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BELLCOMM, INC.

SUBJECT: Lunar Orbiter I Exposure Determination - Case 340

DATE: February 15, 1967

FROM: H. W. Radin

TM-67-1012-2

TECHNICAL MEMORANDUM

I. INTRODUCTION

A. Motivation

As soon as Lunar Orbiter I began returning picture data to earth, it became apparent that the moderate resolution pictures were considerably overexposed, and that the exposure difference between the high and low resolution pictures was quite large. In the face of these discrepancies the exposures for Orbiter II could not sensibly be chosen without a good knowledge of the results from Orbiter I, and therefore a systematic study was made of the exposures obtained on the first mission. This report presents the results of that study.

B. Usefulness

These results were transmitted informally to I. Taback, Lunar Orbiter Spacecraft Manager at NASA Langley Research Center, for use during Orbiter II mission operations, and led to the inclusion of a neutral density filter to partially correct the overexposure on Orbiter III; also, the technique described here will be used for real-time analysis of Orbiter III priority readouts at the SFOF. A further use of the data may be as a beginning on the problem of refining our knowledge of the lunar albedo and photometric function.

II. GENERAL APPROACH

A. Use of Video Rather Than Photo

The logical starting point was to measure the average density of the reconstructed photographs, compare their average density with the edge-printed gray scale (see Section B), and thus arrive at average exposure values. Two difficulties arose, however. First, and most important, flare in the Ground Reconstruction Equipment (GRE) caused a density compression in the high contrast gray scale but not in the low contrast portions of the picture data, thus impairing the correspondence between the two. Second, obtaining the average density of a number of frames is a fairly tedious sampling process.

A more productive approach was to make the measurements earlier in the processing chain, as close as possible to the spacecraft film -- directly from the tape-recorded video signals.

B. Source of Exposure Data

The edge of all Lunar Orbiter film has been printed with calibration and diagnostic data prior to launch, including resolution charts, registration bars for the reassembly printer, gray scales, etc. A photograph of two blocks of edge data is shown in Figure (1), enlarged from a strip of 35 mm GRE film.

The gray scales in the edge print are of particular importance to us because they provide the only exposure calibration which is independent of spacecraft video amplifier gain changes, film processing variations, etc.

C. Method of Obtaining Gray Scales

It was desired to measure the actual received video voltages corresponding to the edge print gray scale steps. In order to do this a circuit was designed (see Section IIIB) which selects and presents on the oscilloscope a single video scan through the gray scale. In a similar manner a single scan may be selected nearly anywhere in any framelet.

D. Method of Obtaining Average Voltages

The video from the detector was connected directly to an R-C integrator (low-pass filter) and hence to a chart recorder, making it possible to monitor an entire frame. The average voltage was then obtained by drawing upper and lower bounds on the voltage fluctuations and averaging these.

III. RECEIVED VOLTAGE VS LOG EXPOSURE CALIBRATION

A. Edge Print Data

The edge print is applied to the film along its full length by repeatedly flashing a lamp through a small reticle, with a repetition period slightly smaller than the width of a framelet. This ensures that each framelet has a complete data block.

An enlargement of two adjacent data blocks appears in Figure (1); these are adjacent because the spacecraft scanner reverses direction when it comes to the film edge.

The "effective" incremental exposures given to the gray scale steps are listed in the calibration package for Orbiter I,

and are reproduced in Table (1). Two points should be noted here:*

1) The calculated exposures given to the edge gray scale are somewhat different from the "effective" ones, because of flare in the edge printer.

2) The effective log exposure (meter-candle-seconds) given to gray scale step #2 (next to the least exposure) is $\bar{2}.75$ (sometimes written as 8.75-10).

   This has been incorporated into Table (1).

Other parts of the edge print are also useful to us. A large area near the film edge side of the edge print is exposed uniformly to a low "background density", equal to the density of step 2, and this area (sometimes called the "focus line area") is used in setting the spacecraft video gain. At the start of a readout, the spacecraft's mechanical scanner is stopped in this area, and the gain is adjusted until the received voltage equals an average of 5 volts. This voltage varies somewhat in the electrical scan direction because the electrostatic focus of the spacecraft line scan tube is correct only at two points along the scan, resulting in a brightness variation along the line. The shape of this variation is termed the photo system "signature"**, and is adjustable by spacecraft focus commands. The PS signature is considered here because it modulates the gray scale.

The edge print also contains a row of bars (black on the S/C film) about 3 times as long as the spaces between them, which extends the full width of the data block. These are used for registration of the framelets in the reassembly printer, but serve two ancillary purposes here; as a unique pattern to synchronize the "scan locator" circuit (see Section B), and as a fairly well-controlled high density region separate from the gray scale.

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*George Keene, Eastman Kodak Co., private communication

**A precise evaluation of spacecraft signals should take into account the variations due to the PS signature, since the peak-to-peak variation is about 12% of the full-scale (5 volt) signal. The effect should be a slowly varying one for relative photometry in Orbiters I and II, since the variation is nearly orthogonal to the phase plane for low-inclination orbits; but for high-inclination orbits it will introduce a high frequency periodic variation (with a period of about 200 m) into the slope determination on a high resolution photo.

Before Orbiter I was launched, a piece of the spacecraft leader was removed (at Cape Kennedy), exposed to a standard calibration wedge, and bimat-developed on the ground. This results in an independent calibration of the edge print gray scale. This piece of film has been examined with a microdensitometer,* and all of the above mentioned regions have been traced, including a number of gray scales. These appear as Figures (2) - (18), included here for future use in data analysis.

B. Scan Locator

It has already been pointed out (see Figure (1)) that the edge print data blocks occur back-to-back, in pairs, in the spacecraft readout. In order to display a single video scan, the video is clipped, amplified and used to drive an 8 kc tuned circuit, corresponding to the repetition rate of the registration bars in the edge print. When the spacecraft scanner encounters the registration bars the tuned circuit oscillates, and the resulting 8 kc signal is used to start a one-shot multivibrator having a pulse duration of about 3 seconds.

The leading edge of the multivibrator pulse is used to trigger the delaying sweep of an oscilloscope. The time interval between the start of scanning through the registration bars of the first data block and the start of scanning through the gray scale of the second data block is about 2.65 seconds, and if the sweep delay is set at this value the oscilloscope just picks out the gray scale. By this means only the second data block may be explored, but with a later design other areas are accessible as well. The duration of the multivibrator pulse is uncritical, so long as it lasts until the second set of registration bars has been scanned; this is to prevent accidental retriggering. In order to photograph the gray scale one must simply open the camera shutter when the multivibrator turns on, and close it again when it turns off. By adjusting the oscilloscope time delay, one can obtain a single scan anywhere in the data block, and as far into the picture data as the maximum oscilloscope sweep delay will permit. Photos of gray scales and other edge print data are shown in Figures (19) - (27).

C. Analysis of Gray Scale Data

The objective of photographing gray scales is to provide a calibration curve of received video voltage vs. log exposure on the S/C film, and a first order result can be obtained simply by measuring the voltages on one of the gray scale photos

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*Note that the measured density of a given piece of film may be quite different when it is examined by a microdensitometer, a visual-diffuse densitometer, or the spacecraft readout scanner. See Reference 1.

and plotting it against the log exposure values* supplied by Eastman Kodak [see Table (1)]. This is not too satisfying, however, since it requires full dependence on the gray scale exposure values, and a little more investigation is in order.

A good test of reasonability of the results is based upon the assumption that the system is linear from the light intensities transmitted through the film in the spacecraft to the received voltage on the ground (in between are a photomultiplier, transmitter, receiver, detector, tape recorder, etc., but these are usually fairly linear devices). The light transmitted through the film will be proportional to the transmission of the film, which is given by 10^{-D}, where D is the film readout density.** Since the D vs log E curve is known a priori (Figure (28))***, one can find film transmission values corresponding to the edge print gray scale step exposures. Plotting the measured voltages**** vs these transmission values results in Figure (29), drawn as a straight line.

Only the following rough argument remains: Most of the steps in the gray scale are fairly noisy, some of the noise coming from the electronics and some from the actual gray scale densities. (See the microdensitometer traces in Figures (2) - (18)). There is therefore an uncertainty in the values read, although the general trend of the gray scale is probably right. Also, the PS signature will have a small modifying effect on the gray scale, which will depend on the relative phase between the PS signature variation and the gray scale (recall that the gray scale repetition rate is incommensurate with the framelet rate, while the PS signature is not). Thus the straight line assumption for the V-T characteristic is probably better than the accuracy of the points measured, and it is reasonable to take the straight line rather than the data points.

With the V-T characteristic thus forced linear, a smooth V-log E curve may be obtained by reading transmission values corresponding to arbitrary voltages, converting to density values by $T = 10^{-D}$, and finding the corresponding exposures from the D-log E curve. The result is plotted as Figure (30).

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*See Reference 2

**See Reference 1

***See Reference 1

****These voltages are averages of a number of gray scales (See Table 2).

It should be possible to verify the D vs log E curve of Figure 28, by measuring the densities of the steps on a visual densitometer and plotting them against the appropriate log E values (see Table 3). Also, the corresponding densities may be read from the microdensitometer trace in Figure 7. Finally, comparisons may be made with the curve of Figure 28, replotted in terms of visual density (see Reference 1). These three curves are plotted, for purposes of comparison, in Figure 36.

It appears that there is a significant difference between the D vs log E curve published by Eastman Kodak Co. and the one obtained from the spacecraft leader. The Eastman Kodak curve will be used for all measurements discussed in this memorandum.

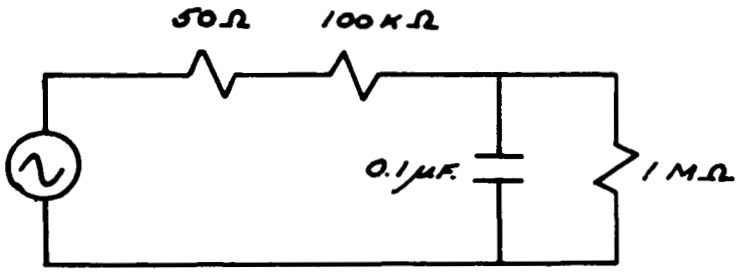
IV. OBTAINING THE AVERAGE EXPOSURES

A. Chart Recorder and Integrator

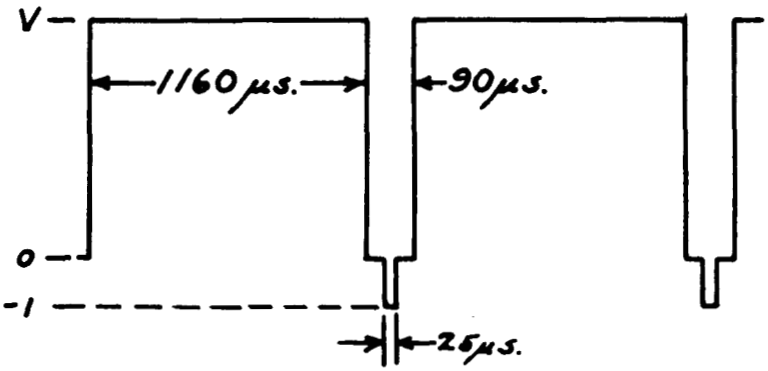
One of the two reasons for working from video signals rather than from pictures is the ease of displaying an entire frame in a way which makes measurement simple. The video is connected to an R-C integrator (low-pass filter) having a time constant of 0.01 seconds (about 8 scans long), and the output is connected to a strip chart recorder. After an entire frame has been recorded, lines are drawn bounding the voltage fluctuations, and the voltage values corresponding to the bounds are then averaged. [It is recognized that this is not quite the same as averaging the log exposures, since the V-log curve is not linear -- this effect is negligible, as can be seen by working a specific example with the curve in Figure 30]. The log E value corresponding to this average can then be found from Figure (30).

B. Calibration of the Chart Recorder

It is easily seen that the voltage values read from the recorder will not be the same as the values attained by the video signal corresponding to the picture data. For one thing, the input impedance of the chart recorder is not infinite (about a Megohm compared to 100 K for the integrator resistor); for another, the signal is zero during the retrace interval, except for the short sync pulse period during which it is -1 volt. Both of these effects may be calculated, as follows:



$$F_1 = \frac{1.0M}{1.0M + 0.1M} = 0.909$$



$$V_{AV} \cdot 1250 = V \cdot 1160 - 1 \cdot (25)$$

$$\frac{V_{AV}}{V} = 0.928 - \frac{0.02}{V} \doteq 0.928$$

$$F_2 \doteq 0.928$$

$$F = F_1 \cdot F_2 \doteq 0.843$$

Actually, we can finesse the whole calibration problem by making use of a special signal generated by the GRE. It consists of an (adjustable) constant voltage video scan, interrupted by a retrace period and sync pulse exactly like spacecraft video. We simply connect this "external video" signal to the integrator and chart recorder and measure its voltage on the oscilloscope. This was done each day, and at a number of voltage values; the resulting calibration staircase appears at the beginnings of some of the charts. The reduction factor is quite close to the one calculated above, and varies only slightly from day to day. The variations are probably due largely to errors in reading the oscilloscope.

C. Achieving Long Time Constants

Ideally, one would like to have the chart recorder draw a single straight line corresponding to the average exposure of a frame. Not only would this simplify the job of obtaining a log exposure number corresponding to the frame, but it would improve the accuracy -- manual averaging of upper and lower limits of a fluctuating signal is bound to be imprecise. The only limitation on the time constant would seem to stem from available components for the circuit, but the snag is calibration, again.

As the time constant is increased, the integrator eventually becomes unable to follow the mechanical retrace gaps between the framelets, and simply averages them into the video data. This would be all right if the transmitter signal in the gaps were accurately known because it could then be calibrated out; but even though the gaps are repetitive, alternate ones are different and the signal in the data block gap, at least, is quite complicated.

One way around this problem is to disconnect the signal from the integrator during the retrace gap, thus averaging into the signal the value immediately preceding rather than the unknown value corresponding to the retrace. has been augmented by a gate and a field-effect transistor, controlled by a pair of multivibrators which shut off the integrator during mechanical retrace. This is called a "sample and hold" circuit.

The calibration method used earlier does not apply because the GRE external video calibration signal runs continuously, without the mechanical retrace gaps characteristic of the spacecraft, and thus no retrace pulse is available to switch the gate. To meet this difficulty the circuit has been designed so that it can free-run, for calibration purposes, when the external video signal is used; the calibration signal is thus interrupted by the circuit in the same way as is the spacecraft video.

V. RESULTS

A. Charts

A number of charts of partial or complete frames are included in Figures 31-33; Figure 34 is a chart of the Goldstone test tape (MT-2). High and medium resolution frames were recorded from each of sites A-1, A-3, A-5, A-6, and A-7, and the computed exposures appear in Table 4.

It is important to note that an average exposure was obtained for the moderate resolution (MR) pictures, based upon the entire frame; since time was limited usually only samples of the high resolution (HR) pictures were taken, at the ends of the frames. Thus care must be taken when comparing the MR and HR results -- see Section D.

B. Edge Print Data

Gray scales and other edge print data were obtained for each site, and are presented in Figures (19) - (27). For each site, the small circled numbers on the chart correspond to the similarly numbered gray scale photos. The scale for all of these photos is 1 volt per large division.

C. Predicted Exposures

The predicted exposures may be calculated, with the benefit of hindsight, using the best values now available for the variables. Appendix A illustrates this calculation for site A-3, and predicted exposures for five sites are presented in Tables 5 and 6.

D. Analysis of Data

1. HR exposures - averaging method

As stated in Section A, voltage traces were taken at the ends of the HR frames, and the traces were averaged over several framelets near the frame ends; these averaged voltage traces lead to the HR exposures shown in Table (4). The predicted exposures, however, are computed using on-axis values for lens transmission (see table 5), and thus a disparity exists.

The measured average values must therefore be corrected by the ratio of on-axis to edge transmission of the 24" lens or $\log \frac{0.68}{0.55} = 0.092$. Note that 0.68 is used here rather than the 0.64 value used to compute the on-axis predicted exposure -- the latter value includes the losses of the mirror in the HR light path, and the present correction involves only the lens.

Measured values corrected in this way are presented in Table (7), alongside the predicted values. The agreement is quite good; the mean log overexposure is - 0.02, and the standard deviation is 0.03.

2. MR exposures - averaging method

The integrated voltage traces for the MR frames were averaged over the entire frame (or half a frame, which is equivalent due to symmetry); the resulting measured exposures must be increased by the ratio of the on-axis transmission to the average transmission of the lens.

An approximate value for the average transmission of the lens may be obtained by assuming that the lens off-axis characteristic is linear between its central and peripheral values:

$$\eta_{AV} = \frac{\int_0^{2\pi}\int_0^R \eta(r)\, r\, dr\, d\theta}{\pi R^2}$$

$$= \frac{2}{R^2}\int_0^R \left(0.92 - \frac{0.48\, r}{R}\right) r\, dr$$

$$\eta_{AV} = 0.92 - 0.32 = \underline{\underline{0.60}}$$

Since the lens characteristic is concave downward, this value is probably a bit lower than the true average, and hence will cause us to overestimate the exposure slightly in the succeeding paragraph.

The measured values (see table 4) for the MR exposures must now be increased by $\log \frac{0.92}{0.60} = 0.186$, in order to permit a comparison between the measurements and the on-axis predictions. The corrected values appear in Table 8, alongside the predicted values.

The mean log overexposure, relative to the predicted exposures, is 0.39, and the standard deviation is 0.04.

3. HR & MR Exposures - point measurement method

As a check on the validity of the above averaging, a high and low resolution frame (not included in this memorandum) from the same lunar area were compared by measurements at their centers. In each frame, the centers of the center five framelets were measured and averaged; the results appear below.

HR 165		MR 163	
17.5 mm		4.2 mm	
16.7	AVG = 17.2 mm	3.7	AVG = 3.76 mm
17.0	(1.99 volts)	3.8	(0.435 volts)
17.1	Log E = 1.37	3.1	Log E = 1.84)
17.7		4.0	

Δ Log E = 0.47

We know that the on-axis transmissions of the lenses (including the mirror in the HR case) are 0.92 and 0.64; $\log \frac{0.92}{0.64} = 0.16$; hence the unaccounted for exposure difference is 0.47 - 0.16 = 0.31. This checks fairly well with the average exposure method.

VI. SUMMARY AND CONCLUSIONS

The Lunar Orbiter I medium resolution camera, in flight, overexposure its pictures by a log exposure of 0.39 (a factor of about 2.5), relative to predictions based upon preflight measurements and calibrations. The high resolution camera, in flight, performed approximately as predicted. The above results are summarized in Table 9. Preliminary results from Orbiter II photography indicate a similar overexposure condition.

The cause of this overexposure is presently unknown. The Lunar Orbiter Project Office has placed an 0.2 D neutral density filter in front of the 80 mm lens, which should correct for about half of the observed overexposure; the entire correction of 0.39 D should be added to Orbiter IV.

VII. ACKNOWLEDGEMENTS

This work was sponsored and encouraged by I. Taback of NASA/Langley Research Center, and benefited greatly from the cooperation of many people in the Lunar Orbiter Project Office.

I would particularly like to thank J. Rawlins of NASA/LRC, who designed and built some rather complicated circuitry which proved to be the key to the whole task, also R. Oxhandler and his people of the Boeing Company.

Finally, my thanks to D. D. Lloyd, who first suggested the need for this project.

H. W. Radin /cjB

1012/HWR/dmc

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Attachments
Appendix A
Tables 1-9
Figures 1-36

REFERENCES

1. LOP Engineering Note L-022992-KU, October 7, 1966, S. Heinmiller, Eastman Kodak Co.

2. Summary of Photo Data System Calibrations For Lunar Orbiter I (S/C #4, PS #4, Serial #3), T. P. Hansen, Lunar Orbiter Project Office, NASA Langley Research Center (Refer to IOM-2151-TPH).

3. Supplement to Quality Control Data Package For Photographic Subsystem Serial #3. Available from T. P. Hansen, NASA/LRC.

APPENDIX A

It is desired to calculate the actual amount of light energy (exposure) incident in the film, expressed in meter-candle-seconds ($\frac{\text{lumen-seconds}}{\text{meter}^2}$). We recall first that the lunar surface luminance is given by

$$B = \frac{\rho \phi s}{\pi} \qquad \frac{\text{candles}}{m^2}$$

where ρ = normal albedo
ϕ = photometric function
s = solar illuminance of the Moon = $14 \times 10^4 \ \frac{\text{lumens}}{m^2}$

The illumination of the film is

$$I_f = \eta \frac{\pi B}{4N^2} = \frac{\eta \rho \phi s}{4N^2} \qquad \frac{\text{lumens}}{m^2}$$

The exposure given to the film in t seconds is

$$E = \frac{\eta \rho \phi s t}{4N^2} \qquad \frac{\text{lumen-seconds}}{m^2}$$

For site A-3 (frame H 96),

ρ = 0.075
ϕ = 0.14 (phase angle = 69°)
t = 0.032 seconds
η = 0.64 (on-axis transmission of 24" lens & mirror)
N = 5.6 (f-number)

$$E = 0.282 \ \frac{\text{lumen-seconds}}{m^2} = \text{meter-candle-seconds}$$

$$\log E = \bar{1}.449$$

TABLE 1

EFFECTIVE EXPOSURES OF EDGE PRINT GRAY SCALE STEPS

STEP NUMBER	LOG EXPOSURE (METER-CANDLE-SECONDS)
1	$\bar{2}.62$
2	$\bar{2}.75$
3	$\bar{2}.89$
4	$\bar{1}.02$
5	$\bar{1}.18$
6	$\bar{1}.39$
7	$\bar{1}.56$
8	$\bar{1}.72$
9	$\bar{1}.88$

TABLE 2

VOLTAGES OF GRAY SCALE STEPS

STEP NO.	A-1 PHOTO #6	A-3 PHOTO #2	A-5 PHOTO #1	A-6 PHOTO #1	A-7 PHOTO #4	AVERAGE
1	--	--	--	5.40	--	5.40
2	4.8	4.65	--	4.85	4.95	4.81
3	4.3	4.2	4.0	4.30	4.75	4.31
4	3.1	3.35	3.85	3.50	4.00	3.56
5	1.95	2.35	2.85	2.85	2.80	2.96
6	1.65	1.35	1.70	1.65	1.50	1.57
7	1.05	0.90	1.00	1.00	0.85	0.96
8	0.75	0.70	0.65	0.65	0.65	0.68
9	0.65	0.55	0.45	0.45	0.45	0.51

TABLE 3

MISSION A SPACECRAFT LEADER DENSITY VS LOG EXPOSURE

STEP #	LOG EXPOSURE	VISUAL (DIFFUSE) DENSITY	MICRODENSITOMETER DENSITY (FIG. 7)
1	$\bar{2}.73$	0.44	0.42
2	$\bar{2}.90$	0.48	0.475
3	$\bar{1}.04$	0.58	0.575
4	$\bar{1}.24$	0.78	0.788
5	$\bar{1}.38$	0.94	1.00
6	$\bar{1}.54$	1.16	1.25
7	$\bar{1}.72$	1.42	1.55
8	$\bar{1}.84$	1.61	1.76
9	0	1.81	1.98
10	0.17	2.01	2.23
11	0.33	2.18	
12	0.47	2.32	
13	0.61	2.44	
14	0.74	2.52	

TABLE 4

MEASURED EXPOSURES - UNCORRECTED

SITE	TAPE	FRAME	AVERAGE VOLTAGE	LOG EXPOSURE
A-1	WT-66-1	HR 58	2.78	$\bar{1}.20$
		MR 56	0.55	$\bar{1}.78$
A-3	MT-56-1	HR 98	2.24	$\bar{1}.30$
		MR 96	0.60	$\bar{1}.75$
A-5	GT-59-1	HR 124	3.41	$\bar{1}.08$
		MR 122	1.40 } Avg.	
		MR 122	1.10 } =1.15	$\bar{1}.55$
	GT-57	MR 133	0.95 }	
A-6	WT-42	HR 148	2.35	$\bar{1}.28$
		MR 146	0.65	$\bar{1}.73$
A-7	MT-34	HR 169	2.50	$\bar{1}.25$
		MR 168	0.40	$\bar{1}.88$

TABLE 5

PREDICTED EXPOSURES (HR LENS ON AXIS)

SITE	ρ (Albedo)	α (Phase Angle)	Φ (Photometric Function)	t (Shutter Time-Sec)	E (Exposure)	Log E
A-1	0.081	60.9°	0.20	0.019	0.220	$\bar{1}.342$
A-3	0.075	69.3°	0.14	0.0375	0.282	$\bar{1}.449$
A-5	0.076	68.6°	0.15	0.019	0.155	$\bar{1}.190$
A-6	0.125	54.1°	0.25	0.01	0.223	$\bar{1}.349$
A-7	0.076	58.3°	0.22	0.019	0.227	$\bar{1}.356$

Assumed on-axis lens transmission (including mirror) = 0.64

Albedo and phase angle values obtained from Langley Working Paper LWP - 323

Shutter speeds are averages of shutter speed ranges supplied by T. Hansen of NASA/Langley Research Center

TABLE 6

PREDICTED EXPOSURES (MR LENS ON AXIS)

SITE	ρ (Albedo)	α (Phase Angle)	Φ (Photometric function)	E (Shutter Time-Sec)	E (Exposure)	Log E
A-1	0.081	60.9°	0.20	0.02	0.333	$\bar{1}.522$
A-3	0.075	69.3°	0.14	0.03175	0.342	$\bar{1}.534$
A-5	0.076	68.6°	0.15	0.02	0.234	$\bar{1}.369$
A-6	0.125	54.1°	0.25	0.0109	0.340	$\bar{1}.532$
A-7	0.076	58.3°	0.22	0.02	0.343	$\bar{1}.536$

Assumed on axis lens transmission = 0.92

Albedo and phase angle values obtained from Langley Working Paper LWP-323

Shutter speeds are averages of shutter speed ranges supplied by T. Hansen of NASA/Langley Research Center

TABLE 7

COMPARISON OF MEASURED AND PREDICTED EXPOSURES (HR LENS ON AXIS)

SITE	MEASURED[1] LOG E	CORRECTED[2] LOG E	PREDICTED[3] LOG E	DIFFERENCE (CORR-PRED)
A-1	$\bar{1}.20$	$\bar{1}.292$	$\bar{1}.342$	-0.050
A-3	$\bar{1}.30$	$\bar{1}.392$	$\bar{1}.449$	-0.057
A-5	$\bar{1}.08$	$\bar{1}.172$	$\bar{1}.190$	-0.018
A-6	$\bar{1}.28$	$\bar{1}.372$	$\bar{1}.349$	+0.023
A-7	$\bar{1}.25$	$\bar{1}.342$	$\bar{1}.356$	-0.014

Notes: 1) Exposure at Edge of Frame

2) Exposure on Axis; Correction = Log $\frac{0.68}{0.55}$ = 0.092

3) Exposure on Axis

μ = Mean Log Overexposure = -0.02

σ = Standard Deviation = 0.03

TABLE 8

COMPARISON OF MEASURED AND PREDICTED EXPOSURE (MR LENS ON AXIS)

SITE	MEASURED[1] LOG E	CORRECTED[2] LOG E	PREDICTED[3] LOG E	DIFFERENCE (CORR-PRED)
A-1	$\bar{1}.78$	$\bar{1}.97$	$\bar{1}.522$	+0.45
A-3	$\bar{1}.75$	$\bar{1}.94$	$\bar{1}.534$	+0.41
A-5	$\bar{1}.55$	$\bar{1}.74$	$\bar{1}.369$	+0.37
A-6	$\bar{1}.73$	$\bar{1}.92$	$\bar{1}.532$	+0.39
A-7	$\bar{1}.88$	0.07	$\bar{1}.536$	+0.34

NOTES: 1) Average Exposure of Frame

2) Exposure on Axis; correction = Log $\frac{0.92}{0.60}$ = 0.19

3) Exposure on Axis

μ = Mean Log Overexposure = +0.39

σ = Standard Deviation = 0.04

TABLE 9

SUMMARY OF RESULTS

SITE	LOG OVEREXPOSURE (MCS)	
A-1	-0.050	+0.45
A-3	-0.057	+0.41
A-5	-0.018	+0.37
A-6	+0.023	+0.39
A-7	-0.014	+0.34

High Resolution Log Overexposure:

$\mu = -0.02 \qquad \sigma = 0.03$

Medium Resolution Log Overexposure:

$\mu = +0.39 \qquad \sigma = 0.04$

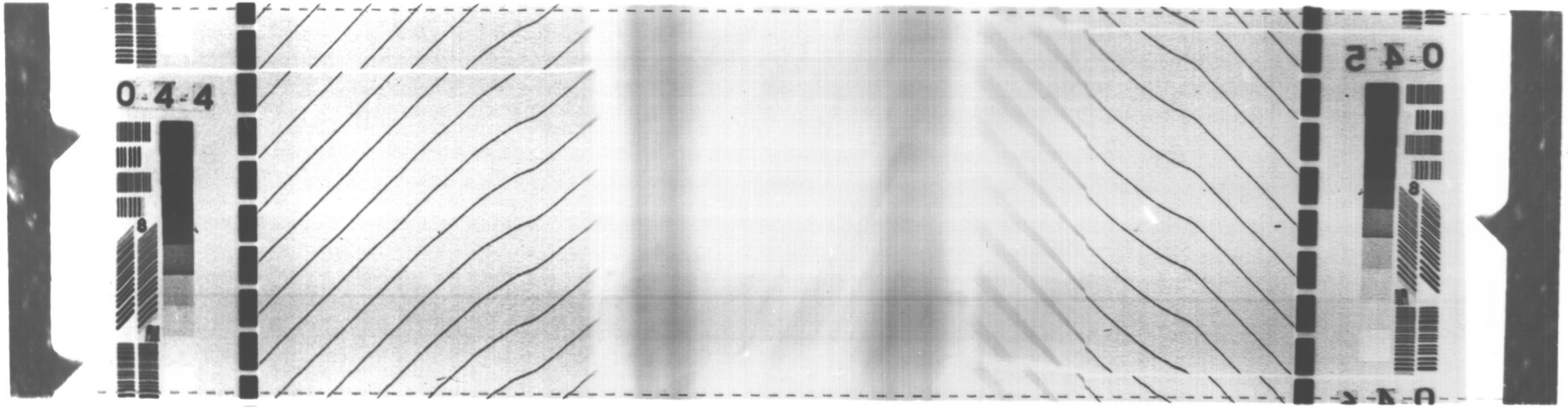


FIGURE 1 - ENLARGEMENT OF EDGE PRINT

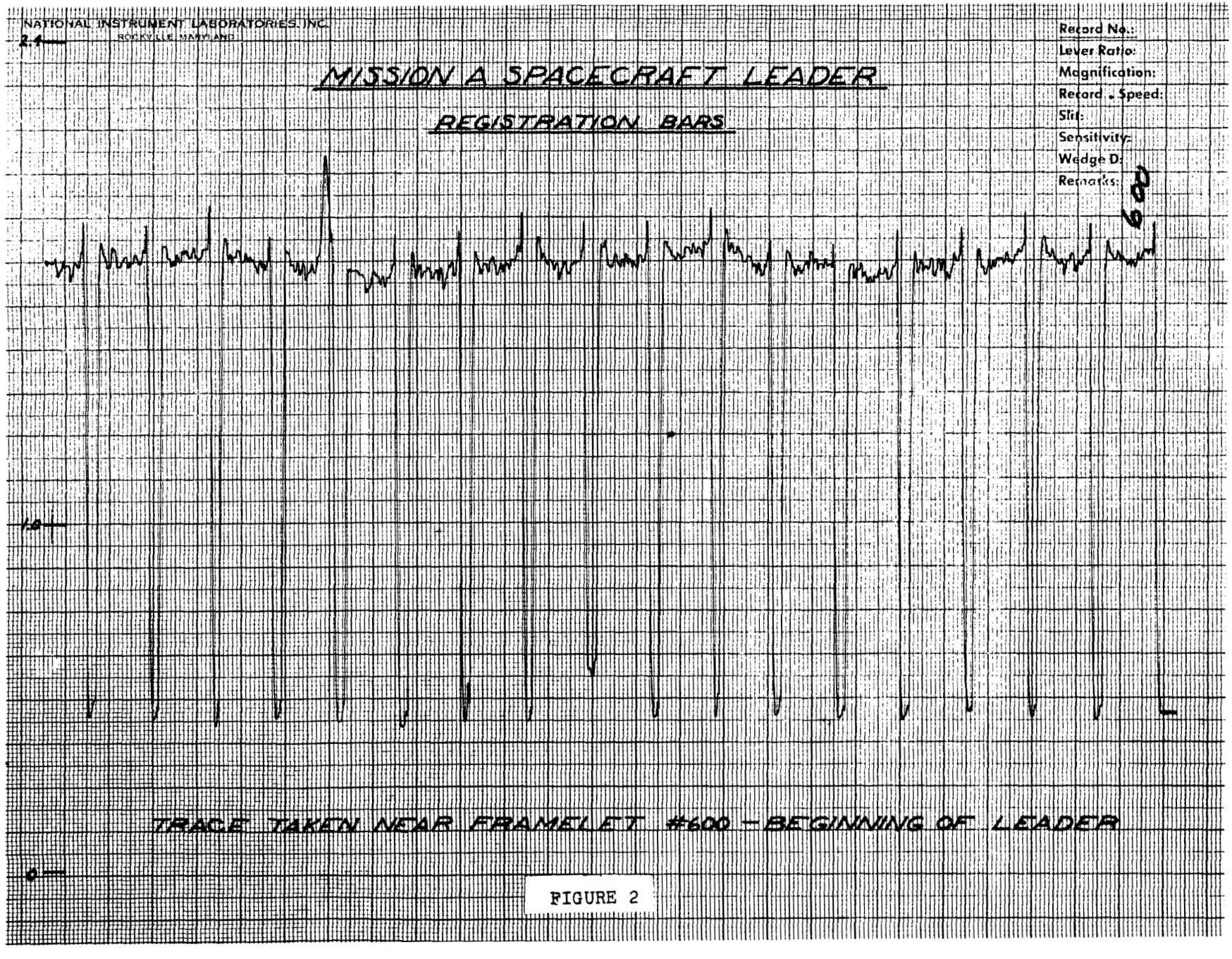

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
2.4
1.8
0
MISSION A SPACECRAFT LEADER
REGISTRATION BARS
Record No.:
Lever Ratio:
Magnification:
Record. Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:
600
TRACE TAKEN NEAR FRAMELET #600 – BEGINNING OF LEADER

