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ALL COATED LIMITED EXPERIMENT IN THE JIPP T-II TOKAMAK

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RESEARCH REPORT

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ABSTRACT

All the aperture limiters in JIPP T-II were changed to be TiC coated graphite. The maximum density in this condition is 7.6 x 10^{13} cm^{-3} with the safety factor of 4.5, which is 2.7 times as high as the value obtained by the Murakami scaling. The Z_{eff} values with this density and with a medium density of 2.4 x 10^{13} cm^{-3} are both close to unity after discharge cleaning for only 3 days. The behavior of limiter material release was found to be steady within a factor of two during the discharge, suggesting that the release mechanism is ion sputtering. Residual gas analysis also suggested that this sputtering is not chemical, which may be partly because the limiter surface temperature during the discharge is below 150°C.

1. Introduction

Low to medium atomic number (Z) limiters and walls are widely recognized to be in preference in order to reduce impurity radiation from tokamak plasmas. The first material candidates are carbon and silicon carbide which have successfully been used in PLT[1] and JFT-2[2], respectively. Experts, however, worry about chemical sputtering with carbon and evapolation characteristics with SiC. Titanium carbide has then been introduced to give better evapolation characteristics, although Ti is a medium Z material. The reason of permission to use medium Z materials appears to be that stainless steel limiters have been used in ISX-A[3] and PLT[4] with good energy confinement results.

TiC coated limiters have been used in PDX[5], ISX-B[6], Doublet-III[7], and JFT-2[8]. General trends are that TiC behaves guite well with these plasmas. One may however notice that in all of these experiments, the TiC coating limiters were installed so as to interact with the plasma shaped by intrinsic metallic limiters such as stainless steel and titanium ones. In the experiment described in this paper, all the limiters were changed to be made of TiC in the JIPP T-II tokamak. Both high density limits and plasma impurity informations were studied in this condition with Ohmically heated plasmas.

2. Experimental details

The JIPP T-II device[9] is a combination of tokamak with stellarater, although only the tokamak mode was used in this experiment. The machine major radius is 91 cm. Fig. 1 shows the location of the two aperture limiters used in the present experiment. The two were located 180° away in the toroidal direction each other. The minor radii of these two apertures are 17 cm and 17.3 cm, respectively. The surface temperature of the limiter with the smaller minor radius was observed by an infrared camera. The aperture consists of four pieces of TiC coated graphite, the one of which is shown in Fig. 2. The limiter thickness in the toroidal direction is 5 cm. Thermal testing of this material has shown that good thermal and mechanical contacts are provided between coatings and substrates[10]. It has also been shown that the outgassing rate of this material is of the order of 10^{-12} Torr·ℓ/s·cm^2 after baking for 24 hrs in 250°C[11].

The machine was opened to air to install the limiters and then discharge-cleaned. Two types of discharge cleaning were simultaneusly applied for 3 days after closing the vacuum enclosure. The one was assisted by electron cyclotron heating power source with the toroidal magnetic field of 875 G. The other is a 50 Hz discharge cleaning which also heats the stainless steel vacuum chamber up to 250°C by adjusting the duty of the discharge automatically. These discharge cleanings are detailed elsewhere[12].

Observation methods include a 2 mm microwave interferometer for electron density, Thomson scattering and electron cyclotron (EC) radiometer for electron temperature, visible spectroscopy for impurity radiation, residual gas mass analyzer, and IR camera for limiter surface temperature.

3. Results and discussion

Two discharge conditions (Cases A and B) were selected to study the discharge performance with the TiC limiters. Table 1 shows the main plasma parameters with these two conditions. In Case A, the mean line-of-sight electron density $\bar{n}_e$ is 2.4×10^{13} cm^{-3}, whereas it was tried to be raised as high as possible in Case B. The temporal behaviors of the plasma current I_p, loop voltage V_ℓ, central electron temperature $T_e(0)$, and $\bar{n}_e$ for Case B are shown in Fig. 3. The maximum $\bar{n}_e$ is 7.6×10^{13} cm^{-3} in $q = 4.5$ where q is the plasma safety factor. This $\bar{n}_{e,\ max}$ is 2.7 times as high as the value obtained by the Murakami scaling developed in ORMARK[13], being comparable to the situation attained in DITE[14] and JFT-2[15] by applying Ti sublimation onto the wall.

