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QUANTUM ELECTRONICS DIVISION TECHNICAL REPORT

Magnetic Measurements of Light Weapons of U. S. and Communist Bloc Origin

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I. INTRODUCTION

The purpose of the described measurements is to provide data from which to assess the feasibility of using magnetometer sensors for surveillance purposes against arms-bearing personnel.

The tests were performed at the Varian Associates Webb Ranch Test Facility, Menlo Park, California, using a V-4938G Rubidium Gradiometer as described on the attached data sheet. The sensor, whose principle of operation is described on this data sheet, measures the total intensity of the earth's magnetic field with a sensitivity of approximately 0.003 gamma (3×10^{-8} gauss). The signal from the sensor is a frequency determined by an atomic constant which is 4.67 cps per gamma. Thus the frequency is directly proportional to the total intensity at this rate.

The sensor measures only the scalar magnitude of the total intensity and as such measures only changes in length of the total intensity vector A small disturbance vector, say 100 gammas or less, will change the length of the 50,000 gamma total field vector by an amount equal to the projection of the disturbance vector on the total field. Expressed in other terms, the rubidium sensor is a total field-determined component magnetometer.

This component property is utilized in making the dipole moment measurements in the following way. The field at the Webb Site dips 65" to the magnetic north. A horizontal line of known length is established magnetically east of the sensor. The object is then rotated at the end of this line in a vertical plane containing the total field. The object will cause a maximum perturbation on the total field at the sensor when parallel to the total field. This position of the object with respect to the point of measurement is known as Gauss' Position II. It is important to realize, however, that the sense of the dipole is seen inversely at the sensor as one can see by drawing the dipole flux lines at a point perpendicularly away from the axis of a dipole.

Under the above arrangement, if the length of the object is much less than one-tenth the distance to the point of measurement, the following is true:

$$\Delta F = \frac{-M}{r^3}$$ where ΔF = perturbation of the total field,

M = magnetic dipole moment, r = distance between the point of measurement and the object, and the negative sign expresses the orientation of the dipole as explained above. When rotating an object with a permanent dipole moment through 360", a one-cycle sinusoidal curve is observed which is twice as large as the maximum effect of the dipole if it were simply present or absent in any fixed orientation. (See Figure 1.)

The induced dipole moment is due to the "soft" components which themselves act as magnets in the presence of the earth's field. Since it is the earth's field which is the principal direction determinant, the "sense" of the induced moment should be independent of the sense of the orientation. The presence of this induced moment then offsets the field and thus the average value of the permanent moment as observed during a rotation. The long dimensions of the object are also important, however, in establishing the magnitude of this induced moment. If, for example, the dipole moment of a long object originates entirely to induction and not to permanent magnetization, then rotating the object through 360" produces two equal amplitude sine waves, their maxima occuring when the long dimensions are parallel to the field. Measurement of the rifles have produced various combinations of these permanent and induce? moments. (See Figure 1.)

Measurement of any small changes in the earth's field are limited by the time variations of the earth's field which originate in the ionosphere from solar effects. Two sensors near each other sense the same time variations and their difference is-therefxe constant. In the rubidium gradiometer, such a differential scheme is used where one sensor is near the object to be measured and the other far removed Any change in the difference is due to a change nearer to one. The frequencies from the sensors are mixed to obtain this difference which is then demodulated and recorded on a strip chart recorder.

Measurements were made on a variety of weapons manufactured in the U. S. and in certain communist countries. The weapons used by the Viet Cong and North Vietnamese troops are usually either captured or traded U. S. weapons or they represent weapons manufactured with interchangeability of parts in Communist China, Czechoslovokia or the Soviet Union. The weapon design, however, is from the Soviet Union. A few rounds of ammunition manufactured of steel cases and projectiles in Communist China were also measured to estimate the magnetic effects of a few loaded magazines or belts in which all the rounds are maintained parallel. This arrangement is usually but not always the case and the number of rounds may also vary greatly, of course.

II. NOTES ON THE PERMANENT DIPOLE MOMENT OF RIFLES AS A FERROMAGNETIC ANOMALY IN THE EARTH'S FIELD

A. One-half peak-to-peak disturbance from a particular rifle at a distance of 3 meters from sensor:

1. on a line parallel to the earth's field and joining the centers of the rifle and sensor is 16.5 gammas. (Gauss Position I) and

2. on a horizontal line magnetically east of sensor is 8.1 gammas (Gauss Position II) Gauss Positions I and II can be shown analytically that for a dipole the anomaly will indeed be in the ratio of 2:l respectively. Thus, as a function of the orientation of the rifle, the anomaly behaves as a dipole source.

B. For one rifle, one-half the peak-to-peak disturbance

3 meters east of sensor is 12 gammas,

6 meters east of sensor is 1.4 gammas,

12 meters east of sensor is 0.195 gammas,

The anomaly varies inversely with the cube of the distance and thus at the basis of fall off with distance, the anomaly behaves as a magnetic dipole (See Figure 2.).

C. The permanent moment of all rifles tested including M-14, M-16, M-l, M-l carbine, Ak-47, RPD, and DPM had their permanent moments directed towards the stock end of the weapon. Only the P-58 was directed towards the muzzle.

D. The permanent dipole moments along the long axis of the M-14 rifles varied by more than a factor of two as evidenced by the measured moments of 5 rifles:

3500, 2880, 2180, 1780, and 1500 cgs units.

The induced dipole moments, however, were all identical (within the accuracy of the measurement) and found to be 405 cgs. The permanent dipole moment in a direction normal to the long axis of the rifle was also observed for the rifle with long-axis dipole moment of 2180 cgs and found to be 242 cgs or approximately 0.1 of the former.

E. The moments of the rifles depend upon the 'hardness" of the steel, the thermal and shock history of the weapon, the ambient field when. annealed or cooled, and the relative positions of the component parts each with their own specific histories.

The effective dipole moments, however, for both permanent and induced magnetization for a variety of average iron and steel objects ranging from small articles up to automobiles or even ships can be estimated using the following valve for the dipole moment M_{i+p}

$$10^5 \text{ cgs/ton} < M_{i+p} < 10^6 \text{ cgs/ton} \quad \text{or} \quad M_{i+p} \approx 5 \times 10^5 \text{ cgs/ton}$$

It is interesting to note that the average maximum dipole moments of the rifles differed from the figure on the right by less than a factor of 2. For an order of magnitude estimate on the magnetic anomalies of other rifles perhaps, it might be sufficient merely to use the value, $5/2 \times 10^5$ cgs/ton, for the magnetic moment.

