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JULY 16th NUCLEAR EXPLOSION: TOTAL RADIATION

WORK DONE BY:

Dudley Williams

Philip Yuster

REPORT WRITTEN BY:

Dudley Williams

Philip Yuster

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ABSTRACT

Thermopile measurements give a value of 1.22×10^7 ergs/cm^2 as the value for the radiant energy per unit area at the 10,000-yard Stations. It is believed that this value is accurate to $\pm$ 15 percent. Integration without correction for ground reflection or for attenuation gives 3060 metric tons of TNT equivalent as the value for the total radiant energy emitted.

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JULY 16th NUCLEAR EXPLOSION: TOTAL RADIATION

APPARATUS

The detectors used in the measurement of total radiation from the test shot were radiation thermopiles constructed by Pettit of the Mount Wilson Observatory. The thermal elements were Taylor-process wires of bismuth and bismuth-tin alloy. The radiation receivers were copper strips 3.5-mm x 0.48-mm x 0.002-mm and were coated with platinum black. Each thermopile was mounted in a massive brass housing equipped with a crystalline-quartz window of 1-mm thickness.

In order to be prepared for the measurement of a considerable range of radiant energies it was decided to use four galvanometers of different sensitivities with each thermopile. The galvanometers were connected in parallel[1] and, as used, provided for the measurement of total radiation from 0.001 sun-second to 15 sun-seconds[2]. The actual measurements were made on the least sensitive galvanometer.

Two complete setups were employed. One was located at North 10,000 yards; the other at West 10,000 yards.

CALIBRATION

In calibrating the measuring equipment a standard lamp supplied by Mount Wilson was used as a primary standard. Projection bulbs of 500-watt and 1000-watt ratings after comparison with the primary standard were used as secondary standards. As a result of the small size of the received the inverse-square law was applicable even with the multi-filament projection bulbs. A typical inverse-square-law plot is shown in Figure I.

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1) Interaction between the galvanometers did not seriously interfere with the measurements. This fact was established during the preliminary calibration.
2) Note: 1 Sun = 1.94 cal/cm^2-min. (i.e. Mean Solar Constant outside the earth's atmosphere)

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Two methods were used in measuring the radiation: (1) observation of the ballistic throw of the galvanometer, and (2) determination of the integral of galvanometer deflection with respect to time as determined from the photographic record obtained with a moving-picture camera. The chief seeming disadvantage of the ballistic method lay in the relatively short period of the galvanometers. A disadvantage of the second method was in the possibility of variations from the desired number of photographic exposures made per second.

In determining the ballistic response of the galvanometer a calibrated camera shutter was used. The shutter was placed in front of the thermopile window so that the receiver could be exposed to radiation from the standard lamps for known time intervals. Figures 2 and 3 show plots of galvanometer deflection as a function of total energy per unit area. Exposure times are indicated on the graph. The results shown in Figures 2 and 3 indicate that the circuit "integrate" fairly well for exposure times as long as 2 and 3 seconds.

The determination of total energy from the time-integral of deflection as obtained from the photographic record depends upon the following analysis. In the analysis the following symbols are used:

x = Galvanometer deflection

T = Period of Galvanometer

τ = Cooling constant for thermopile

θ = Temperature rise of thermopile

b = Damping constant of galvanometer

k = Proportionality constant depending upon characteristics of thermopile and galvanometers.

$f(t)$ = A function proportional to the incident radiation per unit area per unit time.

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The differential equation describing the galvanometer deflection can be written as follows:

$$\ddot{x} = -\frac{4\pi^2}{T^2}\,x - b\dot{x} + k\theta \quad \text{-------------- (1)}$$

and the temperature θ of the thermopile can be expressed in terms of $f(t)$ by the following equation:

$$\dot{\theta} = -\theta/\tau + f(t) \quad \text{---------------- (2)}$$

Eliminating θ between equations (1) and (2) and integrating with respect to time, one obtains:

$$\int_0^\infty f(t)\,dt = \frac{4\pi^2}{T^2\tau k}\int_0^\infty x\,dt \quad \text{------------- (3)}$$

From equations (1) and (2) it can be seen that

$$\frac{4\pi^2}{T^2\tau k} = f_o/x_o \quad \text{-------------------- (4)}$$

where x_o is the static deflection produced by steady radiation f_o.

