AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

PPPL-CFP--3091
Conf-940580--5

Real-Time Boronization in PBX-M Using Erosion of Solid Boronized Targets

H. W. Kugel, J. Timberlake, R. Bell, A. England[1], Y. Hirooka[2], R. Isler[1],
B. LeBlanc, M. Okabayashi, S. Paul, W. Tighe, A. Post-Zwicker[1]

*Princeton Plasma Physics Laboratory, Princeton University, P.O. Box 451,
Princeton, NJ 08543, USA*

[1] *ORNL, Fusion Energy Division, Bldg. 9201-2, P.O. Box 2009,
Oak Ridge, TN 38731, USA*

[2] *University of California at Los Angeles, IPFR, 139-44 Engr. IV Bldg.,
Los Angles, CA 90024, USA*

Abstract

Thirty one real-time boronizations were applied to PBX-M using the plasma ablation of solid target probes. More than 17 g of boron was deposited in PBX-M using this technique. The probes were positioned at the edge plasma to optimize ablation and minimize spallation. Auger depth profile analysis of poloidal and toroidal deposition sample coupon arrays indicate that boron was transported by the plasma around the torus and deep into the divertors. During discharges with continuous real-time boronization, low-Z and high-Z impurities decreased rapidly as plasma surfaces were covered during the first 20-30 discharges. After boronization, a short-term improvement in plasma conditions persisted prior to significant boron erosion from plasma surfaces, and a longer term, but less significant, improvement persisted as boron farther from the edge continued gettering. Real-time solid target boronization has been found to be very effective for accelerating conditioning to new regimes and maintaining high performance plasma conditions.

1. Introduction

The real-time solid target boronization (STB) technique involves the deposition of boron on machine surfaces by ablation from boronized target probes inserted into edge plasmas either during special discharges for boronization or during typical experimental discharges [1-3]. Boron deposited by STB is an effective getter for typical plasma impurities and its deposition results in a significant improvement in tokamak plasma properties [1, 2]. STB is useful for maintaining boron coated surfaces in high duty cycle and long pulse discharges during which thin boron films applied before plasma operations, are eroded quickly from near-plasma surfaces. STB does not introduce undesirable hydrogen species into machines being prepared for deuterium operation, and it does not require a bakeable vessel. STB is environmentally benign, intrinsically safe, non-toxic, inexpensive to install and maintain, and convenient to apply. These advantages were demonstrated in initial experiments [1-2], and motivated the first extensive application of STB during 31 boronizations in PBX-M. In this paper, we report on the PBX-M STB procedure, STB performance during plasma operations, and the relative simplify and effectiveness of STB as a routine, real-time impurity control technique.

2. Experimental Geometry

Fig.1 shows a partial schematic elevation view of PBX-M showing passive plate stabilization system and other hardware. The circled numbers identify deposition sample locations discussed below. The STB probe was inserted on the midplane into the edge plasma.

The initial boronization of PBX-M used an STB probe in a mushroom shape and consisted of a 10.7% boronized 2-D carbon-carbon composite containing 3.6 g of boron in a B_4C binder [4]. The improvement in PBX-M plasma performance [2] was similar to that observed on TdeV [1]. These results motivated the development of procedures for routine, real-time STB of PBX-M. Recent STB depositions have used rectangular graphite-felt probes consisting of about 85% boronized graphite-felt composites containing about 30 g of 40 micron diameter boron particles loosely-held in the felt matrix [2]. These probes a characterized by a high boron yields per probe (1 to 8 g), high boron-to-carbon fraction ($\leq$86% boron), high thermal shock resistance and low thermal conductivity (< 2000 that of graphite) for rapid heating in edge plasmas.

The STB probe was mounted on a carbon-carbon composite and attached to the probe drive mechanism. The probe assembly was electrically isolated from the vessel and inserted into the edge plasma via a bellow mechanism at one toroidal location. Only one probe was inserted into PBX-M per STB application.

3. STB Procedure, Performance, and Results

The procedure used for STB on PBX-M was evolved from the experience accrued during 31 STB applications. Typically, STB depositions were performed as part of the conditioning process in preparation for achieving suitable plasma conditions. At other times, for special experiments, STB was performed during the actual experimental discharges. In particular, boronizations were performed to aid plasma starting conditions, to aid start-up after vessel openings to atmosphere, to recover from degraded plasma conditions, and to achieve high performance plasma conditions for normal double-null diverted plasma operations with NBI and active profile control using LHCD and IBW.

The preparations for an STB application began by establishing indented, bean-shaped, 250 kA, diverted deuterium plasmas with strike points that were swept during the discharge across the inner passive plates and into the divertors. This was done so as to aid the spreading of boron over the passive plate surfaces and the transport boron into deep divertor regions. These plasmas were either ohmic or NBI heated depending on the circumstances. Ohmic plasmas, for example, were convenient for STB while awaiting NBI conditioning.

New probes were moved through the torus port and positioned inside the vessel at the outer wall for several hours to allow slow heating and undergo and any residual outgassing. Previously used probes were promptly positioned about 1 cm outside the plasma edge and then moved inward about 0.25 cm per discharge. The optimum probe edge position was selected using a plasma TV camera, probe floating potential, and UV spectroscopy.