III. SUMMARY OF MAGNETIC DIPOLE MOMENTS FROM MISCELLANEOUS LIGHT WEAPONS AND AMMUNITION OF U.S. & COMMUNIST CHINESE, CZECHOSLOVAKIAN or RUSSIAN MANUFACTURE.

	Approx. weight (in kg)	Permanent Moment (in cgs)	Induced Moment (in cgs)	Maximum Moment (in cgs)	Maximum Disturb. at 10 meters (in gammas)	Maximum Disturb. at 20 meters (in gammas)
A. WEAPONS						
1. M-16 Rifle origin U. S.	3.1	288	190	47%	0.048	0.006
2. M-14 Rifle (5 weapons measured) Max.	4.3	3500	405	3905		
Min.		1500	405	1905		
Origin U. S. (Av. of 5 weapons)		2370	405	2775	0.278	0.035
3. M-l Rifle origin U. S.	4 . 5	526	566	1092	0.109	0.014
4. M-l Carbine origin U. S.		310	162	472	0.047	0.006
5. DPM automatic Rifle - origin Communist China, Czechoslovakia, or USSR	11	90	2500	2590	0.259	0.032
6. RPD Automatic Rifle - origin C.C., Cz.,USSR	7.3	990	890	1880	0.188	0.024.
7. P-58 Rifle origin C.C,Cz. USSR	4.1	-324	432	756	0.076	0.010
8. AK-47 Rifle-origin C.C.,Cz.or USSR	4.1	365	405	770	0.077	0.010

(positive moment directed towards stock)

B. AMMUNITION	Permanent Moment (in cgs)	Induced Moment (in cgs)	Maximum Moment (in cgs)	Maximum Moment 90 rds. in mag. (in cgs)	Maximum Dist. of 90 rds. at 10 m (in gammas)	Maximum Dist. of 90 rds. at 20 m (in gammas)
1. M-43						
7.62 mm rounds	wt = .0180 Kg.					
origin C. C.						
Average of 3						
rounds	0.56	0.68	1.24	112	.0ll	.00l
single round-						
possibly						
anomalous	18.2	1.0	19.2			
2. M-1930 Soviet-						
type						
7.62 mm rounds	wt = .0225 Kg.					
origin CC.	22.0	1.52	13.5	1210	.121	.015

IV. PROFILES OF RIFLES CARRIED IN THE VICINITY OF THE MAGNETOMETER SENSOR

Rifles were carried on N-S and E-W lines at various distances from the sensor. The rifles were carried at port arms, horizontally over the shoulder, and under the arm, muzzle inclined downwards to simulate how they might be carried in a battle-ready state or on a patrol mission. More than one rifle would almost always be present and represent an increase in the disturbance over that from one weapon alone. Of course, there are maximum and minimum orientations for any weapon but due to induced effects and due to the fact that one must traverse and therefore be in different positions with respect to the sensor, there will always be an anomaly from a ferromagnetic-weapon-bearing soldier. The problem, though, lies in obtaining sufficient sensitivity, reducing the time variations, and recognizing the signature of a moving weapon.

Figures 3 through 10 represent the profiles of a differential magnetometer with one sensor very far removed from the vicinity of the weapons and the other used and referred to as "the sensor". By using these profiles, the measured moments of the various rifles, and methods of total field calculations, it is possible to compute the signature of and number of weapons in various orientations, in different directions, and under- different magnetic field conditions.

V. CONCLUSIONS

The first limit one reaches in trying to detect the small anomaly from a moving rifle is the time variations or micropulsations of the earth's magnetic field. Typically they are sinusoidal and have the character of rifle signatures (See Figure 11). The micropulsations have a wide spectrum but in the range of interest exhibit peak-to-peak variations of a few tenths of a gamma at periods of 15 to 30 seconds. This phenomena is largely absent in the local nighttime hours. At random times, however, there may be pulsations of several gammas every few seconds or minutes, or tens of gammas every few minutes during times of high magnetic activity such as bays or especially magnetic storms.

The differential magnetometer effectively removes these disturbing effects as explained in the introduction It is important to realize that in order to-detect rifles at more than a few meters and remove the possibility of false alarms, a differential magnetometer, in fact, must be used. One sensor in an array can be used for a common reference for many others at hundreds or perhaps a thousand meters distant. Clearly an array of sensors can be set by at intervals determined by a conservative detection distance and overlapping coverage. The sensors can be buried arid the frequency modulated signals, radio telemetered and mixed without losing any sensitivity.

The profiles of single weapon traverses are included to demonstrate the type and appearance of these anomalies. The noise levels of the differential magnetometer are also shown as the portions of the records where no anomaly appears. The above rifle signatures must be superimposed on the noise to permit one to assess the probability of actually detecting and recognizing the signature on the differential magnetometer. Many methods can be used to aid in resolving this anomaly, for example: a bandpass filter from, say, 0.5 seconds to 0.01 seconds in the dc circuits of the display unit of the magnetometer; increased sensitivity such as the 0.001 gamma already achieved in gradiometer mode; a limit switch on a meter of the demodulated differential signal which would trip at a predetermined amplitude; etc.

Within the framework of the measurements and experimental procedure outlined in this report, it should be possible to compute the probability of detecting a specific rifle at any distance and orientation from the sensor. It is not practical, however, to include nor is it easy to interpret the meaning of the statistics that produce these probabilities. Instead, a conservative estimate has been made of the detection distance from one sensor of a differential magnetometer at which any one rifle might be detected considering rifle orientation, magnetic field parameters, and average magnetic moments. The maximum, but conservative detection distance is estimated to be approximately 9 meters; this number is perhaps the essence of this report.

