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To: DYNAMIC PATIENT TREATMENT TASK FORCE

From: KEN HOGSTROM

Subject: EVALUATION OF DYNAMIC PATIENT TREATMENTS BASED ON WATER PHANTOM DOSIMETRIC MEASUREMENTS

I. Introduction

Dosimetric measurements in a water phantom have been made on the currently best available dynamic pion beams (i.e., the fan tune, Mike's run 466, and the spot tune, Mike's run 467). Data will be shown characterizing each beam. The data is then analyzed by comparing for the static (tunes 23 and 52), fan, and spot beams, those qualities which influence treatment planning, namely beam flatness, beam edges, dose rates, beam shaping, LET distributions, and ease of treatment planning. Results indicate that fan and spot beams can deliver superior (in terms of dose distributions) treatments than the static beams, although neither beam is superior in all qualities to the other. For this reason I feel that both dynamic treatment modes should be developed as in some cases the fan tune would give superior treatments while in others the spot tune would.

As we are slowly progressing toward dynamic treatments we must emphasize the need for complete three dimensional LET characterization of each beam tune, accurate three dimensional calculation of isodose distributions, meaningful biological criteria for the effect of LET variation, and improved methods of daily localization and treatment verification. Although it can be demonstrated that superior physical dose distributions can be accomplished through dynamic treatments, the effects of the above could be just as important in administering the superior treatment to the individual patient and hence deciding on the best mode of treatment.

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For purposes of clarity five modes of treatment will be defined:

1) static - collimation of fixed broad beam with a single range shifter function per port.

2) fan with static collimation - a dynamic one-dimensional scanning fan beam with static collimation and a range shifter function which may vary with position in the scanning dimension.

3) spot with static collimation - a dynamic two-dimensional scanning spot beam with static collimation and and a range shifter function which may vary with with position in the two scanning dimensions.

4) fan with dynamic collimation - same as 2) except that dynamic collimation may be correllated with range shifter motion.

5) spot with dynamic collimation - same as 4) except that dynamic collimation may be correllated with range shifter motion.

Each mode refers to the method of delivering dose to a single port and the superposition of multiple ports would define treatment planning. This report will discuss only modes 1)-3), as no dosimetry presently exists for 4) and 5).

II. Results

A. Fan Tune Data (Mike's Run 466)

The present tune has a beam penetration of approximately 14.75cm in water and could treat field sizes up to approximate 12cm wide in one transverse dimension by any length in the scanning dimensions. This would be one of eight beam tunes (12 required for static beams) required

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to treat most any tumor; 4 penetrations, each with a 12cm and 20cm width fan. The depth dose curve for the tune is seen in figure 1. Due to convergence in the Y plane the peak to plateau ratio is greater than the static beam. However, this is of no consequence as once the pions are spread laterally and range shifted, the peak to plateau ratio depends only on the range shifter stroke and is relatively independent of beam tune (convergence, momentum, or momentum spread).

The convergence of the fan is seen in figure 2, a plot of decrement lines in the YZ plane. The profile width (FWHM) is approximately 3.6 cm while the 80%-20% falloff is approximately 1.9 cm. To some extent the smallness of the former is important to the ability of beam shaping. The latter makes the fan tune appear to not need collimation in the Y dimension however later results will show this to be not necessarily true.

The divergence of the fan in the XZ plane is not so apparent. The beam is broad in X and must be collimated similar to the static beams. It is therefore important to have a relatively uniform and symmetrical beam in X. Mike Paciotti's measurements indicate this criteria is met, in fact so well that fields up to approximately 15 cm in the X dimensions could be treated within the 80% level. Dosimetric measurements do not agree with these results as seen in figures 3A -D , which show a skewed component in the beam.

This disagreement will be resolved early in the next treatment cycle. If the dosimetric results hold true, then some fine tuning of the fan tune will be required prior to its use with patients.

The peak dose rate of the fan tune is 32 rads/min. This is an insignificant number in estimating dose rates, the important

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number being the flux rate which is approximately 1.11 MU/uA-sec. This more accurately represents the number of pions available for treatment. The fact that this rate is some 18 % less than tunes 23 and 52, means that one loses that amount in treatment dose rates irregardless of collimation, range shifting, and other treatment conditions.

B. Spot Tune Data (Mike's Run 467)

The present tune has a beam penetration of approximately 14.5cm in water, the depth dose curve being plotted in figure 4. Again the peak to plateau has no consequence to treatment planning. This tune would be one of four beam tunes required to treat most any tumor.

The peak dose rate is 76 rads/min, but again the more significant quantity, flux rate, is only .91 MU/uA-sec. This is approximately 33 % less than tunes 23 and 52.

The transverse extent of the spot is quite large. In figures 5A, 5B an XY scan at depths in water of 2 cm and 12 cm show the radial FWHM to be approximately. 6.3cm. This large size is a disadvantage in the shaping of the beam as it limits the available resolution.

The 80%-20% falloff of the spot is approximately 2.9 cm. This becomes greater upon superimposing spot tunes so that collimation is indeed necessary. The ability to collimate the spot tune is demonstrated in figures 6A, 6B where the collimated profiles in the X and Y dimensions are compared to the uncollimated profiles note the change in 80%-20% falloff from 2.5 cm to 2.2 cm for X and 3.6 cm to 2.4 cm for Y.

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C. Evaluation of Treatment Modes with Relation to Beam Flatness, Edges, and Dose Rates

One proposed advantage of dynamic beams over static beams is their ability to produce uniform dose distributions in the scanning direction. This is true of one dimension (Y) for the fan tune and two dimensions (X,Y) for the spot tune. A measure of transverse beam uniformity is defined as the 95%-80% falloff. This quantity is compared for tune 23, tune 52, spot tune, and fan tune in figures 7A-7D, being 1.8cm, 1.6cm, 1.4cm, and .8cm respectively. Each plot is either an XZ or YZ scan with a 6cm flat range shifter function and a transverse width of approximately 8-10cm. The dynamic beams, spaced 2cm apart, are both superior to the static tunes. The broad static beam tune 52 is better than the narrow static tune 23, whereas the fan tune being narrower than the spot tune produces a more uniform beam in its scanning dimension. Of course in the non-scanning dimension of the fan beam, uniformity can be expected to be similar to the static beams, whereas both transverse dimensions of the spot beam should be comparable.

Figure 8 shows an XY plot of the superposition of 36 spot tunes inside a 10cmx10cm area. Note the complexity of the weighting as indicated in the figure at the location of each spot tune. The degree of uniformity could possibly be improved, however this data represents approximately twenty iterations (3-4 hrs work). Of course once one begins varying the range shifter function, these weighting factors will undoubtedly vary. The point is that due to the size of spot tune, each spot influences the dose over a very large neighborhood so that treatment planning becomes very difficult and might be compared to the problem of trying to develop a three dimensional range shifter function. This implies that treatment planning a single spot

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beam dynamic port could be three orders of magnitude more difficult than present treatment planning.

Another consideration among the three modes is beam edges. It is certainly clear from figures 7C, 7D, and 8 that the 80%-20% edges of uncollimated dynamic beams are inferior to the collimated edges of the static beams. This implies that all dynamic beams will need to be collimated and that no improvement in beam edges should be expected from dynamic beams.

Originally it was speculated that dynamic beam treatment modes would give increased dose rates. This was based on the belief that little beam would be lost due to collimation in the scanning dimension(s). The speculation was fallacious. First, there is a transmission loss of pions through the channel as shown earlier by the decreased MU/μA-sec of the dynamic beams. Second, the size of the spot tune produces poor edges which means that a significant fraction of the beam is still thrown away with collimation. Of course the collimation of the fan beam in the non-scanning direction throws away just as much beam in that dimension as the static beams. A comparison of dose rates for approximately identical treatments in figures 7A-7D, with the other dimension assumed to be 10cm, yields dose rates at 300 μA (main proton current) of approximately 9.0 r/min for tune 23, 5.8 r/min for tune 52, 7.0 r/min for the fan tune, and 8.0 r/min for the spot tune. The dynamic beams do not produce any significant changes in dose rate. However one must consider dose rate and uniformity simultaneously. The dynamic beams have dose rates comparable with tune 23, but significantly better uniformity. On the other hand, tune 52 has uniformity comparable to the dynamic tunes but a smaller dose rate.

Therefore it is concluded that dynamic beams are superior to static beams for the "uniformity-dose rate tradeoff" criteria. It is also concluded that the fan tune gives excellent uniformity in the scanning dimension with fair uniformity in the non scanning dimension; whereas the spot tune gives good uniformity in both transverse dimensions.

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D. Beam Shaping

Perhaps the most significant advantage of dynamic scans over the static is their ability to correlate the range shifter with their scanning dimension(s). Consider a tumor which is 8-10cm long (e.g., 8-10 CT slices) and whose thickness in the direction of the beam varies from 2-10cm over that length. For static beam treatments a single 10cm range shifter function would be required resulting in a significant over doseage to normal tissue at places where the tumor thickness is less than 10cm. In figures 9A, B, the dose distributions obtained from fan beams and spot beams for such a tumor are plotted. In both bases the 80% line does not completely encompass the treatment volume. This is due partly to improper weighting (the same weightings were used as in figures 7D, C) , but the improvement over the "box" distribution of static beams as depicted in figures 7A, 7B are clear. The spot tune results are inferior to those of the fan tune because of the large size of the spot. The spot tune cannot be shaped as accurately as the fan tune along its scanning dimensions; however, the fan tune cannot be shaped in the other transverse dimension as the spot tune can.

Another important point is the gain in dose rate. An approximately 10-15% increase in dose rate over the dose rate for treating with a single 10cm constant range shifter function can be expected. This would be a significant gain in dose rate for the dynamic beams over that expected with static beams.

Another important feature is that the decreased dose to surrounding normal tissue contains very little high LET dose. In figure 10 the high LET dose distribution for the fan tune treatment port of figure 9A is compared to the treatment volume. This distribution is in "high LET" rads relative to 100 peak rads of figure 9A, and has been calculated assuming the high LET dose profiles are near identical to the total dose profiles,

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One point to realize concerning the high LET dose distribution is that where it is possible to achieve uniform total and high LET dose distribution using parallel ppposed overlapping static beams, this will not be true for overlapping parallel opposed dynamic ports. At any XY point the high LET dose distribution will be uniform in Z but will differ for XY points under different width range shifter functions.

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III. Conclusion

The properties relevant to the comparison of static, fan and spot beam treatments discussed above are summarized in Table 1. Based on dosimetric results neither dynamic mode of treatmet is superior to the other although both are superior to static beams. In light of apparent difficulties in the treatment planning of spot tunes, it is my recommendation that we proceed first with fan tune treatments as outlined in my earlier memo.