During the probe insertion process, the incandescence of the probe tip was monitored by a plasma TV system and recorded with a VCR for inspection between discharges. This probe-viewing diagnostic was considered essential for achieving controlled steady ablation and avoiding arcing or spallation from fast heating due to edge conditions or to the depth of insertion. The use of an 850 nm filter found adequate emission intensity for observation and a qualitatively similar behavior to that observed using an unfiltered view. Fig. 2 shows the results of integration of the visible light intensity detected by this system which exhibited a rise time characteristic of an approximately constant applied power density and an exponential-like decay.

The use of a new probe permitted the probe drive indicator to accurately indicate the probe position relative to the plasma. As the probe tip was slowly eroded during many STB applications, however, the probe drive indicator gave a less accurate indication of true probe position relative to the edge plasma. The effective probe radial edge position could be monitored using the probe floating potential. Fig. 3 shows floating potential of an STB probe against apparent position given by the probe drive indicator. As a probe slowly eroded, during many boronizations, the floating potential could be used to position the probe in the edge plasma.

During STB, UV spectroscopic measurements of changes in the boron, carbon, oxygen, and metallic impurities emission intensities were useful for monitoring the effectiveness of the boron deposition rate and the resulting plasma conditions. Fig. 4 shows boron (BIII) and oxygen (OVI) impurity behavior during STB. As the boron intensity increased, the oxygen intensity decreased by about 3.5. Typically about 12 light impurity and metal UV peak emission intensity waveforms were observed during STB to monitor deposition and cleanup progress.

After deuterium discharges, the volatilization of boron compounds was monitored via mass analysis of residual gases in the vessel and exiting via the pumping system. The only boron mass (A) intensities observed were A = 47 corresponding to D_2BO_2, and, tentatively, a difficult to resolve mass intensity at A = 29 corresponding to DBO.

In order to measure the distribution of boron applied by STB from one probe location, thin stainless steel sample coupons were attached to the passive plates and other machine surfaces, in poloidal arrays at different toroidal locations and subjected to 29 STB applications. In Fig.1, the circled numbers indicate the 24 poloidal locations of impurity deposition samples. A similar 24 sample poloidal array was located at each of four toroidal locations, about every 90 degrees, for a total of 98 deposition samples. Auger electron spectroscopy analysis depth profiling was performed on these samples [5]. Some Auger electron spectra exhibited boron energy shifts indicative of oxide, boride, and possibly the carbide compounds. Fig.6 shows the results for the boron poloidal and toroidal thickness distributions. At the STB probe position (62 degrees toroidally), the boron depositions on the outer midplane passive plates are about 30-40 Angstroms and mostly greater than 10 Angstroms at the other poloidal locations farther from the midplane. At the other toroidal locations, the boron deposition thicknesses are in the range from about 1 to 5 Angstroms. This is also seen, in particular, at the poloidal sample array at 247 degrees, which is toroidally opposite the STB probe, and for which the line-of-sight to the probe is occulted by the center column of the vessel. These results indicate that there is extensive boron toroidal distribution due to plasma transport, and extensive boron deposition near the probe due to line-of-sight evaporation. Some poloidal locations at toroidal 157 and 337 degrees, within line-of-sight of the STB probe, also tended to receive thicker depositions consistent with this model. The poloidal positions No. 4 and No. 20 are deep in the upper and lower divertors, respectively, and exhibited about the same deposition thicknesses as other nearby poloidal locations. This is attributed to the effect of sweeping the plasma strike points during the discharge across the near divertor region and then deep into the divertors, and possibly some scattering from the main plasma although this region is not within line-of-sight of the main plasma. The relatively thin depositions at some sample locations and the role of preferential sputtering requires additional investigation.

Thirty one, real-time STB depositions were applied to PBX-M using the initial mushroom probe (BP-1) for 2 applications and 3 graphite-felt probes (BP-2,-3,-4) for 29 applications. Fig. 5 shows a photograph of STB graphite felt probe BP-3 after exposure to PBX-M plasmas during 16 boronizations of varying duration and ablation rate. The ions were incident from the right. The total boron ablation was 8.3 g. The final probe tip is about 50% shorter than before exposure.

Each STB application consisted of inserting a target probe into the edge plasma and ablating boron using either OH or NBI heated discharges for 1-2 hours per application (20-30 discharges lasting about 800 ms). The number of available applications per probe varied with the boron content and the ablation rate. More than 17 g of boron was deposited in PBX-M using this technique.

The effectiveness of STB in PBX-M, during and after the 31 applications was consistent with initial results reported in detail previously [2]. During discharges with continuous real-time boronization, boron was transported by the plasma around the torus and into the divertors, and low-Z and high-Z impurities decreased rapidly as plasma surfaces were covered during the first 20-30 discharges, and more slowly thereafter.

During discharges after boronization, a short-term improvement in plasma conditions persisted prior to significant boron erosion from plasma surfaces, and a longer term, but less significant, improvement persisted as boron farther from the edge continued gettering [2]. About 3-4 applications per week seemed adequate for PBX-M 800 ms discharges at duty cycles of about 4 min. After STB, UV emission data indicated that disruptions stimulate boron emissions and gettering. Fig. 6 shows the behavior of impurities during IBW experiments following STB. The clean plasma conditions achieved with STB allowed the exploration of new regimes. Fig. 7 shows TVTS results after STB which exhibit the behavior of the IBW enhanced core-confinement mode following boronization [6].

Real-time solid target boronization has been found to be very effective for accelerating conditioning to new regimes and maintaining good plasma conditions. The technique is applicable to the deposition of other coatings such as Be, Li, and Si.

Acknowledgment

We wish to acknowledge the helpful contributions of G. Gettelfinger, J. Semler, E. Thorsland, and the PBX-M Technical Staff. The PBX-M project is supported by US DoE Contract No. DE-AC02-76-CHO3073.