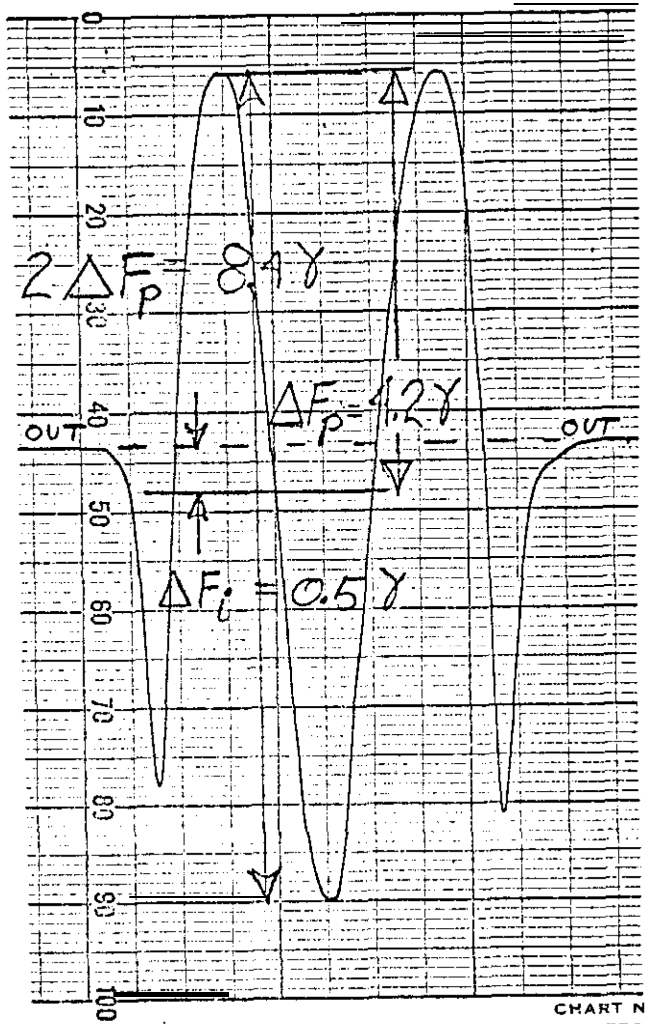
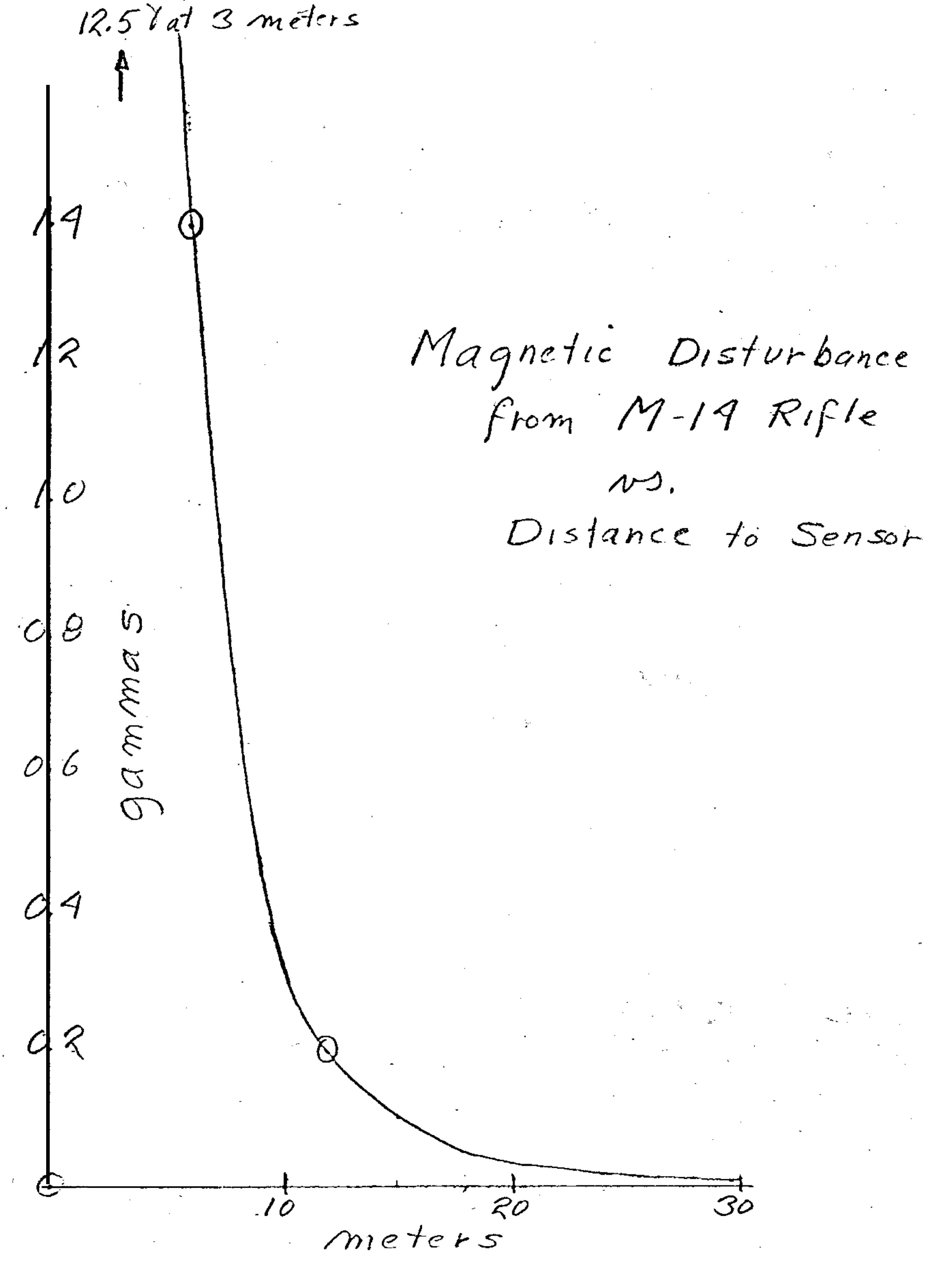


Figure 1. Rotation of rifle in a vertical N-S plane at the end of a horizontal E-W line of known length. The perturbation on the total field from the effects of the permanent moment is noted as AF $_p$ The permanent moment effects either increase or decrease the total intensity whereas the perturbation ΔF_i, from the induced moment always adds to the total intensity when the Long dimensions of the object are parallel to the field.



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VARIAN associates ENGINEERING SKETCH