Radial scan of EC emission showed that the radial distributions of T_e for Cases A and B are approximately given by

$$T_e(r) = T_e(0)\ (1 - (r/a)^2)^2$$

where a is the plasma minor radius. Utilizing this profile, I_p and V_ℓ in the quasi-steady state of discharge, and parabolic n_e profiles, we estimated the mean effective ionic charge ($Z_{eff} = \sum_{i=1}^{k} Z_i n_i{}^2/n_e$ where Z_i is the ion electric charge and n_i the ion density). The obtained Z_{eff} values are very close to unity not only for Case B but also for Case A where the $\bar{n}_e$ value is still modest. This shows that the JIPP T-II vacuum chamber as well as the TiC limiters could be cleaned very quickly by discharge cleaning.

Figure 4 shows the temporal behaviors of $\bar{n}_e$ and impurity line radiations (CV, TiII and OII). Although the density is substantially increased during the discharge, the CV and TiII lines behave steadily within a factor of two. These results suggest that the impurity influxes into the plasma tend to stay constant during the discharge. The most probable mechanism of impurity release in this way appears to be ion sputtering. The behavior of the CV line radiation suggests that the carbon content in the plasma is gradually reduced with density increase. The O II line intensity, in contrasts, increases almost proportionally to the electron density increase. This suggests that the density limit with Case B is determined by oxygen impurity radiation as has been observed in JFT-2[15].

The CV, Ti II, and Mo I line radiations with the TiC limiter are compared with those provided by the Mo limiter in table 2. The electron density was kept constant for these comparisons. The carbon impurity with the Mo limiter is considered to be originated from the adsorbed species on the limiter and the wall. The CV intensity increased only by a factor of 1/4 when the limiter material was changed from Mo to TiC. The Ti impurity with the Mo limiter is ascribed to Ti sublimation onto the wall which had been applied in JIPP T-II to controll the oxygen impurity in the plasma. The Ti II intensity increased by a factor of 2 when the limiter was changed to be TiC. The Mo I intensity, on the other hand, was decreased to 5/7 of the initial value by the same limiter material change. The Mo source with the TiC limiter is the wall because the Mo atoms had been deposited to the wall while the Mo limiter been used. These comparisons clearly indicate that the C or Ti atom release from the TiC limiter is of the same order as that from the Mo limiter and the wall.

Fig. 5 shows the temporal behavior of the pressure of CH_4 gas released from the limiter and the wall. The CH_4 signal has a peak about 2 s after the discharge initiation. This peaking appears to be determined by reaction between the limiter/wall and the adsorbed hydrogen atoms[15]. It is noticed that the peak value with the TiC limiter is 1.25 times as large as the one with the Mo limiter. This indicates that chemical reaction between the TiC limiter and the adsorbed hydrogen is comparable to the situation when the Mo limiter is used. We, thus, eliminated chemical sputtering for the mechanisms of limiter material release.

Fig. 6 shows the temporal behavior of the surface temperature rise of the aperture limiter on the inner side of the torus. The plasma position was controlled so that the plasma shift determined by magnetic measurement showed slight inward motion. The limiter surface temperature rise during the discharge is 40 to 50°C in this condition. This temperature rise corresponds to the one determined by the following plasma conditions which have been observed in the scrape-off layer of JFT-2[17] : $n_e = 5 \times 10^{12}\ cm^{-3}$; $T_e = 30$ eV; and electron heat transmission rate = 5.

4. Conclusions

All the limiters in JIPP T-II were changed to be TiC coated graphite. The maximum $\bar{n}_e$ obtained with the TiC limiter is $7.6 \times 10^{13}\ cm^{-3}$ with q = 4.5, which is 2.7 times as high as the value given by the Murakami scaling. It should be noticed that this number is among the highest achieved in the present tokamaks with the same kind of discharge conditions. The Z_{eff} values with this maximum $\bar{n}_e$ and with a medium density of $2.4 \times 10^{13}\ cm^{-3}$ are both close to unity. These conditions were achieved by utilizing discharge cleaning for only 3 days.

