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PARTICLES PUMPING IN TORE SUPRA

BONNEL P.- CHAPPUIS P.- LIPA M.
Association EURATOM-CEA, Centre d'Etudes Nucleaires de Cadarache,
13 - Saint-Paul-lez-Durance (FR). Dept. de Recherches sur la
Fusion Controlee

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P. BONNEL - P. CHAPPUIS - M. LIPA

Association EURATOM-CEA
Département de Recherches sur la Fusion Contrôlée
Centre d'Etudes Nucléaires de Cadarache
13108 SAINT-PAUL-LEZ-DURANCE CEDEX. FRANCE

ABSTRACT FORM

TORE SUPRA and its peripheral equipments are provided with routine clean high vacuum by turbomolecular pumping.

During plama discharges large quantity of very hot gases activating at plasma edge and plasma density in scrape off layer has to be controlled before they strike violently solid wall provoking increase in impurities content and make density up to disruptive level. A Magnetic Ergodic Divertor made of six winding structures - MED - six Vertical Pumped Limiters - VPL - and one Horizontal Pumped Limiter - HPL - are set in the vacuum chamber in order to cope with plasma-wall interactions and neutral gas recycling. Each apparatus is equipped at front side with thermal shield respectively made of polycristallin and pyrolitic graphite bolted on stainless steel support for MED and HPL whereas for VPL it is made of CFC Aerolor 05 brazed on hardened copper. The total heat removal capacity of these plasma facing components is 12 MW. Design of particles collection openings and ducts conductance allow 10 % of capture efficiency, that means for TORE SUPRA a flux of 3 x 10^{21} particles/seconde has to be sorbed by water cooled titanium getter pumps, settled at rear side. All those facilities were put into plasma operation at the beginning of present year for a short time. Preliminary observations go along with theoretical predictions, that actions in scrappe-off layer may provoque effects in bulk plasma. Very first results drawn out, show that particle collection and heat removal were effective by MED, VPL and HPL and that plasma behaviour was not disturbed by their presence and actions but instead tendency to improvement was observed.

1 - INTRODUCTION

Limiters so far are successfully used in tokamak experiments to define plasma boundary and to prevent direct contact between hot ionized gas and vacuum metallic wall.

TORE SUPRA provides in nominal operations plasma of 30 m^3 with 30 secondes pulse duration and an additionnal heating got by injecting 25 MW, 10 MW from fast neutral beam and the remaining from RF heaters. Assuming that particles confinement time lasts 0.1 s that means the whole ionized particle content 3×10^{21} ions are recycling ten times per second between material wall and plasma bulk. These strong edge actions lead to make the pure light fuel gaz introduced on purpose to perform plasma, fastly be overwhelmed by high Z impurities. It appears then, mastering plasma edge activities becomes a crucial task to undertake properly before expecting further long duration plasma performances.

TORE SUPRA has not a classic poloidal magnetic built-in divertor. It was proposed to equip the machine with modular small size pump limiters for density control and for heat removal. Whereas, a magnetic ergodic divertor is designed to investigate the impurities production and transport problems, in creating adiabatic compression (nT = cst) on ionized particles along perturbed magnetic field lines as a classical divertor does, to decrease edge temperature by increasing edge density.

Many other machines by the world have demonstrated that pumped limiters are effective in particles removing [6] but so far TORE SUPRA is the first one to be equipped so extensively with and to put those advanced facilities on trial with high grade and long duration plasma discharges, far longer than any plasma time constant. Data collected under such conditions in fields of density control and of impurities production and transport will be specifically valuable for futur large tokamak design stepping towards reactor-like plasmas.

2 - LIMITER CONFIGURATION

So far, TORE SUPRA is running with a toroidal magnetic field at 1.85 T in ohmic regime with specific plasma up 1 MA lasting over 10 s duration and containing just below 1 MW power. For this starting experimental period the vacuum vessel is equipped with three inertial graphite head limiters, without active pumping. All three are set in the same meridian plane, the most massive in horizontal position while the two slender in the same vertical line at top and at bottom of the vacuum vessel, their roles are to shape up newly built plasmas and to protect vacuum chamber and its inner miscellaneous equipments against strong disruptions. The horizontal one has graphite head bolted on stainless steel frame. The power received is dissipated mainly by radiation. Whereas the vertical two have their graphite tiles bolted on hot water cooled circuit (170°C x 3.8 MPa). To complete these bumpers, for density control and for heat removal study, four vertical modular limiters with active pumping are set at the bottom side of the vacuum vessel, all centered on toroidal circle of R = 2.360 m and a large horizontal pump limiter set in the equatorial plane of the machine.

Later on, when TORE SUPRA will be performing nominal plasma at : 30 m^3 - 10^{20} H^+ m^{-3} - 30 s - 15 MW limiter configuration will be as follow : one massive horizontal bumper without active pumping, six modular vertical limiters with active pumping and a large horizontal limiter throughouly instrumented, also with active pumping.

3 - TITANIUM GETTER PUMP

TORE SUPRA laboratories have developped titanium getter pumps for its needs, based on evaporating Ti on thin metallic supports water cooled at room temperature. To make getter surfaces active, First evaporation cycles have to depose roughly 5000 monolayers of Ti on supports, when this last one is saturated by sorbed gas a desorption session by heating the pump in high vacuum up 380°C during one hour gives back initial caracteristics [7].