Fig. 2

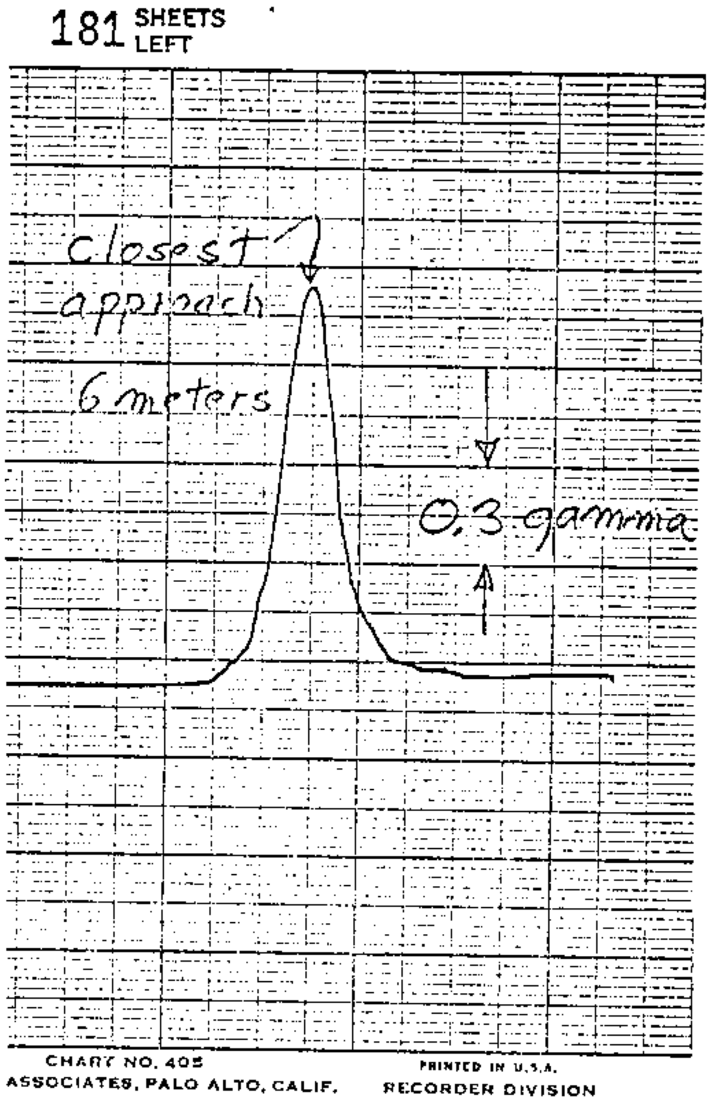

Figure 3. M-14 rifle carried (in arm, pointing down) on line 6 meters west of sensor.

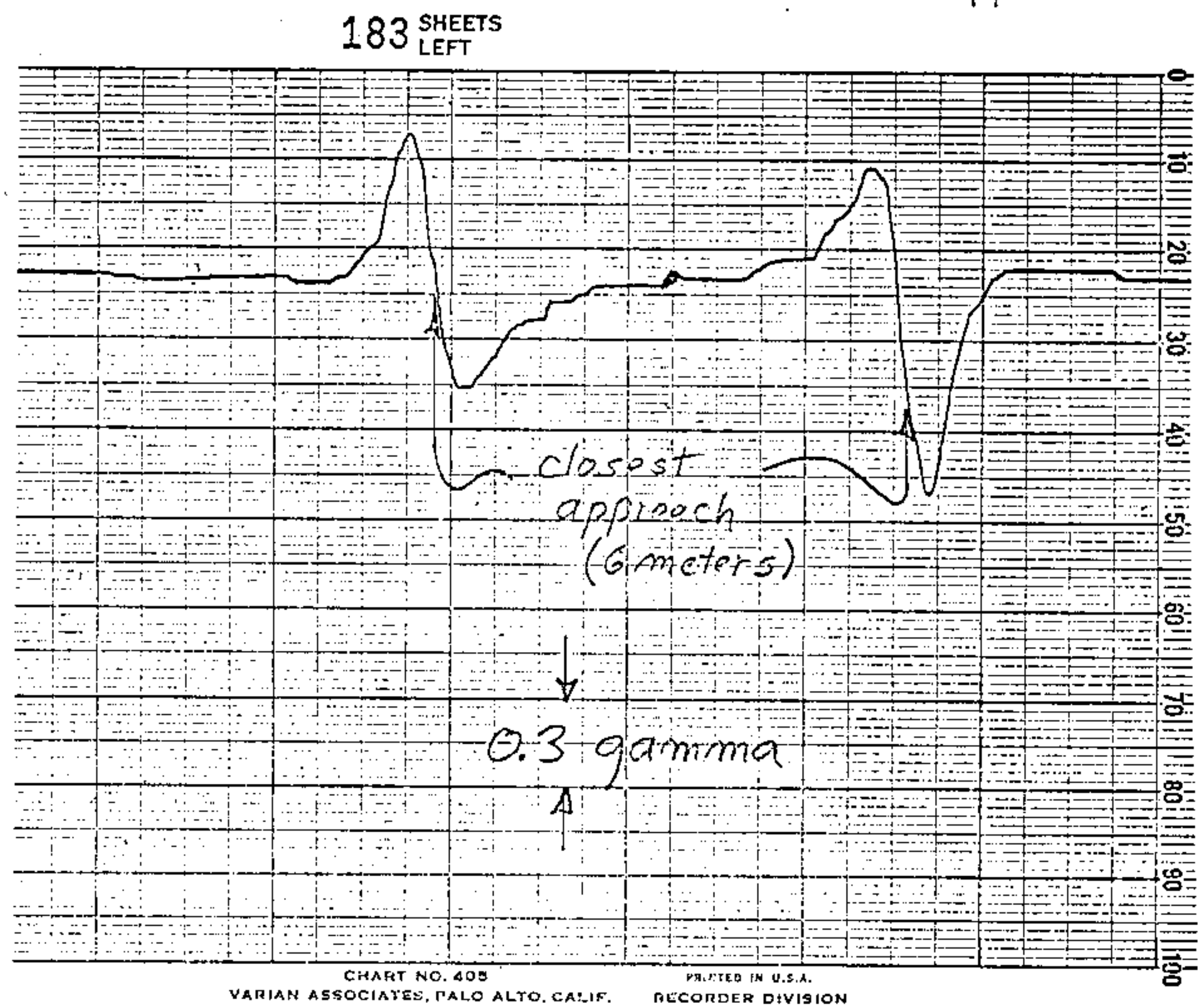

Figure 4. M-14 rifle carried (over shoulder, horizontally) on line 6 meters west of sensor.