TABLE 1

Summary of Static vs. Dynamic Treatment Porperties
Based on Dosimetry Measurements

Qualities	Static	Fan	Spot
uniformity in X	fair	fair	good
uniformity in Y	fair	excellent	good
collimation & beam edges	fair	fair	fair
dose rate	good	good	good
YZ dose shaping	bad	excellent	good
XZ dose shaping	bad	bad	good
high LET uniformity from parallel opposed ports	good	bad	bad
difficulty in Rx planning	good	fair	bad

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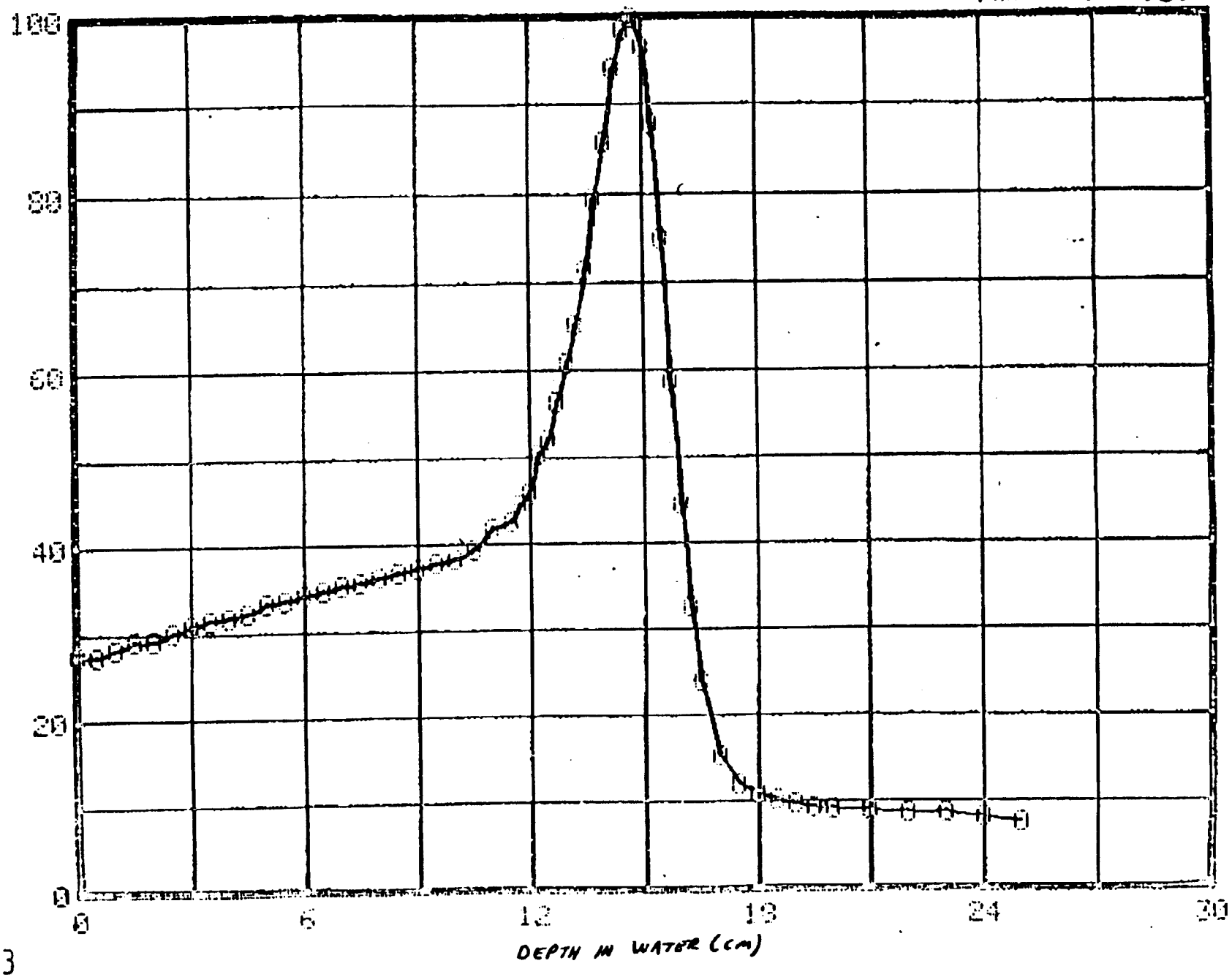
FAN TUNE %DD



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DRTA SCAN 1490D (1490-YZ DECREMENT)
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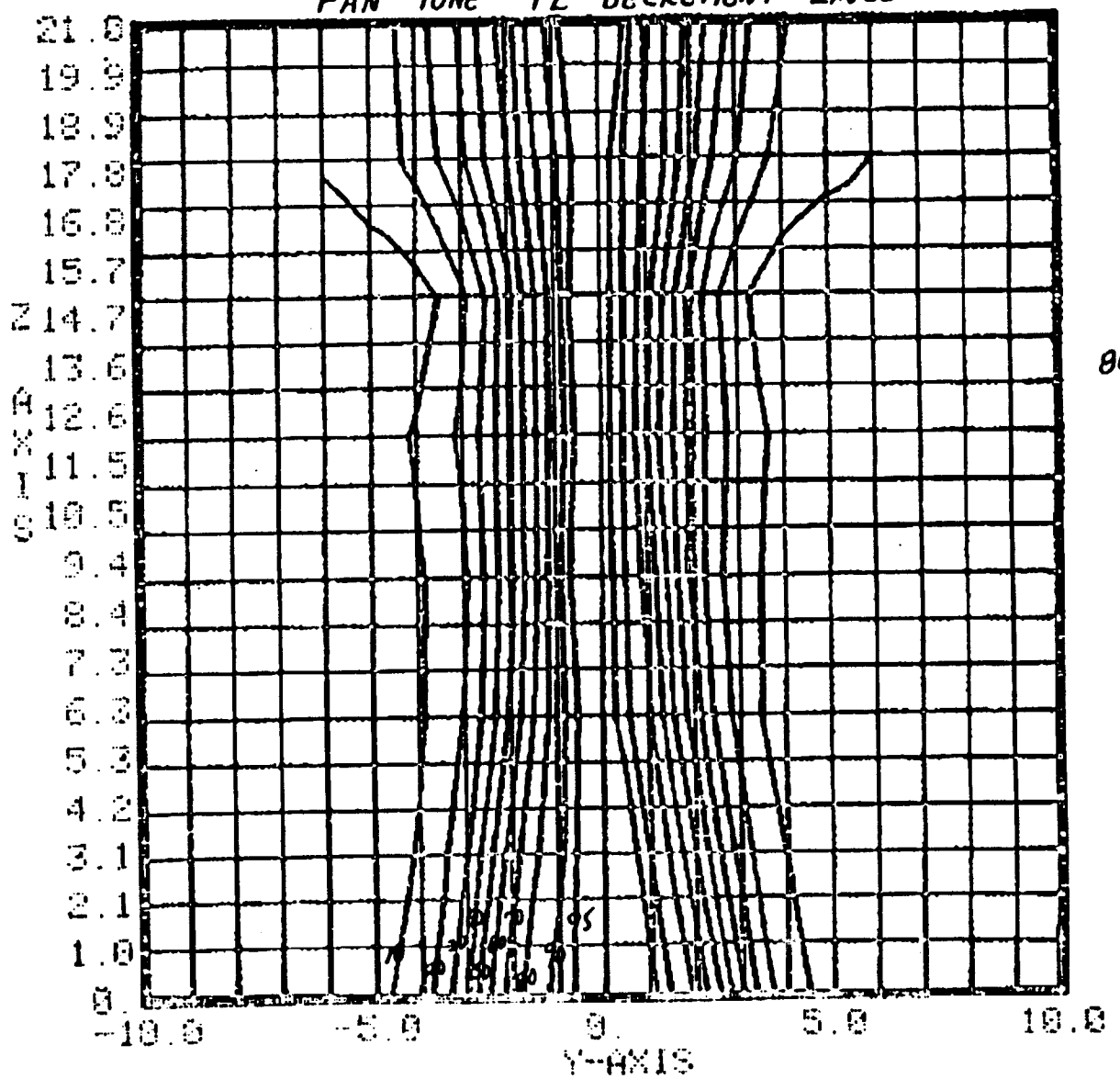
DISPLACEMENT OF PLANE FROM ORIGIN = 0.00 CM

FAN TUNE YZ DECREMENT LINES



80% = 20% ≈ 1.9cm
FWHM ≈ 3.6cm

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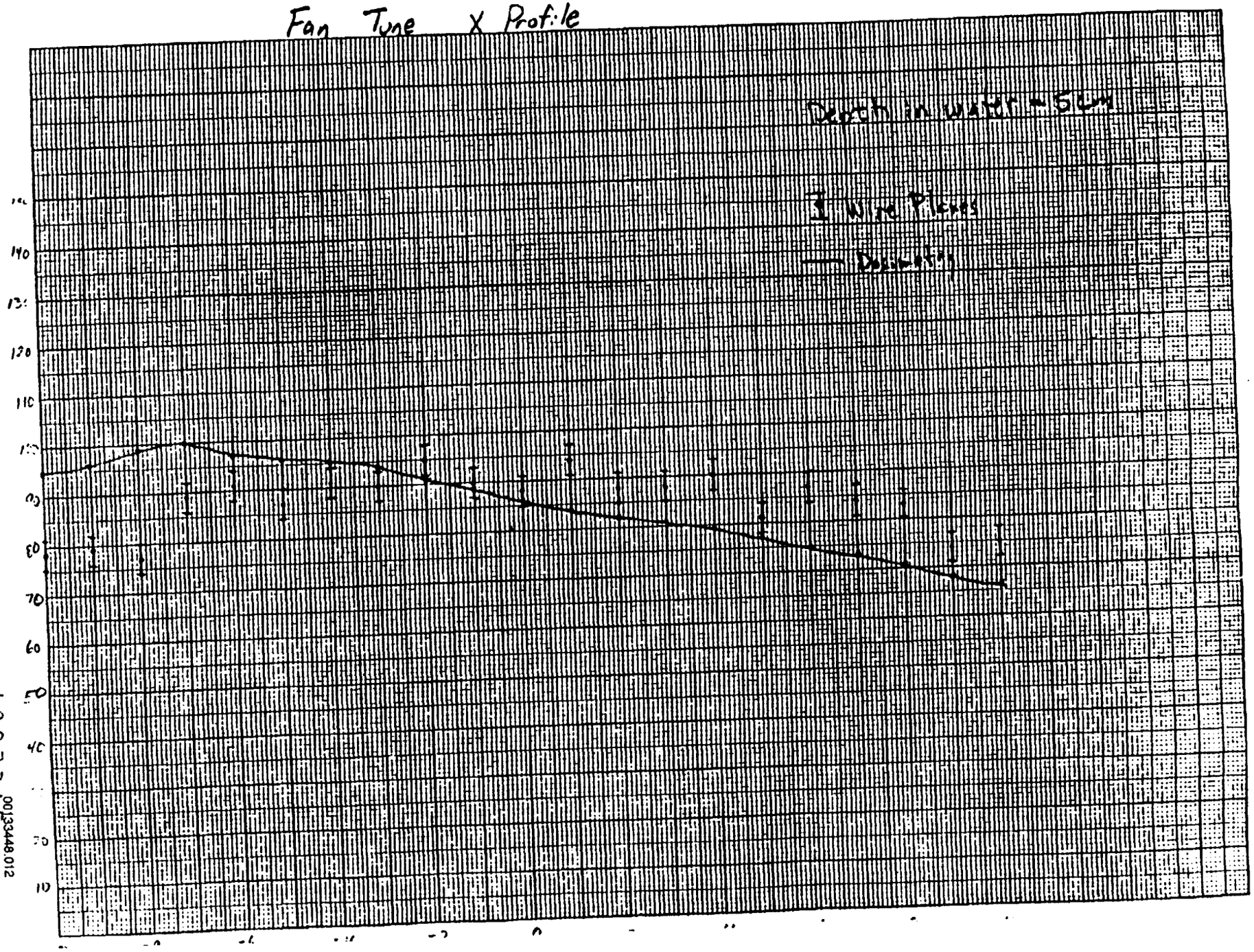
SQUARE 10 X 10 TO 10X CENTIMETER AS-0014-C0

