FR 9302753

DRFC/CAD EUR-CEA-FC-1477

PROBING NEUTRAL DENSITY AT THE PLASMA EDGE OF TORE SUPRA WITH CX EXCITED IMPURITY IONS

W.R. HESS, M. MATTIOLI, R. GUIRLET, M. DRUETTA

Janvier 1993

CEA EURATOM

ASSOCIATION EURATOM-C.E.A.
DEPARTEMENT DE RECHERCHES SUR LA FUSION CONTROLEE
C.E.N./CADARACHE
13108 SAINT PAUL LEZ DURANCE CEDEX

PROBING NEUTRAL DENSITY AT THE PLASMA EDGE OF TORE SUPRA WITH CX EXCITED IMPURITY IONS

HESS W.R., MATTIOLI M., GUIRLET R., DRUETTA M.*

Association EURATOM-CEA CEN-Cadarache

F-13108 St Paul-lez-Durance France

* Université de St Etienne, France

1.INTRODUCTION

In Tokamak plasma physics renewed interest in visible spectroscopy has grown for two reasons. The use of fiber optics (even inside the vacuum vessel) allows observation of local sources of both impurities and of hydrogen by observing radiation of low ionisation states. Theoretical calculations are available to connect the number of ionisations to the emitted photons [1]. Moreover, charge exchange spectroscopy (CXS) [2,3] with either auxiliary or heating neutral beams is a standard technique to determine the ion temperature and impurity density profiles. Suitable near UV or visible lines are observed following charge exchange collisions populating highly excited levels. Generally lines from recombined hydrogen-like ions up to Ne are observed. Since carbon is in some devices the most abundant element the 5290.6 Å CVI 8-7 line is almost universally analysed to deduce from line broadening, lineshift and radiance, respectively, the ion temperature, rotation velocity and the fully stripped carbon ion density. These lines are also observed in the absence of beams where they are characterized by small widths, the emission being at the plasma periphery. In the presence of beams the hot component is superposed on the cold one and deconvolution is necessary. The quantitative interpretation of the hot component is quite reliable since the upper level of the visible transitions is produced by charge exchange collisions with ground state neutral hydrogen isotopes for which a large amount of theoretical data is available. Collisions (both with electrons and protons) redistribute the ions over the l-states. Detailed knowledge of the involved cross sections is not critical since the l-mixing is quite large at typical plasma parameters. On the other hand, the quantitative interpretation of the cold feature is much more delicate since both electron collisions from the ground state of C^{5+}

ions and CX collisions with neutral hydrogen isotopes have to be considered. For the former, atomic physics calculations are generally performed up to n=5 states and extrapolated to higher n states. For the latter, since for ground state neutrals the cross sections for populating C^{5+}(n=8) states decrease rapidly for decreasing collision energies, only excited neutrals must be considered as electron donors for the CX collisions at peripheral plasma collision energies. Calculations show that n=2 donors populate mainly the C^{5+}(n=8) states. Such collisions are effectively influencing the plasma emission of Tokamak plasmas as experimentally observed in Alcator [4] and in JET [5]. Broad spectral lines emitted at very large quantum numbers n have been observed in both devices, emitted from Ar^{16+} ions in Alcator ($1s^2$-1s np series) and from C^{5+} ions in JET (Lyman series).

In this report, after a short description in section 2 of the experimental setup and the ergodic divertor of Tore Supra (TS), we shall present in section 3 two discharges in which space-resolved observations of the CVI (8-7) line clearly show the presence of CX-related effects. In section 4 we shall discuss a well isolated spectral line at 5304.6 Å . Tentative identification as CIII ($1s^2$ 2s, 7-5) is suggested.

The conclusion of section 5 will address the usefulness of the reported results for probing neutral density at the plasma edge by detecting CX excited impurity ions. It will be also stressed that highly ionized C^{6+} ions exist in the MARFE regions. To the best of our knowledge, only very low ionisation C and O ions (such as CIII or OIV) have been previously reported in these regions.

2.1 EXPERIMENTAL SETUP

It is now a common technique, especially on Tokamaks with a high radiation level to use UV-grade fused Silica fibers to transport the photon flux to the detection system behind the biological shield. In long duration TS discharges (20 to 60 s) virtually the whole spectral range from 280 to 750 nm can be scanned with a 2-dimensional CCD camera. The radiation of 9 fibers, each corresponding to a precisely mapped viewing line (see fig.1) is recorded on 9 traces on the CCD chip (1 trace=384 pixel ~40 Å). Slit width and grating position of the Czerny-Turner spectrometer (f=1 m, 2000 & 3600 grooves/mm gratings) can be changed during the discharge, so that a spectral range of typically 500 Å is available in high resolution (dispersion=0.1 Å/pix; instrumental function=0.4 Å). Light is collected from a cone expanding from 25 mm at the entrance pupil (EP) of the telescope (fused Silica triplet lens f/2; f=50 mm; wide angle 30°) to a spot of Ø=60 mm at the inner carbon wall. A rotating dichroic sheath polarizer mounted at the EP allows analysis of the σ or π polarized Zeeman pattern. This simplifies the spectrum, especially in the π (parallel to B_t) position . The intensity ratio I_π/I_σ is better than a factor of 10.

2.2 THE ERGODIC DIVERTOR (ED) AS A TOOL FOR PLASMA EDGE DIAGNOSTICS.

The ED on TS is a unique device which allows modification of the plasma edge heat & particle transport without modifying the plasma bulk characteristics [6,7]. The ED consists of 6 octopolar coils. They are equally spaced toroidally. Each panel covers a toroidal angle of $\Delta\varphi = \pi/14$. The panels with their 8 current bars are localized on the low field side (LFS) of the torus. The poloidal extension is $\Delta\theta = \pi/3$. The spectrum of the magnetic perturbation is such that the magnetic surfaces are destroyed for q values ranging between 3.5 and 2.5. The ergodicity of the field lines is characterized by the "diffusion" of the field lines D_{FL} (~10^{-4} m^2/m) and the stochasticity by the length L_K (~πqR) which governs the exponential divergence of neighbouring flux lines. The diffusion coefficient with the usual units (m^2/s) is obtained by multiplying D_{FL} with the thermal velocity of the particles. This picture is modified if one introduces a wall in this layer. The field lines are then connected to the wall and thus exhibit a finite wall to wall connection length. One can readily expect the basic properties of the stochasticity to hold provided the distance along the field line to the wall, the connection length L_{wall}, is larger than L_K. When L_{wall} is smaller than L_K, the distance to the wall is too short to allow a stochastic behaviour, this defines the laminar domain. The width of this domain, $\Delta r_{laminar}$, can be computed from the diffusion in the ergodic domain over the length L_K, $\Delta r_{laminar} \sim (D_{FL}L_K,)^{1/2} \sim 5.10^{-2}$ m. This defines the boundary between the laminar and ergodic regions [7]. This laminar zone corresponds to the usual scrape off layer (SOL) with the same connection length. Depending on the ionization length λ_i neutral atoms (molecules) are ionised within the laminar or ergodic region. Their chance to reach the hotter, better confined regions of the plasma depends on the radial excursion of the field line on which the ion was born. Roughly, ionization within the laminar zone means quick return to wall i.e. increased recycling. This is observed for instance on hydrogen isotopes or low ionization states of impurity ions.