FIGURE 2

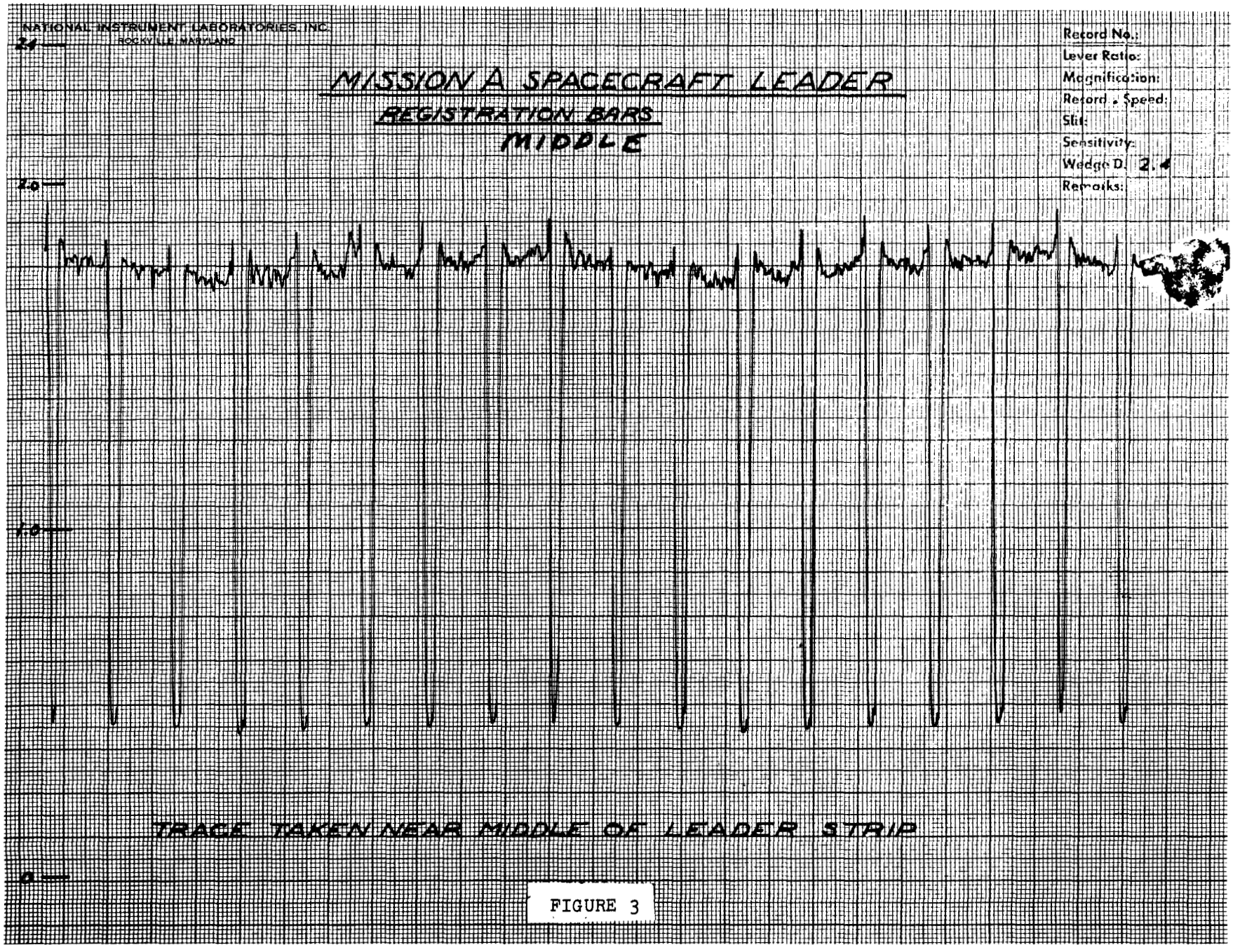

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
2.4
2.0
1.0
0
MISSION A SPACECRAFT LEADER
REGISTRATION BARS
MIDDLE
Record No.:
Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge D. 2.4
Remarks:
TRACE TAKEN NEAR MIDDLE OF LEADER STRIP

FIGURE 3

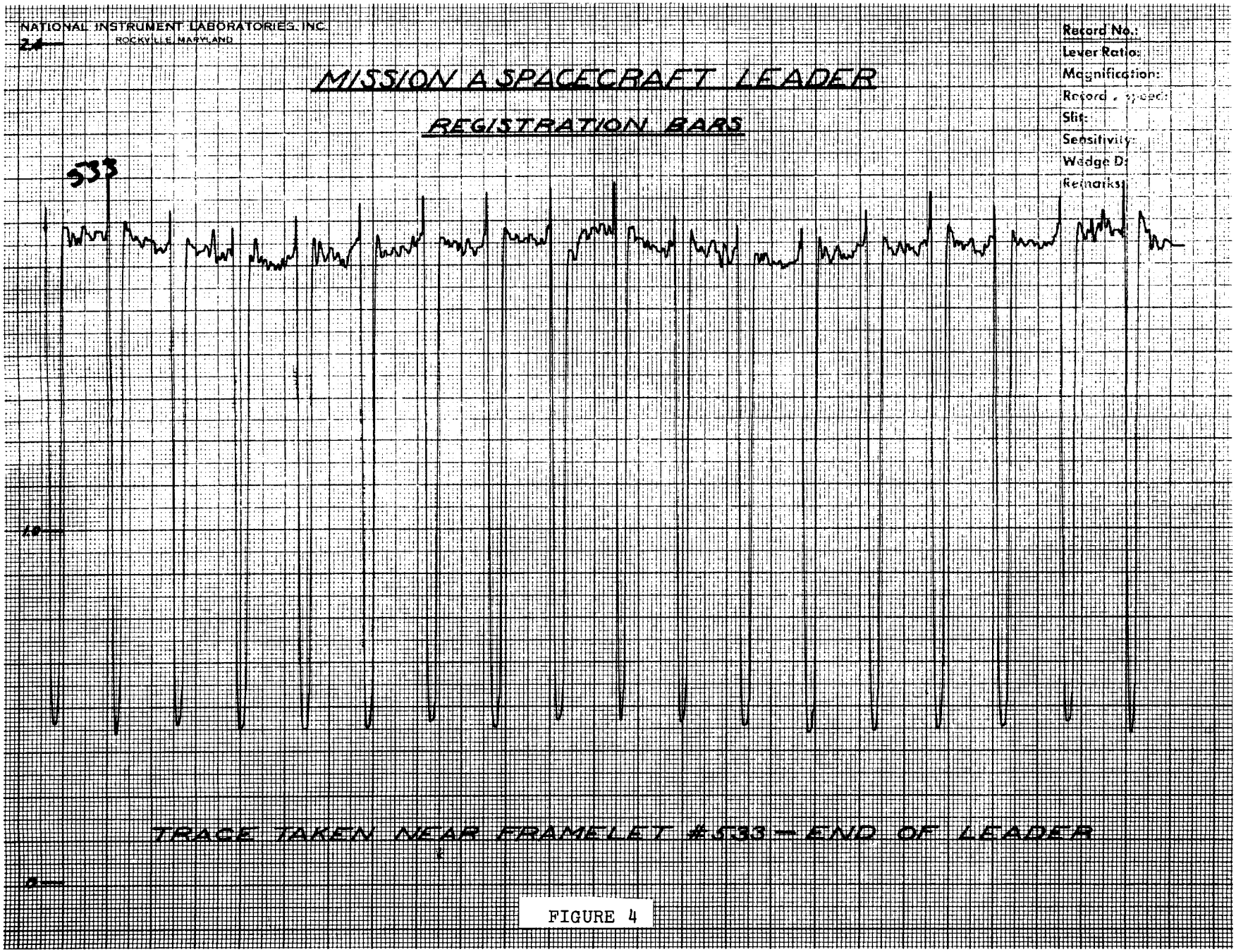

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
MISSION A SPACECRAFT LEADER
REGISTRATION BARS
Record No.:
Lever Ratio:
Magnification:
Slit:
Sensitivity:
Wedge D:
Remarks:
533
TRACE TAKEN NEAR FRAMELET #533 — END OF LEADER

FIGURE 4

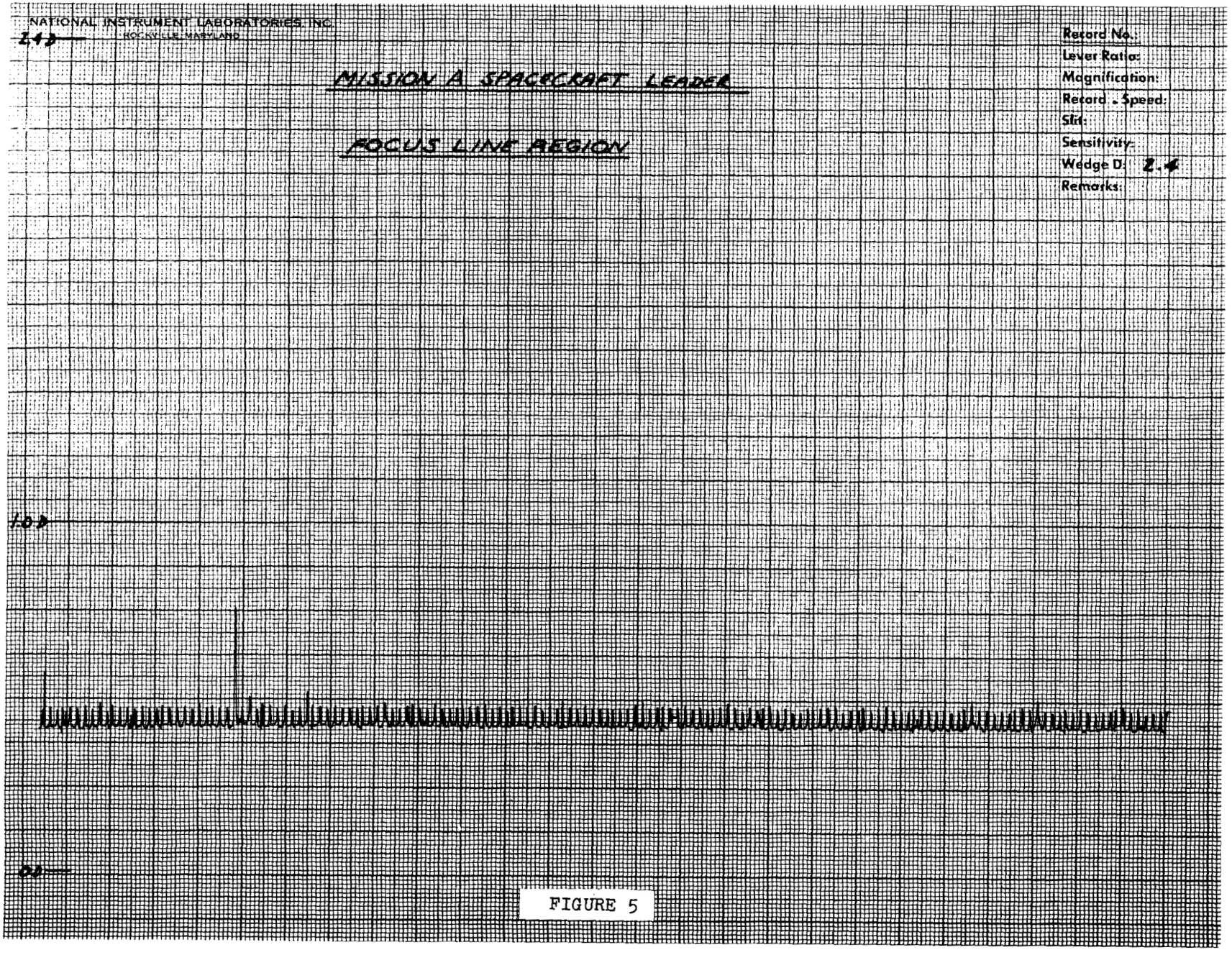

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
MISSION A SPACECRAFT LEADER
FOCUS LINE REGION
Record No.:
Lever Ratio:
Magnification:
Record - Speed:
Slit:
Sensitivity:
Wedge D: 2.4
Remarks:
2.4
1.0
0.0

FIGURE 5

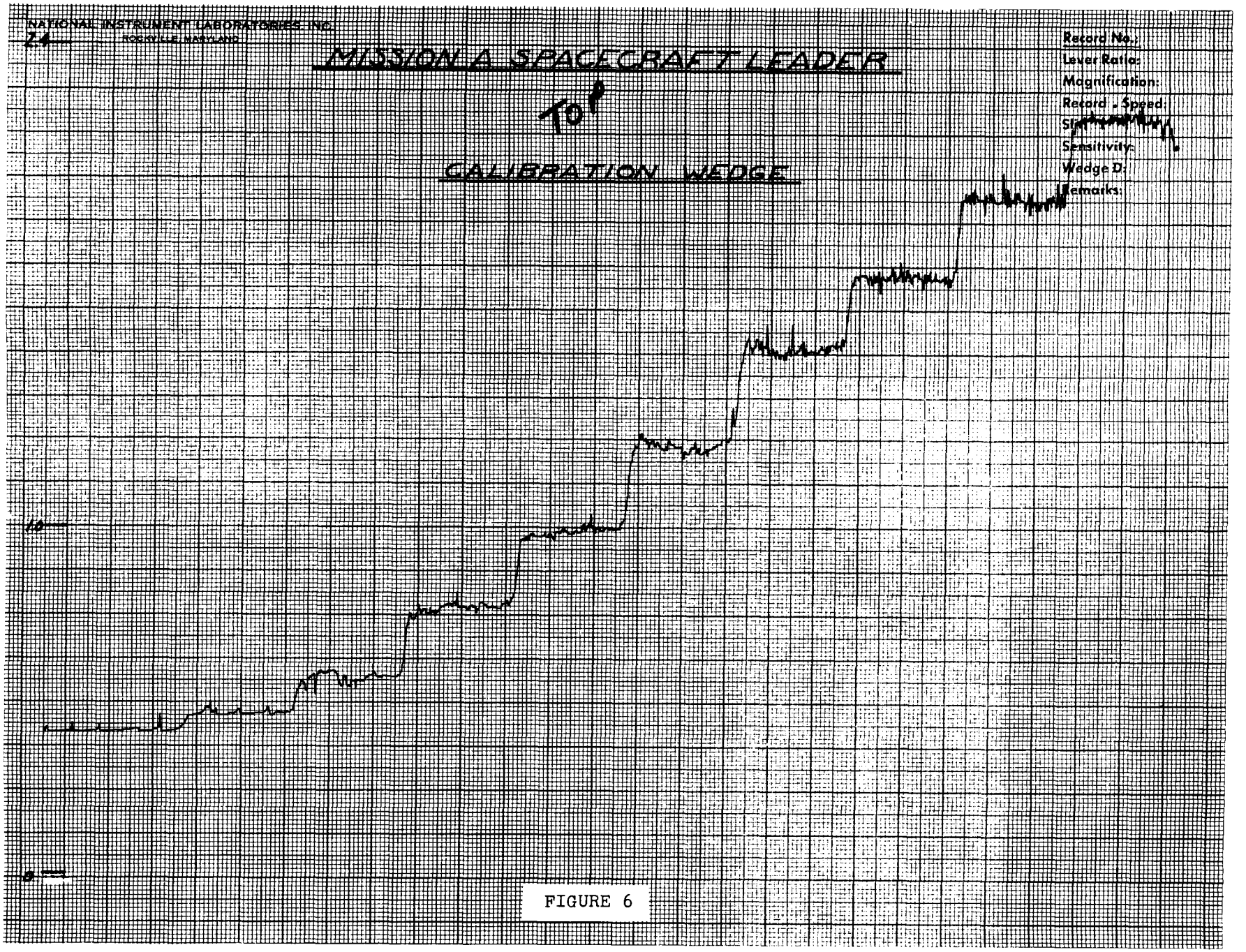

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
MISSION A SPACECRAFT LEADER
CALIBRATION WEDGE
Record No.:
Lever Ratio:
Magnification:
Record Speed:
Sensitivity:
Wedge D:
Remarks:

FIGURE 6

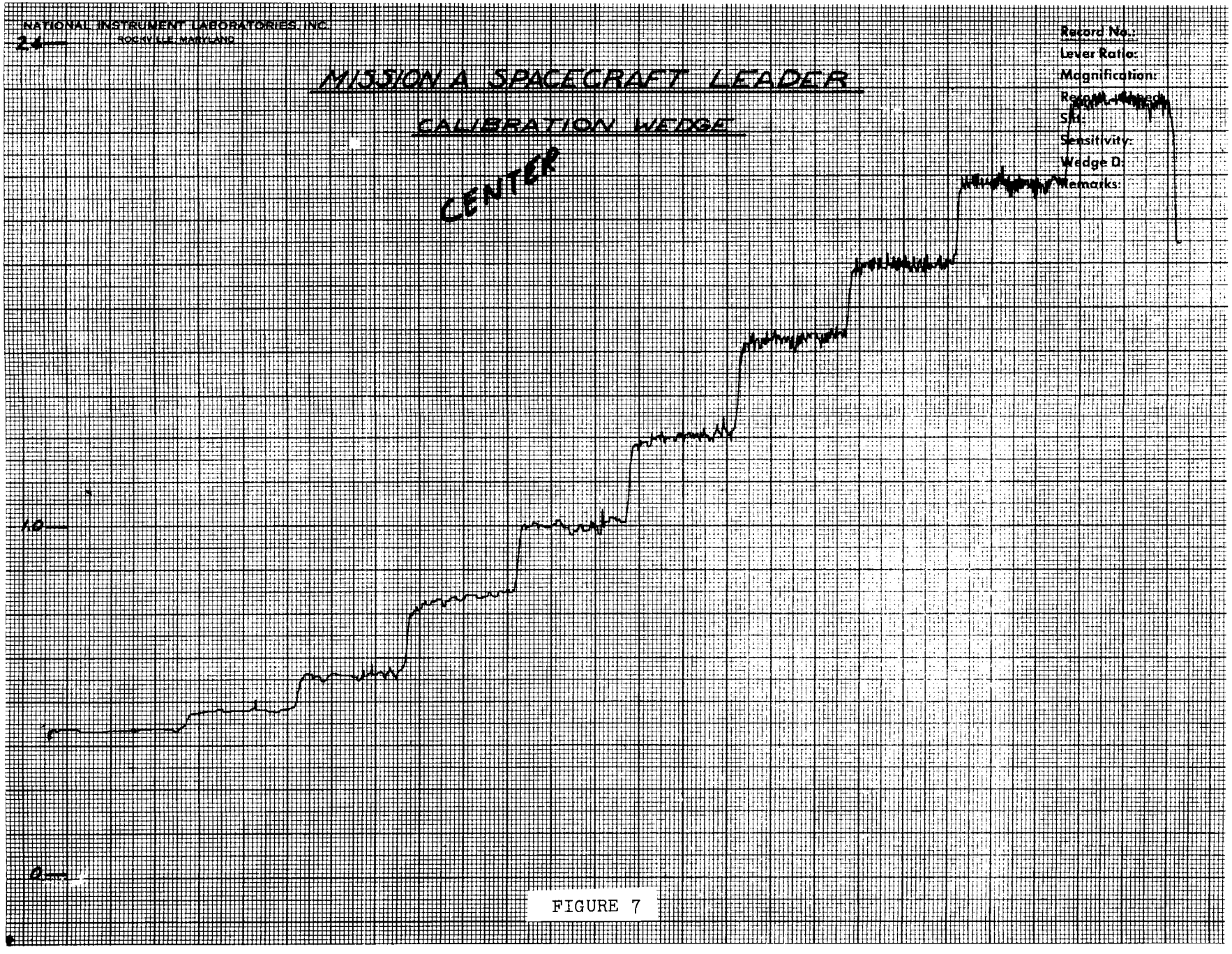

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
MISSION A SPACECRAFT LEADER
CALIBRATION WEDGE
CENTER
Record No.:
Lever Ratio:
Magnification:
Sensitivity:
Wedge D:
Remarks:
1.0
0

FIGURE 7

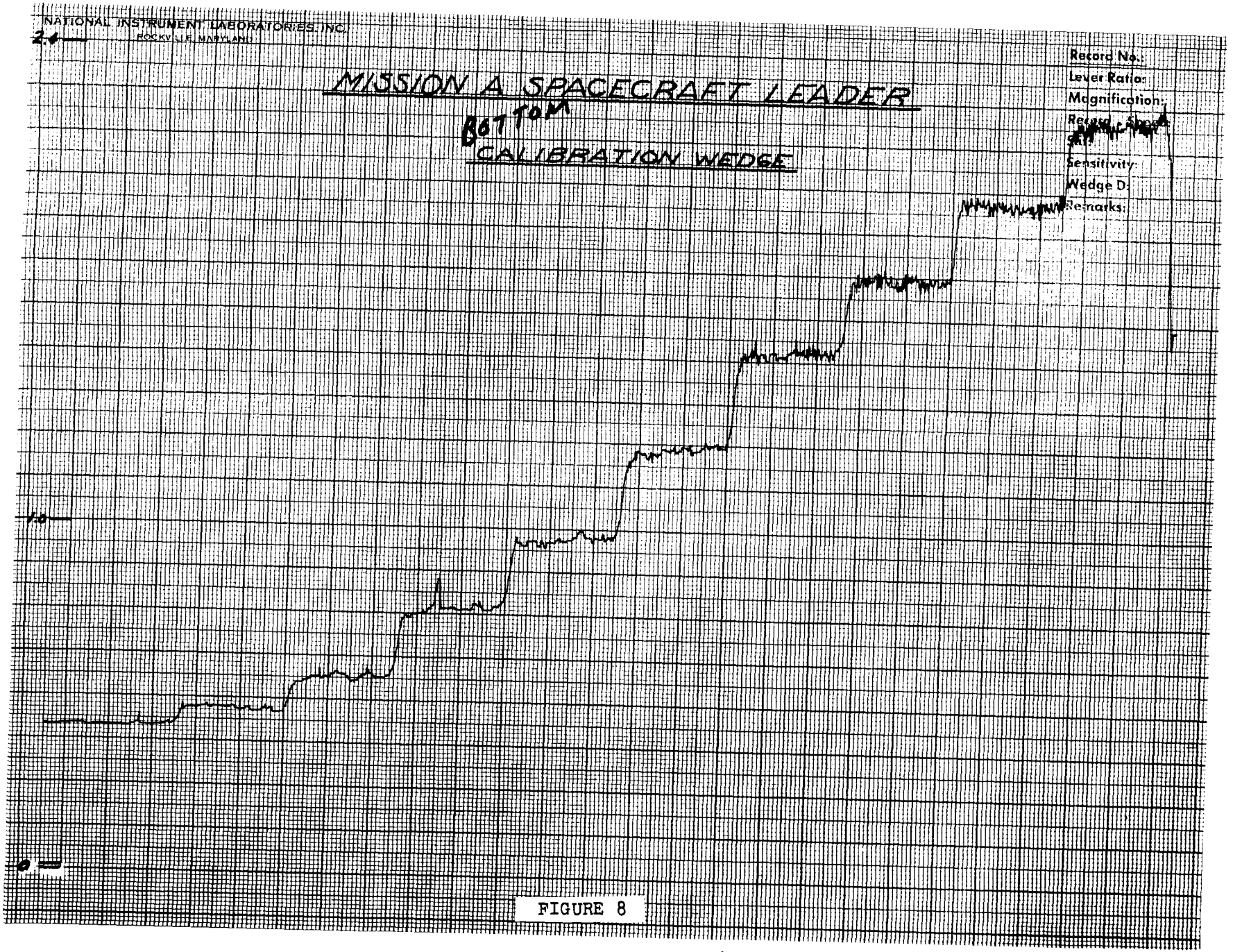

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
2.4
1.0
0
MISSION A SPACECRAFT LEADER
BOTTOM
CALIBRATION WEDGE
Record No.:
Lever Ratio:
Magnification:
Sensitivity:
Wedge D:
Remarks:

FIGURE 8

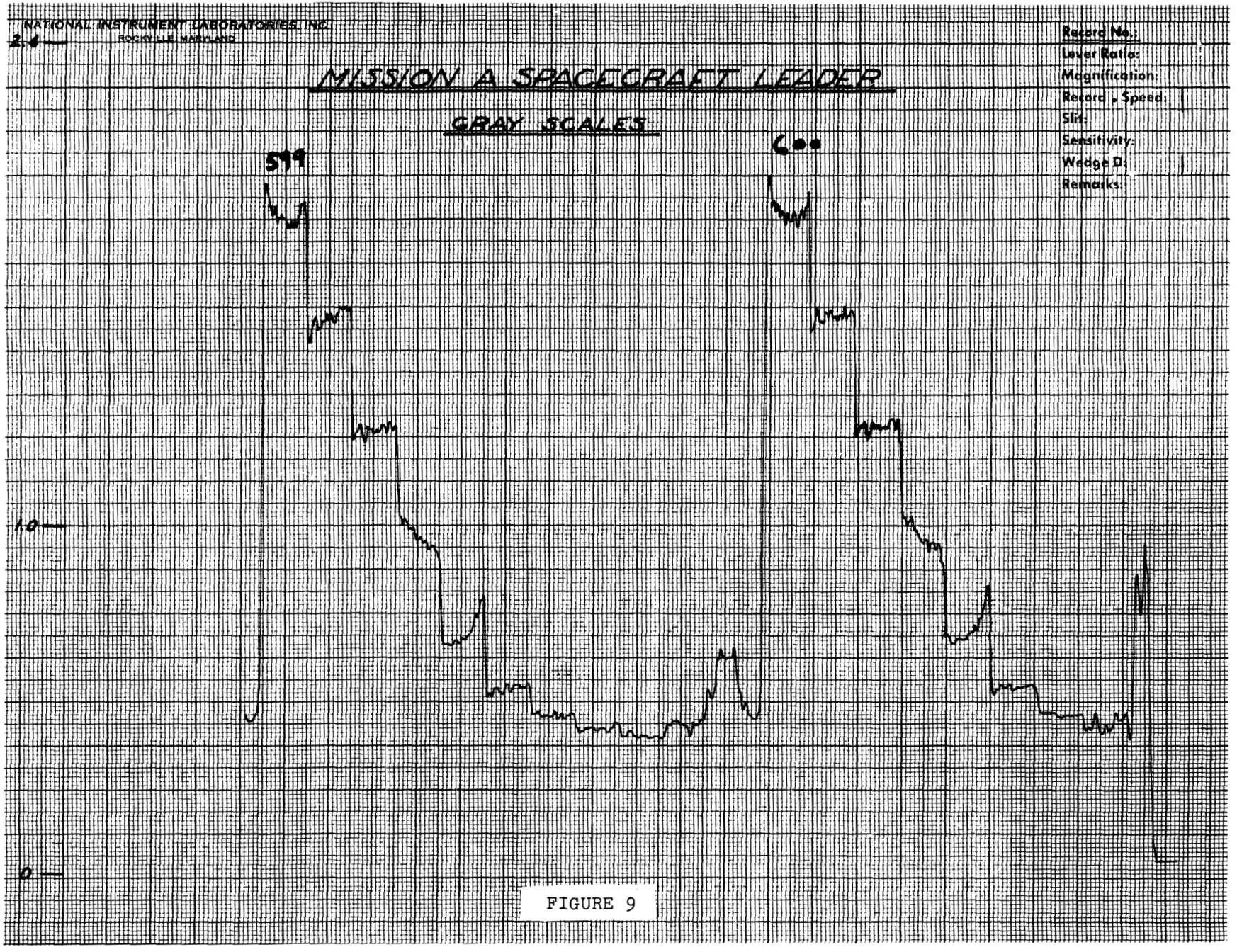
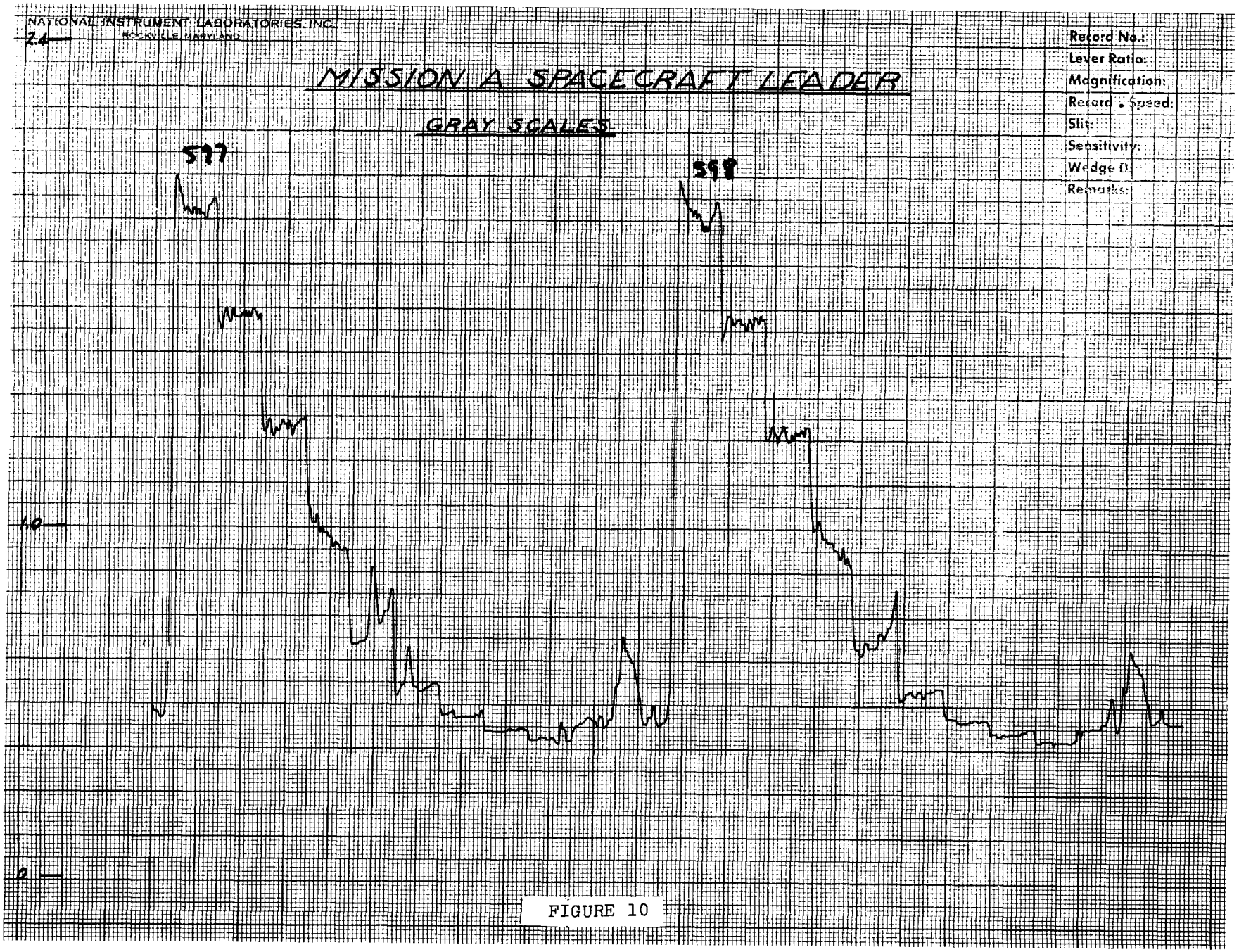

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
2.0
1.0
0
MISSION A SPACECRAFT LEADER
GRAY SCALES
599
600
Record No.:
Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:

FIGURE 9


NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE MARYLAND
MISSION A SPACECRAFT LEADER
GRAY SCALES
597
598
2.4
1.0
0
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Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:

FIGURE 10

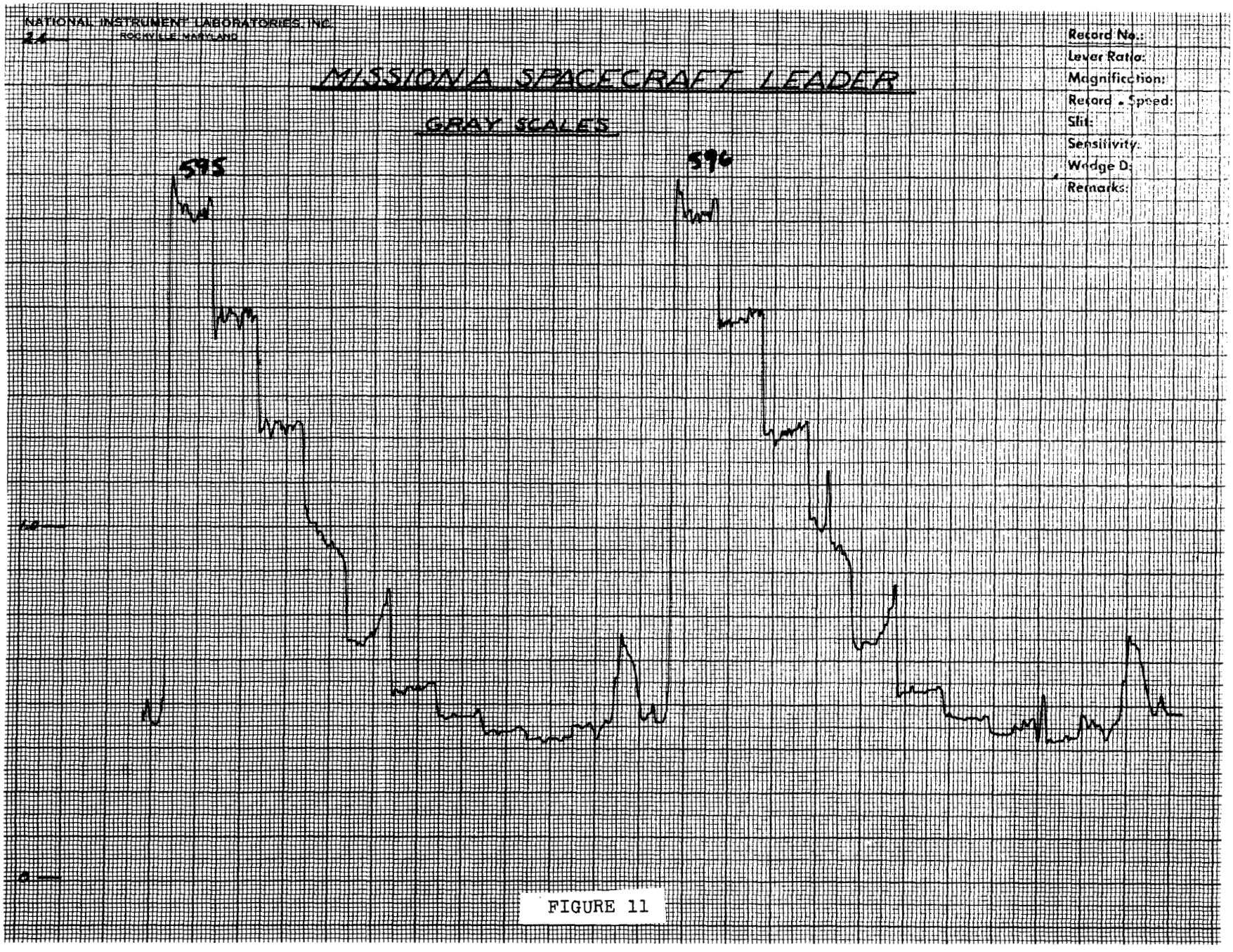

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
Record No.:
Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:
MISSION A SPACECRAFT LEADER
GRAY SCALES
595
596
10
0

FIGURE 11

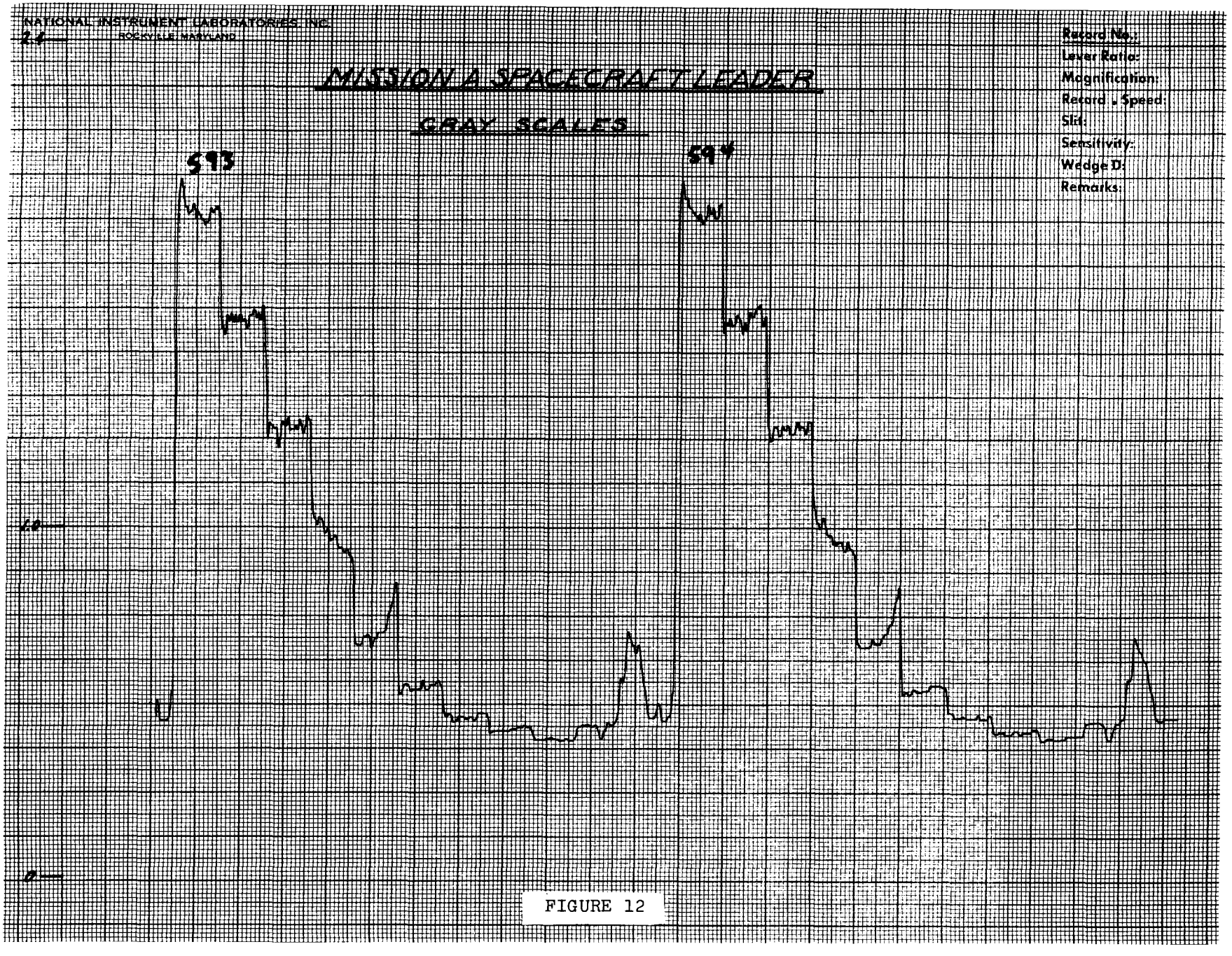
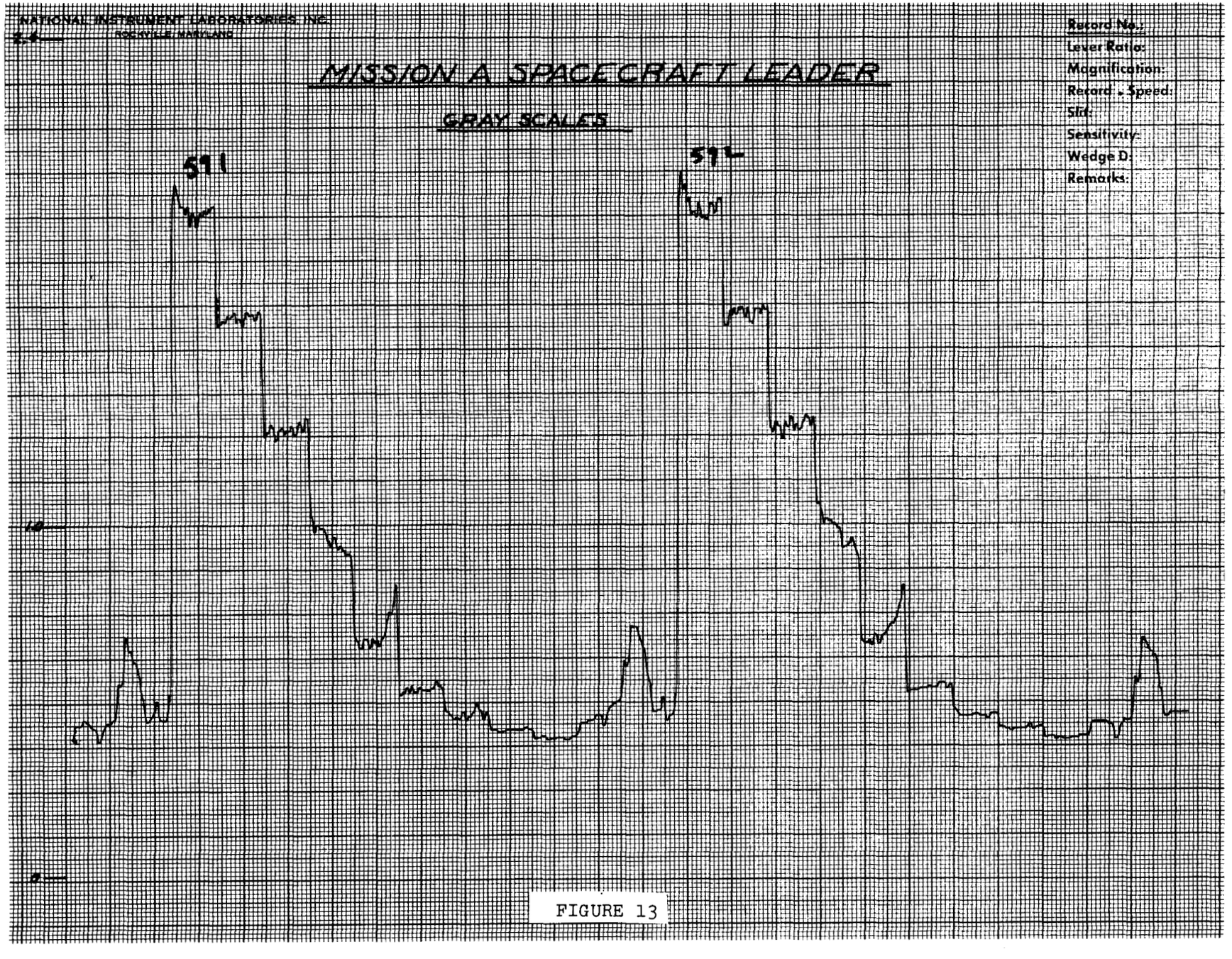

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE MARYLAND
2.4
1.0
0
MISSION A SPACECRAFT LEADER
GRAY SCALES
S93
S94
Record No.:
Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:

FIGURE 12


NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
MISSION A SPACECRAFT LEADER
GRAY SCALES
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Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:

FIGURE 13

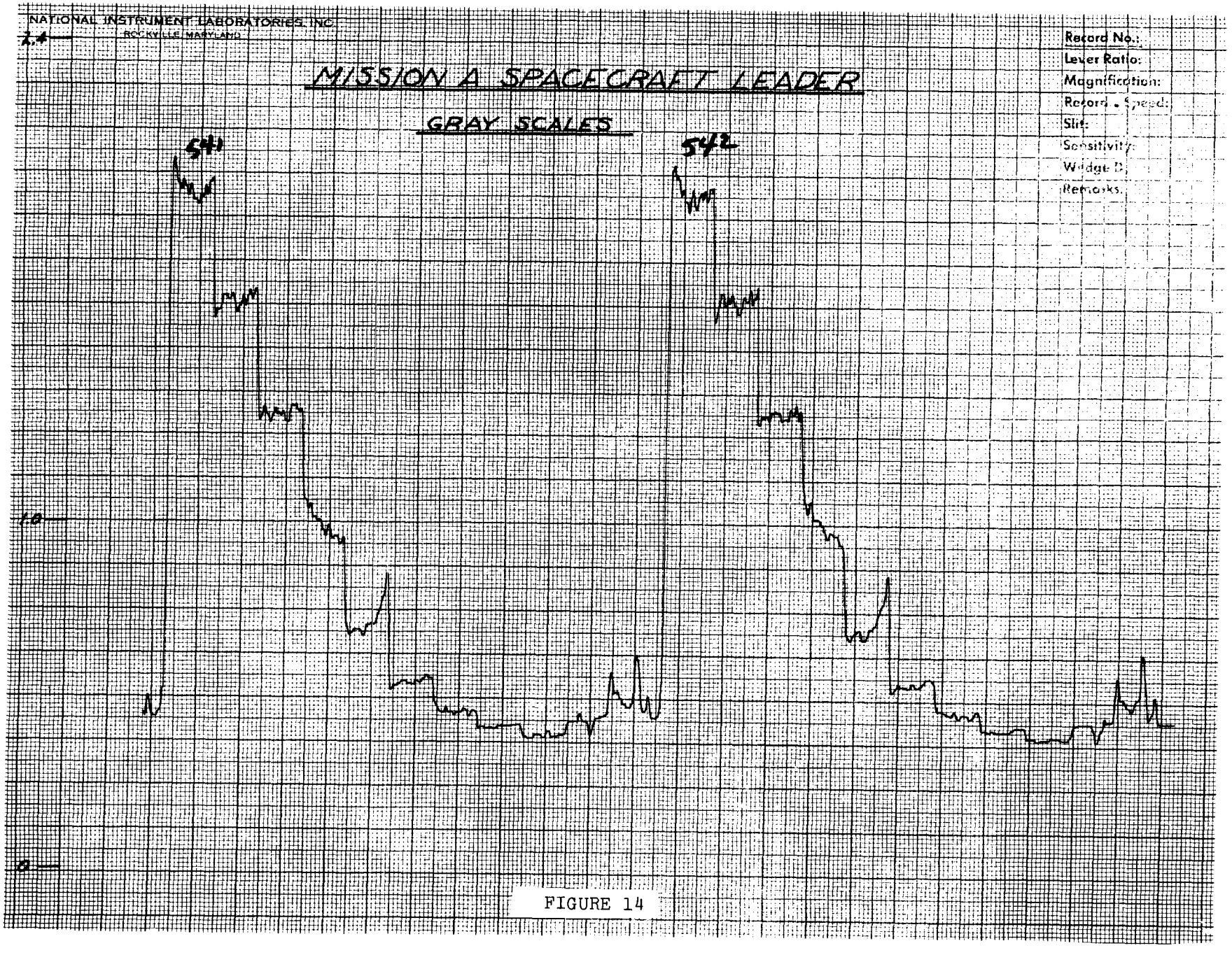

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
2.4
1.0
0
MISSION A SPACECRAFT LEADER
GRAY SCALES
541
542
Record No.:
Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge ID:
Remarks:

FIGURE 14

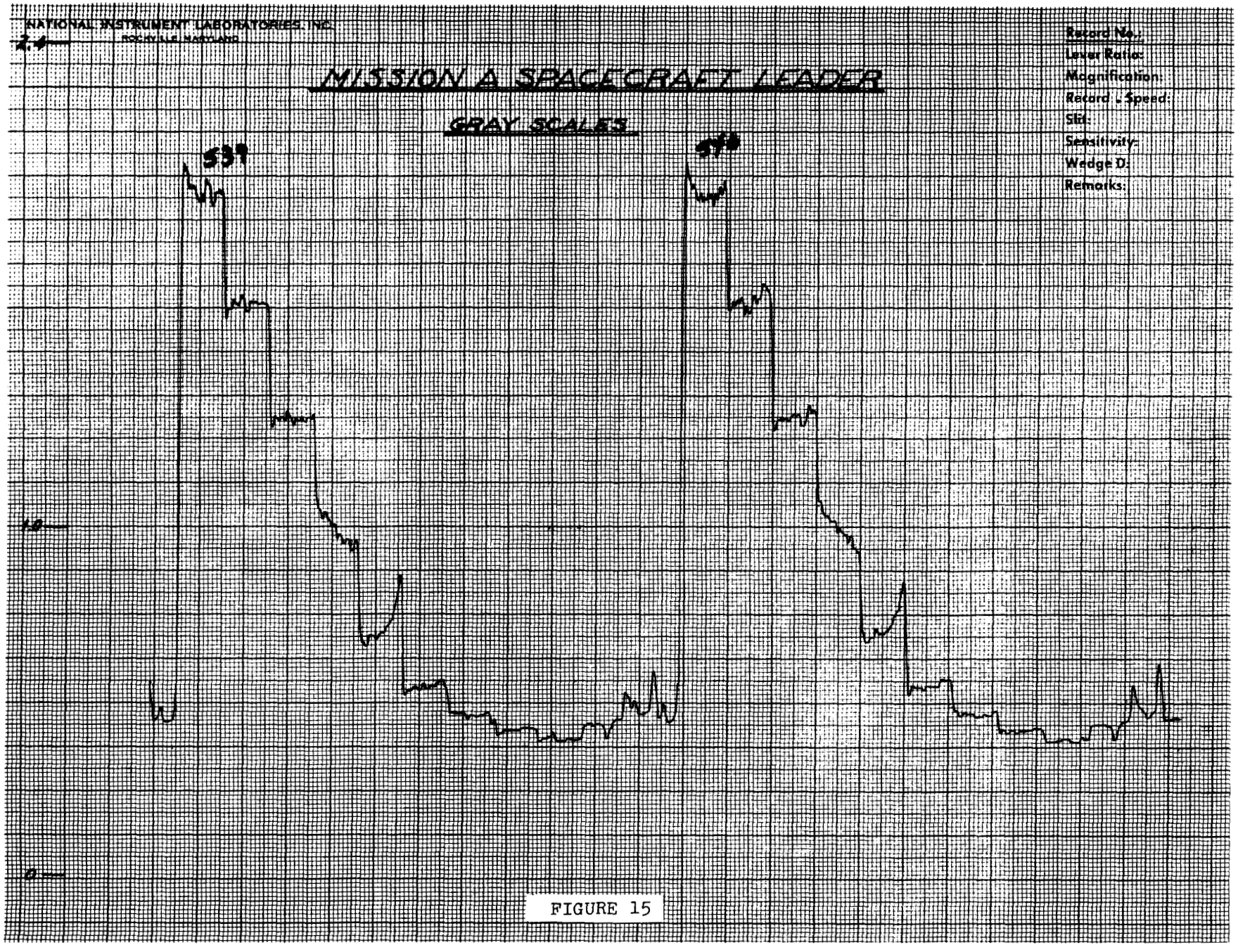

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
MISSION A SPACECRAFT LEADER
GRAY SCALES
Record No.:
Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:
1.0
0

FIGURE 15

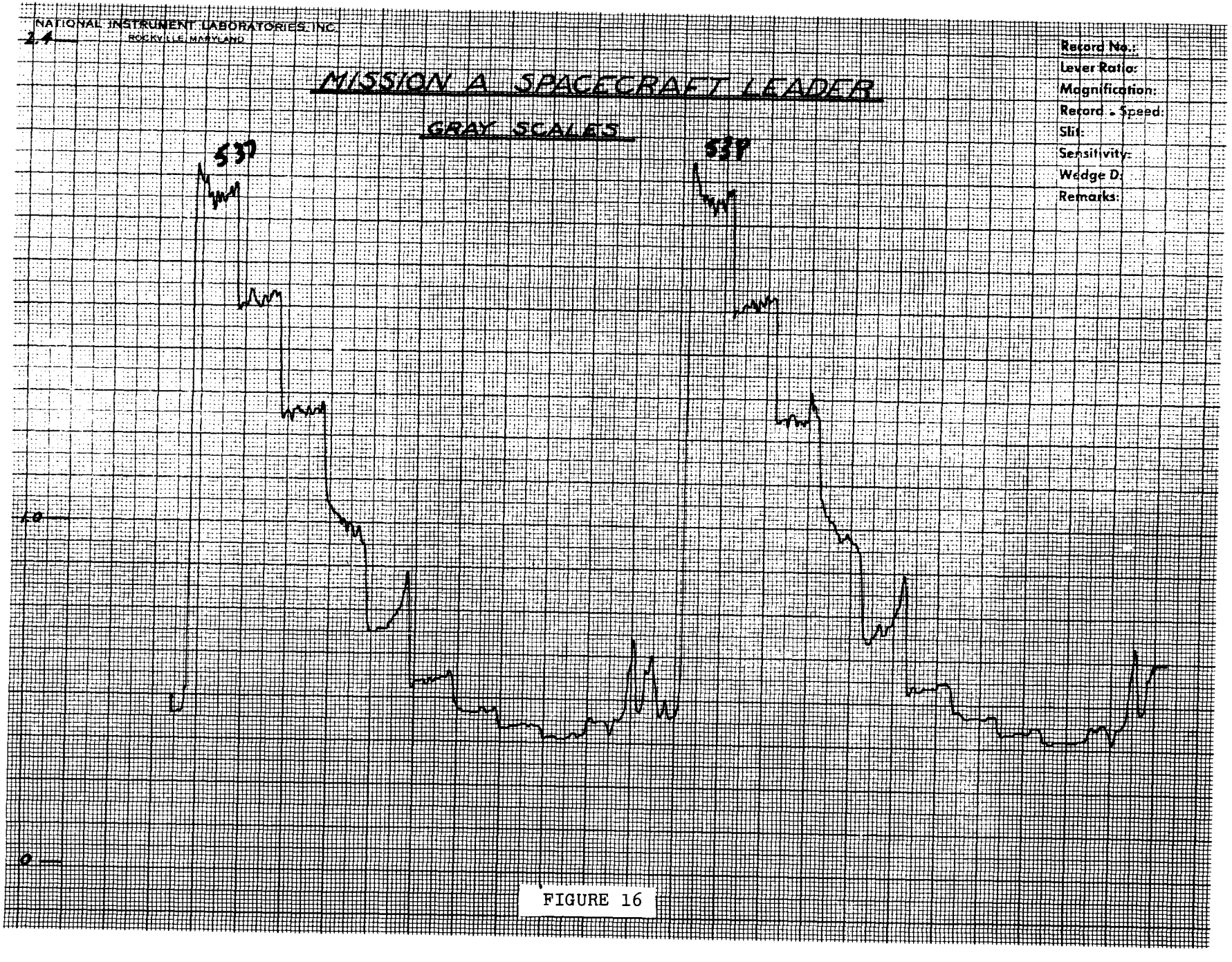

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
2.4
1.0
0
MISSION A SPACECRAFT LEADER
GRAY SCALES
537
537
Record No.:
Lever Ratio:
Magnification:
Record - Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:

FIGURE 16

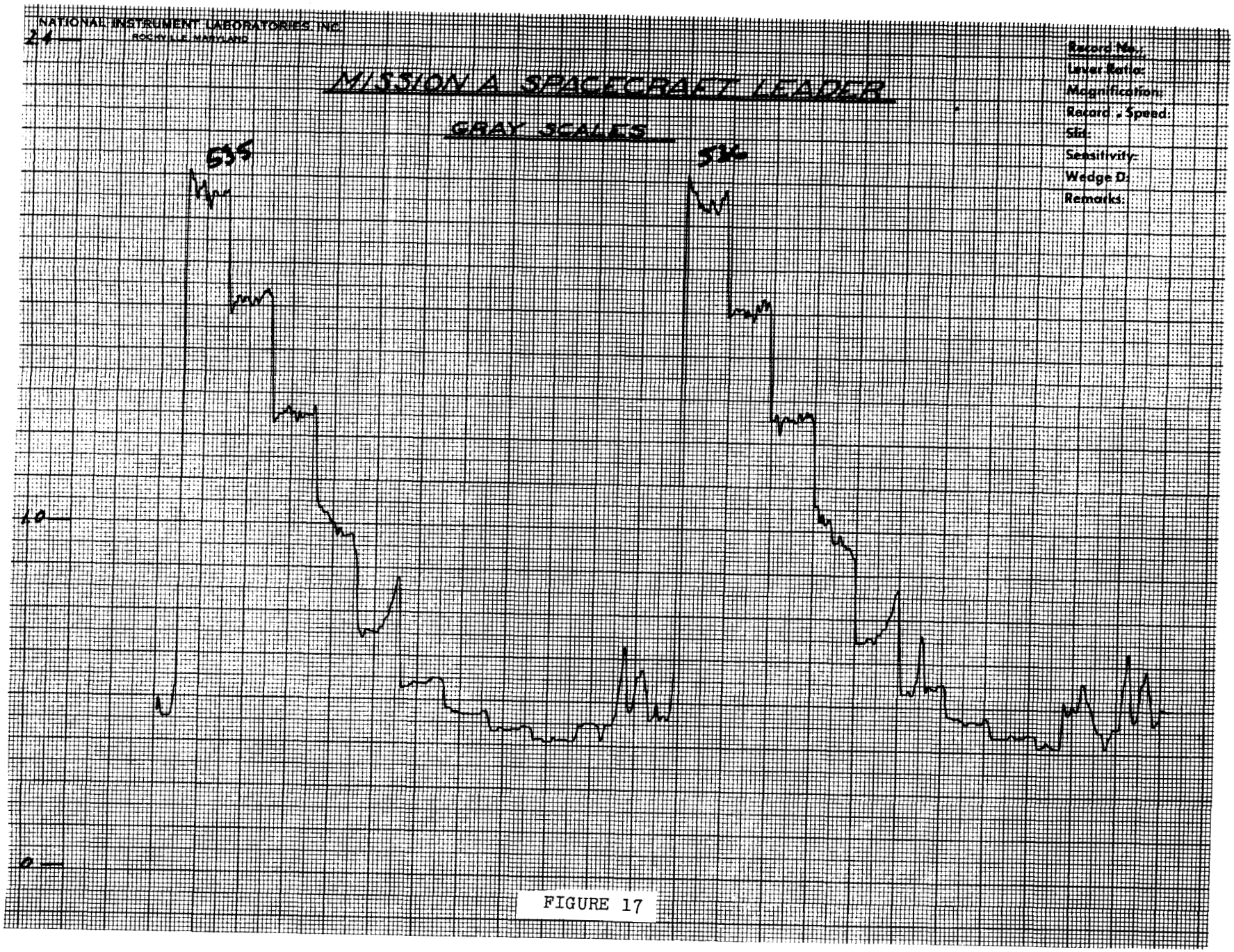

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
MISSION A SPACECRAFT LEADER
GRAY SCALES
535
536
Record No.:
Lever Ratio:
Magnification:
Record Speed:
Slit:
Sensitivity:
Wedge D:
Remarks:

FIGURE 17

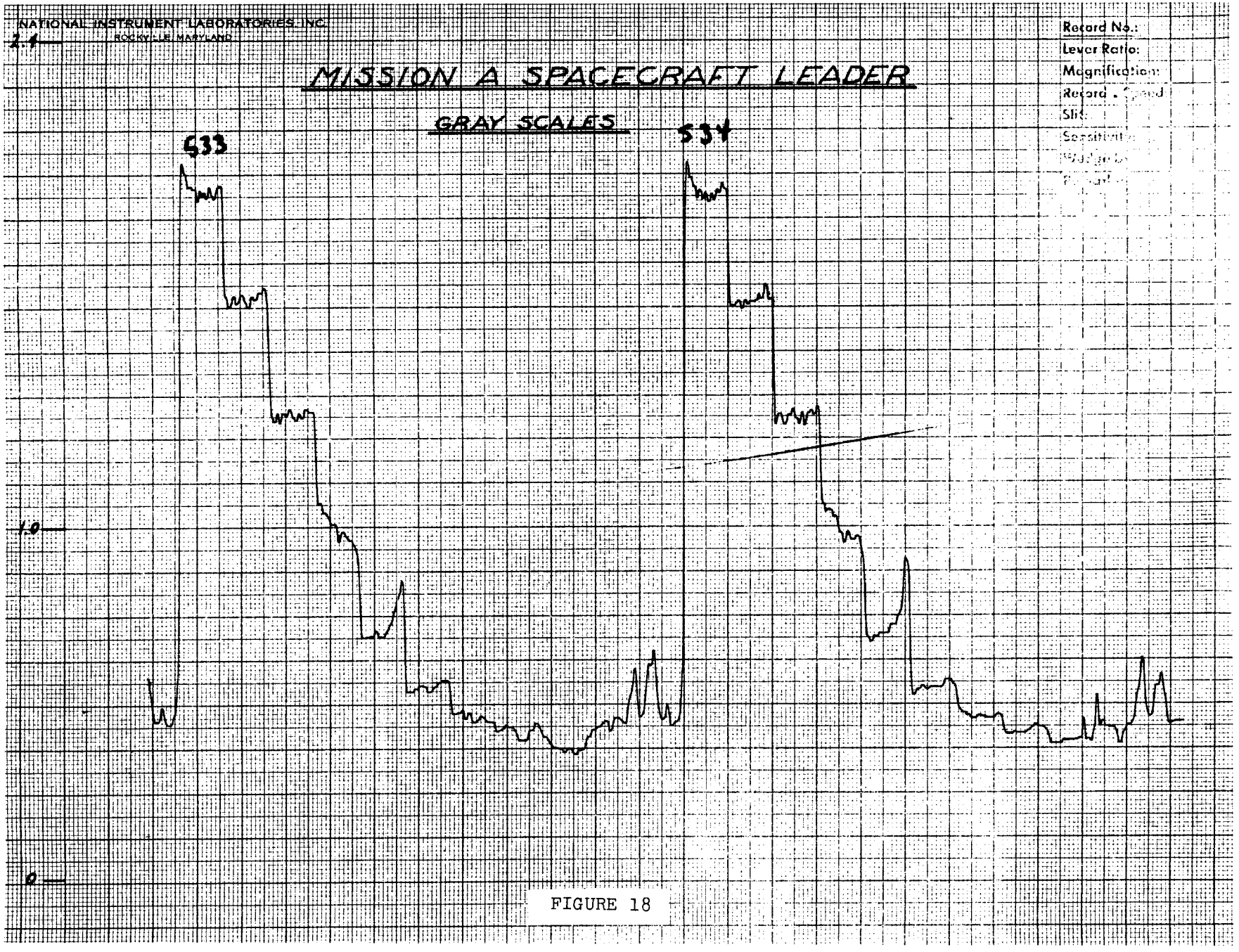

NATIONAL INSTRUMENT LABORATORIES, INC.
ROCKVILLE, MARYLAND
MISSION A SPACECRAFT LEADER
GRAY SCALES
S33
S34
2.4
1.0
0
Record No.:
Lever Ratio:
Magnification:

FIGURE 18

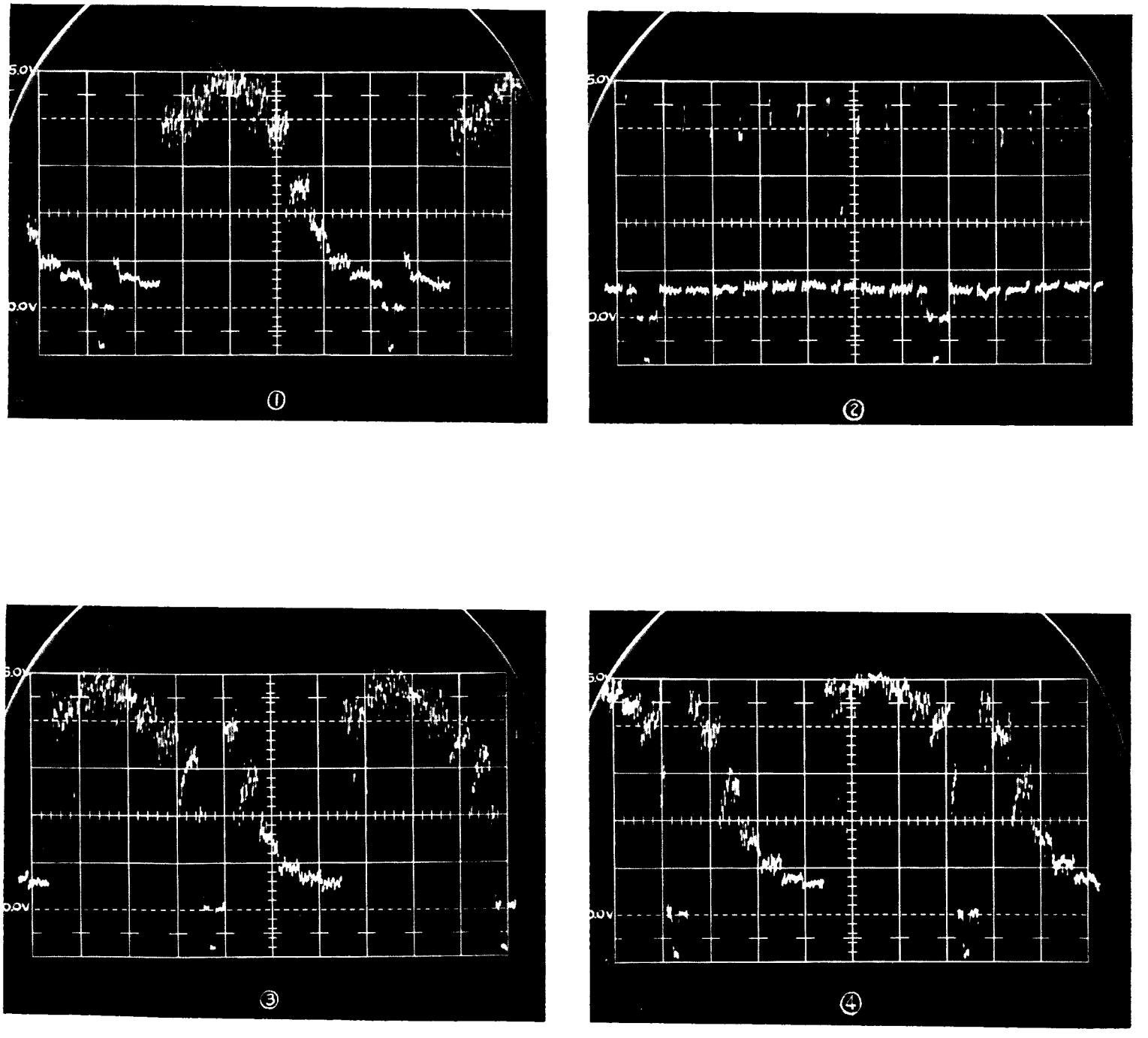
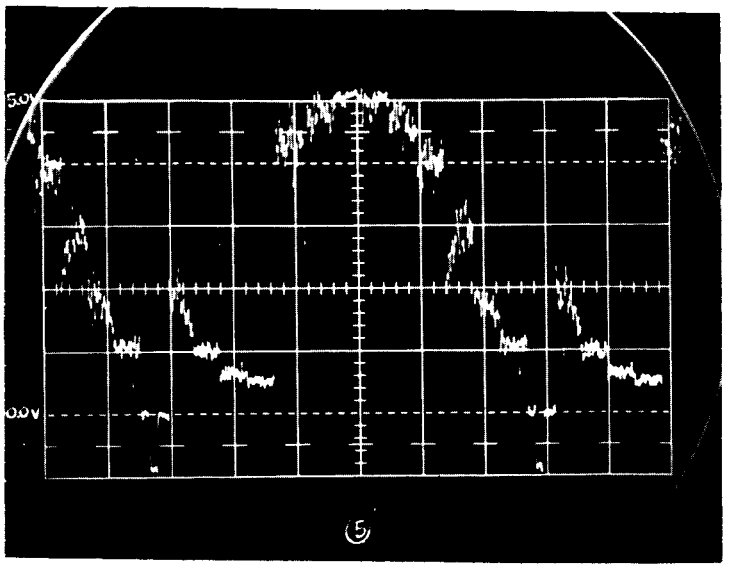
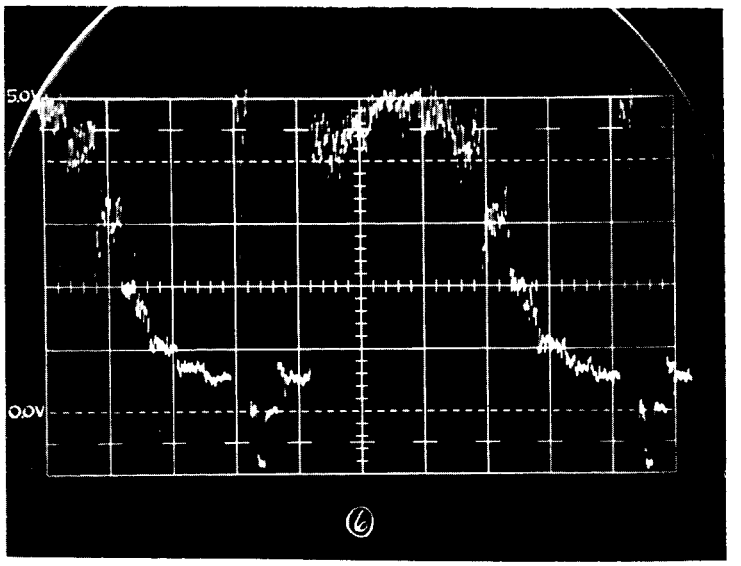
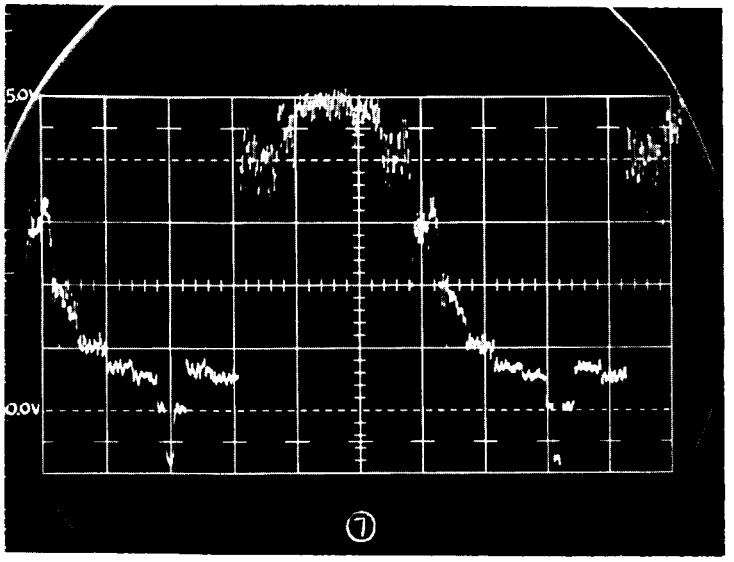
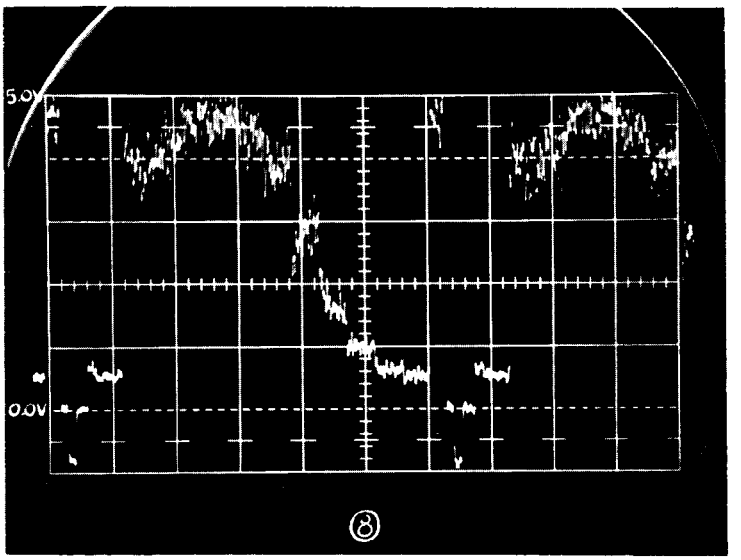


FIGURE 19 SITE A-1 TAPE WT-66-1









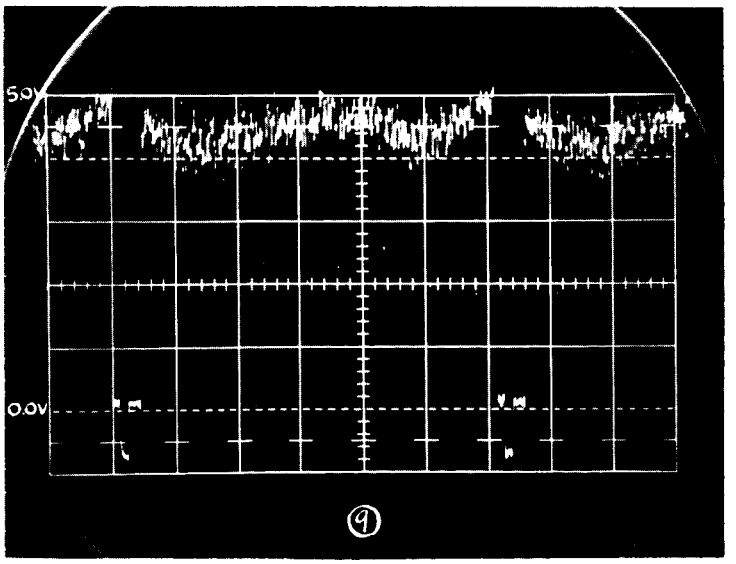


FIGURE 20 SITE A-I TAPE WT-66-I

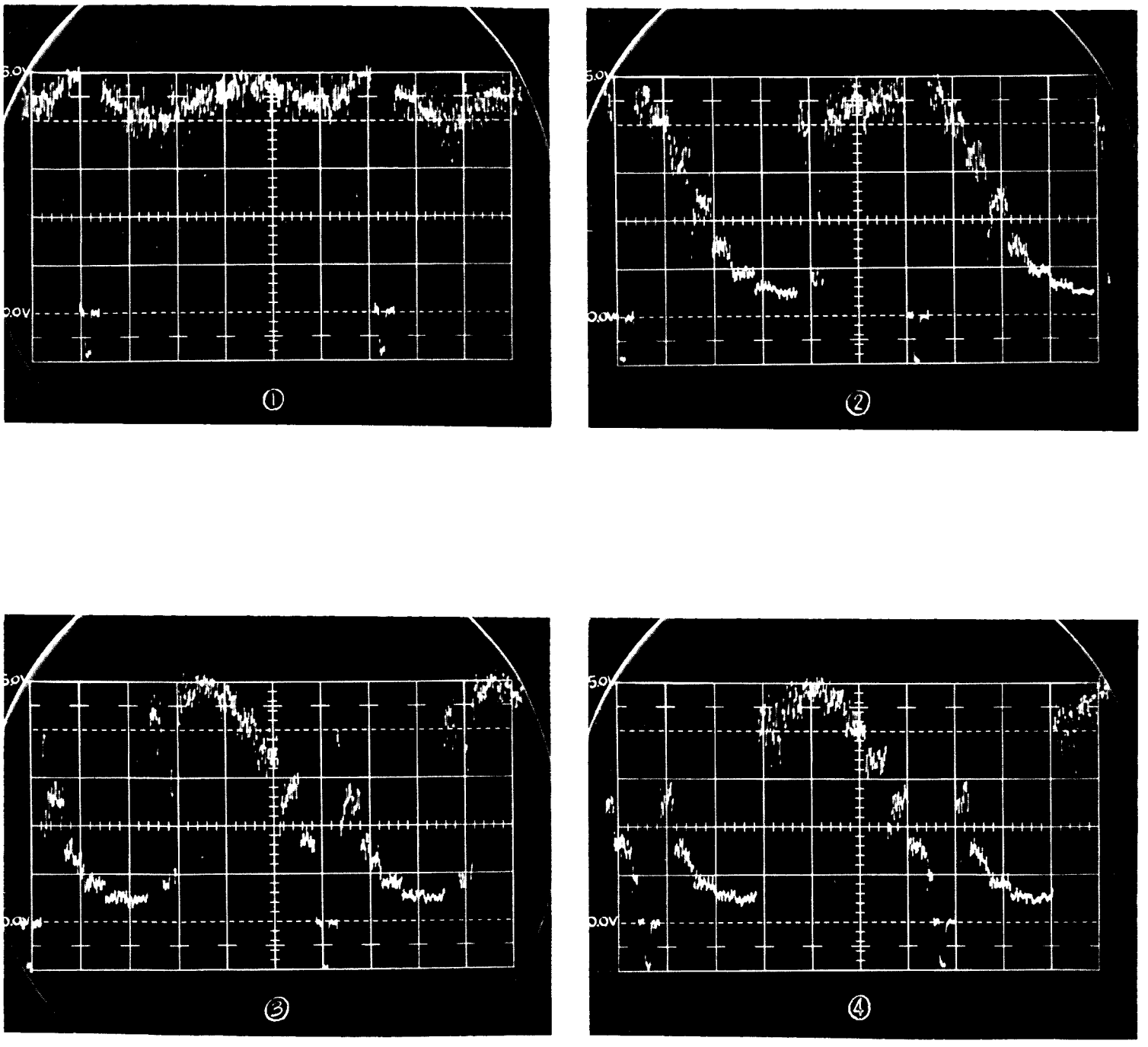


FIGURE 21 SITE A-3 TAPE MT-56-1

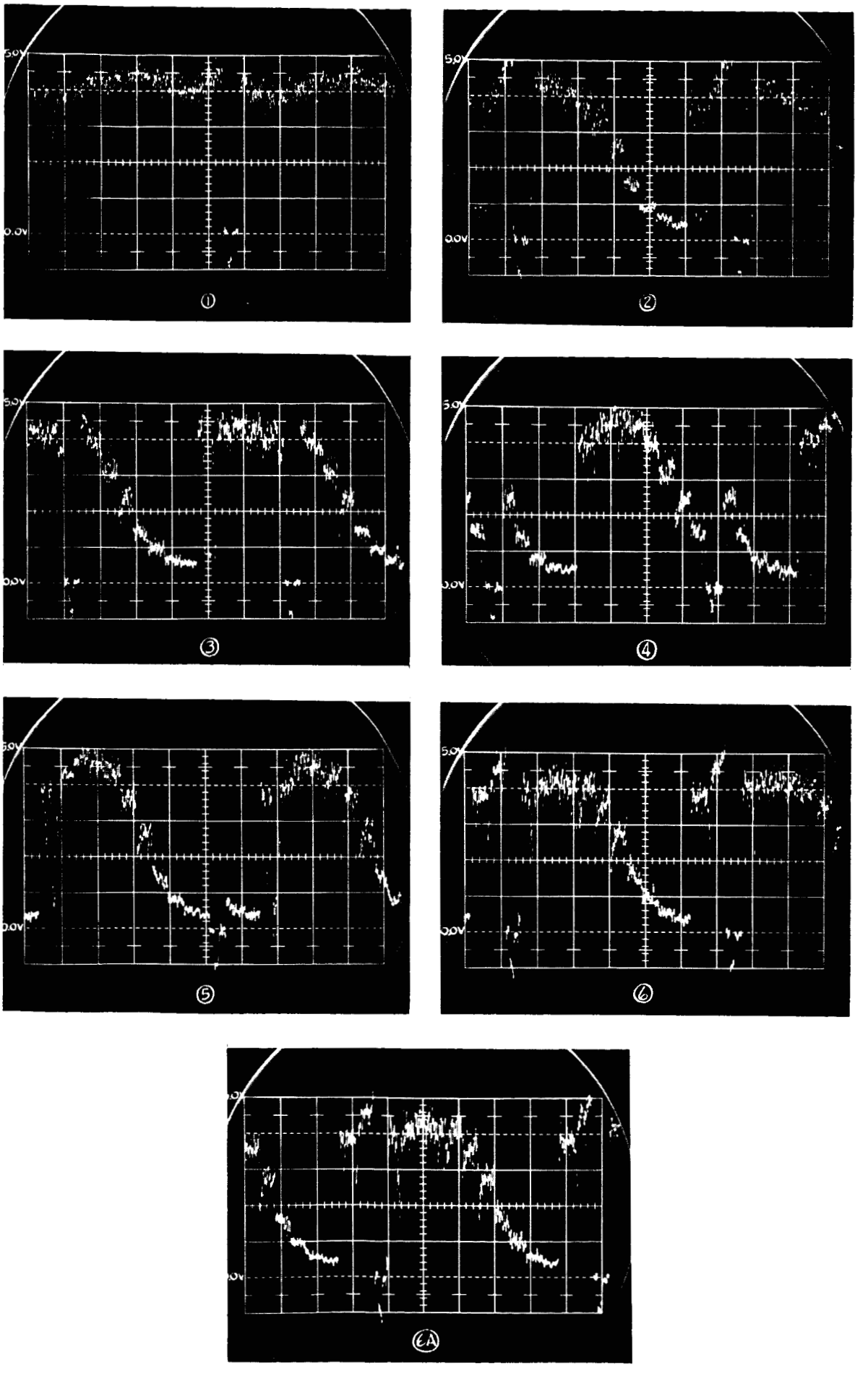


FIGURE 22 SITE A-5 TAPE GT-59-I

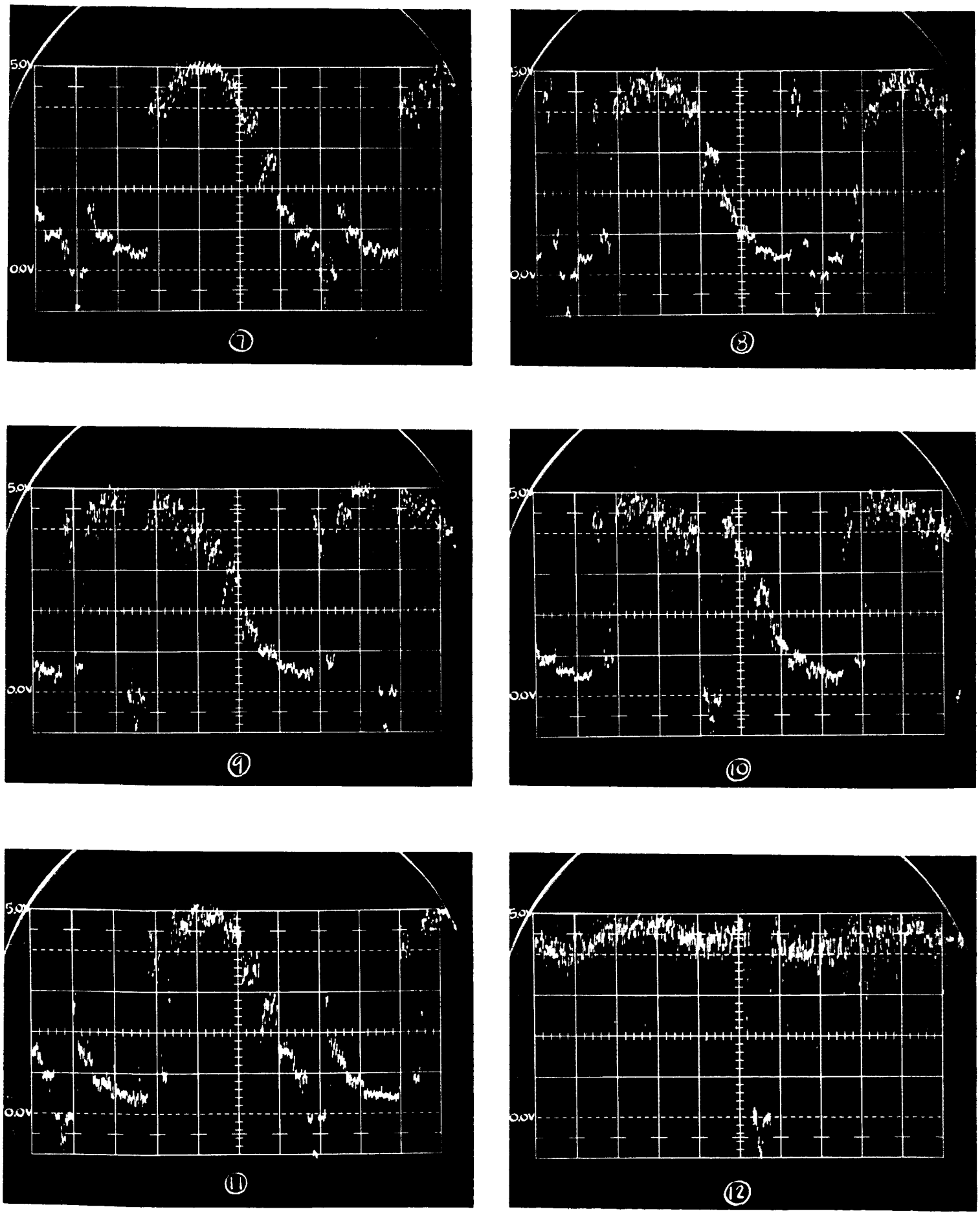
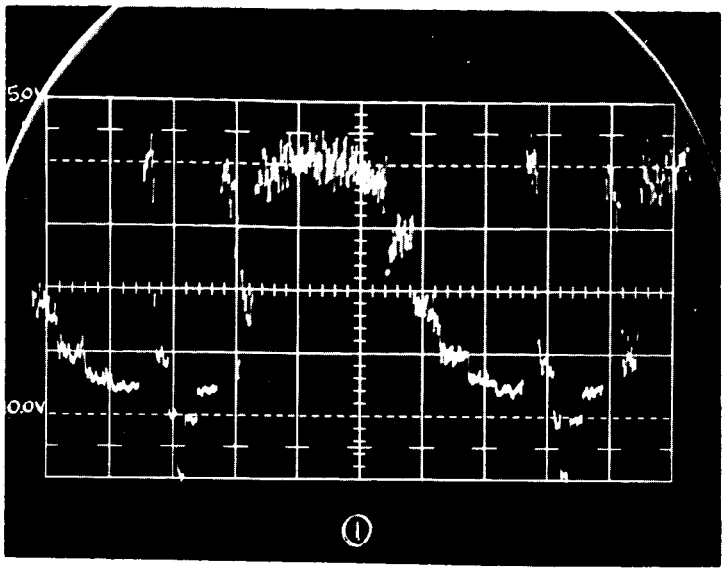


FIGURE 23 SITE A-5 TAPE GT-59-I



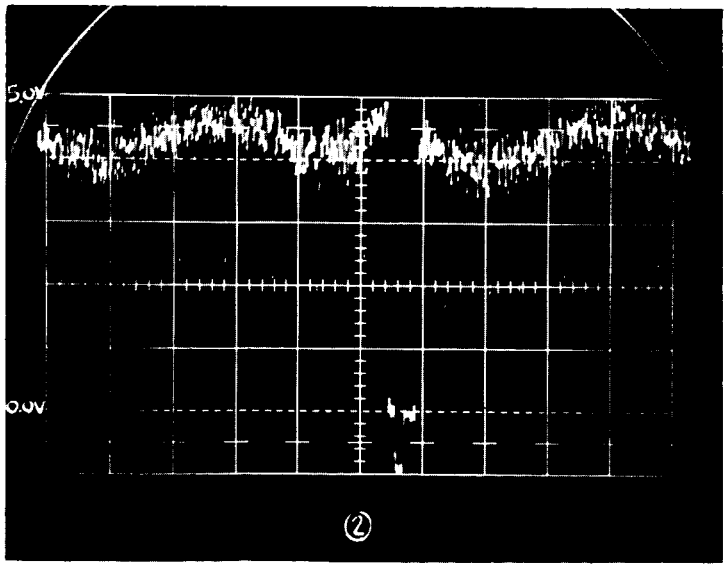
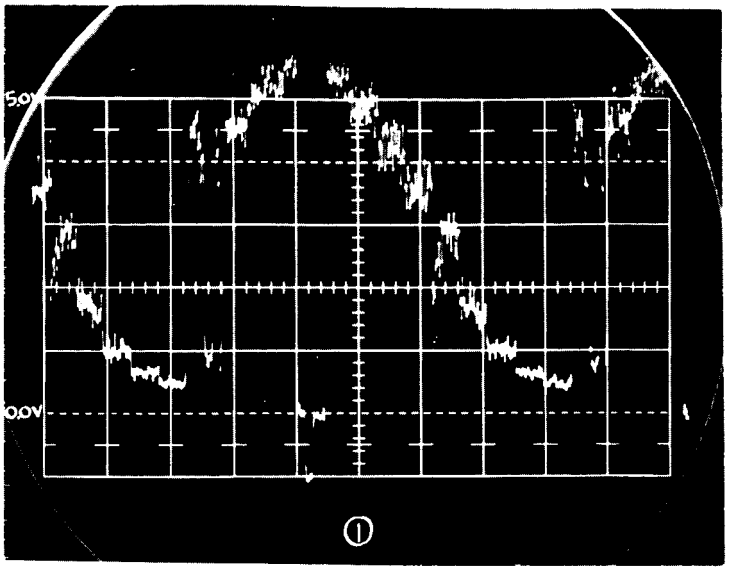
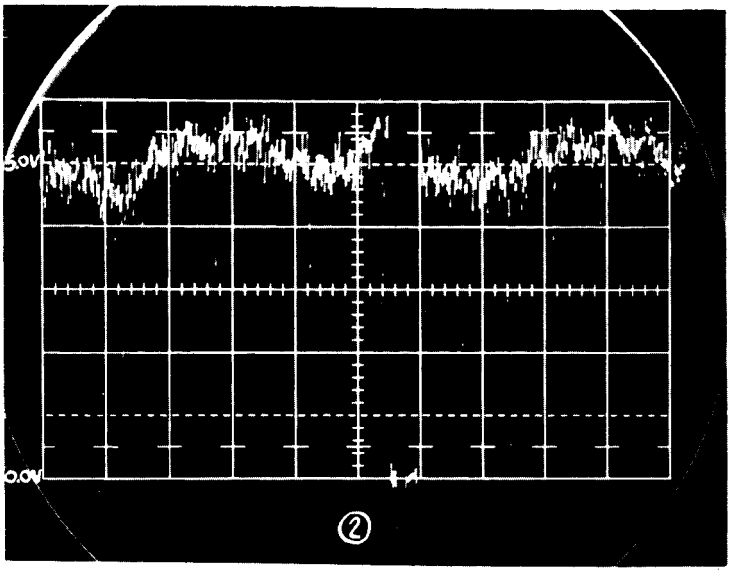


FIGURE 24 SITE A-5 TAPE GT-57





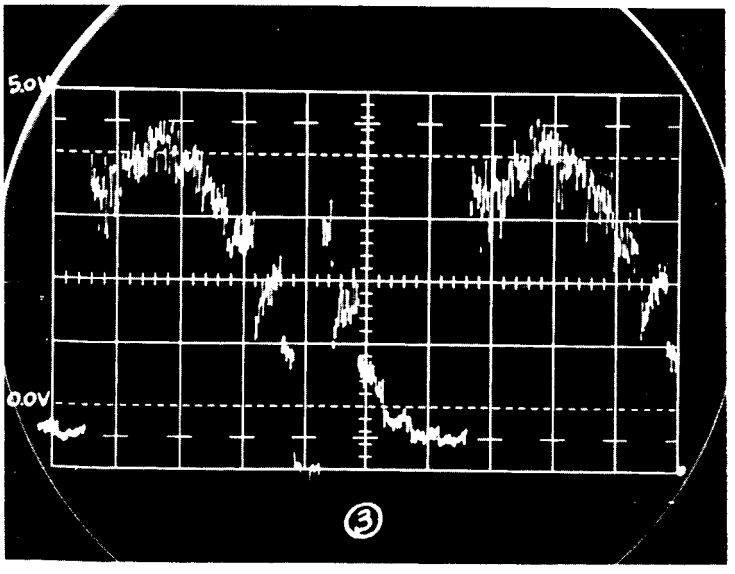
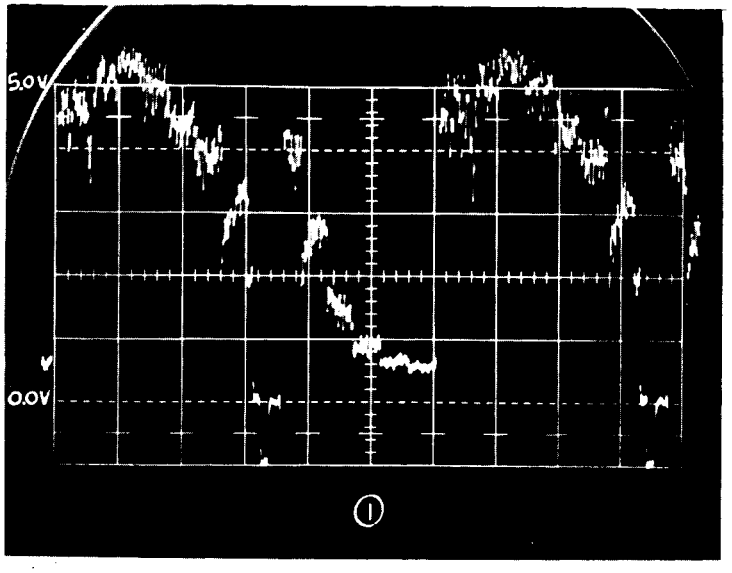
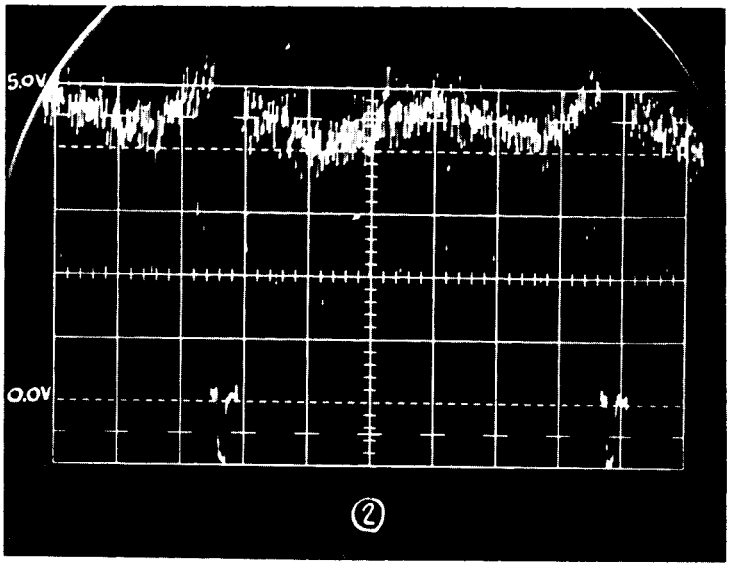
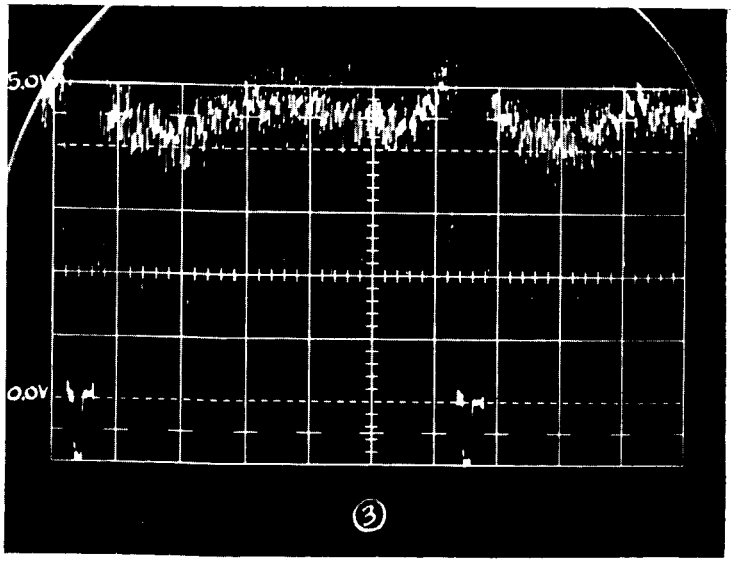


FIGURE 25 SITE A-6 TAPE WT-42







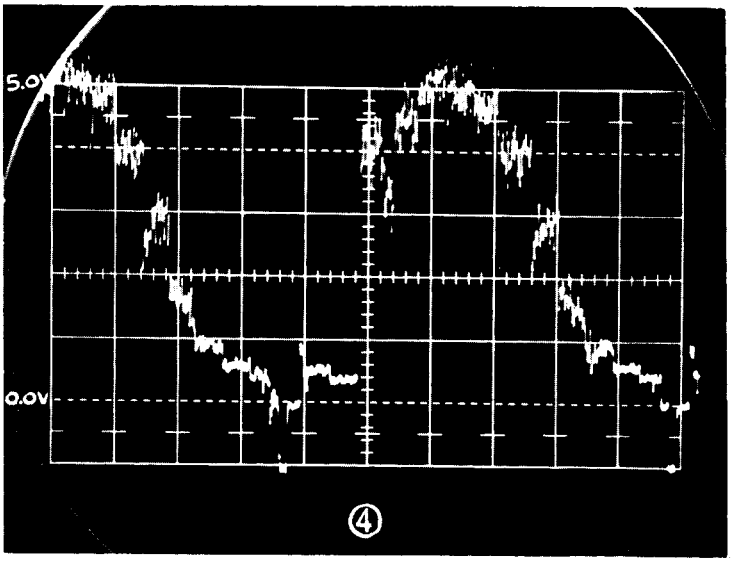
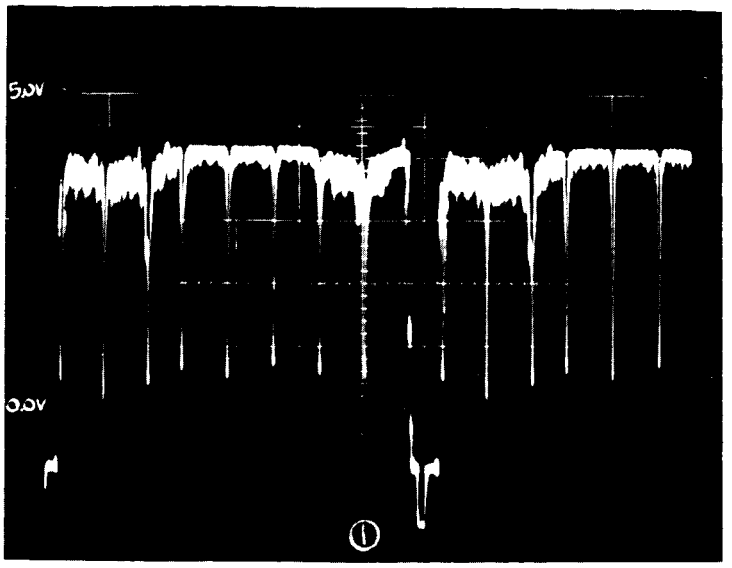
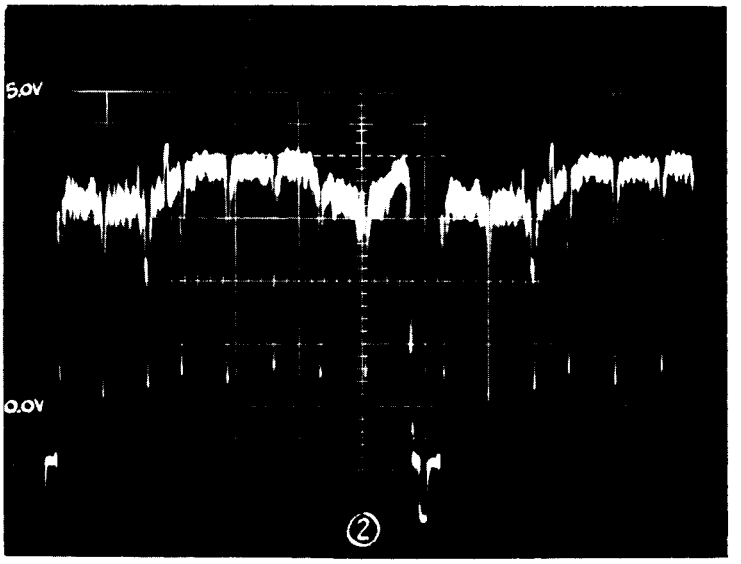