Fan Tune X Profile



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SQUARE 10 X 10 TO THE CENTIMETER AS 8014-60

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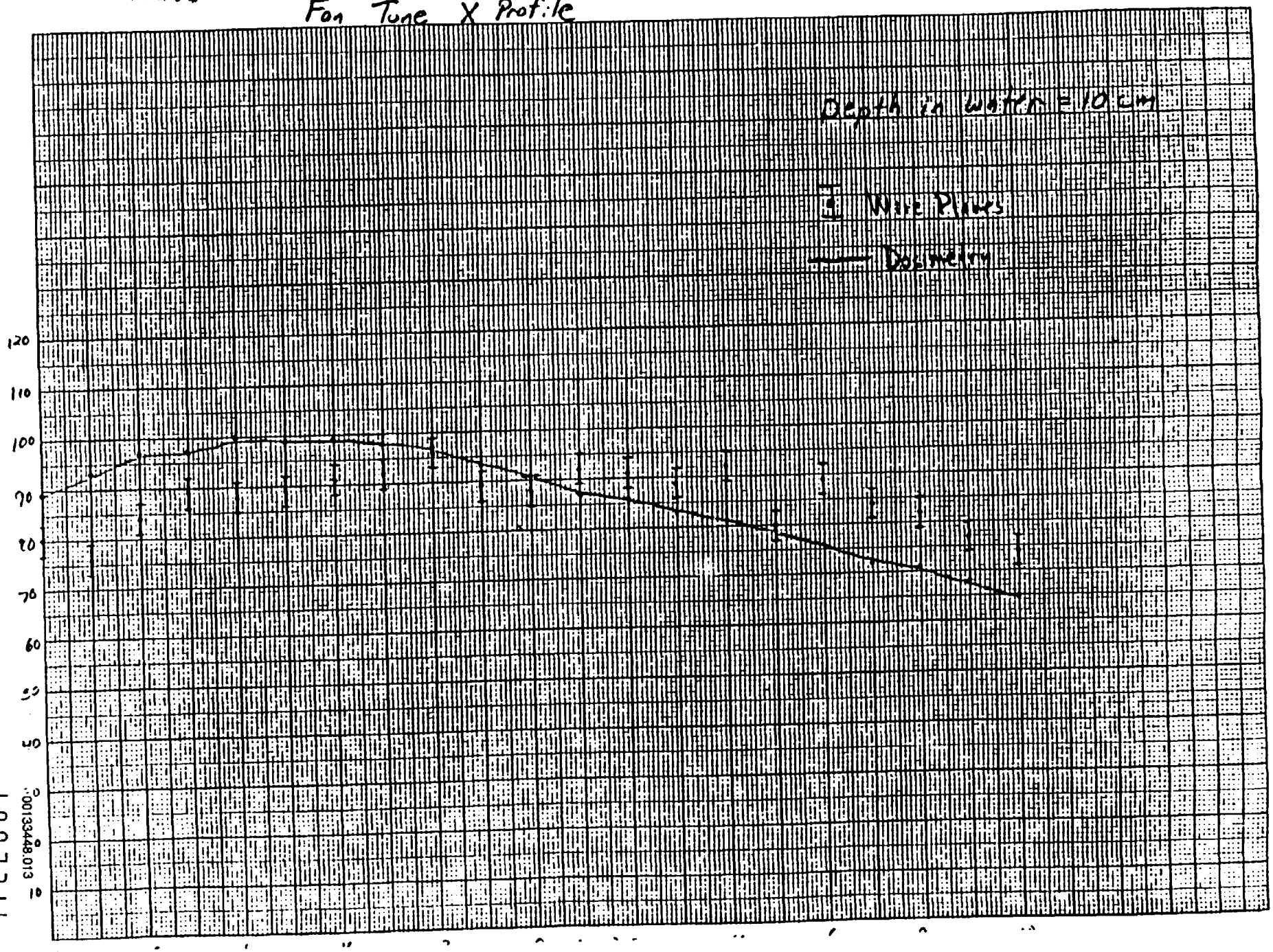
Fan Tone X Profile



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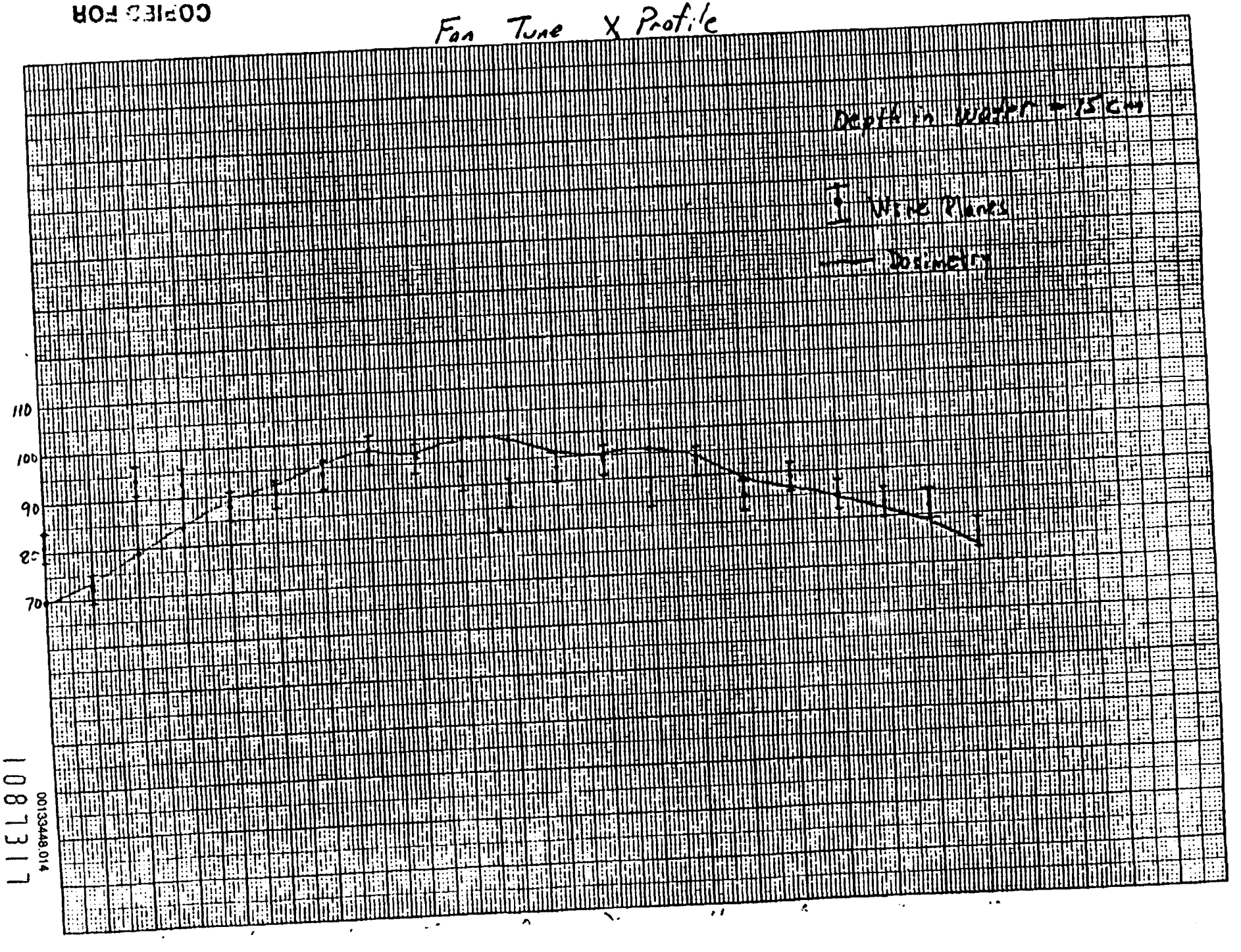
Fan Tune X Profile



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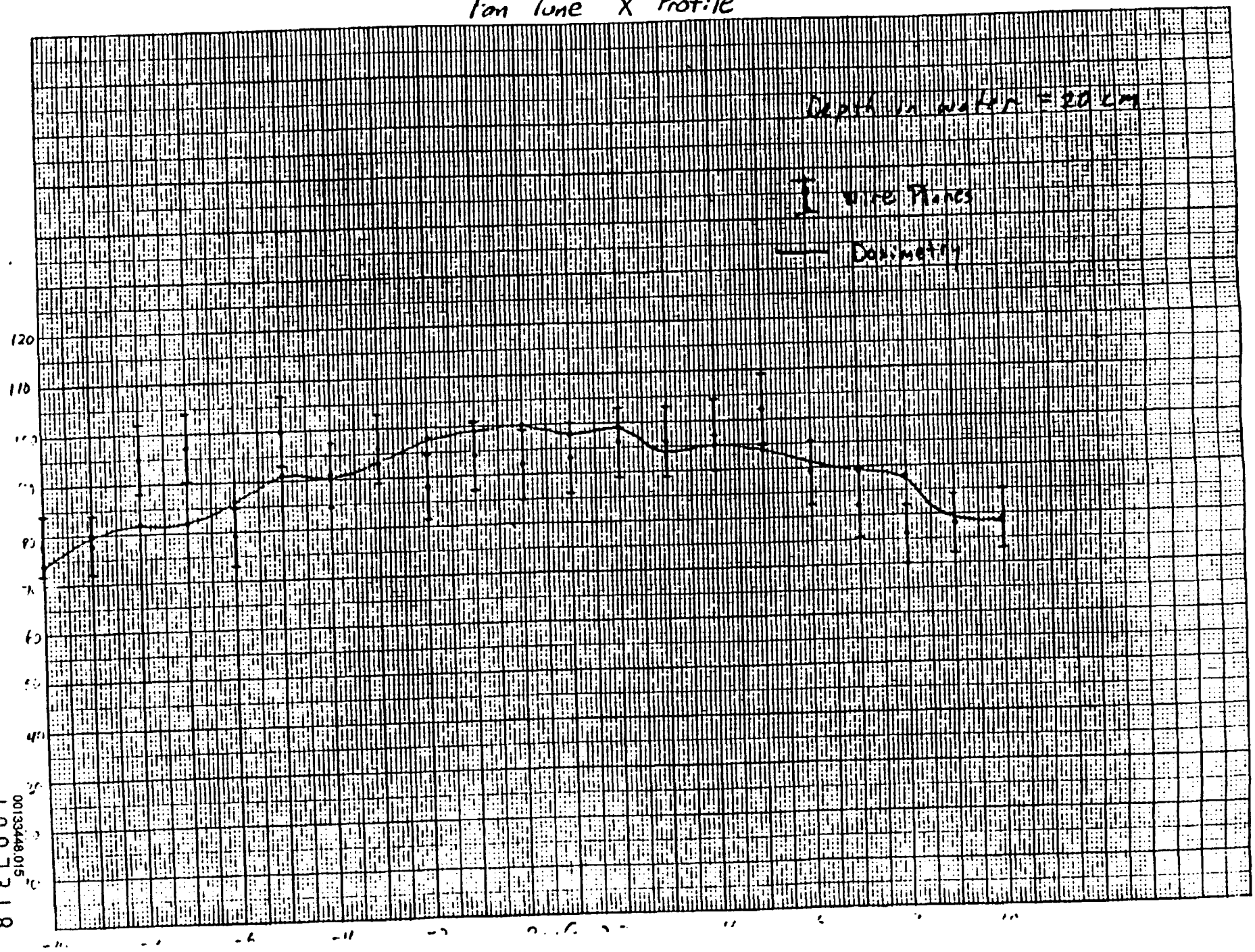
Fan Tune X Profile