3.RESULTS

3.1 CVI EMISSION WITH HIGH DENSITY PLASMA, MARFE AND DETACHED PLASMA (TS 6851)

A high electron density discharge limited by the LFS (low field side) limiter is first considered. Some plasma parameters are shown in figure 2 (Ip = 1MA, Bt = 3T, a = 0.75m, R = 2.39 m). This discharge is characterised by the formation at t = 4.9 s of a MARFE (a highly radiating plasma region, toroidally symmetric on the HFS) [8]. Its presence is clearly visible in fig. 2 showing a strong increase in c) CII (5145 Å) radiance, d) the bolometer signal and e) the visible bremsstrahlung signal. At the same time in a) the mean electron density <ne> and in b) the CVI Lyα signals decrease. We note that the viewing line in a) is vertical and thus avoids the MARFE while all the others intercept the MARFE. At t = 9.5 s the plasma detaches and the total radiated power approaches the ohmic power [8]. In this case the signals a) through e) show behaviour similar to that for the MARFE . Figure 3 shows the absolute radiance (both polarisations π, σ included) of the CVI (5290 Å) as a function of the chord height (h) at different times. The detector integration time is t = 0.3 s. Excepting during the MARFE (t = 4.9 s), the profiles have the expected shape for a poloidally symmetric emitting shell. The viewing line of fiber H, totally within the emission shell, is situated at h = 670 mm and has a spatial extent of ± 25 mm. For this discharge we do not have a CVI Lyα profile, but under similar non-MARFE experimental situations it has the same shape as CVI 5290 Å of figure 3 [9].

The carbon content has been obtained by means of an impurity transport code as explained in [9]. The atomic physics data used for carbon are the same as given in [5] but recently the CVI 5290 Å line has been added to the code. The effective excitation rate coefficients for photon emission have been decomposed into the electron impact part Qe (from principal quantum number n extrapolation starting from low n) and the CX contribution Qcx (at thermal neutral particle energies). Excited n = 2 hydrogen isotopes are the most important donors for populating the n = 8 C^{5+} levels. Their relative fractions can be obtained from [10]. The atomic data needed were kindly made available to us by H. Summers (JET Laboratory) and by P.T. Greenland (Harwell Laboratory) respectively for Qe and Qcx.

Simulations of CVI Lyα and CVI 5290 Å lines give for "normal" plasmas (i.e., with poloidally symmetrical emitting shells and with peripheral neutral densities n_o not much larger than 10^{16} m^{-3}) a ratio of Lyα to CVI 5290 Å equal to about 1500. Experimental values give chronically too high radiances for the n=8-7 5290 Å transition (i.e. Lyα / (5290) = 500). Since n_o values larger than 10^{17} m^{-3} can be excluded for these plasmas, the large discrepancy has to be imputed essentially to underestimation of the Qe coefficients, which need to be revised.
With the appearance of the MARFE (profile at 4.9 s) a strong increase of the radiances for fibers B, C, D is seen on figure 3. This emission is interpreted as originating from the MARFE (on the HFS extending poloidally for ±20°). It is important to remark that the CVI Lyα radiance is not perturbed during the MARFE.

The origin of the CVI 5290 Å MARFE emission is puzzling since spectroscopic measurements of MARFE emission radiation reported by other laboratories [8, 11, 12] indicate increased emission only from low ionisation states (e.g., CIII or OIV). Consequently the electron temperature must be about a few tenths of an eV. This value is too low for the excitation of C^{5+}. Thus the CVI 5290 Å MARFE emission must be the result, within the MARFE, of CX processes involving C^{6+} ions with excited hydrogen neutrals. The electron temperature within the MARFE is insufficient to fully strip the carbon ions. Thus we are brought to the conclusion of the existence of a fully ionised carbon flux from the hot plasma into the MARFE. During the detached plasma phase the plasma periphery shrinks and the CVI 5290 Å maximum radiance moves from fiber H to fiber G as it appears in figure 4 but its profile is not as expected for a poloidally symmetric emitting shell since there is too much signal on fibers B and C. This indicates a higher n_o density at the HFS. The profile labelled CIII will be discussed in section 4.

The simulation code though it considers impurity transport in a cylindrical plasma has nevertheless been used to roughly estimate the neutral density inside the MARFE n_{oM} necessary to double the CVI 5290 Å simulated radiance. According to [8] the electron density inside the MARFE n_{eM} ranges between 0.5-1.0·$n_e(0)$. Consequently, the MARFE has been simulated by a peripheral bump on the $n_e(r)$ profile with a radial extension of about 80 mm and with a maximum density of 3. 10^{19} m^{-3} (i.e. ~0.75 $n_e(0)$). On the other hand, always inside the MARFE, the electron temperature T_{eM}, the neutral density n_{0M} and the neutral temperature T_{nM}

were adjustable parameters in the simulations. The n=2 population was evaluated under the assumption of an optically thin plasma following [10]. However, opacity of the hydrogen Lyα line cannot be excluded (it would increase the n=2 population by more than an order of magnitude). Satisfactory enhancements of the CVI 5290 Å radiance have been obtained for suitable choices of the adjustable parameters $n_{oM} \sim 3.10^{17}$-10^{18} m^{-3}, $T_{eM} \sim 25$ - 40 eV, $T_{nM} \sim 40$ - 100 eV. The indicated n_{oM} values must be considered as giving just the order of magnitude. T_{eM} and T_{nM}, rather than true temperatures, must be considered as being related to the n=2 population and to the relative velocity of the colliding particles in the CX processes .

3.2. DISCHARGE WITH ERGODIC DIVERTOR AND MULTIPLE PELLET INJECTION (TS 6446)

3.2.1. CVI EMISSION

In this second type of discharge the peripheral effects at the plasma edge show again the importance of CX processes. Some plasma parameters are shown in figure 5 (Ip = 1.5 MA, B_t = 3.35 T, a = 0.73 m, R_o = 2.4 - 2.32 m). During the current plateau (2.5 < t < 8.5 s) seven deuterium pellets are injected, three of them during ED activation. Up to t = 7 s the plasma is limited on the LFS and is subsequently moved toward the inner carbon wall (HFS). As seen in figure 5c, the major plasma radius R_o changes from 2.40 m to 2.32 m.

Figure 5e shows the reduction of CVI Lyα always observed during ED activation. This is interpreted as an indication of Carbon screening induced by the ED [9]. On the other hand peripheral carbon lines as CIII in fig. 5f increase, which indicates increased recycling at the edge with little penetration towards the center. The dips in Hα and CIII radiances (fig. 5d, 5f) show that H and C recycling is temporarily reduced at the moment of pellet injection especially during ED activation. The initial level is recovered within 180 ms which is close to τ_p the mean particle life time.

As in the previous section 3.1, before ED activation the CVI (5290 Å) profile is poloidally symmetric as seen in figure 6 at t = 2.9 s. During ED activation (with pellet injection at t=5.9 s, fig. 6) the poloidal symmetry is lost. As with the MARFE the enhanced signal of fibers B, C, D is caused by CX with increased neutral deuterium density. This is consistent with increased Hα/Dα recycling seen on figure 5d). The increase in CVI 5290 Å is even stronger without ED at t=7.4 s (fig. 6) when the plasma is leaning on the inner Carbon wall. As already stated the CVI Lyα profile remains poloidally symmetric in all situations. The reduction of CVI Lyα is not seen on the visible CVI (8-7) line, which increases during ED activation. This increase can only be due to CX with supplementary n=2 neutral excited Deuterium at the plasma edge.

3.2.2. PLASMA EDGE ION TEMPERATURE

Another interesting effect of the ED is shown on the spectral line profiles of CVI 5290 Å (figures 7, 8 and 9) for three viewing lines : respectively central, ergodic zone and SOL. For each viewing line are shown three spectral profiles: 1) before, 2) during pellet injection, and 3) pellet injection with ED. The line structure shows an asymmetry towards shorter wavelengths [13]. This is due to fine structure, the low l-component being shifted in the shorter wavelength direction. The use of a polarizer simplifies the Zeeman structure. Only the π - component is transmitted ($I\sigma/I\pi \leq 0.1$). Fine structure effects are clearly visible at low temperatures when the Doppler broadening is less or comparable to the fine structure (e.g. fig. 9). Relative intensities and precise wavelengths for all (8-7) transitions under the hypothesis of complete l-mixing were kindly made available to us by H. Summers (JET Laboratory). On the assumption of pure thermal Doppler broadening of the most intense transitions between the 8th and 7th principal quantum shells of CVI with the corresponding wavelength shifts a gaussian sum profile can be fitted to the measured line shape. In fig.10 an example of the calculated spectral profile (π - component) is shown for the pellet with ED case of fig. 9. The instrumental function (0.4 Å) has been convoluted with each fine structure component of Doppler width 10 eV. The line shape is obtained by adding all components.