Filament used is shaped off by winding a Ti wire round tantalum rod support at desired length. One meter of filament contains 40 g Ti, that is sublimated at 1500°C by ohmic power delivered at 140 A x 32 V/m. Evaporation flux under such condition is set at 5 g/h x m. Sorbtion capacity is one mole of H2 per 100 g Ti and one square meter of activated surface displays 10 m^3 s^{-1} as adsorbtion speed.

Oxygen, water vapor and any matters that obstruct titanium porous crystalline structure in a irreversible way diminish sharply gettering speed and titanium layer life time [7].

4 - VERTICAL PUMPED LIMITER - VPL

VPL was designed with in mind that these facilities will be modular and identical, so they will be easily be mounted without modifications up side or down side on to any the 24 vertical ports of the vacuum chamber.

TS started plasma operations in ohmic regime with four VPL and one Horizontal Pumped Limiter, the first number will be completed to 6 VPL by 1989 summer. All the six are set at the bottom side of the vacuum vessel. This positioning was thourougly investigated [5] to optimise overall TS performances, working at high density by pellet injection, high additional heating power and with the entire range of edge security factor q allowed. Assuming that the ions temperature on the last magnetic surface closed to limiter is 150 eV, the adopted configuration will be able to handle with 2 Pam^3 s^{-1} as particles exhaust and 5-8 MW removal, or 3 Pam^3 s^{-1} for 4 MW. Even the regime of 1 Pam^3 s^{-1} and 15 MW, closed to NBI regime, is acceptable provided the power will be sharing with actively cooled inner graphite wall.

To withstand the corresponding very high heat flux strucking on limiter head, extensive tests were performed by SANDIA NLA and TS laboratories on advanced technologies that cope successfully with 8 MW as heat charge. Thermal shield are made of high density graphite -Aerolor 05 from Carbone Lorraine- brazed on harden copper with several interlayers [3]. Tubing configuration was choosen to construct VPL head, because the fragmentation of the eddy current circuit in small parts diminishes induced electrodynamic forces, by the way cooling action is more even throughout the whole exposed surface. Tube ends are made of hardened copper to better withstand mechanical stresses, then they are joint to SS in/out coolant tubes by friction welding Fig. 1.