RESULTS

The galvanometer deflections as determined from the photographic record are shown in Figures 4 and 5. The cameras used in obtaining the records were both set for 16 frames per second.

The results are given in Table I. The results for energy per unit area obtained at the two stations by the ballistic method are in excellent agreement. The values obtained from the time integral differ from the mean value by approximately 20 per cent. A large part of this difference is probably due to the fact that the camera speed was not actually 16 frames per second. Consideration of the errors involved in the measurements and in the calibration of the instruments indicates that the average values shown in the table are probably good to ± 15 percent.

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The values given in Table I for the total radiant energy from the shot are obtained by integrating the measured energy per unit solid angle over 4π. The values listed have not been corrected for reflection from the ground or for attenuation during transmission. Two experiments were performed in order to determine the magnitude of the contribution of ground reflections to the measured radiation. One of these experiments performed by the writers was carried out on a concrete floor on a scale of approximately 1:700 ; the results indicated that ground reflections were responsible for not more than 4 percent of the measured radiation. A second mock-up experiment on a scale of 1:150 was performed near the West 10,000 yard station by members of J. E. Mack's group and gave approximately 1.7 percent as the correction due to ground reflection. Since the atmospheric conditions existing immediately after the shot could not be reproduced, no attempts were made to determine losses during transmission. Reproduction of the spectral distribution of radiation from the shot would also make such a determination extremely difficult.

The writers wish to express their appreciation to J. E. Mack for assistance in obtaining photographic records and in determining corrections attributable to ground reflection and to E. Fermi for suggestions concerning analysis of the data.

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TABLE I

TOTAL RADIATION MEASUREMENTS

Station	Energy Per Unit Area at 10,000 Yards		Total Radiant Energy from Shot**
West 10,000 yards	ERGS/cm2	Sun-Seconds*	TNT Equivalent in Metric Tons***
Ballistic Analysis	120×10^5	8.6	3000
Integral Analysis	148	10.5	3700
North 10,000 yards			
Ballistic Analysis	122	8.7	3050
Integral Analysis	100	7.2	2500
Average	122×10^5	8.75	3060

* 1 Sun is 1.94 cal/cm2-min.