References

[1] Y. Hirooka, *et al.*, Nuc. Fus. **32** (11), 2029 (1992).

[2] H. W. Kugel ,et al., to be published in Fus. Techn. July, (1994).

[3] D. J. D. Hartog, *et al.*, University of Wisconsin, Report DOE/ER/53198-205, October 1992. Refer also to D. J. H. Hartog et al., in this confernce.

[4] Y. Hirooka and R.W. Conn, IPFR, University of California, Los Angeles, Report UCLA PPG #1478, March 1993, and in *Atomic and Plasma-Material Interaction Processes in Controlled Fusion* , ed. R. Janev, IAEA, (1993), Vienna.

[5] R. L. Moore, Evans East Inc., 666 Plainsboro Road, Suite 1236, Plainsboro, NJ 08536.

[6] B. LeBlanc, *et al.*, to be published in Physics of Plasmas.

Figure Captions

Fig.1. Partial schematic diagram of PBX-M showing passive plate system and internal hardware probe. The circled numbers indicate deposition sample locations.

Fig. 2. Waveform of visible TV signal intensity during STB.

Fig. 3. Floating potential of an STB probe against apparent position given by the probe drive indicator.

Fig. 4. Oxygen emission intensity (OVI) decreases during STB as boron (BIII) emission intensity increases during boronization.

Fig. 5. Photograph of an STB graphite-felt probe after exposure to PBX-M plasmas.

Fig. 6. Boron poloidal and toroidal deposition thickness distributions.

Fig. 7. STB reduces impurities during IBW.

Fig. 8. STB prepared high performance plasma for enhanced core-confinement mode during IBW.

PPPL#94X0127

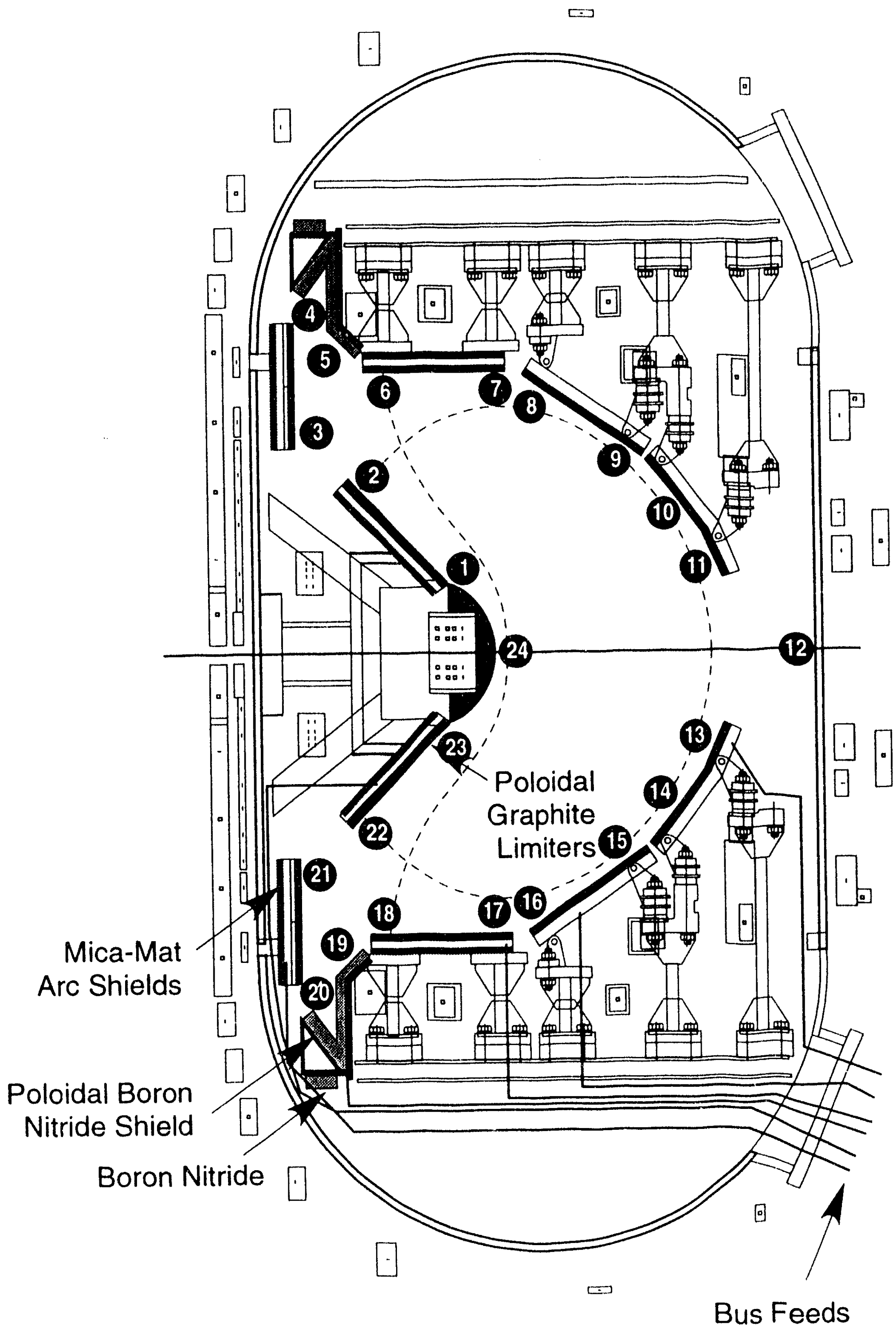

FIG. 1
H. W. KUGEL et al.