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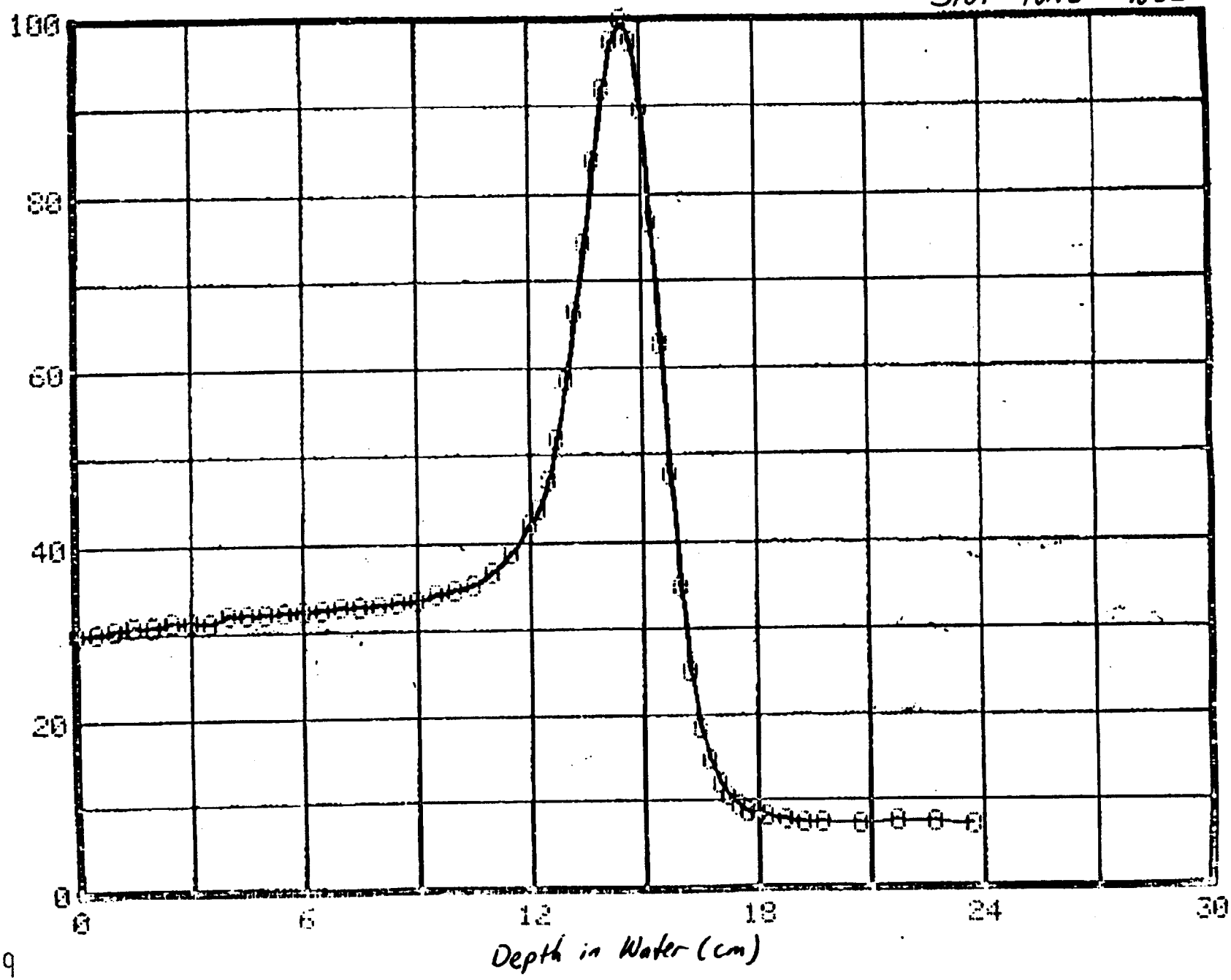
SPOT TUNE %DD



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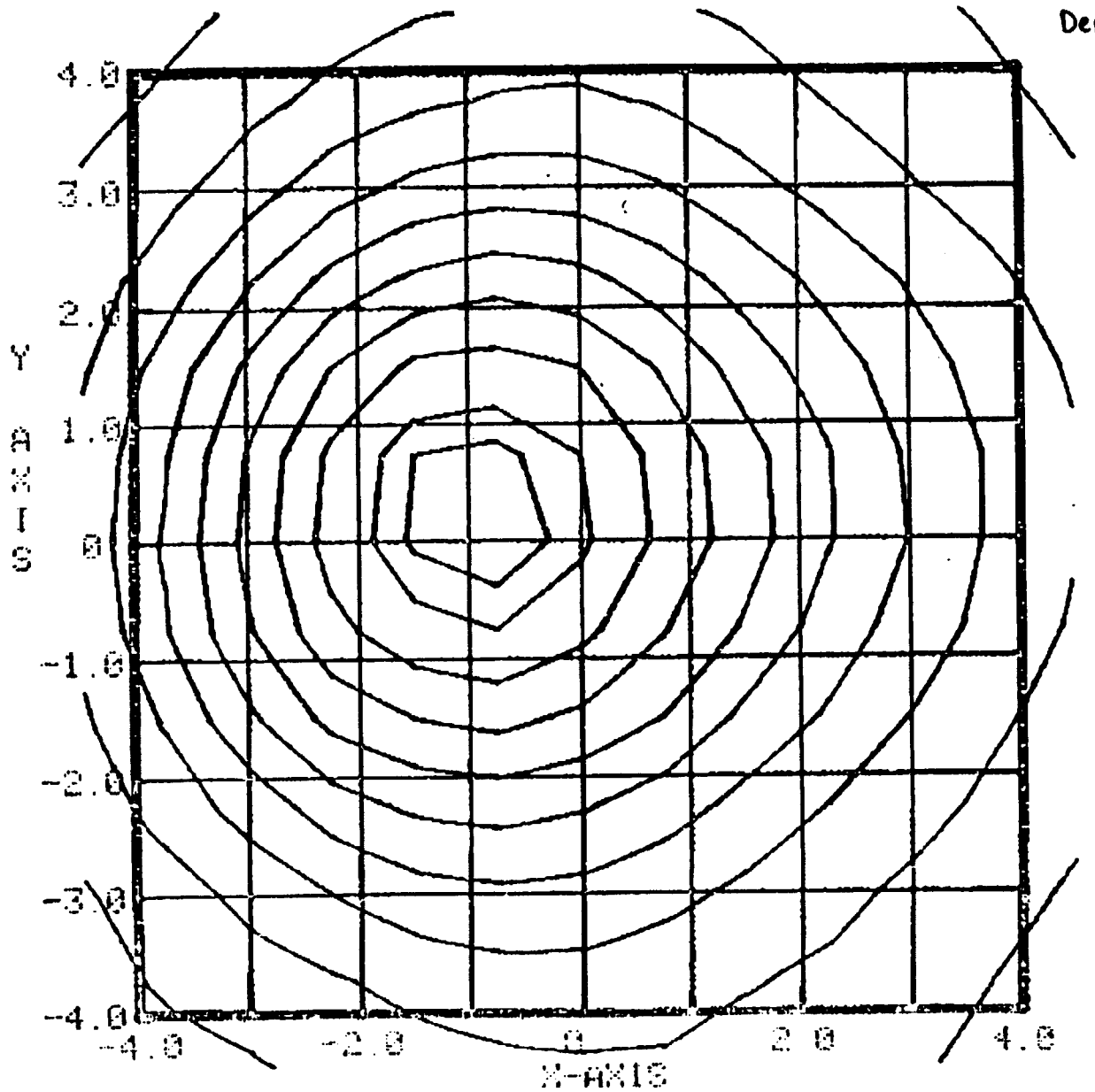
SPOT TUNE
Depth = 2cm



