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DATE: May 13, 1977

TO: A.R. Smith, J. Somers, C.A. Kelsey, J.N. Bradbury, M.M. Kligerman

FROM: K.R. Hogstrom

SUBJECT: IN-VIVO DOSIME RY, EXP. 271

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I. Progress to Date

During cycles 12 and 13 of 1977 development of an off-line dosimetry system has progressed. The purpose of the experiment is to develop an in-vivo dosimetry system for pion therapy beams which can measure total, "high", "medium", and "low" LET dose. Measurements have been made using silicon diodes, LiF thermoluminescent dosimeters (TLD 100), and activation analysis (done in conjunction with J. Dicello, and M. Zaider). Results of these experiments will be presented with the exception of + activation data which is presently being analyzed by Dicello and Zaider. Results below indicate that it is now feasible to perform in-vivo dosimetry to approximately 10% accuracy down to a dose level of approximately 10 rads with total dose and high LET dose being delineated. It is recommended that proper equipment be purchased immediately if these dosimeter are to be used on patients.

II. Practical Considerations

Using present in-vivo methods, it is technologically feasible to determine total and high LET dose to approximately 10% or better. It is also practical to measure beam profiles for patients, i.e., under collimators and at field abuttments. But in order to do this properly a permanent system should be constructed which would replace the present system of borrowed equipment which is either inadequate or malfunctioning. Below is a list of needed equipment:

TLD

Harshaw Thermoluminescent Detector and Automatic Integrating Picoameter		5,000
(presently a unit is on loan from H Division which is partially broken)		
sub total		$5,000

Activation

* 2 Ortec 490 Amplifier and SCA	555 ea.	1,110
2 Ortec 121 Presmplifier (opt)	260 ea.	520

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1 6 V Nimbin and Power Supply	900
1 3" X 3" NaI crystal phototube integral assembly, well counter	965
1 1.5" X NaI 1.5" crystal phototube integral assembly, (no well)	225
1 HV power supply	600
* 2 Ortec 776 Counter & Timer 1,200 ea. (above item are presently borrowed from LEEP or MP-1)	2,400
Sub total	6,720

* Could get by with these two items until others arrived

Silicon Diode

No additional equipment required at present	0
TOTAL	$11,720

III. Results

A. Experiment #1, Activation:

The purpose of the first activation experiment was to find an activated nuclei which could be used as a high LET dosimeter. Such a nuclei must have the following properties:

1) Emit a gamma ray in an energy range capable of being efficiently detected in a NaI (TL) crystal;

2) Have a half-life long compared to patient irradiation time, so that precise time records need not be kept;

3) Have increased production in the peak which comes from direct capture or short ranged secondary interactions;

4) Have sufficient yield above background so that practical sized dosimeters are available.

The experiment was performed in a water phantom exposed to tune 23. There was no collimator or range shifter and the dose peak occurred at a depth of 18 cm in water which was located at the 100 QTD. Targets of Cu and Al, which were 7 cm dia discs, 4.47 gm/cm^2 and 4.05 gm/cm^2 respectively, were exposed at front plateau, mid-plateau, peak, and post peak. All targets were exposed to approximately the same number of monitor units corresponding to approximately 900 peak rads in 100 min.

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The activated material was then removed from the beam and counted in 4 consecutive 1000 sec intervals. Copper spectra, shown in figure I have not been extensively analyzed as closely spaced gamma peaks does not make NaI a good detector for optimal peak separation. On the other hand the Aluminum had a fewer number of peaks including one ideal one. In figure 2 there is a plot of the gamma spectra at each of the four locations. The peaks are identified as:

.511 MeV - ^{18}F - $T_{\frac{1}{2}}$ = 109.8 min

.84,1.013 MeV - ^{27}Mg - $T_{\frac{1}{2}}$ = 9.5 min

1.369 MeV - ^{24}Na - $T_{\frac{1}{2}}$ = 14.96 hr

1.78 MeV - ^{28}Al - $T_{\frac{1}{2}}$ = 2.3 min

Quite often the 1.78 MeV peak had decayed away by the time counting had begun. The 1.369 MeV peak satisfies conditions 1) and 4) above. Obviously ^{24}Na production is enhanced by approximately a factor of 10 in the peak region. Additional irradiations with thicker targets in the peak confirm that condition 3) is fulfilled.

Subsequently 1 cm dia X .6cm thick Al cyclinders were fabricated as dosimeters. Additional studies show that these .5cc dosimeter could be made smaller, perhaps .2cc and still give approximately 10% accuracy for a dose level approximately 10 rads.

Due to background considerations and a strong ^{28}Al production under cerrobend collimation, it was not practical to use the 1.369 MeV ^{24}Na gamma. Fortunately ^{24}Na emits a 2.754 MeV coincidence gamma in 100% of its decays, so this gamma is used for in-vivo activation dosimetry.

B. Experiment # 2, Dosimeter response to Central Axis Depth One:

The purpose of this experiment was to measure the response of silicon diodes, TLD 100, and Al pellets as a function of depth for a typical patient setup. Irradations were performed using tune 23, RS=BEAM 8K (flat stopping distribution) and an 11 X 9 X 3.5 elliptical collimator with a water depth of 15 cm beneath the collimator at the 100 QTD.

25 newly purchased Si diodes were irradiated to 75, 150, 250, and 350 peak rads along central axis at front and mid-plateau and front, center, and rear peak. The diode response follows the relation $D=K \ln (V_f/V_i)$, a typical plot at mid-plateau as seen in figure 3. The constant changes with depth indicating a change in response with beam quality (see table below). These numbers are not yet suitable for patient usage as a readout of diode voltage vs. time, plotted in figure 4, indicates a problem which is probably due to readout temperature varying and diode fading. An attempt to understand these effects is presently underway.

Diode Response vs Depth

depth	K
3	5600
6	5000
9	5100
12	4450
15	5200

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TLD 100 were irradiated to 100, 200, and 400 peak rads, and then using ^{60}Co TLD 100 standards, the individual reading were converted into ^{60}Co rads. TLD 100 response varied linearly with exposure at each position along central axis. A plot of ^{60}Co rads vs dose given, as measured by an ionization chamber is plotted in figure 5. We see that the TLD 100 response/pion rad is generally greater than that for ^{60}Co, and varies with depth.

Cylindrical Aluminum dosimeters 1.0 cm DIA X .6 cm thick were exposed to a peak dose of 200 rads, and the ^{24}Na activation was measured immediately following irradation by counting the 2.75 MeV photopeak in NaI (Tl). As expected the response was directly related to the stopping distribution. In figure 6 a comparison of the data with Chaim Richman measurements show excellent agreement for the stopping distribution which is directly related to High LET dose. These results show that the methods is not only good for in-vivo dosimetry, but also for measuring stopping distribution for different range shifted beams.

Total dose can only be calculated by a weighted sum of TLD 100 and Al activation response. In figure 7 a weighted sum of the two dosimeters has been made conserving total dose; hence a one parameter fit agrees with total dose to about 10% or better, when total dose is measured using a .1cc EGG TE ionization chamber. A comparison also of high LET dose with that calculated by PIPLAN are in good agreement.

C. Experiment # 3, Dosimeter response accross the beam:

In order to have a useful in-vivo system, the response of the dosimeters must be constant in the plane perpendicular to the incident pion beam. A comparison of TLD 100, silicon diodes, and activation response for a Y profile at mid peak for the setup described above shows excellent agreement with ion chamber readings. These results are plotted in figure 8.

V. Future Experiments

In order to understand the limitations of these dosimeters, future work should include measurements for the unrange-shifted beam, and various shapes or sizes of the range shifted beams. It would also be interesting to look at π^+ response to try and separate out star response.