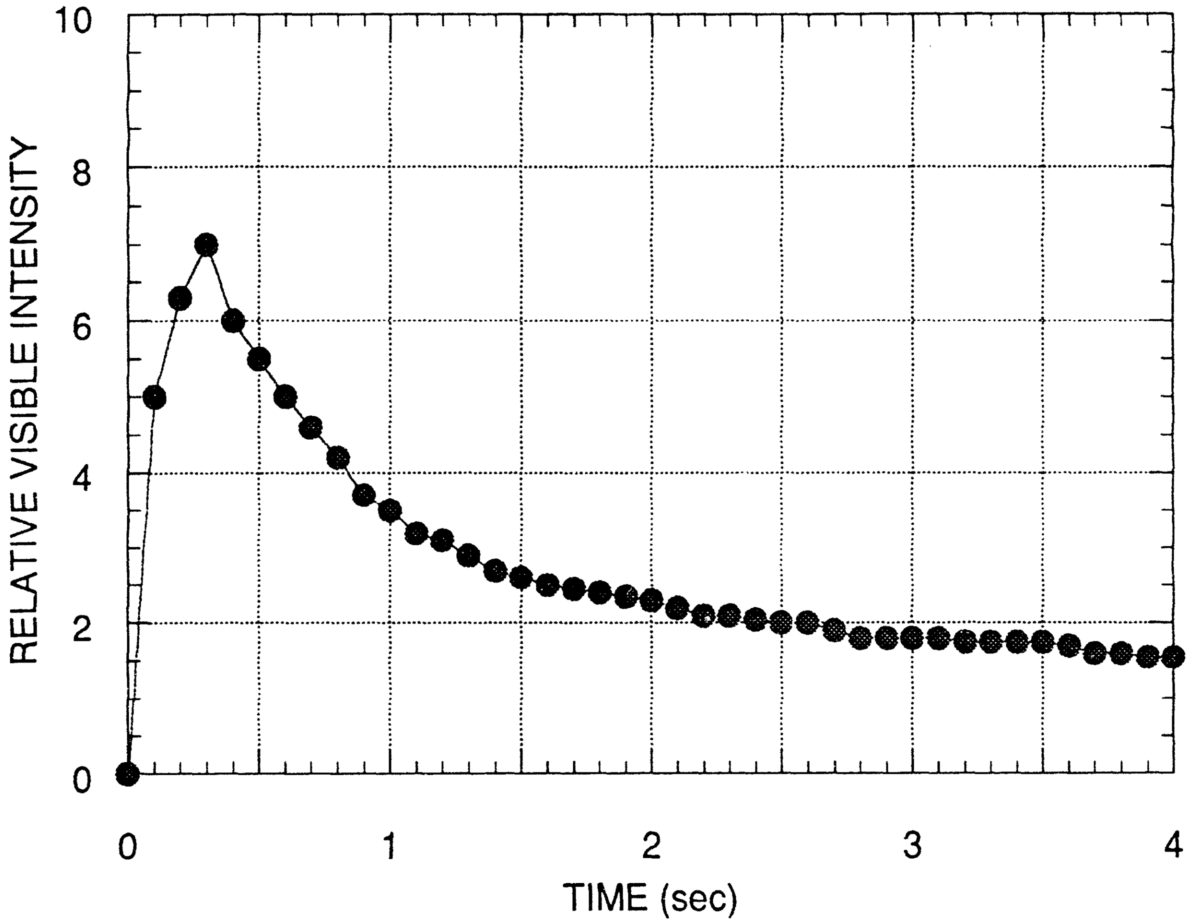

FIG. 2
H. W. KUGEL et al.