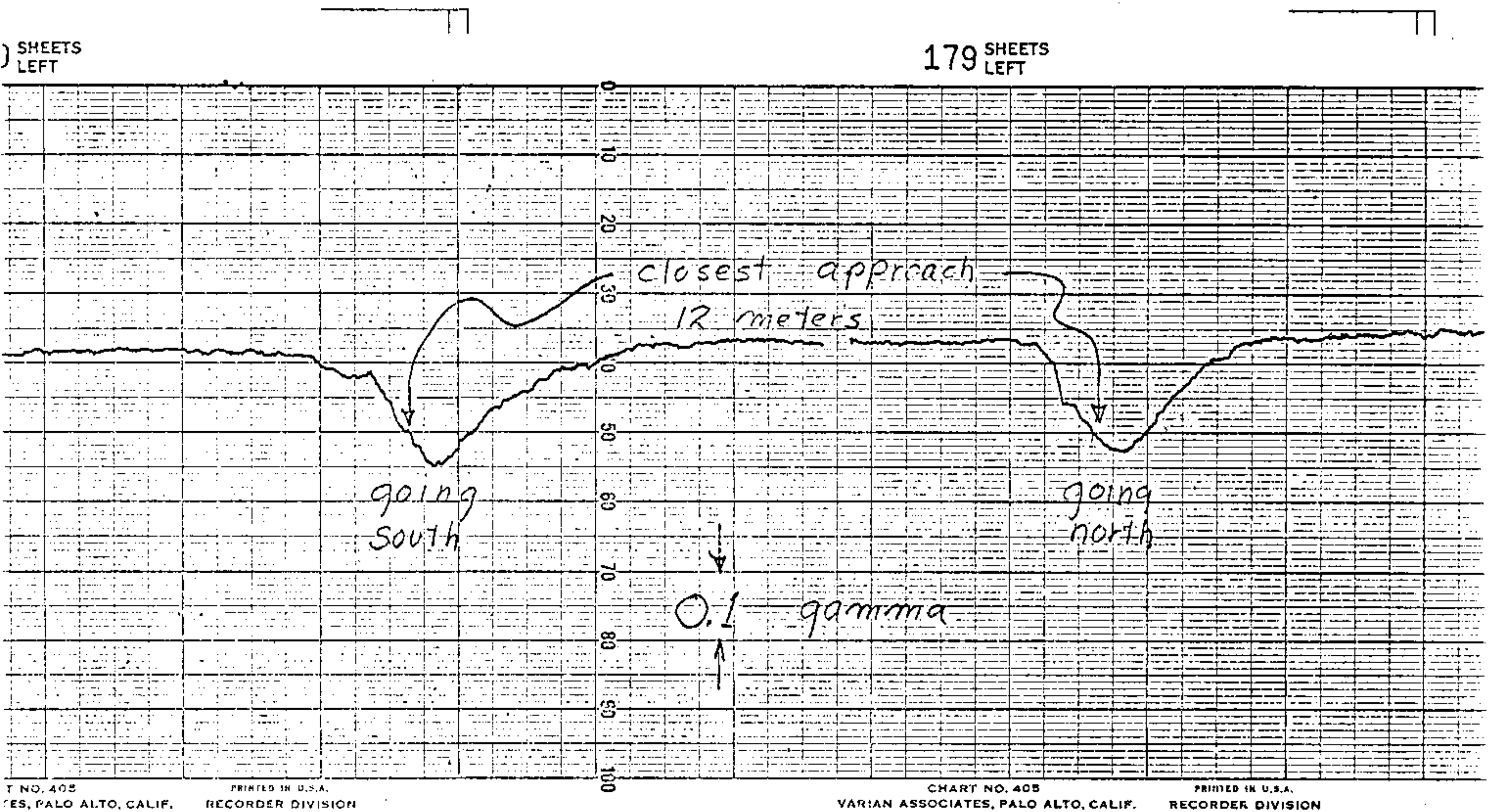

Figure 5. M-14 rifle carried (at port arms) on line 12 meters west of sensor.

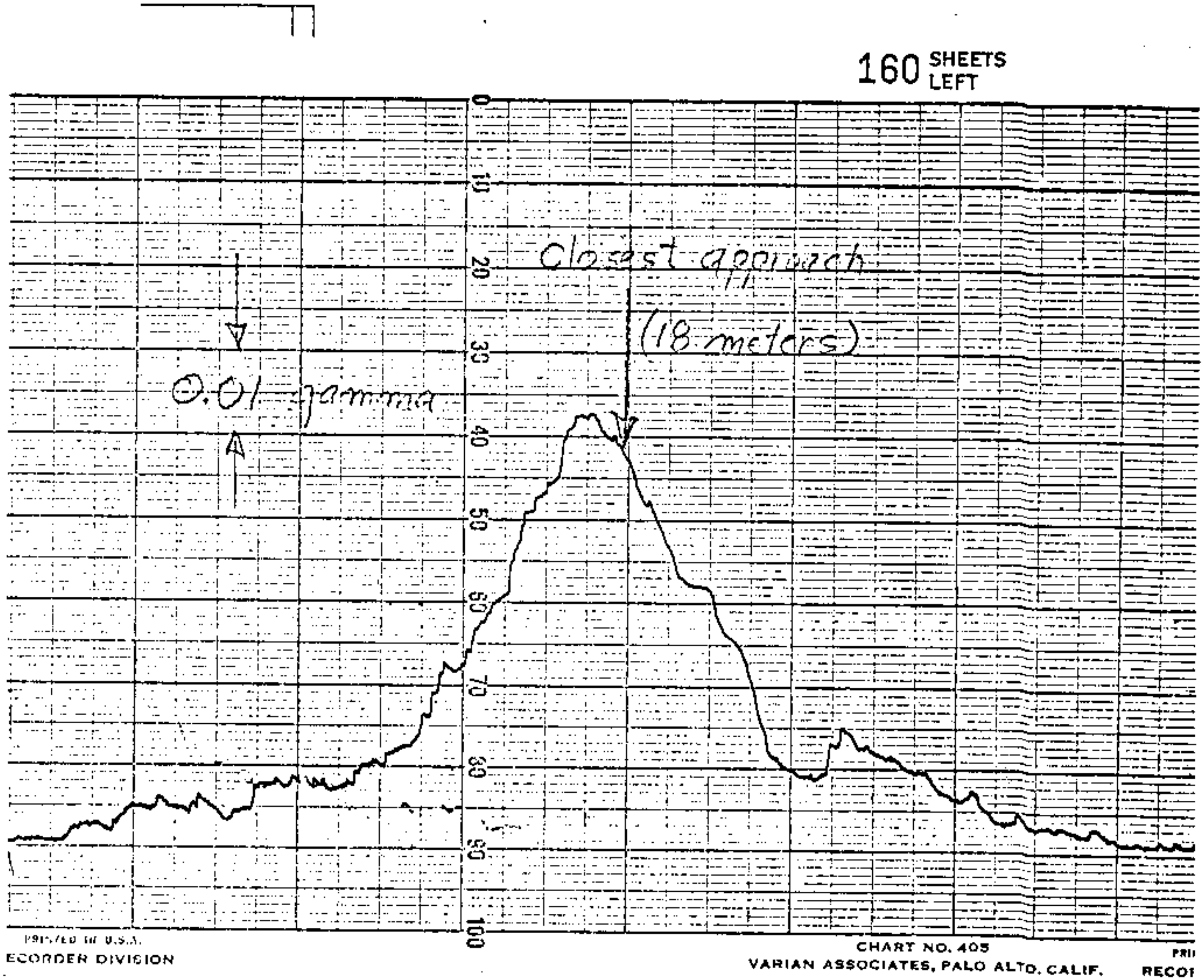

Figure 6. M-14 rifle carried at port arms (muzzle up and to north) on line 18 meters north of sensor.