Calibrated systems are required for patient use. The TLD 100 is already calibrated as well as possible with the current TLD reader. The activation system has not been completely calibrated. Although this is not a difficult task, permanent electronic installation whould be required in order to accurately set windows and count background.

The silicon diode system cannot be accurately calibrated until temperature and fading effects are made quantitative. No additional equipment will be required for this task.

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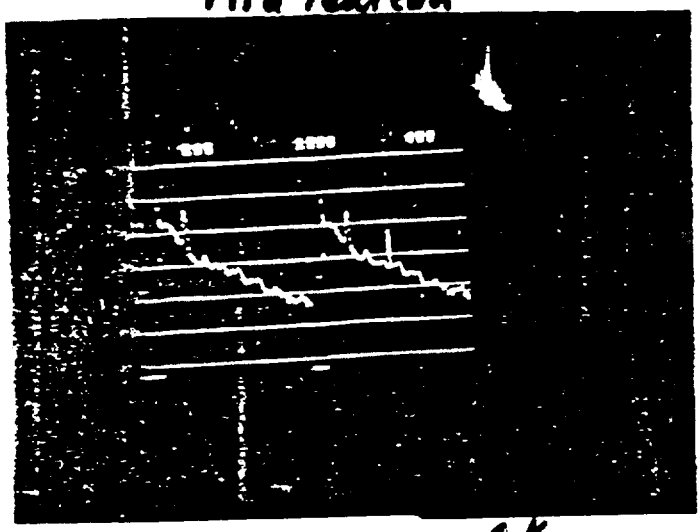
Figure —
Cu Results.

Mid Plateau



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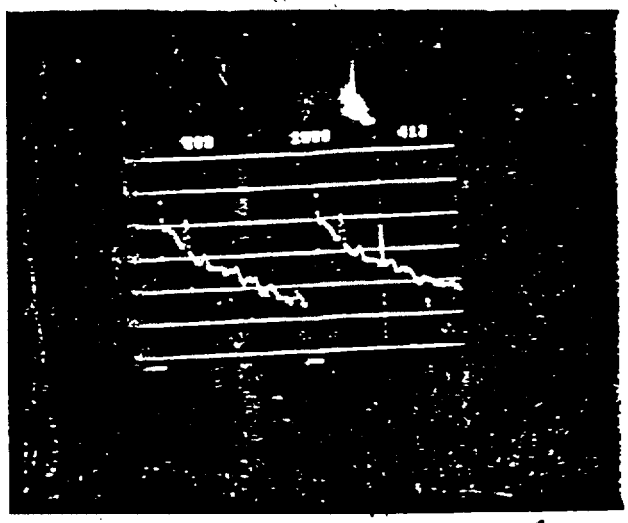

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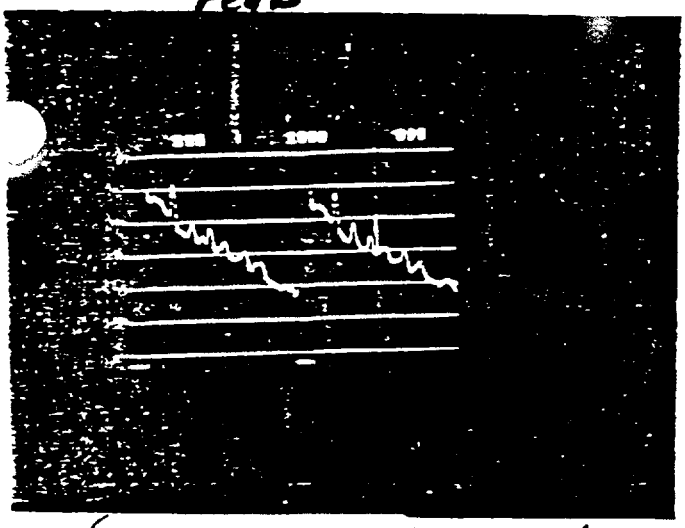
Peak



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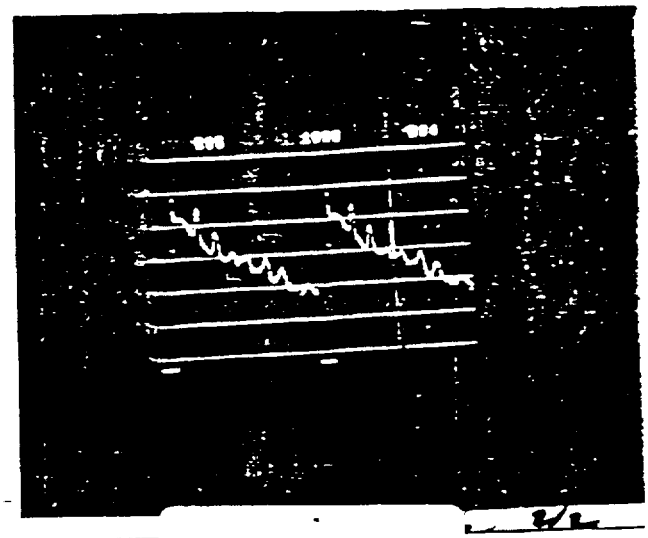

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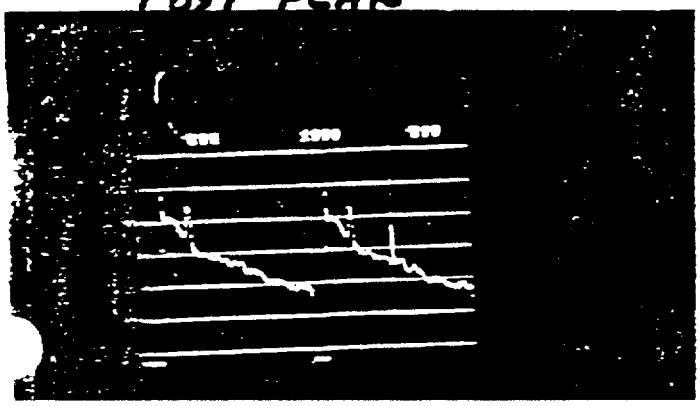
POST PEAK



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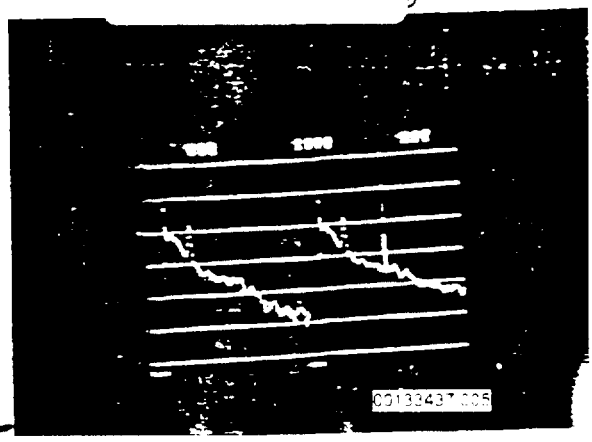

