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SCANNING SYSTEM FOR MEASURING UNIFORMITY OF LASER DETECTOR RESPONSE AND LASER BEAM DIMENSIONS

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U.S. DEPARTMENT OF COMMERCE, Robert A. Mosbacher, Secretary
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Scanning System for Measuring Uniformity of Laser Detector Response and Laser Beam Dimensions

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A computer-controlled scanning system constructed at NIST/Boulder moves a detector or a pinhole attached to a detector in a plane perpendicular to the axis of a stationary laser beam. A linear detector monitors the laser beam. The system measures the uniformity of laser detector response and the laser beam dimensions. The device to be measured is attached to computer controlled X-Y translation tables that scan a maximum area of 15 cm x 15 cm with 10^{-4} cm resolution along each axis. Detector and monitor outputs are digitized with a computer board. Output versus position is represented in contour maps and surface graphics on the computer, the plotter, or the printer. Choice of matrix dimensions and step sizes of the scanned area determine the resolution of graphics. Maximum, minimum, average and variance data of the Z output of a detector for a chosen X-Y area provide additional uniformity information. High precision fiber couplers can be used to spatially filter and/or collimate the beam. Available sources are conventional lasers from the visible and the near infrared wavelengths or laser diodes at 0.82, 1.3 and 1.55 μm wavelengths. A precision positioner along the optical axis moves the measurement device and controls the size of the beam entering it. Beam dimensions and detector response data are given. This report documents the use of the system to calibrate detectors.

Key words: beam dimensions; computer-controlled scanning system; detector and beam graphics; detector and beam scanning; laser detector response; laser power monitor; linear detector; uniformity

1. Introduction

The reliability of detector calibration depends upon the uniformity of detector response and the dimensions of the interacting laser beam. This report describes a computer-controlled scanning system for measuring these parameters.

Appendixes A through J present many important details needed to understand and use the system. Appendix J describes the linear detector (ROSY 7-1) that monitors the detector under calibration in the scanning system.

The device to be measured is scanned in a plane perpendicular to the axis of a stationary laser beam. Software using output and position data give (1) surface graphics and information, and (2) beam radius and shape [1]. To determine linearity, measurements are made at two or more power densities. The user may determine experimentally the effect of changing beam size on uniformity measurements.

Uniformity scans in this report fluctuated more for smaller beams than larger ones. They were smoothed and rounded for beams larger than coordinate steps.

The scanning system provides greater control and information of the beam and detector surface than the system in which rotating mirrors scan the beam over the detector surface [2]. In the latter system, an oscilloscope plots the response of the surface.

The remainder of this report describes:

2. System Layout and Interfacing Parts
3. Software
4. Measurement Procedures, Examples, and Applications
5. Conclusions
6. Acknowledgments
7. References
8. Figures
9. Appendixes

2. System Layout and Interfacing Parts

The computer-controlled scanning system measures the uniformity of laser detector response and the laser beam dimensions. The system layout and interfacing are described in figures 1-6. These figures show a system that delivers a laser beam to a monitor and detector and digitizes the outputs, and a computer that controls the detector motion in a laser beam and provides two or three dimensional graphics and surface response.

The various parts of the system in figures 1-6 are now discussed. Conventional and diode laser sources are available. A spatial filter and collimator are mounted in two high-precision fiber couplers. A microscope objective focuses a laser beam into one end of a single-mode or multimode fiber, and the beam at the other end of the fiber is collimated with a microscope objective [3]. These components are by-passed when the laser beam is usable without them. Each laser diode pigtail output enters a microscope objective suitable for the wavelength to collimate the beam. The multiplexer, in front of a microscope objective, passes either of two laser diode beams. A mirror moved into the system directs the diode beam into the beam splitter wedge. Two irises through which the main beam passes are used to align the laser along an optical axis.

The wedge beams are identified as follows: transmitted beam (m=0), beam reflected from the back surface (m=+1), and beam reflected from the back and front surfaces (m=2). A 2° beam splitter wedge reflects the (m=+1) beam into the monitor and also transmits the (m=2) or (m=0) beam through a microscope objective, suitable for the wavelength, into the detector or pinhole attached to a detector.

A Z adjustment micrometer along the optical axis controls the distance between the microscope objective and the measurement device and, consequently, the size of the beam entering it. The micrometer and measurement device are attached to the X and Y linear translational tables of the scanner.

A motion controller directs scanner motion (see figure 2, Interfacing of scanning system). By use of the joystick, the operator may determine home coordinates for the measurement device. The computer interfaces the motion controller through program Unidex, the National GPIB card, QuickBASIC 4.0, and the IEEE Bus.

Following the monitor and measurement device are precision amplifiers for measuring low voltages. The amplifiers feed A/D converter boards that are connected to the computer. The boards have pseudodifferential termination without grounding and a ± 10 V scale at channel 1 for the monitor and ± 10, ± 1, ± 0.1, or ± 0.02 V scale at channel 0 for the measurement device. The amplifiers may be omitted if the gain of the boards is adequate to amplify the signals.

The computer records the monitor output and the measurement device output, and X and Y positions in the beam. It controls the measurement process and data. The software produces two-and three-dimensional graphics for the screen, printer, or plotter. See appendixes F, G, and H for further descriptions.

3. Software

Three kinds of computer programs control motion and data processing of the scanning system:

(1) Combine3.

This program works with the daughter board in the bipolar mode and is meant for testing the equipment. It takes data, one point at a time, only when prompted. You are able to choose the gain you need. It will take up to 100 data points.

(2) Scan1010, Scan2525, Scan5050, and Scan6363.

These programs are used with the daughter board in the bipolar mode and read off of an unknown and a monitor. You are able to choose the gain you need on the unknown, but the monitor is default at 1. They give a 10x10, 25x25, 50x50, or 63x63 matrix of data [numbers in programs identify matrix]. The program scans the unknown detector in a beam to determine its uniformity.

(3) 2525PINO.

This program is used with the daughter board in the bipolar mode, and reads off of an unknown and a monitor. It is to scan a pinhole in a beam to determine the beam radius and shape. It gives a 25x25 matrix.

The motion controller boot program is: Boot 25 G7 [X and Y translational tables go to coordinates 0,0].

4. Measurement Procedures, Examples, and Applications

The scanning system will measure uniformity of detector response below saturation and beam dimensions. We recommend that you study sections 2 and 3 of this report, the figures, and the appendix; they provide essential information on system layout, interfacing, and procedures. Plan beam and detector measurements for your device. It may take a number of runs to get the resolution, beam dimensions, and detector measurements needed. Follow measurement procedures below:

- Turn on scanning equipment rack.
- Select and run laser for warmup period before proceeding further.
- Align beam through irises.
- Spatially filter and/or collimate beam, when helpful, using the high-precision fiber couplers.
- Align beam splitter wedge by reflecting the (m=2) beam (two reflections in wedge) back on itself and superimposing the (m=3) beam (three reflections in wedge) on the (m=2) beam. Use wedge holder adjustments.
- Connect the monitor and the device to be measured to the amplifiers and terminal board attached to the daughter board without attaching leads to a ground. See appendixes A and B.

- Check laser stability using monitor in program combine3. See section 2.
- Determine home coordinates and step and feed rate for the unknown detector or the pinhole attached to a detector. See appendixes C and D.
- Select computer program for the desired resolution and measurement. See section 3.
- Turn the motion controller off and then on to reboot it.
- Turn out lights and start run.
- Plot and calculate data. See appendixes E, F, G, and H.
- Refer to appendixes and measurement examples to perform tasks.
- Check whether input power and detector output are linear by changing power by a factor two or more.
- Refer to appendix I for changing beams into the unknown detector.

Measurement examples demonstrate some of the things the scanning system can do. See appendixes F and G. They include two and three dimensional surfaces and contour maps and data of beams and detector responses.

Beam radius is calculated using the $1/e^2$ point and side views and contour maps of the beam. Contours are plotted on an X-Y grid. See appendix G: Examples of graphics.

Measurement applications may include scanning sectionally or completely many kinds of optical beams. Choices of measurements are broad because of the 15 cm x 15 cm area; the 10^{-4} cm resolution; the gains of the nanovolt amplifier, of the daughter board and of the computer software; and detector-pinhole-aperture options.

A laser power stabilizer may be needed to improve the precision of some measurements.

5. Conclusion

The high-resolution, computer-controlled scanning system yields a detailed evaluation of laser detector surface response and laser beam intensity. System users may determine suitable beam dimensions for evaluating detector uniformity and optical systems. Users may improve the system with software and various modifications. Application of the scanning system can contribute to increased understanding of the functioning of detectors and optical systems.

6. Acknowledgments

The authors thank Lee Larson for writing program Unidex, using the National GPIB card with QuickBASIC 4.0 to control the Unidex, the motion controller; David Livigni for adapting the program for three dimensional surfaces and topographical graphics of data; Daniel Habernal for setting up equipment and taking data; Robert Juneau and Joe Skudler for designing and fabricating components of the scanning system and the linear detector; Douglas L. Franzen and Tim Drapela for their assistance on laser diodes and fiber optics; Eric Johnson and Matt Young for their discussions on optics and optical electronics.

7. References

[1] Dickson, L.D. Ronchi ruling method for measuring Gaussian beam diameter. Opt. Eng. 18 (1): 70, 1979 January-March.

[2] Smith, R.L.; Phelan, R.J., Jr. Limitations of the use of vacuum photodiodes in instruments for the measurement of laser power and energy. Appl. Opt. 12 (4): 795; 1973 April.

[3] Oates, C.W.; Young, M. Microscope objectives, cover slips, and spherical aberration. Appl. Opt. 26(11): 2043; 1987 June.

8. Figures

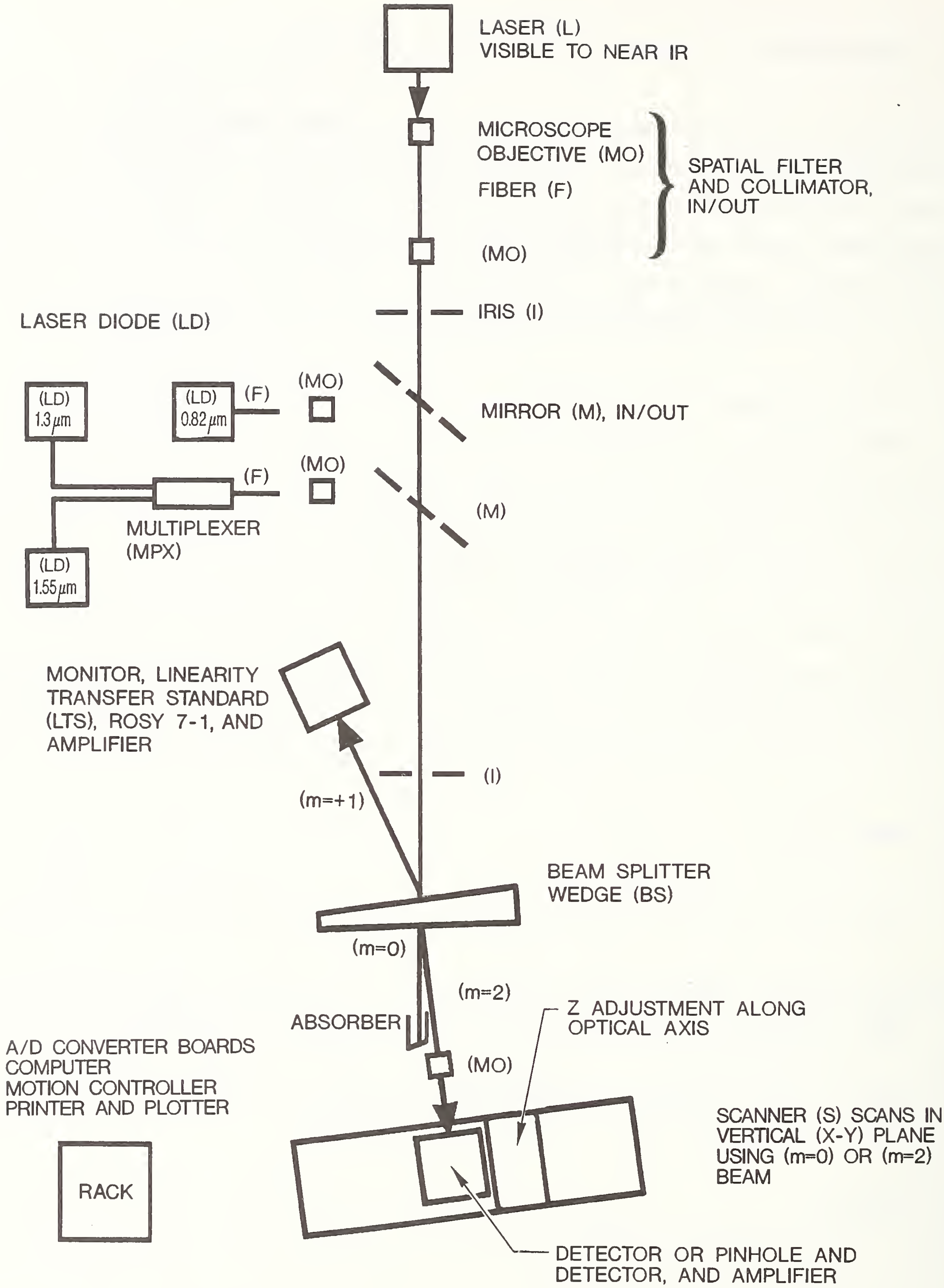


Figure 1. *Layout of scanning system for measuring linearity and uniformity of laser detector response and laser beam profile.*

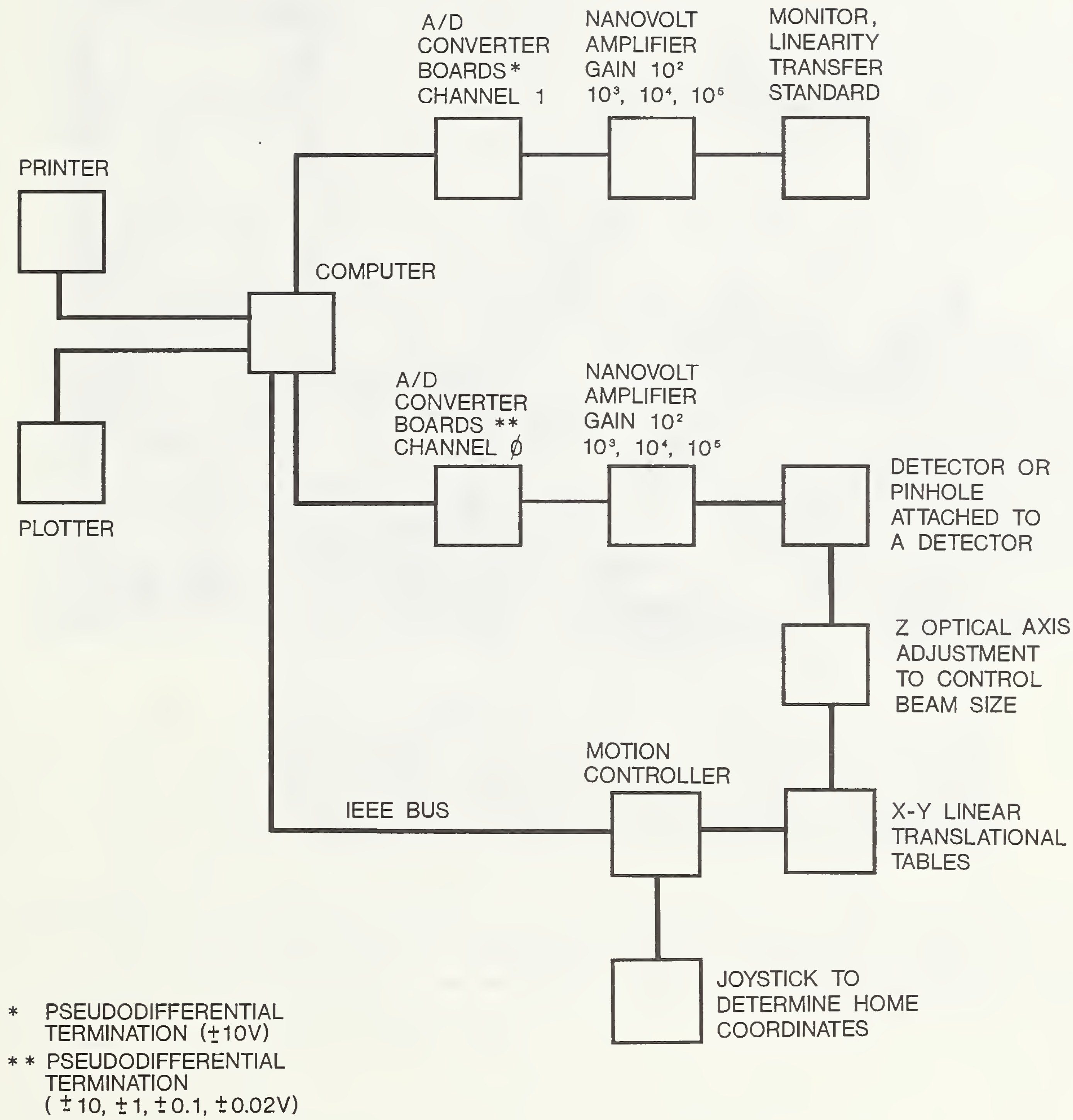


Figure 2. *Interfacing of scanning system.*

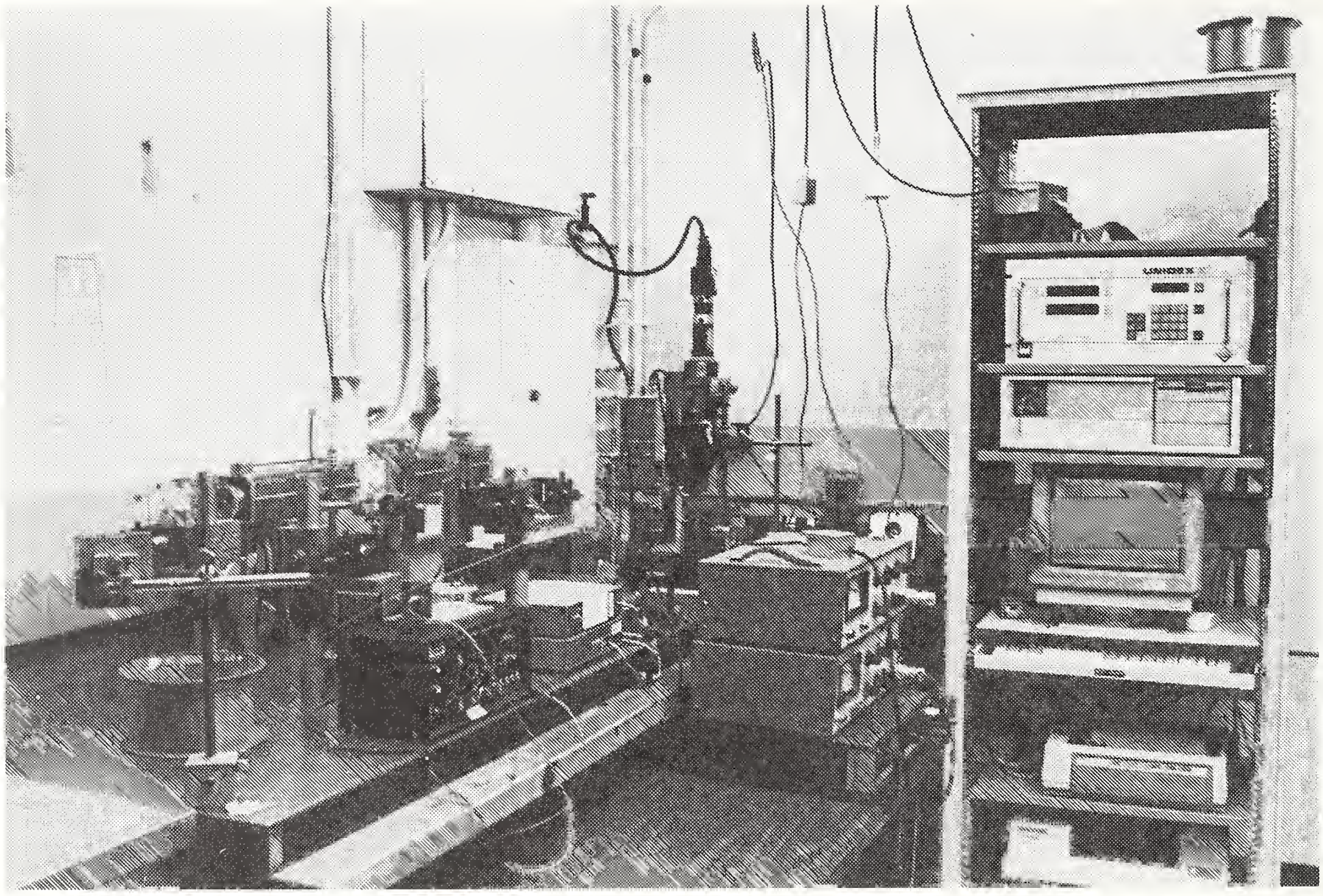


Figure 3. Photograph of scanning system shows mirror holders, fiber couplers, and HeNe and diode laser sources in the foreground; monitor with back of chassis toward viewer, beam splitter with dark frame, and scanner and joystick on the metal table in the rear; nanovolt amplifiers and digital voltmeter on the table to the right; and the terminal and daughter boards, the motion controller, the computer, the printer, and the plotter in the rack starting from the top shelf down. An arm (not shown) with mirror attached to it may direct other laser beams into the system.

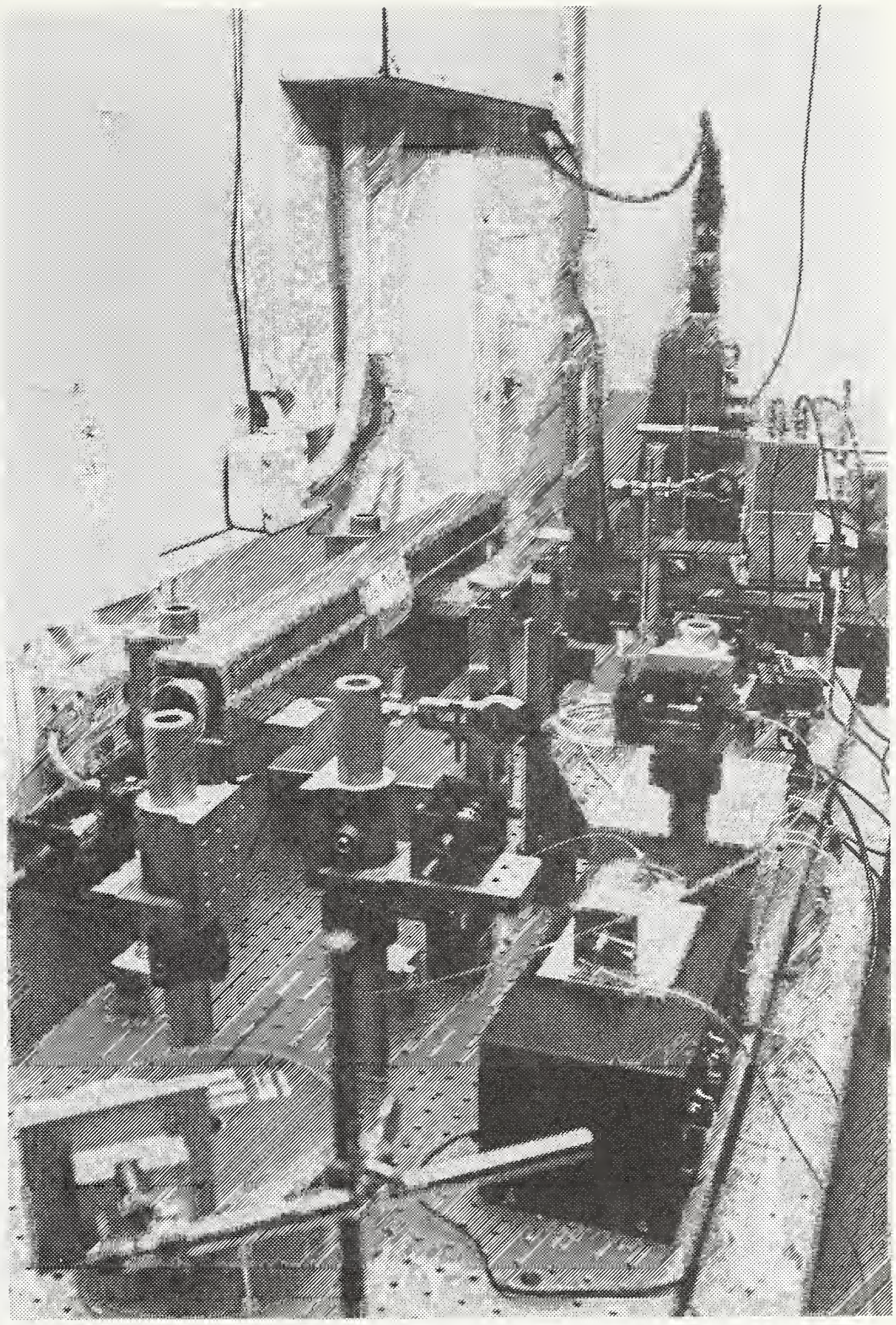


Figure 4. Photograph of the scanning system shows fiber couplers, mirror holders and HeNe and diode laser sources in the foreground; and monitor with back of chassis toward viewer, beam splitter with dark frame and scanner on the metal table in the rear.