For the equatorial viewing line (fiber B, fig. 7), which sees both the cold edge and the hotter part of the plasma two ion temperatures are necessary for the fit. Thus the hot component (before pellet injection) is fitted to give an ion temperature of 460 eV. This means the line originates from the emission shell of C^{5+}. This is in good agreement with the emission profile of CVI Lyα which peaks at 65 cm (r/a = 0.87) at an electron temperature at about 500 eV. This was measured on a discharge with similar plasma conditions [9]. The cold component gives an ion temperature of 50 eV equivalent to the temperature observed on fiber H (fig.8). The latter can be fitted with only one temperature. This is a good approximation for the mean temperature in the ergodic zone within 1 ≤ r/a ≤ 0.86. Figure 11b) shows the temperature variations in this zone as a function of time. The edge temperature drops to 50 eV during ED activation but is then little affected by successive pellets. The outermost fiber J which integrates only through the SOL (r/a>1) shows that the contribution from this region has little weight in the H signal. The total CVI radiance of fiber J is about ten times smaller than the radiance of fiber H. Nevertheless during ED activation the signal to noise ratio of CVI 5290 Å is sufficient (see fig. 9) in order to fit the theoretical line structure already shown in fig. 10. Figure 11a) resumes the values of Ti and Te (Thomson scattering) in the ergodic region. The effect of enhanced heat transport in the ergodic zone during ED activation is clearly seen. Within the error bars Ti equals Te. Interesting is the low SOL temperature of 10 eV which can be explained by outstreaming C^{6+} ions for the following reasons. Firstly, collisionality is high enough to establish thermal equilibrium with the electrons. Secondly, the source of the outstreaming C^{6+} ions is the hot confined zone of the plasma and thirdly, only CX with (excited) edge neutrals produces the observed line. The question about the use of this measurement as a plasma edge diagnostic can be answered as follows : the radial distribution of C^{6+} ions can be measured up to the edge by CXRS (CX recombination spectroscopy) with an auxiliary neutral beam. Therefore the determination of the excited neutral density at the edge is possible with accurate CX cross sections at low energy. It is still necessary to relate the excited neutral density to the ground state density. This diagnostic would be especially interesting for the axisymmetric divertor, where similar plasma conditions are found.

4. IDENTIFICATION OF THE 5304 Å LINE

Among a number of unidentified spectral features the line at 5304.6 ± 0.2 Å (air) is the most persistent and easy to follow. It is well isolated, close to C VI 5290.6 Å (see fig. 8, 9) and at maximum detector sensitivity. The weak neighbour O IV at 5303.8 Å is excluded since it could be easily separated. It is not a Boron line, since it was observed before the 1st boronisation. Its intensity follows closely the intensity of the neighboring C VI line. The 5304 Å line is clearly a CX process related line, since it appears always when the CVI (8-7) is enhanced (e.g. in TS 6851 at 9.5 s). So the best guess is $C^{z+}(nl)$, a member of the Carbon family, which is the major impurity in TS. (The inner wall and all limiters are protected by Carbon tiles). A tentative identification is C III ($1s^2\,2s$,7-5), the measured wavelength being close enough to the theoretical value 5304.9 Å (air) calculated from Grotrian energy levels (7G-5F) [14]. As for C VI (8-7) the spectral shape and intensity seems to be correlated with the neutral density at the plasma edge. Figure 4 shows its radiance as a function of fiber position for TS 6851 (detached plasma phase). The maximum radiance of CIII is closer to the plasma edge. Doppler broadening (see fig. 8,9) is comparable to that of CVI 5290 Å and fine structure is also apparent. We tried to identify closely related transitions as 5F-4D (3884 Å), 7F-5D (4860 Å) and 7D-5P (4673 Å) but unfortunately some of them are close to strong lines (respectively HeI, D_β, CIII) making the identification uncertain in the absence of precise calculations of energy levels.

5. CONCLUSION

The reported results have shown that even in the absence of neutral beams space and wavelength resolved result on the CVI (8-7) line can produce useful information on the peripheral plasma. Precise analysis of the CVI 5290 Å line structure measured with a polarizer for different viewing lines provide plasma edge temperature profiles. The cooling of the plasma edge during ED activation is clearly observed.

In some experimental conditions this Carbon line is affected by CX processes and has a behaviour different from the CVI Lyα line. These CX related processes have been confirmed in the MARFE region, where, as reported here for the first time to the best of our knowledge, large neutral hydrogen densities must exist (very roughly evaluated in the 10^{17} to 10^{18} m^{-3} range). C^{6+} ions must flow from the hot plasma core into the MARFE. With the ergodic divertor the experimental findings are globally similar.

To determine the ground state neutral density at the edge a model is thus required to connect the n=2 population to the ground state population. In this context , reabsorption of hydrogen Lyman α photons must be considered which would increase the n=2 population.

In view of developing methods for probing neutral density at the plasma edge the reported results on the CVI (8-7) line indicate that its study should be pursued. A possible application would be for a low temperature high neutral density plasma encountered in the axisymmmetric divertor region.

The identification of the 5304 Å line as a CIII due to the CX recombination from Li-like C^{3+} ions is being supported by measurements of other lines of the same ion. Observation by measurement of other lines of the He-like C^{4+} and Lithium like C^{3+} producing CX lines in the visible region is in progress. In the absence of precise energy level calculations this identification work is difficult.

REFERENCES

[1] BEHRINGER K. SUMMERS H.P., DENNE B. FORREST M. and STAMP M., Plasma Phys. Contr. Fusion 31, 2059 (1989)

[2] ISLER R.C., Phys.Scr.35, 650 (1987)

[3] FONCK R.J., DARROW D.S. and JAEHNIG K.P., Phys. Rev. A 37, 3288 (1984)

[4] RICE J.E., MARMAR E.S., KALLNE E., and KALLNE J., Phys. Rev. A, 2059 (1989)

[5] MATTIOLI M., PEACOCK N.J., SUMMERS H.P., DENNE B. and HAWKES N.C., Phys. Rev. A 40, 2059 (1989)

[6] GROSMAN A., EVANS T.E., GHENDRIH Ph., CHATELIER M. et al., Plasma Phys. Contr. Fusion 40, 2059 (1990)

[7] NGUYEN F., GHENDRIH Ph., SAMAIN A. and GROSMANN A., 1992 International Conference on Plasma Physics (Proc. 19th Eur. Conf. Innsbruck, 1992) Europhysics Abstracts 16C II-851

[8] LIPSCHULTZ B., J. Nuclear Mater., 145-47, 15 (1987)

[9] BRETON C., DE MICHELIS C., MATTIOLI M., MONIER-GARBET P. et al. Nuclear Fusion 31, 1774 (1991).

[10] JOHNSON L.C. and HINNOV. E., J. Quant. Spectrosc. Radiat. Transfer 13, 333

(1973).

[11] NIEDERMEYER H., BEHRINGER K., BERNHARDI K. et al. Controlled Fusion and Plasma Physics (Proc 11th Eur. Conf. Anchen, 1983); Europhysics Abstracts 7D, I-43.

[12] O'ROURKE J., CAMPBELL O., DENNE B. et al. Controlled Fusion and Plasma Physics (Proc.12th Eur. Conf. Budapest, 1985) Europhysics Abstracts 9F, I-159.

[13] SCHORN R.P. WOLFRUM E. AUMAYR F. et al. Nucl. Fusion 32, 351 (1992)

[14] BASHKIN S. and STONER J. O. Jr. Atomic Energy Levels and Grotrian Diagrams, Vol I, North Holland Publishing (1975).