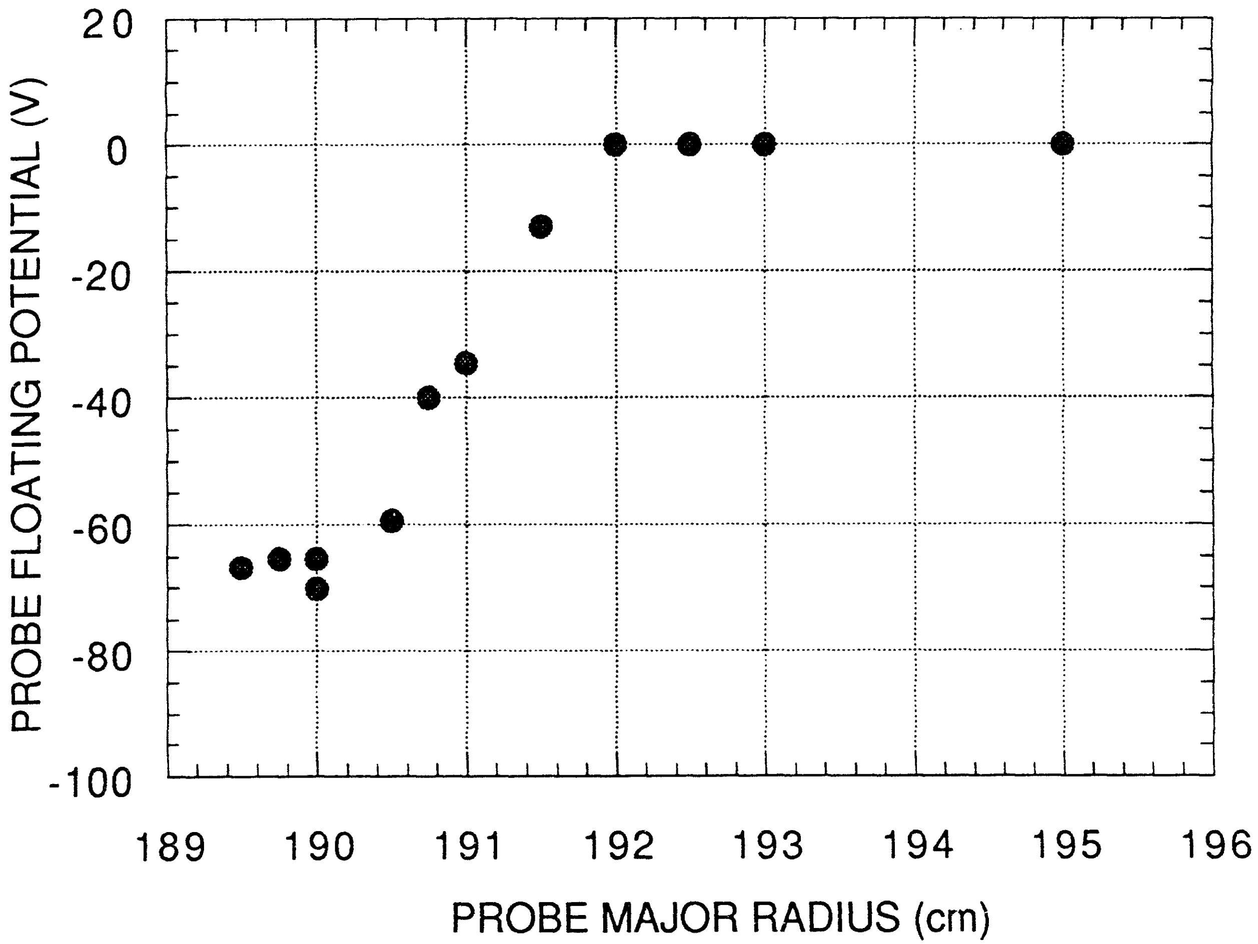

FIG. 3
H. W. KUGEL et al.

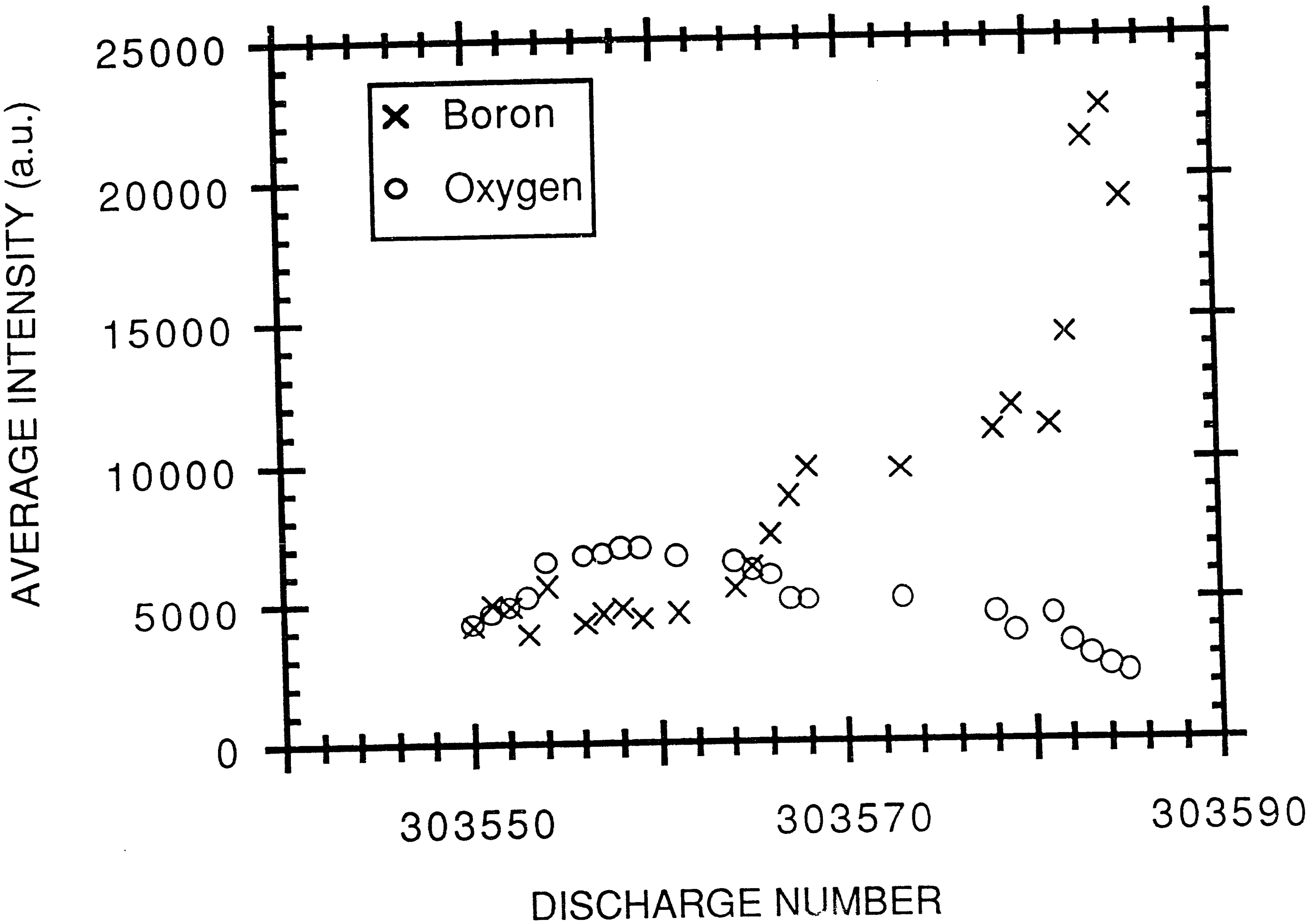

FIG. 4
H. W. KUGEL et al.

