OBSERVATION OF NEUTRON AND X-RAY SAWTEETH IN ALCATOR

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ABSTRACT

Sawtooth oscillations in the thermonuclear neutron production rate have been observed in Alcator. They are correlated with oscillations in soft x-ray emission from the plasma and indicate large (>15%) oscillations of central ion temperature.

Soft x-ray emission from the Alcator plasma has been observed using a multi-diode imaging apparatus built by Petrasso et al [1]. The x-ray flux exhibits the characteristic sawtooth behavior first noted by Von Goeler [2]. In addition, similar fluctuations have now been seen in the emission of D-D fusion neutrons (Figure 1). The strong temporal correlation between these two diagnostic signals indicates that similar processes affect both the electron and ion temperatures during the internal disruption. This would follow if present theories of the disruption process are correct [3, 4].

The rapid growth of magnetic islands from the q=1 surface and reconnection of magnetic field lines is a process which should affect both the electron and ion radial temperature profiles. We have developed a quantitative picture by fitting temperature profiles to the experimental data and studying the effects of the disruptions on the calculated x-ray and neutron emission.

Prior to the internal disruption, the temperature profiles are approximated by Gaussian functions [5]. The peak electron temperature is determined by matching the measured x-ray flux with that calculated using a computer code developed here [6]. The code takes into account the specialized geometry of the detectors and aperture, the transmission effects of various x-ray filters, and the assumed density, temperature, and impurity profiles. The electron temperature calculated by this method is in excellent agreement with temperatures determined by Thompson scattering [7].

Immediately after the disruption, it is assumed that the temperature profile becomes flattened in the central section of the plasma while remaining constant elsewhere (Figure 2). By requiring conservation of total energy (both kinetic and magnetic) during the internal disruption, we can relate the radius of flattening to the temperature of the flattened region, thus leaving only one independent parameter to vary. This parameter was determined by again matching the measured x-ray signal with the computer model.

In a disruption, we theorize that the ion temperature profile is perturbed in essentially the same manner as the electron temperature profile. Previous experimental measurements [8] indicate that the ion temperature in Alcator is lower than the electron temperature by an amount which is related to the ion-electron thermal equilibration time. Therefore, prior to the disruption, the ion profile is assumed to be Gaussian but with a peak temperature 70 eV below the electron central temperature. During the disruption it is postulated that the ion profile flattens out to the same radius as the electron profile. Since the time scale for this process is so short (<20 usec), the electron-ion energy transfer can be neglected; therefore, energy conservation requires that the ion temperature drop be about the same as the electron drop, or approximately 130 eV for the discharge in Figure 1.[1] Given these temperature profiles, the change in the neutron production rate was calculated and was found to agree with that which is observed.

Additionally, the fitted electron temperature profiles were used to calculate the current density immediately before and after the internal

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[1]The neutron signal is averaged with a time constant of 0.5 msec, resulting in the apparent difference in the shape of the neutron and x-ray sawteeth.

disruption. The resulting current density profiles (which are quite flat in the central region due to inductive effects) were then used to determine safety factor profiles, q (r) (Figure 3). The results are in good agreement with theory.

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REFERENCES

[1] PETRASSO, R., SEGUIN, F.A, A Versatile High-Sensitivity X-Ray Imaging System for the Alcator Tokamak, American Science and Engineering, Inc., Report ASE-4107-1 (1977).

[2] VON GOELER, S., STODIAK, W., SAUTOFF, N., Physics Review Letters 33 (1974) 1201.

[3] JAHNS, G., SOLER, M., WADDELL, B., CALLEN, J., HICKS, H., Nuclear Fusion 18 (1978) 585.

[4] ARA, G., BASU, B., COPPI, B., LAVEL, G., ROSENBLUTH, M., WADDELL, B., Magnetic Reconnection and m=1 Oscillations in Current Carrying Plasmas, Massachusetts Institute of Technology, RLE Report PRR - 77/8 (1977).