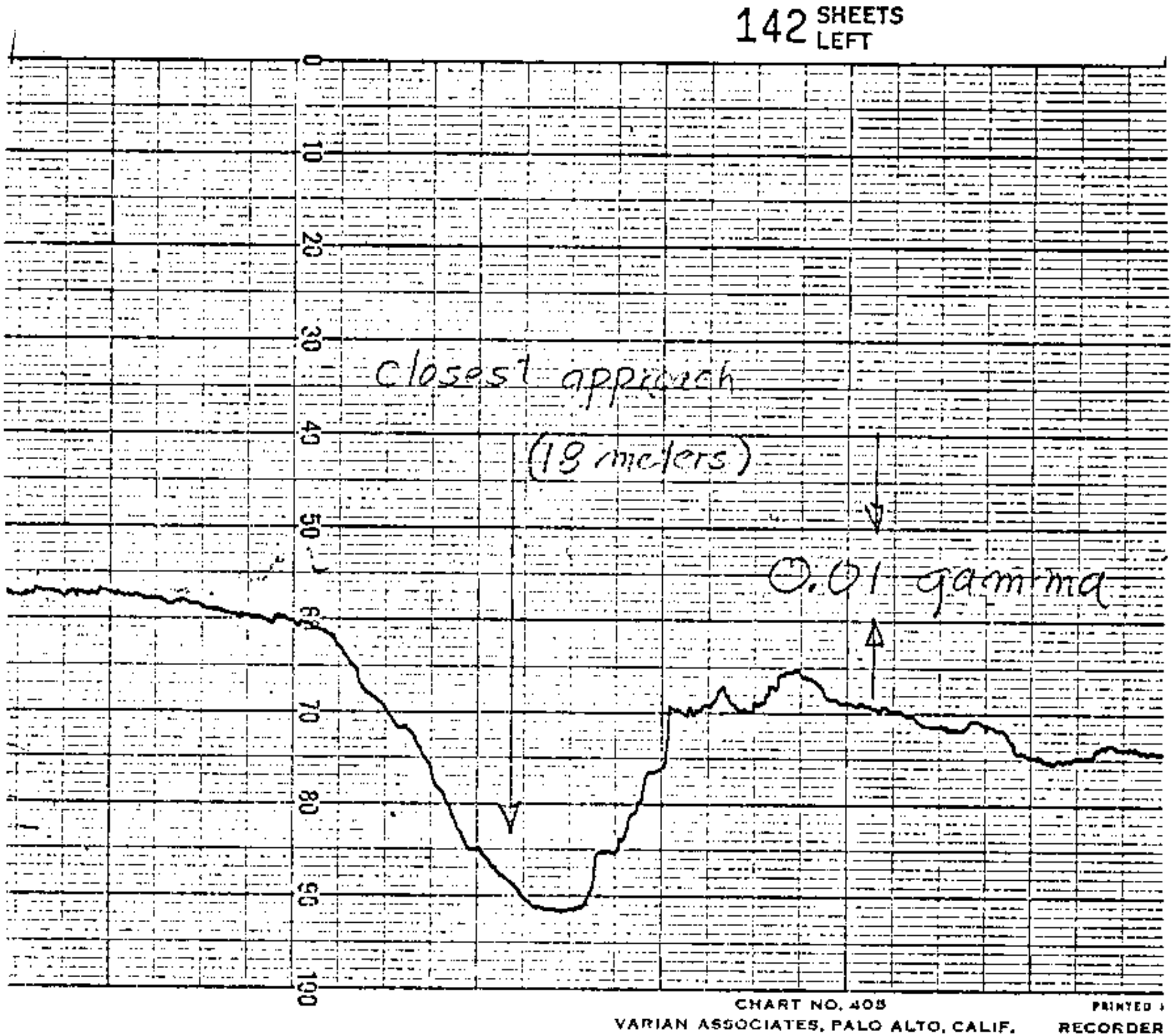

Figure 7. M-14 rifle carried in arm (muzzle inclined downwards) on line 18 meters east of sensor.