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FIGURE 2

Front Plateau

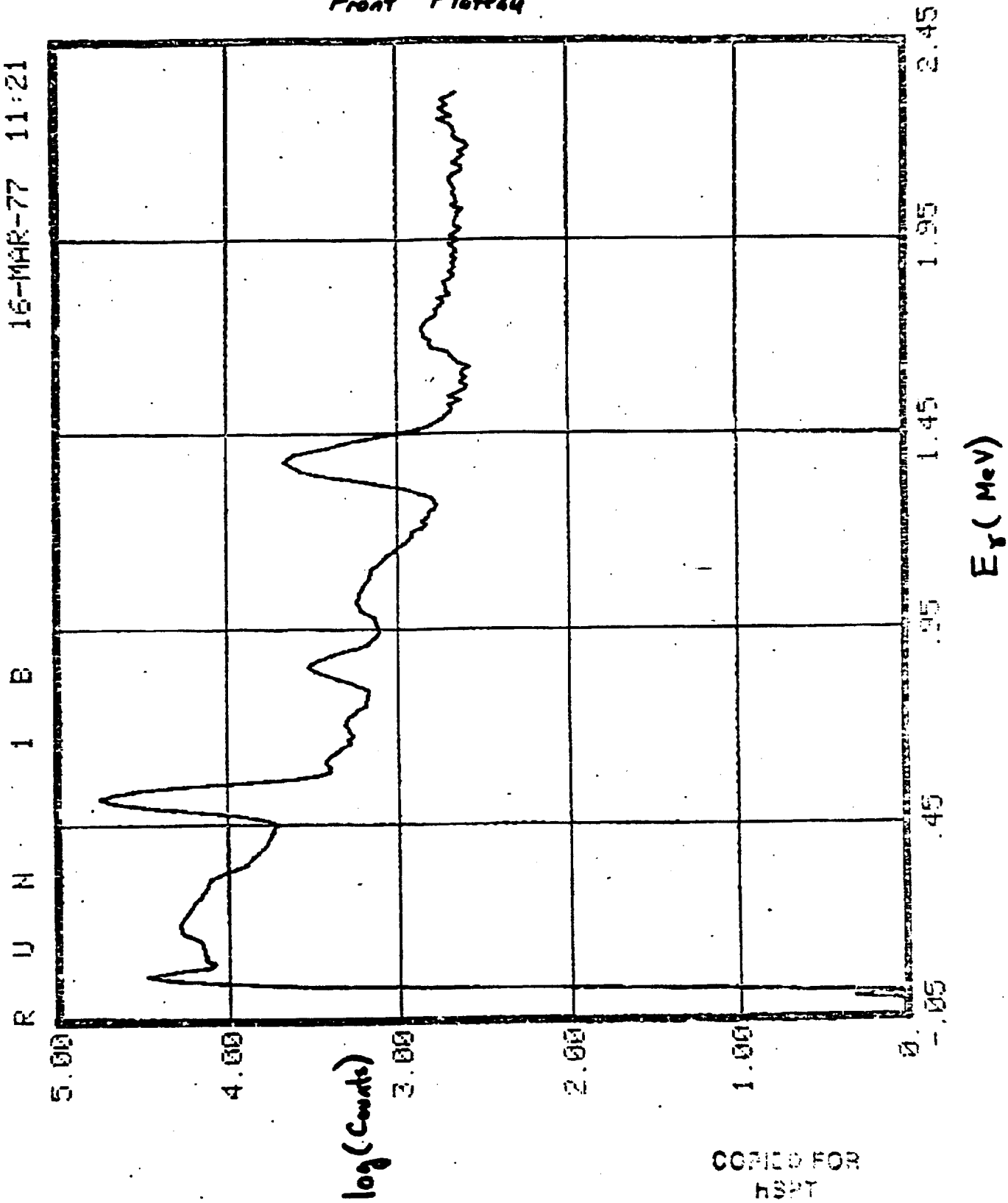

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Figure 2

Mid Plateau

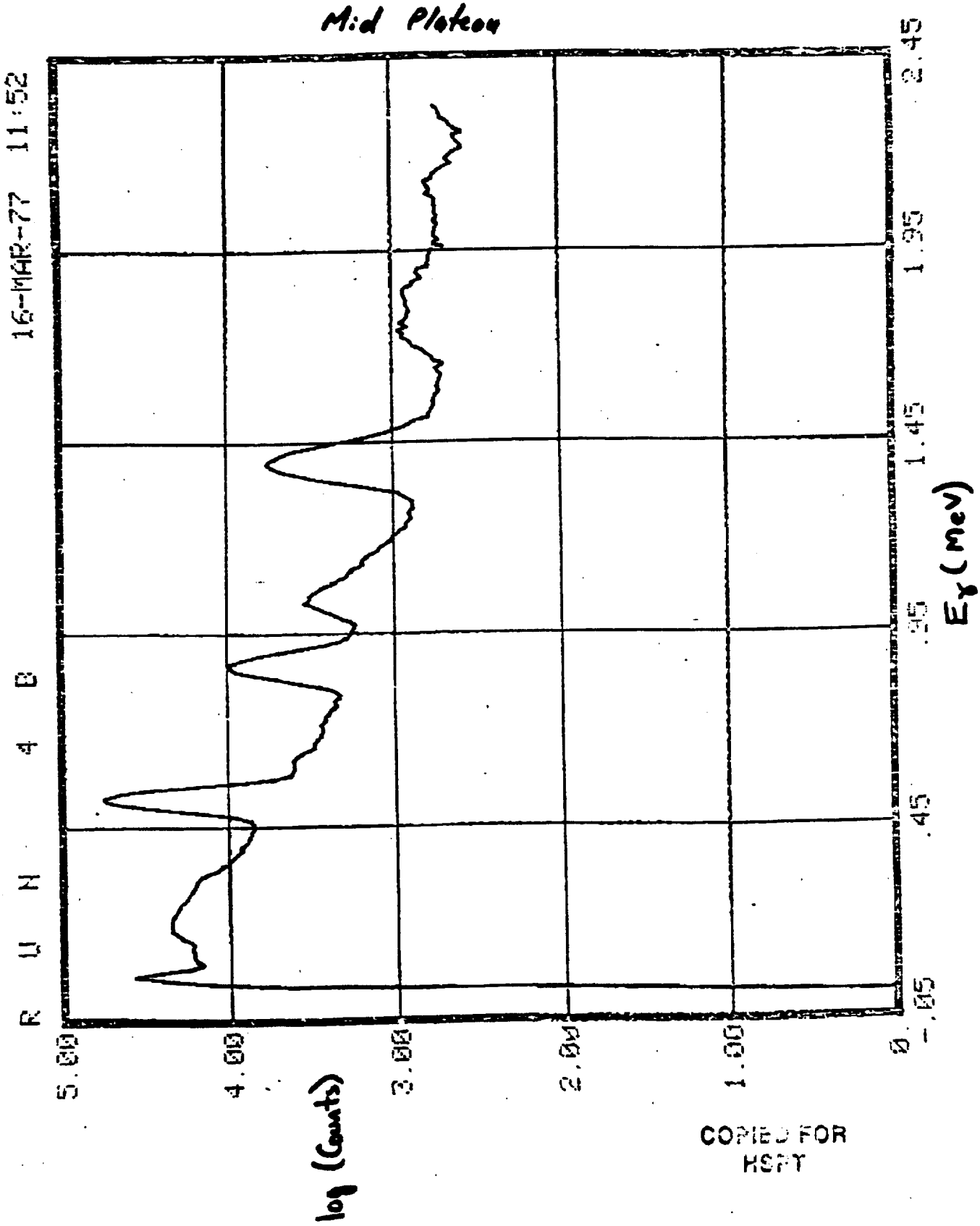