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5A

DATA SCAN 1517 (MIKES 467)
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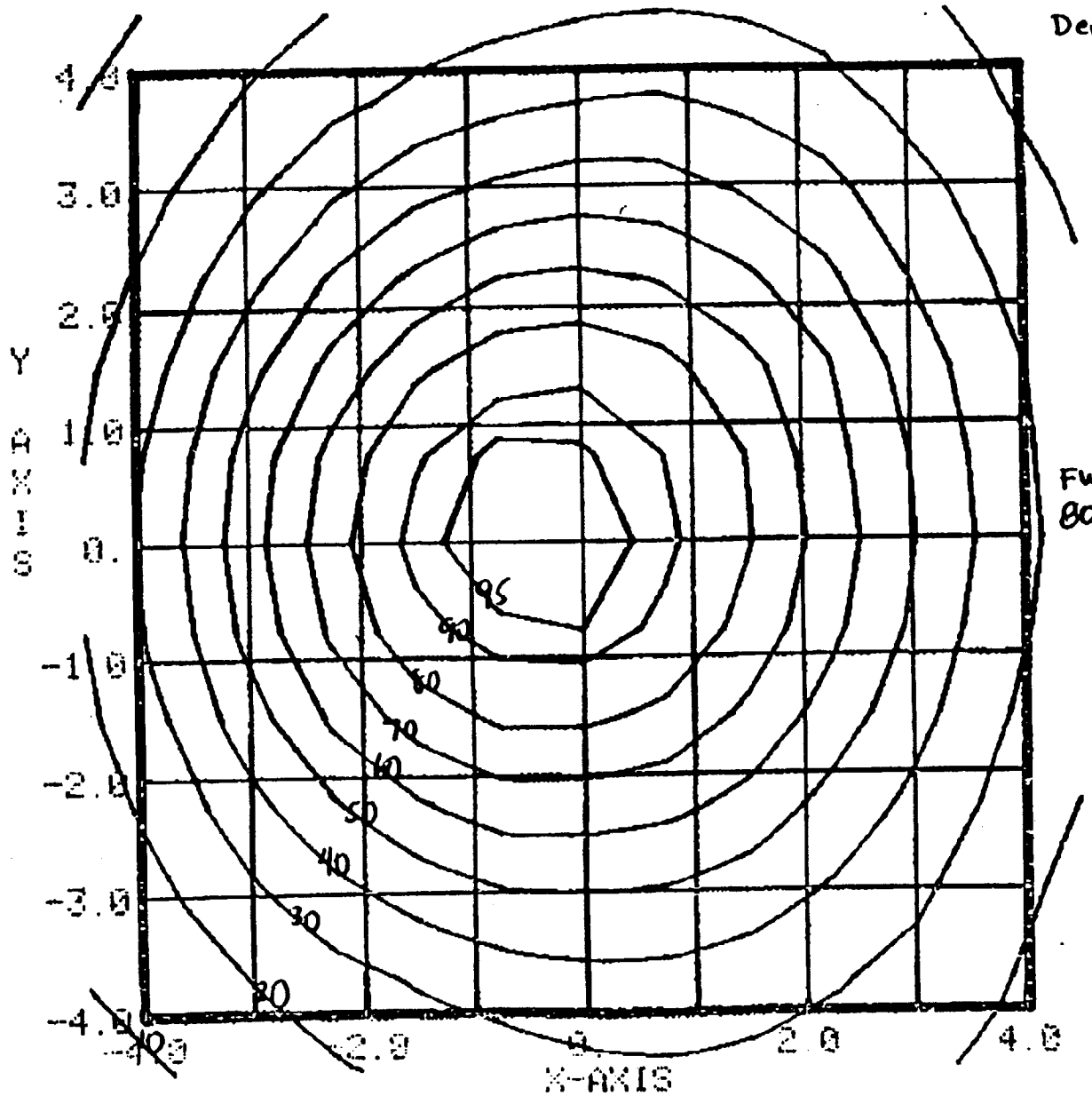
DISPLACEMENT OF PLANE FROM ORIGIN = 12.00 CM

SPOT TUNE

Depth = 12cm



FWHM ≈ 6.3cm
80% - 20% ≈ 2.9cm

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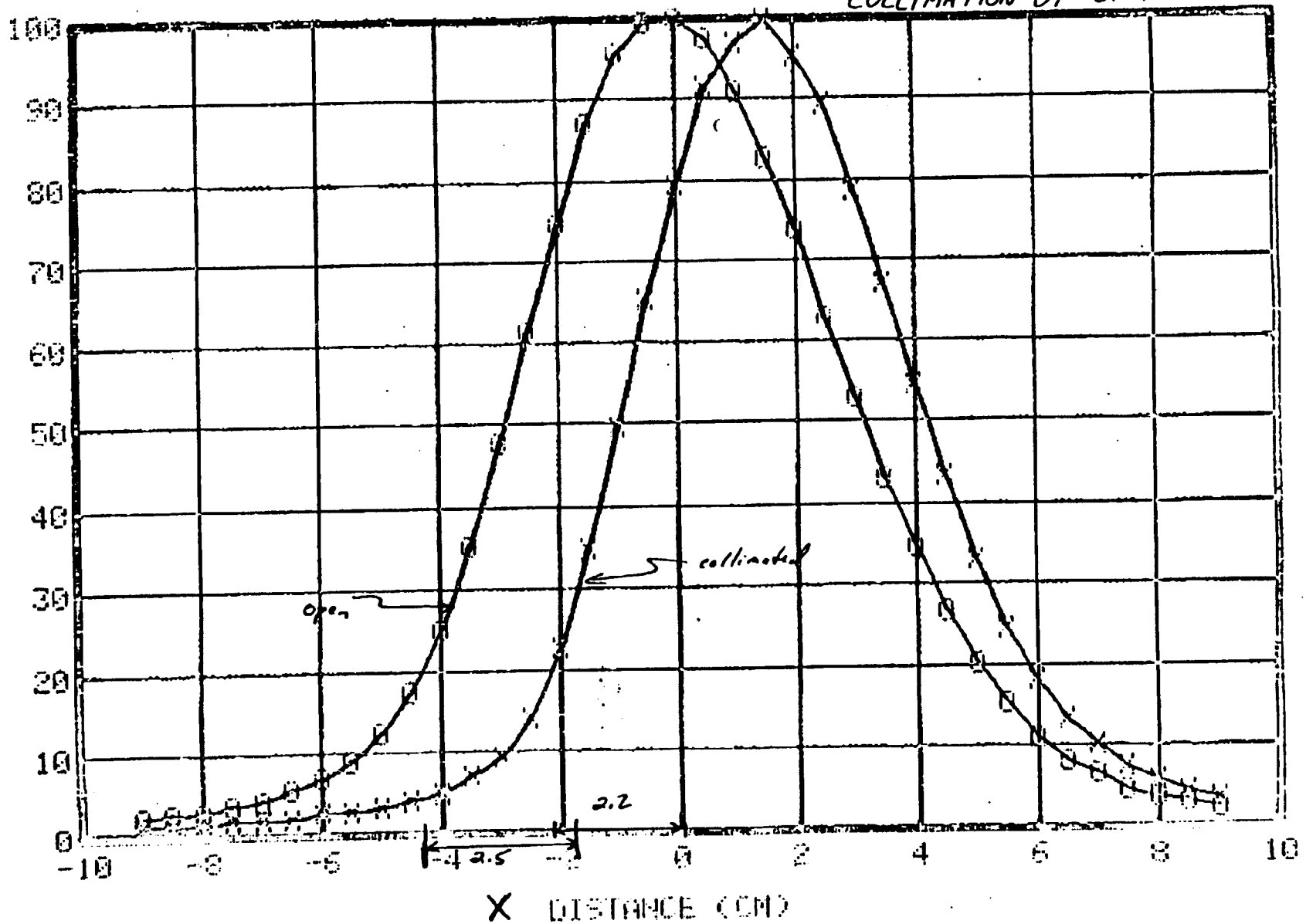
BEAM PROFILE COMPARISON

O PROFILE 1: SCAN 1427 TAKEN ON 16-DEC-77 AT 00:07:21 O
X PROFILE 2: SCAN 1430 TAKEN ON 16-DEC-77 AT 02:55:48 X

COLLIMATION OF SPOT TUNE



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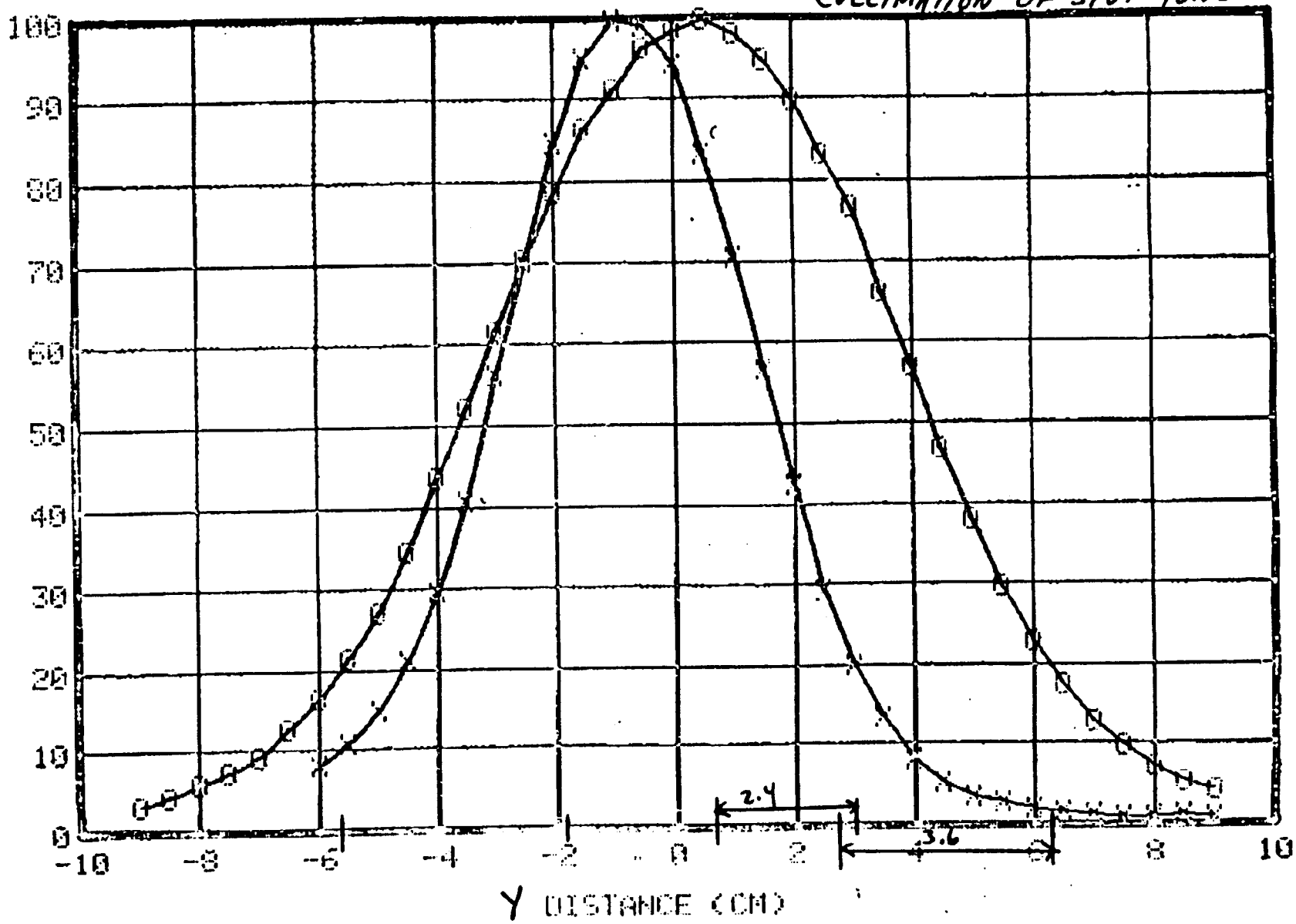
BEAM PROFILE COMPARISON