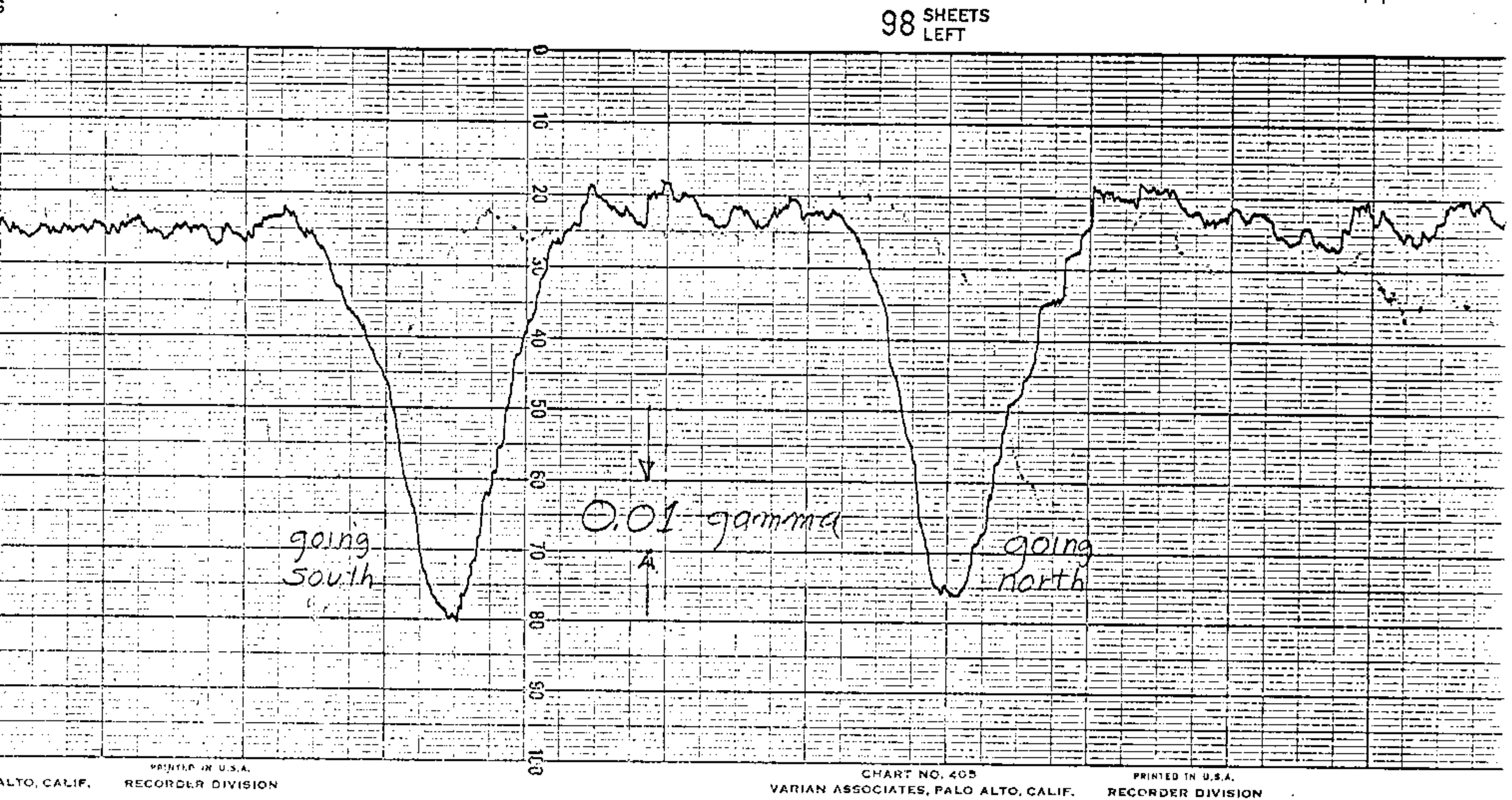

Figure 8. RPD automatic rifle (Communist Chinese or Czeckoslovakian manufacture) carried (at port arms) on line 14 meters east of sensor.

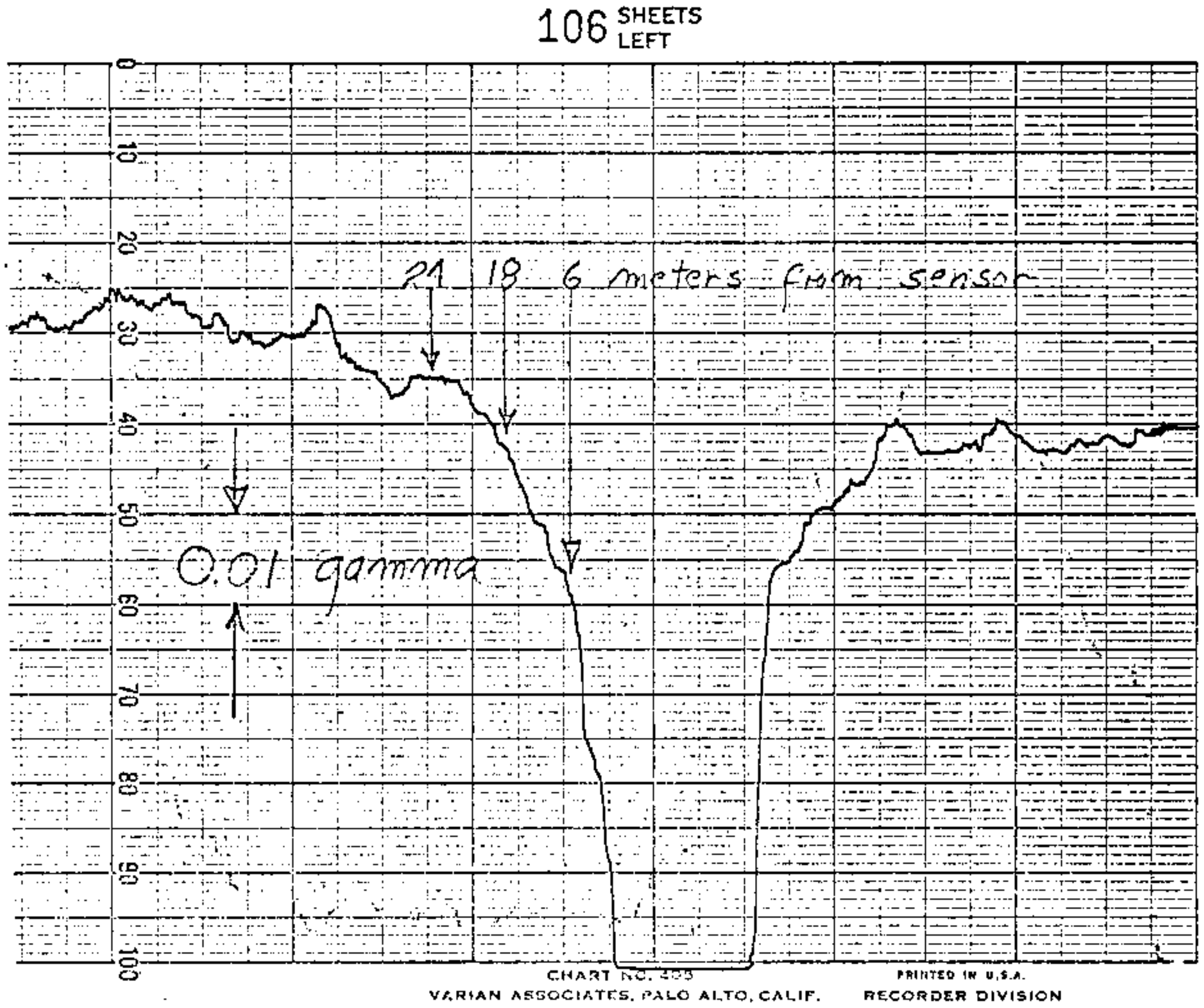

Figure 9. DPM automatic rifle carried towards sensor going west.