Detailed analysis of plasma impurity informations indicated that the main impurity is still oxygen with $Z_{eff} \approx 1$. The Ti or C impurity with the TiC limiter was of the same order as the one with the Mo limiter. The temporal behaviors of these impurity line radiations suggested that the mechanism of limiter material release is ion sputtering. The CH_4 signal also suggested that this sputtering is not chemical, which may be partly because the limiter surface temperature during the discharge is below 150°C.

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References

[1] H. Eubank, R. J. Goldston, V. Arunasalam, et al., Plasma Physics and Controlled Nuclear Fusion Research 1978 Vol. 1 (IAEA, Vienna, 1979) P. 167.

[2] Y. Gomay, S. Konoshima, N. Fujisawa, S. Kasai, M. Maeno, N. Suzuki, T. Hirayama, M. Shimada, Jap. J. Appl. Phys. 18 (1979) 1317.

[3] M. Murakami, K. H. Burrell, T. C. Jernigan, et al., Plasma Physics and Controlled Nuclear Fusion Research 1978 Vol. 1 (IAEA, Vienna, 1979) P. 269.

[4] K. Bol, V. Arunasalam, M. Bitter, et al., ibid P. 11.

[5] M. Ulrickson, J. Vac. Sci. Technol. 18 (1981) 1037.

[6] J. B. Whitley, A. W. Mullendore, R. A. Langley, Thin Solid Films, 72 (1980) 133.

[7] P. L. Sevier, P. W. Trester, G. Hopkins, T. E. Mckelvey, T. S. Taylor, presented at 2nd Topical Meeting on Fusion Reactor Materials, Seattle, 1981 ; General Atomic Company, Report GA-A16384.

[8] H. Nakamura, presented at Jap. Nuclear Society Meeting, Apr., 1982.

[9] J. Fujita, M. Fujiwara, Y. Hamada, et al., Plasma Physics and Controlled Nuclear Fusion Research 1976 Vol. II.(IAEA, Vienna, 1977) P. 95.

[10] Y. Gomay, H. Koizumi, K. Shibuki, J. Nucl. Sci. Technol. 19 (1982) 214.

[11] S. Sukenobu, Y. Gomay, to be published in J. Vac. Sci. Technol.

[12] N. Noda, et al., this conference.

[13] M. Murakami, J. D. Callen, L. A. Berry, Nucl. Fusion 16 (1976) 347.

[14] S. J. Fielding, J. Hugill, G. M. McCracken, J.W.M. Paul, R. Prentice, P. E. Stott, Nucl. Fusion 17 (1977) 1382.

[15] S. Konoshima, N. Fujisawa, M. Maeno, et al., J. Nucl. Mater 76 & 77 (1978) 581.

[16] T. Hirayama, N. Fujisawa, Y. Gomay, et al., J. Nucl. Mater. 76 & 77 (1978) 452.

[17] Y. Gomay, N. Fujisawa, M. Maeno, N. Suzuki, K. Uehara, T. Yamamoto, S. Konoshima, Nucl. Fusion 18 (1978) 849.

Table 1 EXPERIMENTAL RESULTS

	CASE A	CASE B
Toroidal magnetic field (kG)	25	25
Plasma current (kA)	94	105
Loop voltage (V)	1.2	1.7
Minor radius (cm)	17	17
Mean line-of-sight electron density (cm^{-3})	2.4×10^{13}	7.6×10^{13}
Central electron temperature (eV)	650	480
Mean effective ionic charge (Z_{eff})	≈ 1	≈ 1