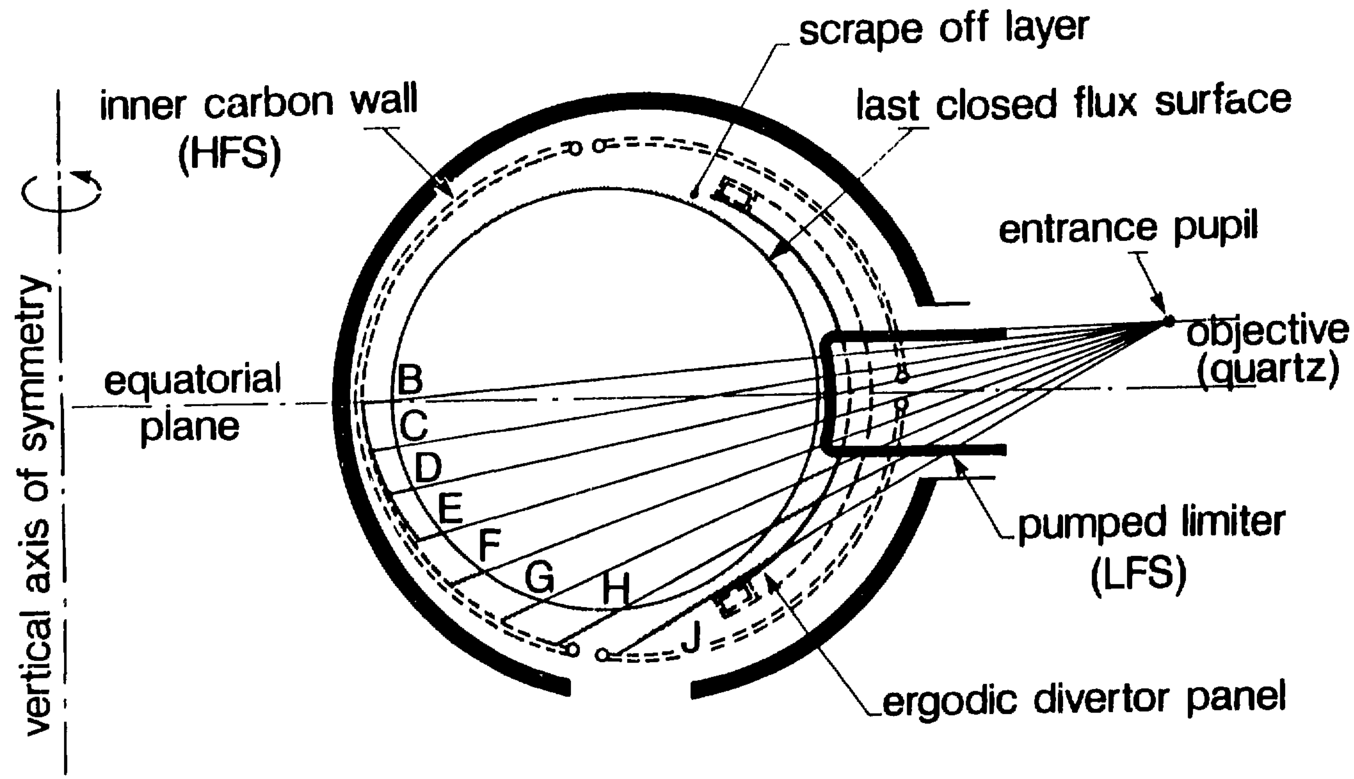
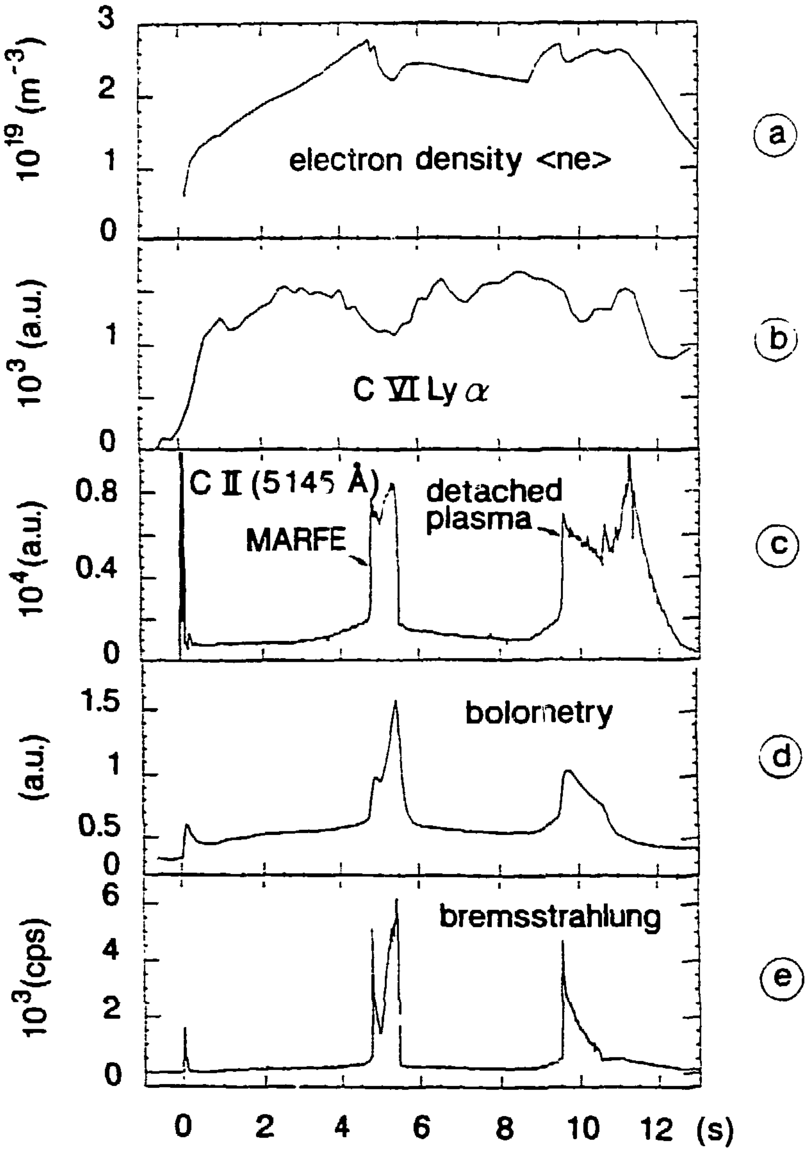