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Figure 2

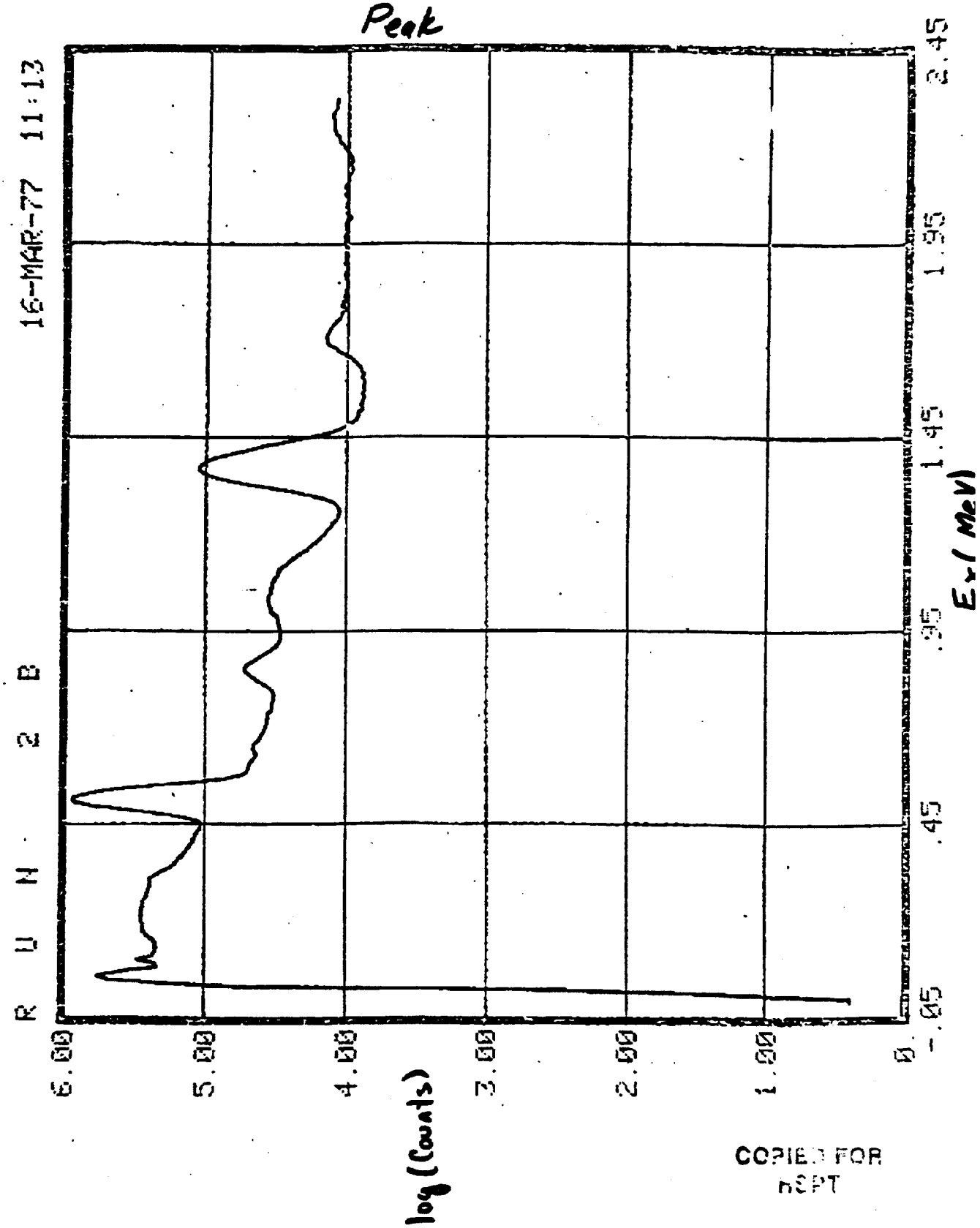

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Figure 2

Post Peak

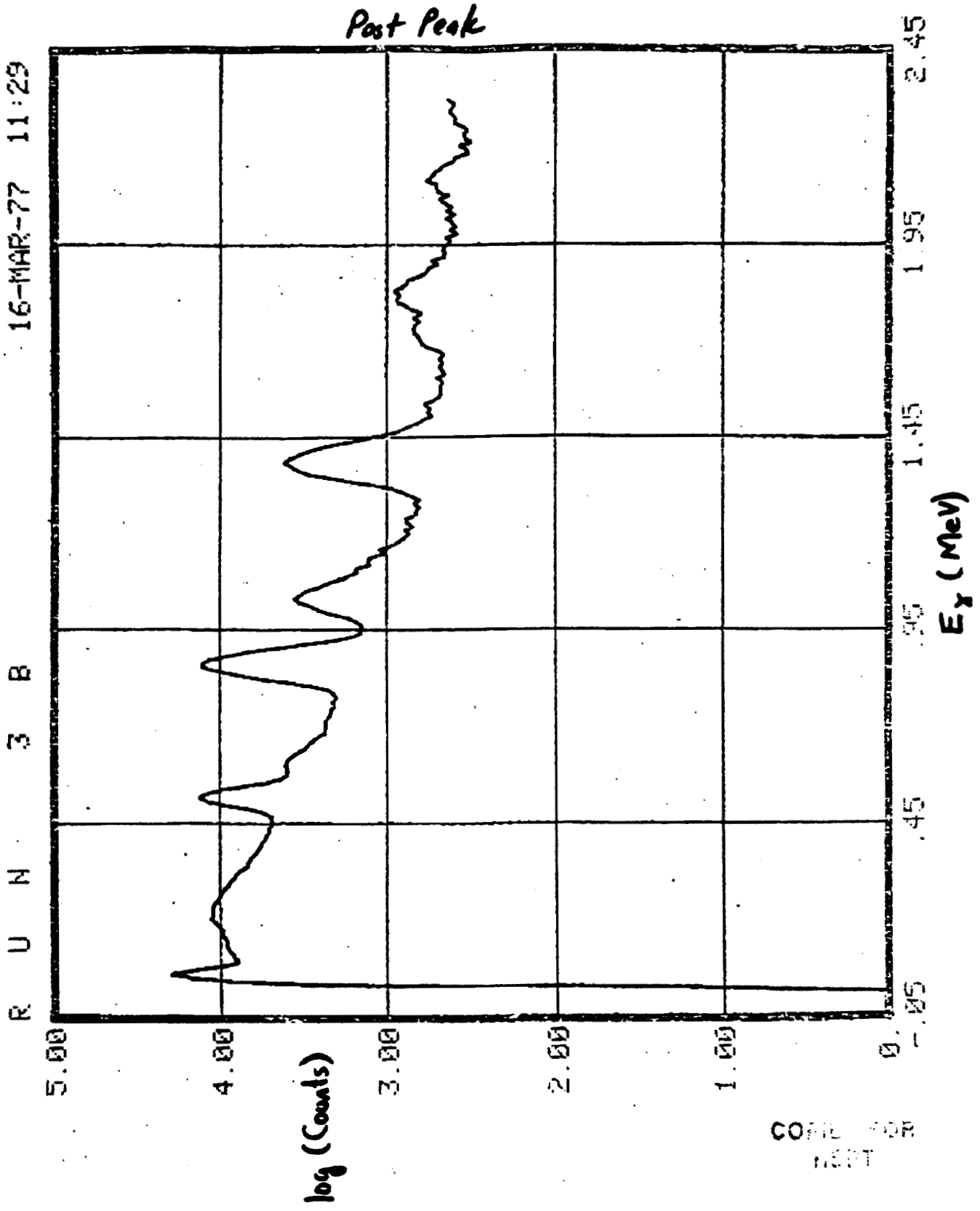