** The values given have not been corrected for ground reflection or for losses during transmission.

*** The heat of detonation of 1 Metric ton of TNT is 4.2×10^{16} ergs.

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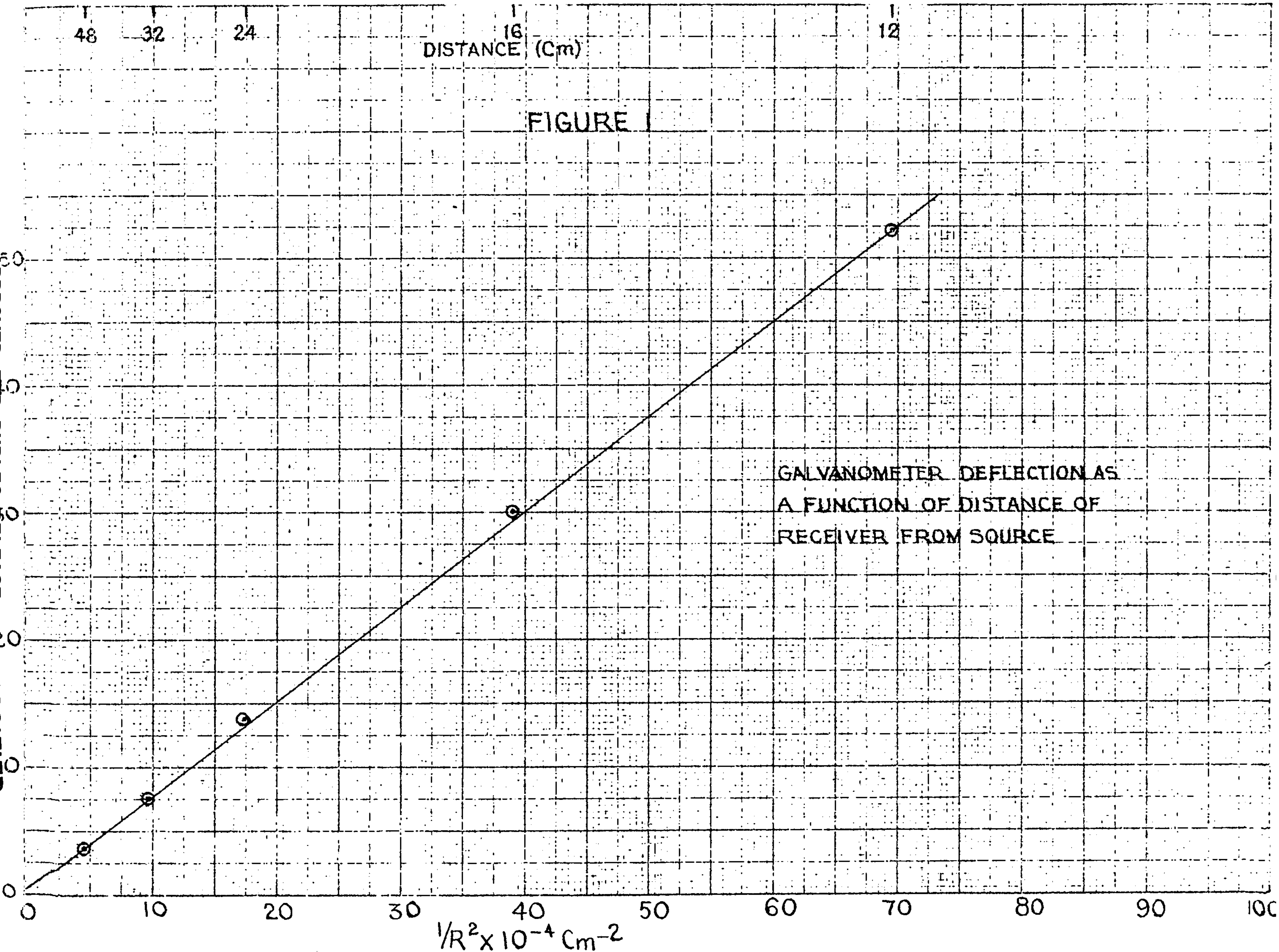
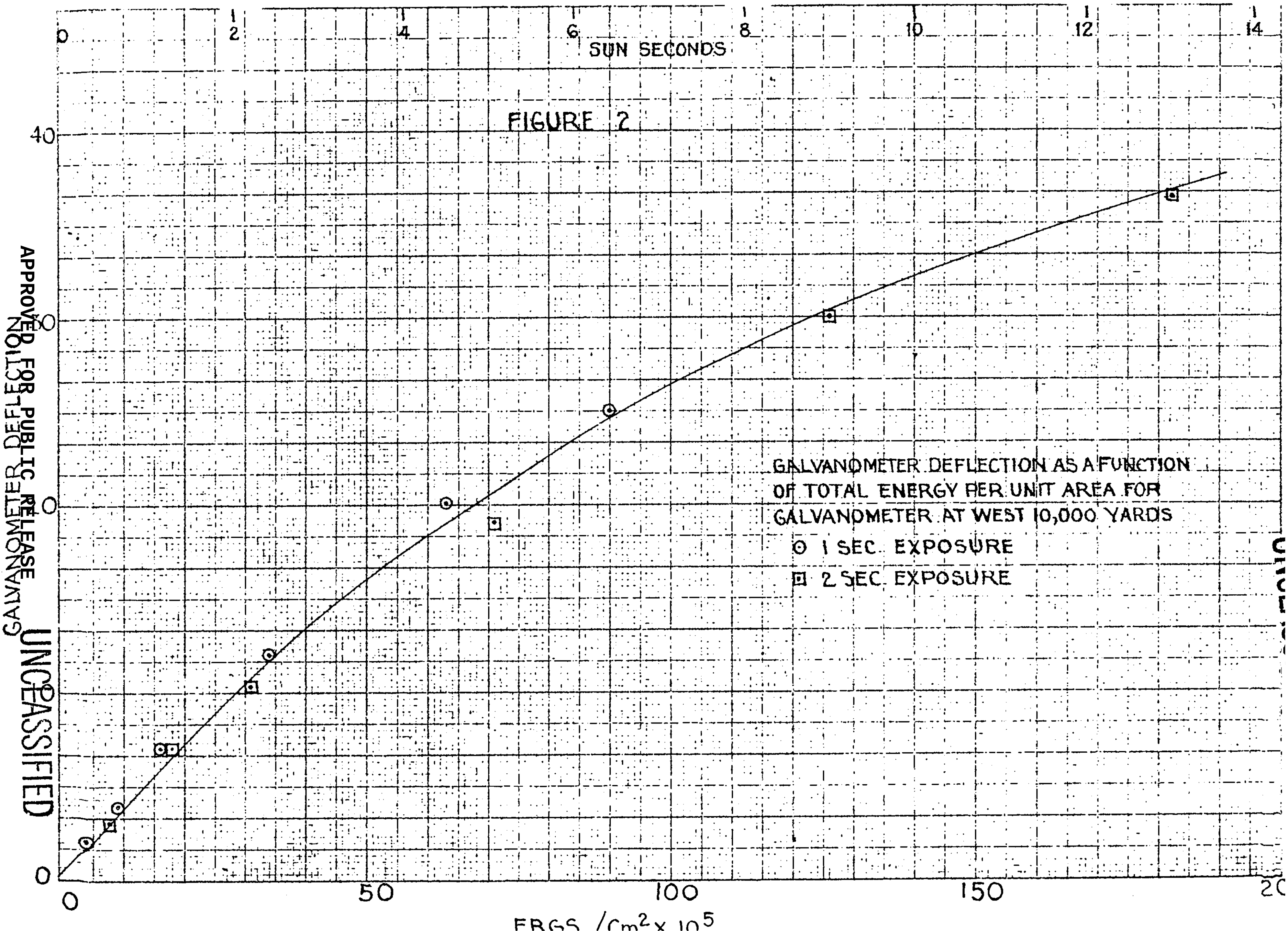
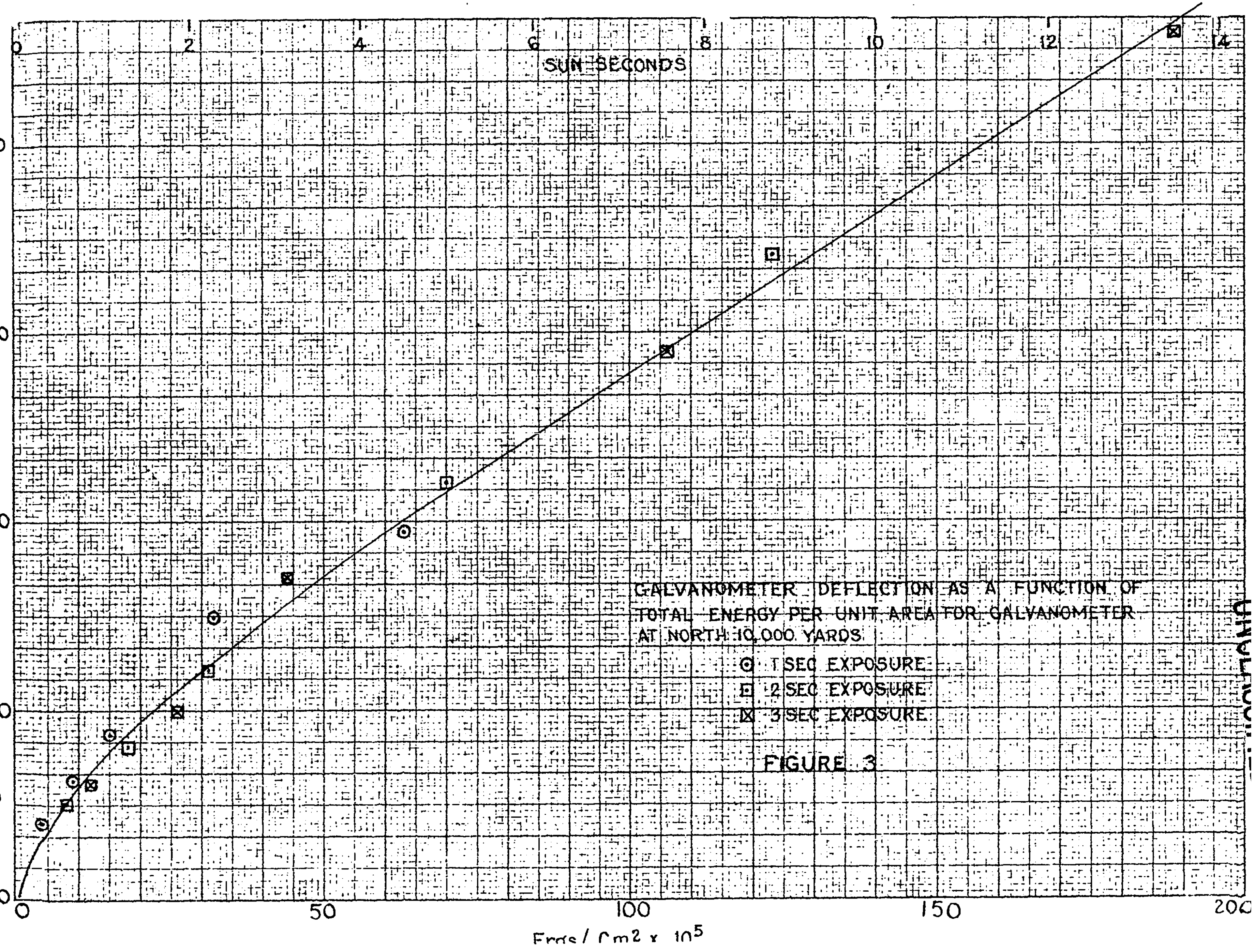