Table 2 RELATIVE IMPURITY LINE EMISSION

LIMITER MATERIAL	CV 2274Å	Ti II 3349Å	Mo I 3798Å
TiC	1	1	1
Mo	0.8	0.5	1.4

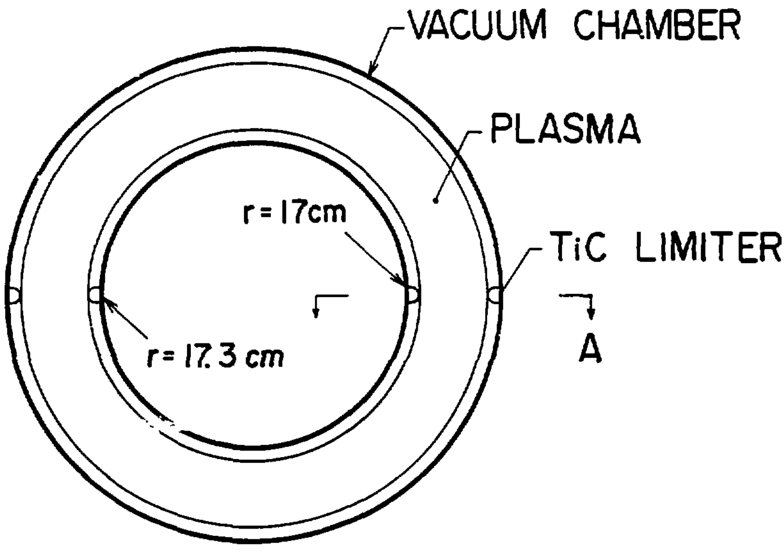

Fig. 1   Location of two aperture limiters.