PUMP LIMITER

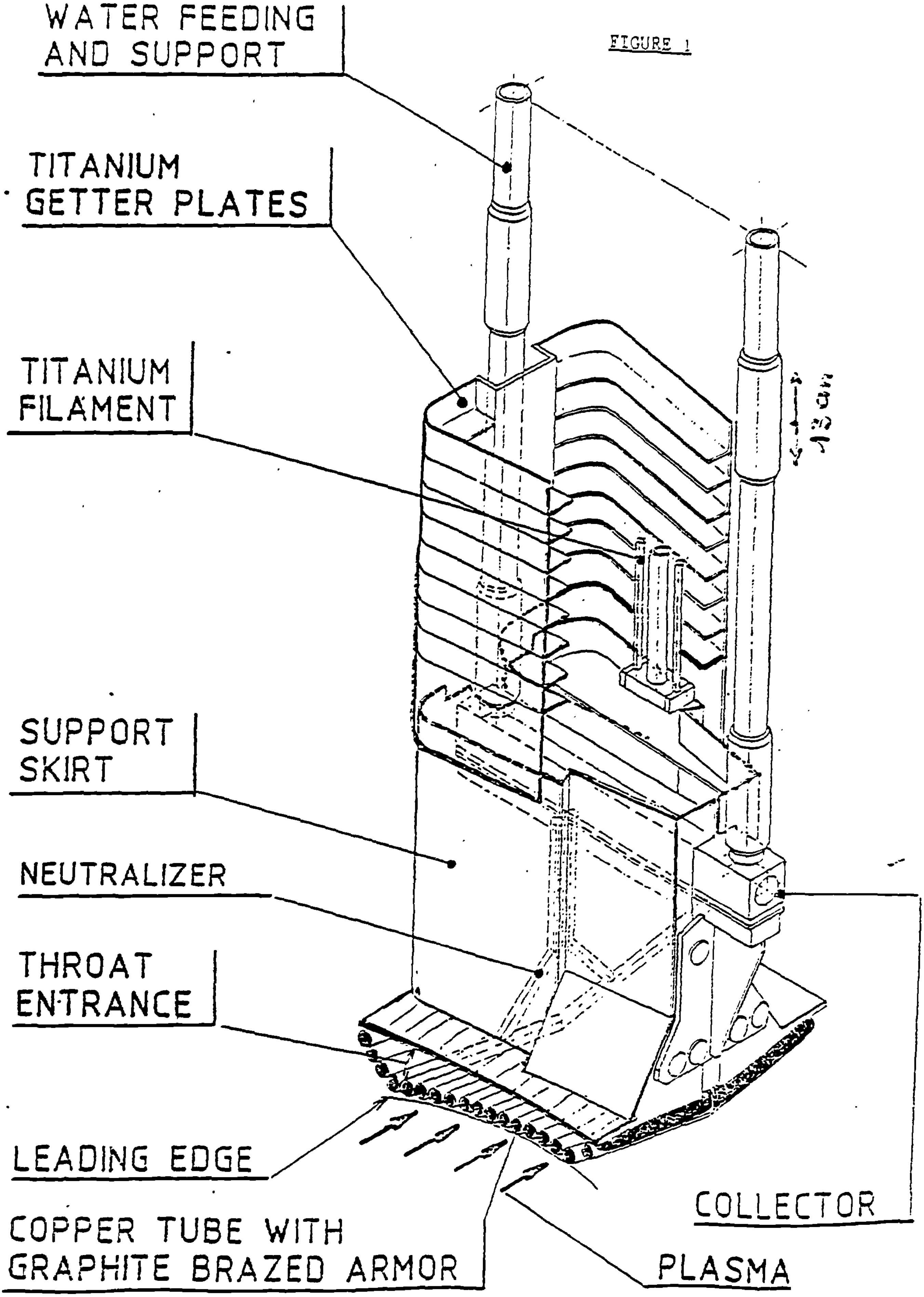


FIGURE 1

As regard to the high heat power falling on graphite barrier to be removed thermohydraulic tests and computering confirm that subcooled boiling water is the right technique to be used. So, a hot water loop was built to supply all face to plasma facilities with a coolant fixed at 170°C - 3.8 MPa as inlet parameters, outlet temperature increases by 60° and the cooling set power peaks up 25 MW on 30 secondes. For the smallness of cooling tubes bore, only 9 mm. that shape off VPL head, heat removal has to be further by speeding up the coolant velocity and in the meantime by making the flow more turbulent, a swirl tape was fitted into the copper tube for this purpose.

Each VPL head, is composed of 25 straight counter flow tubes arranged side by side in parallele in a square shield of 40 cm x 40 cm, shaped to follow a 0.755 m minor plasma radius, centered at R = 2.370 m, with a throat width of 3 cm. Head position can be moved forewards or backwards on atmospheric side by a screw-nut mechanism motorised through air tight bellows.

Particles coming by the throat after have been neutralised on neutralizer plates Fig. 1, go towards the rear end of VPL equipped with titanium getter pump. In order to increase gettering speed as active surface increases, many SS plates have been welded on the pump vessel inner side to receive titanium vapor during activation phase, active surface is by so doing multiplied by many time, full gettering speed got for each VPL is 25 $m^3 s^{-1}$ for hydrogen. A flap pneumatically driven by a cylinder prevent to spread titanium vapor out onto unwanted areas. Two titanium filaments of 0.5 m each long each are set in the centre of the pump vessel. One is in operation whereas the other is in waiting. The first layer is made with 25 g Ti evaporated on support surface, allowing a sorbed capacity of 0.25 mole of hydrogen or 20 plasma shots before be reactivated. Remaining titanium allows 60 refreshing flashes before filament changing.

Each VPL pump is equipped with a high pressure gauge. Two informations are issued from, shot per shot : pressure while pumping and accumulated quantities of sorbed gas.

5 - HORIZONTAL PUMPED LIMITER

This limiter is developped by SANDIA N.L.A. and ORNL in a DOE-CEA collaboration contract.

HPL is set in equatorial plane of the machine facing the outboard layer of plasma ring. The broad head dimensions are : 0.6 m x 0.5 m, it is made of massive pyrolitic graphite blades bolted on SS frame cooled by the hot pressurised water loop. This inertial technique withstands to 2 MW on front side during 10 secondes with a maximum temperature at the tip of the blades in the range of 1600°C.

Two large titanium getter pumps cooled at room temperature equipped the HPL rear side (Figure 2). Pumping elements are made of two cylindrical pump of 3 m length each one, displaying a total pumping speed of 180 $m^3 s^{-1}$ for hydrogen, for sorbed capacity in the first thick layer of 1.2 moles. Referring to SOL caracteristics and throat dimensions, about 3×10^{22} particles have to be captured per discharge, saturation is reached for 40 discharges. Filaments available in situ allow 70 refreshing flashes before be changed.

Pressure instrumentation set on HPL performed total pressure measurement in pump vessel by a gas analyser and a compact structure ionization gauge, while two of the same structure gauges are set to issue pressure from ion side duct and from electron side duct.

Calorimetric measurements are performed by thermocouples fixed on water loop. they are complemented by infrared imaging of the whole head limiter (Fig. 2).

