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INITIAL-TEMPERATURE PROFILES ON THE PDX INNER TOROIDAL LIMITER

By

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ABSTRACT

The temperature profiles resulting from plasma operation on the PDX vertical, large area, inner toroidal limiter have been measured during both ohmic and neutral-beam-heated discharges using a scanning infrared camera. An asymmetric double-peaked temperature profile is seen after neutral-beam-heated discharges. Disruptions in ohmically heated discharges are found to be preceded by a single-peaked deposition and succeeded by an initially symmetric double-peaked deposition. The results were compared with the Schmidt model for scrape-off at a toroidal limiter and it was found that the measured double-peaked temperature profiles yielded scrape-off lengths consistent with previous measurements.

1. INTRODUCTION

The PDX tokamak is configured to allow the study of carbon-rail limited, inner toroidal limited, and Dee-shaped-diverted plasmas. Extensive studies of PDX C-rail limited and Dee-diverted plasmas have been discussed elsewhere.[1-3] In this work, we describe initial measurements of the temperature profiles on the PDX vertical, large area, inner wall toroidal limiter during ohmic and neutral beam heated discharges. These measurements represent the first determination of the power load profiles on a vertical axisymmetric (toroidal) limiter system. Tests of a horizontal, large area, toroidal limiter in ASDEX have been discussed previously.[4]

The PDX inner toroidal limiter was designed to function as an inner wall neutral beam thermal armor, a neutral beam diagnostic, and a vertical, large area, inner toroidal plasma limiter. The inner wall protective plates were designed to absorb 8 MW of neutral deuterium power at maximum power densities of 3 kW/cm^2 for pulse lengths of 0.5 sec in the absence of plasma. The inner toroidal limiter consists of arrays of titanium carbide (20 μm thick) coated graphite tiles supported on the inner wall of the torus opposite the beam. These arrays cover approximately 70% of the circumference of radius 85 cm along the inner wall. The remaining 30% of this circumference is shielded by titanium slats (Fig. 1). Various inner wall diagnostics such as laser dumps, microwave horns, infrared reflectors, MHD sensors, etc. are mounted against the inner wall of the vessel and view the plasma through gaps or special apertures in the limiter. The inner limiter is flat in the vertical direction and is 60 cm high, mounted symmetrically about the midplane (Fig. 2). The graphite tiles are held to stainless steel backing plates by a water cooled copper dovetail design. In this work the inner limiter was not actively cooled. An array of 64 thermocouples mounted in the graphite tiles were used to monitor the toroidal symmetry of the thermal depositions. A detailed description of the inner protective plate design and its development was given previously.[5]

2. EXPERIMENTAL PROCEDURE

These measurements were performed during a period of extensive high-beta plasma studies.[3] The PDX fields and parameters were configured according to the priorities of the high-beta experiments so as to allow convenient changes between C-rail limited and inner toroidal limited discharges. The temperature profiles measured on the inner toroidal limiter were obtained using both co- and counter-injection geometry. The discharges were typically initiated at a larger major radius and then brought into contact with the inner limiter. The inner toroidal limited plasmas had a major radius of 125 cm and a minor radius of 40 cm.

An Inframetrics model 310 scanning infrared camera was used to view the inner limiter from a distance of about 2 m. The camera operates in two wavelength ranges, 3-5 μm and 8-12 μm. The device was used in a line scan mode where the temperature along a single line is recorded. An image rotator was used to permit vertical scans of the inner limiter. The time response of the system was about 125 μsec and a scan was taken every 3 msec. The scans were archived using a CAMAC based computer data acquisition system. The camera and signal processing electronics were calibrated using standard blackbody sources. The emissivity of the limiter surface was determined by uniformly heating the limiter by circulating warm water (~ 50°C) through the limiter cooling lines and comparing the infrared signal to the limiter thermocouples. It was found that the emissivity was different for the two wavelength bands. The emissivity for the 3-5 μm band was 0.95 to 0.98 across the face of the limiter. The emissivity in the 8-12 μm band varied between 0.4 and 0.7. In view of the greater signal-to-background ratio obtained with the 3-5 μm band and the relatively constant emissivity at these wavelengths, the results presented here were obtained using the 3-5 μm band. After the correction for emissivity the temperatures determined from the two wavelength bands agreed within ± 10°C.