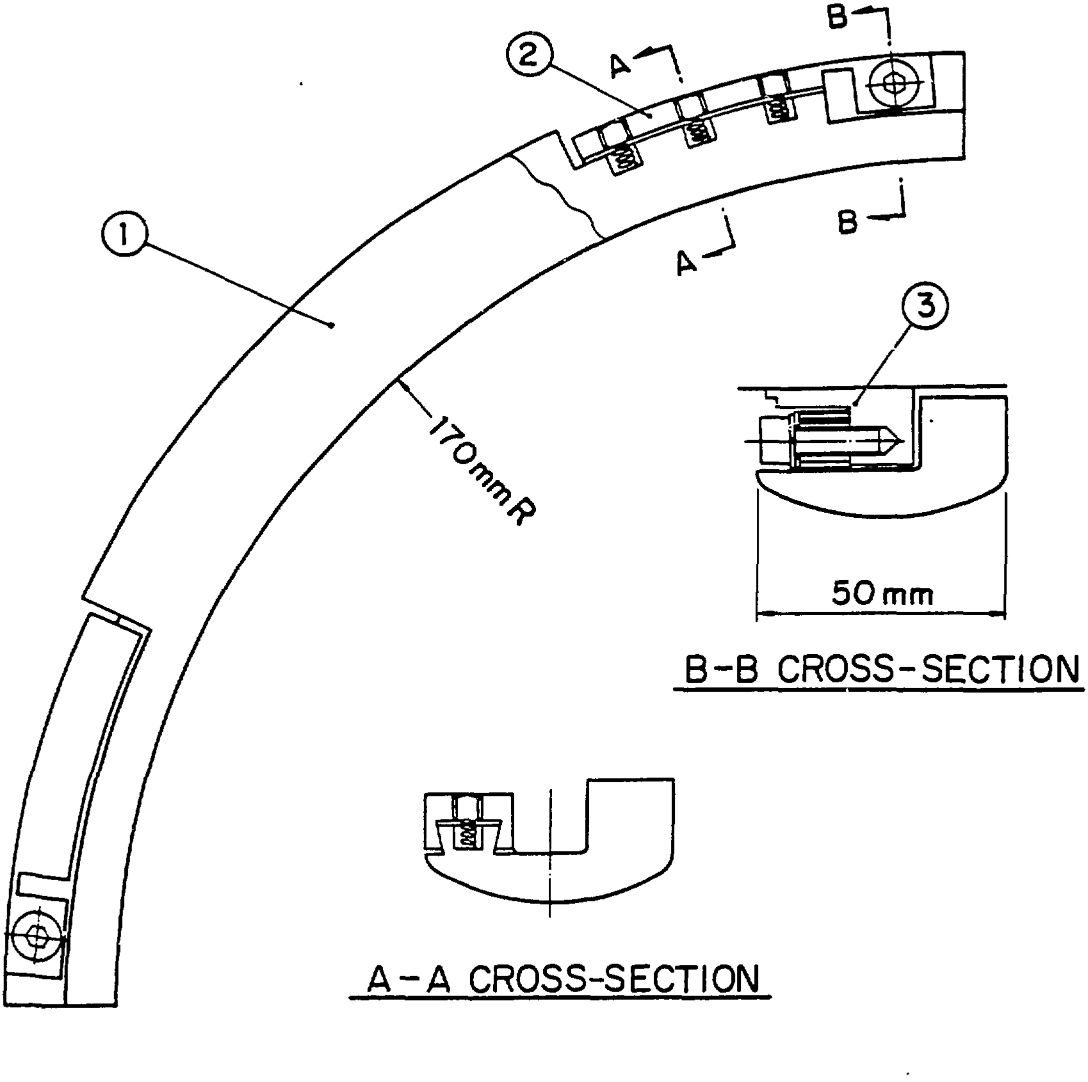

Fig. 2 Details of the TiC limiter : ① TiC coated graphite, ② stainless steel support for TiC/graphite, and ③ limiter support fixed to the vacuum chamber.