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FIGURE 3

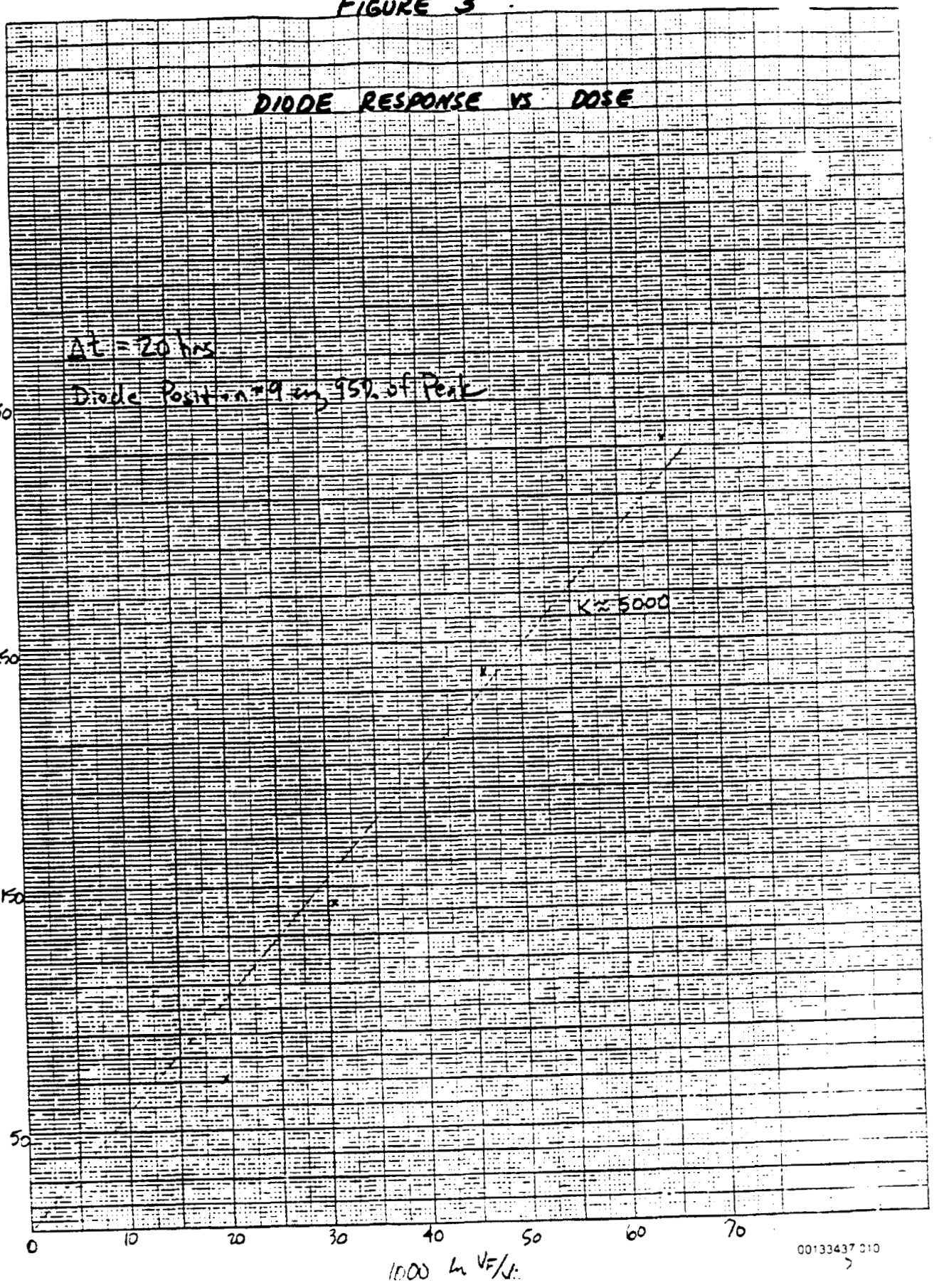

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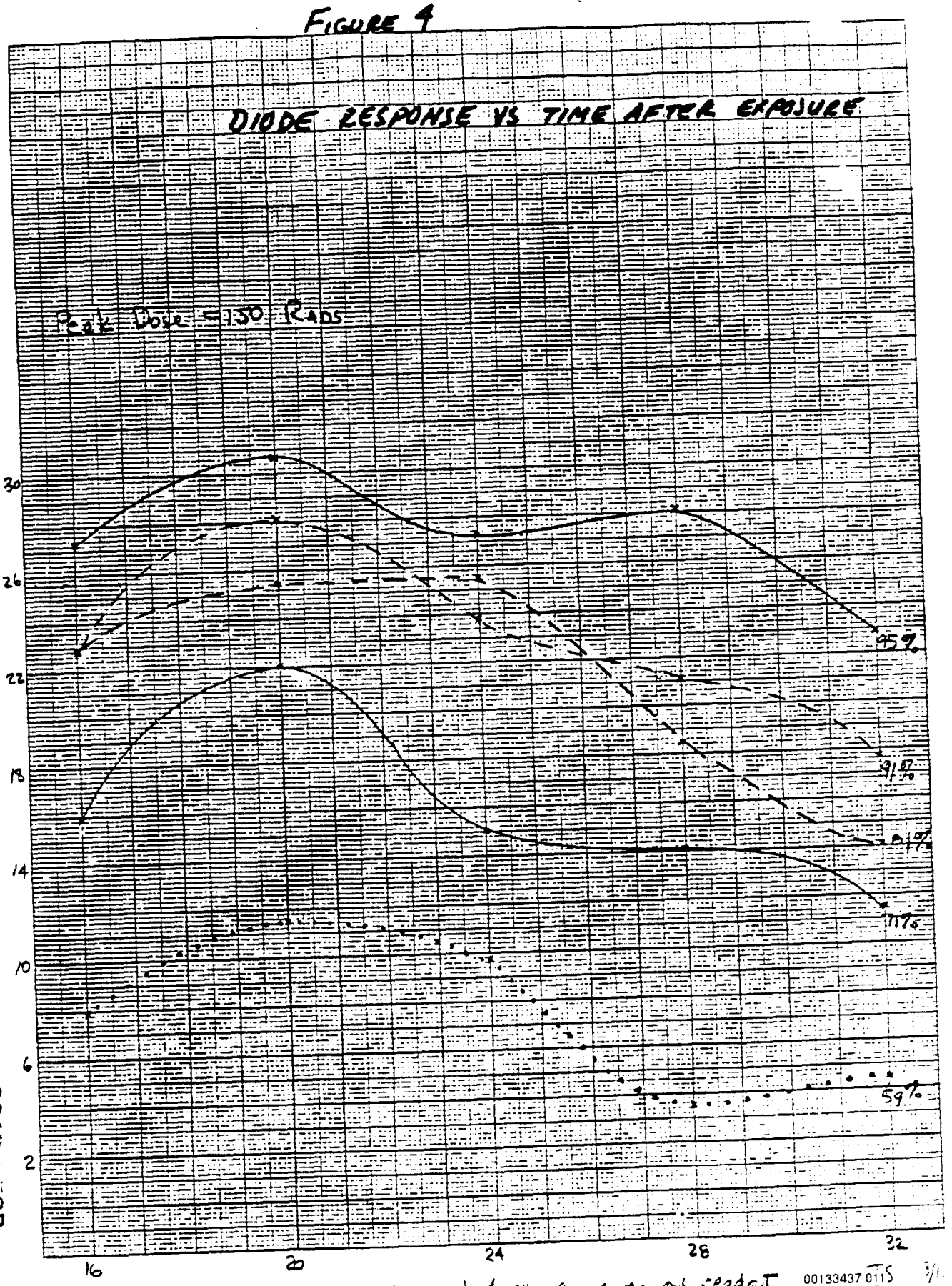
FIGURE 4