3. RESULTS FOR NEUTRAL BEAM HEATED DISCHARGES

Prior to the measurements presented in this work, the inner toroidal limiter was conditioned by approximately 93 discharges most of which were neutral beam heated. The hydrogen plasma parameters were typically; $B_T \sim 12$ kG, $300 < I_p < 350$ kA, $N_e \sim 3.6 \times 10^{13}$ cm^{-3}, and q = 2.5. The full discharge pulse length was 900 msec. The discharges were heated by ~ 4.1 MW of deuterium neutral beam power injected from 400 to 600 msec after the start of the discharge.

Figure 3 shows a typical temperature profile following a beam heated discharge. The shift of the thermal pattern below the midplane (distance = 0 is the midplane in Figure 3) is unexplained at this time. The asymmetry of the two peaks may be due to the directed momentum of the beam particles, but additional studies are needed to confirm this hypothesis. The asymmetry is seen most strongly following neutral beam shots. The ratio of the thermal load in the two peaks is about 0.3. The temperatures are consistent with about 40% of the input power during the beam pulse going to the limiter.

The decay rate for the temperature profiles following beam heated discharges is shown in Fig. 4. The solid line is the result of a theoretical calculation of the limiter front face temperature using temperature dependent material parameters and a peak thermal load of 0.25 kW/cm^2 for 200 msec. The thermal load was deduced from the temperature rise during the beam portion of the discharge. The time dependence of the power load during the beam could not be determined because of noise problems caused by the beam. The noise was due to electrical pickup and possibly beam heating of small bits of dust on the limiter surface resulting in small hot spots. We observed that the predominant thermal load occurs during the beam portion of the discharge. This is consistent with the very small temperature rises observed during nondisruptive portions of ohmic heated discharges discussed below.

The thermocouples showed that the power deposition was toroidally symmetric except in those areas where there were inner wall diagnostic apertures. In these locations power is deposited on the edge of the aperture and/or behind the limiter resulting in slightly higher power deposition.

4. RESULTS FOR OHMIC HEATED DISCHARGES

The measurements of the ohmically heated discharges followed the beam heated discharges described above. The plasma parameters were typically $B_T \sim 12$ kG, $220 < I_p < 270$ kA, $N_e \sim 2.5 \times 10^{-13}$ cm^{-3}, and $q = 3.5$.

Figure 5 shows a typical temperature profile sequence preceding and following a major disruption of an ohmically heated discharge. It was observed that a single peaked precursor profile appeared about 50 msec prior to major disruption with an initial rate of rise of 2.4°C/msec. The temperature profile prior to the disruption could not be determined because the heat flux from the OH discharge was too small to cause measurable temperature differences across the graphite limiter. However, inner wall temperature profile measurements using sensitive thermocouples mounted on a titanium plate on the north side of the inner wall (Fig. 1) found a double peaked profile during normal OH discharges.[2] Note also that the sequence of temperature profiles following the disruption are double peaked and initially symmetrical. Figure 6 shows a typical temperature profile following a disruption in an ohmically heated discharge. The deposition is still shifted down by about the same amount as was found for the neutral beam heated discharges (Fig. 3). Theoretical calculations of front face tile temperatures using temperature dependent material parameters and a thermal load of 5–10 kW/cm^2 for 3–6 msec are consistent with the observed temperatures. This load time is consistent with the measured plasma current decay rate of ~ 42 kA/msec. The temperature histories prior to the disruption indicate a thermal load of < 20 W/cm^2.

5. DISCUSSION

The Schmidt model for scrape-off at a toroidal limiter predicts a double peaked temperature profile.[6] Using this model, the scrape-off length (λ) was derived as a function of the separation of the temperature peaks for the case of a flat, vertical, inner toroidal limiter. The results are shown in Fig. 7 which gives one half of the theoretical peak separation versus λ. The inferred scrape-off lengths are λ = 1.0 cm for the neutral beam heated discharges and λ = 0.5 cm for the post-disruption ohmically heated discharges. These values are consistent with other measurements made on PDX.[7] The observed symmetry in the toroidal direction is predicted by the model. The peak power load of 250 w/cm^2 deduced from the temperature profile agrees with the peak power predicted by the model for 40% of the input power going to the limiter. The filling in of the valley between the peaks indicates the presence of radial transport which is not included in the model in an explicit manner. Similar filling in has been observed on a rail limiter in D-III.[8] While radial transport is implicitly in the scrape-off thickness in the model, the power is assumed to flow only along field lines. This results in the power flux being predicted to be zero at the limiter plasma tangent point (midplane in the PDX case). The same radial transport which results in the scrape-off length will carry power to the tangent point (see Ref. 9) and fill in the profile as was observed. The lack of the double peak before the disruption implies that the radial transport is greatly enhanced just prior to the disruption. While it is true that enhanced radial transport will result in longer scrape-off lengths giving a wider peak separation, it will also result in more filling in of the space between the peaks. Also the longer scrape-off lengths result in lower peak power densities. Under such conditions, the radial transport to the tangent point can dominate the power flow. This could be particularly true if field lines are becoming stochastic prior to a disruption. The few disruptions that we observed are not a statistically significant enough sample to determine whether such observations can be used to control disruptions.