O PROFILE 1: SCAN 1428 TAKEN ON 16-DEC-77 AT 00:16:42 O
X PROFILE 2: SCAN 1431 TAKEN ON 16-DEC-77 AT 03:13:52 X

COLLIMATION OF SPOT TUNE



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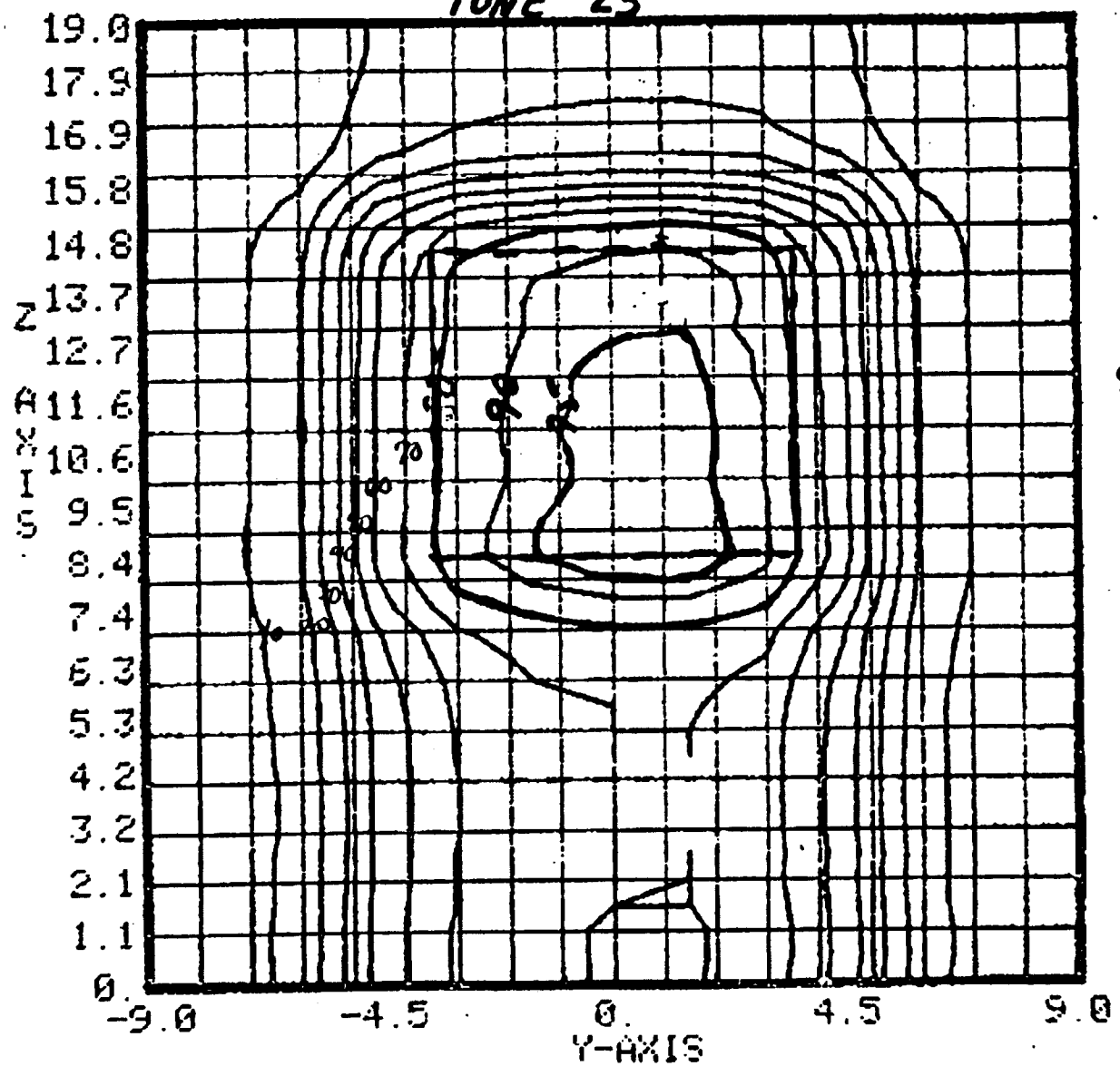
TUNE 23



95% - 80% ≈ 1.8 cm
80% - 20% ≈ 2.5 cm

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7A

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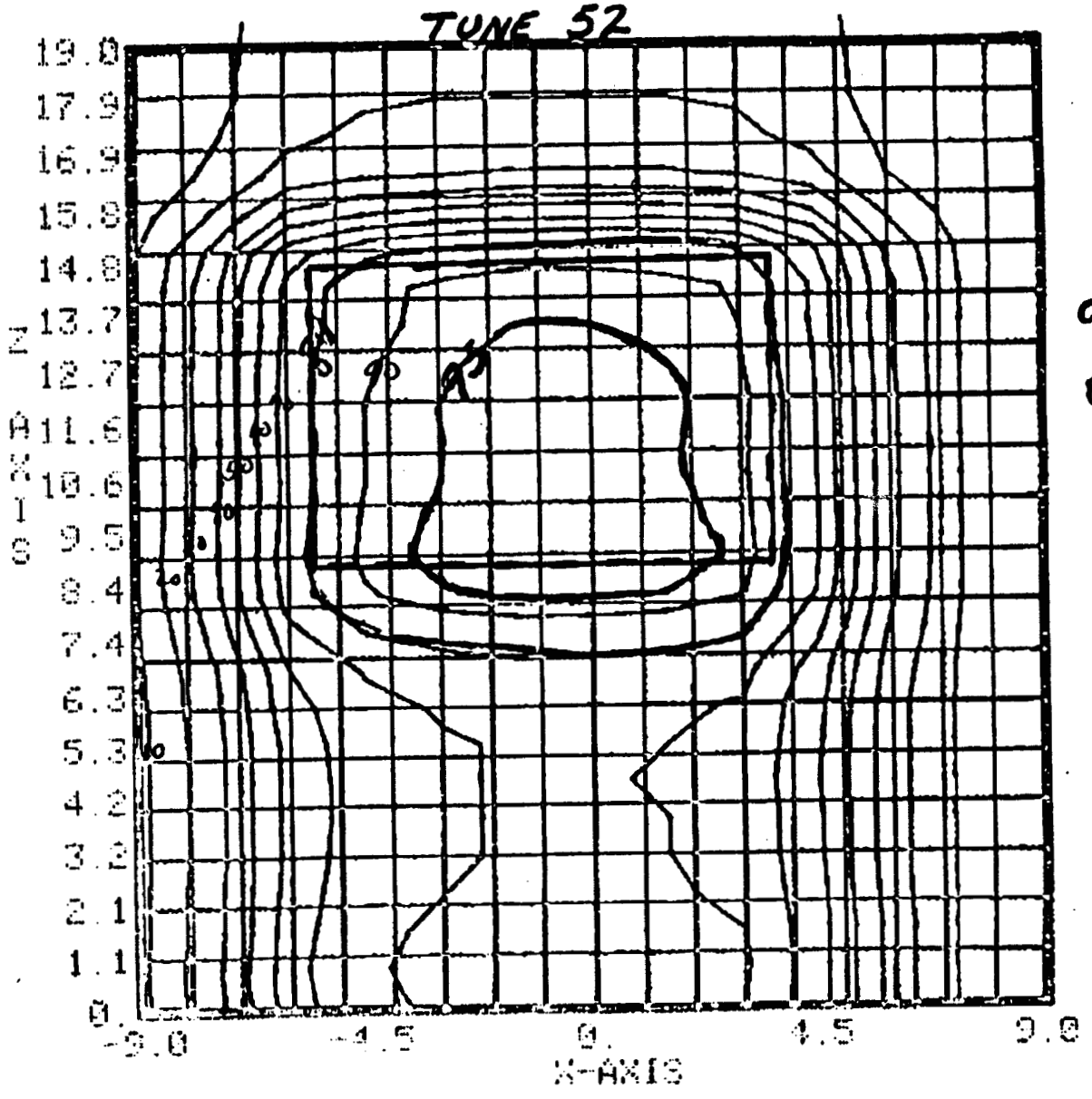

95% - 80% ≈ 1.6cm
80% - 20% ≈ 2.6cm

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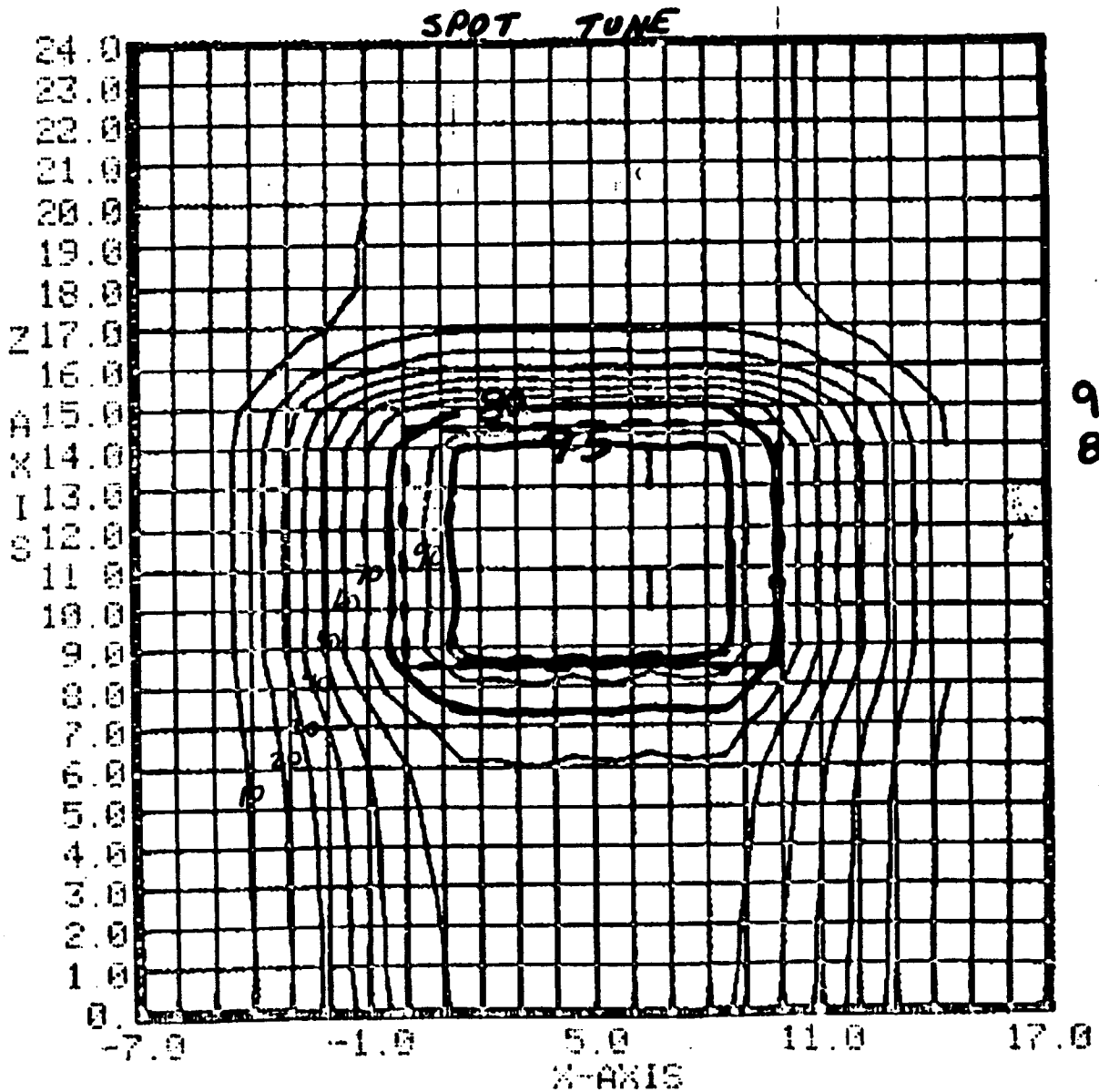

