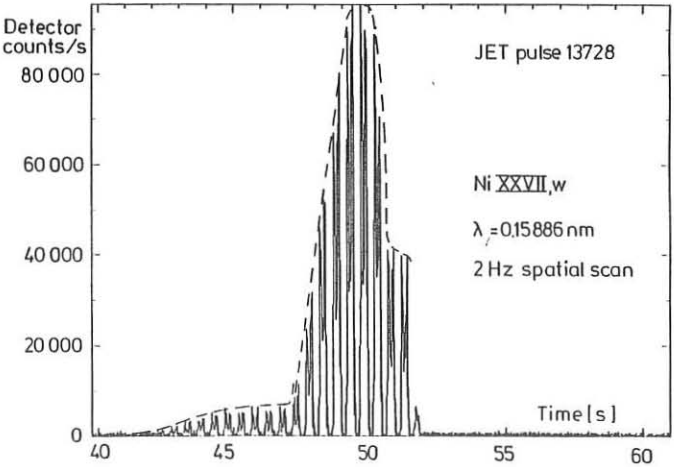

Fig. 2 Example of the count rate versus time for the helium-like resonance line of nickel spatially scanned with 2 Hz

The swivelling of crystal 1 by an angle $\psi$ around the optical axis between the two crystals enables a continuous spatial scanning of the plasma. The detector is a large-area multiwire proportional counter [3]in a shielding block on top of the instrument. A "neutron" collimator is used for the reduction of the neutron and hard X-ray flux from the plasma for background count rate limitation. The neutron collimator, moreover, has to limit the acceptance angle in the non-dispersive direction for crystal 2, in order to obtain a smooth photon throughput as function of swivel angle as well as to define the spatial resolution of the instrument. Details of the properties and the tests of the monochromator as well as the measurements of the relative sensitivity of the instrument using a calibrated large-area X-ray source are described in [4].

For the first measurements LiF(220) crystals (2d = 0.2848 nm) were used allowing the wavelength range from 0.113 nm to about 0.203 nm to be covered with most of the hydrogen- and helium-like transitions of medium-Z impurities (like Ni). For the longer wavelengths of the oxygen lines KAP(001) crystals (2d = 2.6579 nm) will be used.

## 3. First results of spatially resolved X-ray line emission from JET

First measurements of the emission shells of several nickel ionisation stages were performed at JET by means of the spatial scan double crystal monochromator. The radial profiles are quite different for lines of different ionisation stages: The profiles of the lower stages are nearly flat, while those of the hydrogen- and helium-like transitions are peaked around the plasma center.

An example of the detector count rate for the helium-like resonance line (w) of nickel $1s^2\ ^1S_o - 1s2p\ ^1P_1$ taken at 2 Hz scan frequency is plotted in Fig. 2. The peaks just follow the time dependence of the line intensity (as obtained from the high-resolution X-ray spectrometer KX1 at JET, dotted line). Examples of the relative intensity distributions of the hydrogen-like nickel line Ly $\alpha_2$ ($1s^2S_{1/2}$-$2p^2P_{1/2}$) and the helium-like w line are given in Fig. 3 versus radius R in the JET midplane. Abel inversion of these profiles gives the relative emission coefficients of these lines versus the distance ($R - R_o$) from the plasma center $R_o$, plotted in Fig. 4 (solid lines).

The radial profiles of these two nickel lines were also simulated using the impurity transport code [5]with the actual radial distributions of electron temperature $T_e$ and density $n_e$ as well as the atomic physics and transport data input. These simulated emission coefficient radial distributions are added into Fig. 4 as dotted lines. The agreement of measured and simulated profiles is satisfactory within the error bars of the plasma parameters and the assumptions underlying the analysis.

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## References

[1] W.Engelhardt, J.Fink, G.Fußmann, H.Krause, H.-B. Schilling, U. Schumacher, MPI für Plasmaphysik, Report IPP 1/212, IPP III/81, Garching 1982; C.Andelfinger, J.Fink, G.Fußmann, H.Krause, H.Röhr, H.-B. Schilling, U.Schumacher, P.Becker, H.Siegert, H. Belzig, A.Berghausen, R.Veigel, H.Zech, Report IPP 1/226, Garching, 1984

[2] U.Schumacher, Nucl.Instr.and Meth. A251, 564 (1986) and A259, 538 (1987)

[3] G.Rupprecht, JET-Report, to be published

[4] J.Fink, H.W.Morsi, H.Röhr, U.Schumacher, Report IPP 1/240 (1987); H.W.Morsi, H.Röhr,U.Schumacher, Z.Naturforsch. 42a, 1051 (1987); and to be published

[5] K.Behringer, JET-Report JET-R(87)08 (1987)

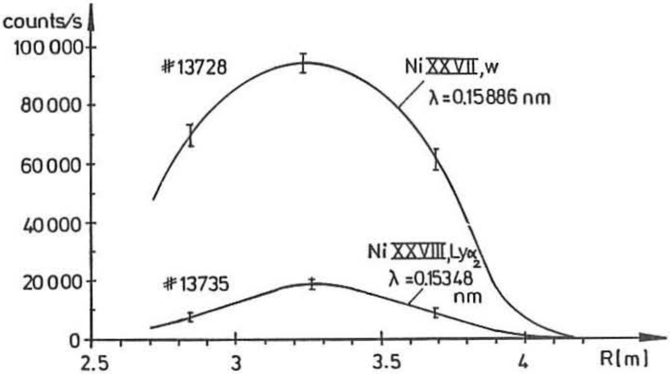

Fig. 3 Relative intensity distributions of nickel hydrogen-like Ly$\alpha_2$ and helium-like resonance line w versus radius R in the JET midplane

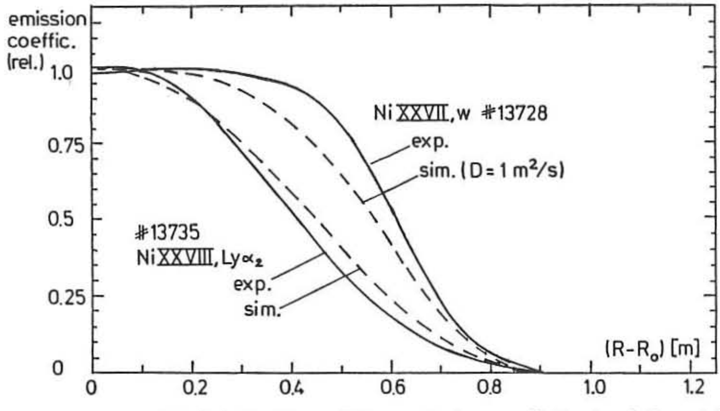

Fig. 4 The radial distribution of the emission coefficients of the nickel lines of Fig.3.