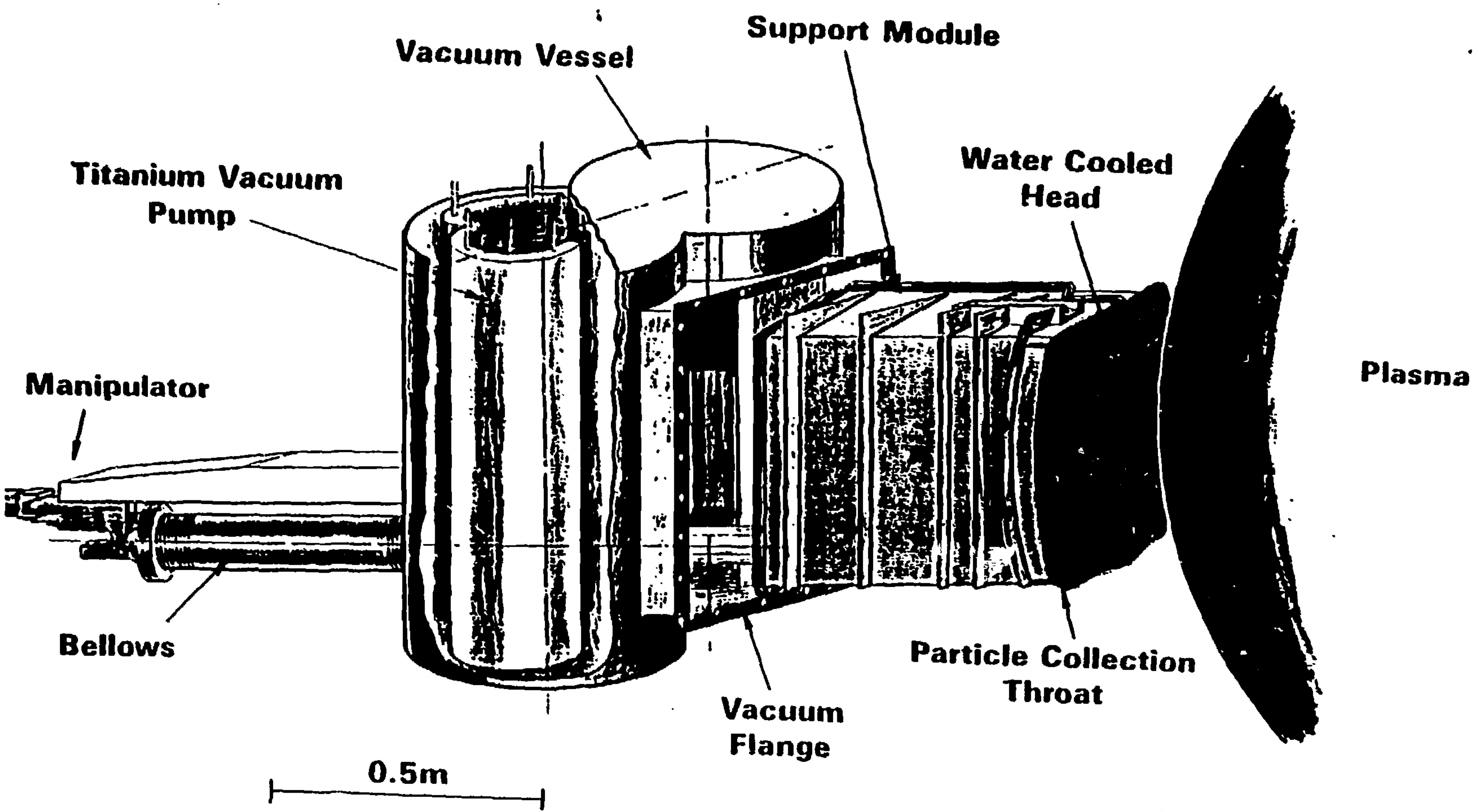


Figure 2 TORE SUPRA PUMP LIMITER

EXPERIMENTAL RESULTS

During the first six months of TORE SUPRA exploitation, experimental parameters are :

- ohmic discharges in helium or in hydrogen,
- $B_T \sim 1.85$ T,
- $I_p \sim .75$ MA ÷ 1.2 MA,
- $t \sim 8.5$ s.

plasmas are formed against the inner brazed graphite wall, then displaced outwards to lean on the HPL, located at :

- R = 2.38 m,
- a = .75 m.

Observations shown that radiative power is nearly twice when multi-limiter is on versus mono-limiter is on , with HPL only. At the end of He discharges, typical temperatures on HPL tip is 270°C, at leading edge 265°C and 22[illegible]°C in a large area in between. Base temperature before shots is 180°C. Mean power flux is estimated at 2.4 MW m^{-2}. At the time of experiment, the scrape off layer characteristics are estimated at :

- $n \sim 5 \times 10^{18}$ m^{-3},
- $T \sim 10$ eV,
- $\lambda_T \sim 2$ cm.

a straighforward calculation with those data gives a capture efficiency for He of about 12 %, knowing that captured gas is relaxing in pump chamber without active pumping. HPL works like a scoop limiter. Slopes at curve tops demonstrate that recycling coefficient is closed to one and is the lowest when HPL is operating (Figure 3).

Shot Nber	1151	1050
Heat Energy	kJ	kJ
W_R	1710	1050
W_C	4600	6330
W_T	6520	7520
W_C^{HPL}	1750	5180
W_C^{VL}	2400	540
W_R^{MED}	210	140
W_C^{MED}	450	610

W_R : Total radiative energy during the discharge (~ 8.5 s).

W_C : Total convection energy during the discharge.

W^{MED} : Energy received by the ergodic magnetic divertor during the whole discharge.

Shot 1151 : multi-limiter configuration.
top-bottom-Horizontal.
without active pumping.
Shot 1050 : one limiter configuration.
HPL only.