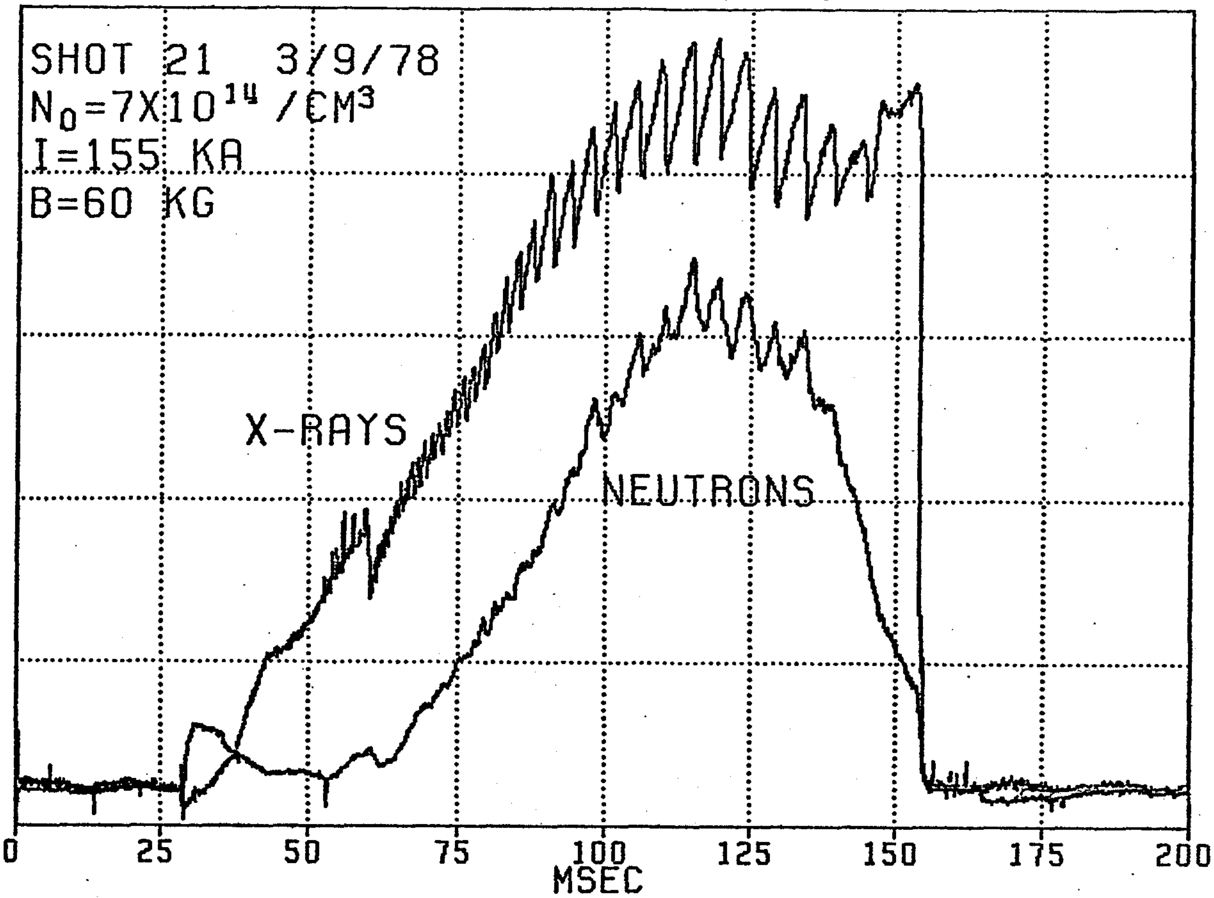
[5] APGAR, E., COPPI, B., GONDHALEKAR, A., HELAVA, H., KOMM, D., MARTIN, F., MONTGOMERY, B., PAPPAS, D., PARKER, R., OVERSKEI, D., in Plasma Physics and Controlled Nuclear Fusion Research (Proc. 6th Int. Conf. Berchtesgaden, 1976) 1, IAEA, Vienna (1977) 247.

[6] GRANETZ, R., Numerical Code for Calculating Soft X-ray Fluxes in Alcator, MIT Plasma Fusion Center Report TR-78-1 (1977).