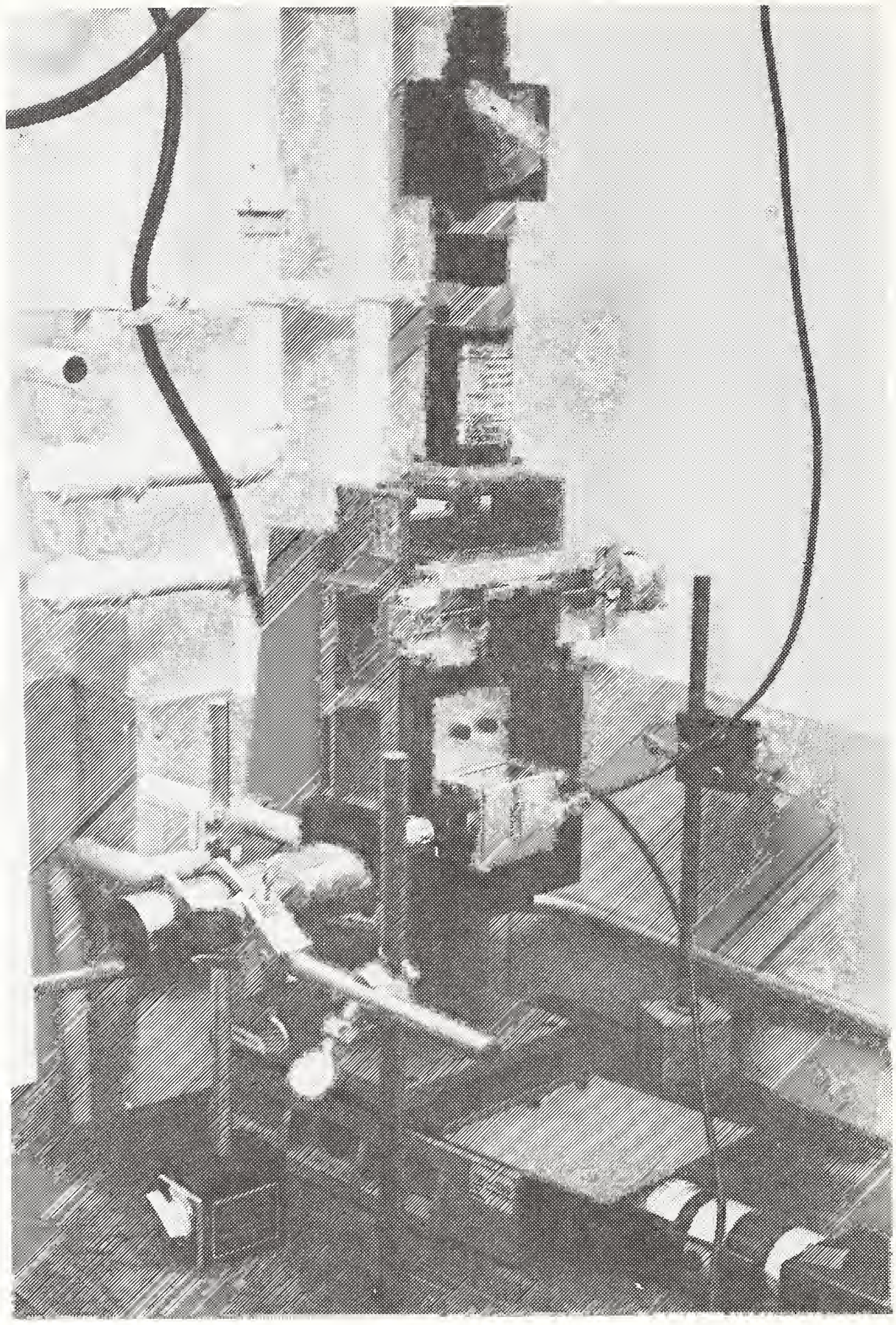


Figure 5. Photograph shows X-Y scanner with Z adjustment micrometer and detector attached on the side. Absorber for capturing an unused beam and microscope objective for controlling beam size are in front of the scanner.

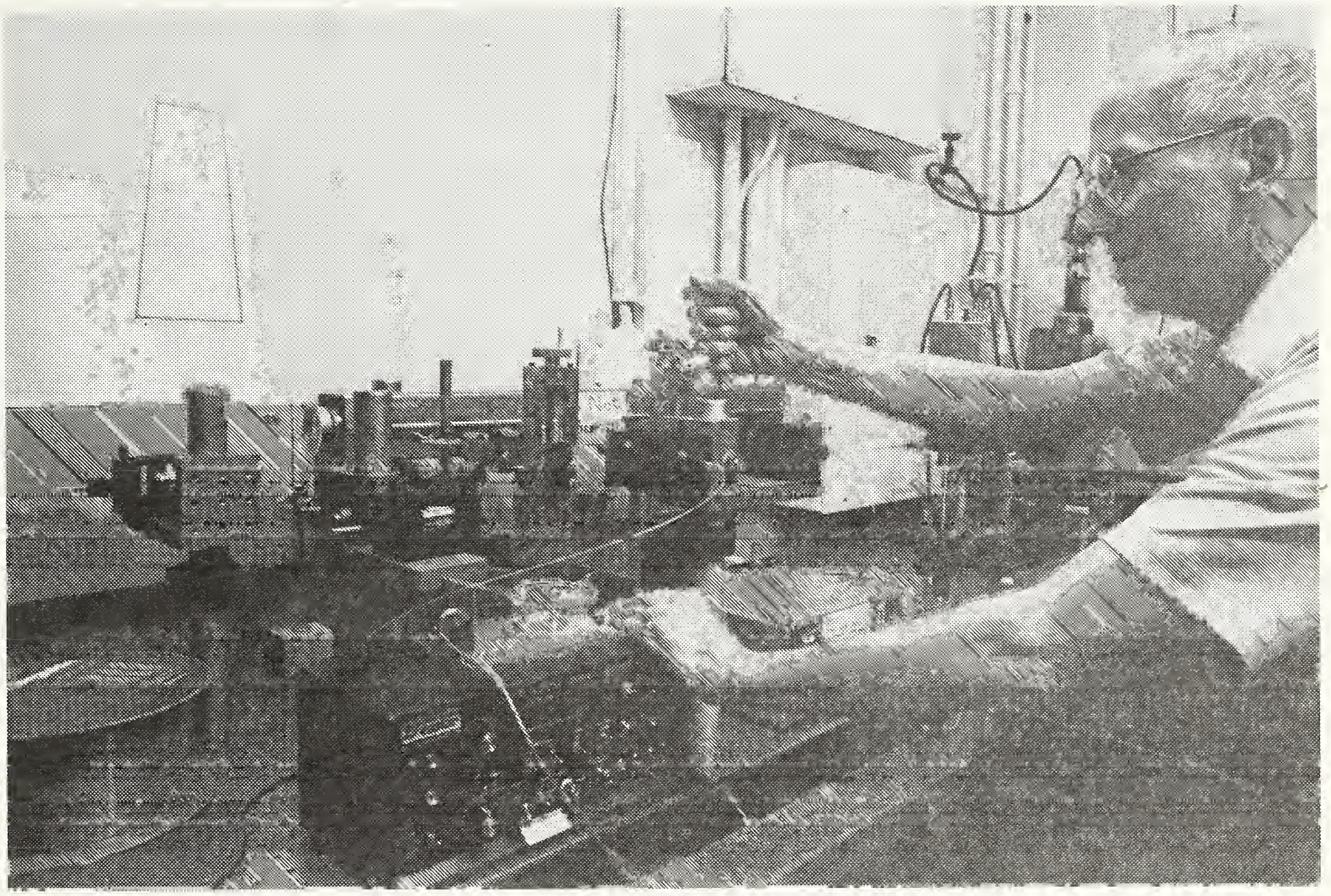


Figure 6. Photograph of a portion of the scanning system shows Alvin Rasmussen adjusting platform holding fiber couplers for laser diode outputs. Near Rasmussen's right hand, structures with small handles each move a mirror into the beam to direct it to the scanner in the rear.

Appendix A: Monitor specifications

1. Readout: A/D card or voltmeter attached to a computer.
2. Nanovolt amplifier: gains 10^2, 10^3, 10^4, and 10^5; 10 V maximum.
3. Detector: silicon PIN photodiode (Rosy 7-1), ~1 cm^2 area, 100 Ω and 1000 Ω load, 0.4-1.1 μm wavelength range.
4. Integrating sphere: cube with a 3.57 cm D sphere inside having a white coating of barium sulfate, 0.766 cm inside D of entrance, ~0.8 cm inside D of exit, ~0.2 throughput (decimal fraction of entrant energy emerging from sphere), beam distributed uniformly on detector, baffle inside sphere stops first reflection entering the detector.
5. Alignment parts: front surface mirror to reflect the beam on itself, iris to center the beam into the detector.
6. Bias power supply: -180.0 V
7. Temperature controller: maintain temperature about 30 ± 0.1°C with a readout of 3.9 kΩ.
8. Temperature controller power supply: 15 V
9. Positioner: with six degrees of freedom: align detector

Appendix B: A/D converter boards and amplifiers attached to monitor and unknown detector

A/D converter: Lab Master DMA with PGL, product 811963.

Components: Terminal, daughter and mother boards connected in that order.

Terminal board:

Channel 0: Unknown detector; gain 1, 10, 100, 500 (gain setting 0, 1, 2, 3); bipolar.

Channel 1: Monitor, gain 1 (gain setting 0), bipolar.

Daughter board: pseudodifferential (low terminal referred to a voltage without ground).

Mother board: Inside computer.

Gain:

Resolution*	Gain	Range	Gainsetting
4.8828 mV	1	± 10 V	0
488.28 μV	10	± 1 V	1
48.828 μV	100	± 0.1 V	2
9.7656 μV	500	± 0.02 V	3

Amplifiers: Nanovolt amplifier

Keithley 140

Gain: 10^2, 10^3, 10^4, 10^5

Uncertainty of gain: 0.01%

* Manufacturer's values

Appendix C: Home coordinates, step, and feedrate for the unknown detector or the pinhole attached to a detector

Manual control or joystick:

Set motion controller to [IMD] [SLW] for maximum speed of about 1 cm/sec. Set motion controller to [IMD] [F - n n n n n] [SLW] to set any speed. [F - n n n n n] is a divisor with default value of 2 for maximum speed and 65535 for minimum speed. The authors use the default speed and gently push the joystick with + X = left and + Y = down. These directions of motion make the beam appear to scan the device rather than the device scan the beam.

Joystick used to find home coordinates of the detector and the beam:

1. Unknown detector home coordinates. Read the coordinates of the lower left hand corner of the unknown detector on the motion controller.
2. Beam home coordinates. Read the coordinates of the pinhole with maximum light passing through it on the motion controller. Use a small mirror to observe the beam on the rear side of the pinhole. Using the pinhole coordinates, estimate the coordinates of the lower left corner of a square containing the beam.
3. Lower left corner coordinates will be smaller than the center ones.

Entering home coordinates in the program:

Place home coordinates in the programs as follows:

CMD1$ = "IG7*G0X(home coordinate) F(current value)Y(home coordinate) F(current value)*G92X0Y0*G10".

Determining step and feedrate:

Estimate the area of the unknown detector or beam. Select the resolution and the matrix needed. Divide by one of the factors of the matrix to obtain the step size. Select a feed rate about the same order of magnitude as the step size.

Examples of entering steps and feedrates in the programs and of the path of the scan:

1. Unknown detector measurements

   Use program SCAN2525. Enter X, Y, and F values.

   Example:

   1000 CMD1$ = "IX500F2000D50"

   2100 CMD1$ = "IX-500F2000D50"

   570 NEXT X

   CMD1$ = "IY500F2000D50"

   Programs with other matrices may be selected.

2. Beam measurements

   Use program 2525PINO.

   Enter X, Y, and F values.

   Example:

   1000 CMD1$ = "IX5F10D50"

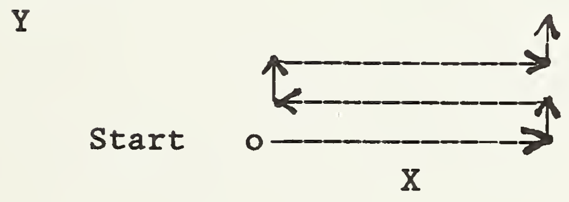
   2100 CMD1$ = "IX-5F10D50"

   570 NEXT X

   CMD1$ = "IY5F10D50"

3. Path of the Scan

   Repeats until XY matrix recovered.



Appendix D: Pinholes, X and Y scale limits, and Z adjustment along optical axis

Pinholes: Diameters 5, 10, 15, 25, 50, and 100 μm. Area about $\leq$ 30% of beam area.

X and Y scale limits: These are the linear translation tables.

Resolution of X and Y, 1 μm; maximum X, 15 cm; maximum Y, 15 cm.

Z micrometer adjustment along optical axis:

Left revolution counter reads to 0.1 mm (accuracy 0.1 mm). Scale and right vernier reads to 0.01 mm (accuracy 0.1 mm/m). Detector is attached to Z, which is attached to the X and Y linear translation tables.

Appendix E: System equations

The power in the monitor W_M is

$$W_M = \frac{V_M}{C_M}$$

where V_M is the voltage of the monitor divided by the gain of the amplifier used and C_M is the calibration of the monitor in (V/W) with the monitor in the (m=+1) beam of the beam splitter wedge. The wedge beams are identified as follows: transmitted beam (m=0), beam reflected from the back surface (m=+1), and beam reflected from the back and front surfaces (m=2). From these designations, we get ratios of beams such as appear in the text.

The power in the unknown W_u is

$$W_u = \frac{W_M}{\frac{(m=+1)}{(m=2)}} = \frac{V_M}{C_M \frac{(m=+1)}{(m=2)}}$$

where (m=+1)/(m=2) is the beam splitter ratio with the monitor in the (m=+1) beam and the unknown in the (m=2) beam of the beam splitter wedge.

The calibration of the unknown C_u with the unknown in the (m=2) beam is

$$\begin{aligned} C_u &= \frac{V_u}{W_u} \\ &= \frac{V_u}{V_M} C_M \frac{(m=+1)}{(m=2)} \\ &= \frac{V_u}{V_M} 34.66 \cdot 12.27 \\ &= \frac{V_u}{V_M} 425.3 \end{aligned}$$

where C_u is in (V/W) and V_u is the voltage of the unknown divided by the gain of the amplifier used. C_M = 34.66 V/W at 0.6328 μm and (m=+1)/(m=2)=12.27 for SF6 glass (the composition of the beam splitter) at 0.6328 μm.

V_u with the unknown in the (m=2) beam is

$$V_u = \frac{C_u\ V_M}{425.3}$$

The equation may be used to determine whether V_u exceeds the scale limits of the readout instrument.

The power in the unknown W_u' is

$$W_u' = W_M \frac{(m=0)}{(m=+1)} = \frac{V_M}{C_M} \frac{(m=0)}{(m=+1)}$$

when (m=0)/(m=+1) is the beam splitter ratio with the unknown in the (m=0) beam and the monitor in the (m=+1) beam of the beam splitter wedge.

The calibration of the unknown C_u with the unknown in (m=0) beam is

$$\begin{aligned} C_u &= \frac{V_u'}{W_u'} \\ &= \frac{V_u'}{V_M} \frac{C_M}{\frac{(m=0)}{(m=+1)}} \\ &= \frac{V_u'}{V_M} \frac{34.66}{12.27} \\ &= \frac{V_u'}{V_M}\ 2.825 \end{aligned}$$

where C_u is in (V/W) and V_u' is the volts of the unknown divided by the gain of the amplifier used. C_M = 34.66 V/W at 0.6328 μm and (m=0)/(m=+1) = 12.27 for SF6 glass at 0.6328 μm.

V_u' with the unknown in the (m=0) beam is

$$V_u' = \frac{C_u\ V_M}{2.825}$$

The equation may be used to determine whether V_u' exceeds the scale limits of the readout instrument.

Finally

$$p = \frac{2(W_u \text{ or } W_u')}{\pi R^2}$$

where P = the peak irradiance in W/cm^2

and R = the radius in cm of the beam at the $1/e^2$ intensity.

Appendix F: Procedures and menus for surfer graphics

Explanation of menu choices for data:

1. Change Parameters.
   To change run, axis, rotation, and tilt parameters.

2. View Surface.
   To plot on screen.

3. Plot Surface.
   To plot on printer or plotter depending upon output device selected in 11.

4. Raise Baseline.
   To eliminate data below new baseline and to expand scale of remaining data.

5. Offset Data so that Lowest Point = 0.

6. Invert Data.
   To change sign of data.

7. Calculate Mean and Deviation of Z-Data over present area.
   To analyze data of a selected area.

8. Convert Data to Percentage of full Scale.

9. Restore Original Data.

10. Topographical Maps.
    To make contour maps.

11. Change Output Device.
    To change output device to either a printer or a plotter, LQ 1500 or 7440A respectively.

12. Enlarge Portion of Graph.

    To observe details.

13. Print Run Information.

    To accompany graphics and to review run information.

20. Exit.

    To exit computer or to enter a program.

Examples of procedures and menus:

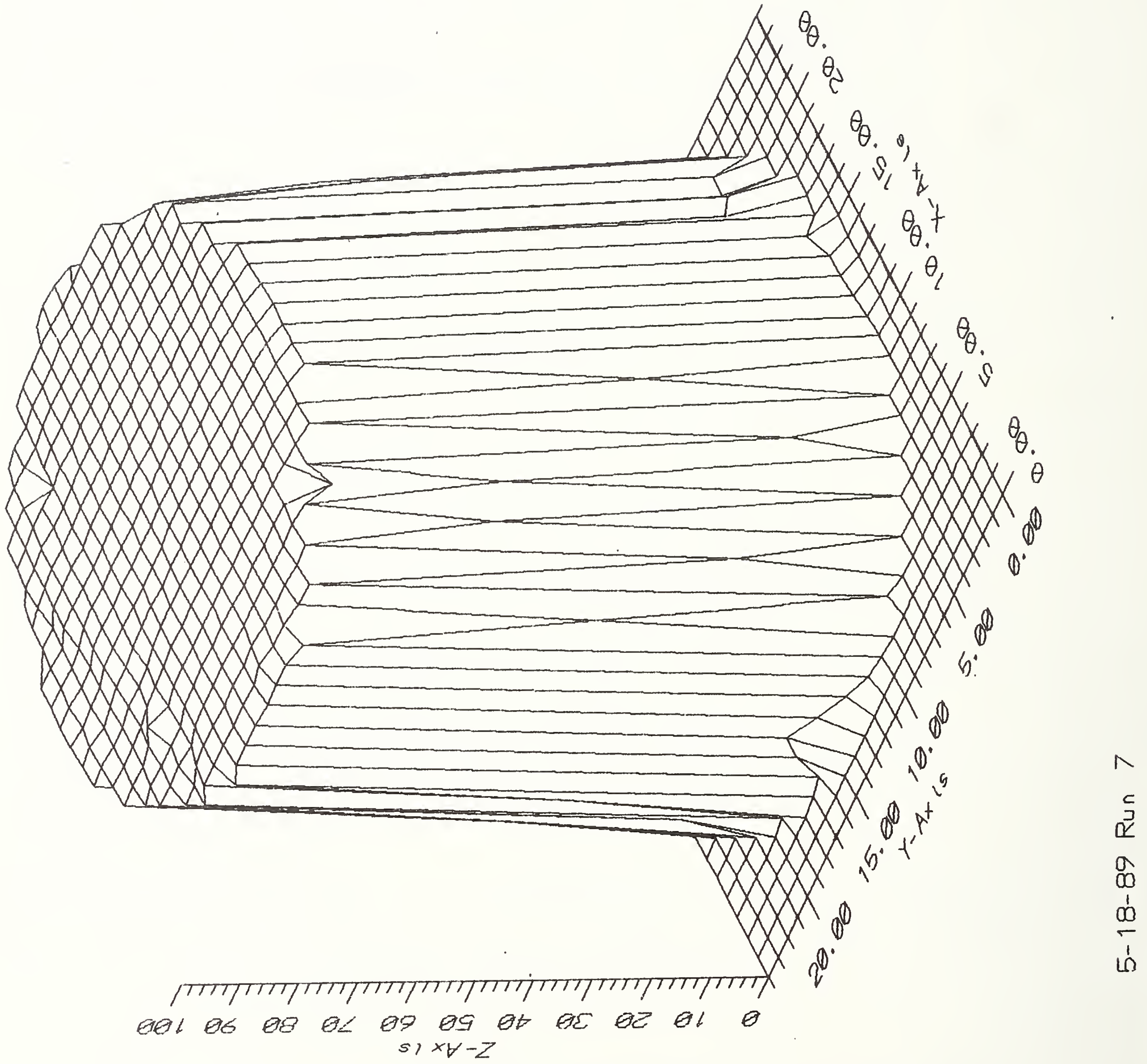
Application of graphics software follows data printout of run

```
 613           -76.8324       -72.53242      -1622.355
 614           -74.65448      -72.53242      -1622.355
 615           -72.25034      -72.25034      -1622.355
 616           -73.79683      -72.25034      -1622.355
 617           -73.29253      -72.25034      -1622.355
 618           -72.67139      -72.25034      -1622.355
 619           -72.26373      -72.25034      -1622.355
 620           -73.38852      -72.25034      -1622.355
 621           -72.68532      -72.25034      -1622.355
 622           -72.84615      -72.25034      -1622.355
 623           -72.89775      -72.25034      -1622.355
 624           -73.29259      -72.25034      -1622.355
 625           -72.07173      -72.07173      -1622.355
mean of unknown =-1029.685
 standard deviation=  720.5662
Percent standard deviation =  Max =        -35.26251
Min =          -1573.761
0-stop
1-copy array data to printer
type number? ? 0

C:\SOURCE>color 01,77

C:\SOURCE>echo off
C:\SOURCE>surf1




Enter Input File Name (default = dump.): ?




Working...
Finished

C:\SOURCE>surf2

C:\SOURCE>echo off
```

```
Input Plot Title (default:  ) ? 5-18-89 Run 7
Input X-Axis Label (default: "X-Axis" ) ?
Input Y-Axis Label (default: "Y-Axis" ) ?
Input Z-Axis Label (default: "Z-Axis" ) ?
Input Rotation About Z-Axis (default:  225  degrees) ?
Input Tilt After Rotation (default:  30  degrees) ?
Input the Number of Z-Axis Decimal Digits Displayed
(default: 3 )? 0
Input Z-Axis Scale Factor or A for Automatic
(default: Auto )
Suggested Value (Auto) =               0.015
?
Input Z-Axis Labeled Tick Spacing or A for Automatic
(default: AUTO ) ? 10



Plot Title = "5-18-89 Run 7"
X-Axis Label = "X-Axis"
Y-Axis Label = "Y-Axis"
Z-Axis Label = "Z-Axis"
Rotation About Z-Axis =  225
Tilt After Rotation =  30
Z-Axis Digits Displayed =  0
Z-Axis Scale Factor = Auto
Z-Tic Spacing =  10

Is This Correct (Y/n)



Input Date of Actual Run (default:  ) ? 5-18-89
Amplifier Gain Setting (default:  0  ) ? 10
Input Laser Identifier (default:  ) ? HeNe
Input Detector Identifier (default:  ) ? 4-8
Input Pinhole Identifier (default:  ) ?



Run Date: 5-18-89
Gain:  10
Laser: HeNe
Detector: 4-8
Pinhole: none

Is This Correct? (Y/n)
```