FIGURE 26 SITE A-7 TAPE MT-34





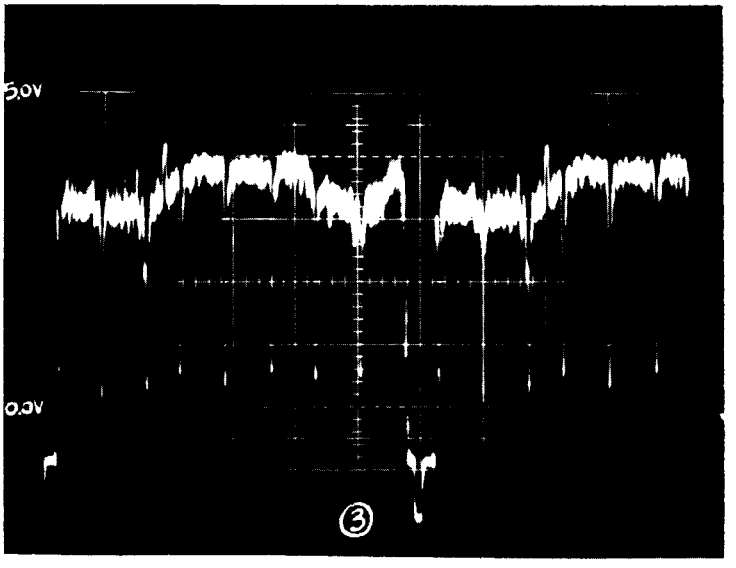


FIGURE 27 GOLDSTONE TEST - TAPE MT-2
PHOTOS TAKEN DURING INITIAL SETUP
PRIOR TO DATA

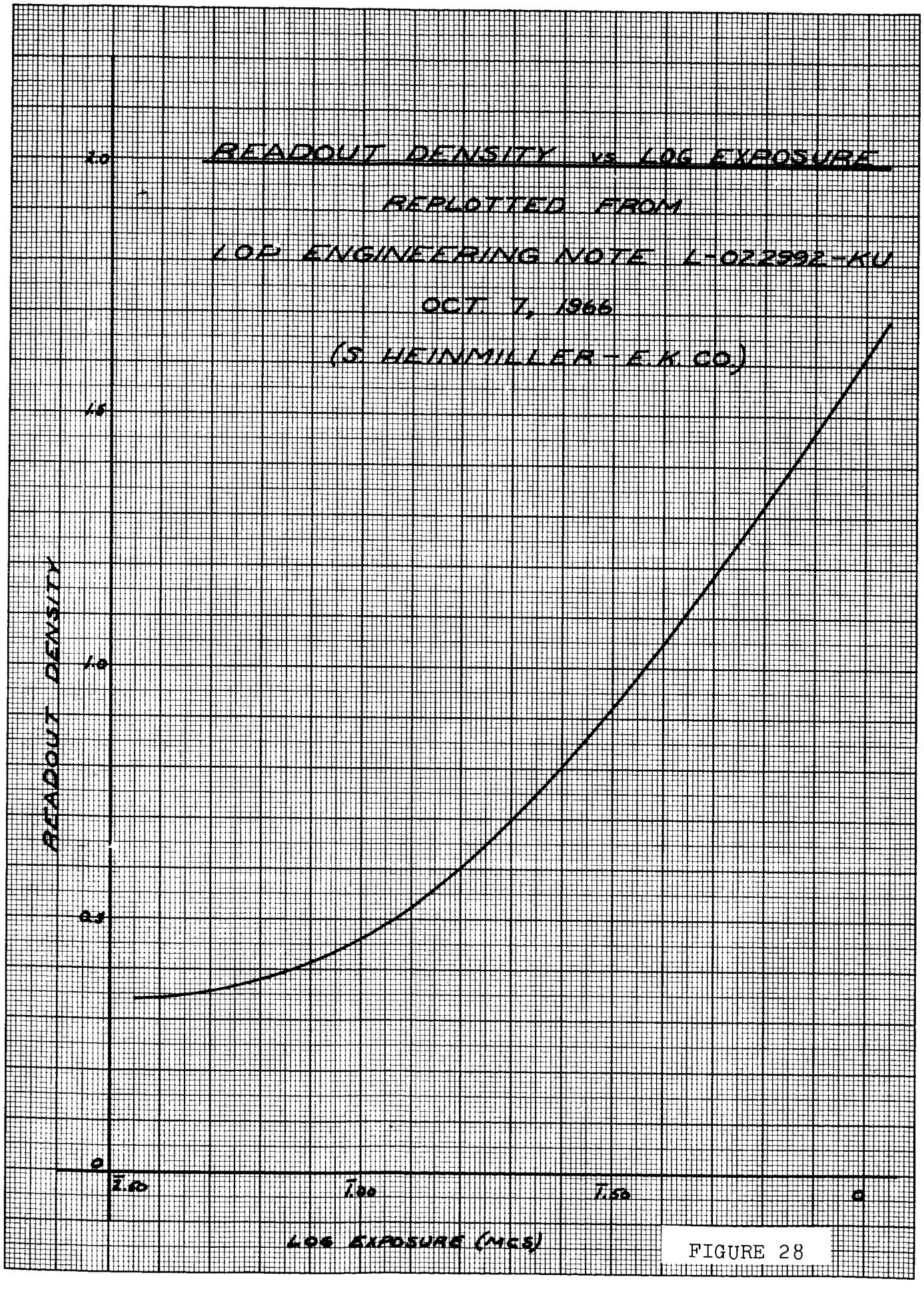

READOUT DENSITY vs LOG EXPOSURE
REPLOTTED FROM
LOP ENGINEERING NOTE L-022992-KU
OCT. 7, 1966
(S. HEINMILLER - E.K. CO.)
2.0
1.5
1.0
0.5
0
READOUT DENSITY
7.00
7.50
LOG EXPOSURE (MCS)

FIGURE 28

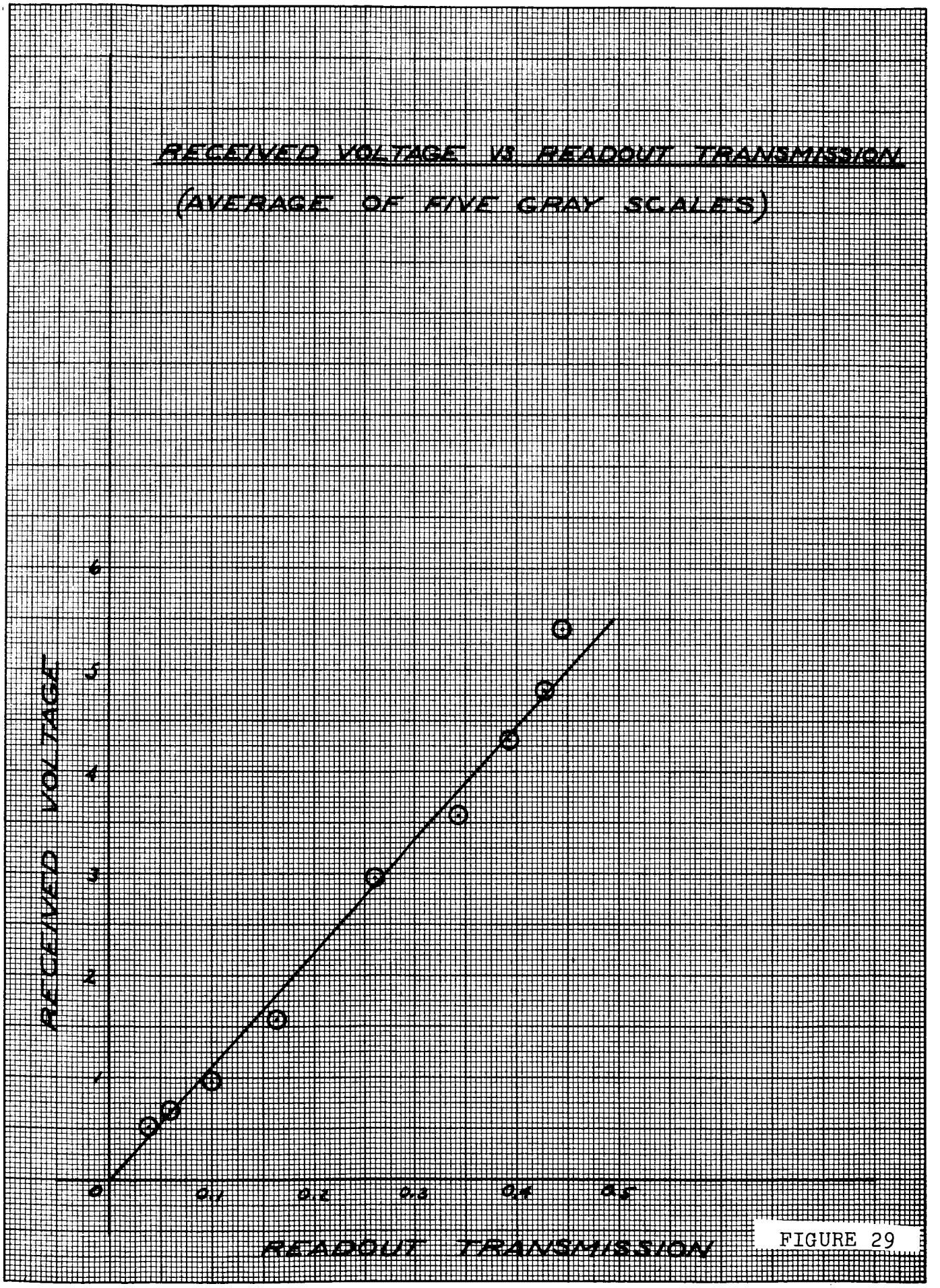

RECEIVED VOLTAGE VS READOUT TRANSMISSION
(AVERAGE OF FIVE GRAY SCALES)
RECEIVED VOLTAGE
6
5
4
3
2
1
0
0.1
0.2
0.3
0.4
0.5
READOUT TRANSMISSION

FIGURE 29

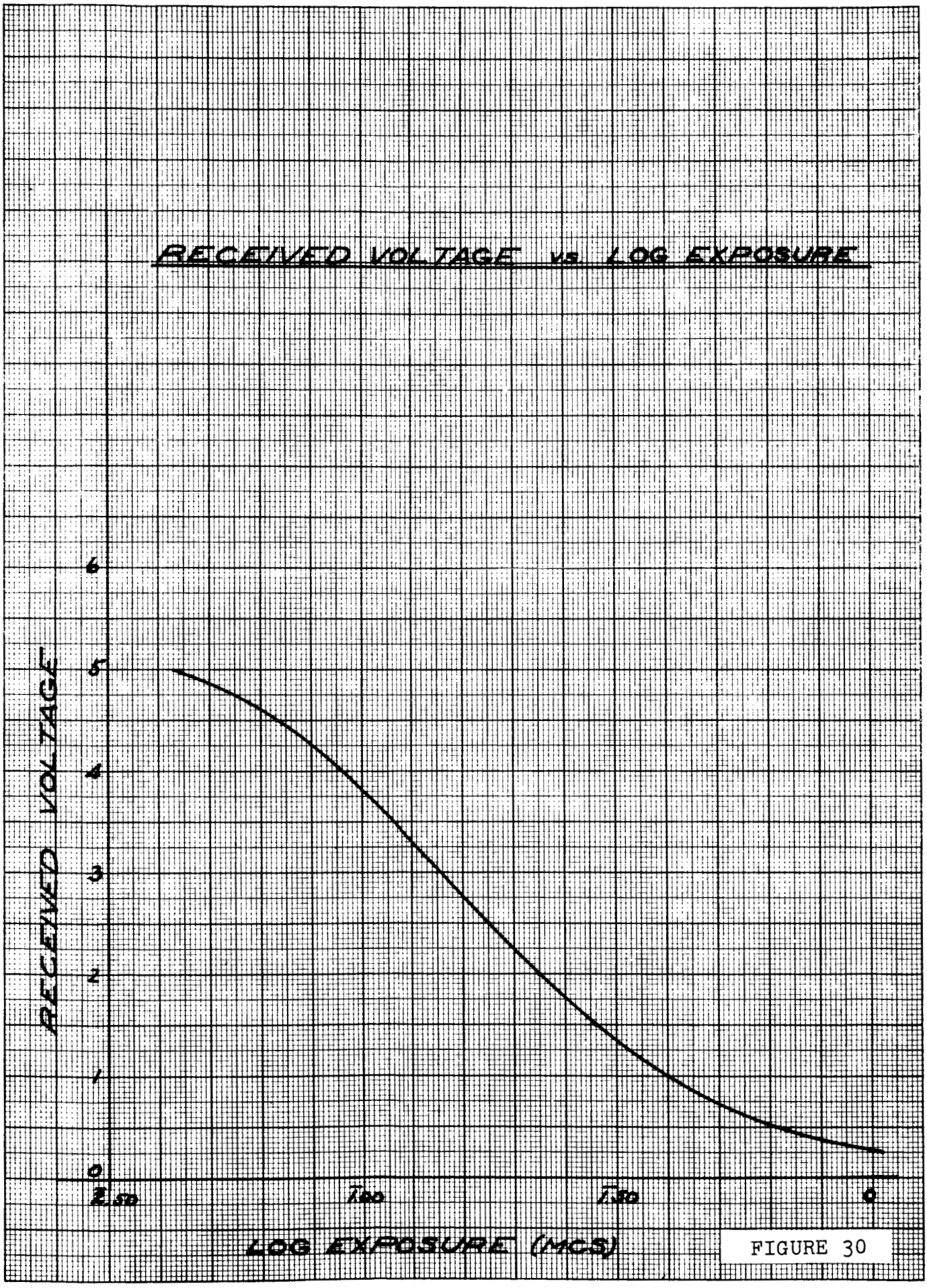
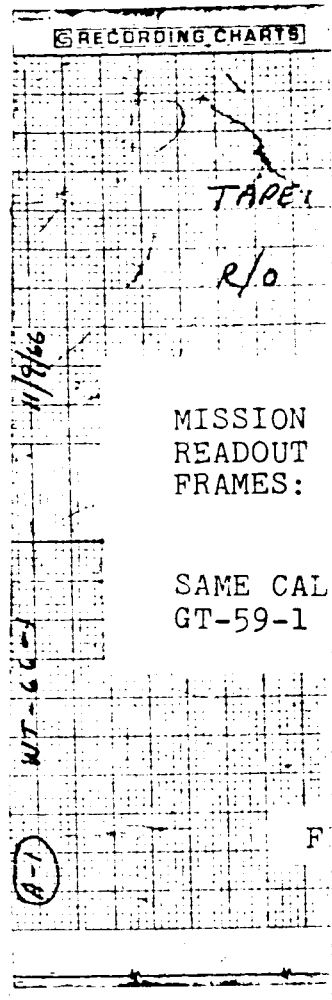
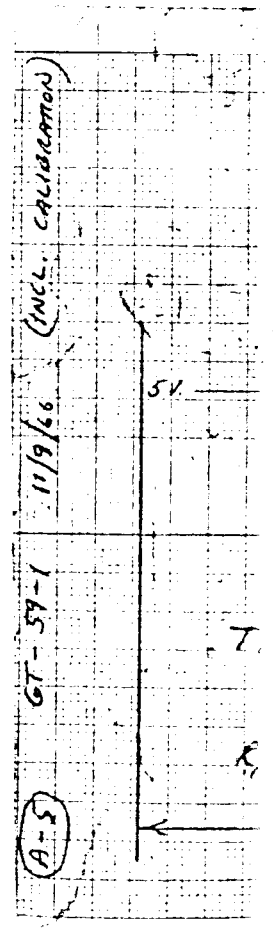
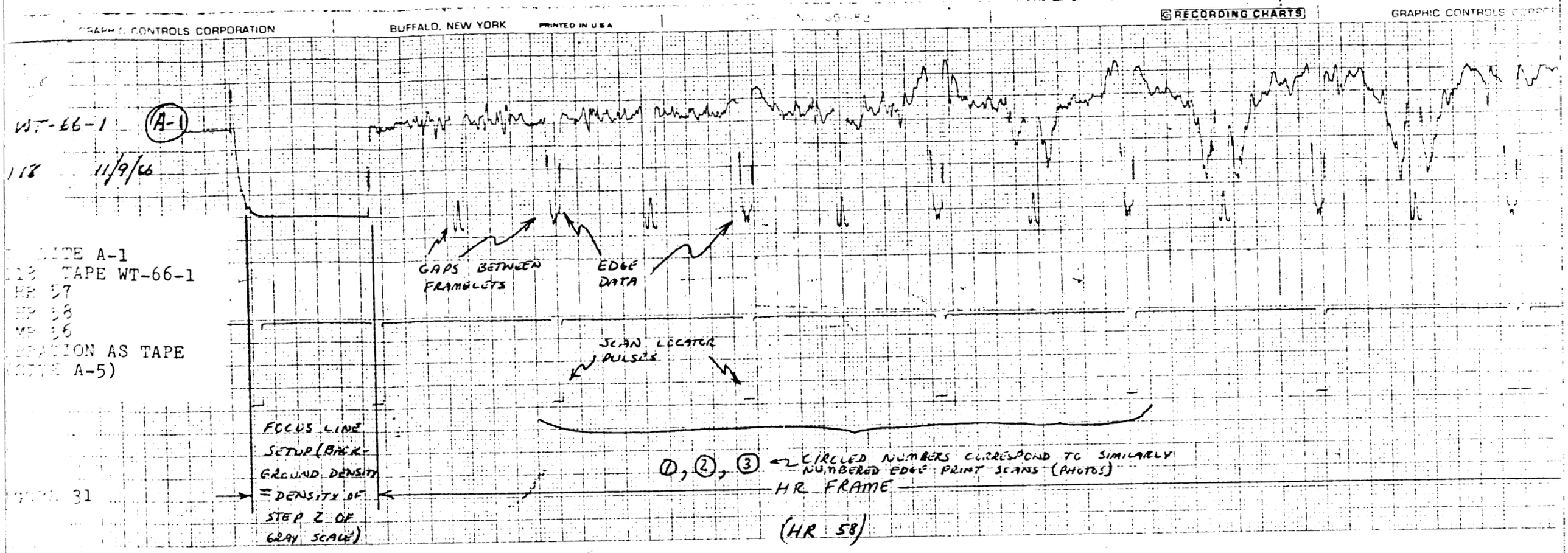

RECEIVED VOLTAGE vs. LOG EXPOSURE
RECEIVED VOLTAGE
6
5
4
3
2
1
0
2.50
2.00
1.50
0
LOG EXPOSURE (MCS)

FIGURE 30


RECORDING CHARTS
TAPE 1
R/O
11/9/66
MISSION
READOUT
FRAMES:
SAME CAL
GT-59-1
A-1


GT-59-1
11/9/66
(INCL. CALIBRATION)
5V
A-5


GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
RECORDING CHARTS
WT-66-1
A-1
11/9/66
SITE A-1
TAPE WT-66-1
HR 57
HR 58
MR 56
ION AS TAPE
A-5)
GAPS BETWEEN FRAMELETS
EDGE DATA
SCAN LOCATOR PULSES
FOCUS LINE SETUP (BACK-GROUND DENSITY = DENSITY OF STEP 2 OF GRAY SCALE)
1, 2, 3 ← CIRCLED NUMBERS CORRESPOND TO SIMILARLY NUMBERED EDGE PRINT SCANS (PHOTOS)
HR FRAME
(HR 58)
31

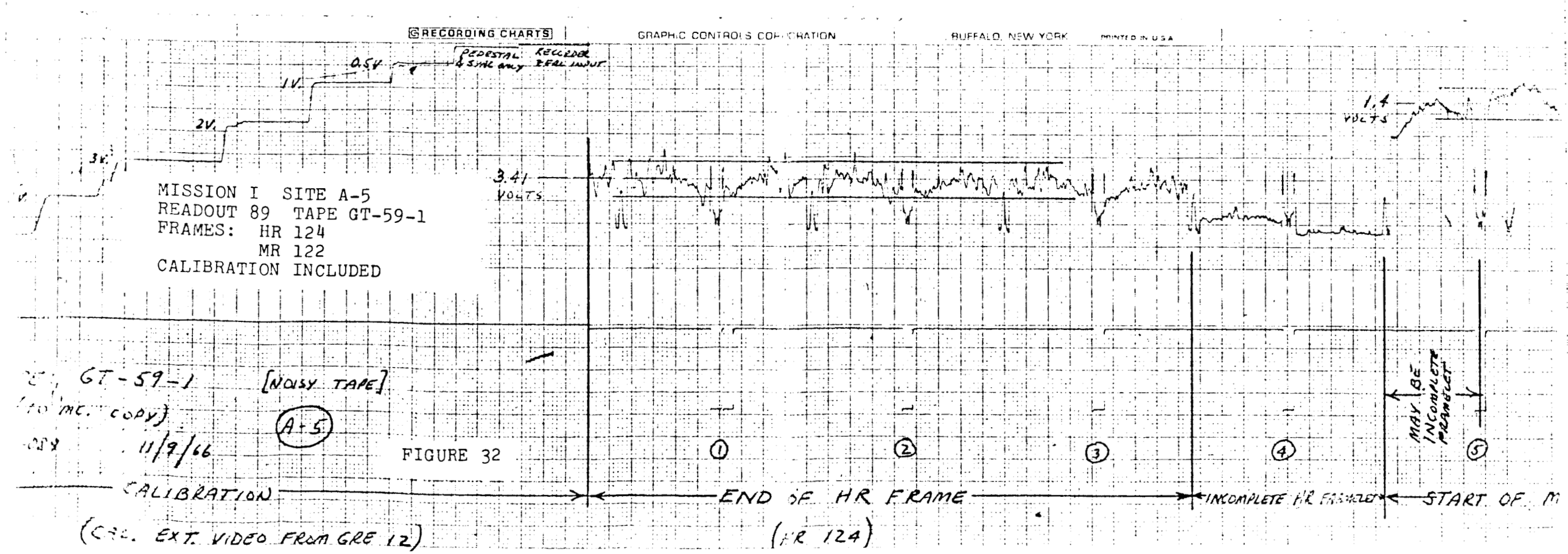
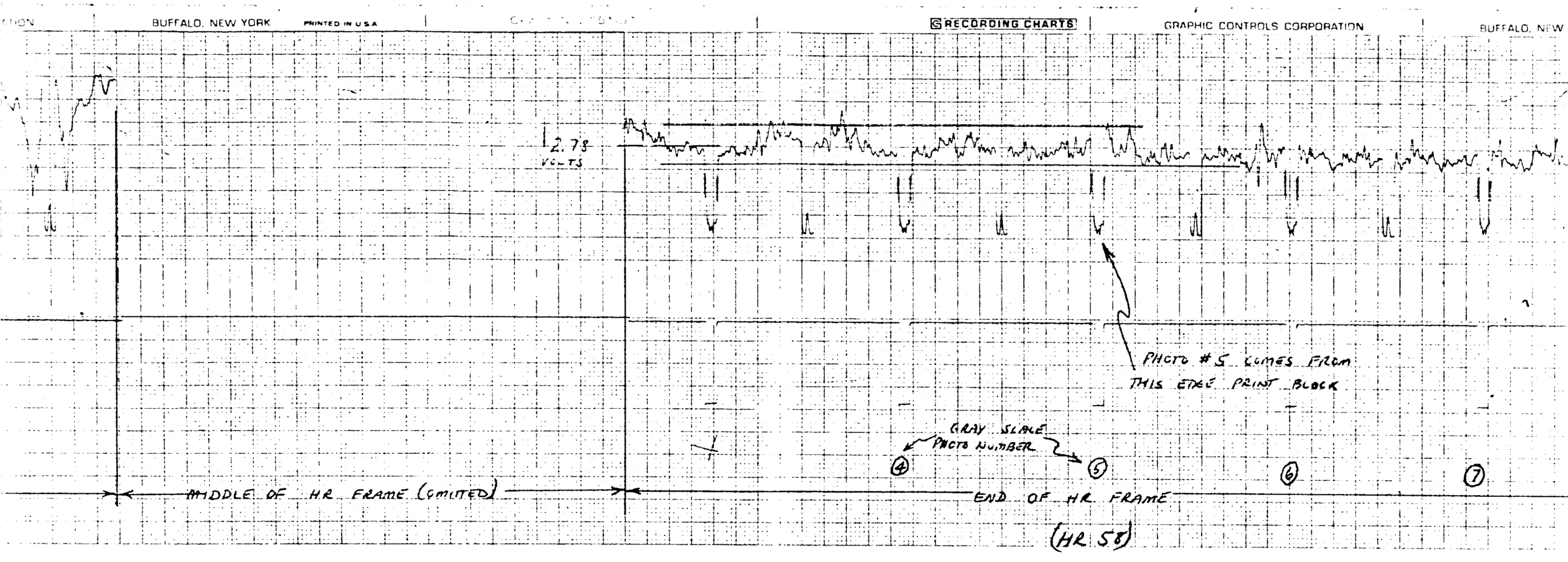
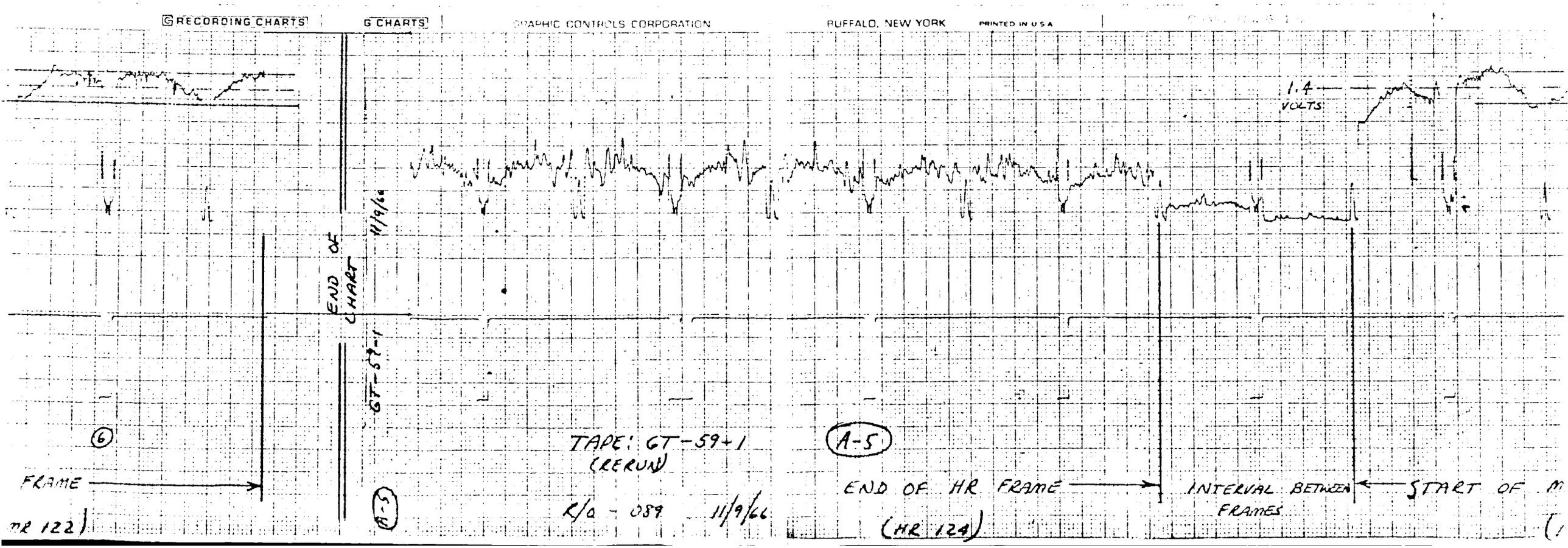
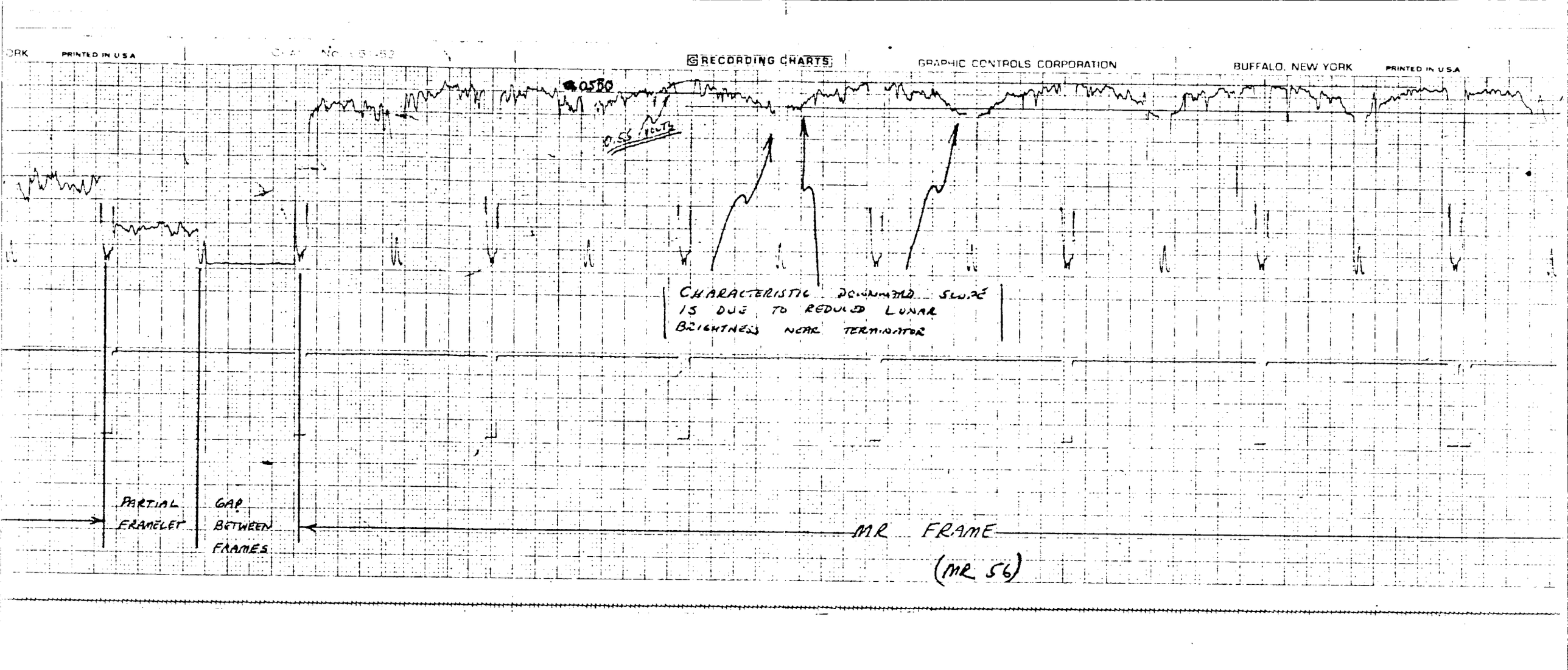
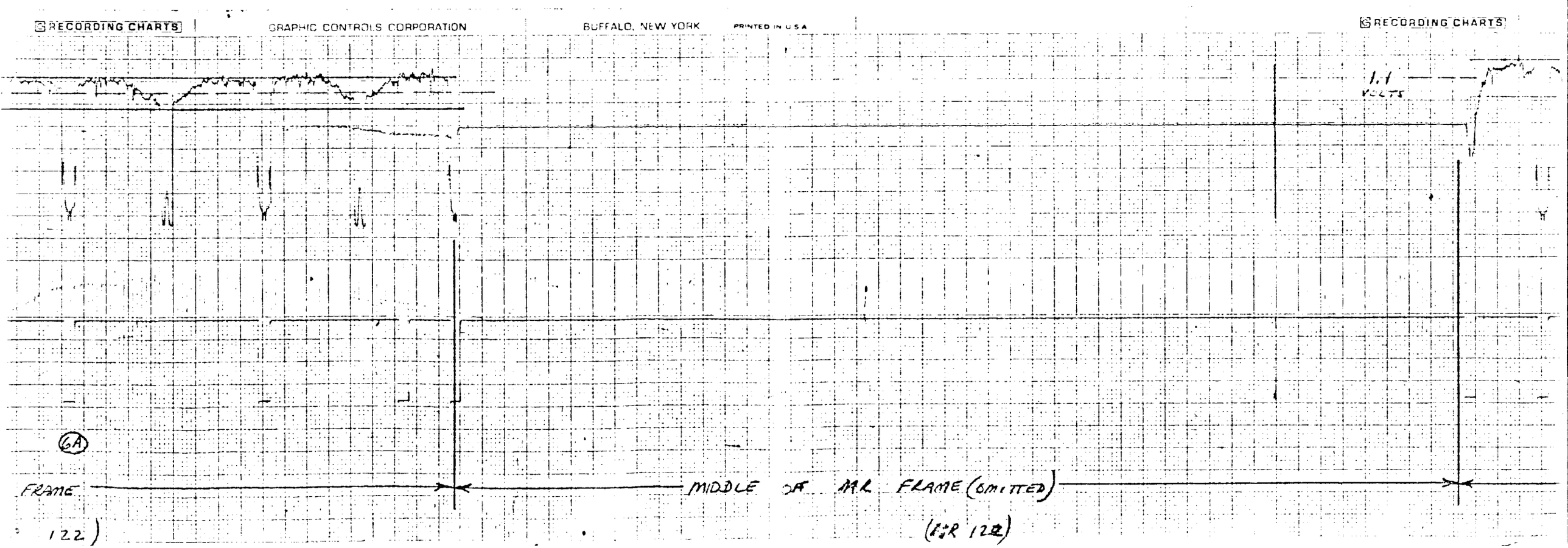

RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
PEDESTAL & SYNC ONLY
RECORDER ZERO INPUT
0.5V
1V
2V
3V
1.4 VOLTS
3.41 VOLTS
MISSION I SITE A-5
READOUT 89 TAPE GT-59-1
FRAMES: HR 124
MR 122
CALIBRATION INCLUDED
GT-59-1
[NOISY TAPE]
(TO MC. COPY)
A-5
11/9/66
1
2
3
4
5
MAY BE INCOMPLETE FRAMELET
CALIBRATION
END OF HR FRAME
INCOMPLETE HR FRAMELET
START OF M
(CAL. EXT. VIDEO FROM GRE 12)
(HR 124)

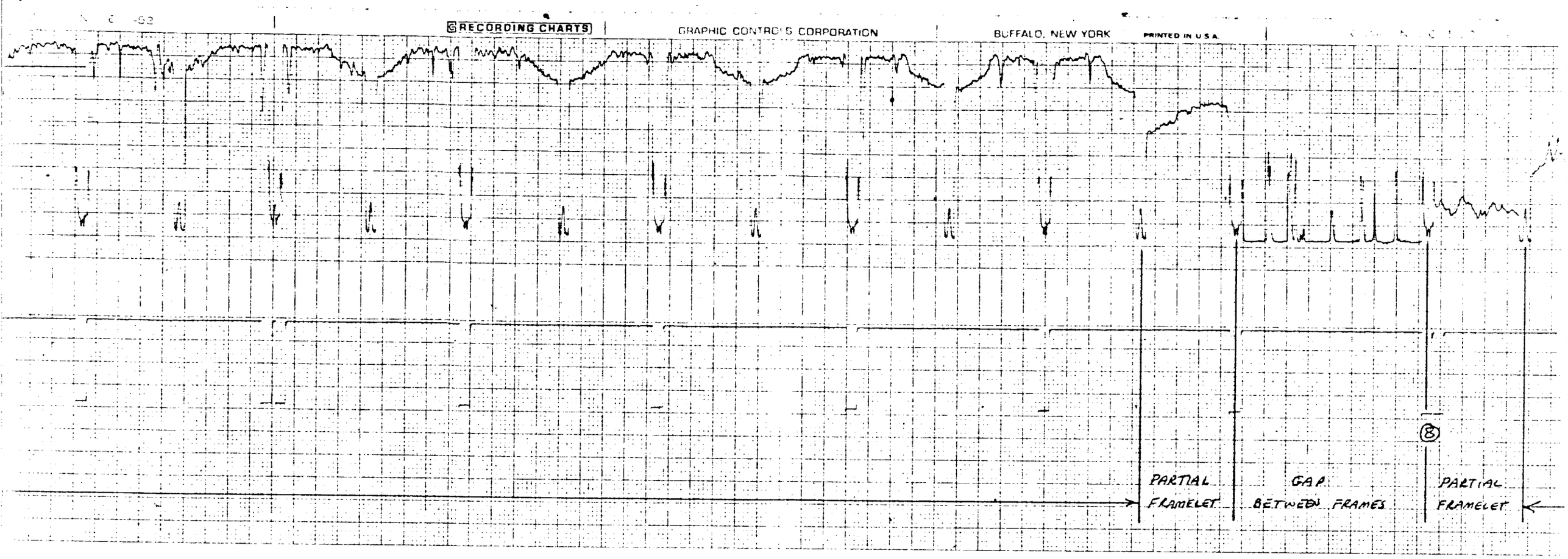
FIGURE 32

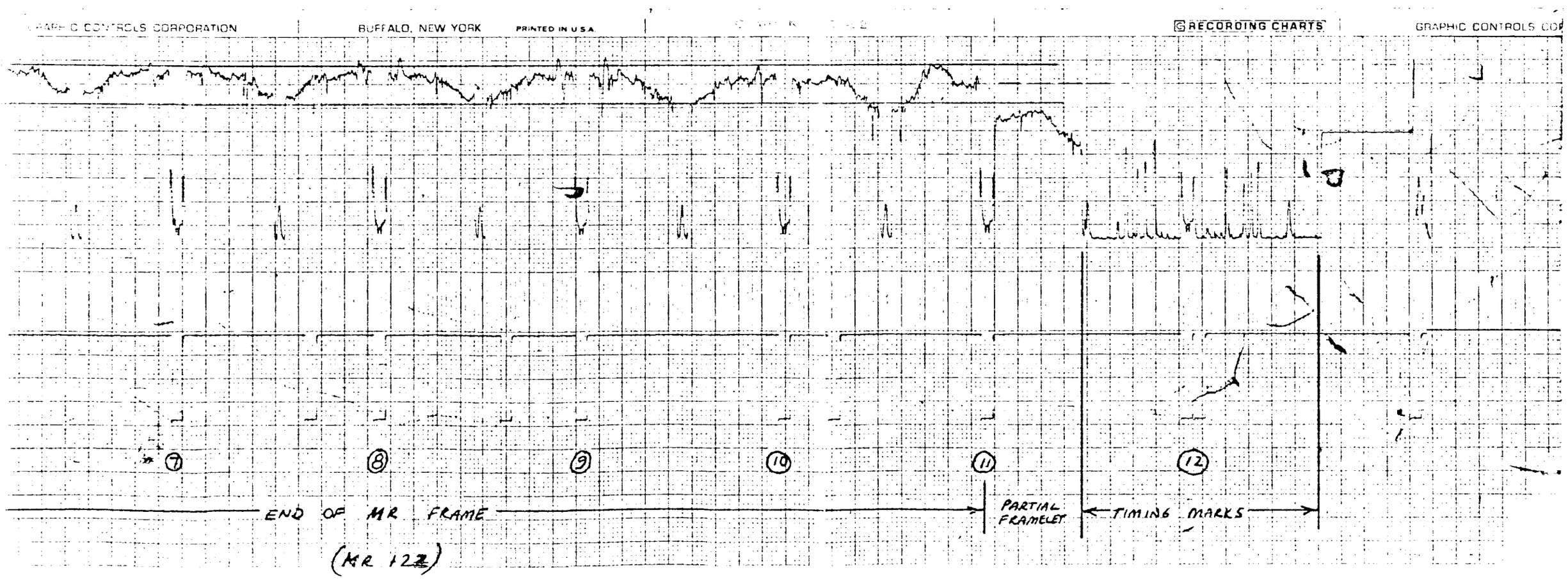

BUFFALO, NEW YORK
PRINTED IN U.S.A.
RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW
2.78 VOLTS
PHOTO #5 COMES FROM THIS EDGE PRINT BLOCK
GRAY SCALE PHOTO NUMBER
4
5
6
7
MIDDLE OF HR FRAME (OMITTED)
END OF HR FRAME
(HR 58)

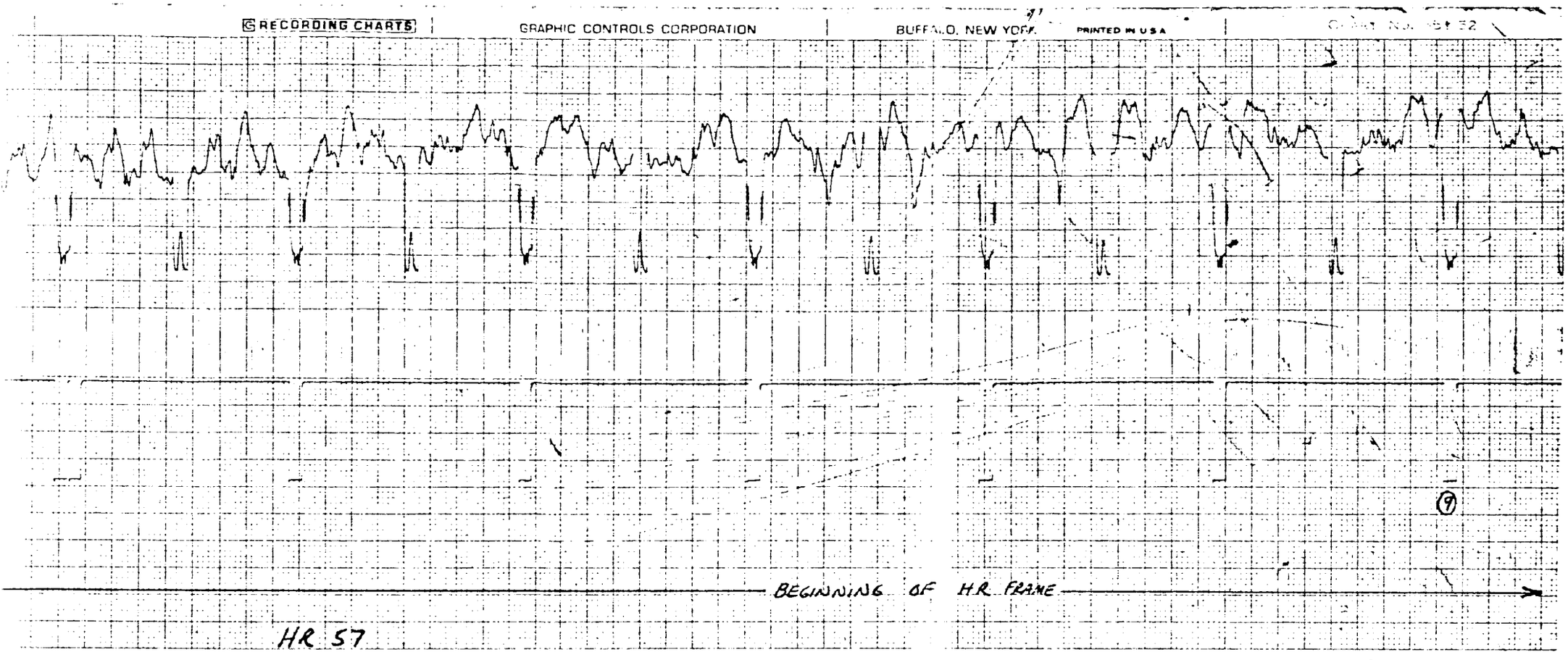

RECORDING CHARTS
G CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
1.4 VOLTS
END OF CHART
11/9/66
GT-59-1
6
TAPE: GT-59+1
(RERUN)
A-5
FRAME
A-5
R/a - 089
11/9/66
END OF HR FRAME
(HR 124)
INTERVAL BETWEEN FRAMES
START OF M
HR 122)


RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
0.55 VOLTS
CHARACTERISTIC DOWNWARD SLOPE IS DUE TO REDUCED LUNAR BRIGHTNESS NEAR TERMINATOR
PARTIAL FRAMELET
GAP BETWEEN FRAMES
MR FRAME
(MR 56)


RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
1.1 VOLTS
6A
FRAME
MIDDLE OF MR FRAME (OMITTED)
(MR 122)


RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
8
PARTIAL FRAMELET
GAP BETWEEN FRAMES
PARTIAL FRAMELET


GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
RECORDING CHARTS
GRAPHIC CONTROLS CORP
7
8
9
10
11
12
END OF MR FRAME
PARTIAL FRAMELET
TIMING MARKS
(MR 122)


RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
9
BEGINNING OF HR FRAME
HR 57

GT-57

R/O-084

MISSION I SITE A-5
READOUT 84 TAPE GT-57
FRAME: MR 133
SAME CALIBRATION AS TAPE
WT-42 (SITE A-6)

FIGURE 32

GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

TAPE WT-42

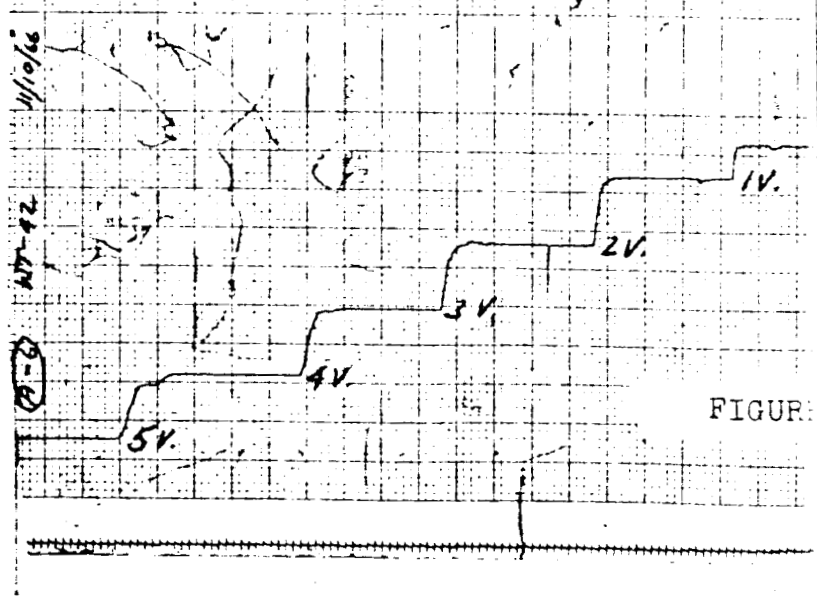
SITE A-6

11/10/66

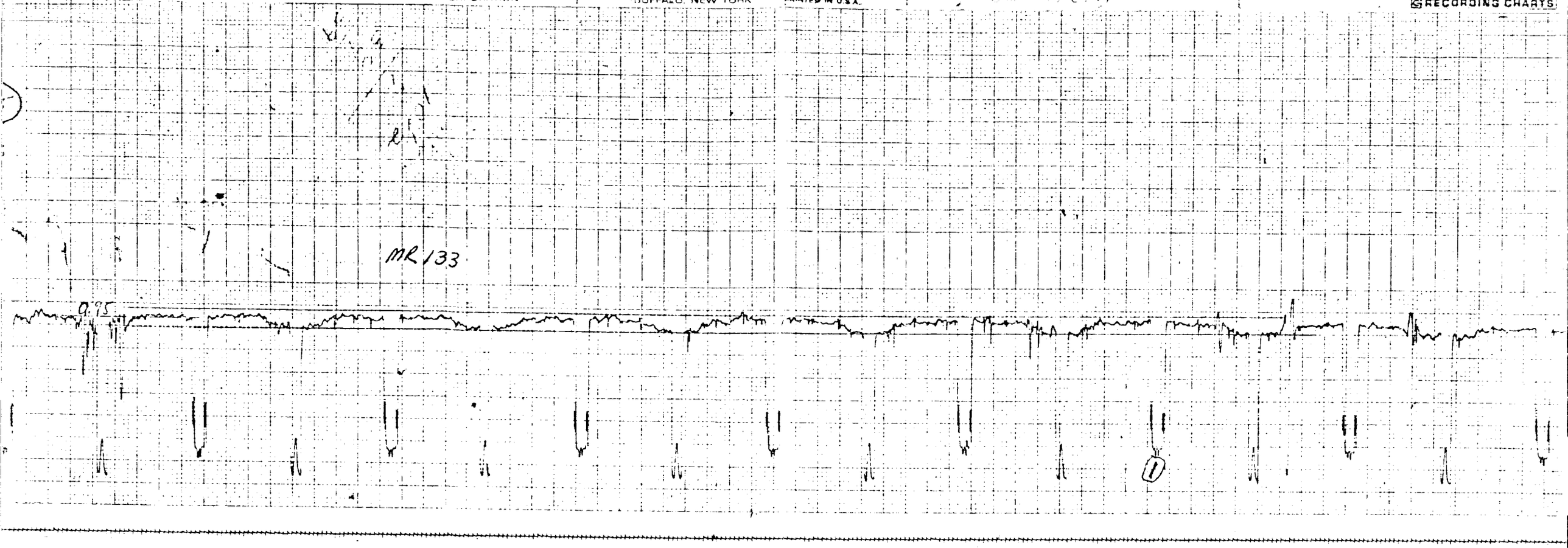
MISSION I
READOUT 7
FRAMES:

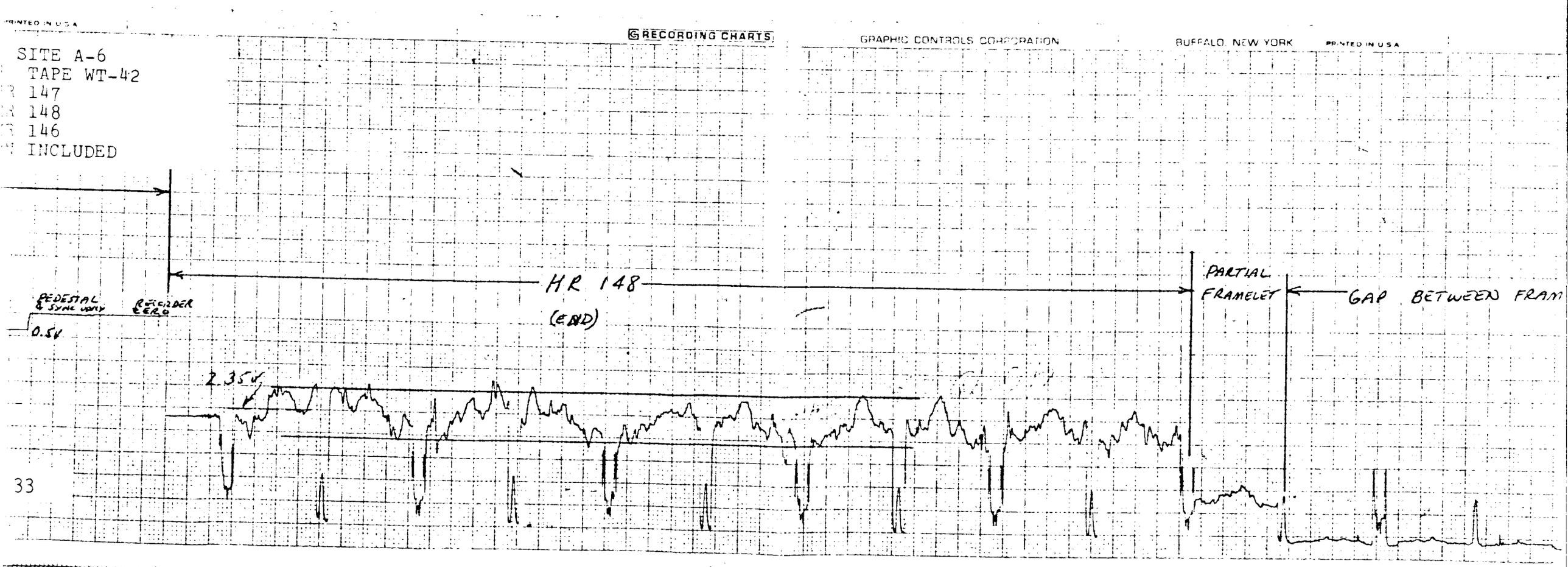
CALIBRATI

CHART RECORDER
CALIBRATION

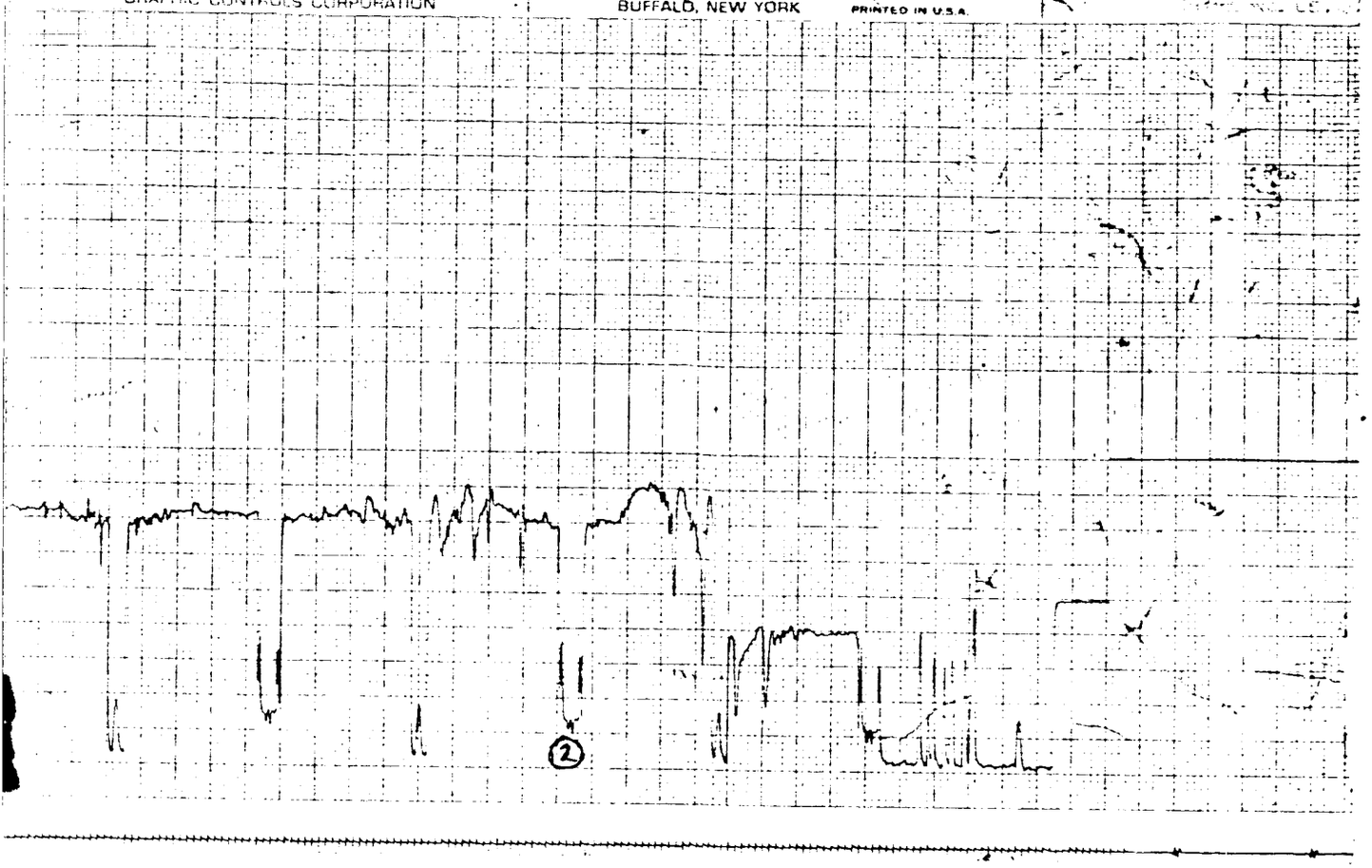


FIGUR

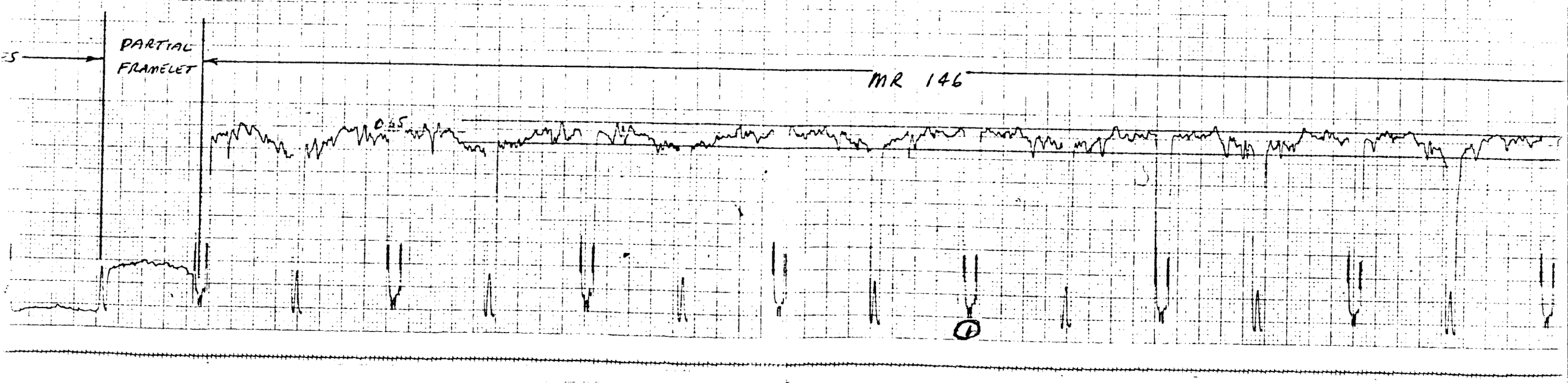

RECORDING CHARTS
MR 133
0.95

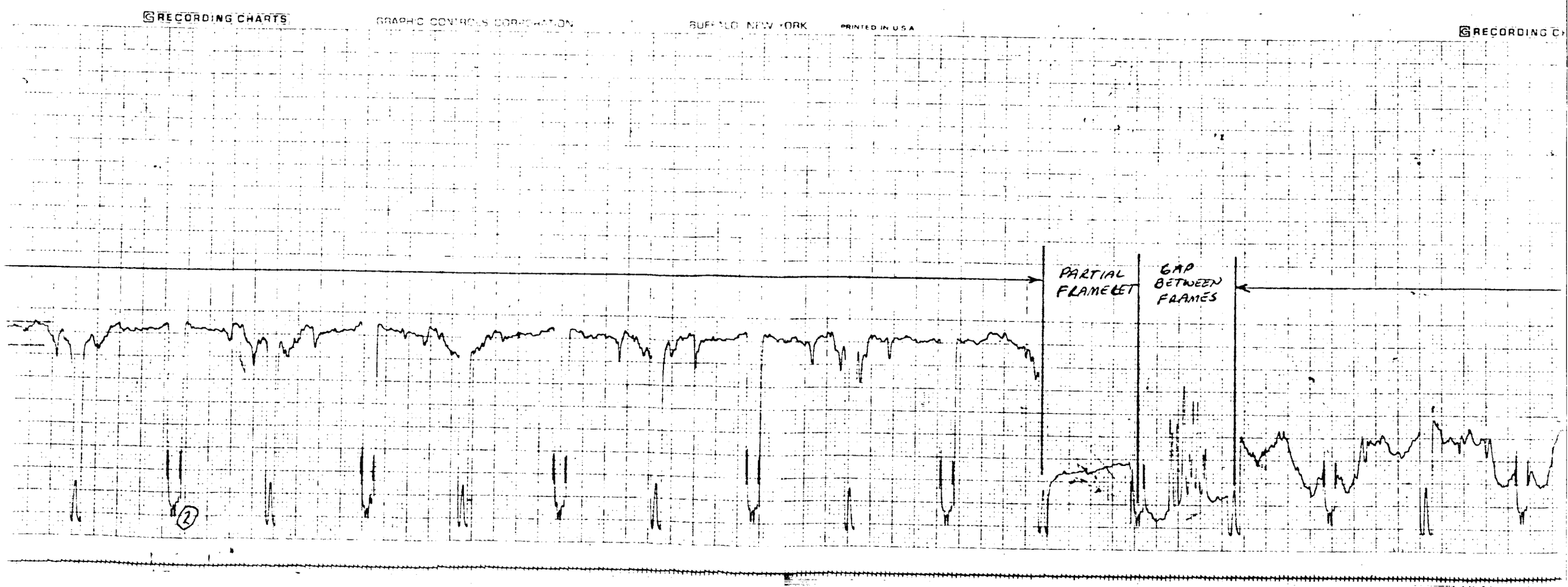

RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
SITE A-6
TAPE WT-42
147
148
146
INCLUDED
HR 148
(END)
PEDESTAL & SYNC VOLT
RECORDER ZERO
0.5V
2.35V
PARTIAL FRAMELET
GAP BETWEEN FRAM

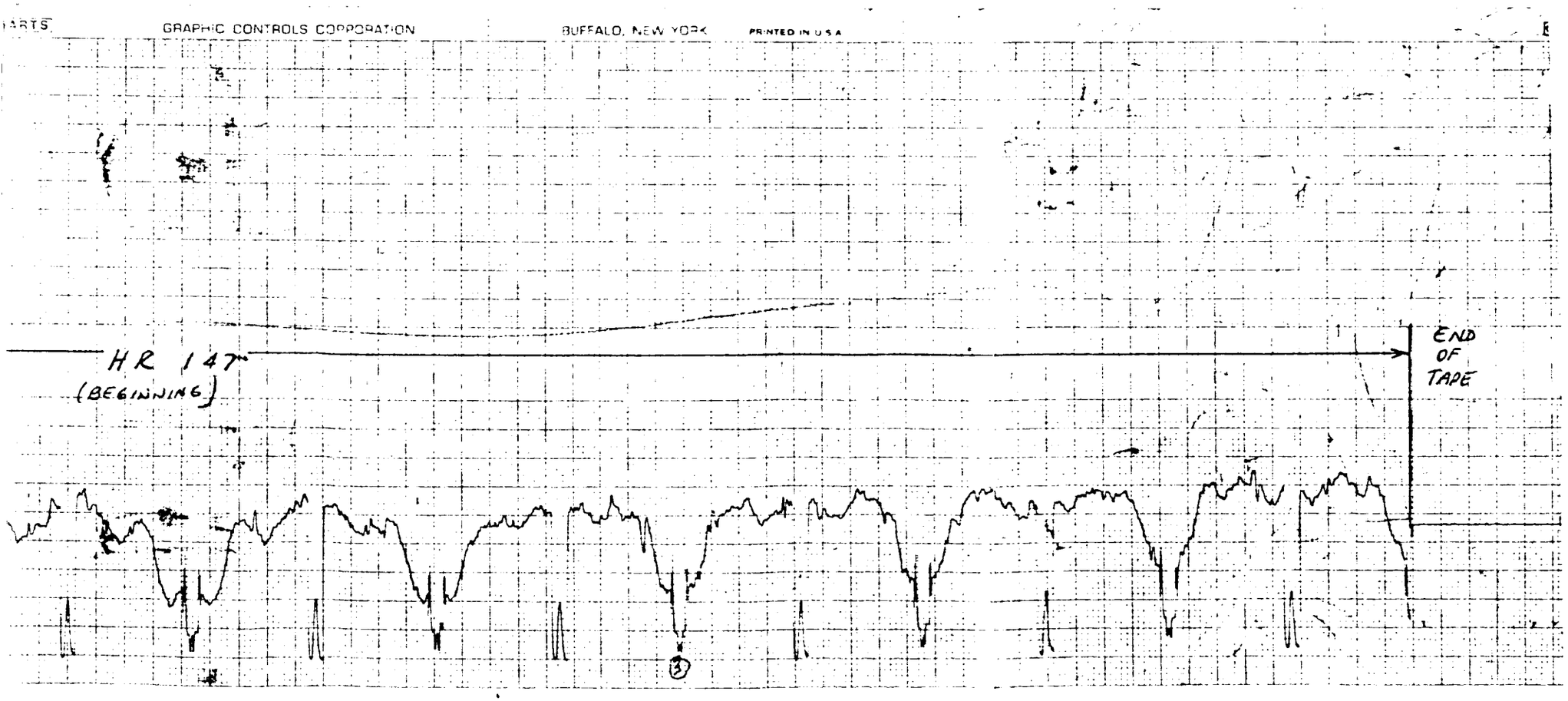
GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK PRINTED IN U.S.A.



RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK PRINTED IN U.S.A.




RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO NEW YORK
PRINTED IN U.S.A.
RECORDING C
PARTIAL FRAMELET
GAP BETWEEN FRAMES
2


ARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
HR 147
(BEGINNING)
END
OF
TAPE

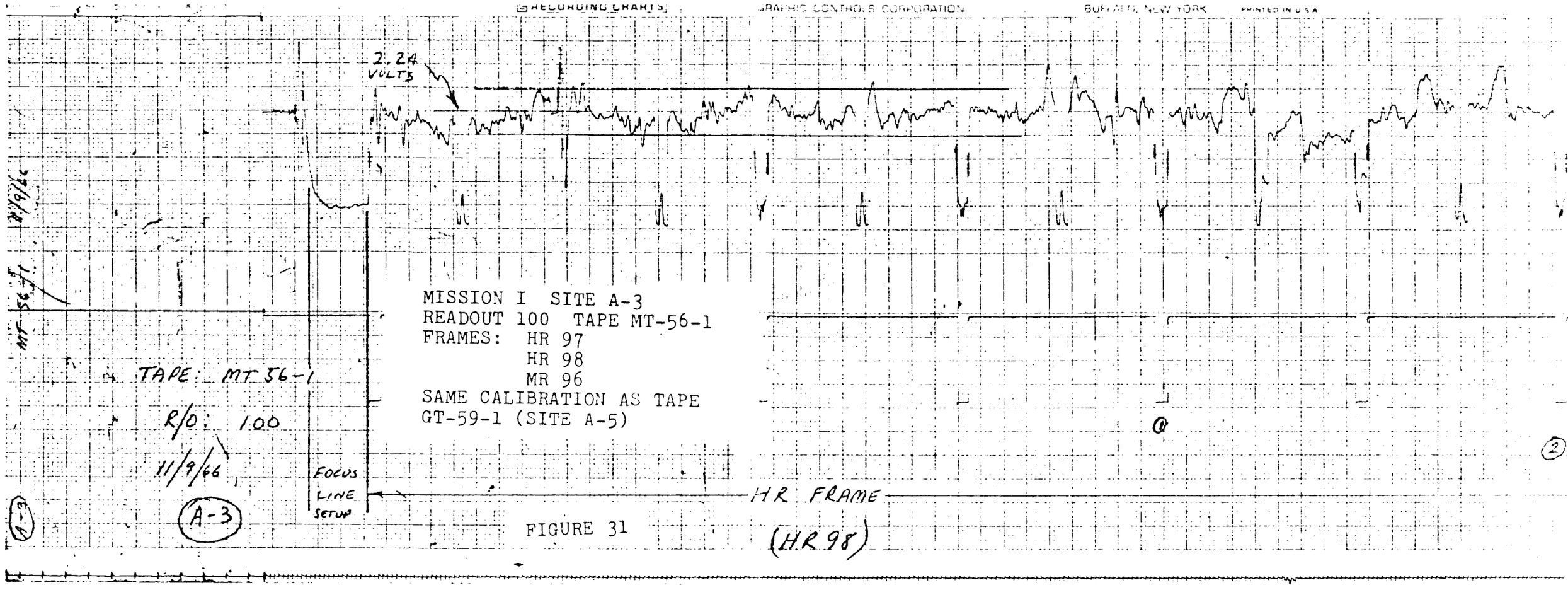


FIGURE 31

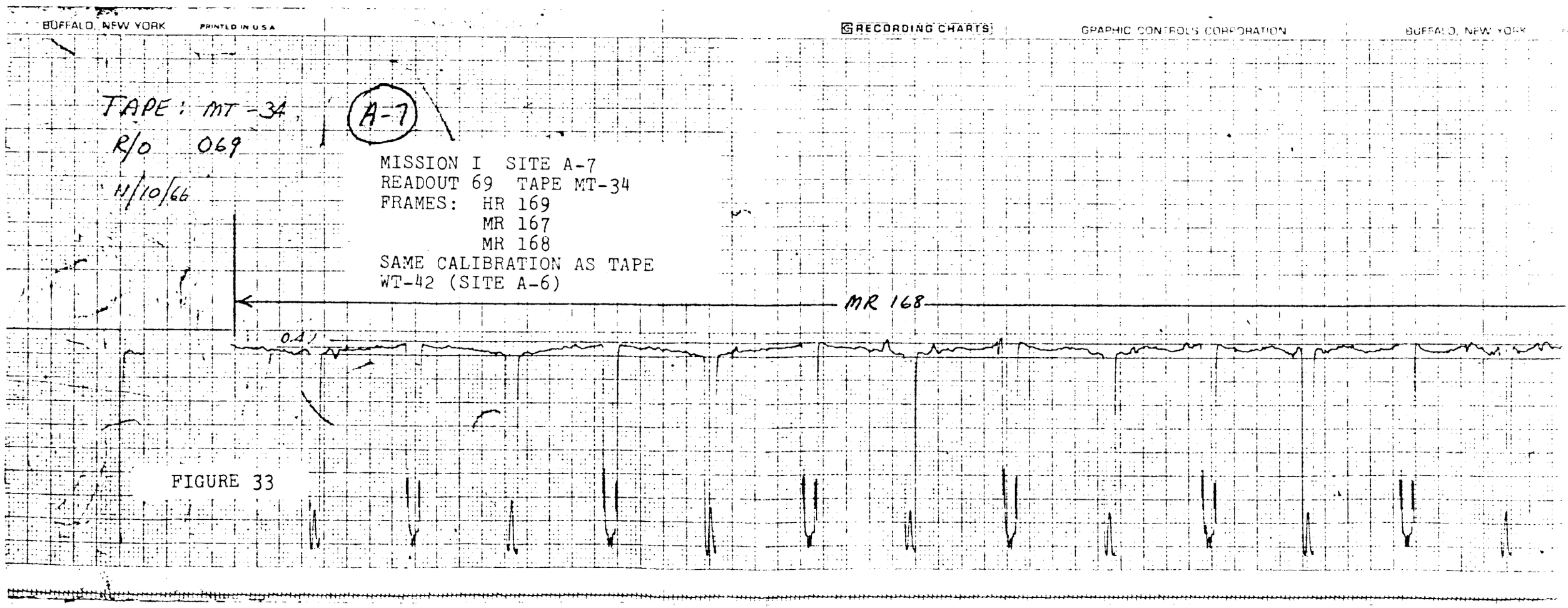
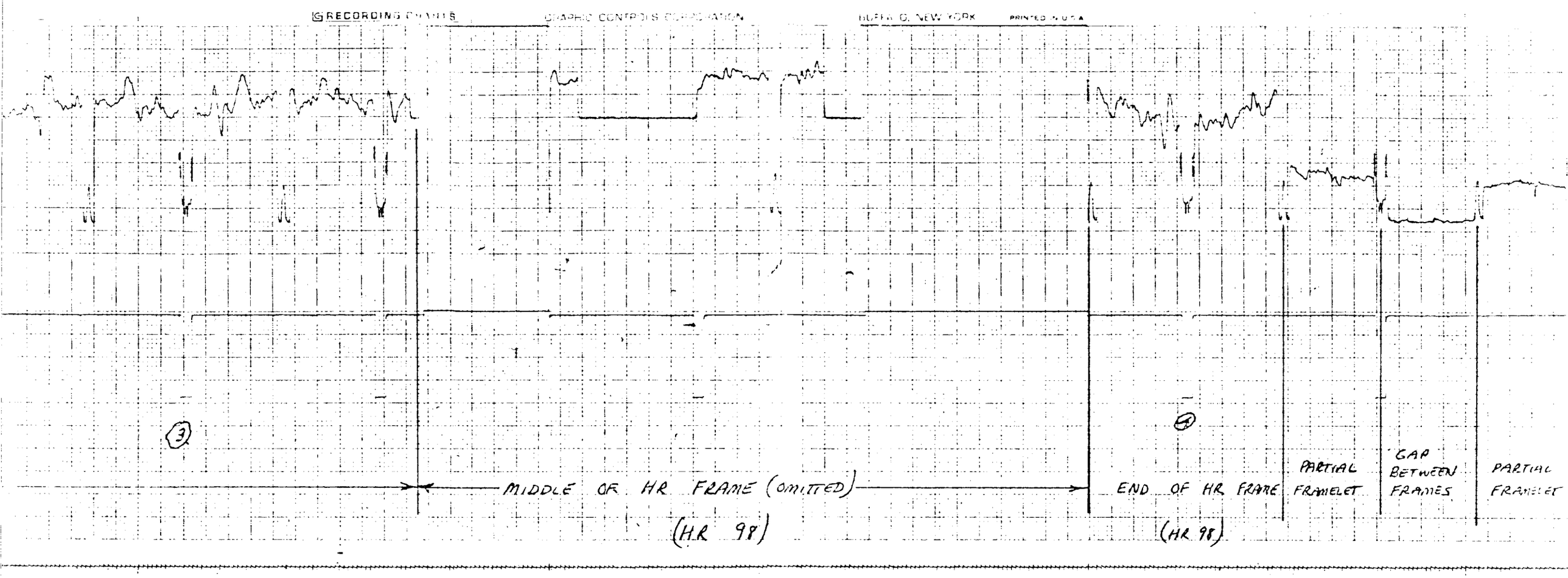
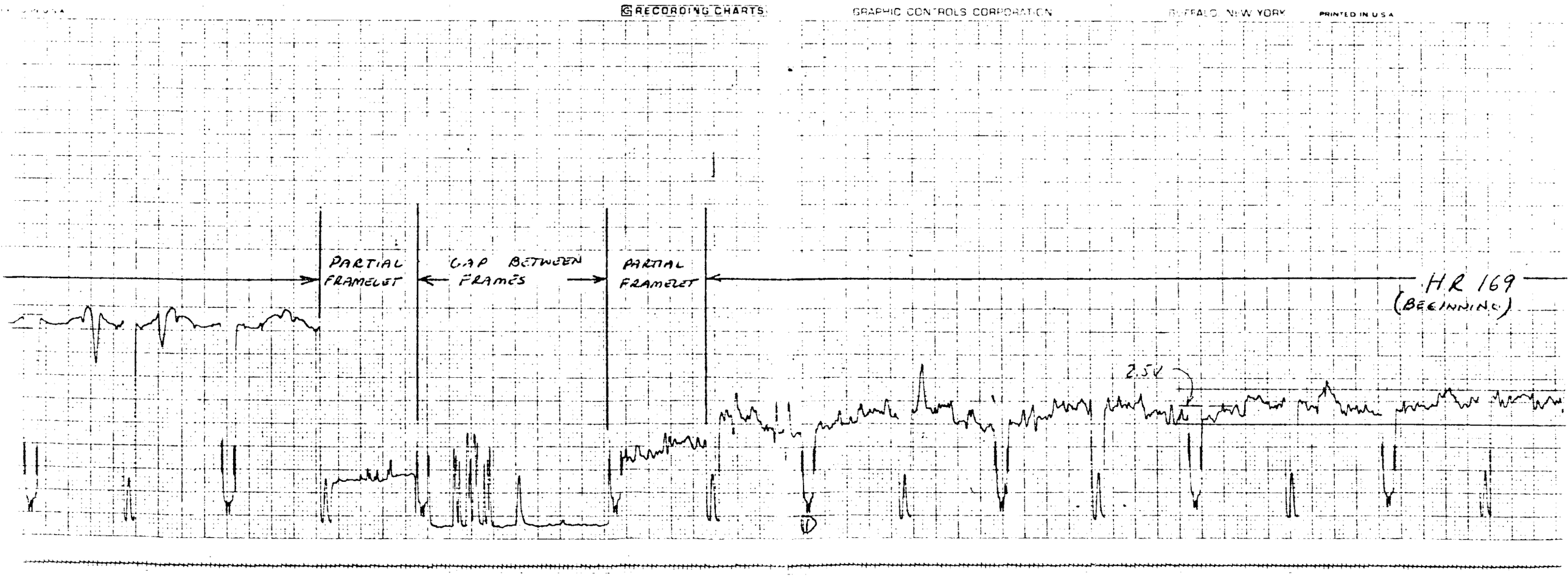
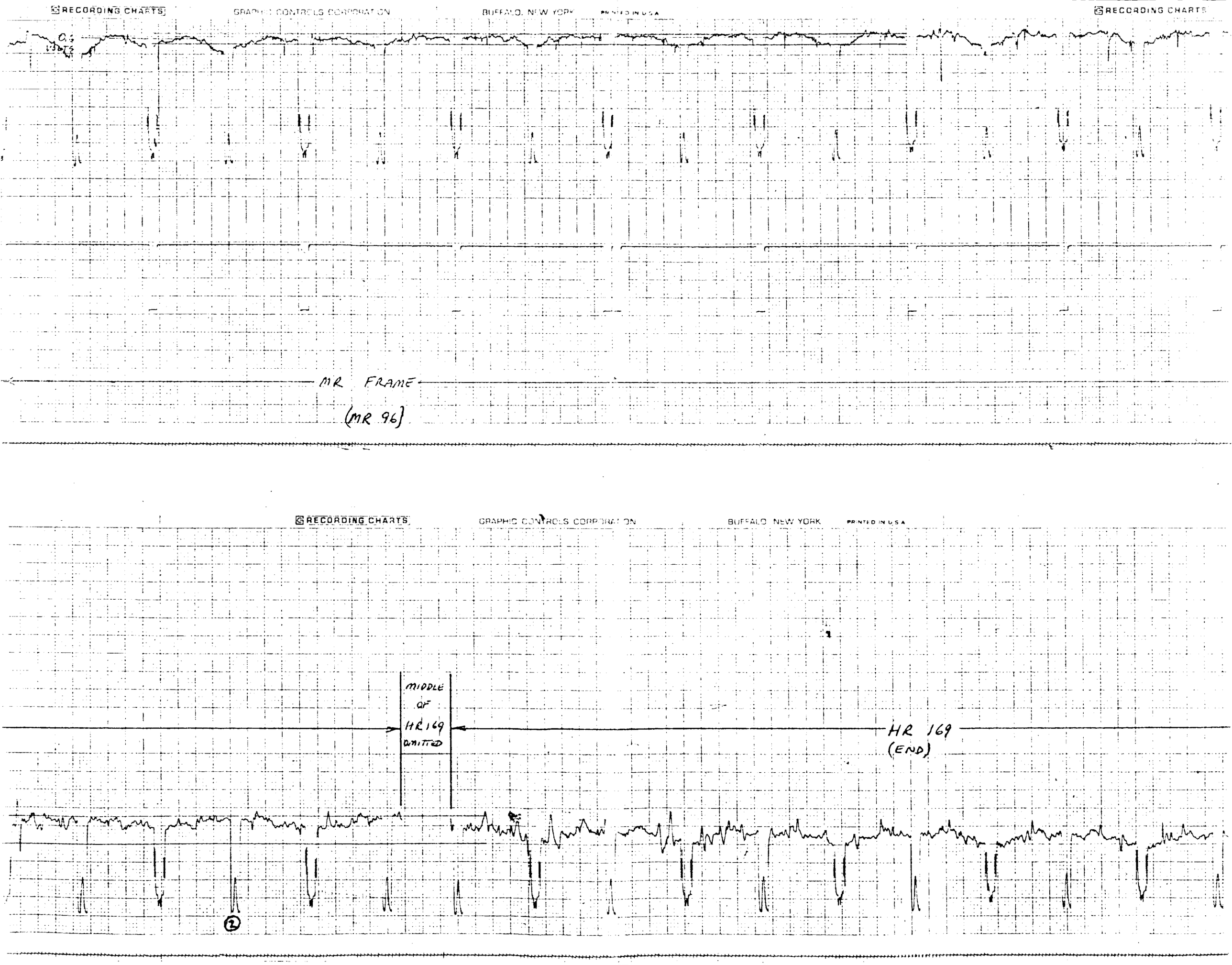
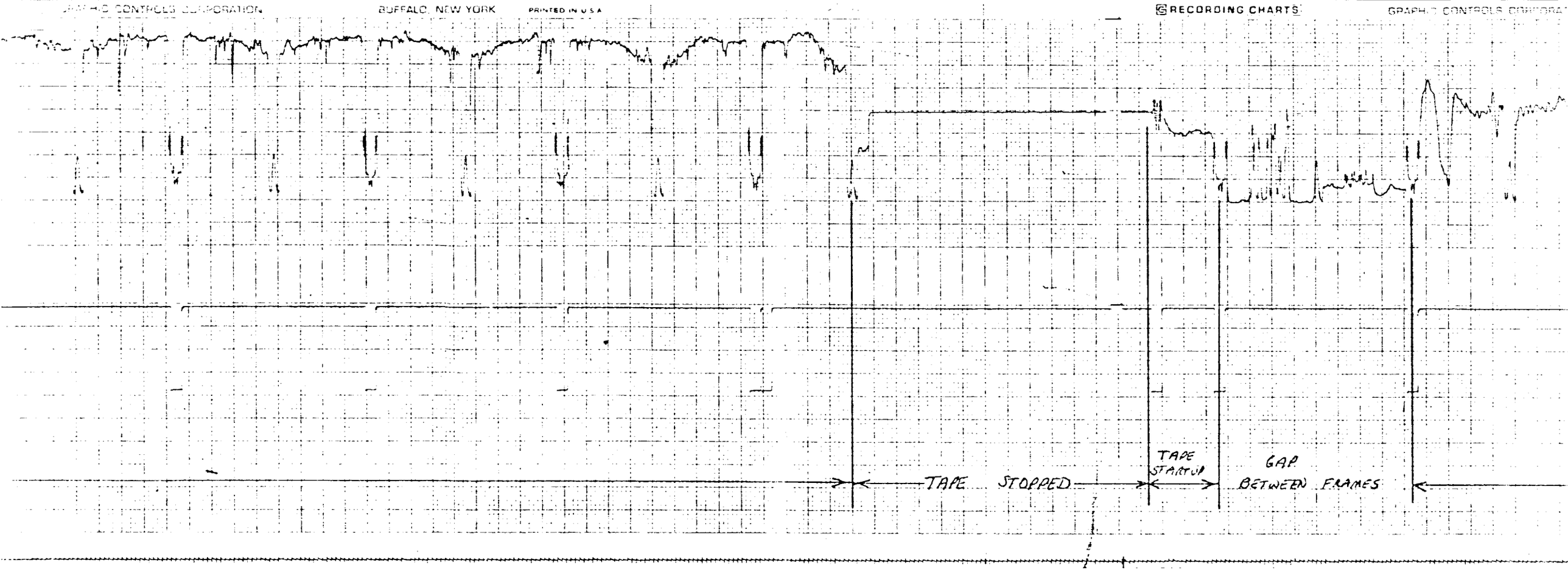


FIGURE 33


RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
3
MIDDLE OF HR FRAME (OMITTED)
(HR 98)
END OF HR FRAME
(HR 98)
PARTIAL FRAMELET
GAP BETWEEN FRAMES
PARTIAL FRAMELET


RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
PARTIAL FRAMELET
GAP BETWEEN FRAMES
PARTIAL FRAMELET
HR 169
(BEGINNING)
2.5V


RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
MR FRAME
(MR 96)
MIDDLE OF HR 169 OMITTED
HR 169 (END)
2


GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
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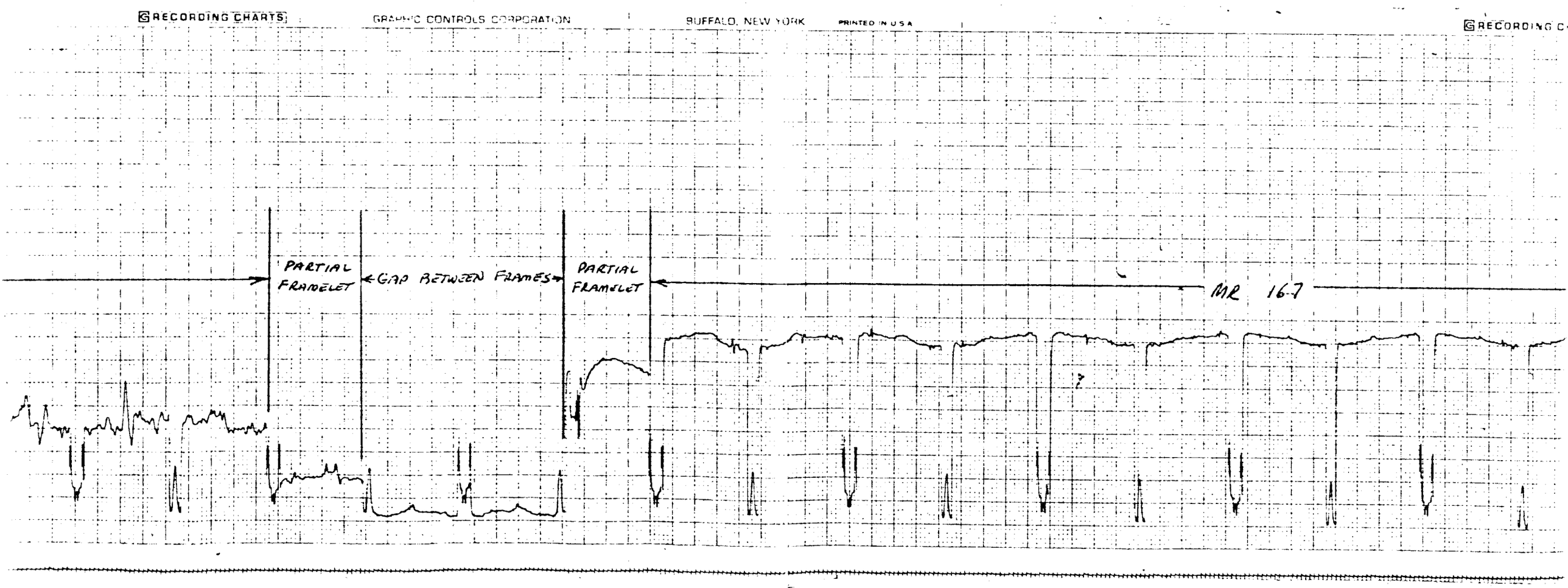
RECORDING CHARTS
TAPE STOPPED
TAPE STARTUP
GAP BETWEEN FRAMES


RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
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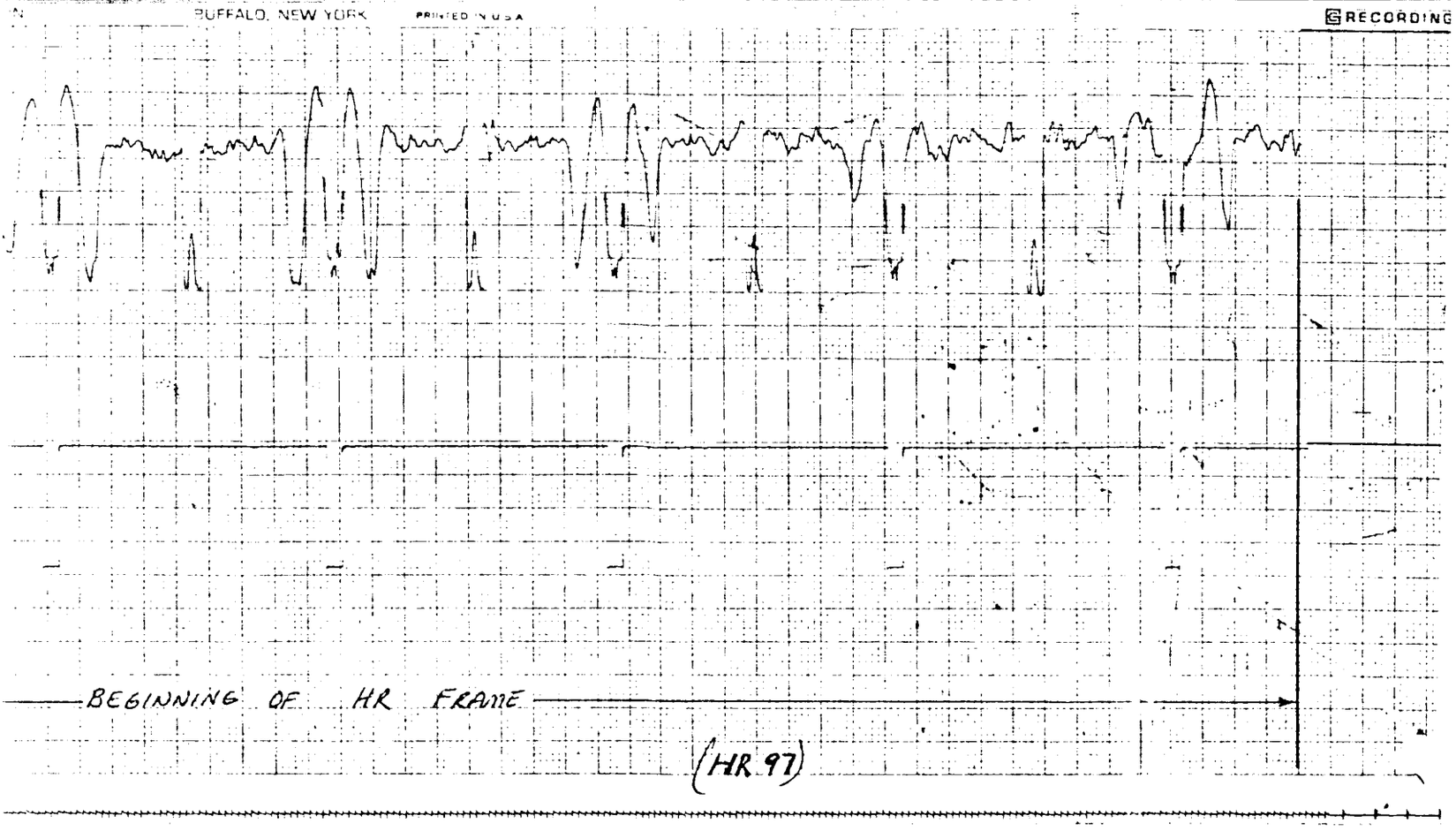
PARTIAL FRAMELET
GAP BETWEEN FRAMES
PARTIAL FRAMELET
MR 16-7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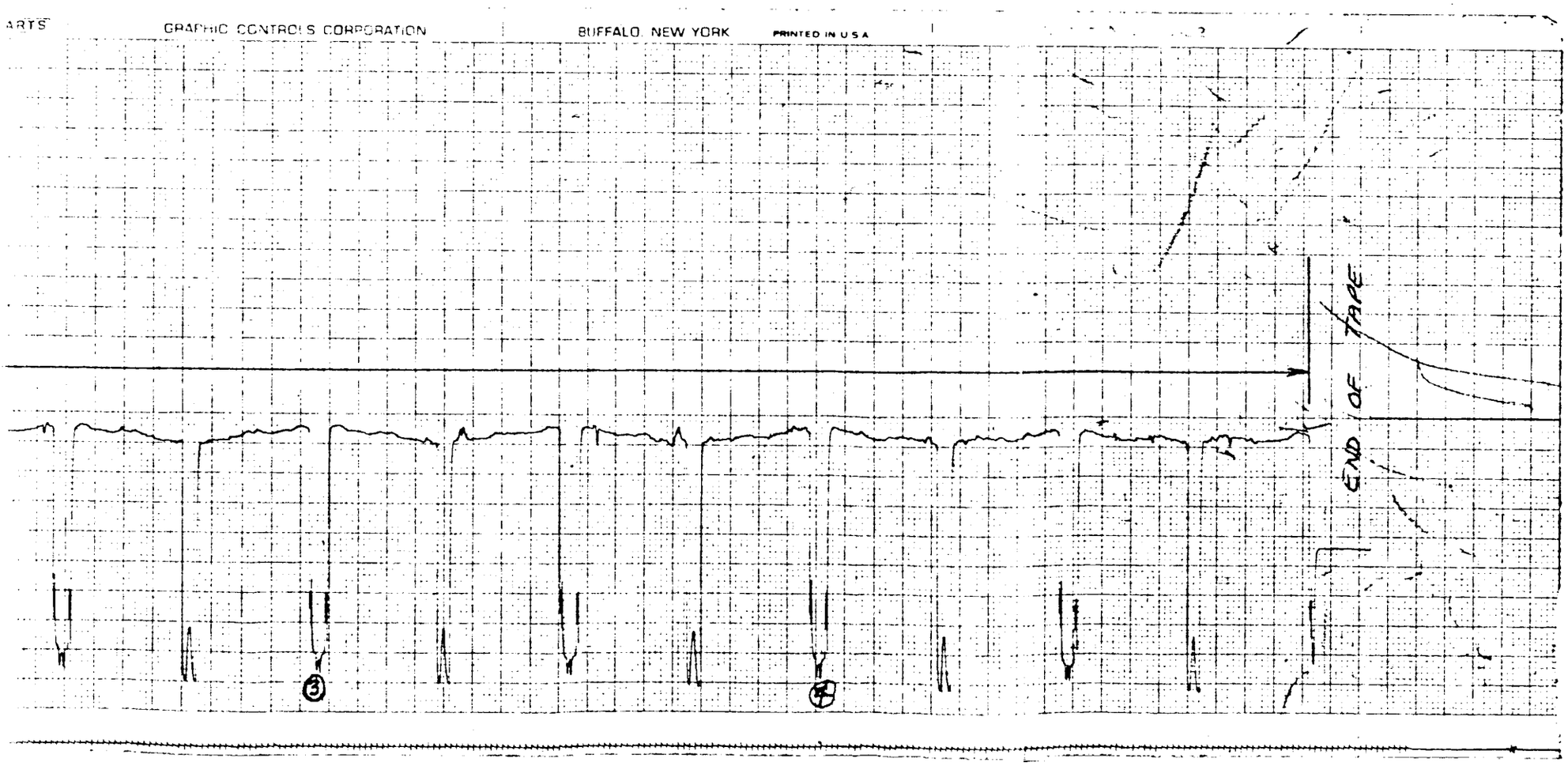
RECORDING
BEGINNING OF HR FRAME
(HR 97)


GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
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END OF TAPE
3
4

135

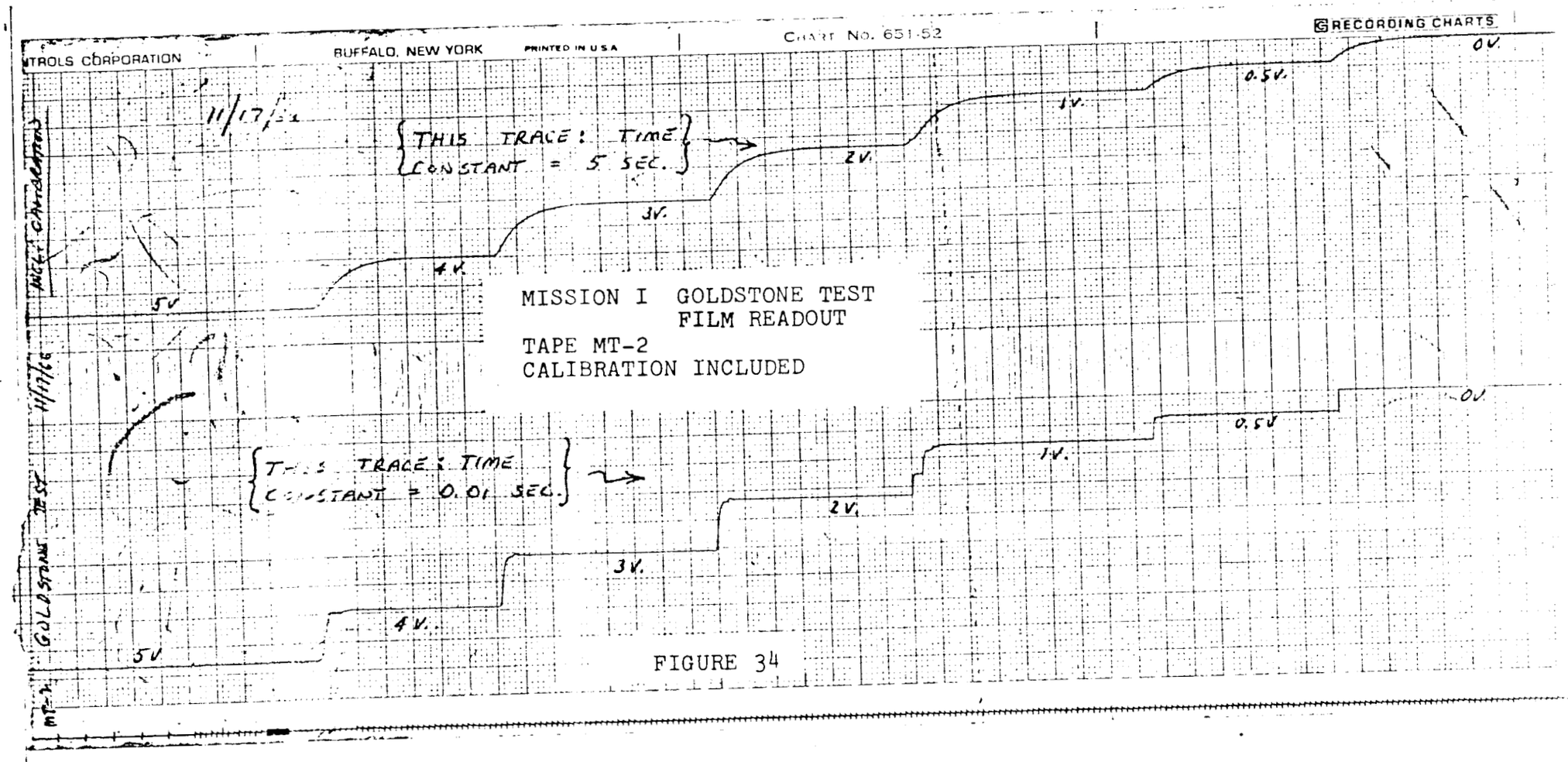
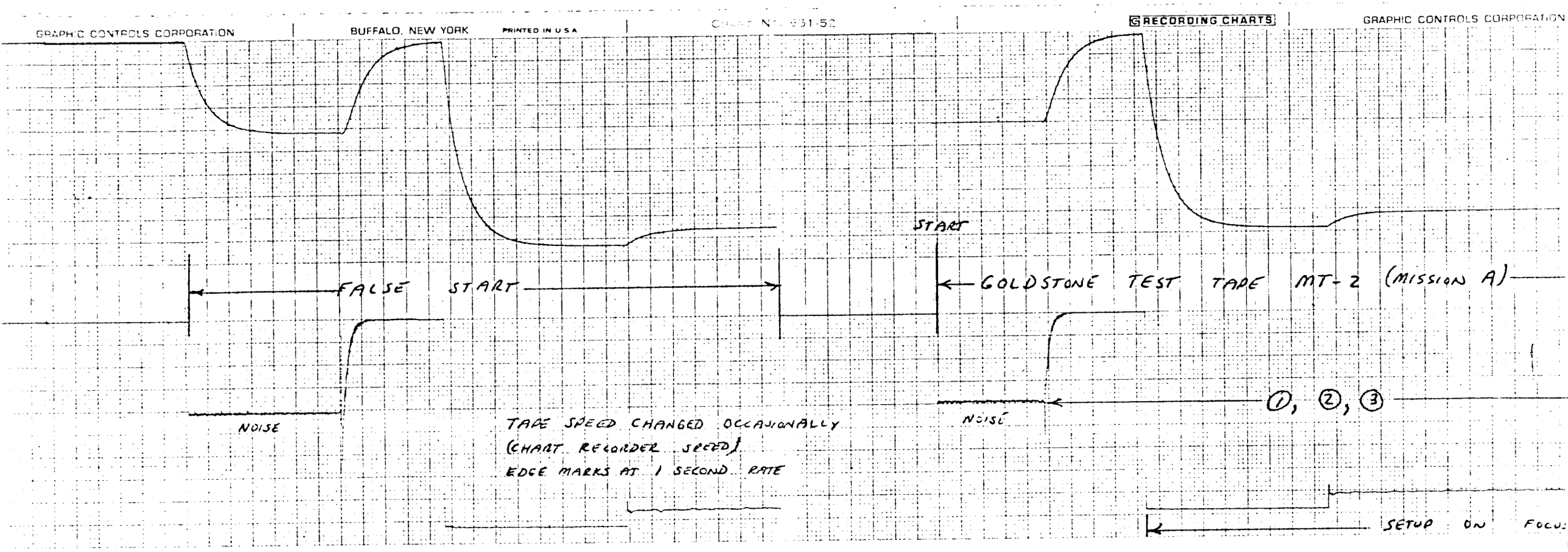
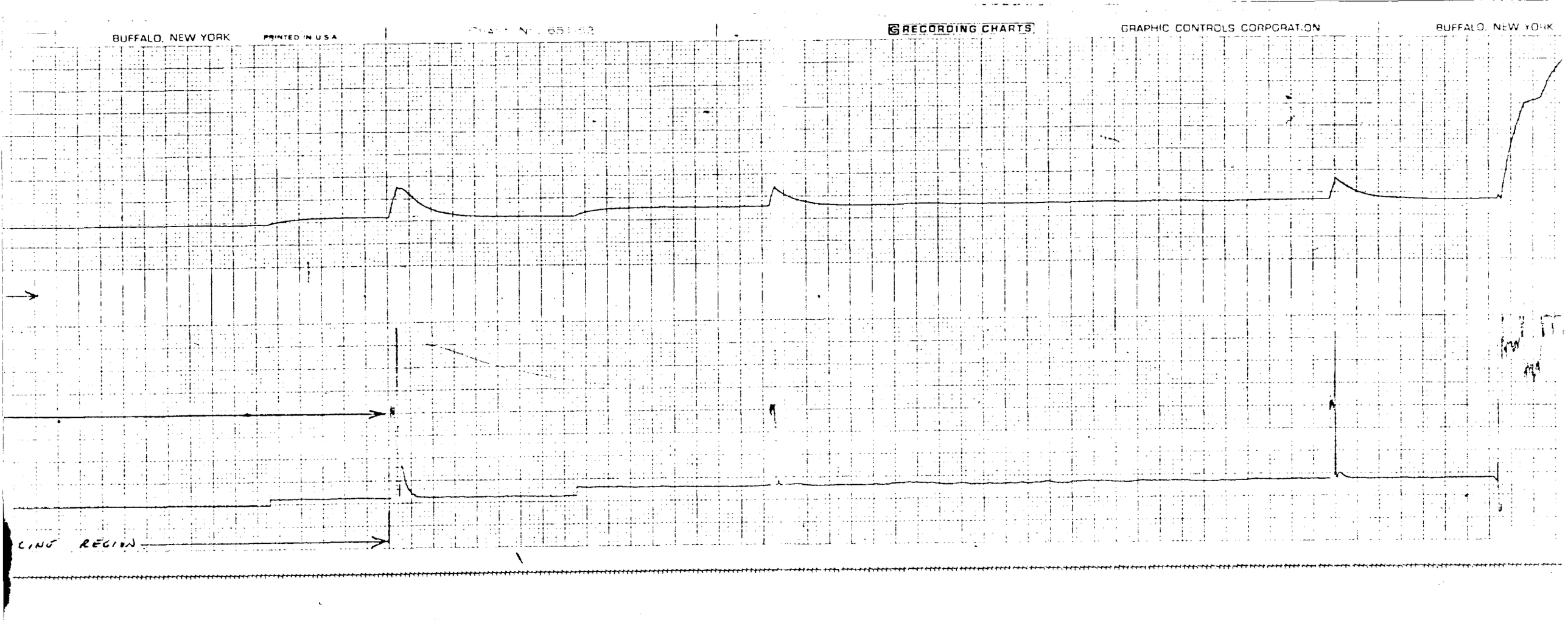