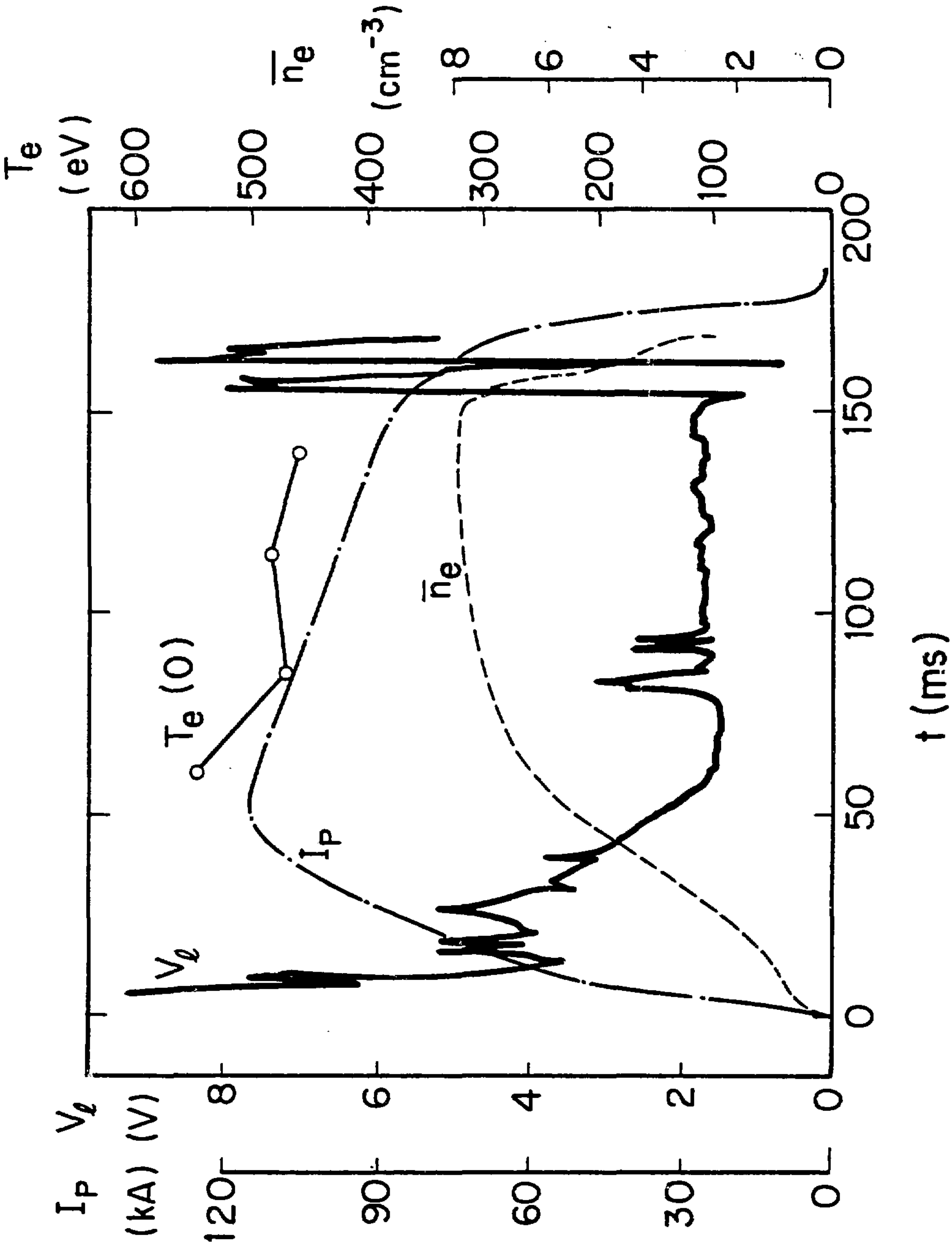

Fig. 3 Temporal behaviors of plasma current I_p, loop voltage V_ℓ, central electron temperature $T_e(0)$, and mean line-of-sight electron density $\bar{n}_e$

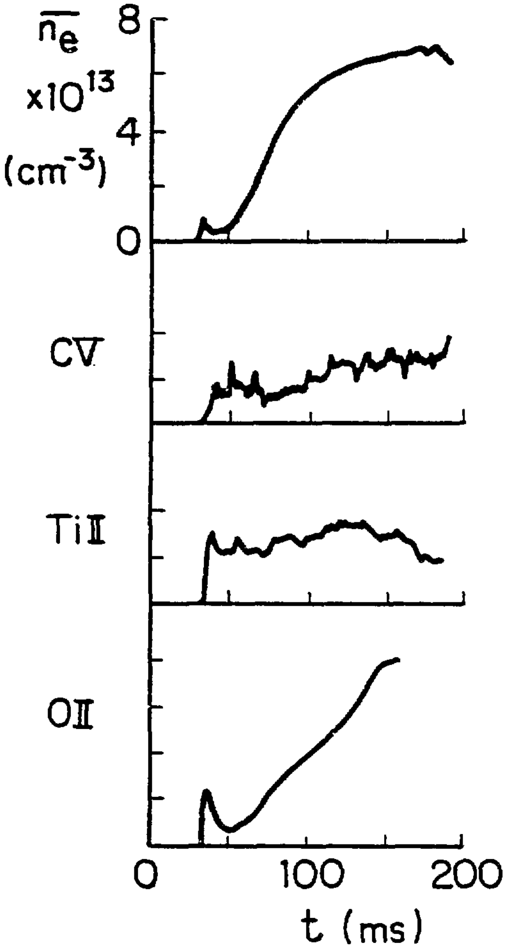

Fig. 4 Temporal behaviors of mean line-of-sight electron density $\bar{n}_e$ and CV, Ti II, and O II line radiations.