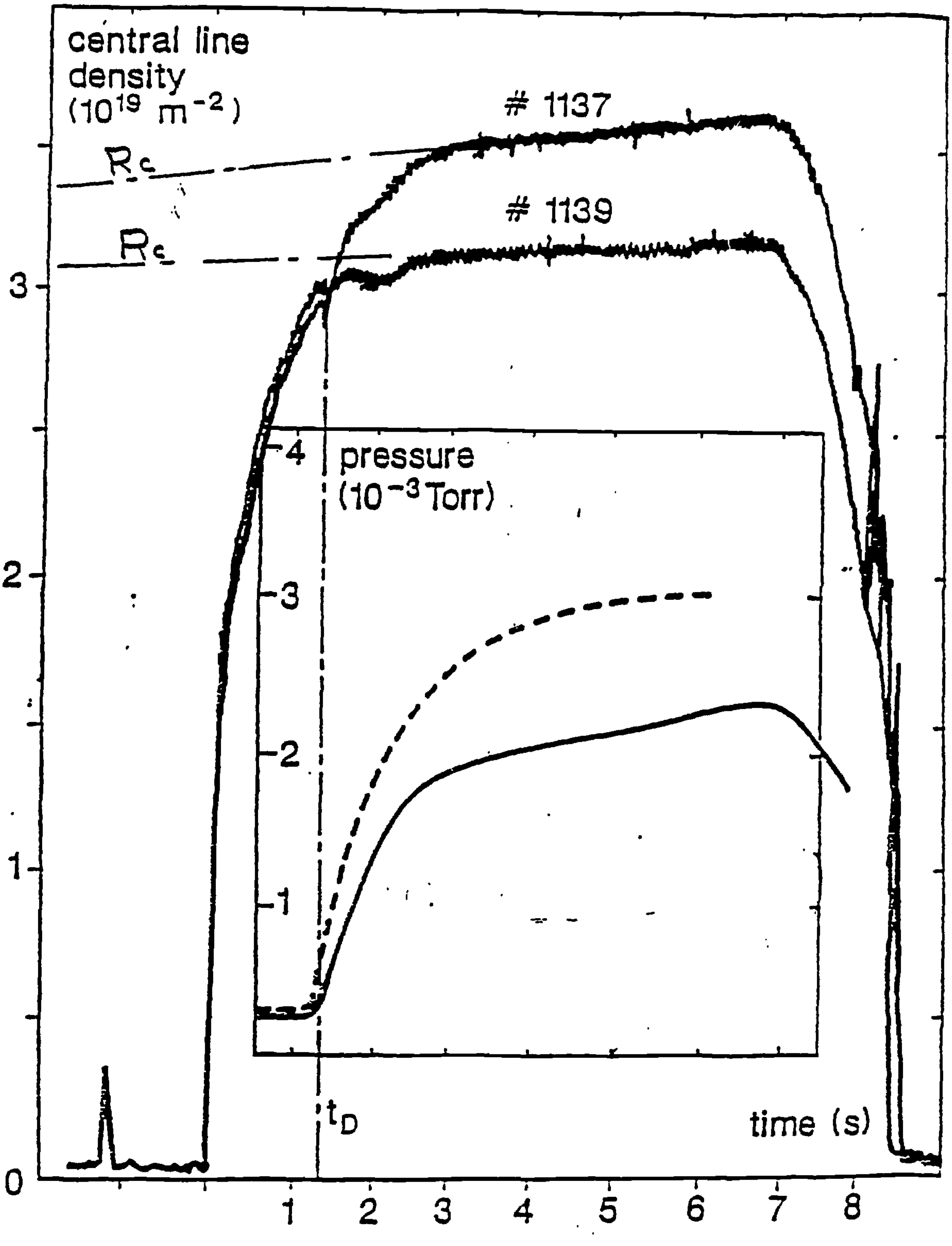


Fig.
CENTRAL LINE DENSITY AS A FUNCTION OF TIME FOR SHOTS WITH THE PLASMA LEANING ON :

1137 the ONPL

1139 the OPL

IN THE INSERT IS THE EXPERIMENTAL (——) AND ESTIMATED (----) PRESSURE IN THE OPL

MAGNETIC ERGODIC DIVERTOR - MED

Powerful and long plasma discharges duration produces high influx of impurities coming from wall-sputtering. An important TS objective is devoted to develop means capable to slowdown this inconvenient. Magnetic Ergodic Divertor was proposed, then designed and manufactured for. Six MED windings are equally spaced around the equatorial circle of the machine. They are fastened on the inner wall of vacuum vessel. These facilities produce in their vicinity a local magnetic field that perturbes the main one on a short radial distance of about 10 cm, slighty in magnitude, about one thousandth ($\langle \delta Br \rangle / B_t \sim 1.5 \times 10^{-3}$). Perturbation is low enough on the q = 2 magnetic surface [illegible] .. Within ergodic layer adiabatic compression (nT = cst) on ionized particles generate two effects : an expected compression rate of a factor 10 on n and a subsequent decrease in T, below the sputtering threshold. A decrease in T, decreases sputtering production and the large particle outflux is expected to enhance the drag out of impurities by viscosity action. Perturbed magnetic lines drive particles towards neutralizer plates. The scattered neutral particles are balistically directed towards titanium pumps (Figure 4). Geometrically speaking, a MED has 15° width in toroidal direction, that represents about 0.80 m and 126° overture in poloidal direction, about 1.75 m with curvatures espousing that of the inner vacuum wall. Electric bars are incased in tight SS boxe wholly TIG welded, may be fed up 45 kA current per bar and are isolated at 5 KVDC. Cooling water is delivered by the pressurized loop.