In summary, the results of these initial measurements indicate that the Schmidt model is generally correct. However, the radial transport of power is not included in the model in sufficient detail and the results imply that radial transport is important. Power loads during disruptions are poorly understood at this time and further investigations are needed. The results do show that the model is correct enough to use the model to design axisymmetric limiters. The low peak heat flux to such a limiter is of great benefit for machines such as TFTR and INTOR which have large input power.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

FIG. 1 PDX partial schematic top view showing the location and injection angles of the neutral beams and the inner wall toroidal limiter.

FIG. 2 Schematic cross-sectional view of PDX with a plasma against the vertical large area toroidal limiter.

FIG. 3 Typical temperature profile following a neutral beam heated discharge.

FIG. 4 Typical decay rate of temperature profiles following neutral beam heated discharges.

FIG. 5 Typical temperature profile sequence preceding and succeeding a disruption in an ohmically heated discharge.

FIG. 6 Typical temperature profile following a disruption for an ohmically heated discharge.

FIG. 7 One half the theoretical peak separation versus scrape-off length.

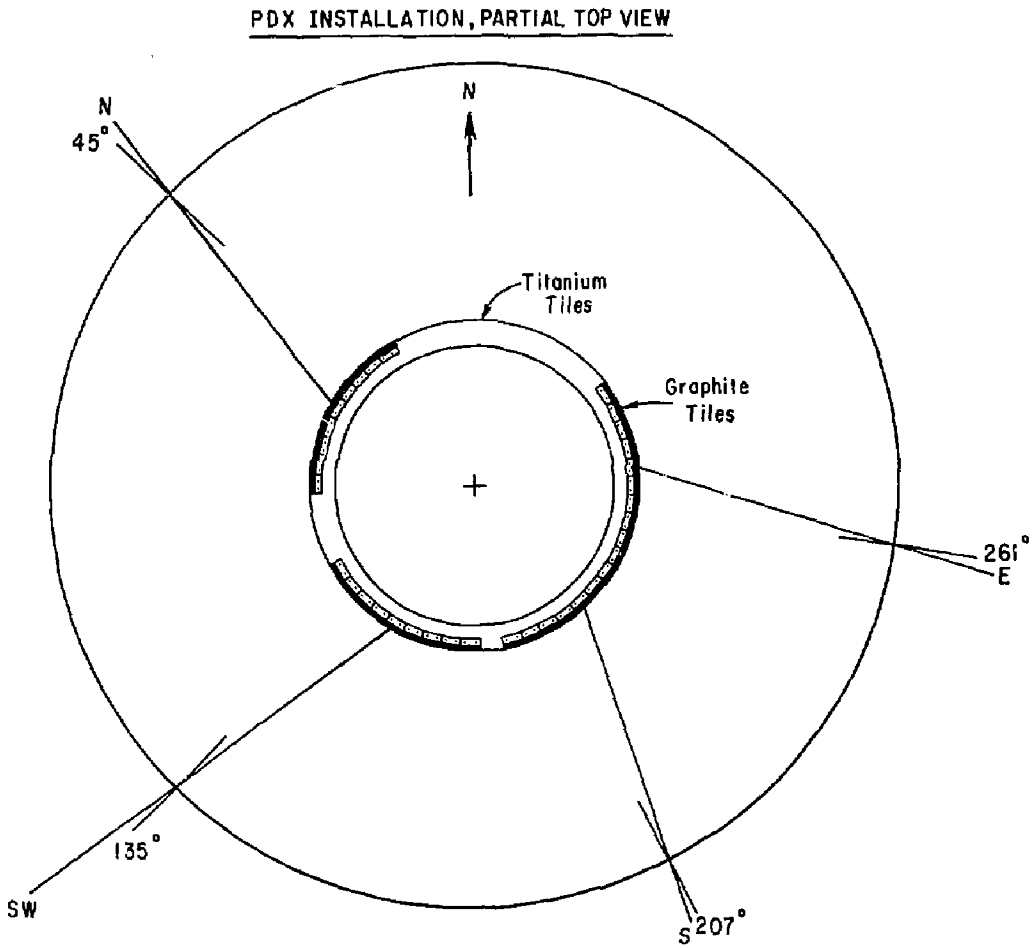
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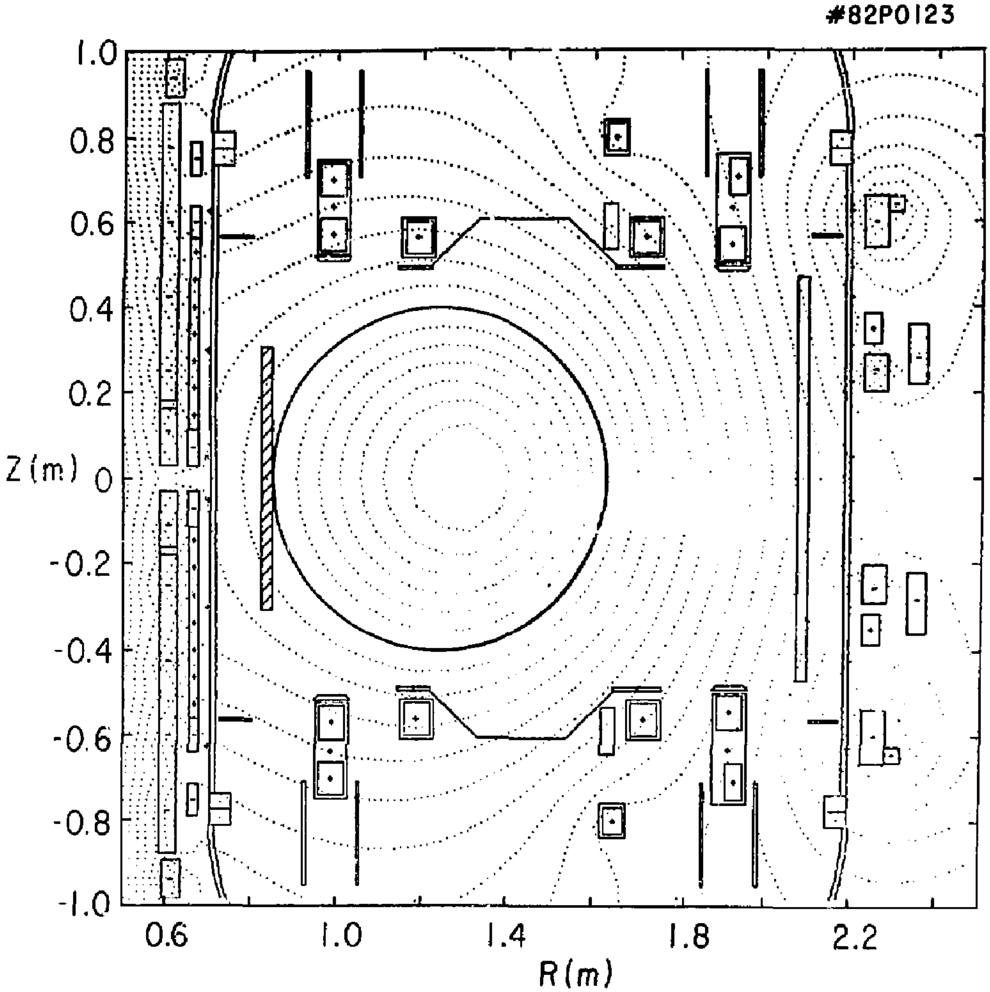
Fig. 1