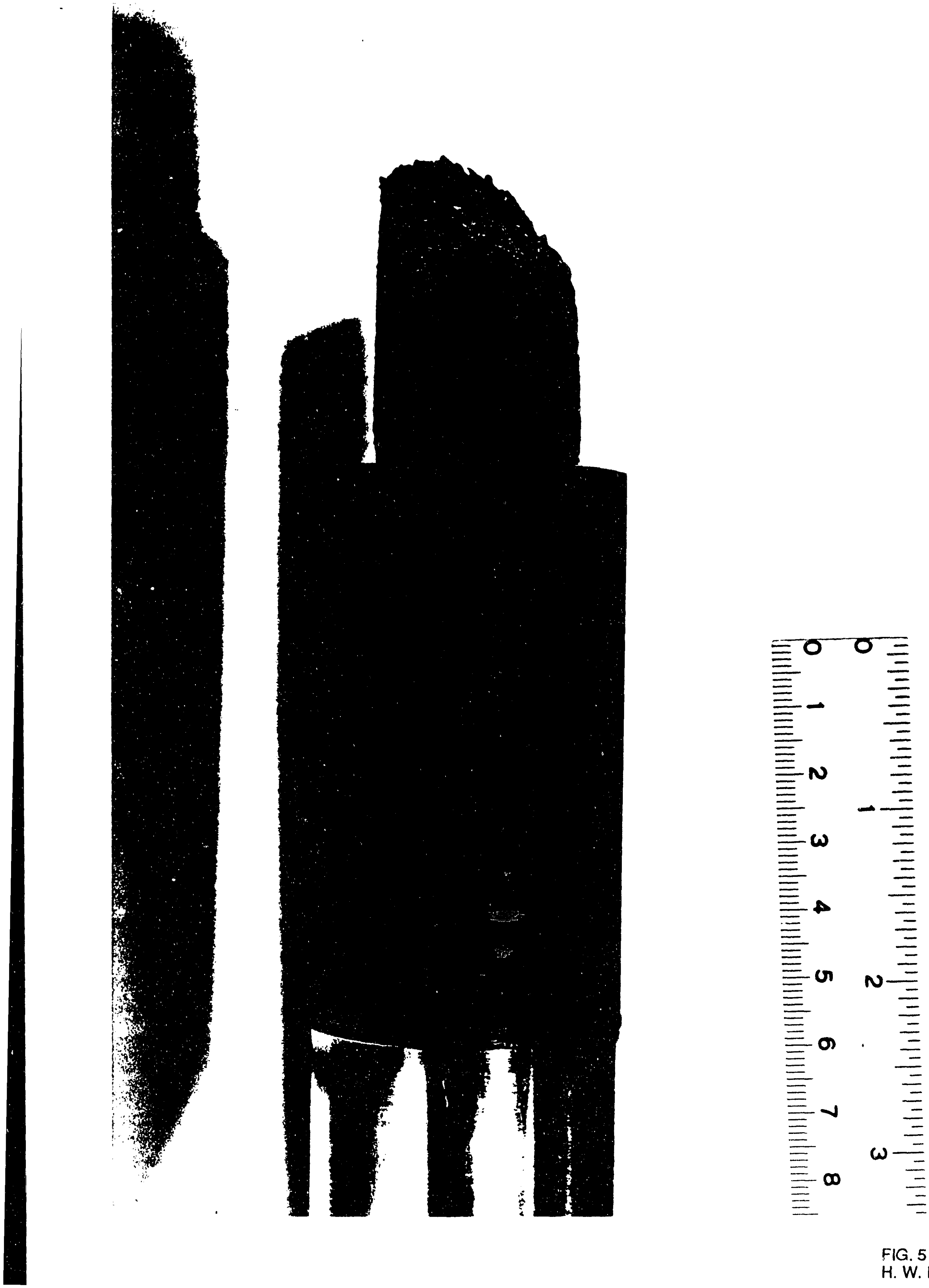

FIG. 5
H. W. KUGEL et al.