Heat shield facing plasma is made of fine grained graphite tiles of 3 mm thickness, brazed on 2 mm MoCu substratum, which are then bolted on the coolant SS circuit. This technique can remove heat load up 0.5 MW m^{-2} x 30 s in keeping graphite temperature below 450°C. On leading edges where neutralizer plates have to cope with 10 MW m^{-2}, pieces of graphite of 4 mm of thickness are brazed on copper block, actively cooled.

At the MED two sides, in toroidal direction, are set titanium getter pumps. A titanium filament of 1.5 m long equips each pump. The first thick titanium layer got by sublimating 20 g Ti/m of filament offers for the two pumps a gettering speed of 20 m^3 s^{-1} for hydrogen and a sorbed capacity for the same gas of 1.2 moles. In autonomy words, that means that the first layer allows only 5 plasma shots before be regenerated at full pumping speed capability and 24 refreshing flashes are available per pump before filament changing.

Power and particles removal capabilities
for 6 divertor windings

- 6 MW
$> 1\ \mathrm{Pa\,m^3 s^{-1}}$

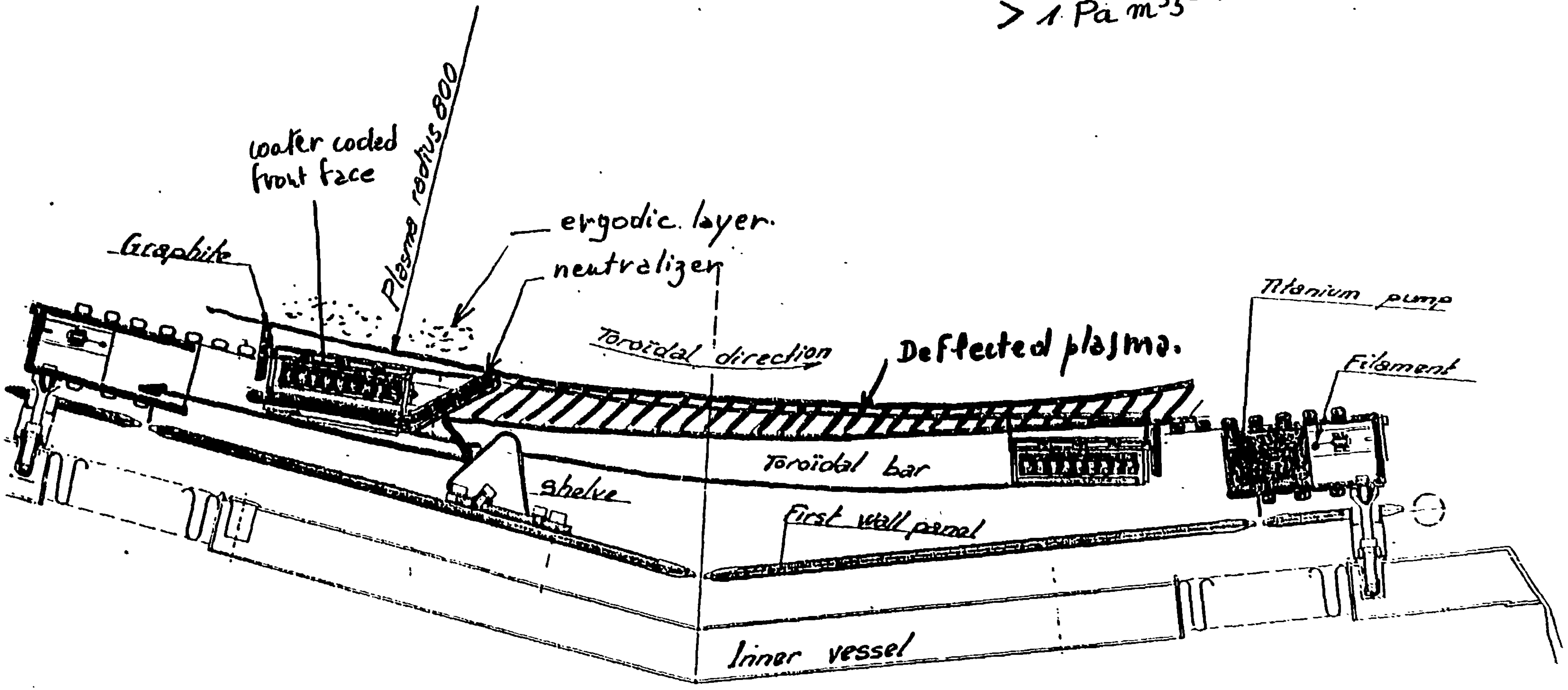


Fig 4 - CROSS VIEW OF THE ERGODIC DIVERTOR IN THE EQUATORIAL PLANE

EXPERIMENTAL RESULTS

MED were introduced in TS plasma experimentation session for a short time in early 89, without active pumping from titanium getters. First objectives were to verify whether MED will be performing as expected with edge plasma. [2] Typical plasma parameters were :

- $B_T \sim 1.8$ T,
- $I_p \sim 0.5 - 1.2$ MA.
- $n \sim 2 - 3 \times 10^{19}$ m^{-3} (He and H_2 gas).

Two configurations were experimented, EXT where plasma was leaning on outer bumper or pump limiter and INT where plasma was leaning on inner graphite wall.

Magnetic perturbations were created on plasma of 0.8 MA by various MED current from 0 to 43 kA.

The effects proved to be resonant for $q = 2.8$ at the plasma edge.