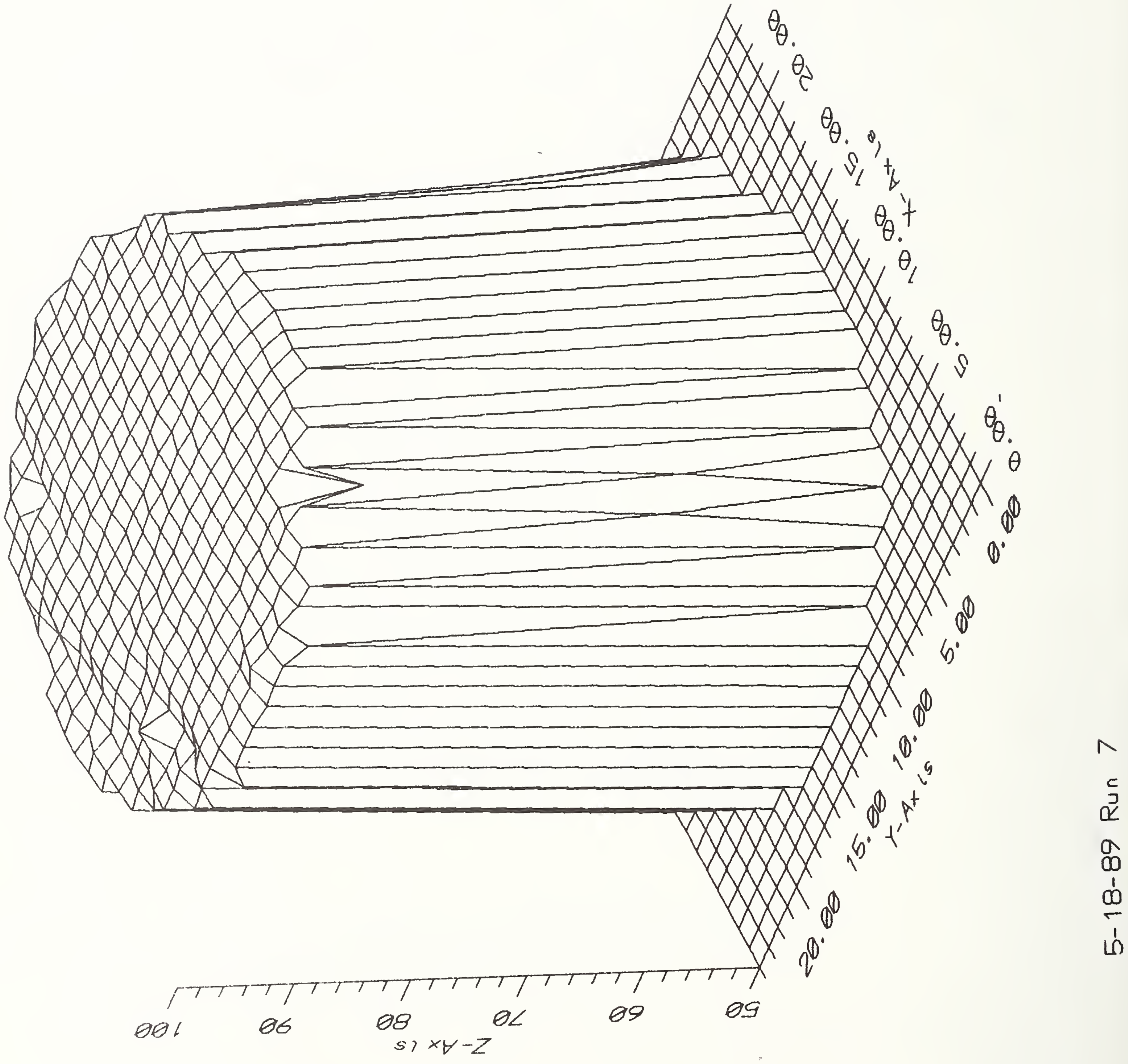
```
Presently:   Min-X =   0   Max-X =   24
             Min-Y =   0   Max-Y =   24
             Min-Z = -1573.761   Max-Z = -35.26251

1.   Change Parameters
2.   View Surface
3.   Plot Surface
4.   Raise Baseline
5.   Offset Data so that Lowest Point = 0
6.   Invert Data
7.   Calculate Mean and Deviation of Z-Data over Present Area
8.   Convert Data to Percentage of Full Scale
9.   Restore Original Data
10.  Topographical Maps
11.  Change Output Device
12.  Enlarge Portion of Graph
13.  Print Run Information

20.  Exit



 Input Number of Desired Option? 6

 Reading: dump.grd  Writing: dump2.grd



 Presently:   Min-X =   0   Max-X =   24
              Min-Y =   0   Max-Y =   24
              Min-Z =  35.26251   Max-Z =  1573.761

 1.   Change Parameters
 2.   View Surface
 3.   Plot Surface
 4.   Raise Baseline
 5.   Offset Data so that Lowest Point = 0
 6.   Invert Data
 7.   Calculate Mean and Deviation of Z-Data over Present Area
 8.   Convert Data to Percentage of Full Scale
 9.   Restore Original Data
 10.  Topographical Maps
 11.  Change Output Device
 12.  Enlarge Portion of Graph
 13.  Print Run Information

 20.  Exit
```

```
Input Number of Desired Option? 8

Reading: dump2.grd  Writing: dump3.grd



Presently:  Min-X =  0  Max-X =  24
            Min-Y =  0  Max-Y =  24
            Min-Z =  0  Max-Z =  100

1.  Change Parameters
2.  View Surface
3.  Plot Surface
4.  Raise Baseline
5.  Offset Data so that Lowest Point = 0
6.  Invert Data
7.  Calculate Mean and Deviation of Z-Data over Present Area
8.  Convert Data to Percentage of Full Scale
9.  Restore Original Data
10. Topographical Maps
11. Change Output Device
12. Enlarge Portion of Graph
13. Print Run Information

20. Exit

Input Number of Desired Option? 3




PLOT Version 4.07
(C) Copyright Golden Software 1988
Press Ctrl-C to abort...

Do you wish to shift the entire plot? No

Do you wish to scale the entire plot? No

Optimizing SURFDATA.PLT for printer output... Please wait

Processing record number 1722

SURFDATA.OPT has been created

Position paper and press any key to plot SURFDATA.OPT...^C



Press any key to return to SURF...
```


Z-Axis
0 10 20 30 40 50 60 70 80 90 100
Y-Axis
0.00 5.00 10.00 15.00 20.00
X-Axis
0.00 5.00 10.00 15.00 20.00
5-18-89 Run 7

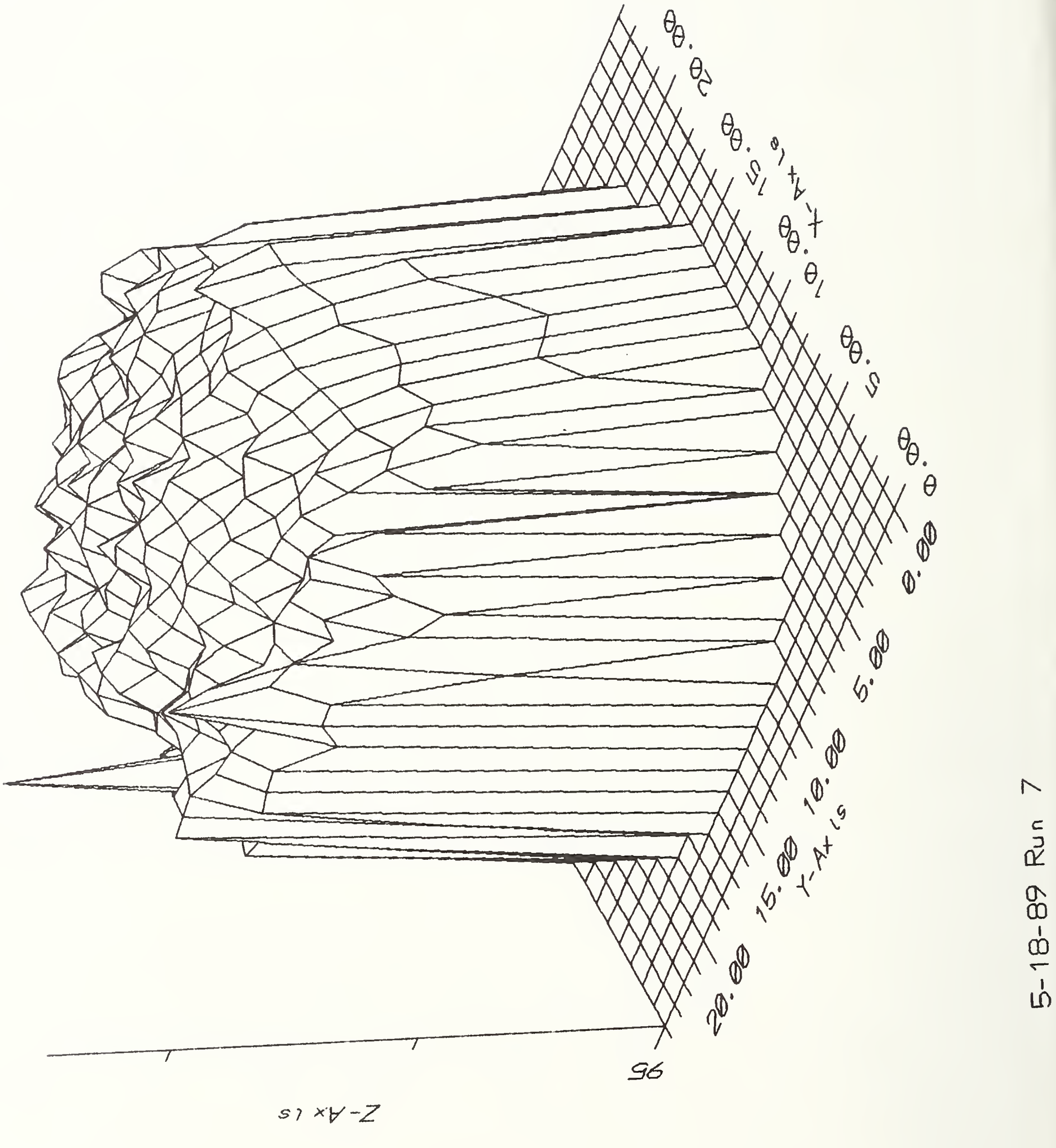
```
Input Number of Desired Option? 4

Presently:  Min-X =  0  Max-X =  24
            Min-Y =  0  Max-Y =  24
            Min-Z =  50  Max-Z =  100

1.   Change Parameters
2.   View Surface
3.   Plot Surface
4.   Raise Baseline
5.   Offset Data so that Lowest Point = 0
6.   Invert Data
7.   Calculate Mean and Deviation of Z-Data over Present Area
8.   Convert Data to Percentage of Full Scale
9.   Restore Original Data
10.  Topographical Maps
11.  Change Output Device
12.  Enlarge Portion of Graph
13.  Print Run Information

20.  Exit

Input Number of Desired Option?
```

Detector Measurement



```
Input Number of Desired Option? 4
Present Z-Values range from:  0  to  100
Input new minimum value for Z: 95

Reading: dump3.grd  Writing: dump2.grd



Presently:  Min-X =  0  Max-X =  24
            Min-Y =  0  Max-Y =  24
            Min-Z =  95  Max-Z =  100

1.   Change Parameters
2.   View Surface
3.   Plot Surface
4.   Raise Baseline
5.   Offset Data so that Lowest Point = 0
6.   Invert Data
7.   Calculate Mean and Deviation of Z-Data over Present Area
8.   Convert Data to Percentage of Full Scale
9.   Restore Original Data
10.  Topographical Maps
11.  Change Output Device
12.  Enlarge Portion of Graph
13.  Print Run Information

20.  Exit
```

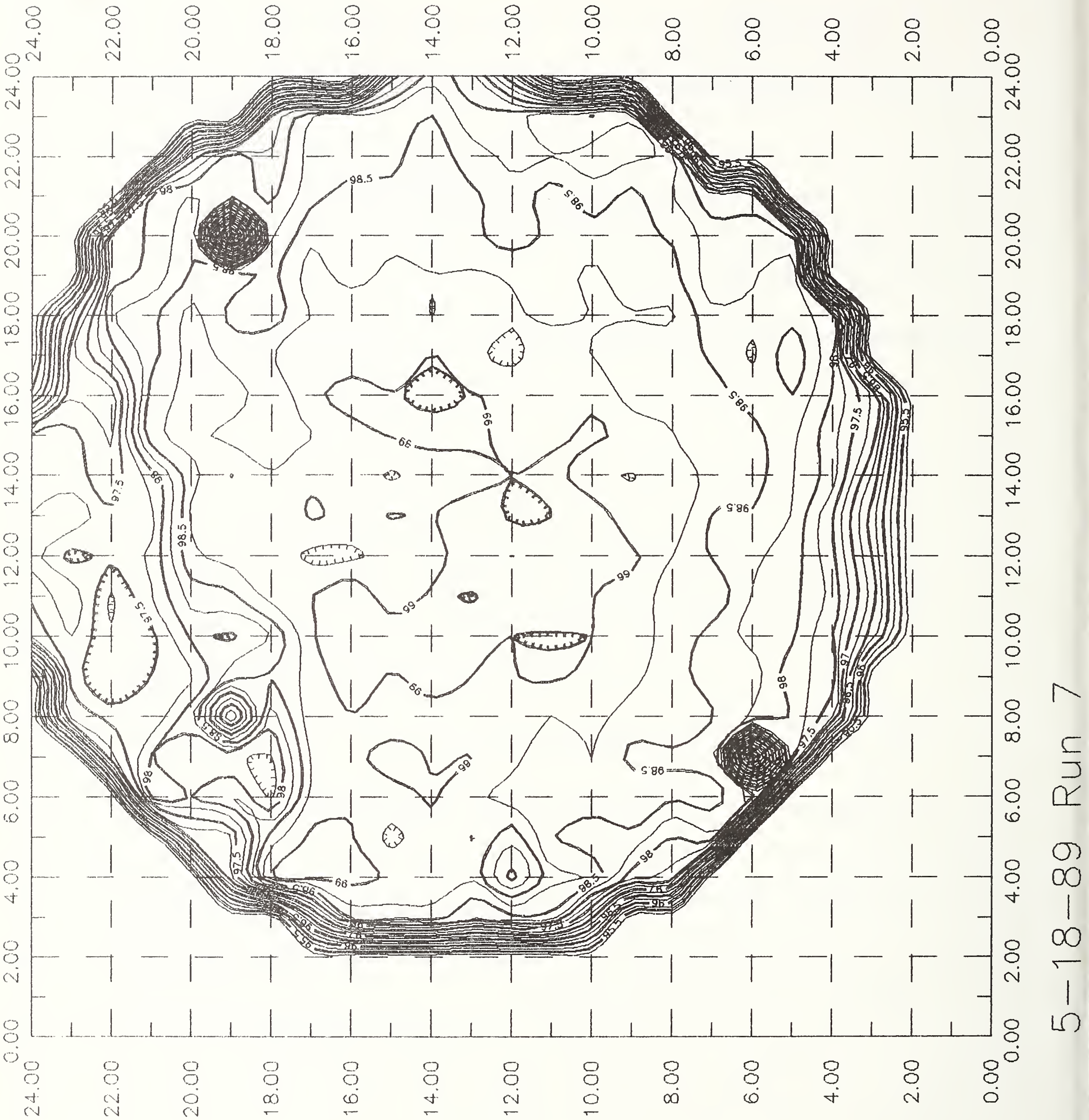
Detector Measurement



```
Input Number of Desired Option? 1



Input Plot Title (default: "5-18-89 Run 7" ) ?
Input X-Axis Label (default: "X-Axis" ) ?
Input Y-Axis Label (default: "Y-Axis" ) ?
Input Z-Axis Label (default: "Z-Axis" ) ?
Input Rotation About Z-Axis (default:  225  degrees) ?
Input Tilt After Rotation (default:  30  degrees) ?
Input the Number of Z-Axis Decimal Digits Displayed
(default: 0 )? 3
Input Z-Axis Scale Factor or A for Automatic
(default: Auto )
Suggested Value (Auto) =                    4.800
?
Input Z-Axis Labeled Tick Spacing or A for Automatic
(default:  10  ) ?



 Plot Title = "5-18-89 Run 7"
 X-Axis Label = "X-Axis"
 Y-Axis Label = "Y-Axis"
 Z-Axis Label = "Z-Axis"
 Rotation About Z-Axis =  225
 Tilt After Rotation =  30
 Z-Axis Digits Displayed =  3
 Z-Axis Scale Factor = Auto
 Z-Tic Spacing = AUTO

 Is This Correct (Y/n)



 Input Date of Actual Run (default: 5-18-89 ) ?
 Amplifier Gain Setting (default:  10  ) ?
 Input Laser Identifier (default: HeNe ) ?
 Input Detector Identifier (default: 4-8 ) ?
 Input Pinhole Identifier (default: none ) ?



  Run Date: 5-18-89
  Gain:  10
  Laser: HeNe
  Detector: 4-8
  Pinhole: none
```

```
Input Number of Desired Option? 10



Enhance the Contour Resolution Of Which Surface?

1. Upper Surface
2. Lower Surface
3. Use Linear Contour Spacing

Input Number of Desired Option (default = linear): ?



Enter Contour Interval Step Size (as a Percentage of Full Scale)
(default =  20  % ) ? 5
Enter Labeled Contour Line Frequency (default =  2  )
?



Choose Labeled Contour Line Type

1. Normal
2. Bold
3. Dashed

Enter Number of Desired Option (default =  1  )
? 2



Do You Want Grid Lines (Yes or No, default = No ) ? yes



Linear Contour Line Spacing of  10  %
Labeled Contour Line Frequency of  2
Labeled Contour Line type: Bold
Plot Grid Lines? Yes

Is This Correct? (Y/n)
```

```
Do You Want To View or Plot the Surface?

1. View Surface
2. Plot Surface
3. Return to Main Menu

Input Number of Desired Option? 1


Do You Want To View or Plot the Surface?

1. View Surface
2. Plot Surface
3. Return to Main Menu

Input Number of Desired Option? 2


WORKING...


Plotting grid


PLOT Version 3.11
(C) Copyright Golden Software 1987
Press Ctrl-C to abort...

Do you wish to shift the entire plot? No

Do you wish to scale the entire plot? No

Optimizing SURFDATA.PLT for printer output... Please wait

Processing record number 6940 .

SURFDATA.OPT has been created

Position paper and press any key to plot SURFDATA.OPT...


Press any key to return to TOPO...
```


5-18-89 Run 7

```
Input Number of Desired Option? 9



Presently:  Min-X =   0   Max-X =   24
            Min-Y =   0   Max-Y =   24
            Min-Z = -1573.761   Max-Z = -35.26251

1.   Change Parameters
2.   View Surface
3.   Plot Surface
4.   Raise Baseline
5.   Offset Data so that Lowest Point = 0
6.   Invert Data
7.   Calculate Mean and Deviation of Z-Data over Present Area
8.   Convert Data to Percentage of Full Scale
9.   Restore Original Data
10.  Topographical Maps
11.  Change Output Device
12.  Enlarge Portion of Graph
13.  Print Run Information

20.  Exit

Input Number of Desired Option?  6



Presently:  Min-X =   0   Max-X =   24
            Min-Y =   0   Max-Y =   24
            Min-Z =   35.26251   Max-Z =   1573.761

1.   Change Parameters
2.   View Surface
3.   Plot Surface
4.   Raise Baseline
5.   Offset Data so that Lowest Point = 0
6.   Invert Data
7.   Calculate Mean and Deviation of Z-Data over Present Area
8.   Convert Data to Percentage of Full Scale
9.   Restore Original Data
10.  Topographical Maps
11.  Change Output Device
12.  Enlarge Portion of Graph
13.  Print Run Information

20.  Exit
```

```
Input Number of Desired Option? 12


Previously:  Min-X =  0  Max-X =  24

 Values will be rounded to the nearest row of data

Input New Minimum X Value,  0  <= X <=  24
? 6

Input New Maximum X Value,  6  < X <=  24
? 18



Presently:  Min-Y =  0  Max-Y =  24

 Values will be rounded to the nearest column of data

Input New Minimum Y Value,  0  <= Y <=  24
? 8

Input New Maximum Y Value,  8  < Y <=  24
? 18



New Values: Min-X =  6  Max-X =  18
            Min-Y =  8  Max-Y =  18

Is This Correct? (Y/n)
```

```
Presently:   Min-X =  6  Max-X =  18
             Min-Y =  8  Max-Y =  18
             Min-Z =  35.26251  Max-Z =  1573.761

1.   Change Parameters
2.   View Surface
3.   Plot Surface
4.   Raise Baseline
5.   Offset Data so that Lowest Point = 0
6.   Invert Data
7.   Calculate Mean and Deviation of Z-Data over Present Area
8.   Convert Data to Percentage of Full Scale
9.   Restore Original Data
10.  Topographical Maps
11.  Change Output Device
12.  Enlarge Portion of Graph
13.  Print Run Information

20.  Exit

Input Number of Desired Option? 7
```

```
Title: "5-23-89 Run 2"

Listing Produced: 05-23-1989  12:55:58

For the Z Data in the Area Enclosed By:

Min-X =  6  Max-X =  18
Min-Y =  8  Max-Y =  18

MEAN        =  1556.126503496504
MAXIMUM     =  1562.303
MINIMUM     =  1538.233
MAX - MIN   =  24.07000000000016
VARIANCE    =  13.64693313110668

Printing...

Do You Want to Print the Run Information? (y/N)
```

```
Presently:  Min-X =  6   Max-X =  18
            Min-Y =  8   Max-Y =  18
            Min-Z =  35.26251  Max-Z =  1573.761

1.  Change Parameters
2.  View Surface
3.  Plot Surface
4.  Raise Baseline
5.  Offset Data so that Lowest Point = 0
6.  Invert Data
7.  Calculate Mean and Deviation of Z-Data over Present Area
8.  Convert Data to Percentage of Full Scale
9.  Restore Original Data
10. Topographical Maps
11. Change Output Device
12. Enlarge Portion of Graph
13. Print Run Information

20. Exit

Input Number of Desired Option? 13



Prepare Printer for Output and Press a Key
Or Enter an 'A' to Abort:




Title:                    "5-18-89 Run 7"

Listing Produced:         06-02-1989  11:33:29

Actual Run Date:          5-18-89
Rotation (degrees):        225
Z-axis Tilt (degrees):     30
Amplifier Gain:            10
Laser Identifier:         HeNe
Detector Identifier:      4-8
Pinhole Identifier:       none
Total Sample Points:       50  x  50

No optical fiber used
Monitor gain 10(2)
Tektronix 600 ohm load used
Detector 9 mm away from the objective
Daughter board gain setting 0
500 um/div
Max = 1574
Min = 35
```

```
Presently:  Min-X =  0  Max-X =  24
            Min-Y =  0  Max-Y =  24
            Min-Z =  0  Max-Z =  100

1.  Change Parameters
2.  View Surface
3.  Plot Surface
4.  Raise Baseline
5.  Offset Data so that Lowest Point = 0
6.  Invert Data
7.  Calculate Mean and Deviation of Z-Data over Present Area
8.  Convert Data to Percentage of Full Scale
9.  Restore Original Data
10. Topographical Maps
11. Change Output Device
12. Enlarge Portion of Graph
13. Print Run Information

20. Exit


 Input Number of Desired Option? 20



 C:\SOURCE>rem Deleting Temporary Data Files...

 C:\SOURCE>del dump2.grd

 C:\SOURCE>del dump3.grd

 C:\SOURCE>del surf*.CMD

 C:\SOURCE>rem finished

 C:\SOURCE>bye



  This utility will park the heads on your hard disk
  Strike any key to park the heads.... Control-Break
  if you wish to abort.
 Strike a key when ready . . .
 Shutdown Utility    Version 2.1    1/10/85

 Shutdown cylinder = 614

 Shutdown Completed -- OK to Turn Power OFF
```

Appendix G: Examples of graphics

Beam and detector graphics data at 9 mm, 15.2 mm, and 25 mm from a microscope objective (x10) with a 9 mm working distance. Beam radii, R, were approximately 70, 400, and 1100 μm, respectively. These data demonstrate system capability and do not include system uncertainties. Distance between divisions was 250 μm. Ten data points were averaged at each XYZ position plotted.

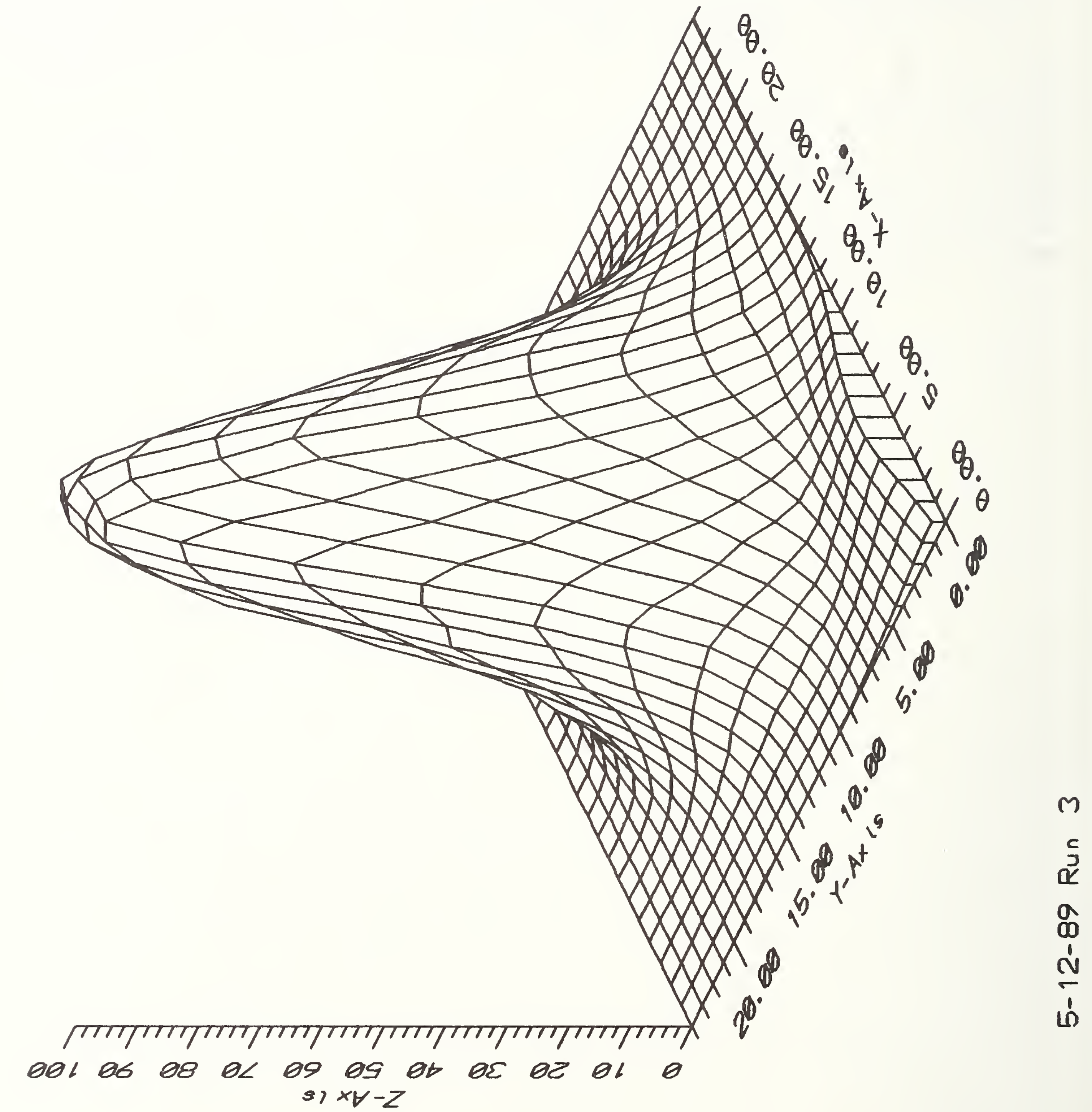
Detector graphics smooths and rounds with increasing beam radius. Raising the baseline from 0 to 50 percent enhances the relief of the response.