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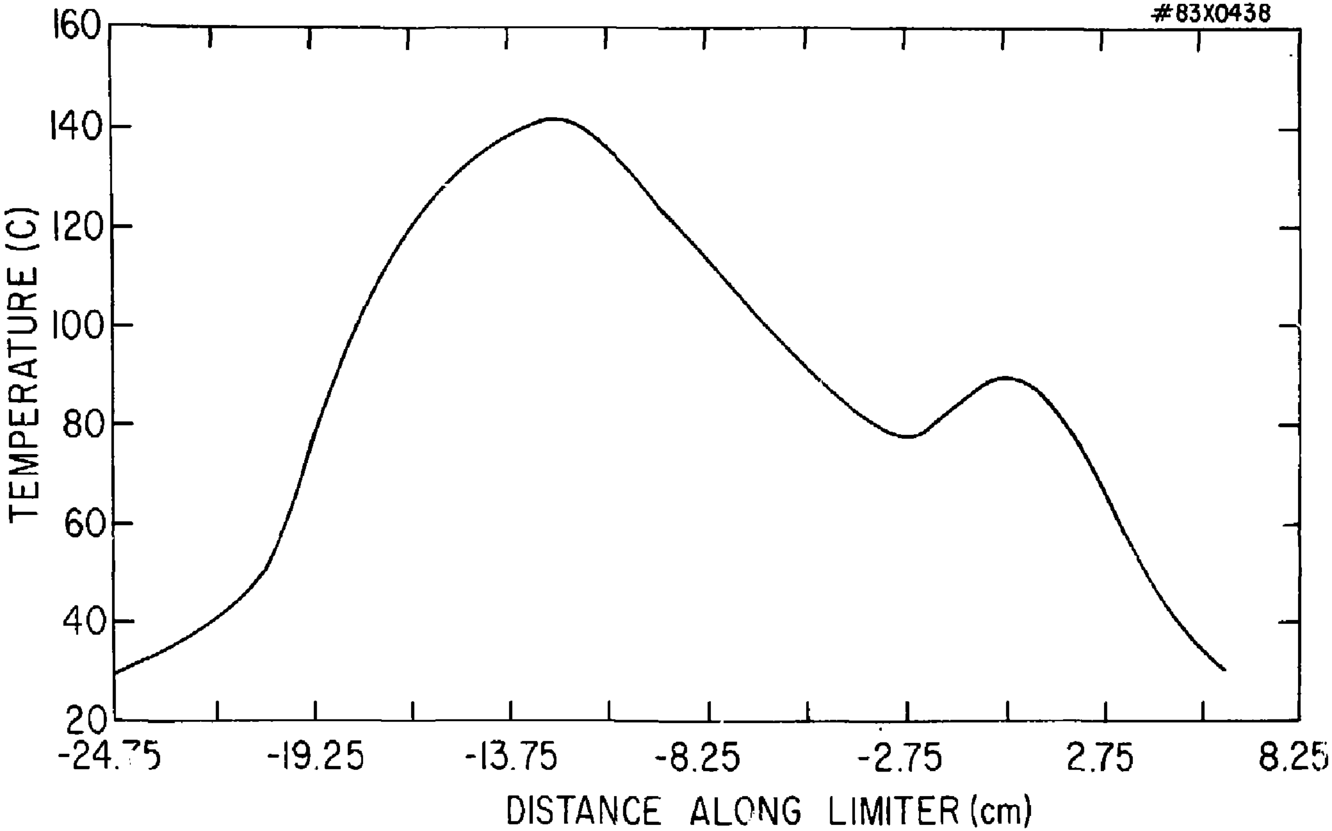
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DISTANCE ALONG LIMITER (cm)