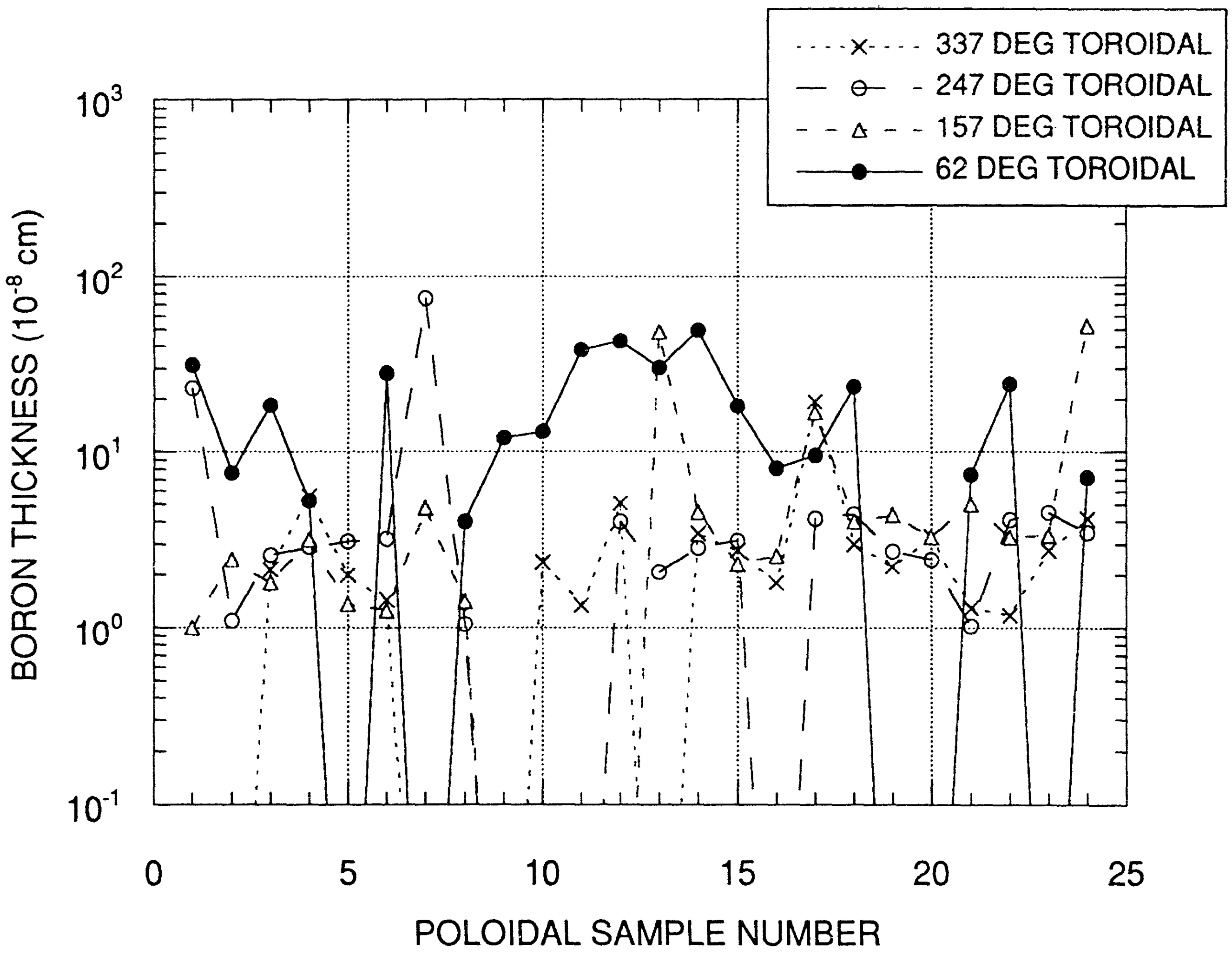

FIG. 6
W. KUGEL et al.