Beam measurement at 9 mm from a microscope objective (x10)

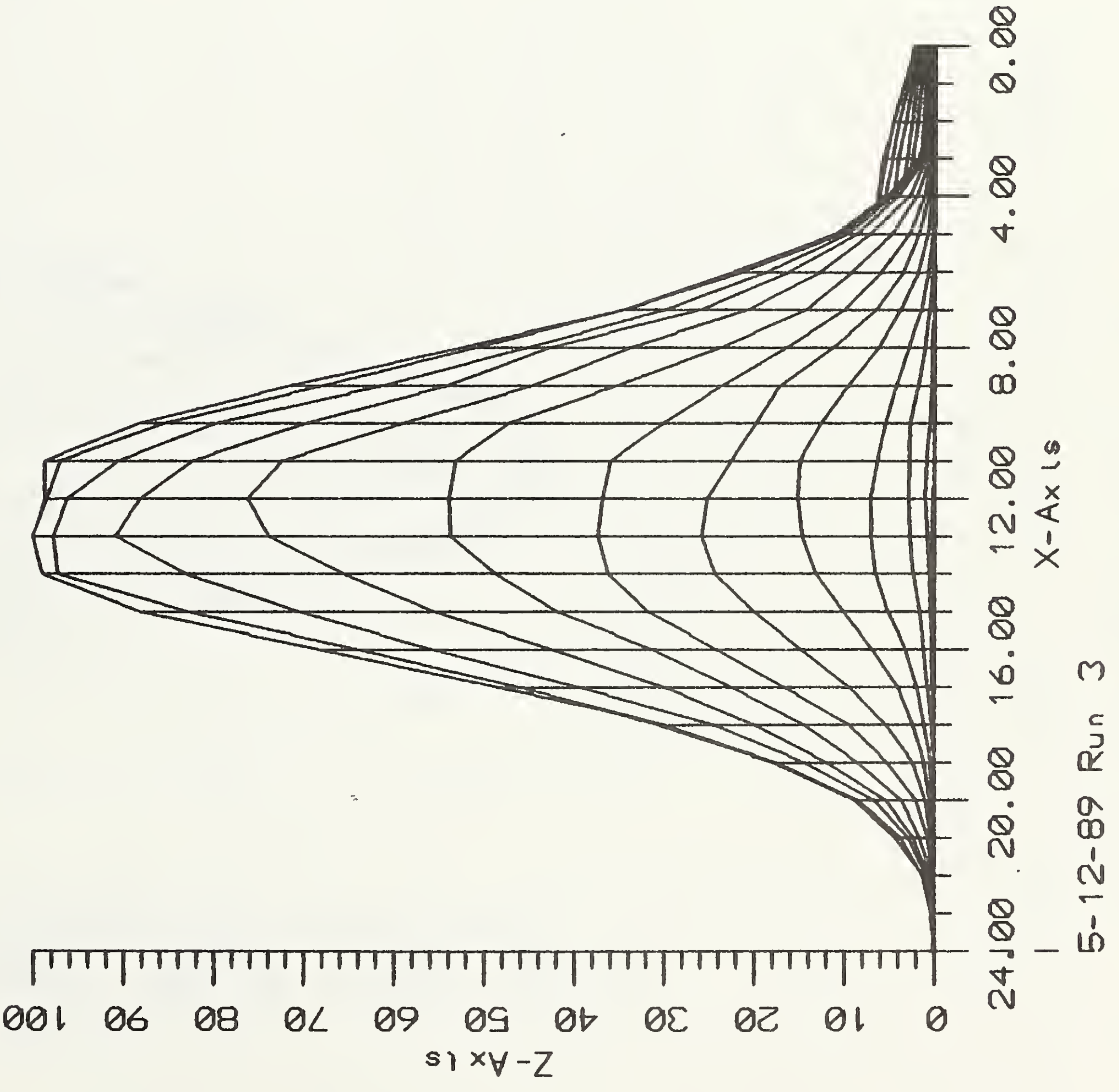
Title:	"5-12-89 Run 3"
Listing Produced:	05-18-1989 09:02:27
Actual Run Date:	5-12-89
Rotation (degrees):	225
Z-axis Tilt (degrees):	30
Amplifier Gain:	10
Laser Identifier:	HeNe
Detector Identifier:	SDC1
Pinhole Identifier:	10 um
Total Sample Points:	25 x 25

No optical fiber used
Monitor gain 10(2)
Tektronix 600 ohm load used
Detector 9 mm away from the objective
Gain setting 0
10 um/div
Max = 1304 Min = 14

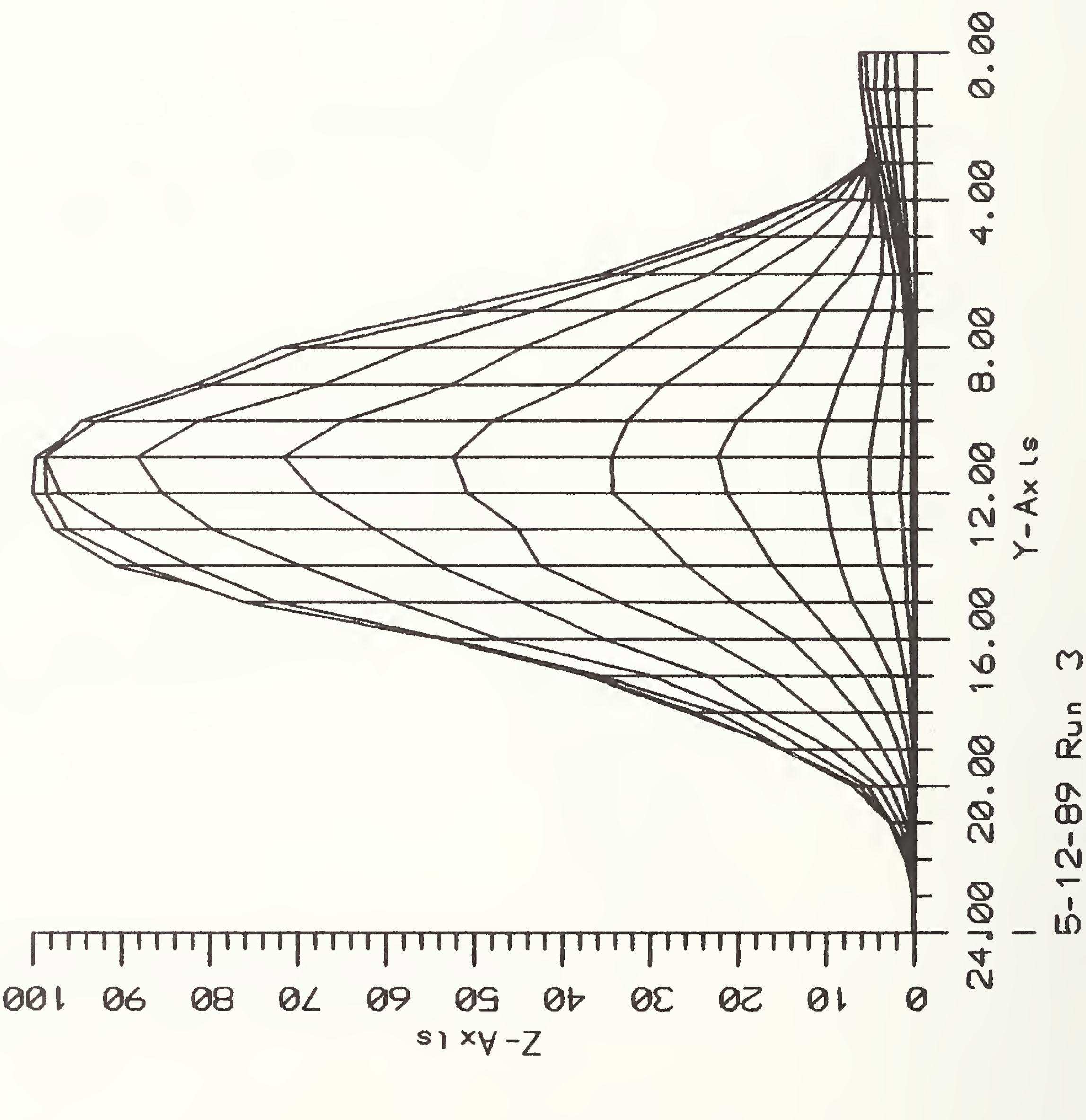
Beam measurement at 9 mm from a microscope objective (x10)



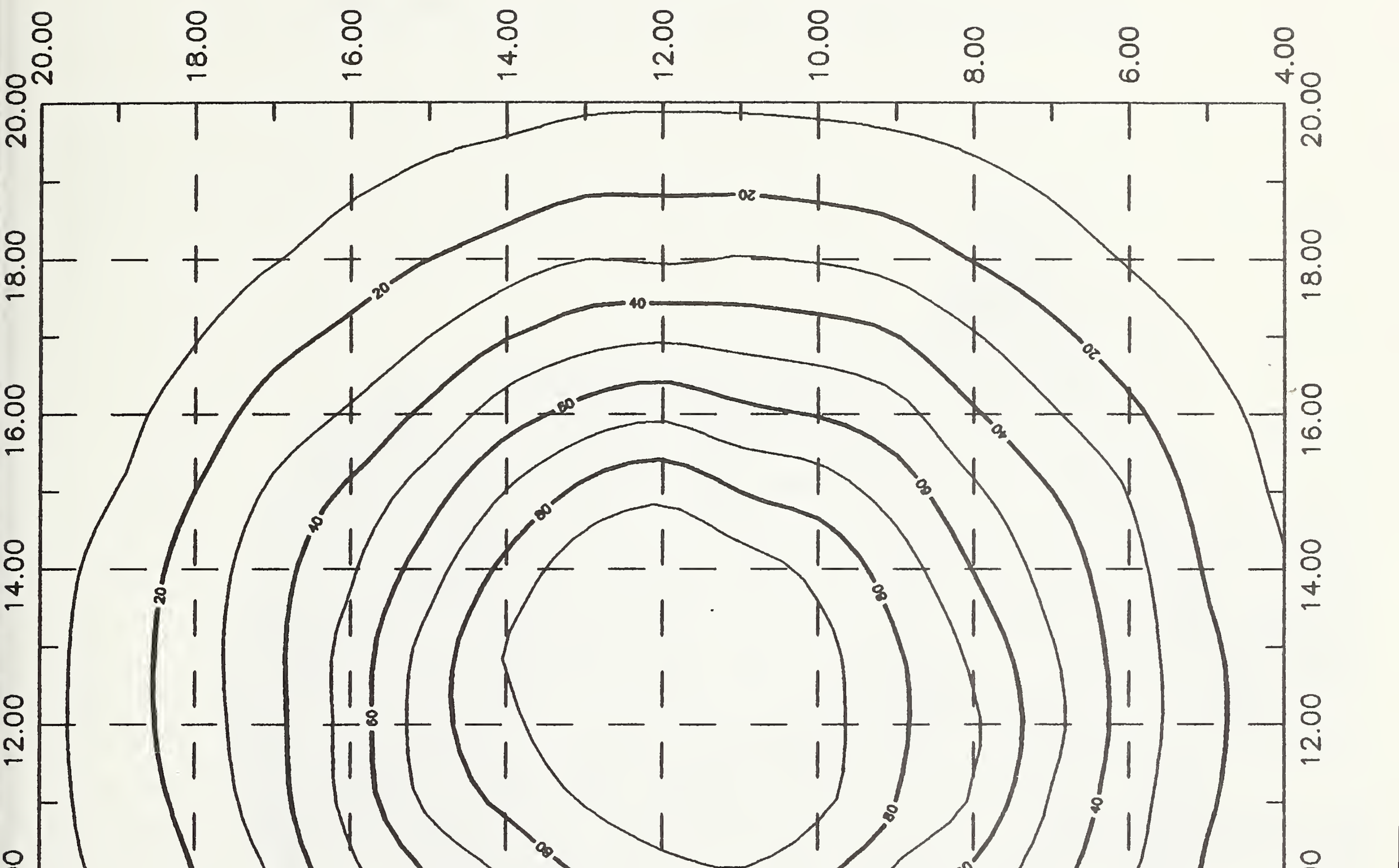
Beam measurement at 9 mm from a microscope objective (x10)



Beam measurement at 9 mm from a microscope objective (x10)



Beam measurement at 9 mm from a microscope objective (x10)

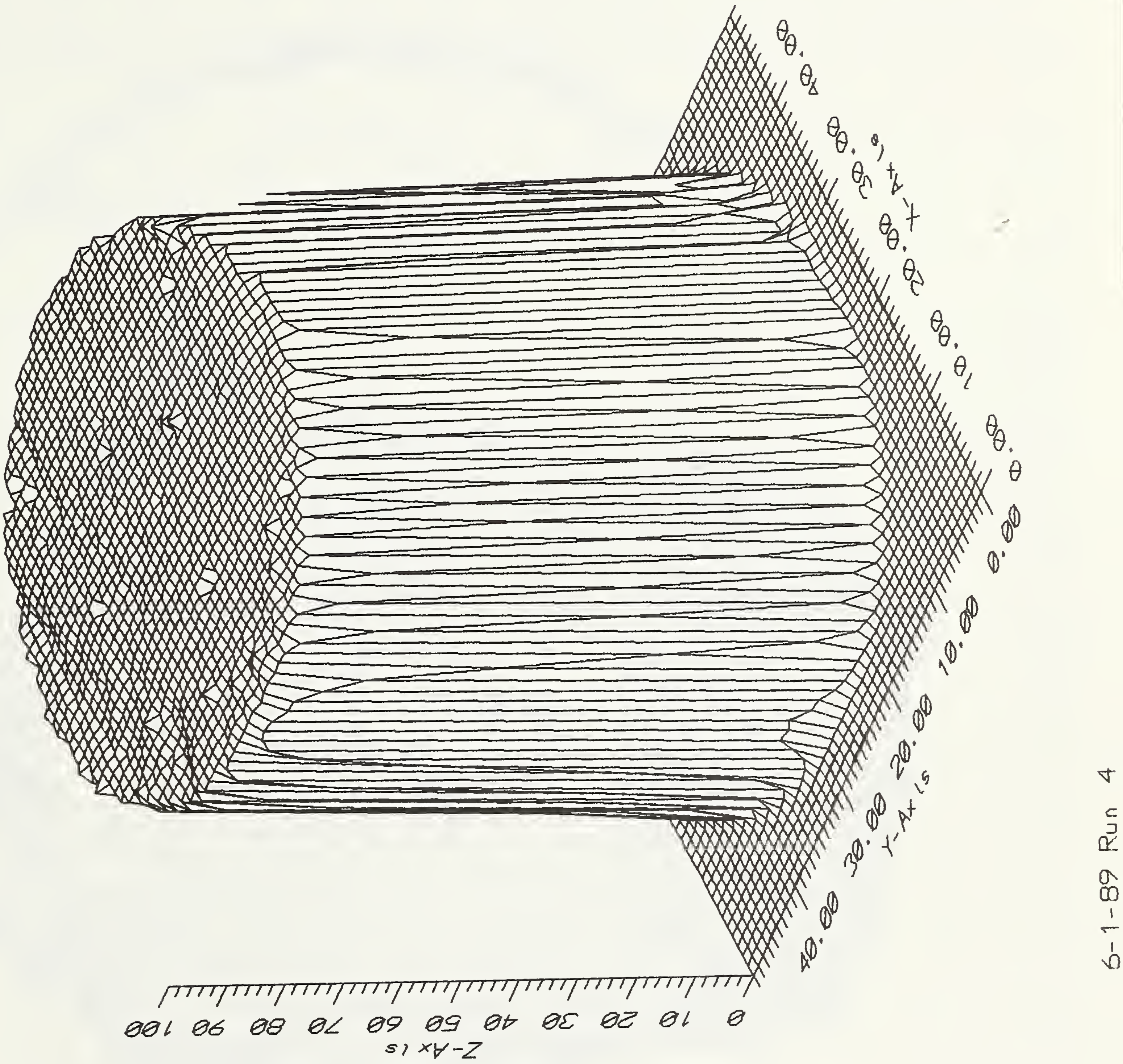


Detector measurement at 9 mm from a microscope objective (x10)

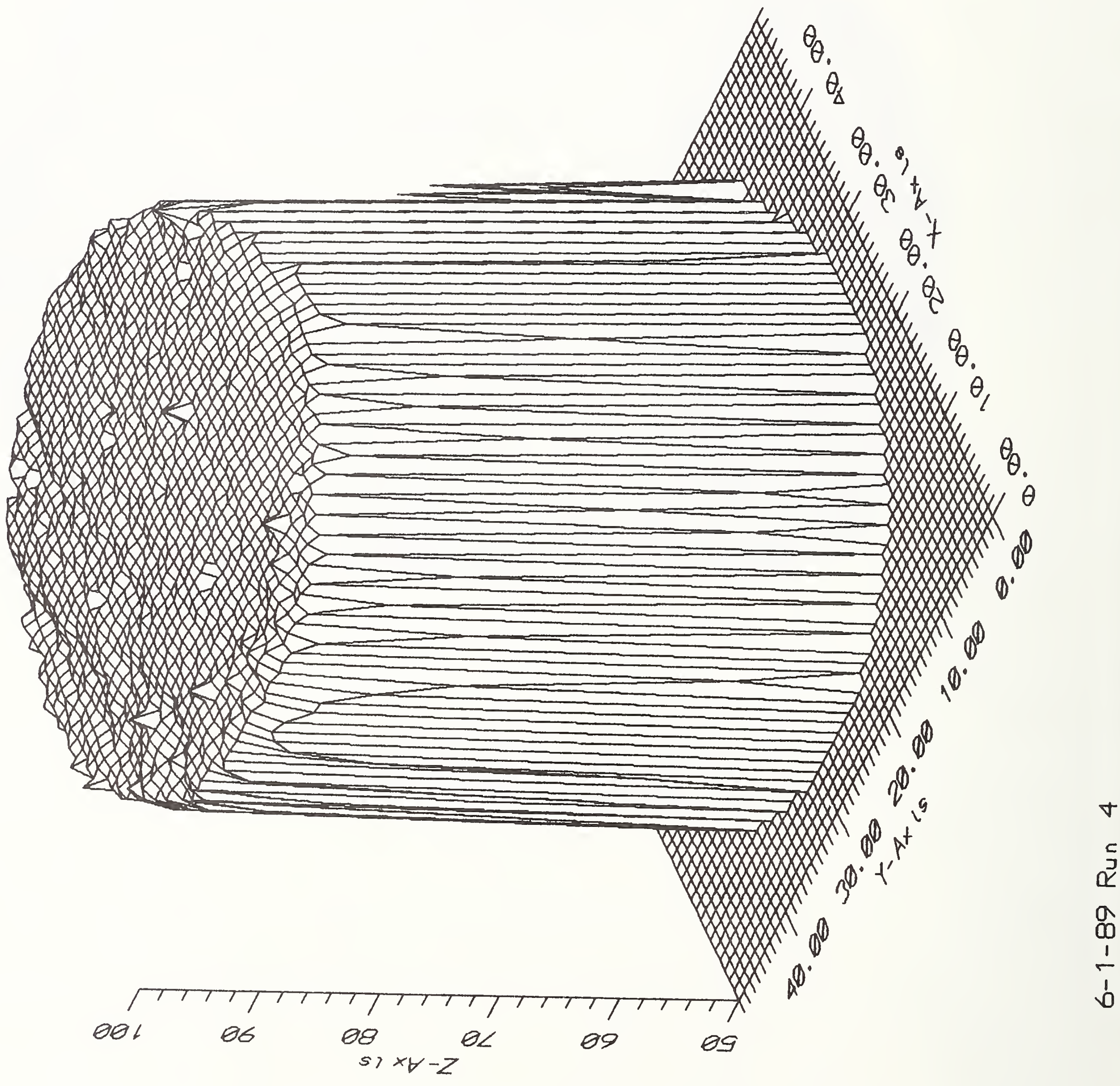
Title:	"6-1-89 Run 4"
Listing Produced:	06-01-1989 14:49:09
Actual Run Date:	6-1-89
Rotation (degrees):	225
Z-axis Tilt (degrees):	30
Amplifier Gain:	10
Laser Identifier:	HeNe
Detector Identifier:	4-8
Pinhole Identifier:	10 um
Total Sample Points:	50 x 50

No optical fiber used
Monitor gain 10(2)
Tektronix 600 ohm load used
Detector 9 mm away from the objective
Daughter board gain setting 0
250 um/div
Max = 1598 Min = 19

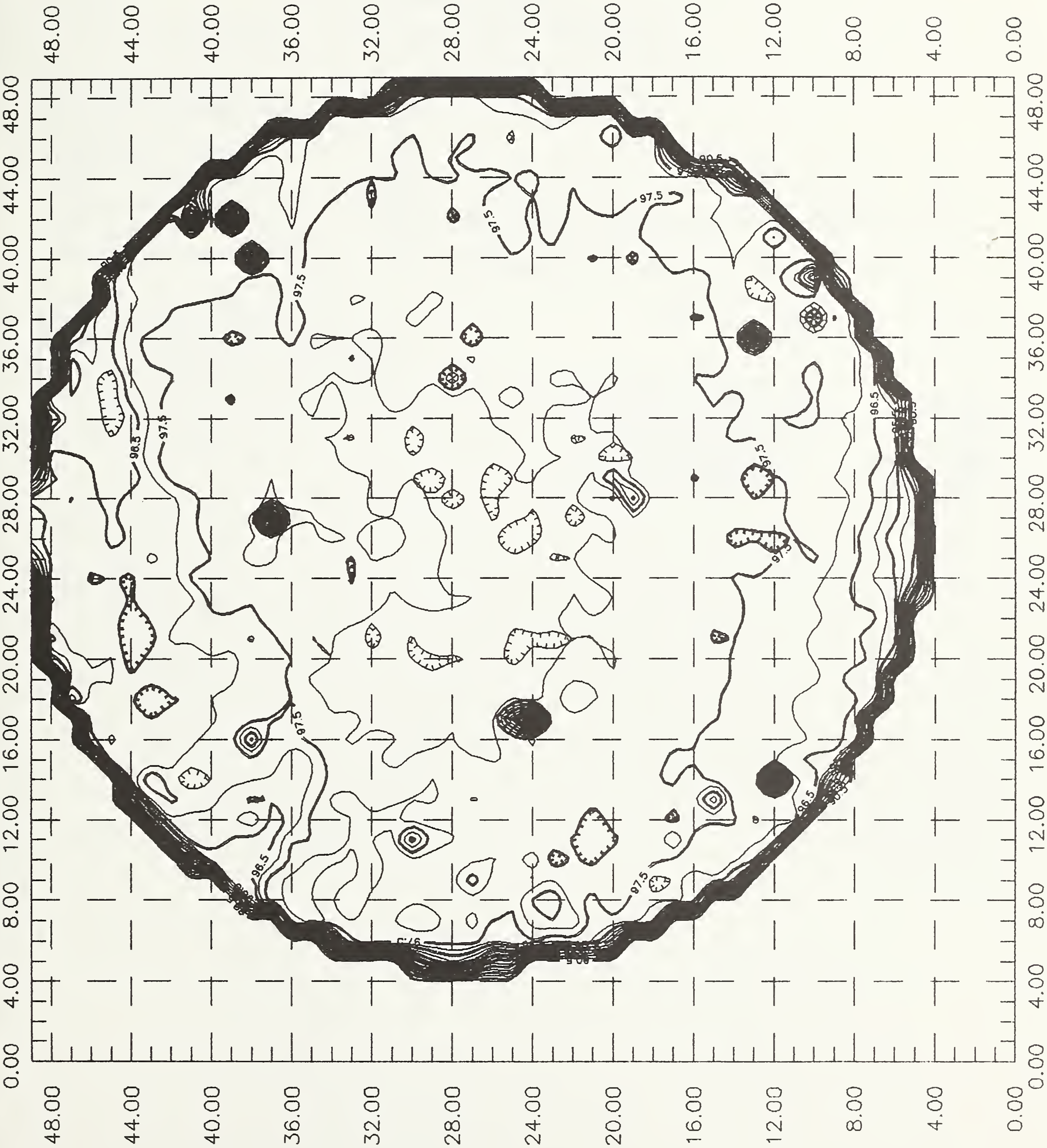
Detector measurement at 9 mm from a microscope objective (x10)



Detector measurement at 9 mm from a microscope objective (x10)
(Z axis baseline raised to 50%)



Detector measurement at 9 mm from a microscope objective (x10)



Detector measurement at 9 mm from a microscope objective (x10)

Title: "6-1-89 Run 4"

Listing Produced: 06-01-1989 15:41:50

For the Z Data in the Area Enclosed By:

Min-X = 16 Max-X = 36
Min-Y = 12 Max-Y = 40

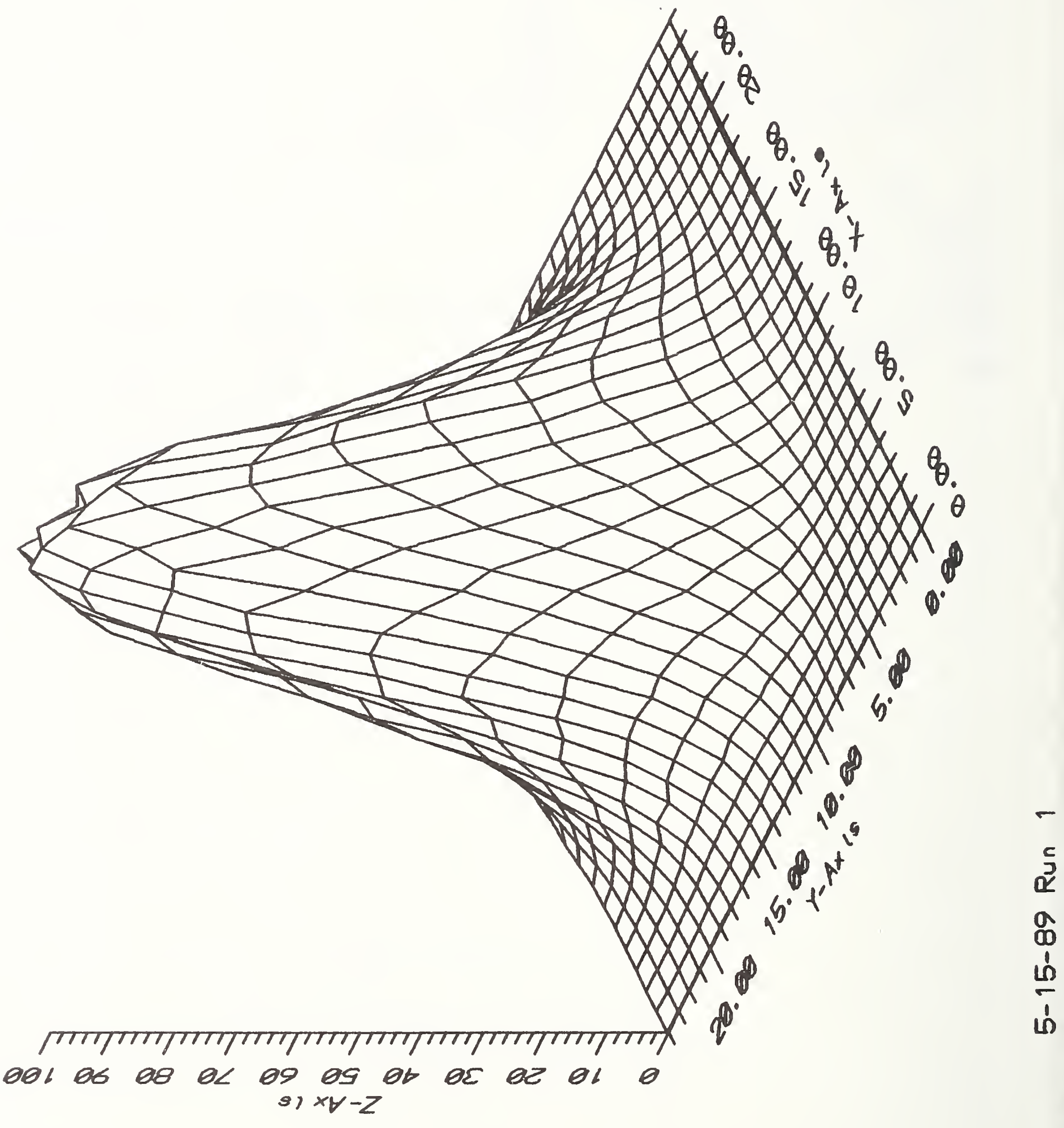
MEAN	=	97.80022295793076
MAXIMUM	=	99.59788842697016
MINIMUM	=	92.16838308509782
MAX - MIN	=	7.429505341872343
VARIANCE	=	.1954804760265207

Beam measurement at 15.2 mm from a microscope objective (x10)

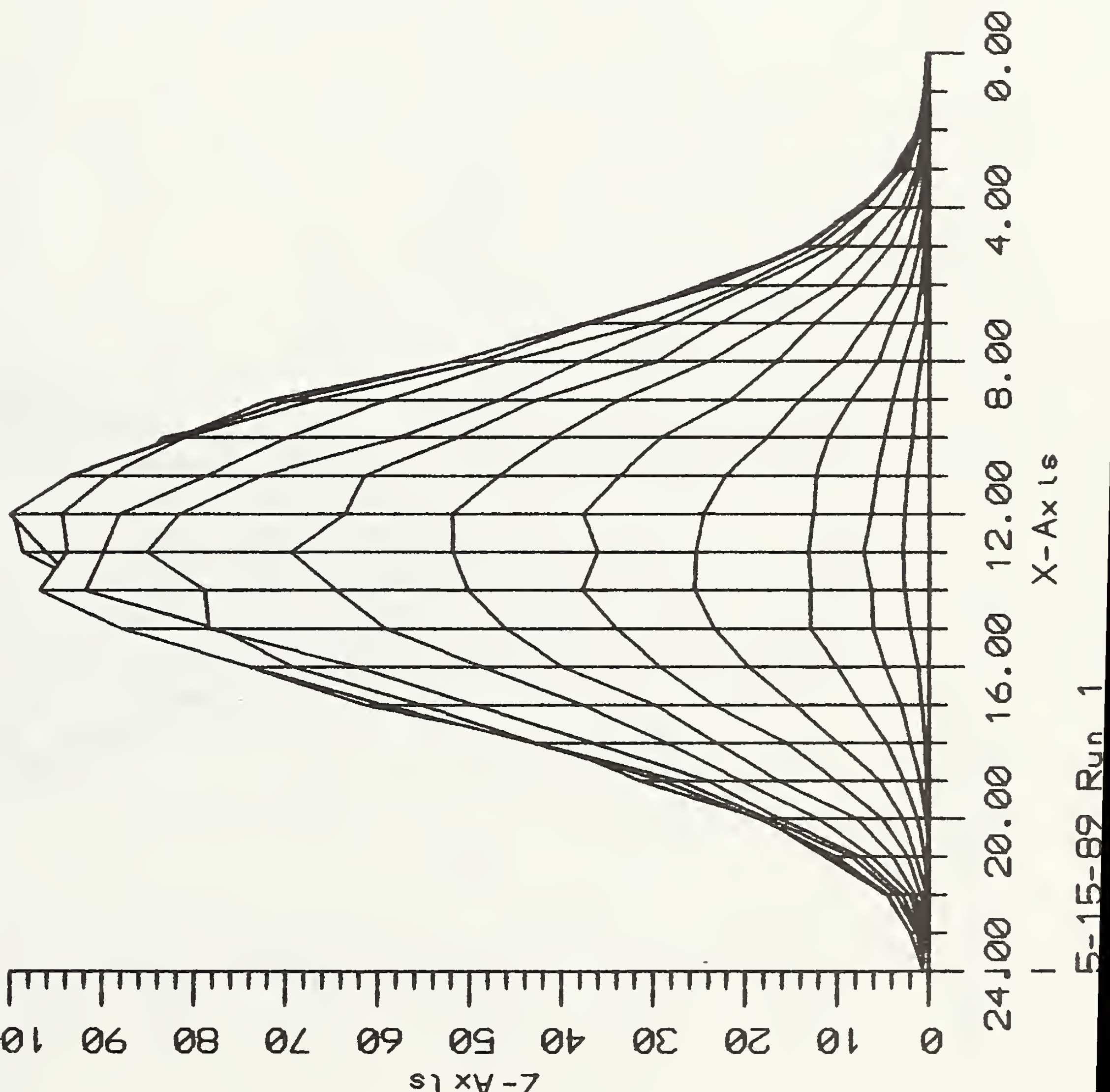
Title:	"5-15-89 Run 1"
Listing Produced:	05-18-1989 09:06:27
Actual Run Date:	5-15-89
Rotation (degrees):	225
Z-axis Tilt (degrees):	30
Amplifier Gain:	10
Laser Identifier:	HeNe
Detector Identifier:	SDC1
Pinhole Identifier:	50 um
Total Sample Points:	25 x 25

No optical fiber used
Monitor gain 10(2)
Tektronix 600 ohm load used
Gain setting 0
Detector 15.2 mm away from the objective
50 um/div
Max = 503 Min = 6

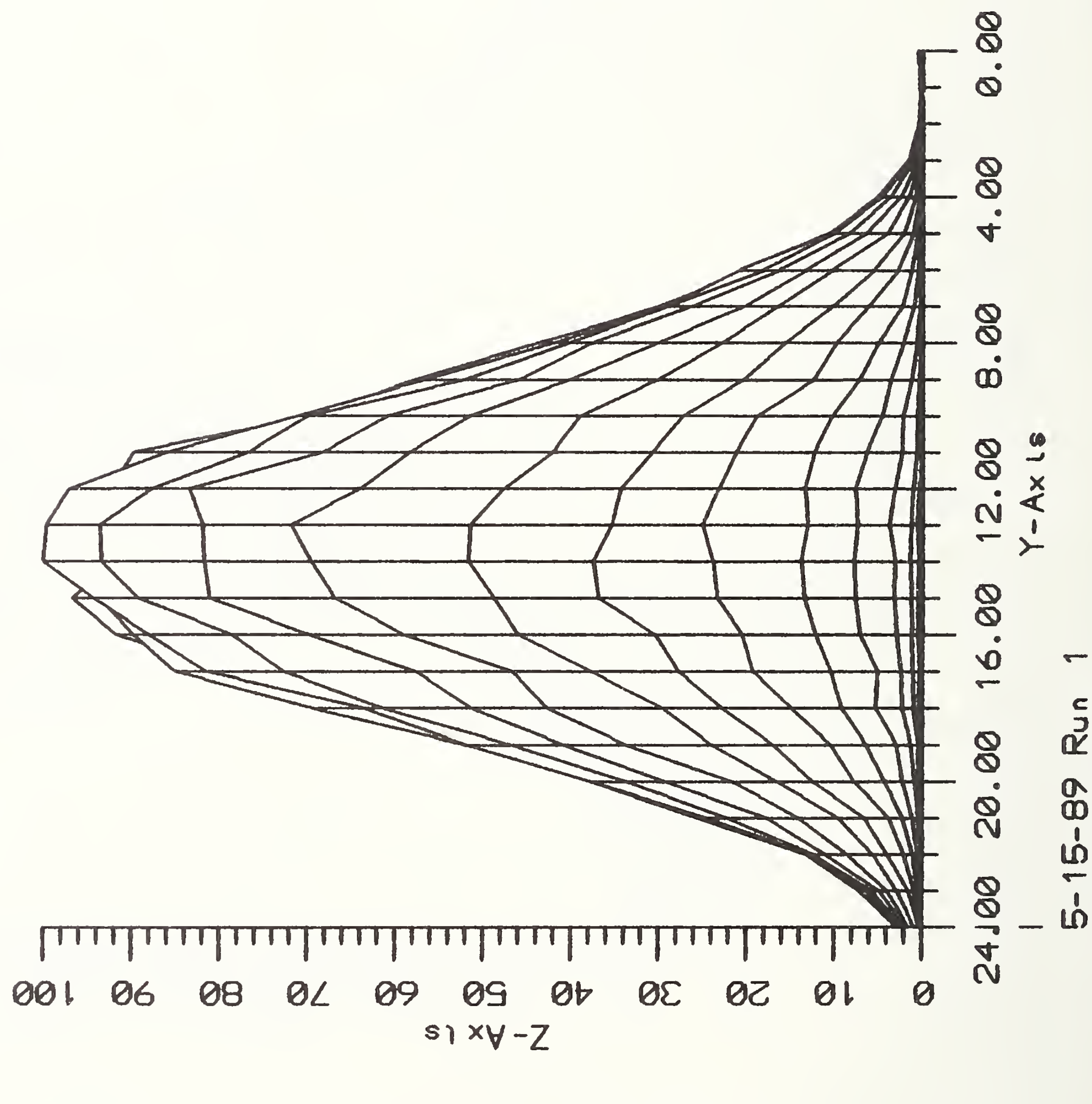
Beam measurement at 15.2 mm from a microscope objective (x10)



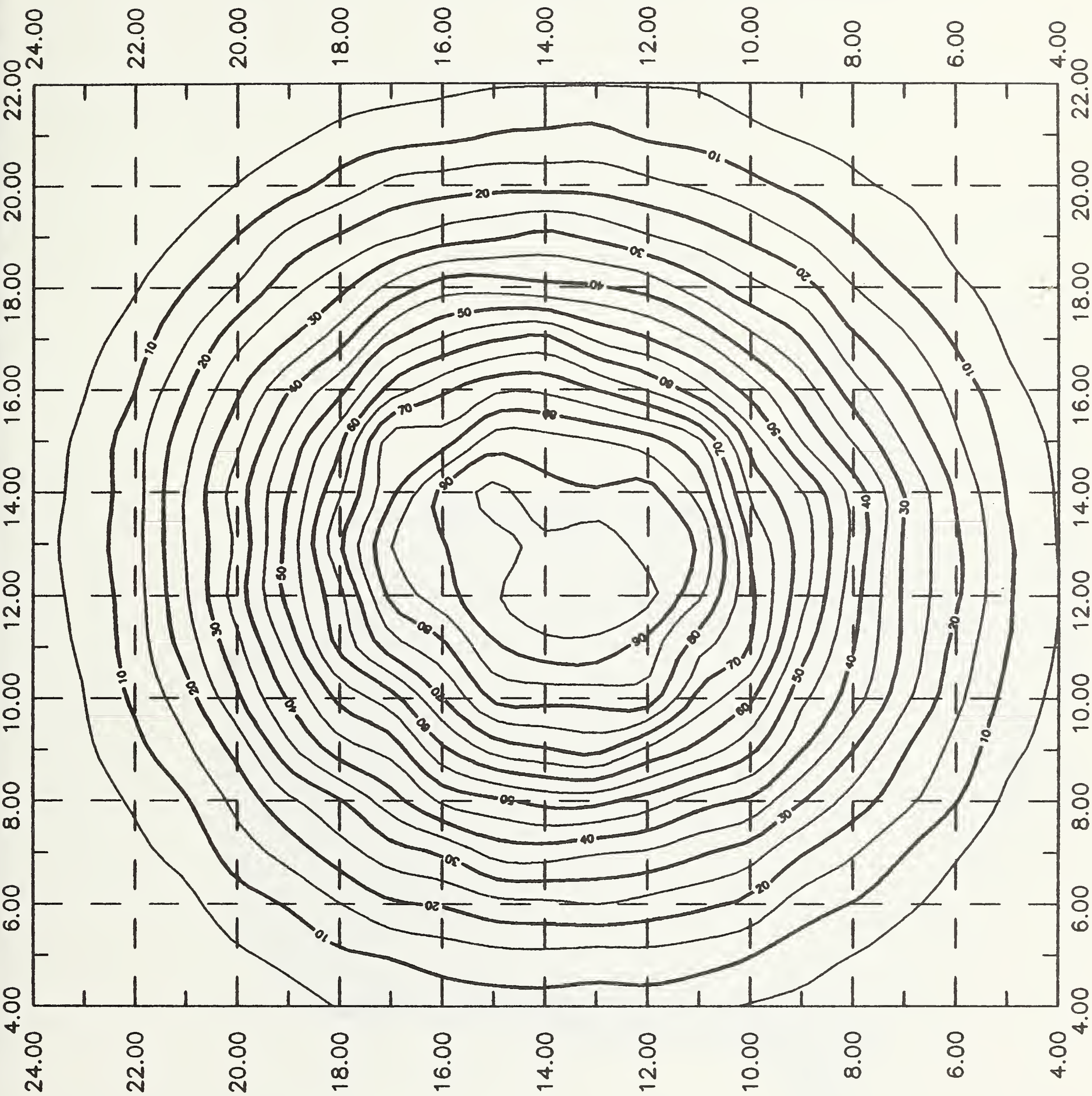
Beam measurement at 15.2 mm from a microscope objective (x10)



Beam measurement at 15.2 mm from a microscope objective (x10)



Beam measurement at 15.2 mm from a microscope objective (x10)

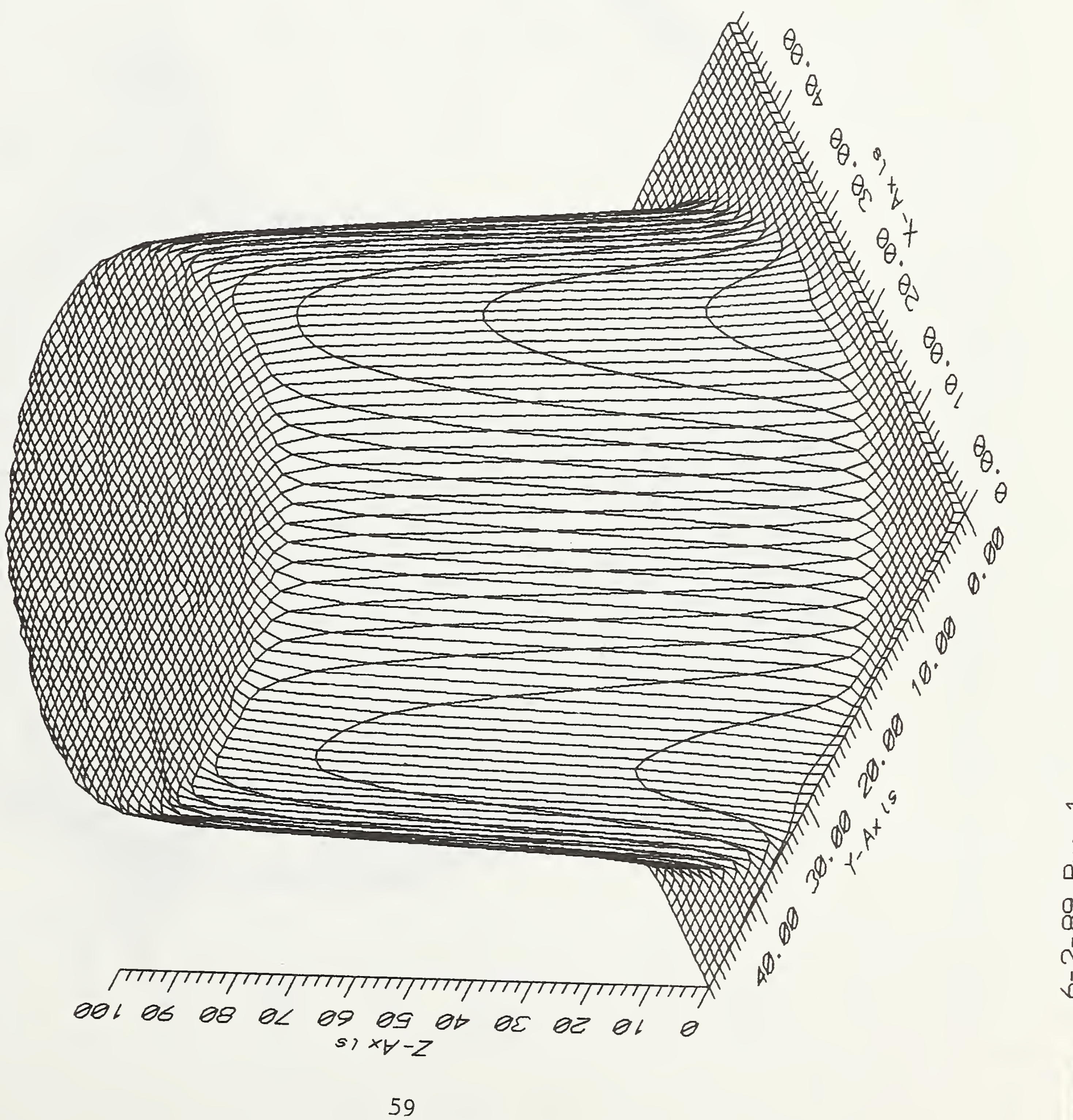


Detector measurement at 15.2 mm from a microscope objective (x10)

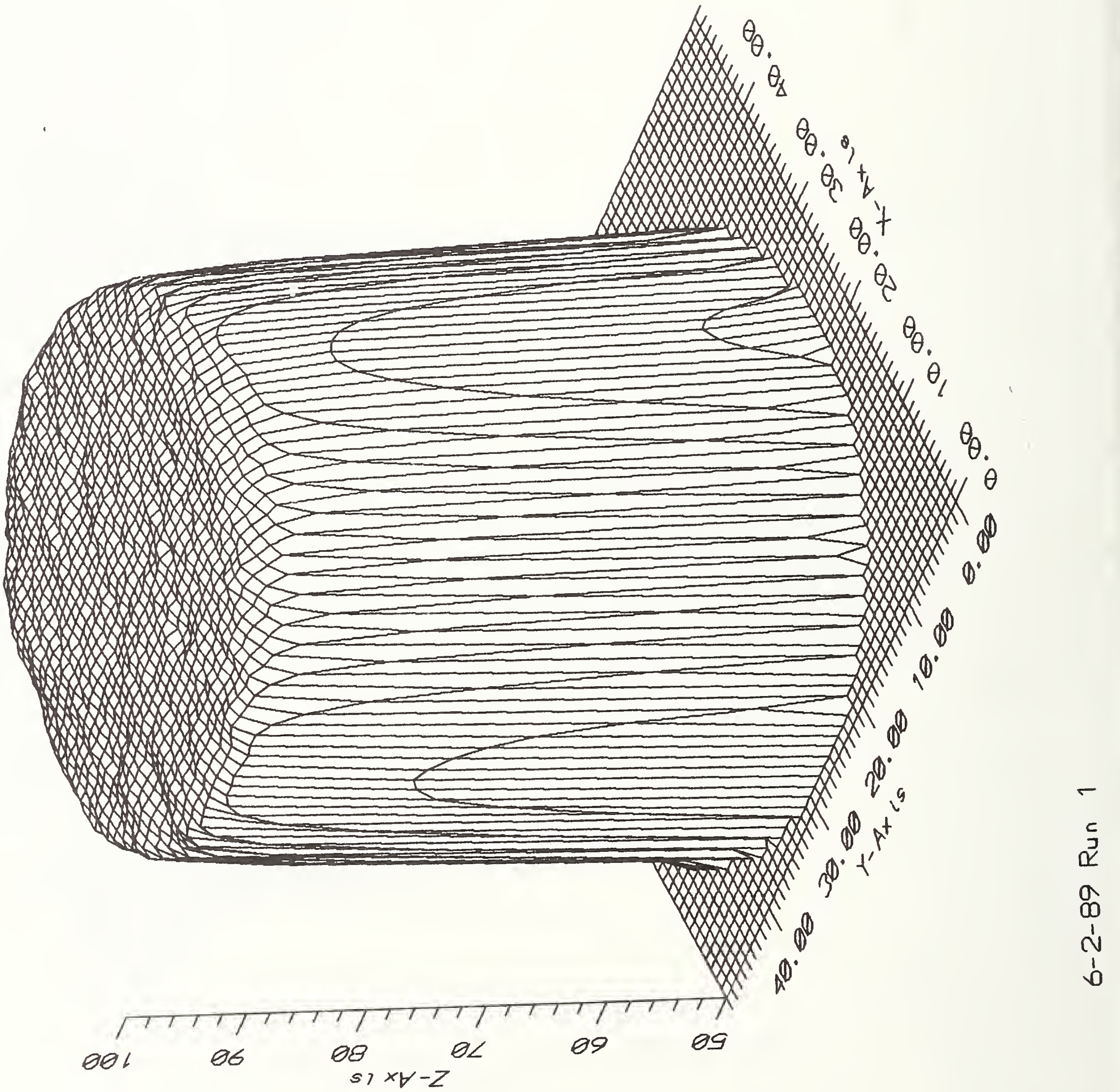
Title:	"6-2-89 Run 1"
Listing Produced:	06-02-1989 08:56:33
Actual Run Date:	6-2-89
Rotation (degrees):	225
Z-axis Tilt (degrees):	30
Amplifier Gain:	10
Laser Identifier:	HeNe
Detector Identifier:	4-8
Pinhole Identifier:	none
Total Sample Points:	50 x 50

No optical fiber used
Monitor gain 10(2)
Tektronix 600 ohm load used
Detector 15.2 mm away from the objective
Daughter board gain setting 0
250 um/div
Max = 1591 Min = 32

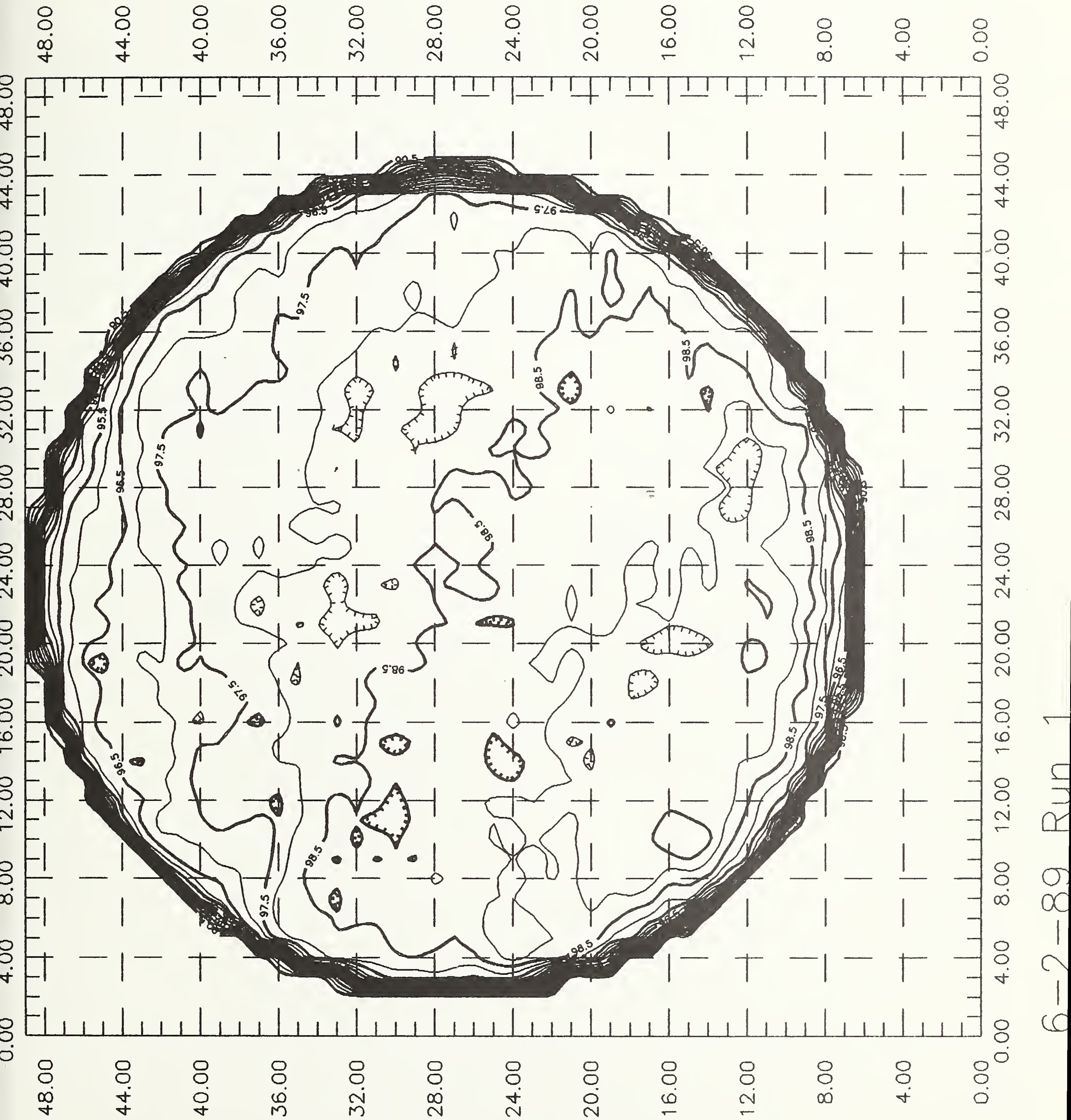
Detector measurement at 15.2 mm from a microscope objective (x10)