FIG. 1 VIEWING GEOMETRY OF FIBERS B ⟶ J IN POLOIDAL PLANE



Ip = 1 MA, Bt = 3 T, Ro = 2.39 m

LFS limiter a = 0.75 m

FIG.2 TS 6851 HIGH DENSITY DISCHARGE (D_2) WITH MARFE AND DETACHED PLASMA

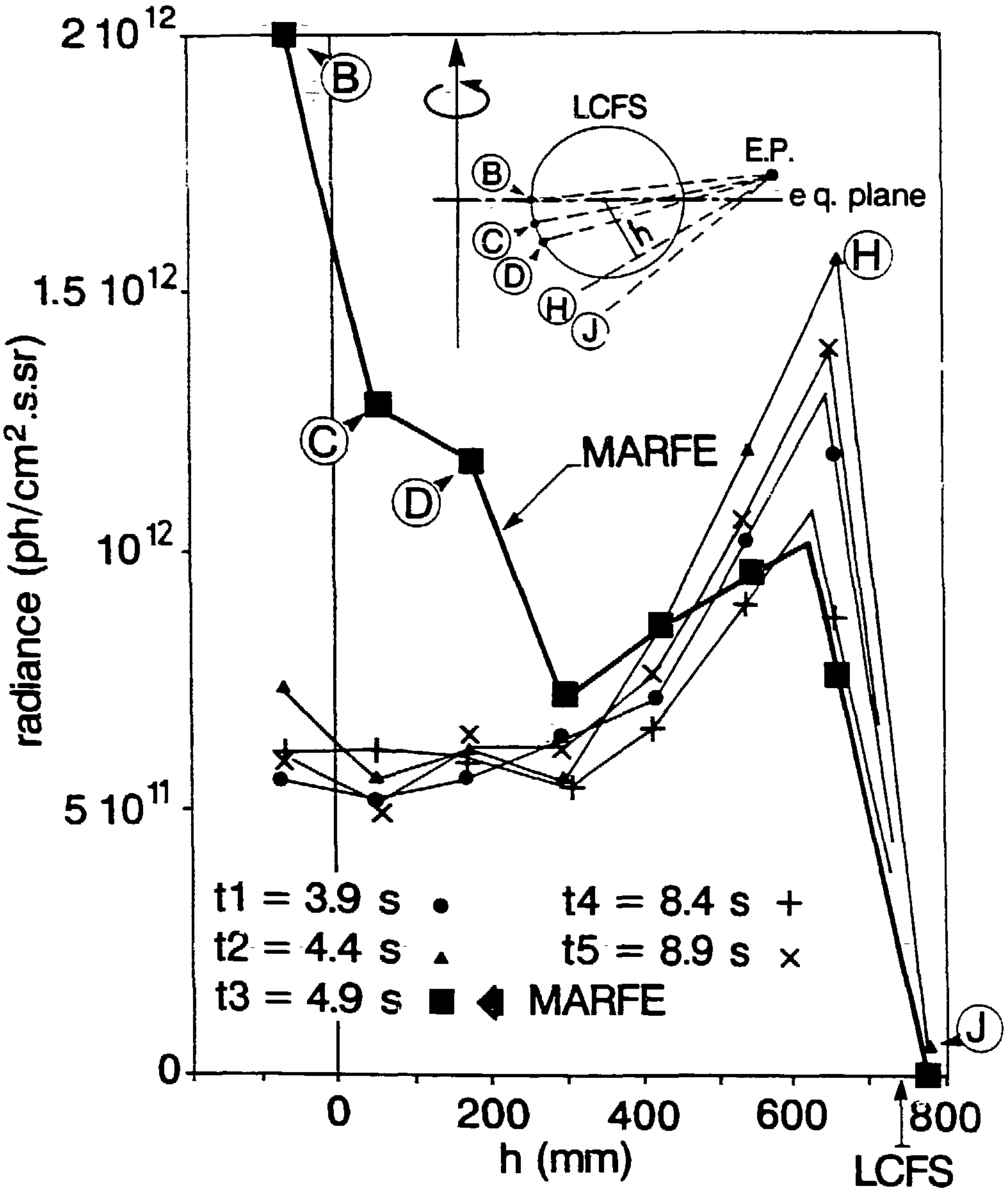


FIG. 3 TS 6851-C VI 5290 Å RADIANCES AS FUNCTION OF VIEWING LINE POSITION h

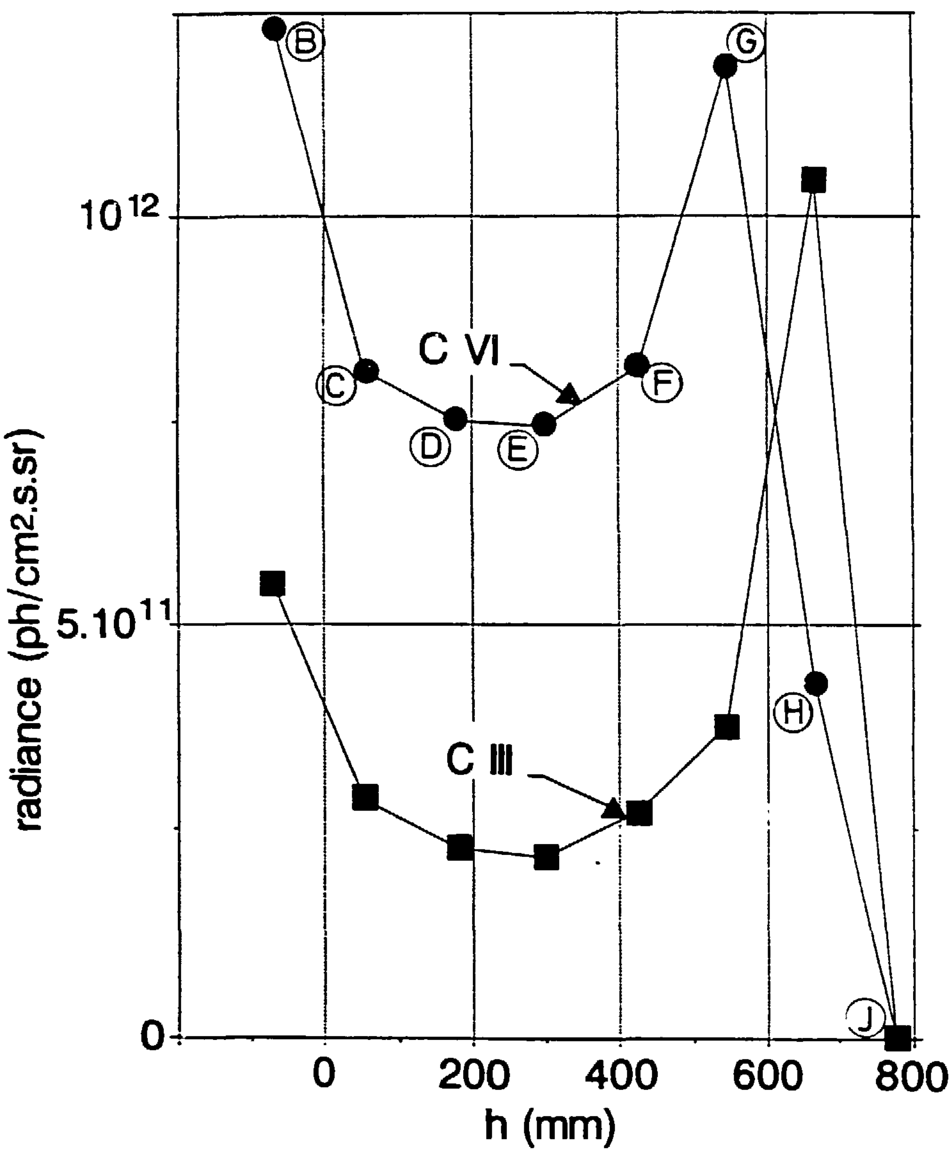