95%-80% ≈ 1.4 cm
80%-20% ≈ 3.5 cm

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7C

MCR>RUN PLTDOS DATA SCAN DYN01 (BRFAN-6RS-5/2)
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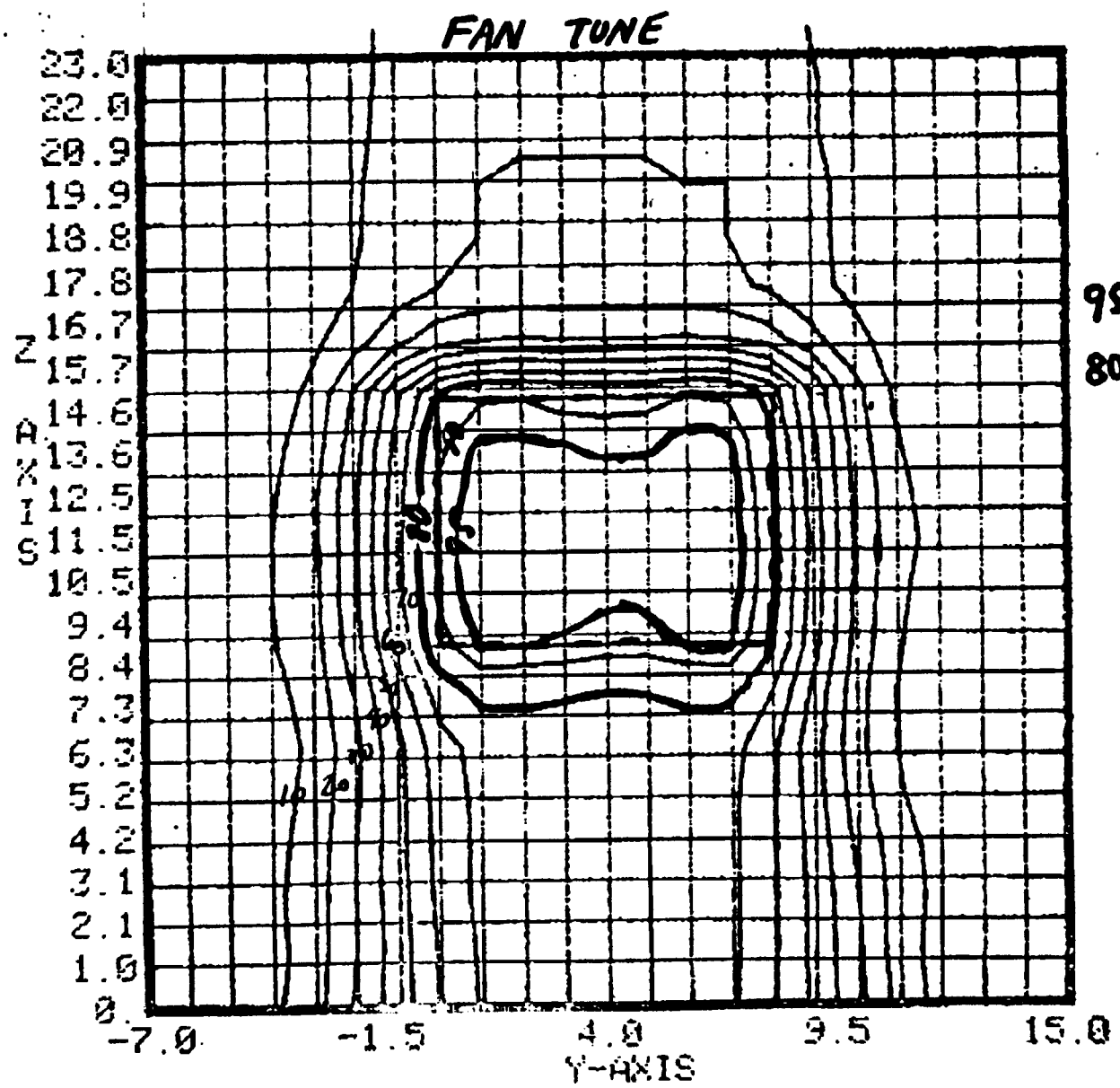

95% - 80% = .8cm
80% - 20% = 2.5cm

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DATA SCAN SPOT2D (SPOT-2X2-10X10)
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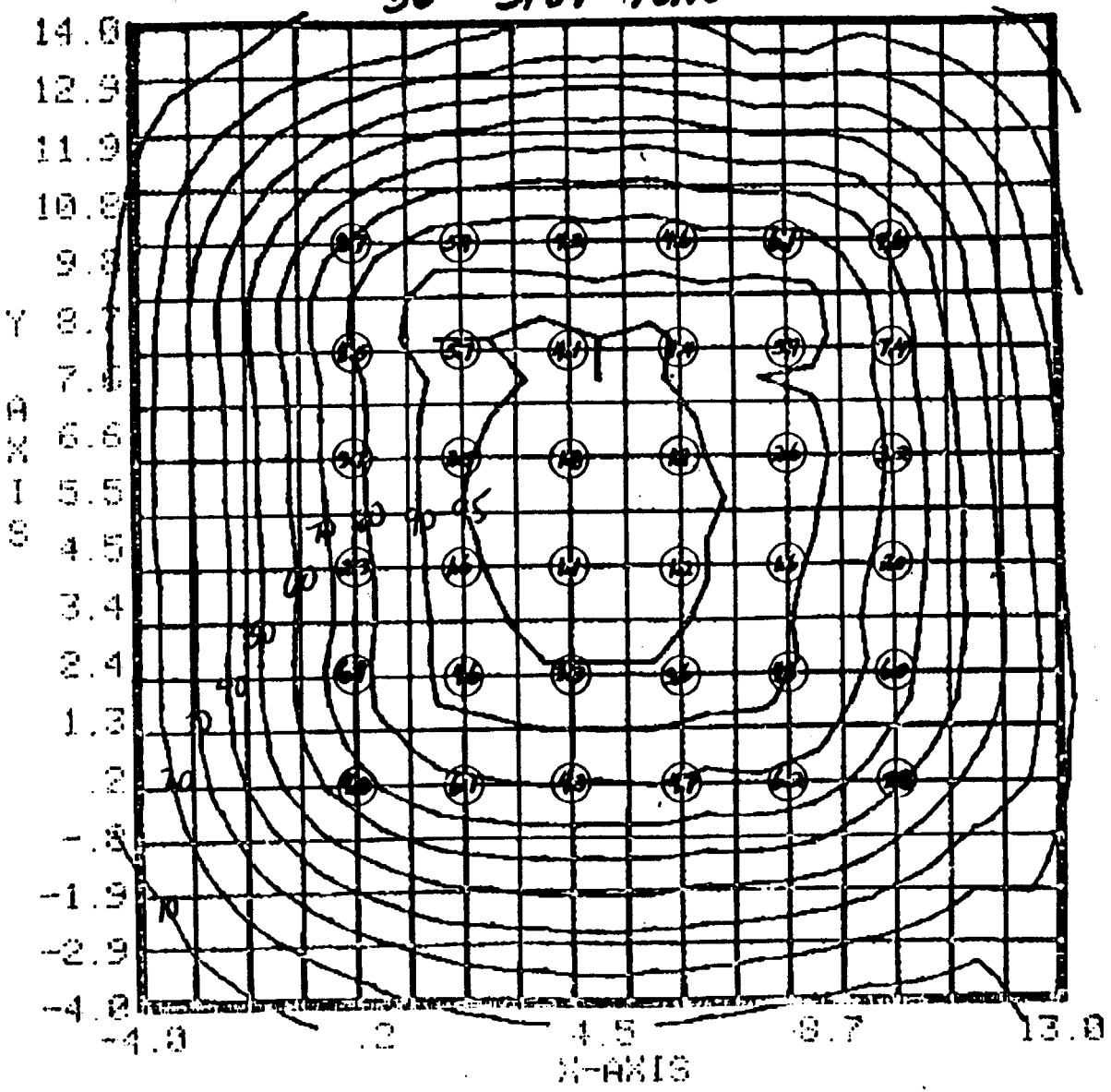
36 SPOT TONES



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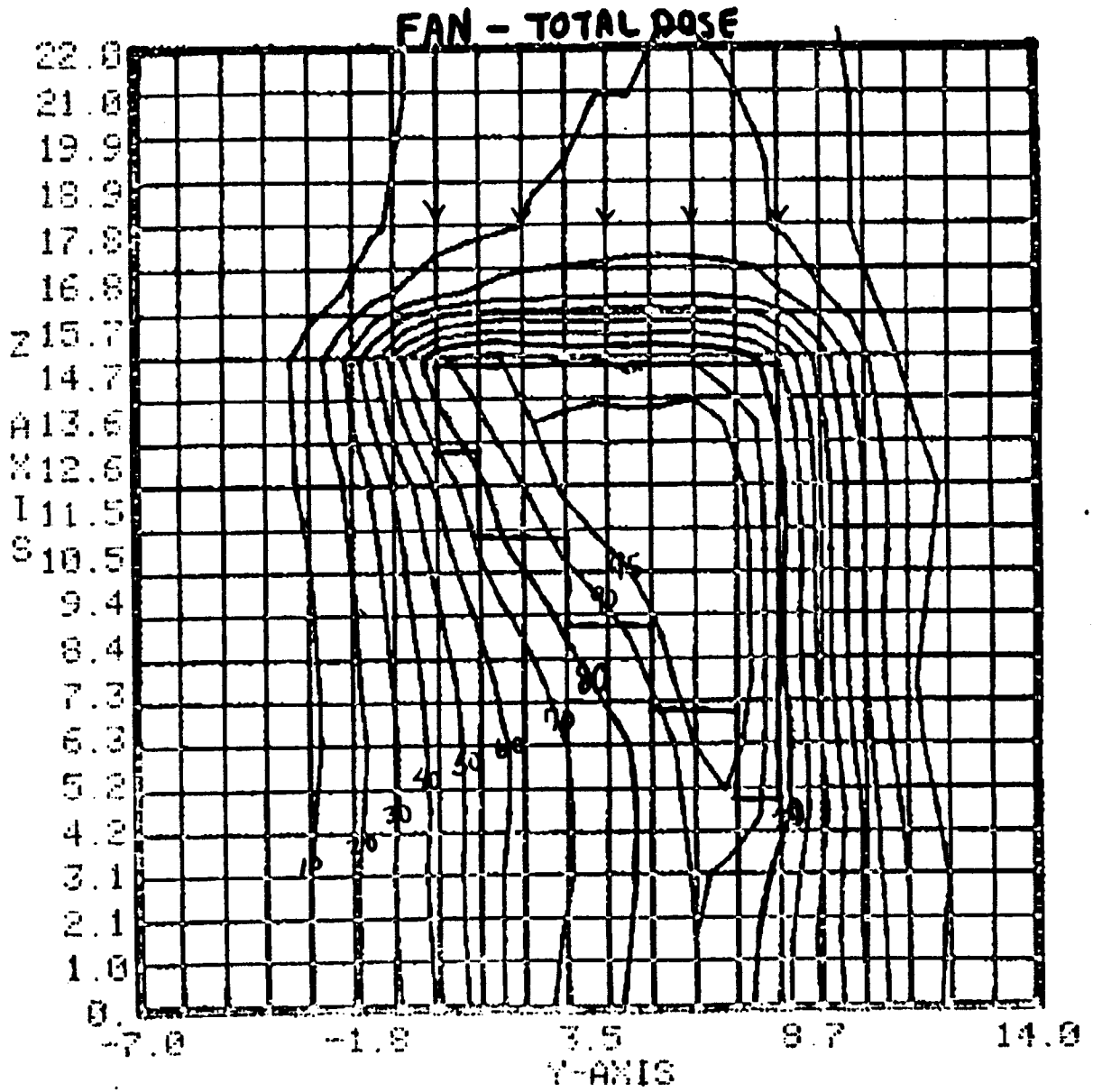