Detector measurement at 15.2 mm from a microscope objective (x10)
(Z axis baseline raised to 50%)



Detector measurement at 15.2 mm from a microscope objective (x10)



Detector measurement at 15.2 mm from a microscope objective (x10)

```
Title: "6-2-89 Run 1"

Listing Produced: 06-02-1989  09:20:12

For the Z Data in the Area Enclosed By:

Min-X =  16  Max-X =  32
Min-Y =  16  Max-Y =  40

MEAN        =  1566.174807058824
MAXIMUM     =  1584.518
MINIMUM     =  1544.179
MAX - MIN   =  40.33899999999994
VARIANCE    =  54.65133210395016
```

Beam measurement at 25 mm from a microscope objective (x10)

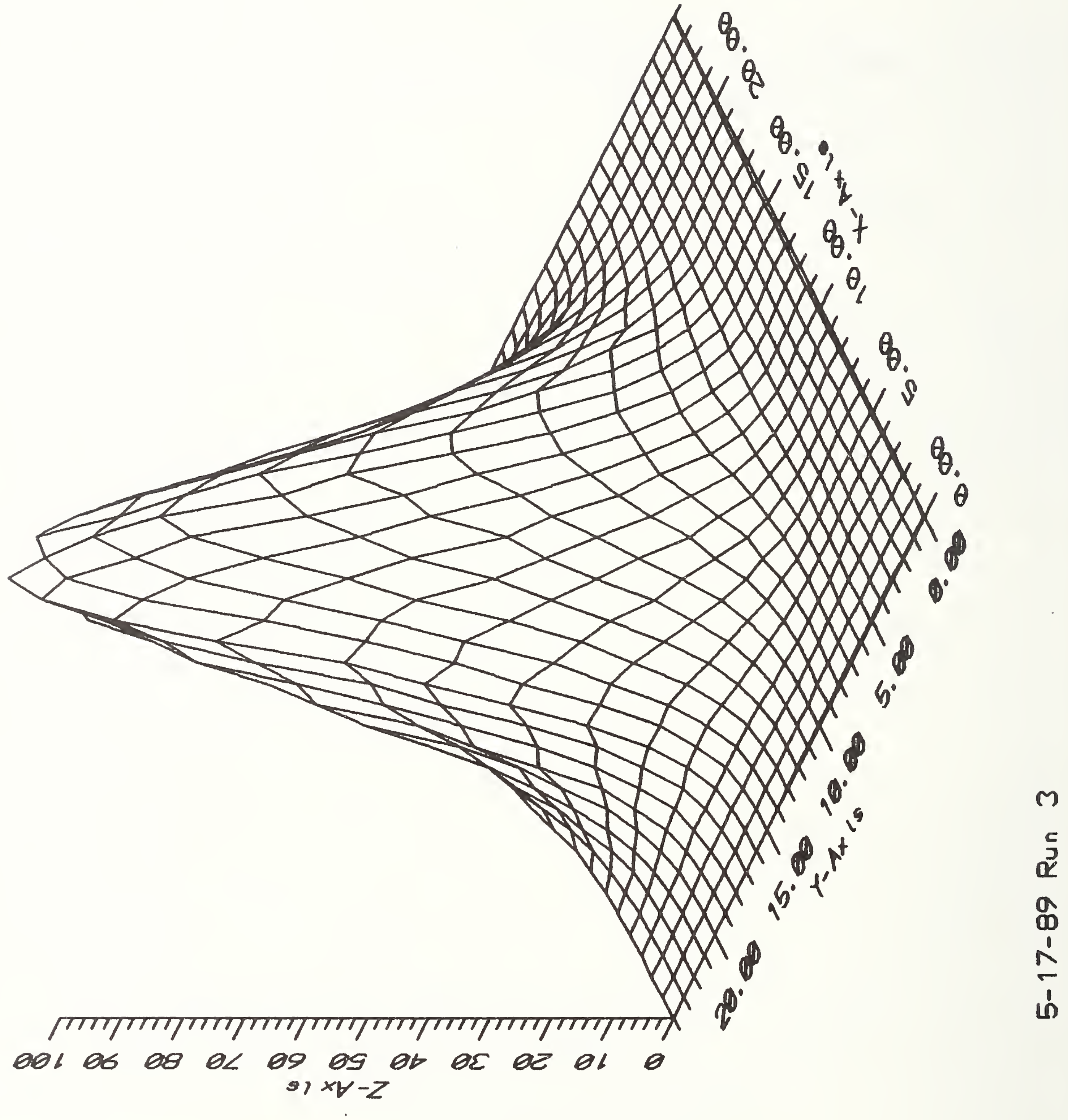
Title: "5-17-89 Run 3"

Listing Produced: 05-17-1989 15:11:28

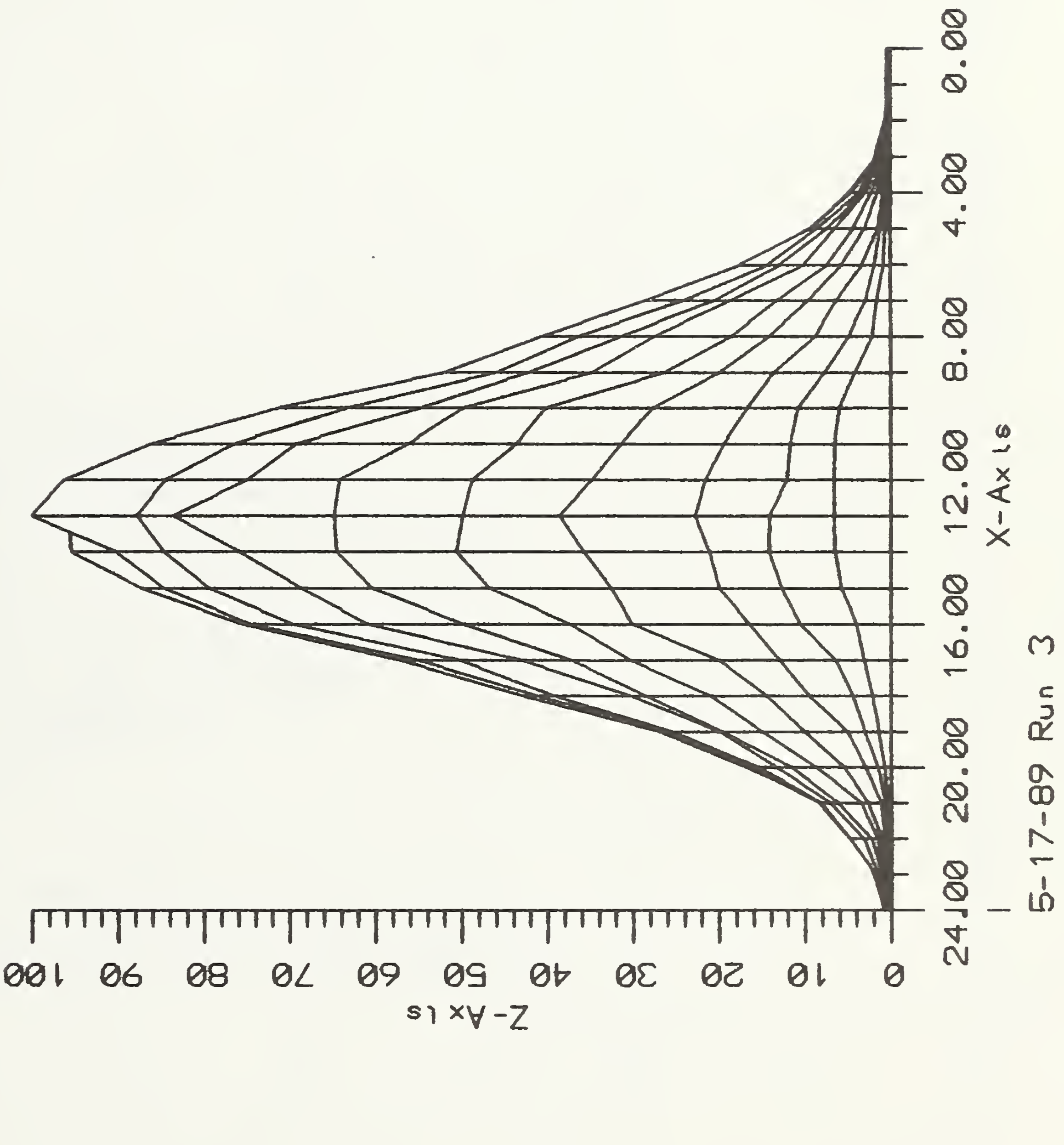
Actual Run Date: 5-17-89
Rotation (degrees): 225
Z-axis Tilt (degrees): 30
Amplifier Gain: 10^{5}
Laser Identifier: HeNe
Detector Identifier: SDC1
Pinhole Identifier: 100 um
Total Sample Points: 25 x 25

No optical fiber used
Monitor gain 10(2)
Tektronix 600 ohm load used
Detector 25 mm away from the objective
Gain setting 0
150 um/div
Max = 611 Min = .6

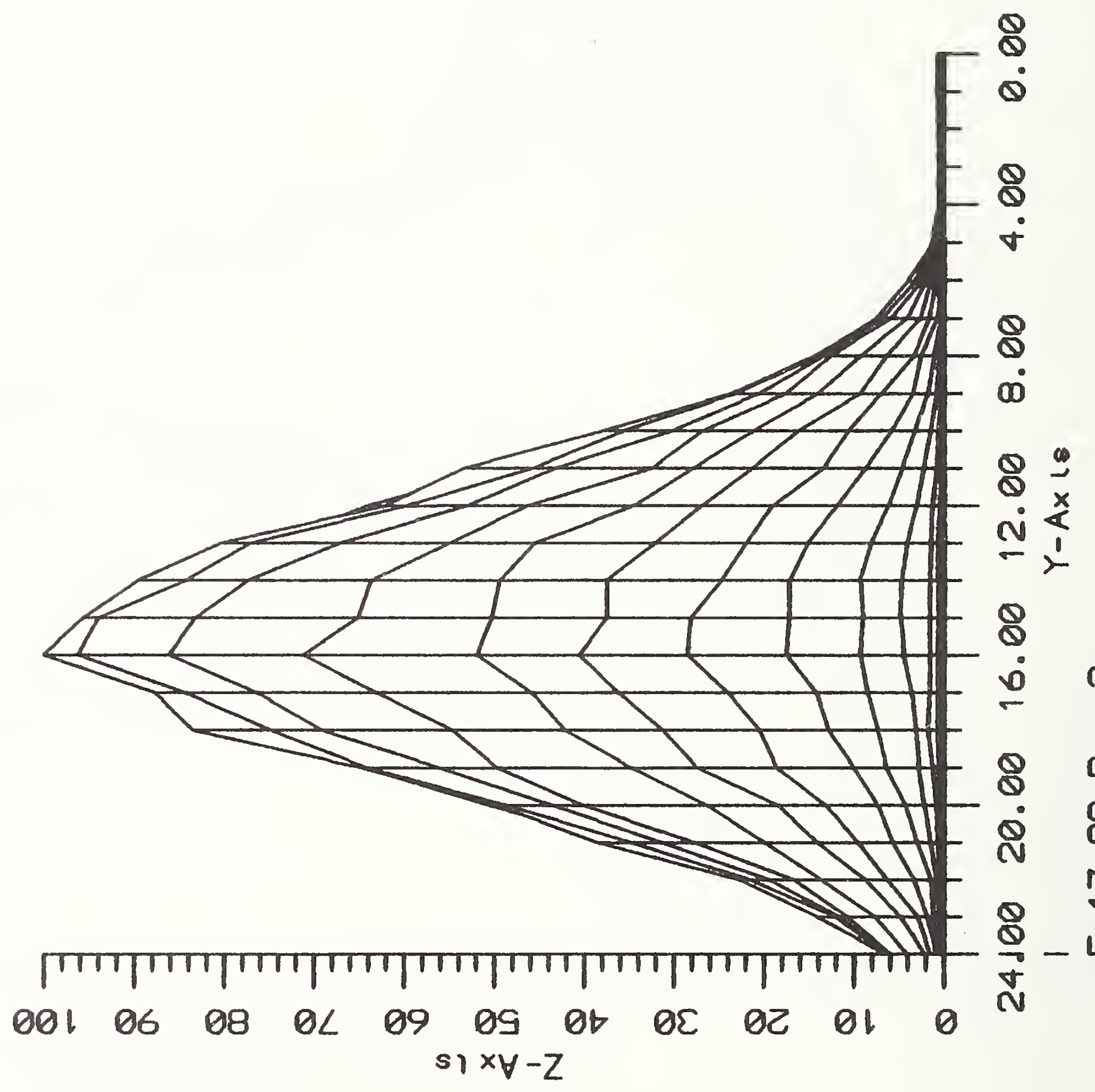
Beam measurement at 25 mm from a microscope objective (x10)



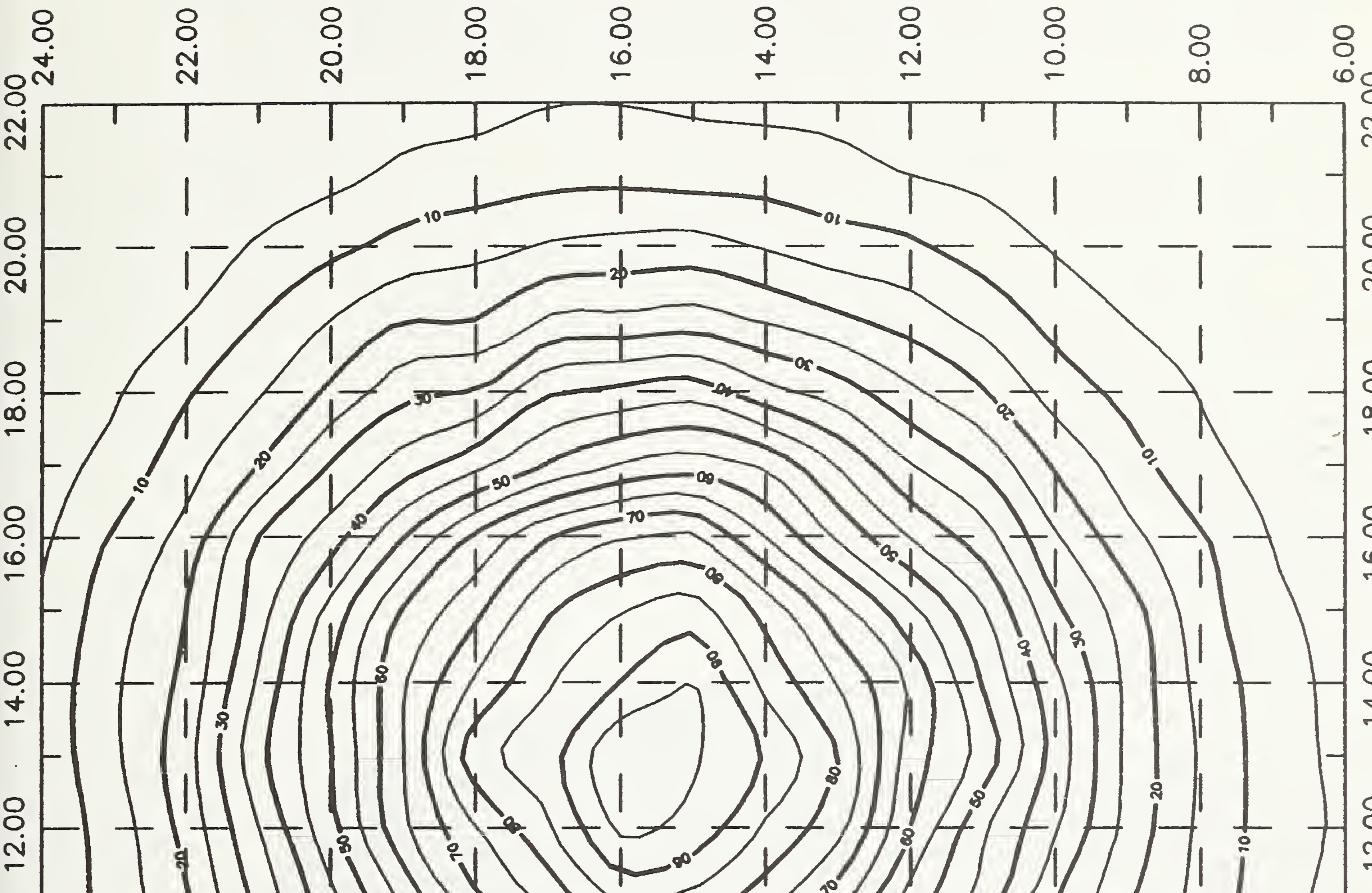
Beam measurement at 25 mm from a microscope objective (x10)



Beam measurement at 25 mm from a microscope objective (x10)



Beam measurement at 25 mm from a microscope objective (x10)



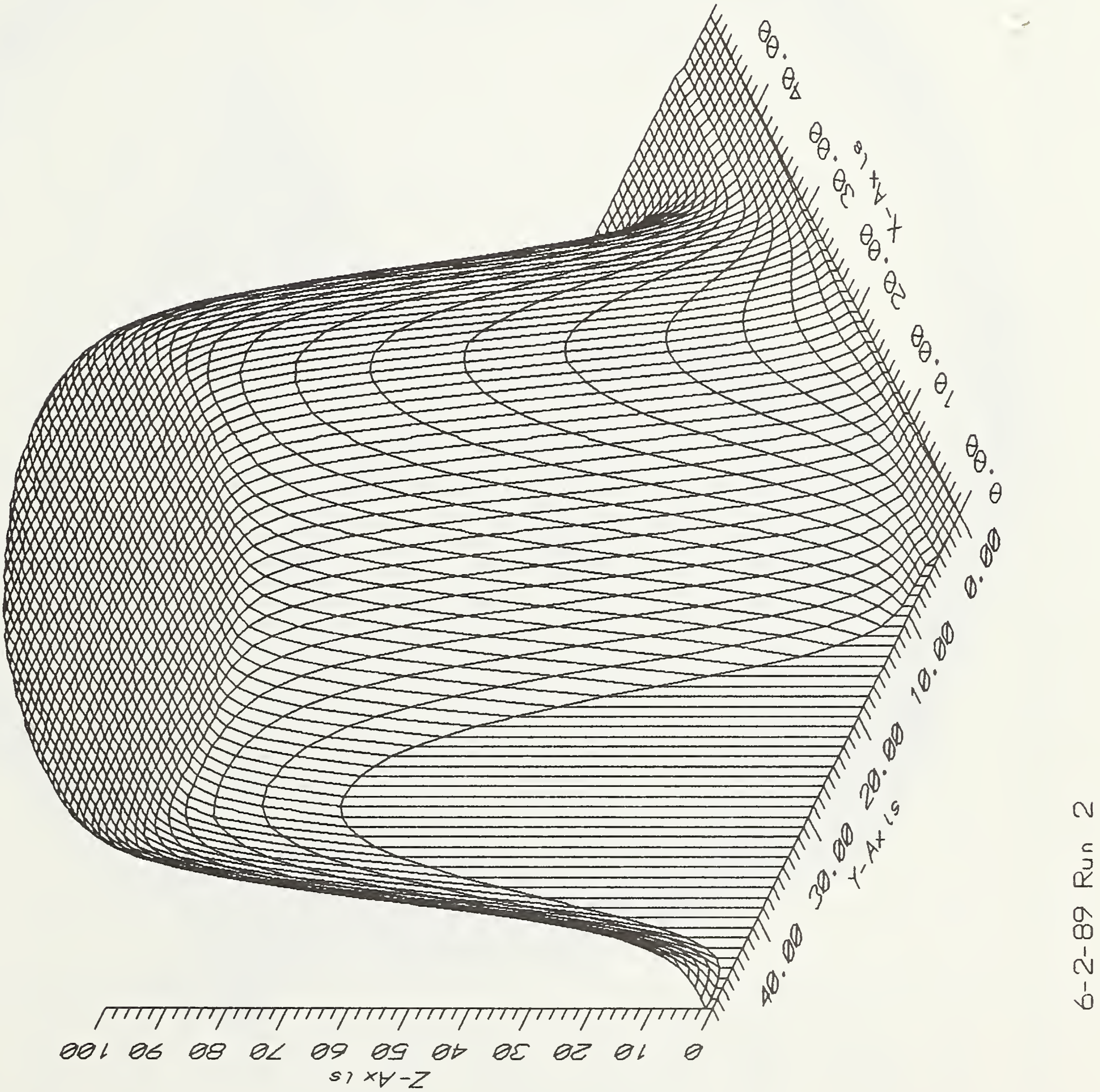
5-17-89 Run 3

Detector measurement at 25 mm from a microscope objective (x10)

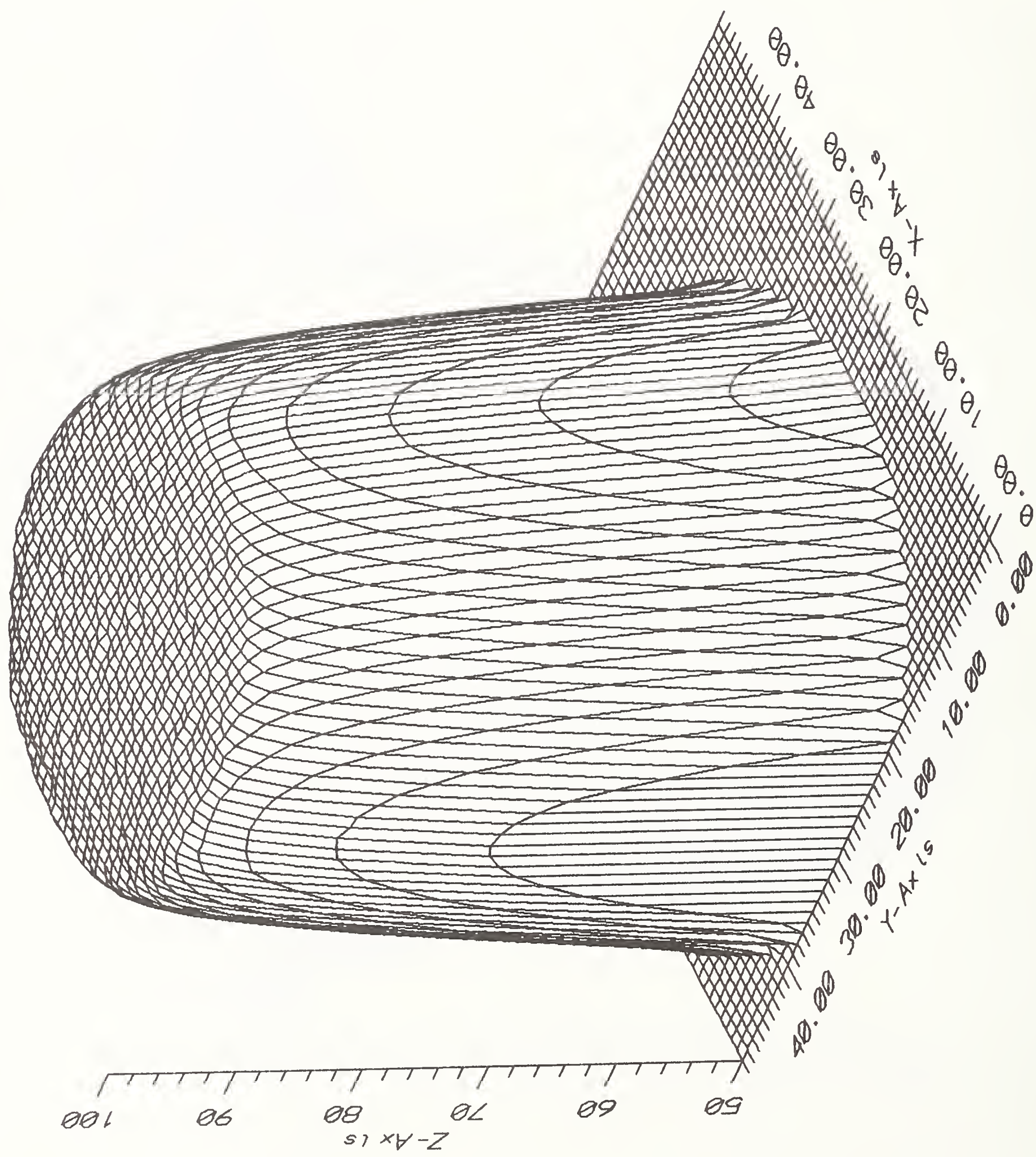
Title:	"6-2-89 Run 2"
Listing Produced:	06-02-1989 10:44:14
Actual Run Date:	6-2-89
Rotation (degrees):	225
Z-axis Tilt (degrees):	30
Amplifier Gain:	10
Laser Identifier:	HeNe
Detector Identifier:	4-8
Pinhole Identifier:	none
Total Sample Points:	50 x 50

No optical fiber used
Monitor gain 10(2)
Tektronix 600 ohm load used
Detector 25 mm away from the objective
Daughter board gain setting 0
250 um/div
Max = 1591 Min = 35

Detector measurement at 25 mm from a microscope objective (x10)