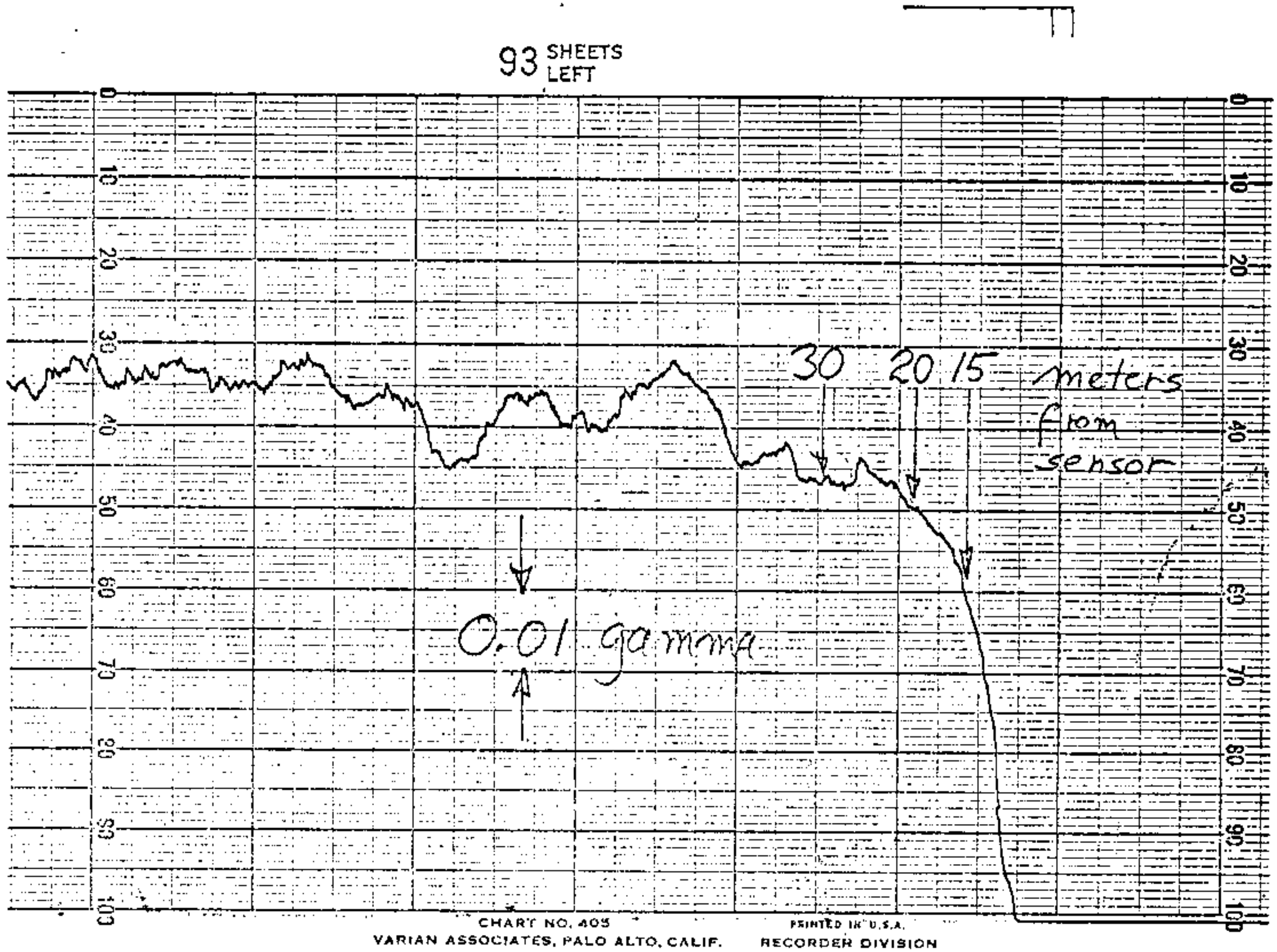

Figure 10. Three men carrying P-58, AK-47, and RPD (at port arms) walking single file towards sensor from west.

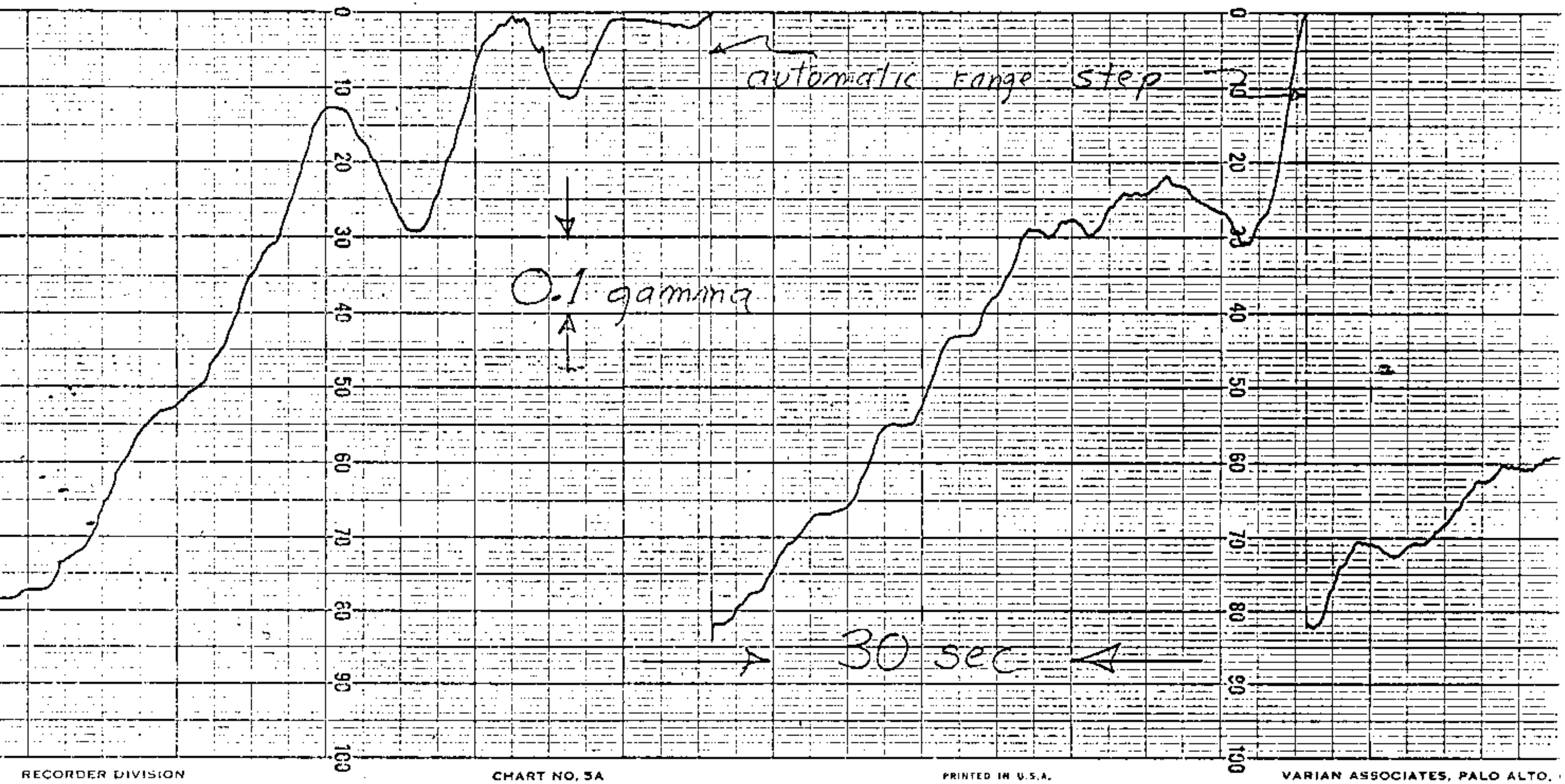

Figure 11. Record of typical daytime behavior of the total intensity at a single sensor, fixed in position. The time variations both long and short period are micropulsations originating primarily in the ionosphere.