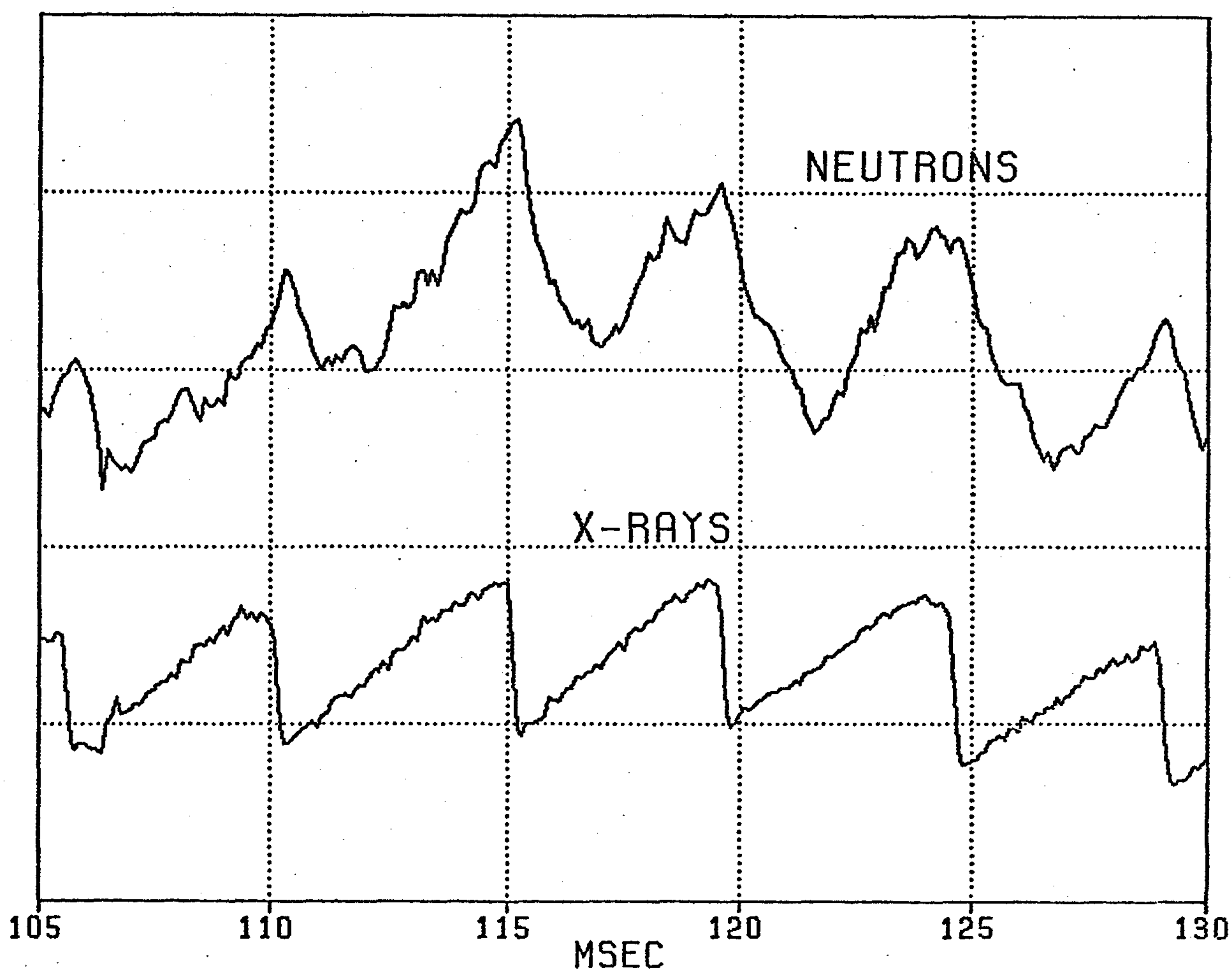
[7] GONDHALEKAR, A., Massachusetts Institute of Technology, private communication (1978).

[8] PAPPAS, D., PARKER, R., Thermonuclear Neutron Production in Alcator Deuterium Plasmas, MIT Plasma Fusion Center Report RR-78-5 (1977).