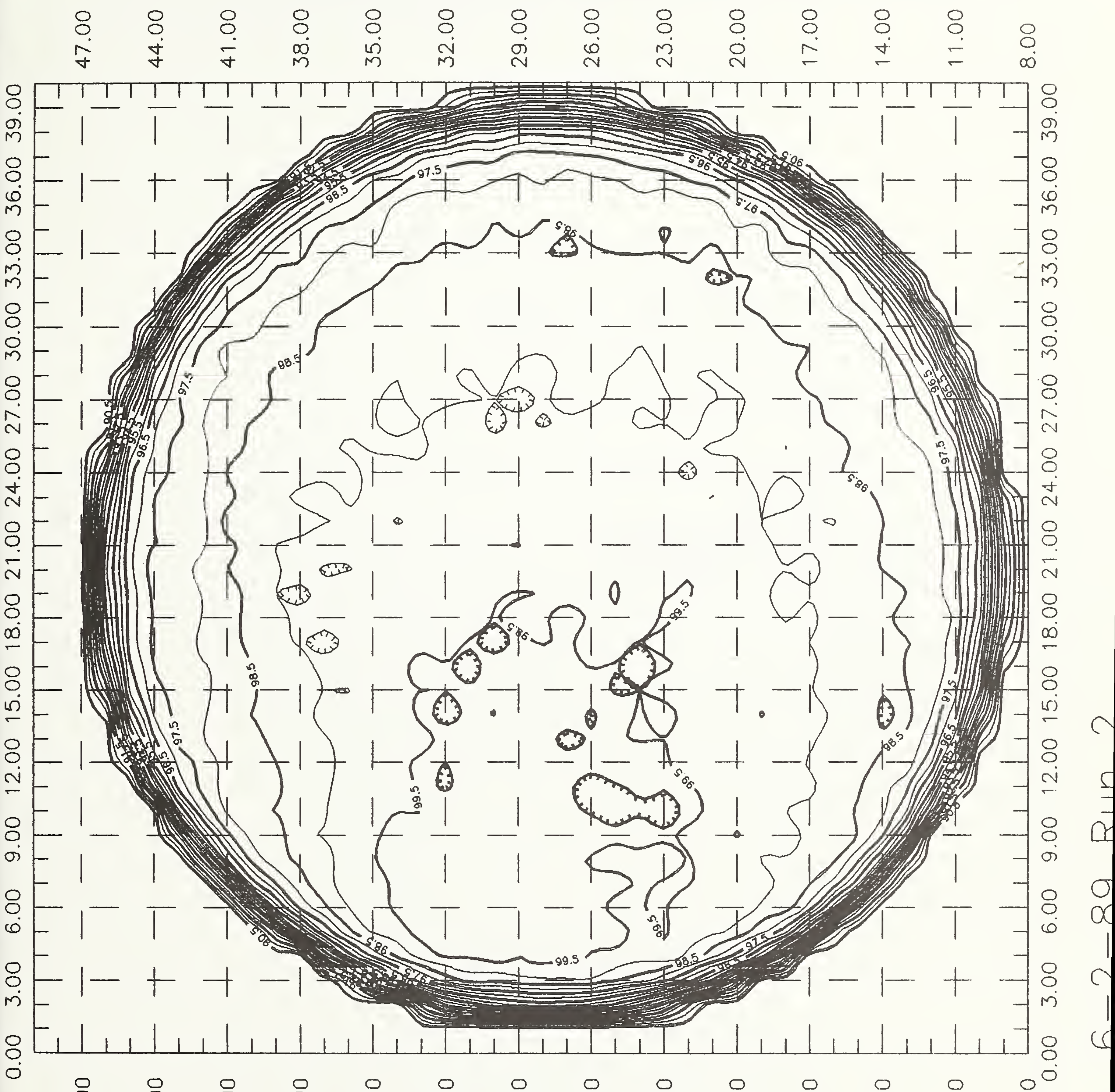


Detector measurement at 25 mm from a microscope objective (x10)
(Z axis baseline raised to 50%)



6-2-89 Run 2

Detector measurement at 25 mm from a microscope objective (x10)



Detector measurement at 25 mm from a microscope objective (x10)

Title: "6-2-89 Run 2"

Listing Produced: 06-02-1989 11:26:32

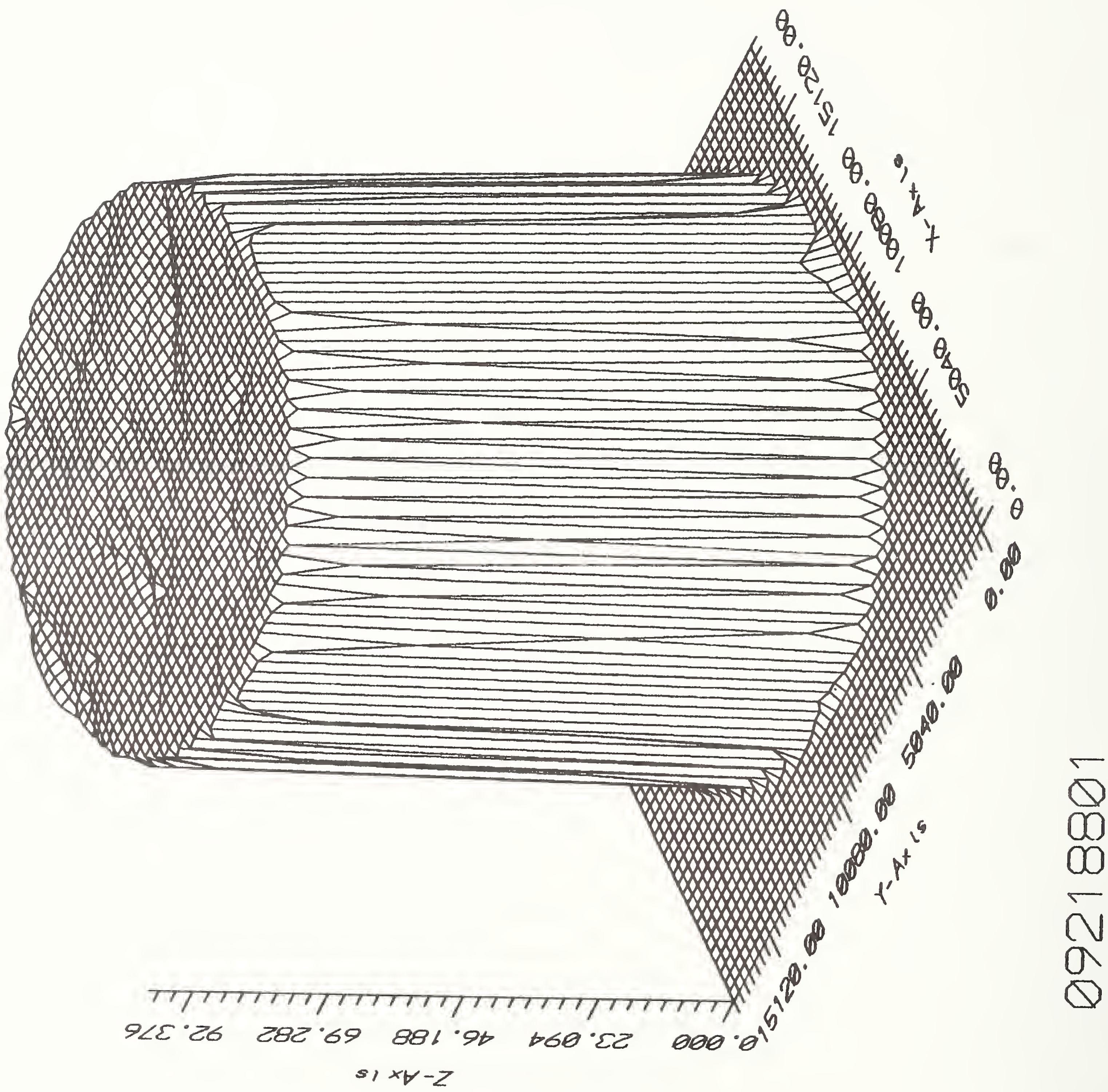
For the Z Data in the Area Enclosed By:

Min-X = 12 Max-X = 28
Min-Y = 16 Max-Y = 36

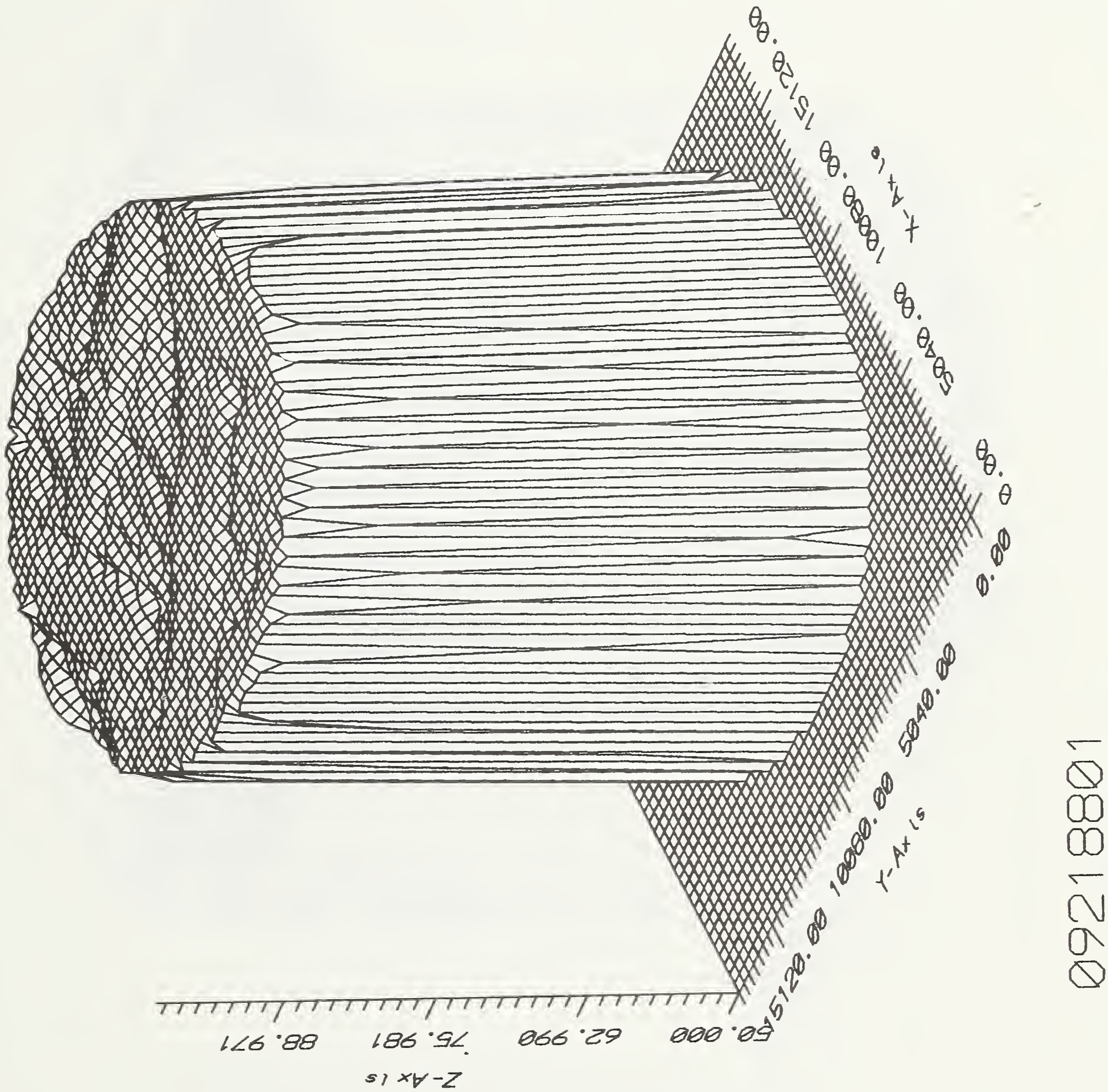
MEAN	=	1559.379941176472
MAXIMUM	=	1568.421
MINIMUM	=	1546.008
MAX - MIN	=	22.41300000000001
VARIANCE	=	16.15271968001316

Examples of measurements of detectors, Pin 4-7 and Pin 4-8, with 0 percent and 50 percent baseline are on pages 74-77.

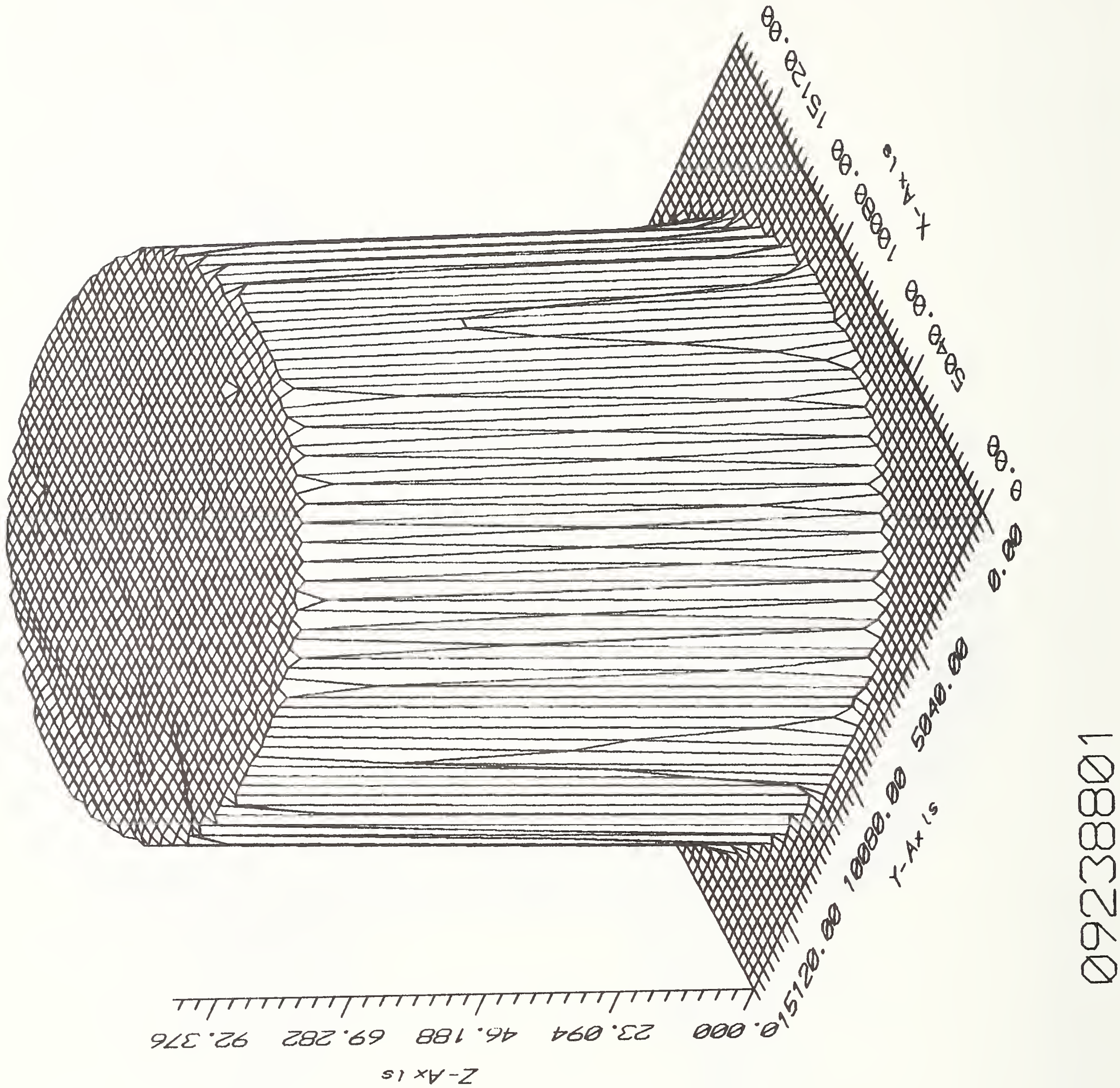
Detector measurement, PIN 4-7. Baseline 0%



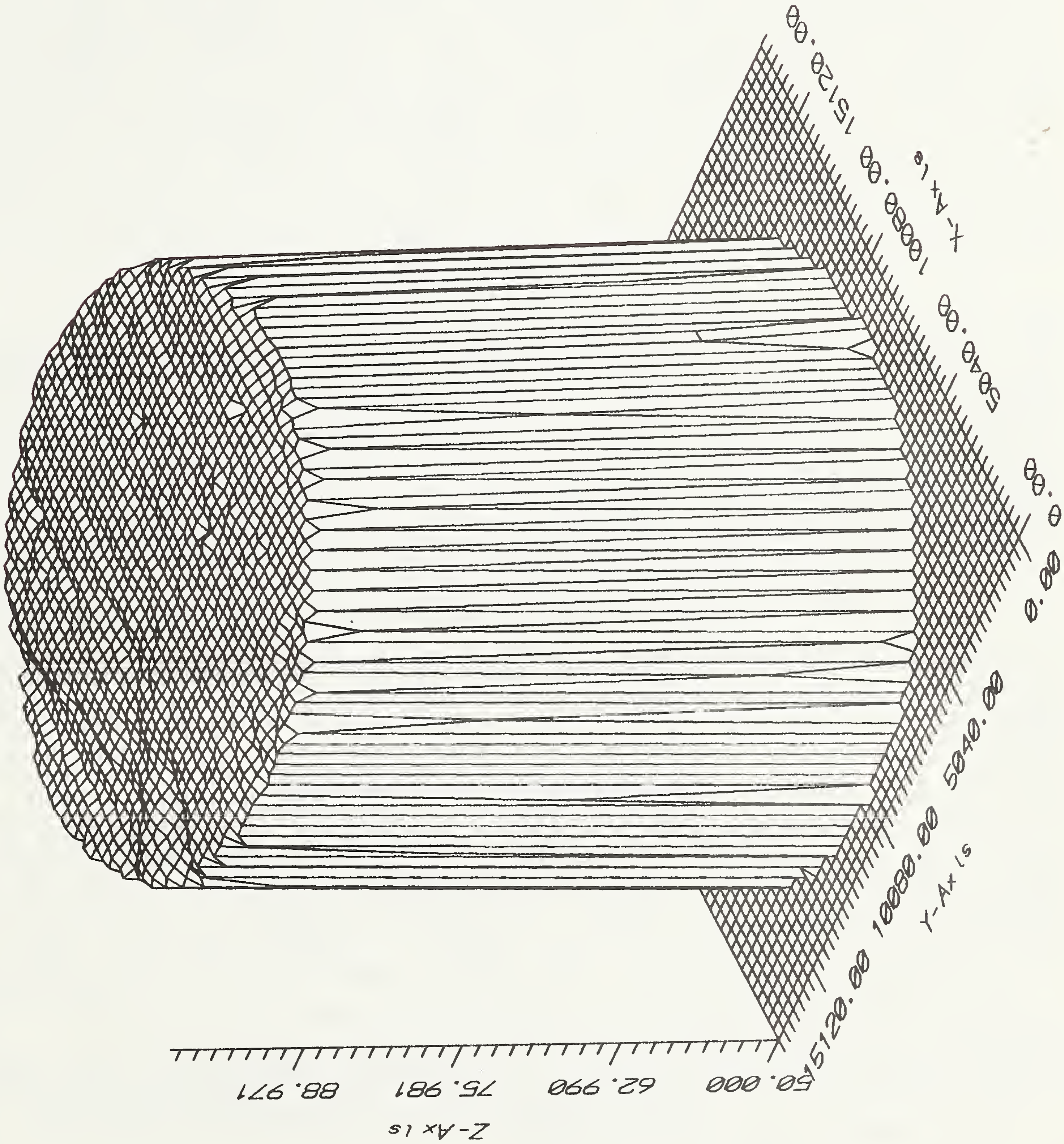
Detector measurement, PIN 4-7. Baseline 50%



Detector measurement, PIN 4-8. Baseline 0%



Detector measurement, PIN 4-8. Baseline 50%



Appendix H: Graphics interface program

A commercial graphics program is used to generate high-quality three-dimensional surface plots and topographical maps. An interface program is used to aid in running the graphics program, and to provide additional data processing options. For convenience, Golden Software Incorporated's Surfer program is used to generate the graphics, and Microsoft Corporation's QuickBASIC and DOS Batch processing are used in the interface program. Other software packages may work equally well. The interface program requires the Batch programs SURF2.BAT and INSTALL.Bat, and the two BASIC programs SURF1.BAS and SURF2B.BAS. It has been tested with DOS versions 3.2 and 3.3, Surfer versions 3.11 and 4.08, and Quick-BASIC versions 4.0 and 4.5. This report describes how the program works, the options it provides, and how the program is used.

SURF1 converts the original three-column data, generated with other programs, into a double precision version of the grid format used by the graphics program. The original data is a three-column ASCII file with the default file name DUMP. It consists of rows containing the X and Y-position of the beam, and a Z-value representing the detector's response at that position, separated by spaces. It is assumed that this data set is square so that there are as many X-values as Y-values, and that all points are present and equally spaced. The order in which the data are listed is arbitrary. SURF1 sorts this data, determines the maximum and minimum X, Y, and Z values, and then writes the files DUMP.GRD and SURFAUTO.HST. DUMP.GRD contains the three-column data converted to double precision grid format. The grid format used consists of lines of text. The first lines contain information describing the data set, such as the dimensions, maximum and minimum values. The remaining lines each contain a row of Z-values, separated by spaces. The numbers are printed as double precision constants, which preserves their precision. The original coordinates of each Z-value can be computed from the descriptive information at the start of the file. Grid format files are much smaller than the three column format files, yet contain the same information. The string "NO" is written to the file SURFAUTO.HST, which is used by SURRF2B along with DUMP.GRD.

SURF2B calls the graphics program so that the operator does not have to be trained in its use. It also provides additional data processing options. SURF2B is a complicated program which is called by the program SURF2.BAT. This is necessary because of the way the graphics program is called. Graphics requires almost all the memory available to produce graphs of 100 x 100 points. Hence, SURF2B cannot call the graphics program in a BASIC command shell, or there will be insufficient memory left for this size of graph. The file SURF2 calls SURF2B, and then jumps to the file SURF4.BAT. SURF4 is created by SURF2B. Depending on the option selected in SURF2B, SURF4 either calls the graphics program and jumps to SURF2, or terminates. This process reduces the memory as seen by the graphics program by only about 2 kbytes, which allows the graphics program to produce the desired graphs if a sufficiently "clean boot" is used. A clean boot loads no or very few memory resident programs so that the maximum amount of memory is available. SURF2B and the graphics program are called from the Batch programs with a new DOS command processor so that control is returned to the Batch file afterwards. For example. SURF2B is called with the command: "COMMAND /C SURF2B.EXE". If DOS version 3.3 or above is used, the faster command "CALL" can be used in place of "COMMAND /C". If SURF2B is terminated abnormally by an error or power failure, these processes can become confused and SURF2B will no longer run. This problem can be corrected by running SURF1 again.

Because SURF2B ends when the graphics package is called, the program's environment must be saved to disk before the call, and restored afterwards. This is done by writing all information that must be retained, such as axis labels, to the history file SURFAUTO.HST. When SURF2B begins, it first checks to see if the first line of the history file contains the string "NO". If it does, no history exists so the user is prompted for label information, Z-scale factor, view angle, and other options. Otherwise, this information is read from the history file.

Once the history information is entered, the operator is presented with the main menu. Options on the main menu are described below.

1. Change Parameters:

   Allows the operator to change the history parameters entered when the program was first run. These parameters consist of: graphics package options including Plot Title, X-Axis Label, Y-Axis Label, Z-Axis Label, Rotation About Z-Axis, Tilt After Rotation, Z-Axis Digits Displayed, Z-Axis Scale Factor, and Z-Tic Spacing; and run information including Run Date, Amplifier Gain, and identifiers for the Laser, Detector and Pinhole used.

2. View Surface:

   Instructs the graphics program to produce a surface plot of the presently active region, and to send the output to the screen. The active region of the data is defined in Enlarge Portion of Graph below.

3. Plot Surface:

   Instructs the graphics program to produce a surface plot of the presently active region, and to send the out put to the hard copy device.

4. Raise Baseline:

   Prompts for a minimum Z-value, and raises all points below the new minimum to the new minimum Z-value.

5. Offset Data so that Lowest Point = 0:

   Adds an offset to all Z-values, so that the minimum Z-value is at 0.

6. Invert Data:

   Changes the sign of all Z-values.

7. Calculates Mean and Deviation of Z-Data over Present Area:

   Calculates the mean and variance (sigma squared) of the Z-values in the presently active region, and displays the results on the screen with a hard copy option. Title, date of printing, coordinates of the active region used, maximum-Z, minimum-Z, and Z-spread are listed along with the mean and variance. If the hard copy option is chosen, the Print Run Information option is presented.

8. Convert Data to Percentage of Full Scale:
   Linearly scales all Z-values so that the minimum Z-value is at 0, and the maximum Z-value is at 100.

9. Restore Original Data:
   Restores the original data set created by SURF1, without modification.

10. Topographical Maps:
   Prompts for information concerning the topographical map, and produces the map as described in the next section.

11. Change Output Device:
   Calls the graphics program's installation program so that the hard copy output device can be changed. The installation program is called through the STALL.BAT program.

12. Enlarge Portion of Graph:
   Prompts for a rectangular area within the data set. This area will become the active region for plotting and some data analysis options.

13. Print Run Information:
   Produces a hard copy listing including: the title; listing date and time; run date; Z-axis rotation and tilt; amplifier gain; laser, detector and pinhole identifiers; and the dimensions of the data set.

20. Exit:
   Terminates the SURF2 program.

Additional information is requested when the Topographical Map option is selected. This information is used by the graphics package's topographical map program. These prompts are described below, in the order in which they will appear.

Enhance the Contour Resolution:

The upper or lower portion of the active region of the surface can be enhanced, or a linear contour spacing can be used. Enhancement of the surface is provided by plotting more contour lines in the area to be enhanced than over the rest of the surface. When enhancement is chosen, the operator is prompted for the amount of the surface to enhance, the contour spacing in the enhanced region, and the contour spacing outside of the enhanced region. If linear contour spacing is chosen, the operator is prompted for a single contour spacing used over the entire surface. All spacings are expressed as a percentage of full scale.