Fig

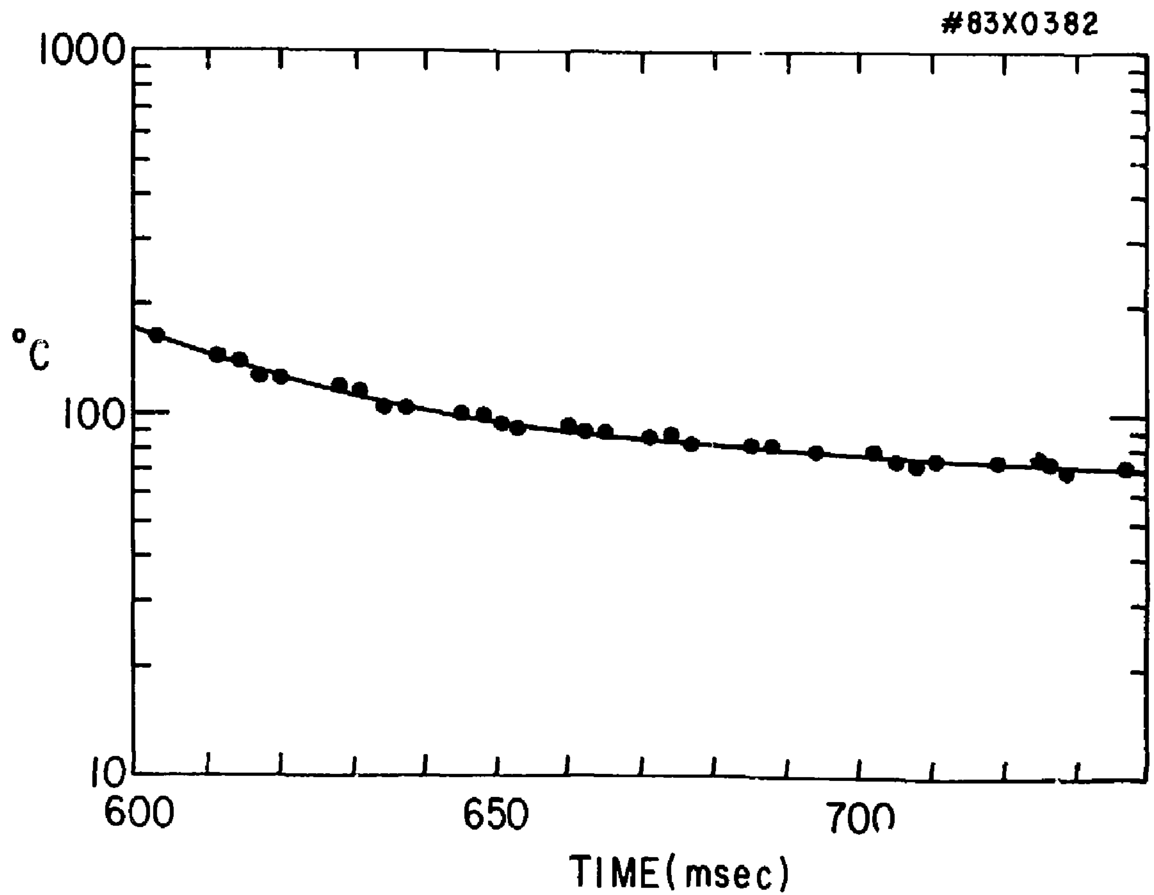
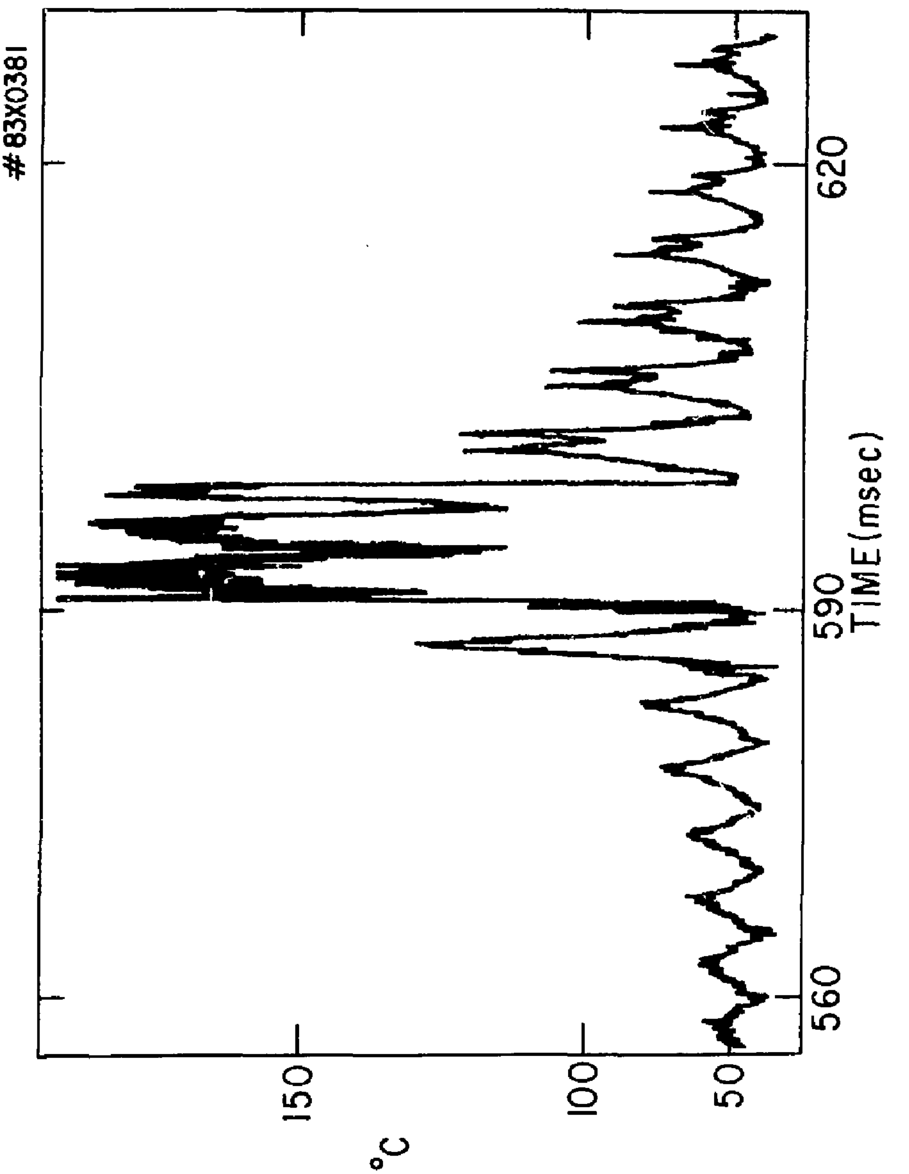