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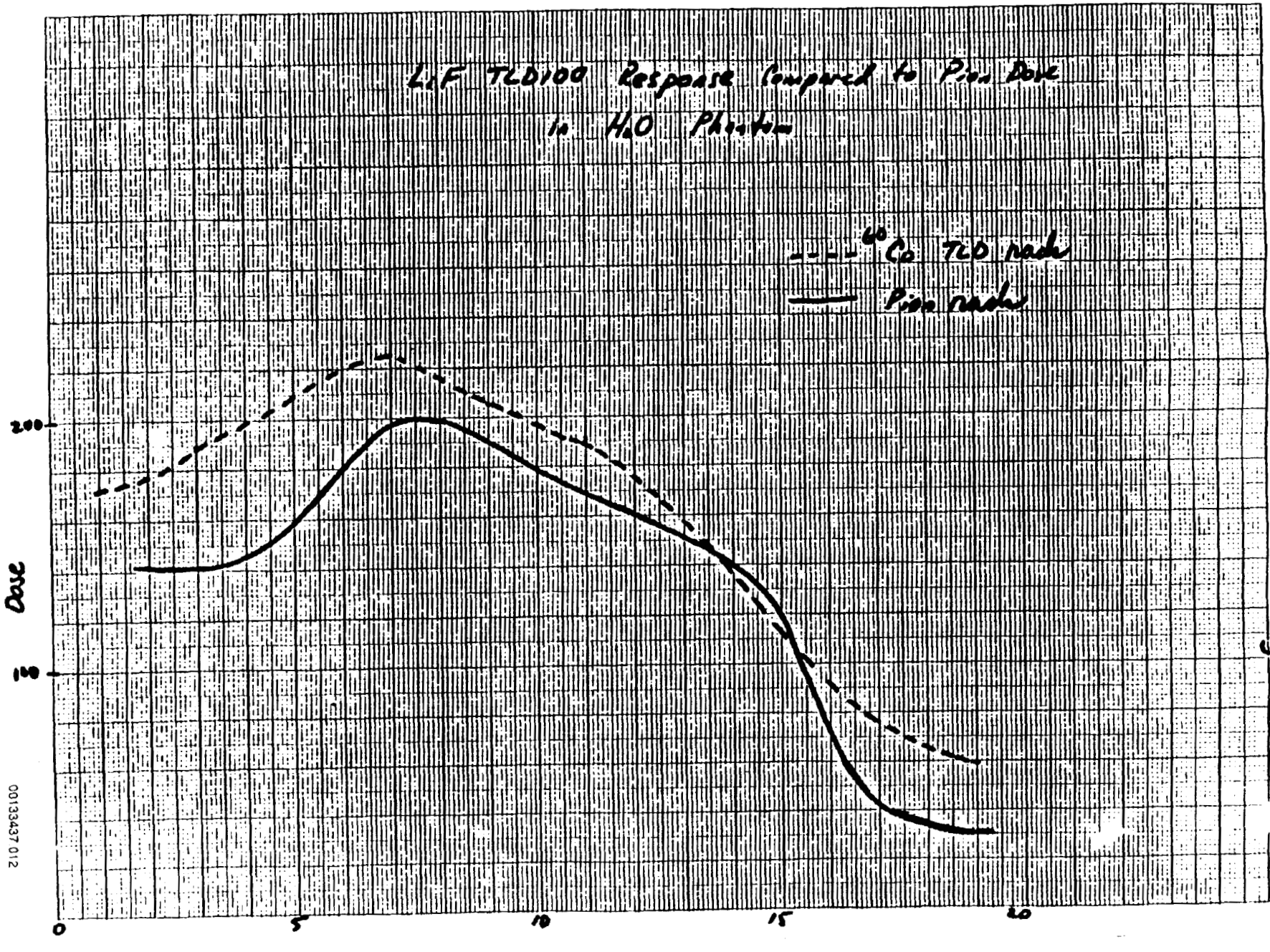