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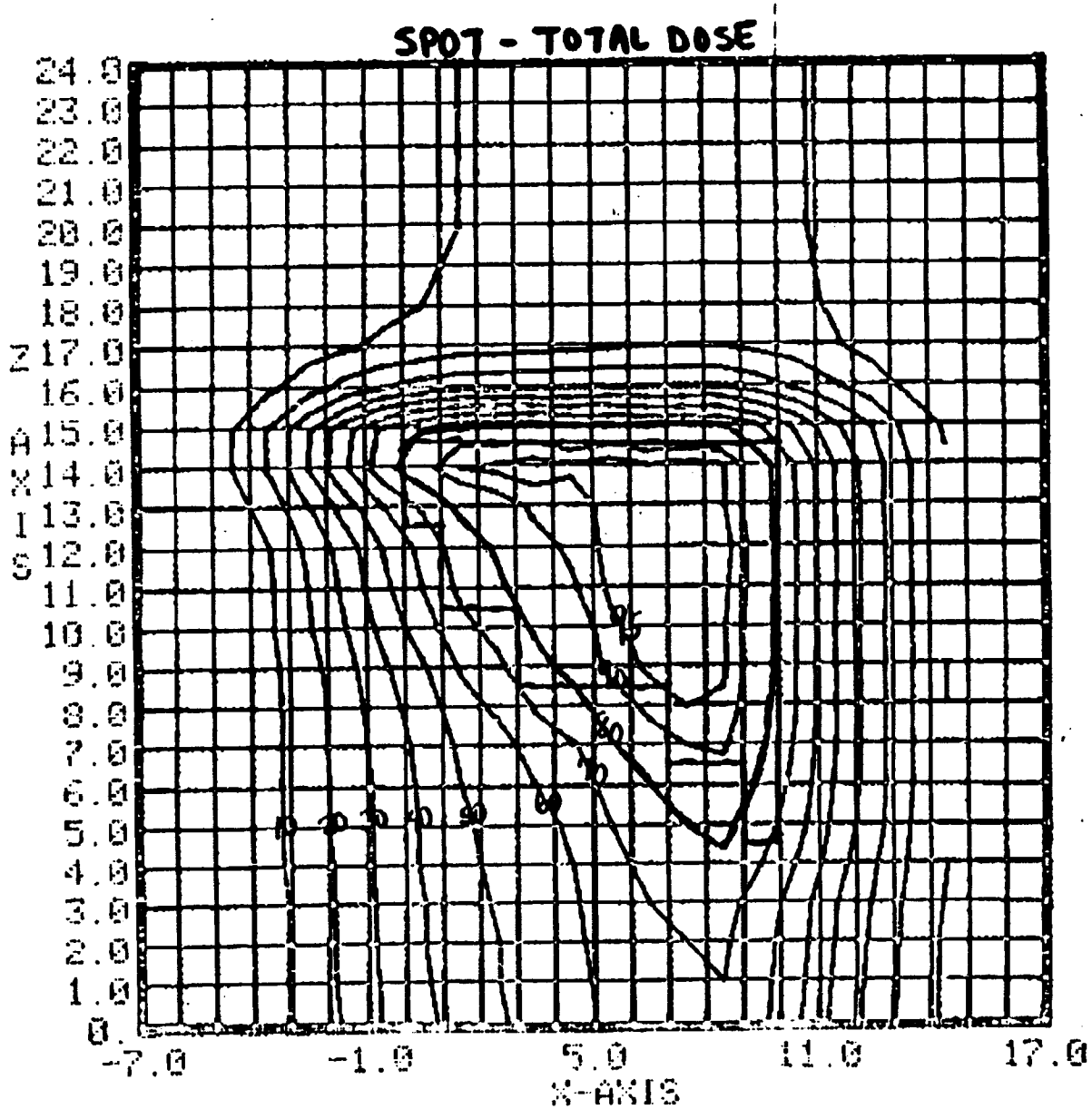

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9B

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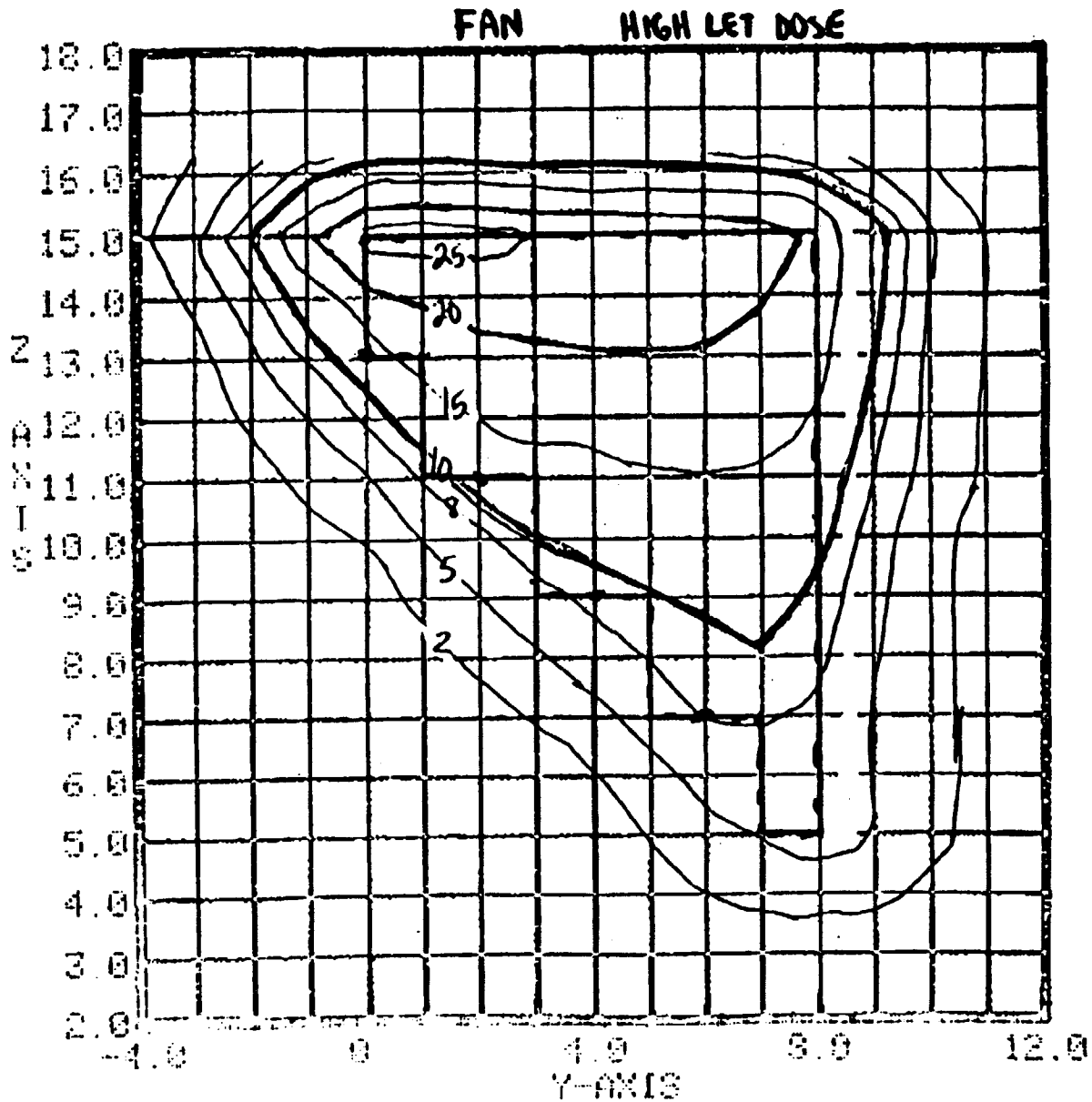

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MAY 3, 1978 Richard Kittell

STATUS of SOFTWARE to SUPPORT DYNAMIC DOSIMETRY and TREATMENT

Dynamic dosimetry is being given first priority, and I expect to meet the June 15 target date set by Ken Hogstrom. The operation of the dynamic dosimetry system has been planned, and I will provide support in 2 phases.

Phase 1 will consist of interfaces between the dosimetry code and the 11/03. I will define subroutine calls later this week or early next week to provide "position couch", "load tables", and "start dosimetry" functions. Isaac Rosen can begin putting these calls into his software immediately. Support at the handler level to make these subroutine calls operational should be ready the week of May 15-19. At that time the basic processing of the dynamic dosimetry codes can be tested utilizing a FORTRAN routine running in the 11/45 to do data aquisition. Ken and Isaac will write that routine with my collaboration.

Phase 2 of the dosimetry development will consist of implementing the data aquisition function of the FORTRAN routine in the MBD. This will take quite a load off the 11/45, allowing treatment planning and program development to proceed more effectively. This phase will proceed in parallel with further development of the dosimetry programs, and the change-over from 11/45 to MBD data aquisition should be transparent.

Dynamic patient treatment support will involve a complete re-structuring of the patient treatment software resulting in a "production" treatment system capable of organizing the highest projected treatment loads in such a manner as to minimize the idle time between irradiations. The system will include a task to monitor the performance of the 11/03 to make sure the couch is where it should be. Here is a quick overview of the treatment system operation. A file is created for that patient containing patient particular data such as history, comments and cumulative doses. This data will be stringently protected against unauthorized access. Also included in the patient file are port identifiers, essentially file names of port files for that patient. Each port file contains data particular to the irradiation of that port, such as dose, channel tune number, treatment tables to drive the couch, collimator jaws, and the range shifter. When the schedule of treatments is determined in the morning, it is entered into a schedule file as a list of patient/port identifiers. The treatment system will be started up and get the port file for the first treatment. The data will be displayed to the operator for verification, and once accepted all hardware set-ups will proceed automatically. The tune number will be passed to the channel control system for setup, and the treatment tables will be loaded into the 11/03. When the treatment room is swept the couch will move to its initial position and treatment will begin when the target is inserted. Upon completion of treatment, the doses will be recorded in the patient's file and the next port from the schedule file will be started. Necessary provisions will include methods of shuffling the schedule file around at any time, updating port information, and maintenance of calibration data in a manner such that it can be updated easily. I expect the development of the treatment system to take from 6 to 9 months, assuming I can give it at least 75% of my effort.

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