FIGURE 1



SHOT 21 3/9/78
$N_0 = 7X10^{14}$ /CM^3
I=155 KA
B=60 KG
X-RAYS
NEUTRONS
0
25
50
75
100
125
150
175
200
MSEC



NEUTRONS
X-RAYS
105
110
115
120
125
130
MSEC

FIGURE 2

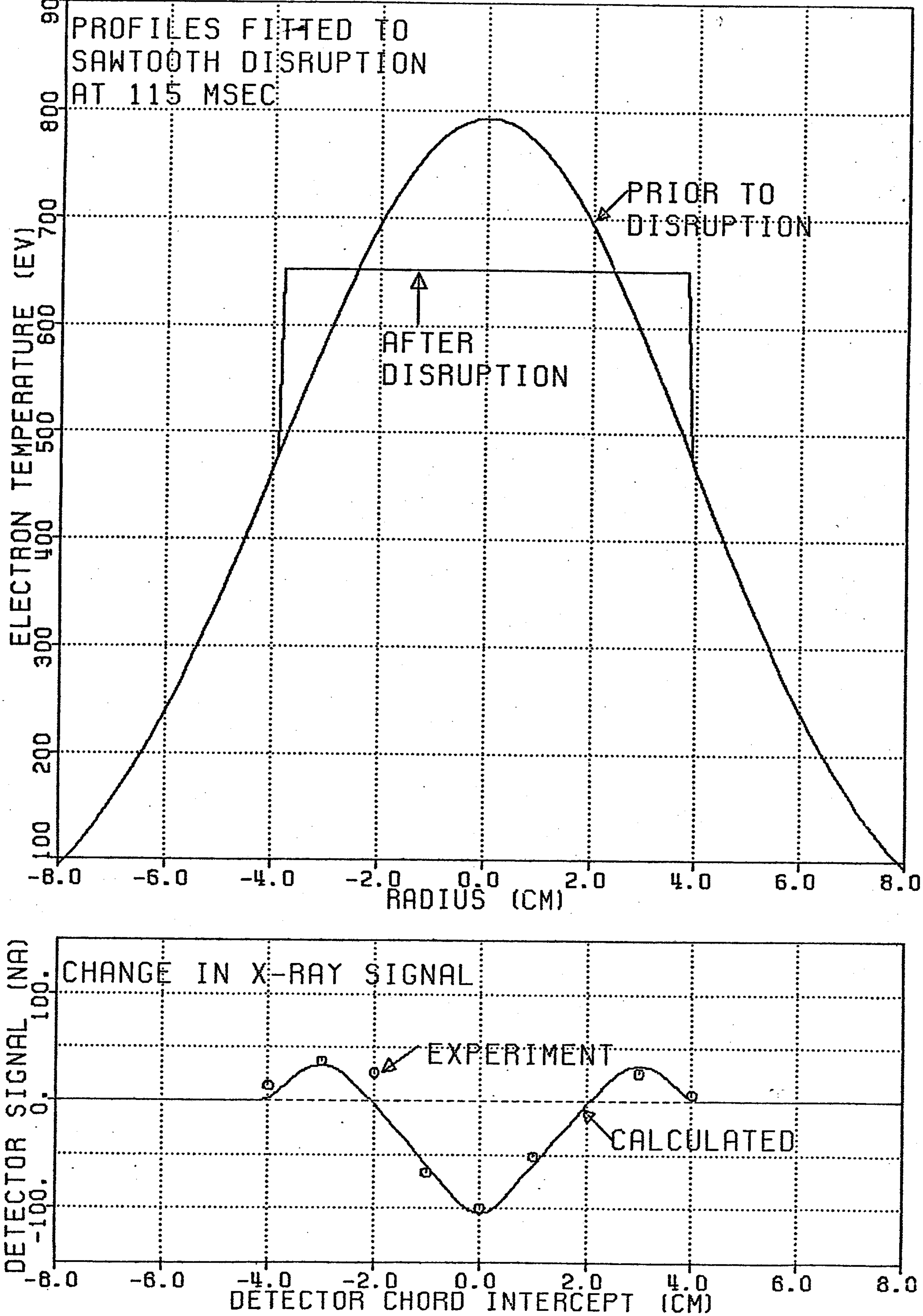
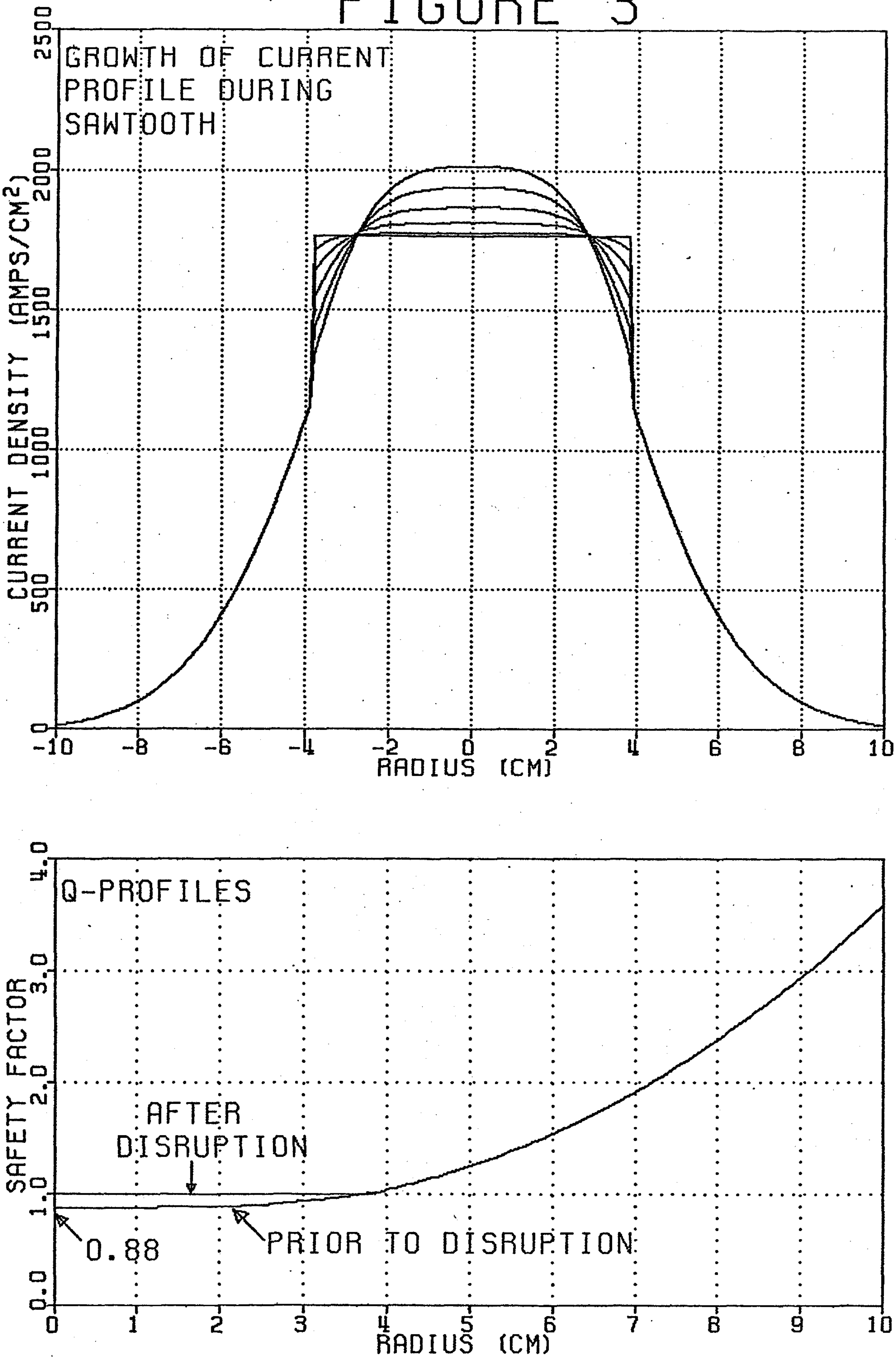

PROFILES FITTED TO
SAWTOOTH DISRUPTION
AT 115 MSEC
PRIOR TO
DISRUPTION
AFTER
DISRUPTION
ELECTRON TEMPERATURE (EV)
100
200
300
400
500
600
700
800
900
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
8.0
RADIUS (CM)
CHANGE IN X-RAY SIGNAL
EXPERIMENT
CALCULATED
DETECTOR SIGNAL (NA)
-100.
0.
100.
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
8.0
DETECTOR CHORD INTERCEPT (CM)

FIGURE 3



GROWTH OF CURRENT PROFILE DURING SAWTOOTH
CURRENT DENSITY (AMPS/CM²)
0
500
1000
1500
2000
2500
-10
-8
-6
-4
-2
0
2
4
6
8
10
RADIUS (CM)
Q-PROFILES
SAFETY FACTOR
0.0
1.0
2.0
3.0
4.0
AFTER DISRUPTION
PRIOR TO DISRUPTION
0.88
0
1
2
3
4
5
6
7
8
9
10
RADIUS (CM)