FIGURE 34


GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
START
FALSE START
GOLDSTONE TEST TAPE MT-2 (MISSION A)
NOISE
NOISE
①, ②, ③
TAPE SPEED CHANGED OCCASIONALLY
(CHART RECORDER SPEED)
EDGE MARKS AT 1 SECOND RATE
SETUP ON FOCU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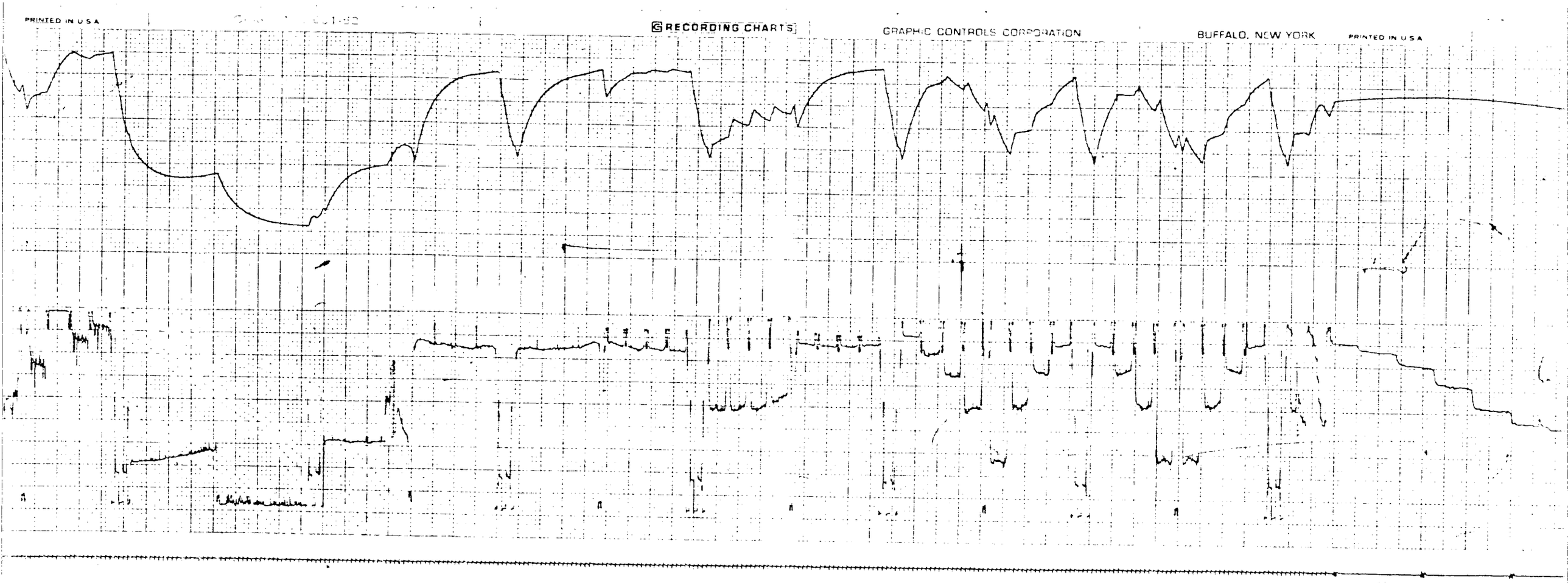
PRINTED IN U.S.A.
RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
CINÉ REGION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GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
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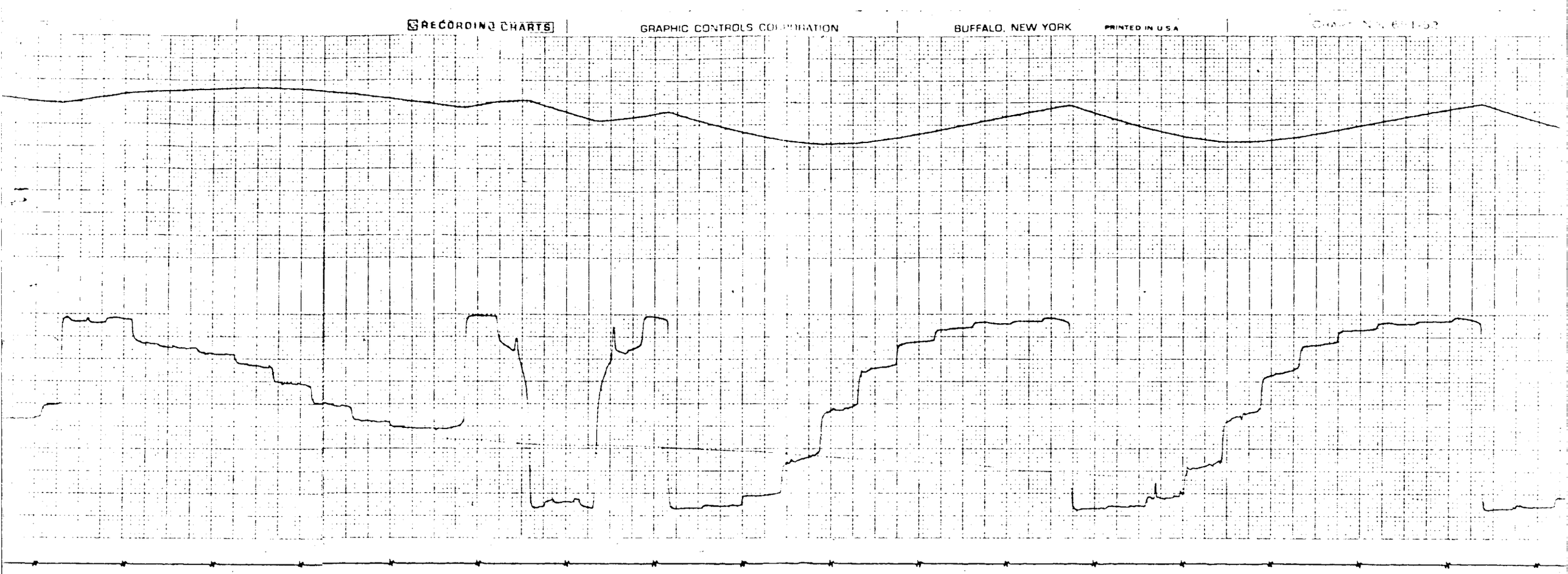
RECORDING CHARTS
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BUFFALO, NEW YORK
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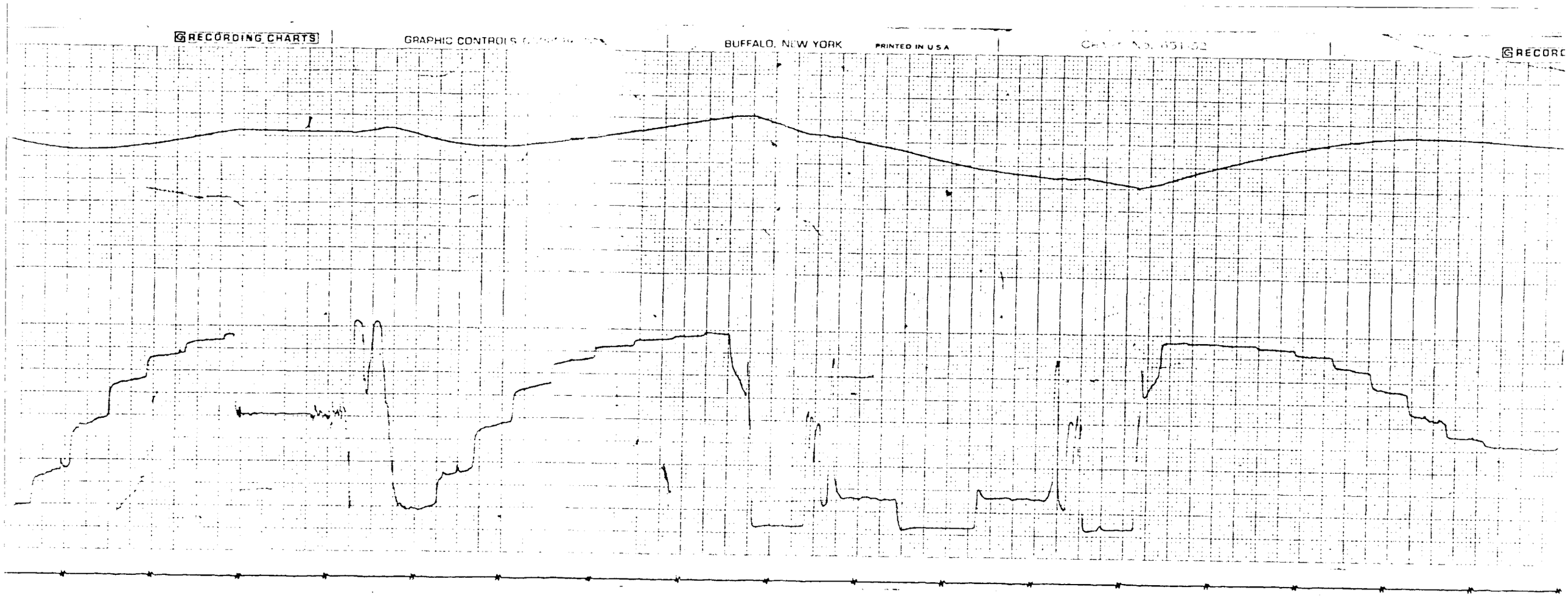
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GRAPHIC CONTROLS
BUFFALO, NEW YORK
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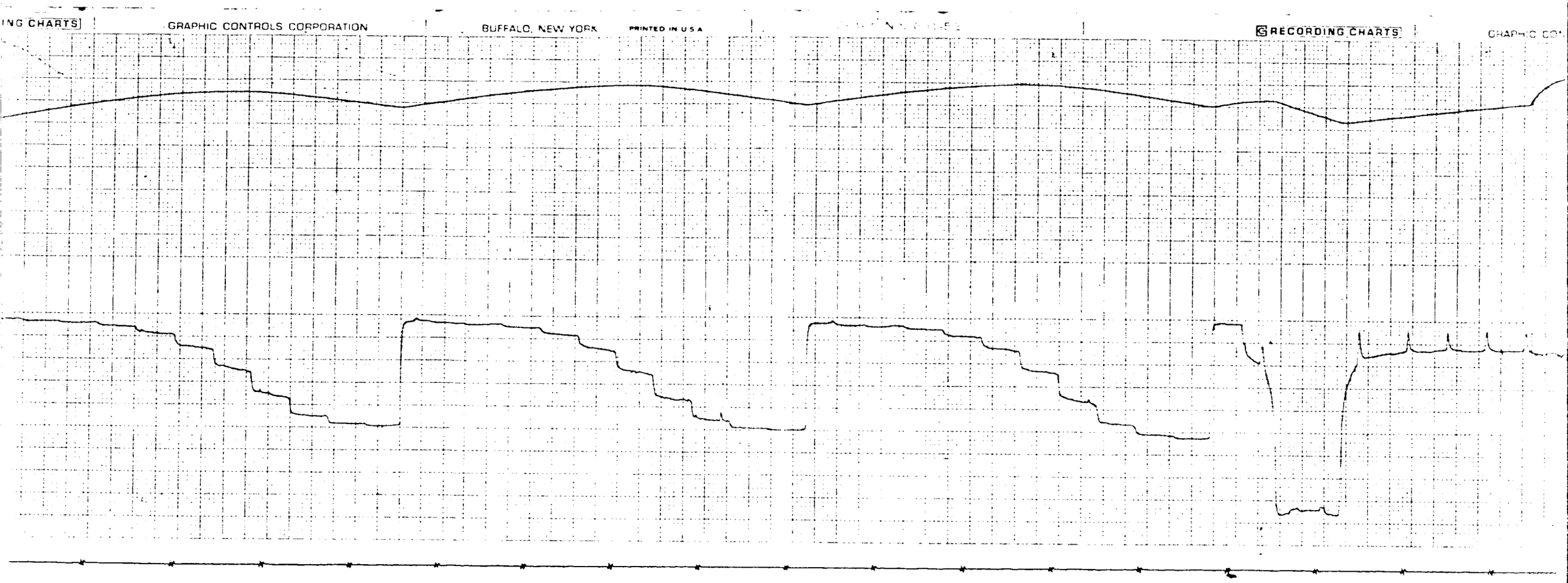
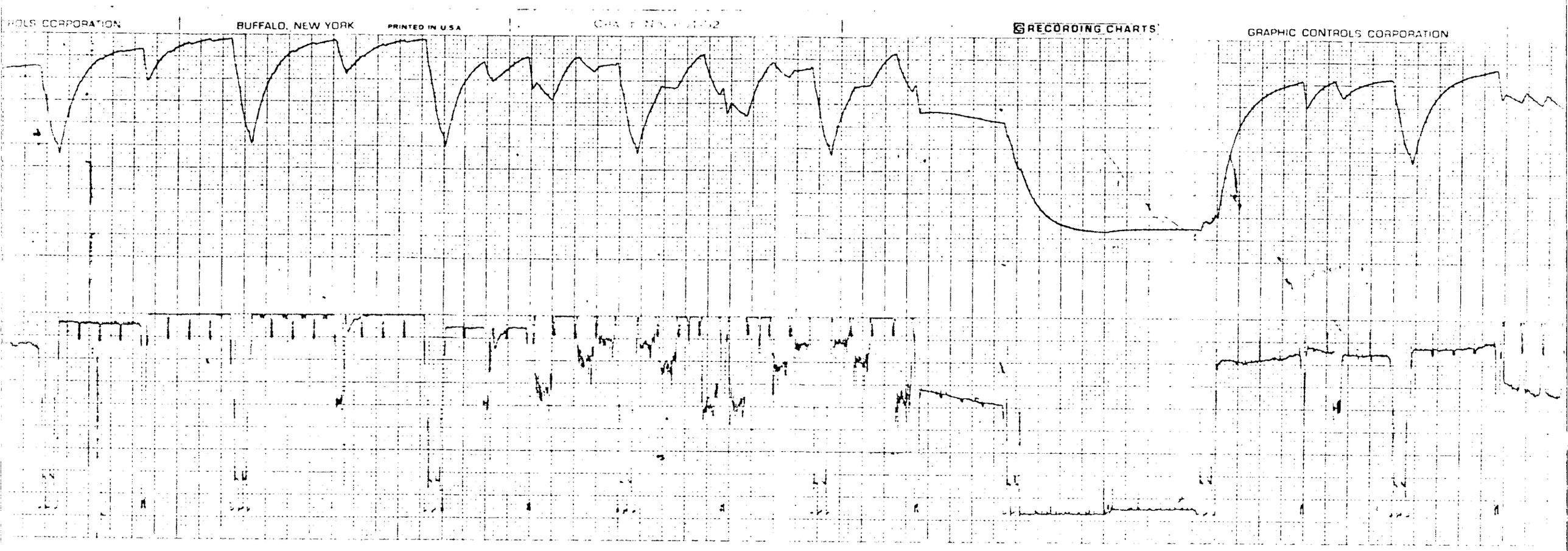

ING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.
RECORDING CHARTS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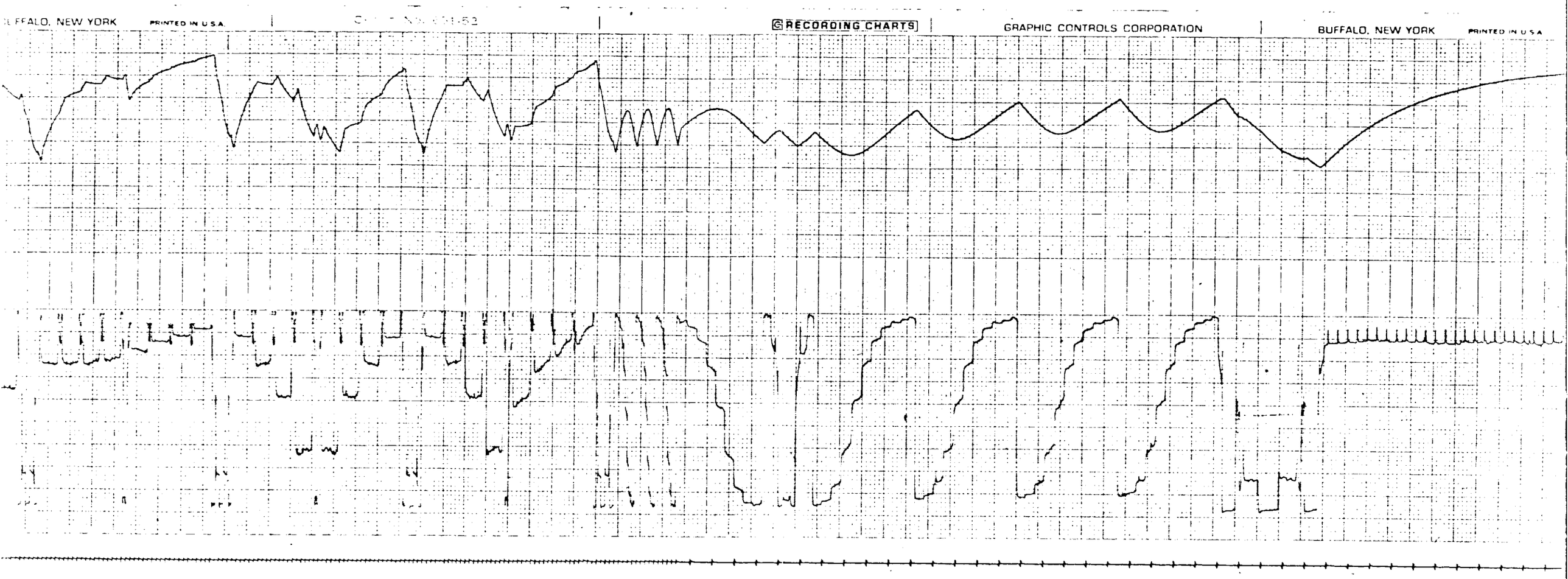
PRINTED IN U.S.A.
RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION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RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
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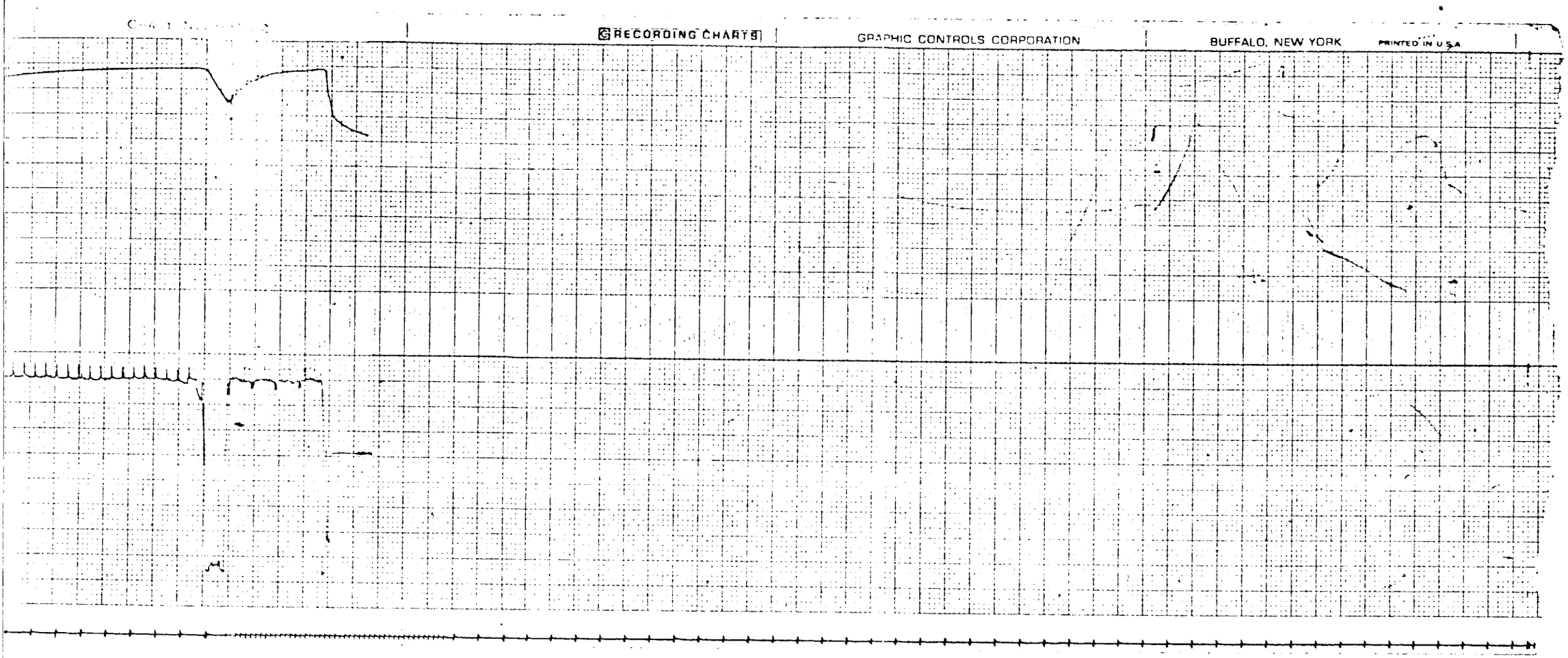
RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
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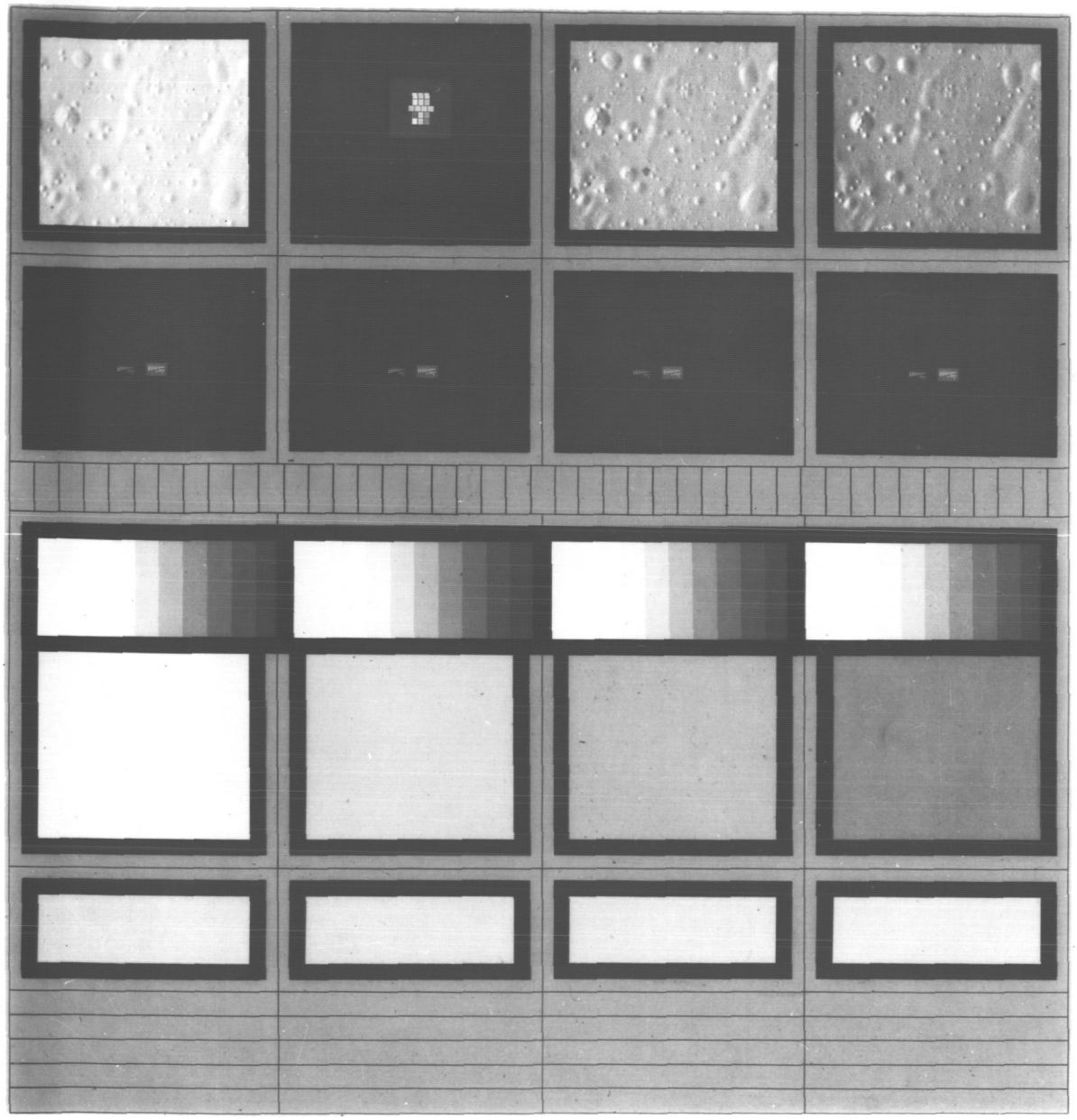
135"



GOLDSTONE TEST FILM

FIGURE 35

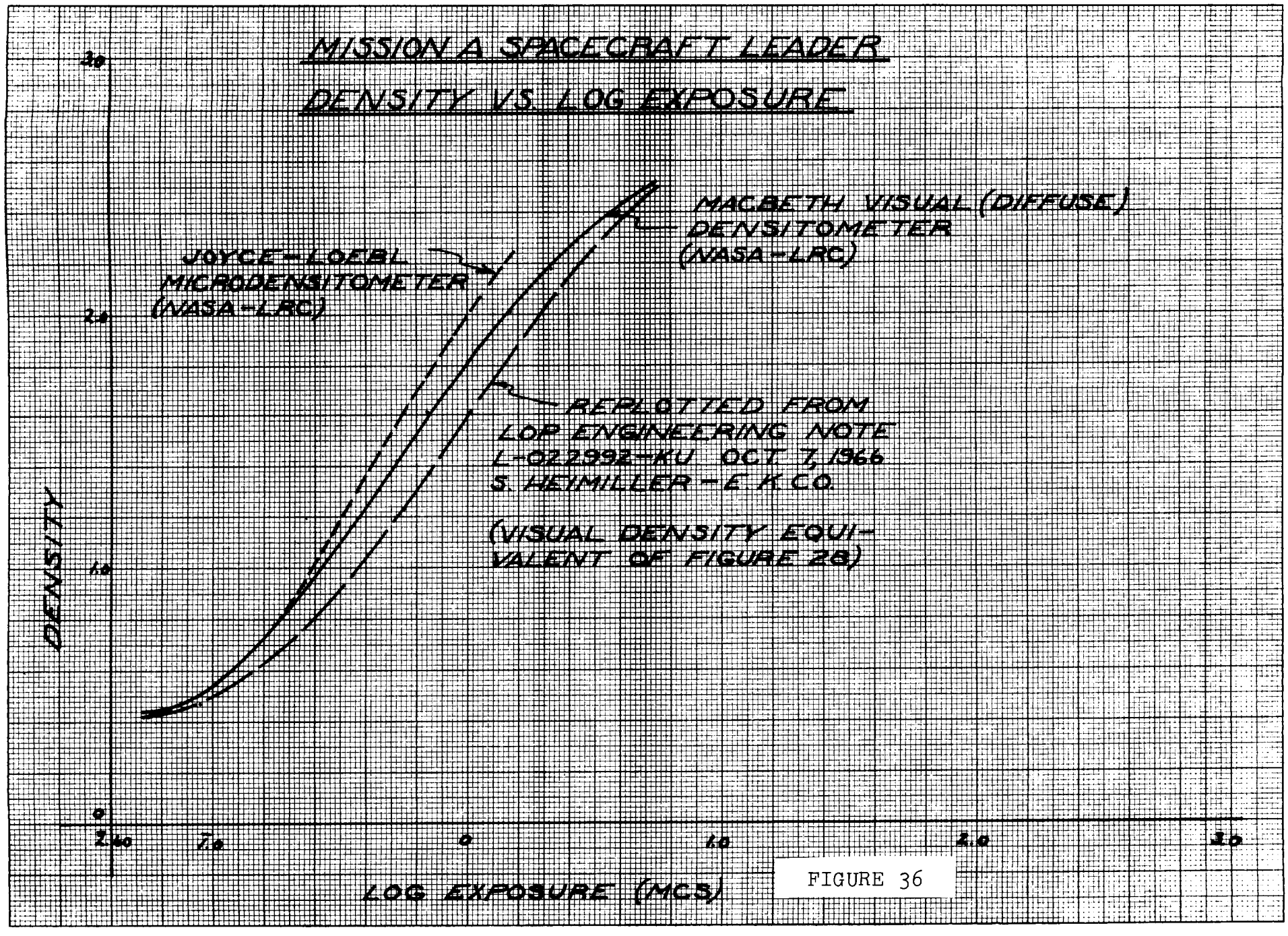

MISSION A SPACECRAFT LEADER
DENSITY VS. LOG EXPOSURE
MACBETH VISUAL (DIFFUSE) DENSITOMETER (NASA-LRC)
JOYCE-LOEBL MICRODENSITOMETER (NASA-LRC)
REPLOTTED FROM LOP ENGINEERING NOTE L-022392-KU OCT. 7, 1966 S. HEIMILLER - E K CO.
(VISUAL DENSITY EQUIVALENT OF FIGURE 28)
DENSITY
3.0
2.0
1.0
0
-2.0
-1.0
0
1.0
2.0
3.0
LOG EXPOSURE (MCS)

FIGURE 36