FIG. 4 TS 6851-ABSOLUTE RADIANCES OF C III 5304 AND C VI 5290 Å FOR A DETACHED PLASMA

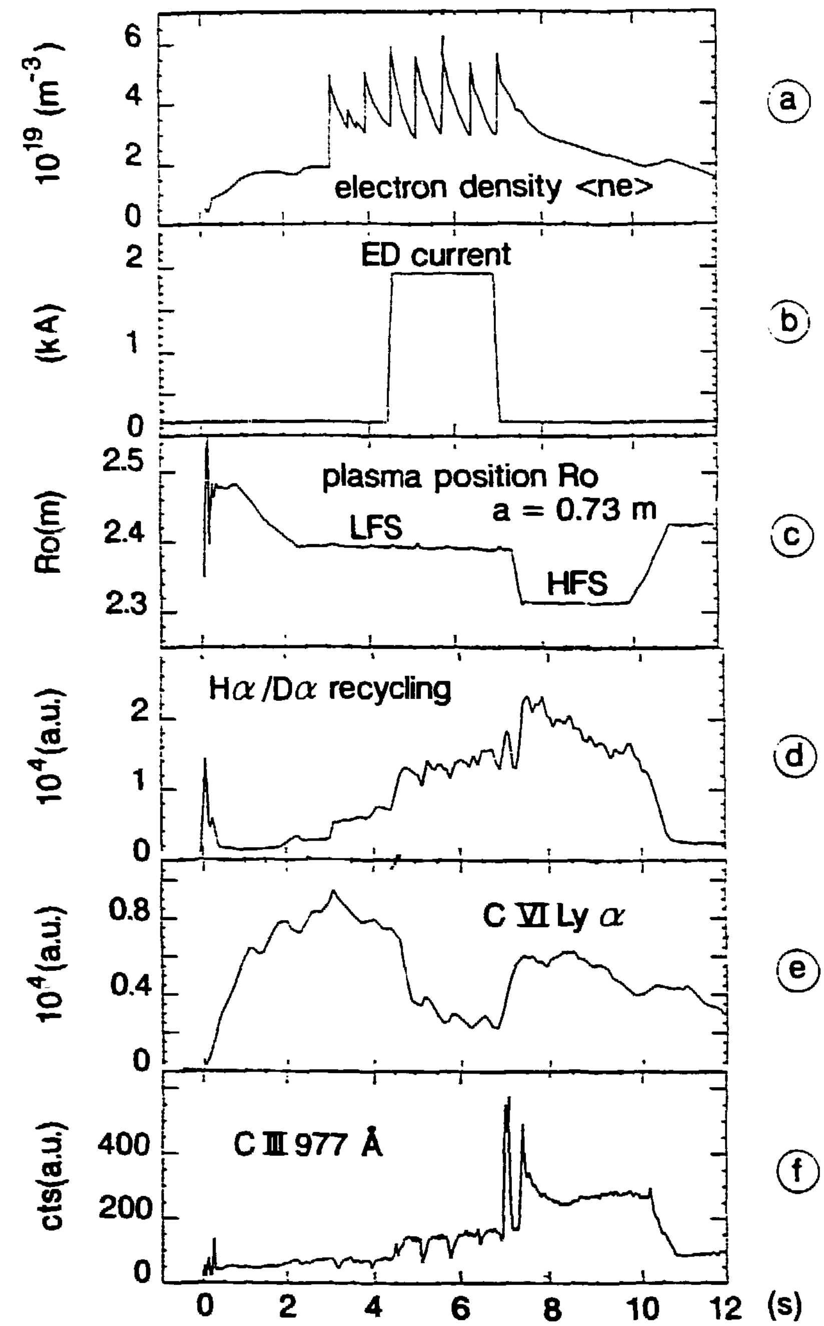


FIG. 5 TS 6446 ERGODIC DIVERTOR AND PELLET INJECTION

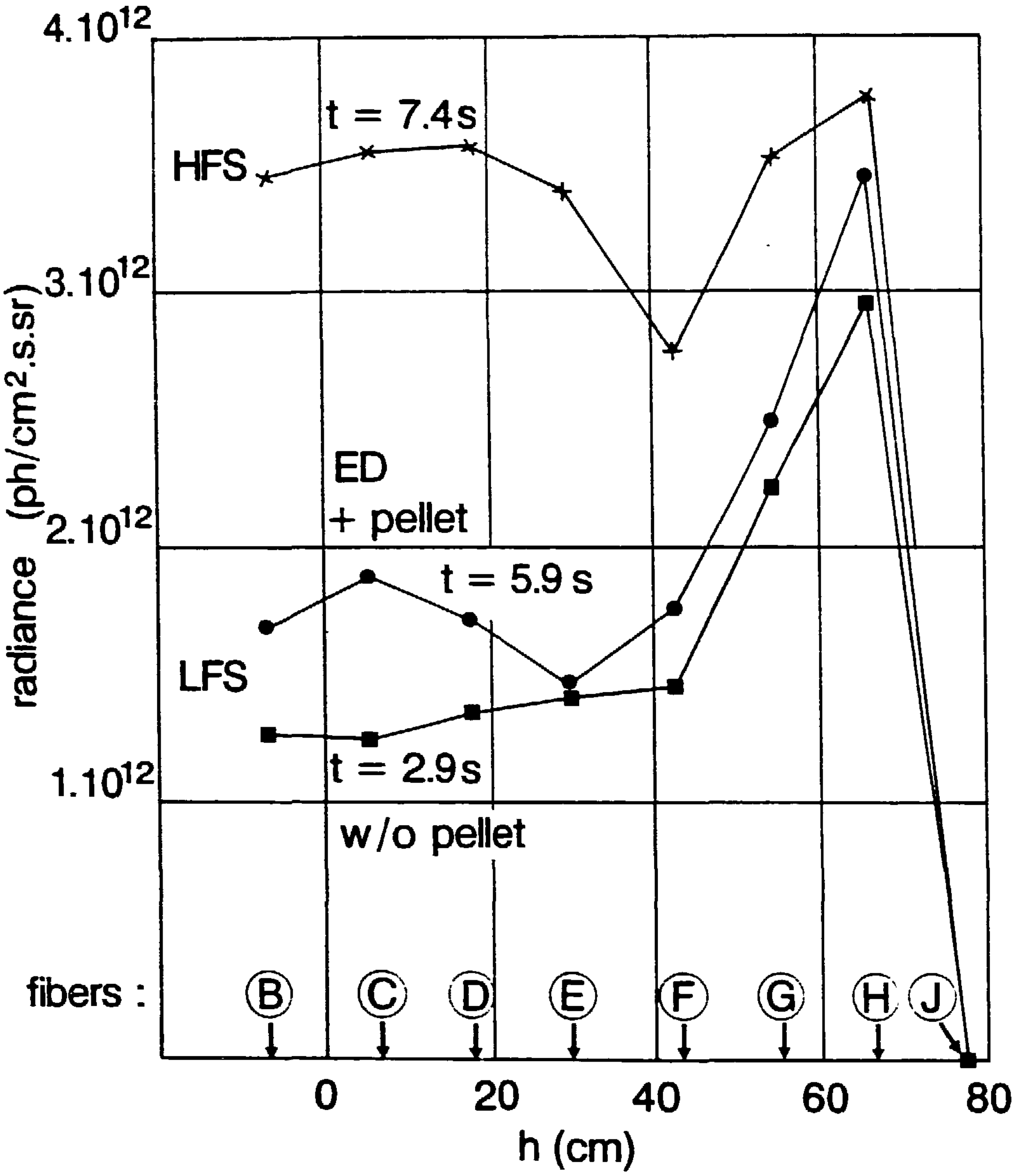


FIG.6 TS 6446 C VI 5290 Å RADIANCES AS FUNCTION OF VIEWING LINE POSITION H

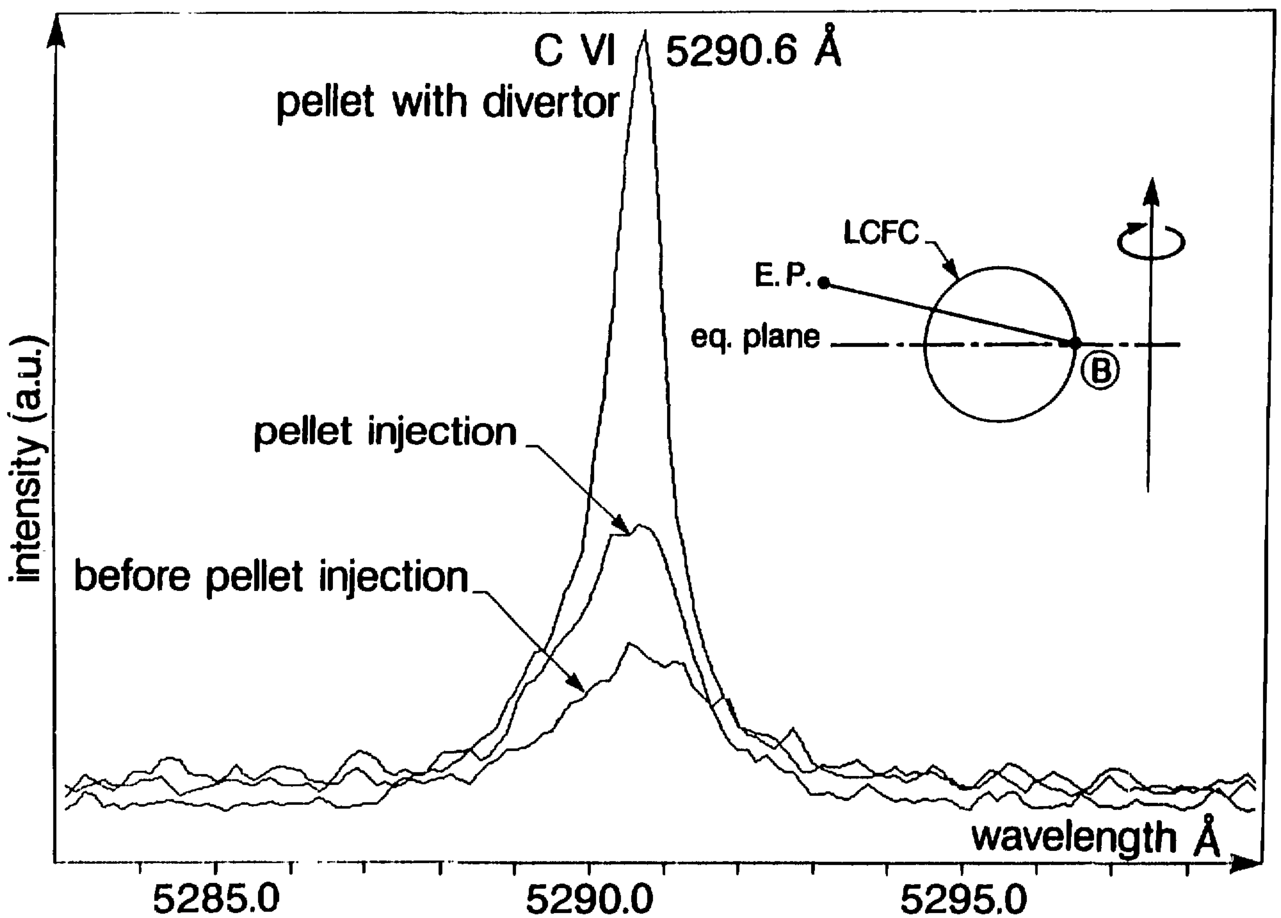


FIG. 7 TS 6446-C VI 5290 Å LINESHAPE EQUATORIAL VIEWING LINE (B)