Labeled Contour Line Frequency:

Not all contour lines are labeled with their Z-values. This parameter determines the frequency of the labeled contours. For example, entering a 0 results in no labels, 1 results in every contour line being labeled, and 2 results in every other contour line being labeled.

Labeled Contour Line Type:

Labeled contour lines can be drawn differently from unlabeled contour lines, to aid in reading the map. Normal, bold and dashed labeled contour lines are supported.

Grid Lines:

Rectangular grid lines are enabled or disabled at this prompt. If enabled, dashed grid lines are printed for each labeled tick on the axes. Labeled tick spacing is determined adequately by the graphics program, so no manual override is provided.

View of Plot the Surface:

This prompt provides the option of sending the map to the screen or hard copy device, or aborting the plot and returning to the main menu. If the map is generated, the graphics program is called at this point.

For ease of use, all options furnish reasonable default values. To perfom some functions, SURF2B may create the temporary double precision data files DUMP2.GRD and DUMP3.GRD, but the DUMP.GRD file containing the original data is preserved. To reduce accumulated roundoff error, all data processing is done in double precision arithmetic, and intermediate results are stored as ascii double precision numbers. However, since BASIC insists on writing a "D" instead of an "E" to designate the exponent when double precision numbers are printed, the grid file is converted to single precision before it is sent to the graphics package. The temporary single precision grid file created is called SURFDATA.GRD. Temporary files are deleted when SURF2 exists.

The additional prompts when producing topographical maps were found to be necessary for production of a useful map. When the topographical map option is selected, the operator is first prompted for which part of the surface, if any, to enhance. The detector data has a characteristic shape resembling the top hat function, there is a raised portion corresponding to when the beam strikes the detector, surrounded by a skirt or steep drop-off to the background level. The background level corresponds to the detector not illuminated. The region of interest is usually the portion of the data corresponding to where the beam strikes the active portion of the detector, and the details of this region are dwarfed by the magnitude of the change to the background level. The contour lines shown on topographical maps are usually equally spaced. But for this surface, equal spacing will result in loosing all detail in the active region or having a great many lines in the skirt. So an option is provided which allows enhancement of either the top or bottom of the surface, by using a finer contour level spacing there than over the rest of the surface. For example, the default uses a spacing of 0.5% over the top 5% of the Z-data range, and a spacing of 20% over the rest of the range. This results in a pleasing map of the entire data set. This contour level information is written to the file SURFLVL.DAT, which is used by the graphics program.

Alternately, the enlarged portion of the graph option can be used to limit the active region to the active detector area. Then linear contour spacing is adequate, but some features near the skirt are cut out. Also, the raise baseline option can be used to enhance the upper portion of the surface by decreasing the height of the skirt. This option may however cut off the bottom of holes in the active area, making them appear less deep than they actually are. These two techniques can be applied to the surface plots as well as topographical maps. With surface plots, the features may become so pronounced that the Z-scale factor, a history parameter, must be reduced for the surface plot to be understandable.

For example, if the raise baseline technique is used with a surface plot, the suggested procedure is to invert the data if necessary so that the surface of interest is on the top. Then, convert the data to a percentage of full scale, and the raise the baseline to as high a percentage as possible without cutting off the data of interest (typically 95%). It may then be necessary to reduce the Z-scale factor if the features are too pronounced.

The options selected by the user, and the data file names are passed to the graphics program via the command files SURFAUTO.CMD and SURFTOPO.CMD. The graphics program used can take instructions from these command files as if they were entered interactively. It should be noted that the surface plot shows the real data points connected with lines, no interpolation or curve fitting is done. Smoothing is available in the graphics package, but is not used because of its distorting effect and memory requirements. The topographical map however is interpolated from the data. Thus, when the contour level spacing is changed, some features may also change slightly.

The interface program provides an easy to use set of commands for generation of high quality surface plots and topographical maps. The complete program source code consists of the files: SURF1.BAS, SURF2.BAT, INSTALL.BAT and SURF2B.BAS. The file SURF4.BAT will be created by SURF2B, and other temporary files are created and deleted. The compiled BASIC programs, the programs, and the three-column data file must be in the default directory when the program is run. The graphics package, BASIC's support file BRUN4x.EXE, and DOS's COMMAND.COM must be accessible through the DOS PATH.

Appendix I: Placing the unknown detector in the (m=0) or (m=2) beams of the beam splitter wedge

The unknown detector is attached to XY linear translation tables. By rotating the latter to another set of holes in the steel table supporting them, the detector is placed either in the (m=0) beam or the (m=2) beam of the beam splitter wedge at 0.6328 μm.

The position of the detector will differ by small angles at other wavelengths. The deviation angles of the (m=0) and (m=2) beams from the beam entering the beam splitter are 1.60° and 8.79°, respectively.

Appendix J: Linear detector for the visible and near infrared laser wavelengths

A.L. Rasmussen

1. Discussion

NIST calibrates laser power and energy measuring detectors that are used as transfer standards. To calibrate transfer standards reliably requires determining their linearity as well as uniformity of responsivity. In order to improve device evaluation, NIST has developed systems to measure these parameters. The purpose of this discussion is to describe the design, calibration, and application of a linear detector of laser power. A system uses this detector to assure operation below saturation. It measures uniformity of detector responsivity and beam dimensions and is described in the main report.

The linear detector of laser power was calibrated with a cw laser at 0.6328 μm in the C series system, the national standard for laser power and energy for visible and near infrared wavelengths [1]. It was called Rosy 7-1 because of the rosy glow of the laser beam emitted from the integrating sphere in front of the detector. Because it is linear at 0.6328 μm, Rosy 7-1 is is assumed to be linear at each operating wavelength from 0.4 to 1.1 μm provided it is not used near saturation. NIST transfer standards made from detectors similar to Rosy 7-1 are linear at 1.064 μm [2].

2. Description

Rosy 7-1 is a temperature-controlled silicon PIN photodiode with -180 V bias and an integrating sphere mounted in front of it. The integrating sphere transforms any beam into a highly uniform beam entering a specific area of the detector [3]. A nanovolt amplifier following the detector delivers -10 V to the readout, either an A/D card or a digital voltmeter attached to a computer. The alignment parts, mirror and iris attached to sphere entrance, and positioner with six degrees of freedom greatly assist in aligning the integrating sphere in the beam. The mirror reflects the beam on itself and the iris helps center the beam. See figures 1 and 2 and the key to figure 1.

3. Calibration

Rosy 7-1 was calibrated with a cw laser at 0.6328 μm in the C series system, which is traceable to SI standards of voltage and current. The power in Rosy 7-1 is determined from the product of the beam splitter ratio and the power in the C series calorimetric standard.

The output of Rosy 7-1 enters a nanovolt amplifier with 0.01% uncertainty of the gain. The amplifier is connected to either an A/D card or a precise digital voltmeter attached to a computer.

Calibration and statistical data of Rosy 7-1 are given in tables 1 and 2. The area of the beam is approximately equal to the area of an iris, located immediately in front of the detector and opened to the $1/e^2$ radius of the beam as determined by power measurements.

Table 1 gives responsivity values in order of ascending power. Two beam splitters and loads had to be used to cover the range. Calibration was from $5 \cdot 10^{-7}$ to $1.5 \cdot 10^{-2}$ W and about $2.5 \cdot 10^{-5}$ to $8 \cdot 10^{-1}$ W/cm^2. The results had 0.2 percent uncertainty of linearity and 0.6 percent uncertainty of calibration.

The linearity of Rosy 7-1 should prevail at each operating wavelength throughout its range as long as it is not saturated. Rosy 7-1 may be used at other wavelengths as a linear detector of laser power.

4. Application

Rosy 7-1 monitors laser output in a system that determines uniformity of detector responsivity and measures beam dimensions. An unknown detector, or pinhole and detector, is scanned in the beam of the system. See Fig. 3. Using the monitor also reduces the effect of laser fluctuations on measurements.

Appendix J References

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Table 1. Rosy 7-1 Linear Detector Calibration Data taken August 1988 at 0.6328 μm HeNe Laser Wavelength

Run Number	Responsivity (V/W)	Input power (W)	Output (V)	Load* (Ω)	BS Ratio**
8	-34.84	$5.025 \cdot 10^{-7}$	$-1.751 \cdot 10^{-5}$	1000	819.3
5	-34.76	$1.213 \cdot 10^{-6}$	$-4.216 \cdot 10^{-5}$	"	"
4	-34.63	$2.047 \cdot 10^{-6}$	$-7.090 \cdot 10^{-5}$	"	"
9	-34.58	$3.606 \cdot 10^{-6}$	$-1.247 \cdot 10^{-4}$	"	"
2	-34.74	$6.382 \cdot 10^{-6}$	$-2.217 \cdot 10^{-4}$	"	"
7	-34.67	$8.663 \cdot 10^{-6}$	$-3.004 \cdot 10^{-4}$	"	"
3	-34.68	$1.071 \cdot 10^{-5}$	$-3.714 \cdot 10^{-4}$	"	"
1	-34.73	$1.591 \cdot 10^{-5}$	$-5.527 \cdot 10^{-4}$	"	"
6	-34.72	$1.943 \cdot 10^{-5}$	$-6.747 \cdot 10^{-4}$	"	"
17	-34.72	$3.081 \cdot 10^{-5}$	$-1.070 \cdot 10^{-3}$	"	11.53
18	-34.56	$6.410 \cdot 10^{-5}$	$-2.215 \cdot 10^{-3}$	"	"
10	-34.57	$1.502 \cdot 10^{-4}$	$-5.191 \cdot 10^{-3}$	"	"
15	-34.55	$1.666 \cdot 10^{-4}$	$-5.758 \cdot 10^{-3}$	"	"
11	-34.64	$1.689 \cdot 10^{-4}$	$-5.849 \cdot 10^{-3}$	"	"
14	-34.55	$4.741 \cdot 10^{-4}$	$-1.638 \cdot 10^{-2}$	"	"
13	-34.56	$7.061 \cdot 10^{-4}$	$-2.425 \cdot 10^{-2}$	"	"
16	-34.55	$9.719 \cdot 10^{-4}$	$-3.358 \cdot 10^{-2}$	"	"
12	-34.62	$1.349 \cdot 10^{-3}$	$-4.670 \cdot 10^{-2}$	"	"
19	-34.62	$1.460 \cdot 10^{-3}$	$-5.055 \cdot 10^{-2}$	"	"
25	-34.75	$2.574 \cdot 10^{-3}$	$-8.942 \cdot 10^{-2}$	"	"
24	-3.469	$2.577 \cdot 10^{-3}$	$-8.940 \cdot 10^{-3}$	100	"
26	-34.78	$2.775 \cdot 10^{-3}$	$-9.652 \cdot 10^{-2}$	1000	"
23	-3.465	$4.137 \cdot 10^{-3}$	$-1.433 \cdot 10^{-2}$	100	"
22	-3.467	$8.091 \cdot 10^{-3}$	$-2.805 \cdot 10^{-2}$	"	"
21	-3.473	$1.164 \cdot 10^{-2}$	$-4.041 \cdot 10^{-2}$	"	"
20	-3.480	$1.537 \cdot 10^{-2}$	$-5.348 \cdot 10^{-2}$	"	"

* 0.1% uncertainty

**BS ratio = beam splitter ratio in C series system

Table 2. **Statistical Data of Rosy 7-1 Linear Detector Calibration data in Table 1 at 0.6328 μm HeNe Laser Wavelength**

Calibration

Average Responsivity (V/W)	SD %	n	Load (Ω)	Beam area (cm^2) (at $1/e^2$ points)
-34.66	0.26	21	1000	$\sim 2 \cdot 10^{-2}$
-3.471	0.17	5	100	$\sim 2 \cdot 10^{-2}$

Power and Power Density Measurement Range

	Minimum	Maximum
Power (W)	$5 \cdot 10^{-7}$	$1.5 \cdot 10^{-2}$
Irradiance (W/cm^2)	$2.5 \cdot 10^{-5}$	$8 \cdot 10^{-1}$

Calibration Uncertainty

C series total uncertainty	Load (Ω)	Total uncertainty	Linearity uncertainty
0.4%	1000	0.60%	0.17%
0.4%	100	0.46%	0.23%

Key to Figure 1

1. Readout: A/D card or voltmeter attached to a computer.
2. Nanovolt amplifier: gains 10^2, 10^3, 10^4 and 10^5; 10 V maximum output.
3. Detector: silicon PIN photodiode (Rosy 7-1), ~1 cm^2 area, 100 Ω and 1000 Ω load, 0.4 - 1.1 m wavelength range.
4. Integrating sphere: cube with 3.57 cm diameter sphere inside with white coating of barium sulfate, 0.766 cm inside diameter entrance, ~ 0.8 cm inside diameter exit, ~0.2 throughput (decimal fraction of entrant energy emerging from sphere), beam distributed uniformly on detector, baffle inside sphere stops first reflection entering the detector.
5. Alignment parts: front surface mirror to reflect the beam on itself, iris to center the beam into the detector.
6. Bias power supply: -180.0 V.
7. Temperature controller: maintain detector temperature about 30°C $\pm$ 0.1°C with a readout of 3900 Ω.
8. Temperature controller power supply: 15 V.
9. Positioner with six degrees of freedom: align detector.

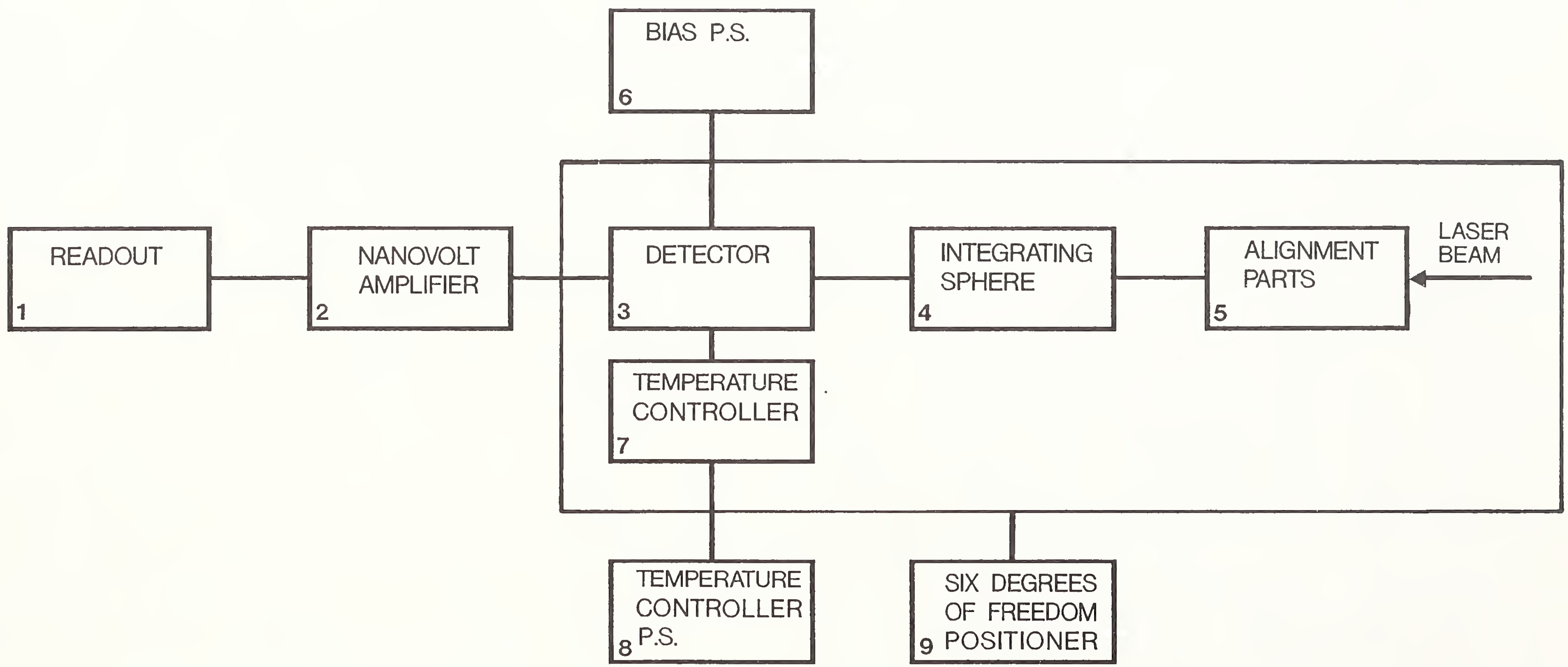

Figure 1. *Linearity standard system.*

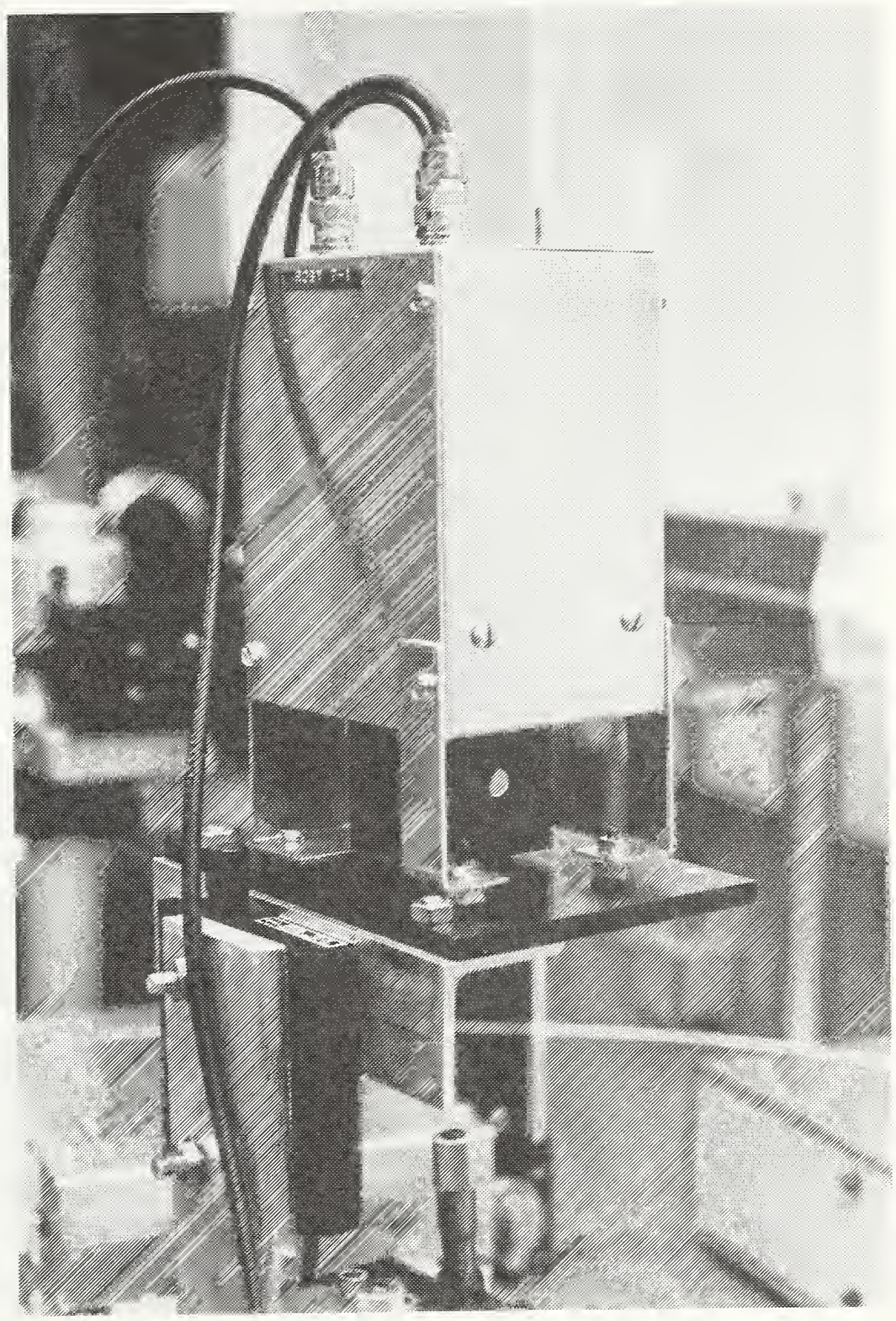

Figure 2a. Front view of the linearity transfer standard Rosy 7-1 shows a black cube containing the integrating sphere below the chassis holding the detector, the temperature controller, and the circuitry. Sphere entrance and positioning knobs below are also shown. A mirror and an iris used to align the sphere are attached to threads surrounding the sphere entrance.

Figure 2b. Rear view of the linearity transfer standard Rosy 7-1 in the scanning system shows Daniel Habernall adjusting the position of the standard. The beam splitter with dark frame and the scanner with motor and cable visible are in the background.

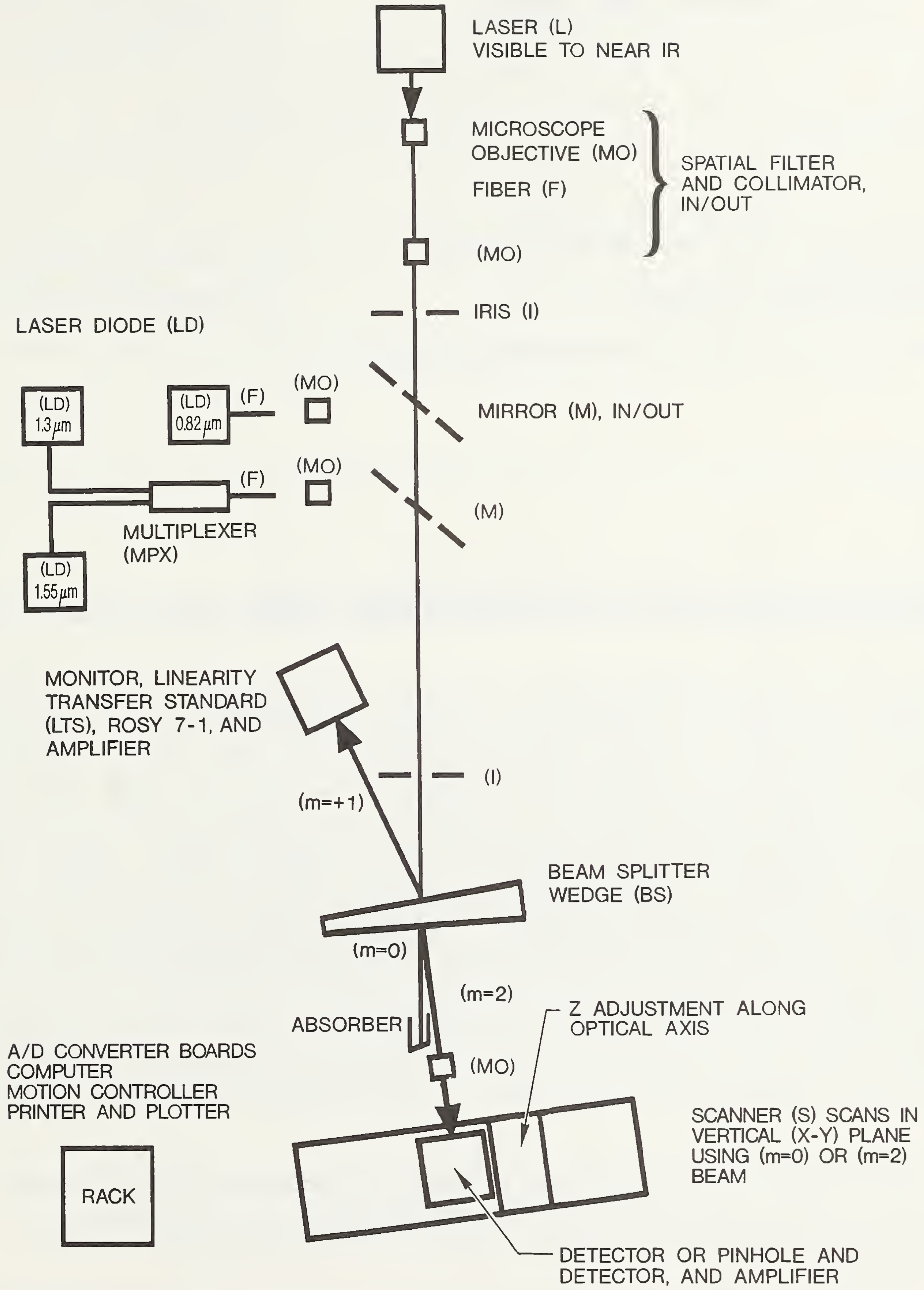

Figure 3. *Detector scanning system using linearity transfer standard, ROSY 7-1.*

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ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

A computer-controlled scanning system constructed at NIST/Boulder moves a detector or a pinhole attached to a detector in a plane perpendicular to the axis of a stationary laser beam. A linear detector monitors the laser beam. The system measures the uniformity of laser detector response and the laser beam dimensions. The device to be measured is attached to computer controlled X-Y translation tables that scan a maximum area of 15 cm x 15 cm with 10^{-4} cm resolution along each axis. Detector and monitor outputs are digitized with a computer board. Output versus position is represented in contour maps and surface graphics on the computer, the plotter, or the printer. Choice of matrix dimensions and step sizes of the scanned area determine the resolution of graphics. Maximum, minimum, average and variance data of the Z output of a detector for a chosen X-Y area provide additional uniformity information. High precision fiber couplers can be used to spatially filter and/or collimate the beam. Available sources are conventional lasers from the visible and the near infrared wavelengths or laser diodes at 0.82, 1.3 and 1.55 μm wavelengths. A precision positioner along the optical axis moves the measurement device and controls the size of the beam entering it. Beam dimensions and detector response data are given. This report documents the use of the system to calibrate detectors.

KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

beam dimensions; computer-controlled scanning system; detector and beam graphics; detector and beam scanning; laser detector response; laser power monitor; linear detector; uniformity

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