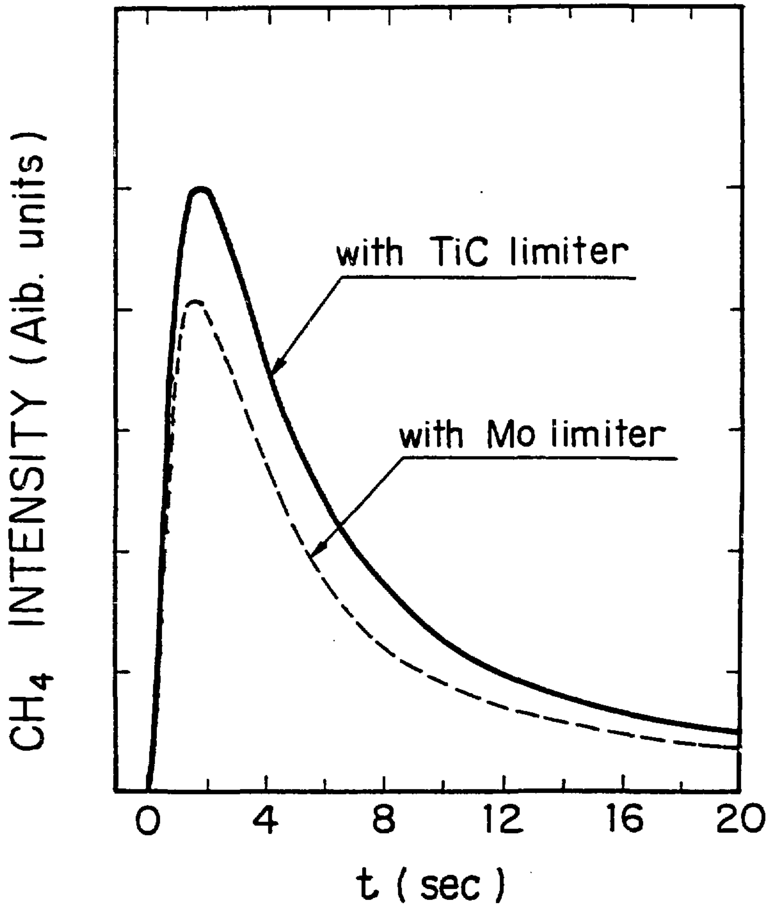

Fig. 5 Temporal behavior of the pressure of CH_4 gas released from the limiter and the wall.

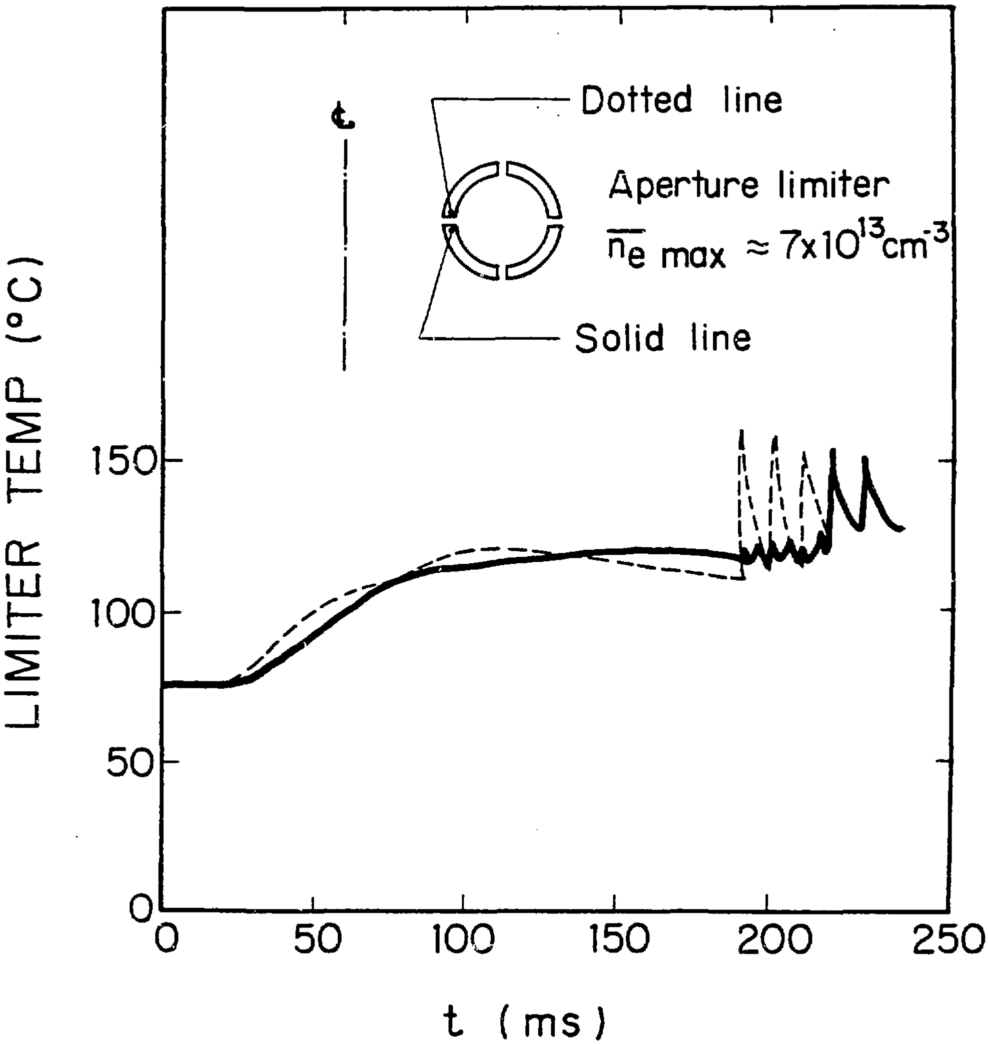

Fig. 6 Temporal behavior of the surface temperature rise of the aperture limiter on the inner side of the torus.