Figure 5

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Figure 6

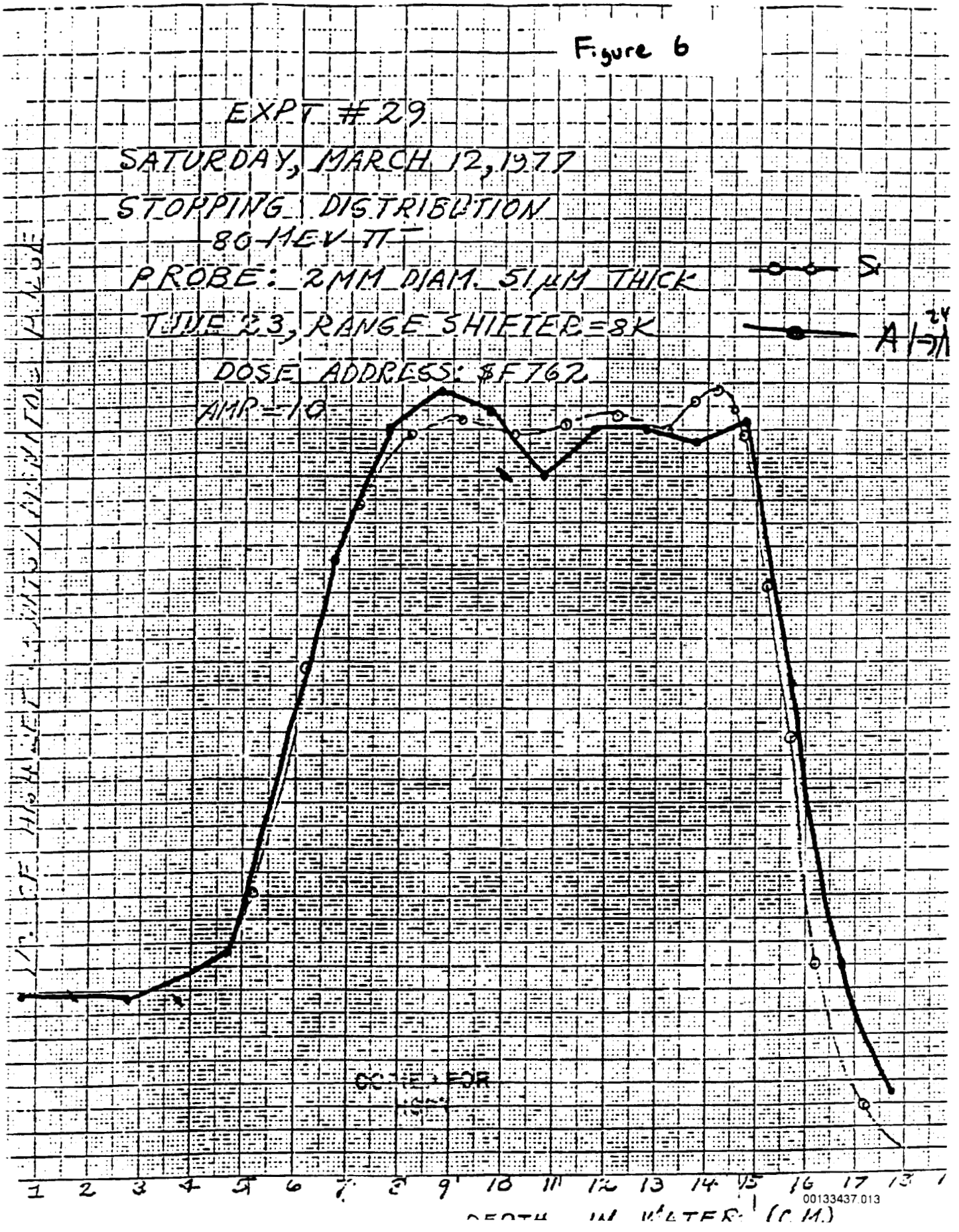

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Figure 7

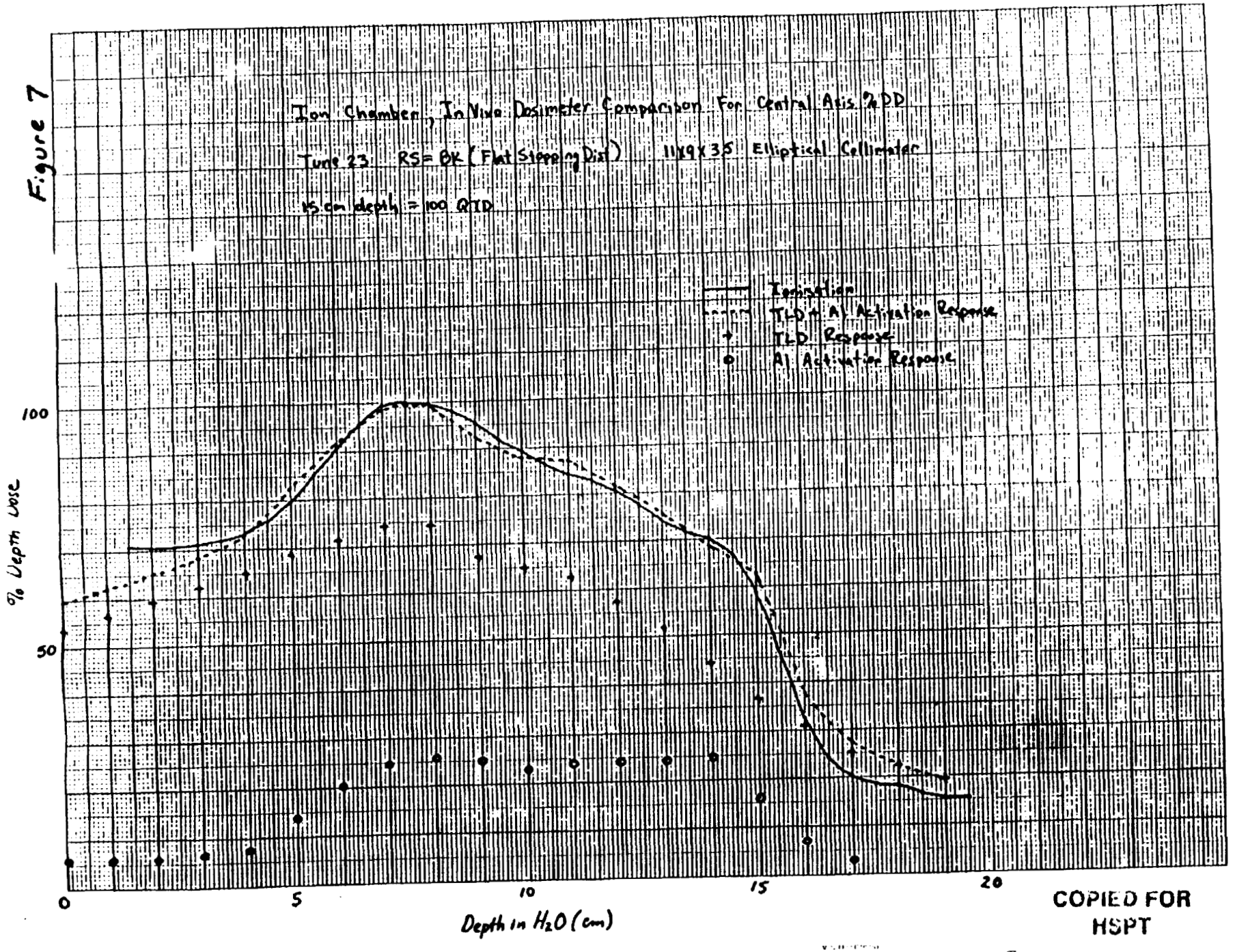

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Figure 8A: Silicon Diode Beam Profiles