PPPL#94X0139

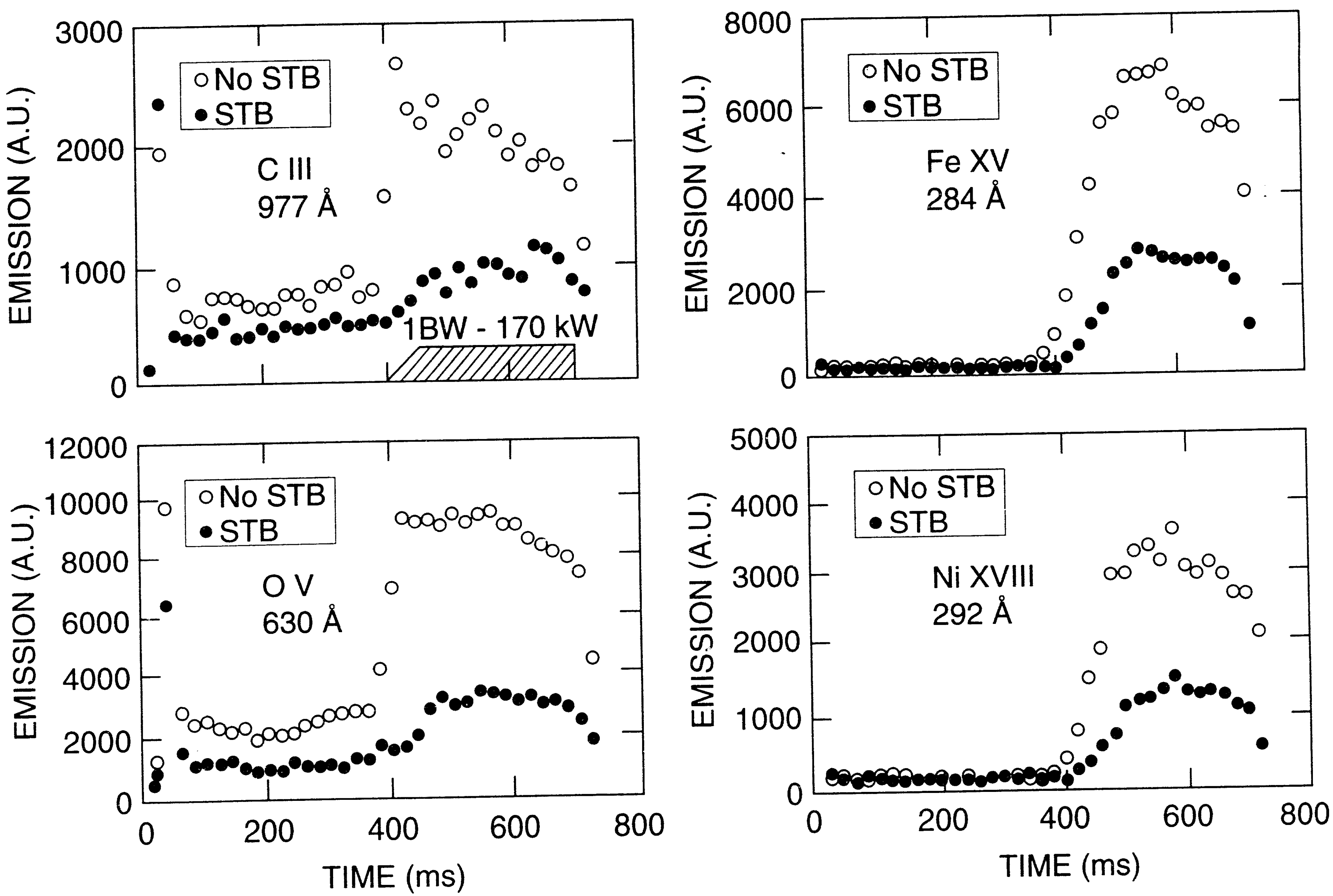

FIG. 7
H. W. KUGEL et al.

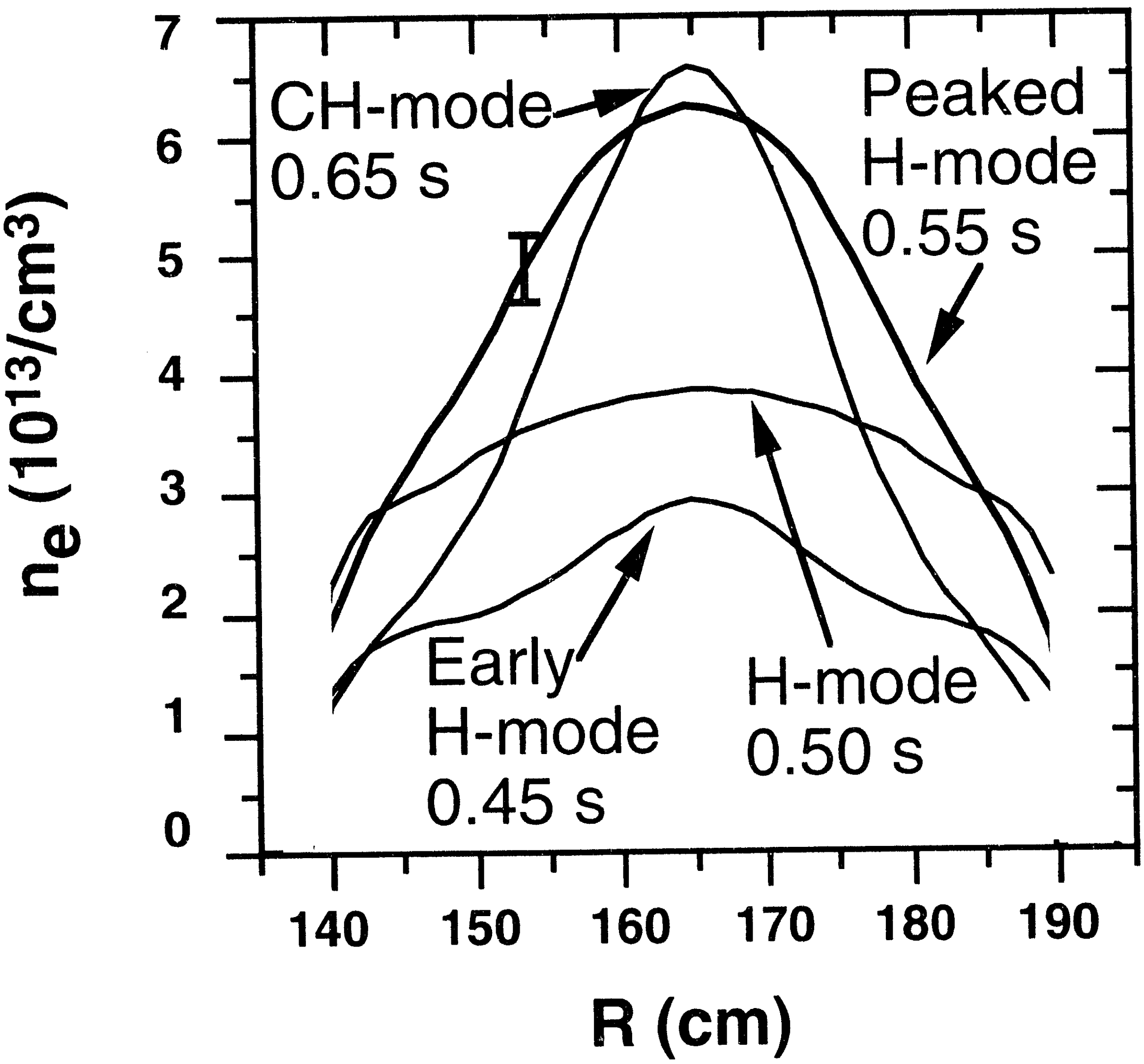

FIG. 8
H. W. KUGEL et al.

DATE FILMED

8/22/94

END