Fig. 4



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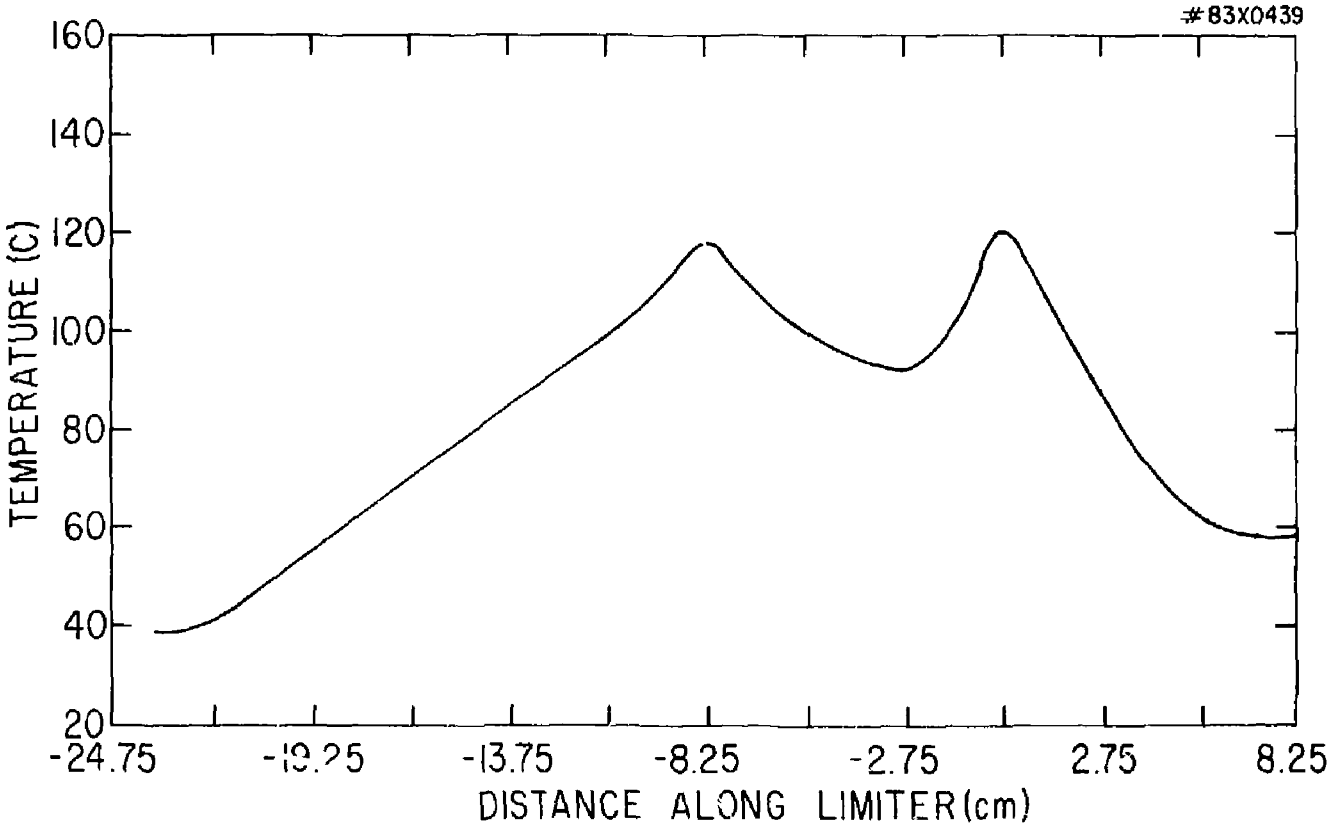
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DISTANCE ALONG LIMITER (cm)