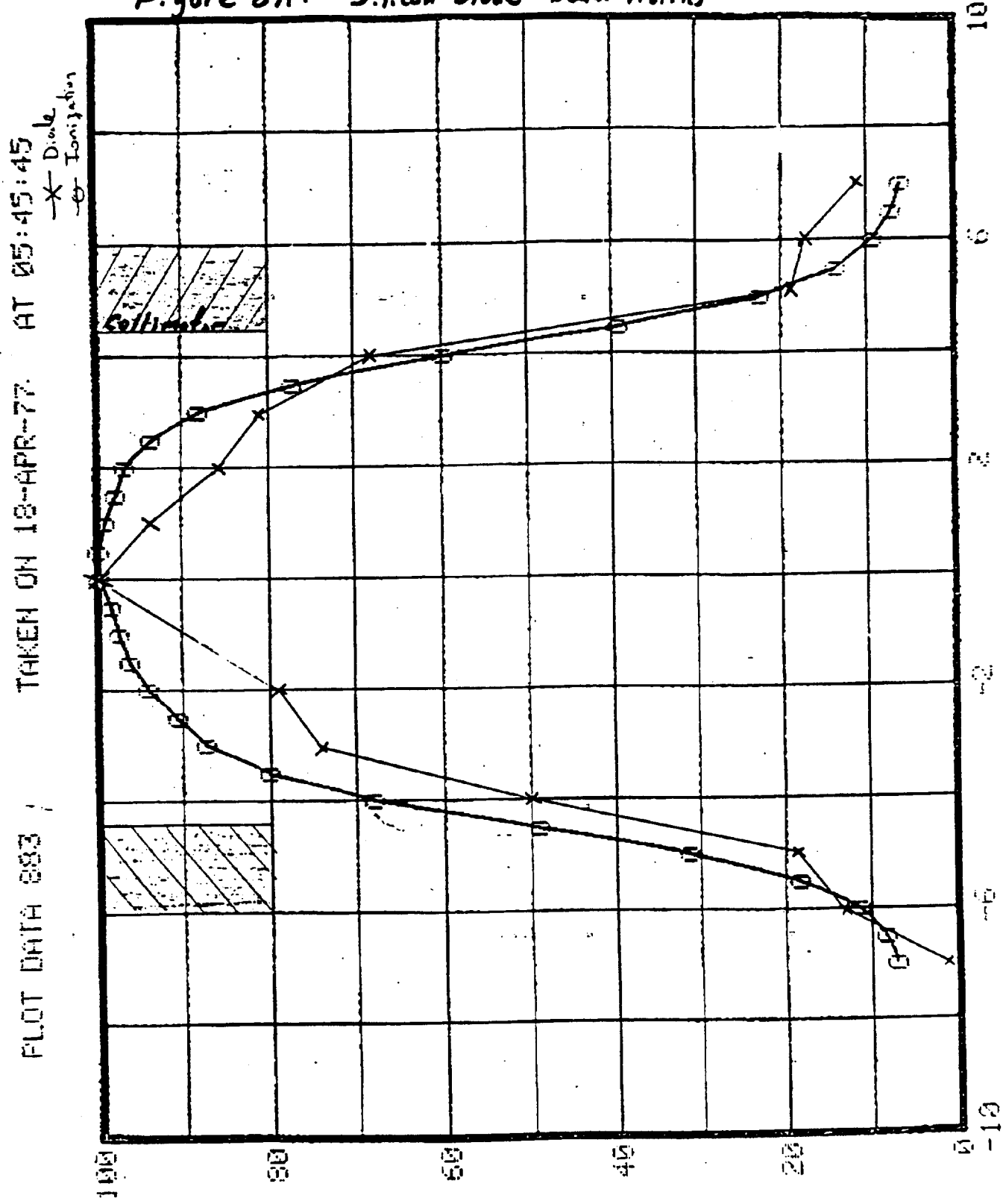

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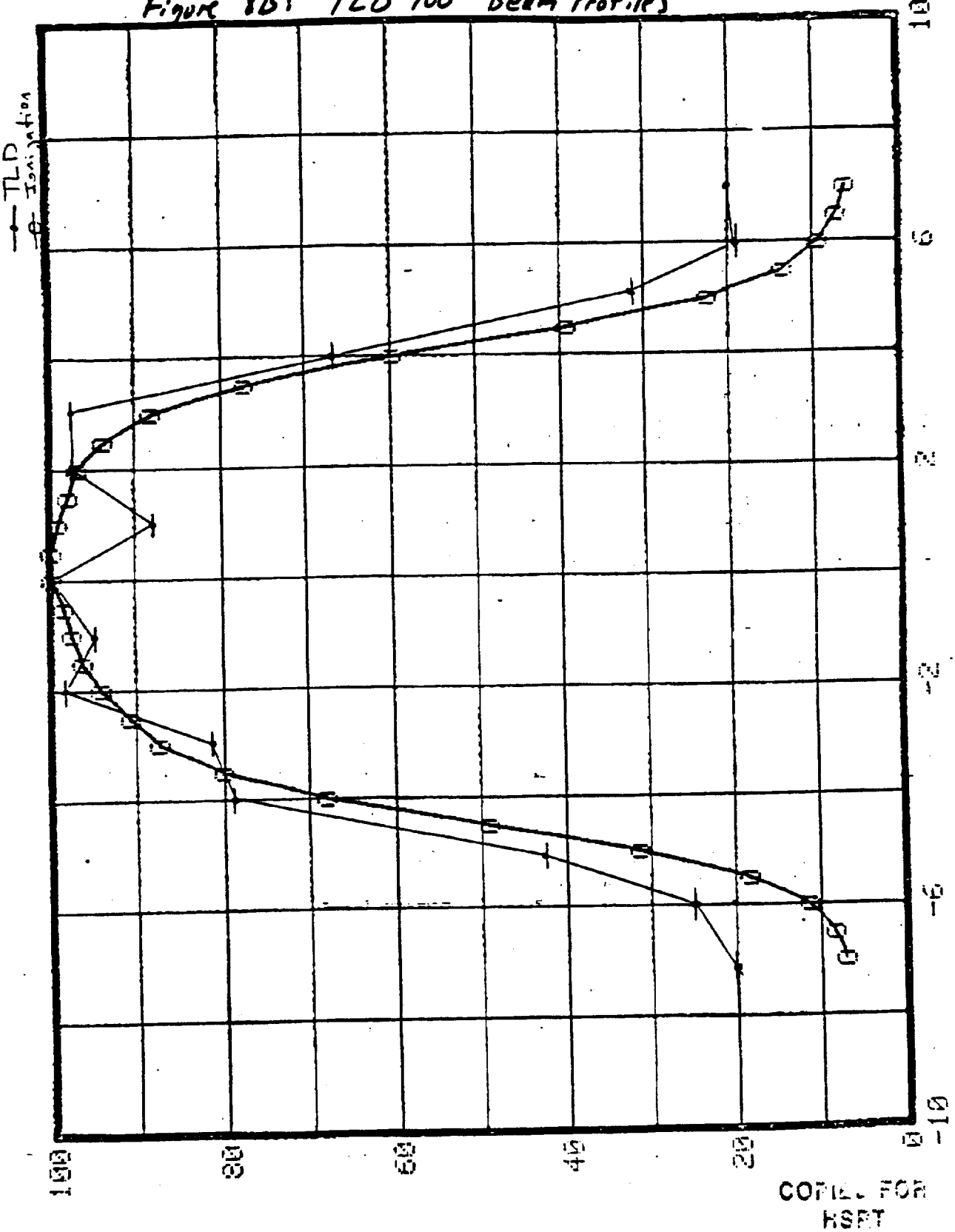
Figure 8B: TLD 100 Beam Profiles



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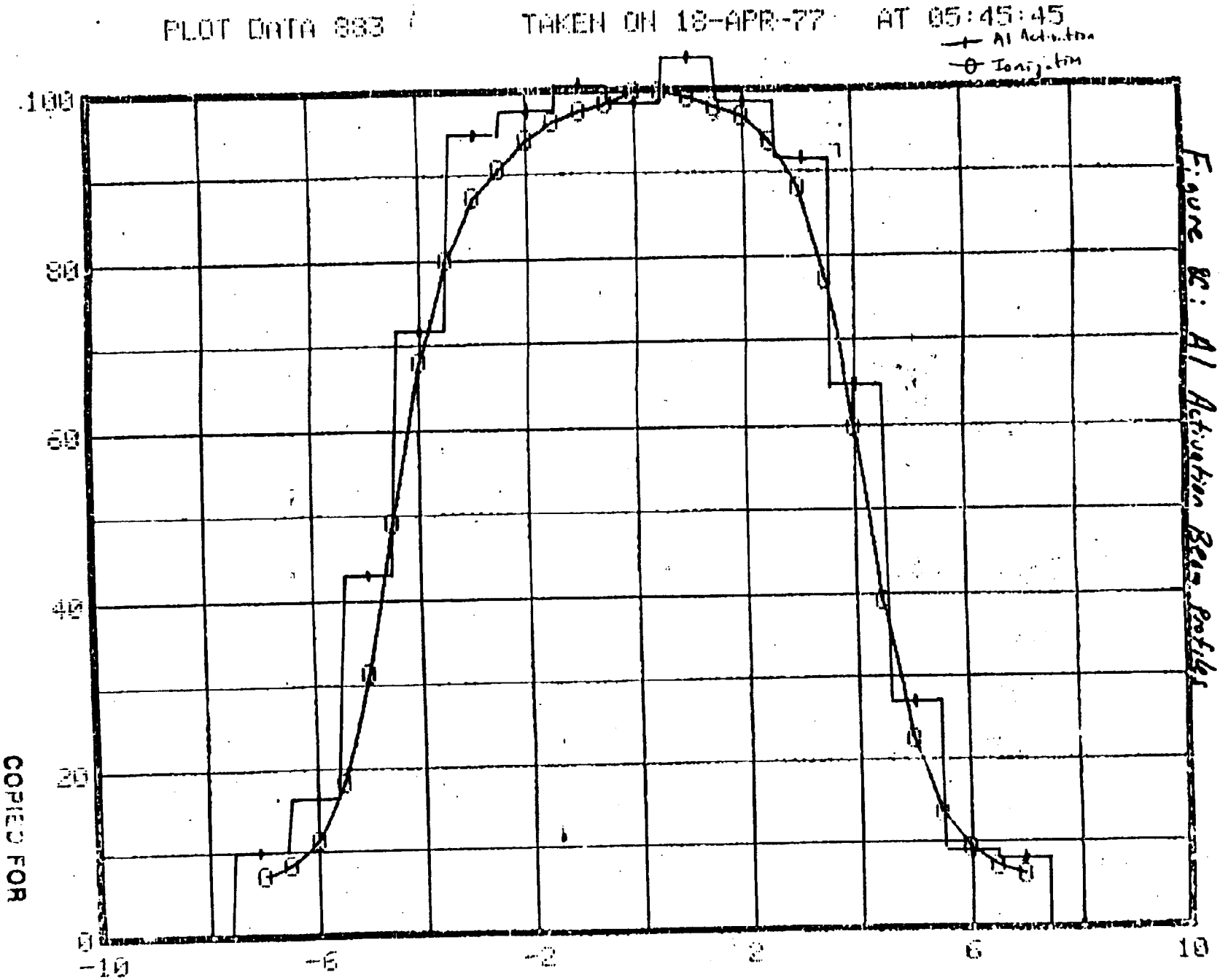

Figure 8c: Al Activation Beam Profile

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