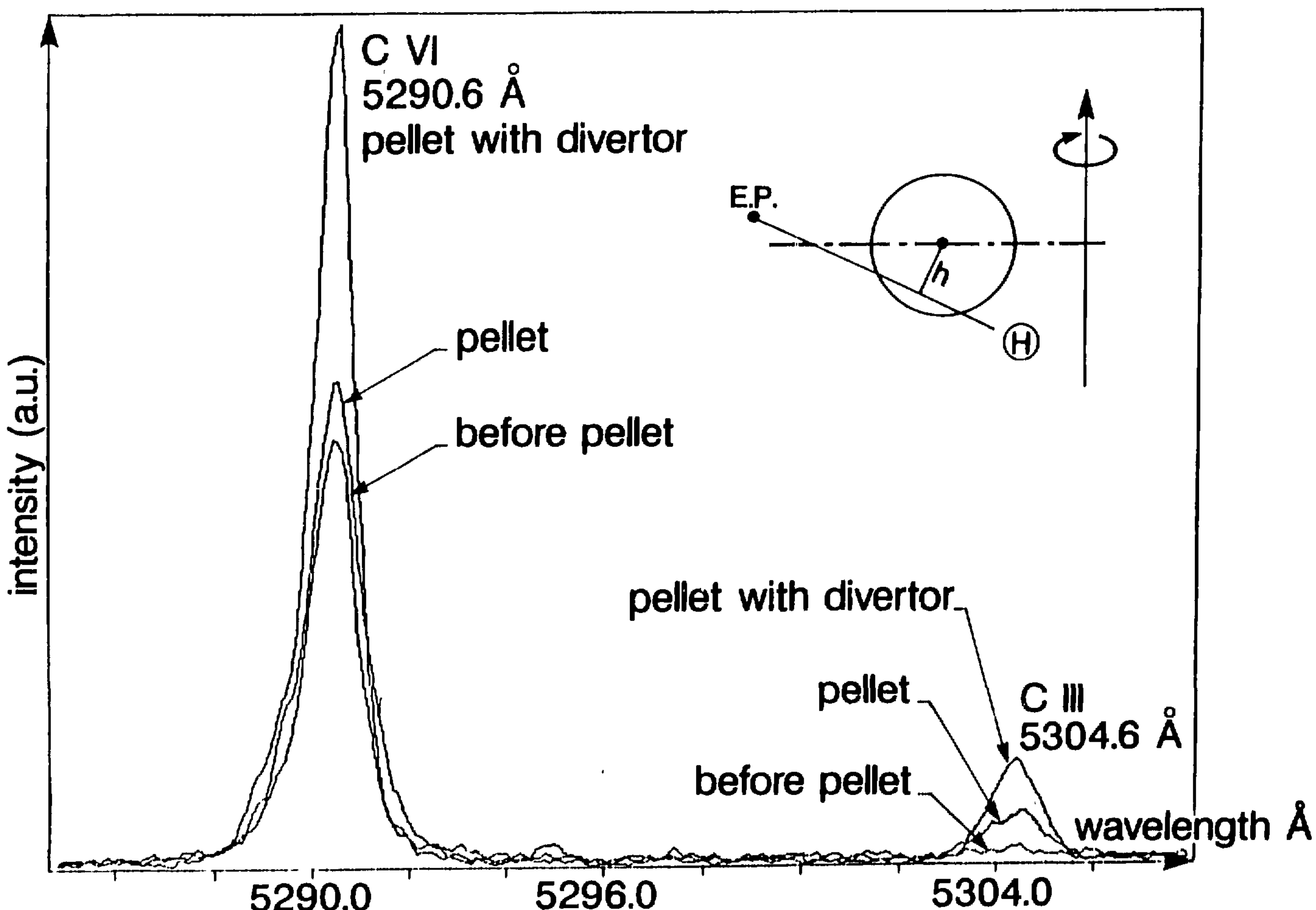


FIG. 8 TS 6446-C VI 5290 AND C III 5304 Å EDGE VIEWING LINE Ⓗ

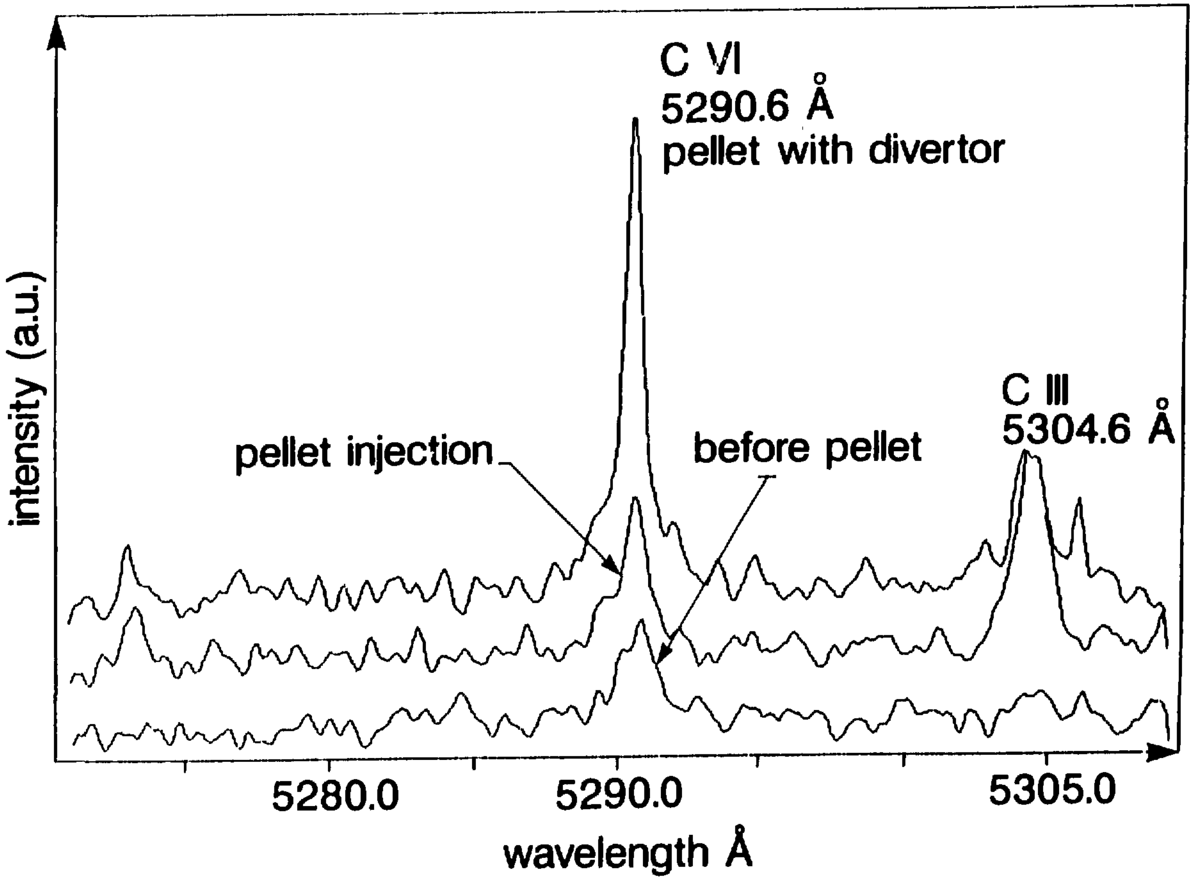


FIG. 9 TS6446 - C VI 5290 Å C III 5304 Å FIBER (J) SCRAPE OFF LAYER

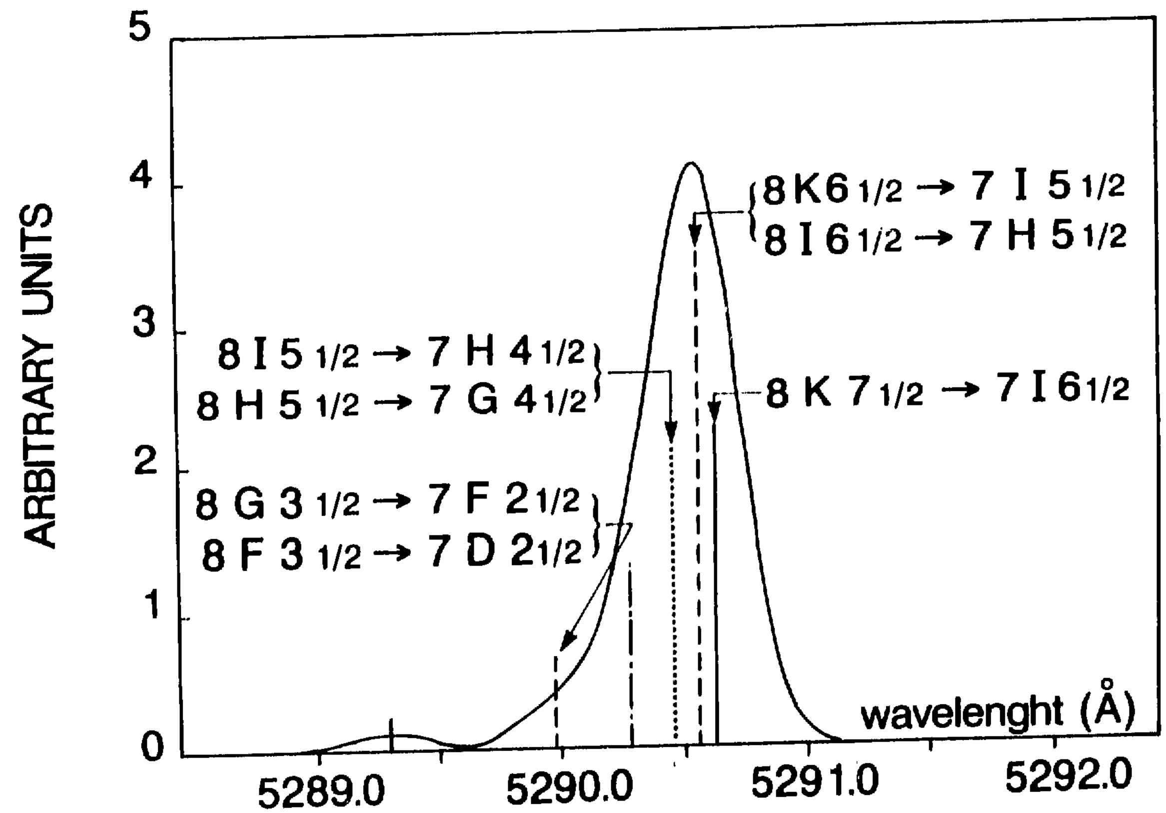
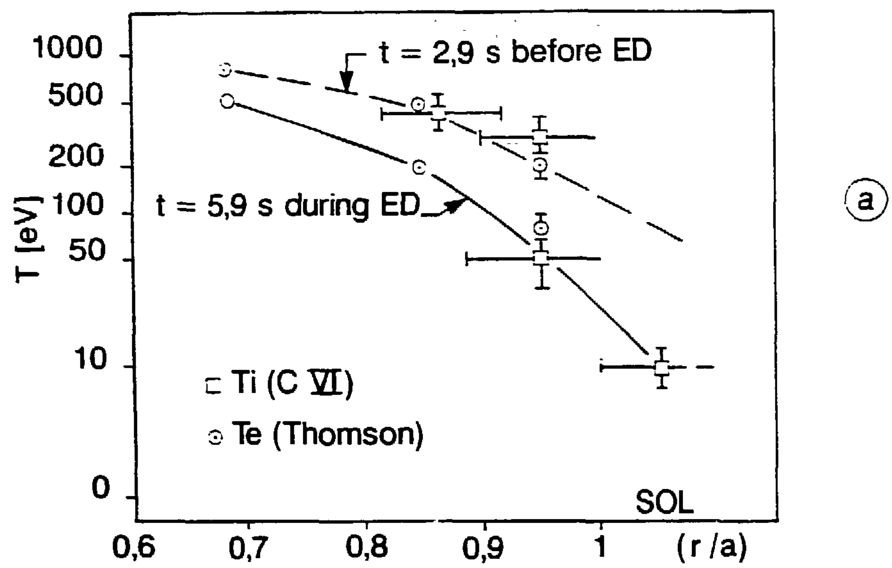