Fig. 6

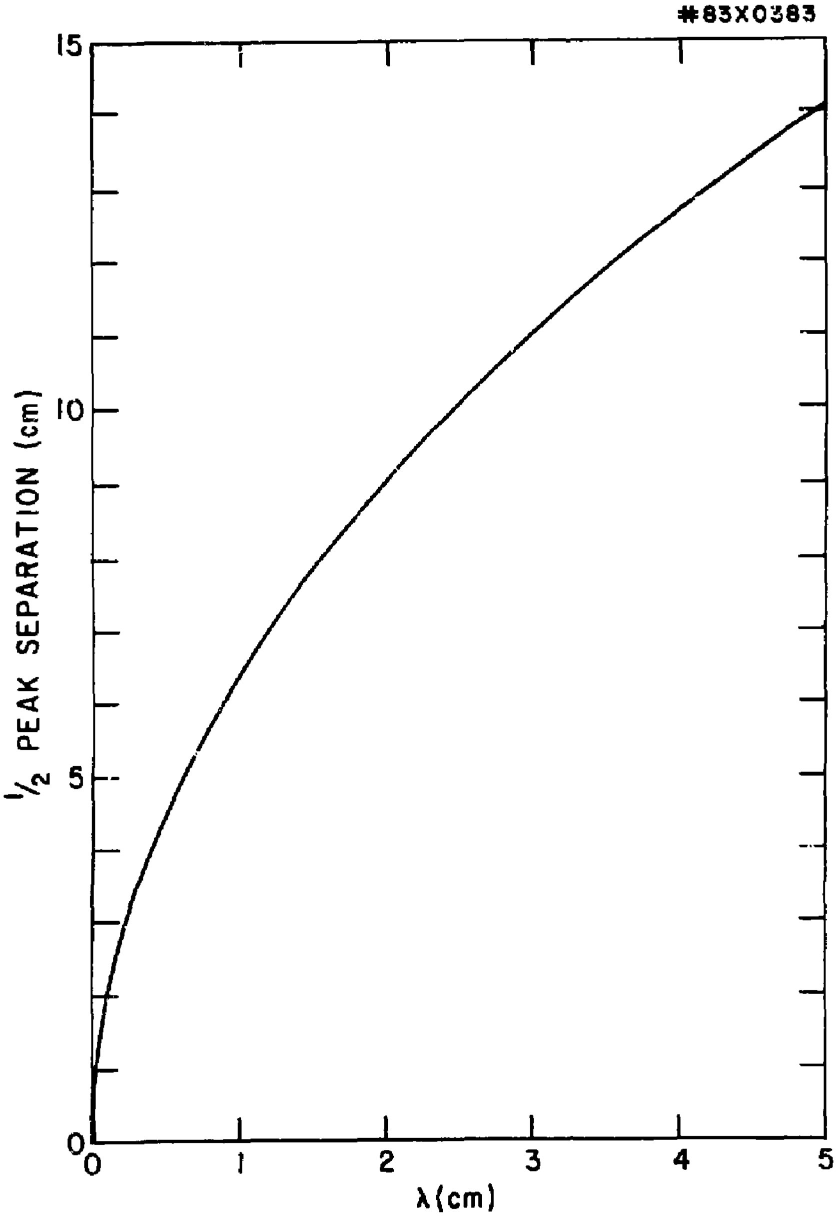

Fig. 7

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