It was observed from Hα (He^+ : 4 -> 6) that recycling pattern increases in EXT configuration and decreases in INT configuration.

Soft X-ray spectrograph recorded noted reduction in CVI and CV production up to 50 % in EXT configuration (Fig. 5).

Bolometer profiles showed reduction of about 10 to 20 % of the power radiated by O VII and O VIII lines.

Meanwhile no pertubation was noticed so far on bulk plasma parameters : plasma density and temperature profiles.

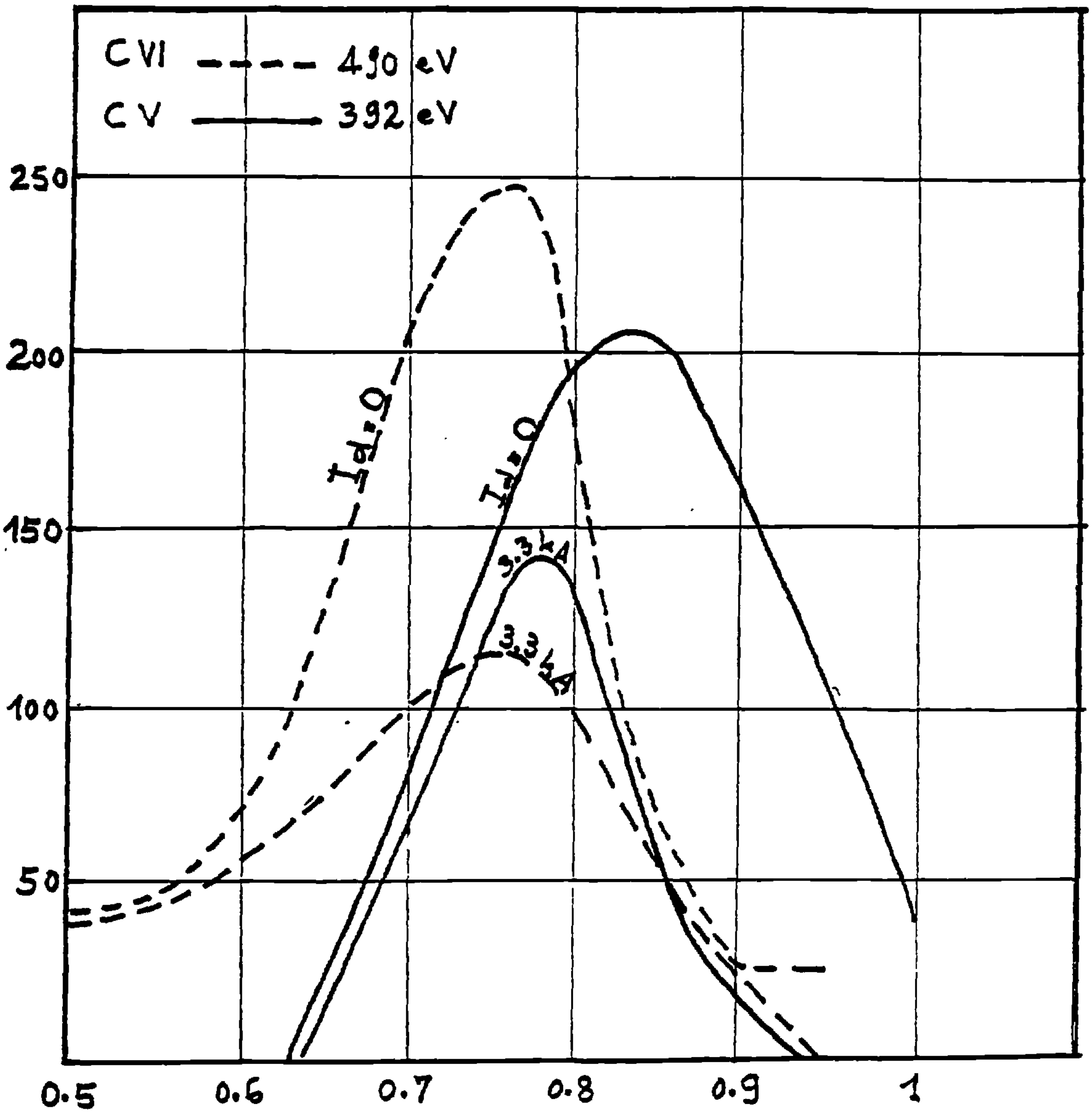
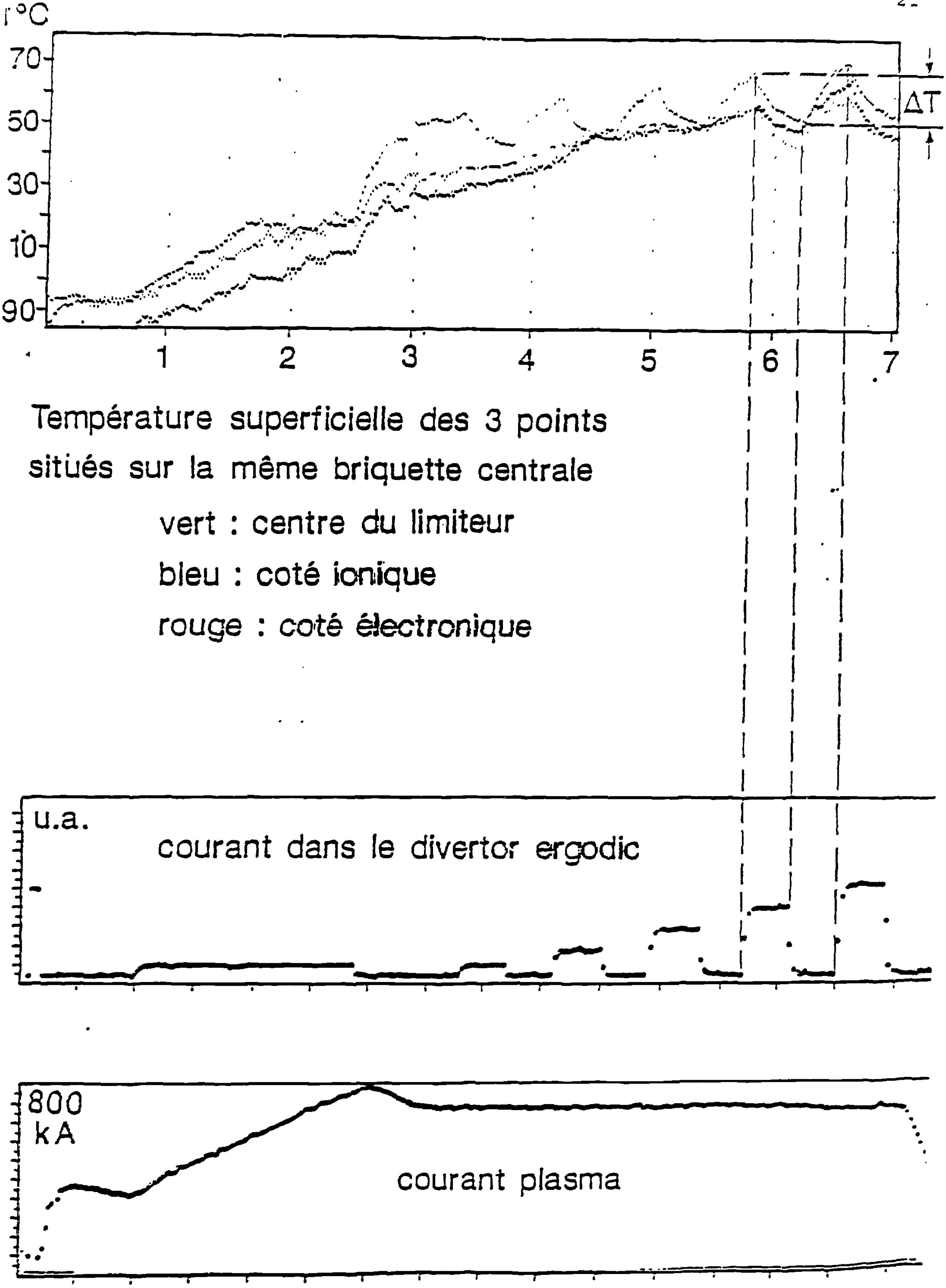