FIG. 10 SPECTRAL PROFILE OF THE MOST INTENSE TRANSITIONS BETWEEN THE 8th AND 7th PRINCIPAL SHELLS OF C VI CALCULATED FOR AN ION TEMPERATURE OF 10 eV WITH COMPLETE STATISTICAL L-MIXING



TS 6446 PLASMA EDGE TEMPERATURE PROFILE BEFORE AND DURING ED ACTIVATION

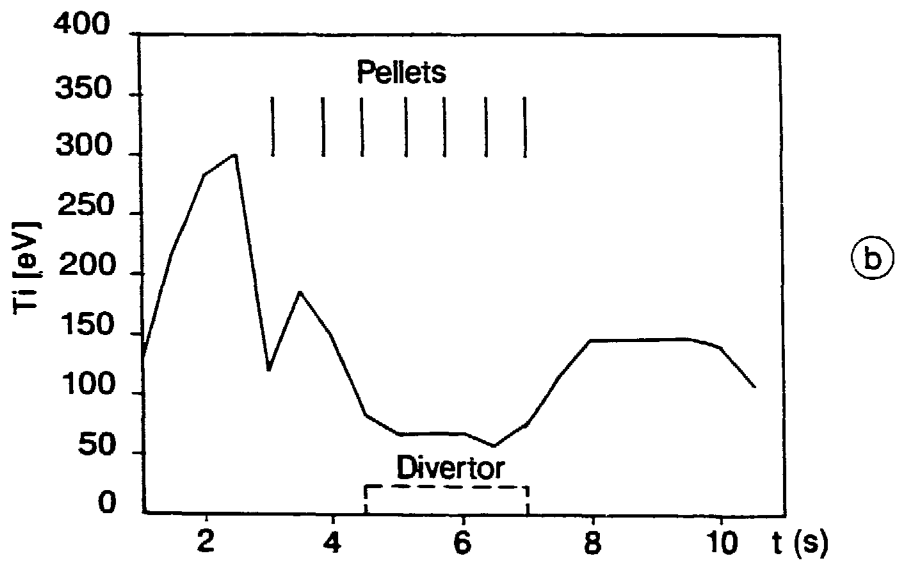


FIG.11 TS 6446 MEAN ION TEMPERATURE IN THE ERGODIC LAYER (FIBER H) MEASURED FROM 5290 Å C VI LINE