Figure 5 : Inverted radial emissivity profiles of the CVI (a) and CV (b) resonance lines at 33.74 Å and 40.27 Å. The ionization potential of each ion is indicated on the figure.

Ergodisation can be clearly seen on IR imaging of the HPL heat acting like a power deposit probe Fig. 6. In general, large changes in power deposition were noticed, especially a decrease of the heat load on the main limiter.

These preliminary observations confirm that MED produces expected ergodisation effects. When titanium getter pumps will be operating, drag out effect on impurities is expected to be improved but it could be followed by a secondary bad side-effect, impurities and oxygen mainly will polute a bit faster titanium layers.

FIGURE 6



Température superficielle des 3 points situés sur la même briquette centrale

vert : centre du limiteur
bleu : coté ionique
rouge : coté électronique

CONCLUSION

Very preliminary results got from pumped limiters and Ergodic Divertor point out encouragement to keep on and further on the way so far followed, particle capture efficiency on SOL plasma by limiters are closed to figure calculated. Divertors clearly show sharp decreases in impurities production no problem either was emerged from heat removal adopted technologies although charges were still low. In near futur, physic programmes will be developped by putting all those facilities in full and joint operations paring with high grade and long duration plasma discharges of TORE SUPRA.

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BIBLIOGRAPHY

[1] R. AYMAR et al. Note TS 51.35.04.

[2] EURATOM - CEA association
Contribution to the 16th European Conference on Controlled Fusion and Plasma Physics.
EUR. CEA - FC 1362.
Venise - 1989 March 13.17.

[3] P. CHAPPUIS et al.
The TORE SUPRA pump limiter system - 15° SOFT - 1988 UTRECHT

[4] M. LIPA et al.
Mechanical design and manufacture of magnetic ergodic divertor for the TORE SUPRA tokamak - 15° SOFT - 1988 UTRECHT

[5] A model for diffusion in the Tokamak Edge and Application to the Modular Pump Limiters on TORE SUPRA by P.T. Mc GRATH
SANDIA Report - Sand. 87 - 2716.UC.20a, c. d.

[6] TEXTOR.

[7] Titanium getter pump for the TORE SUPRA Neutral Beam Lines by Z. SLEDZIEWSKI and J. DRUAUX - 14° SOFT - 1986 - AVIGNON.