48
32
24
16
12
DISTANCE (Cm)
GALVANOMETER DEFLECTION AS A FUNCTION OF DISTANCE OF RECEIVER FROM SOURCE
0
10
20
30
40
50
60
70
80
90
100
1/R² x 10⁻⁴ Cm⁻²

FIGURE I


SUN SECONDS
FIGURE 2
GALVANOMETER DEFLECTION AS A FUNCTION OF TOTAL ENERGY PER UNIT AREA FOR GALVANOMETER AT WEST 10,000 YARDS
1 SEC. EXPOSURE
2 SEC. EXPOSURE
GALVANOMETER DEFLECTION
ERGS /Cm^2 x 10^5



GALVANOMETER DEFLECTION AS A FUNCTION OF TOTAL ENERGY PER UNIT AREA FOR GALVANOMETER AT NORTH 10,000 YARDS

FIGURE 3

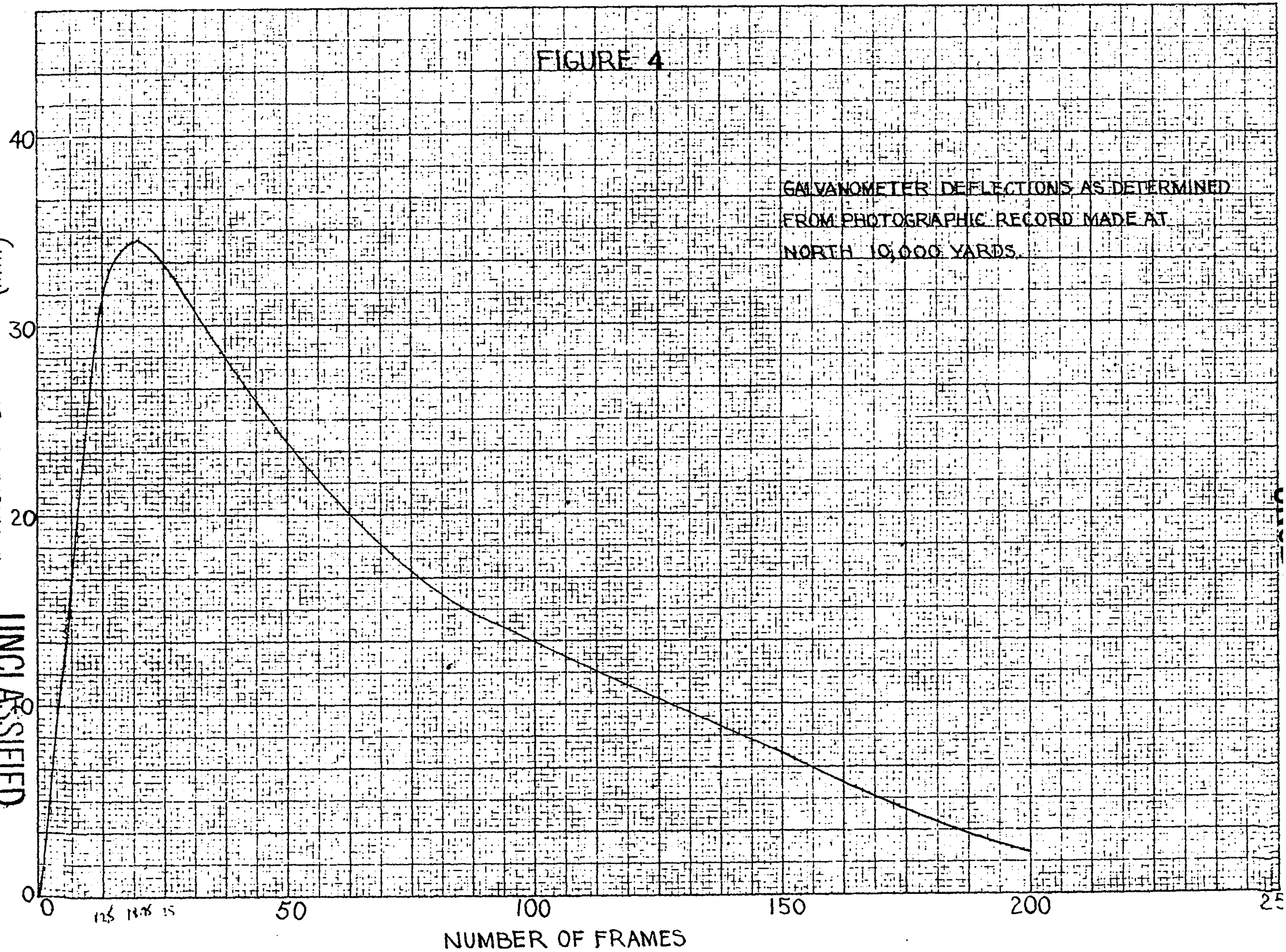
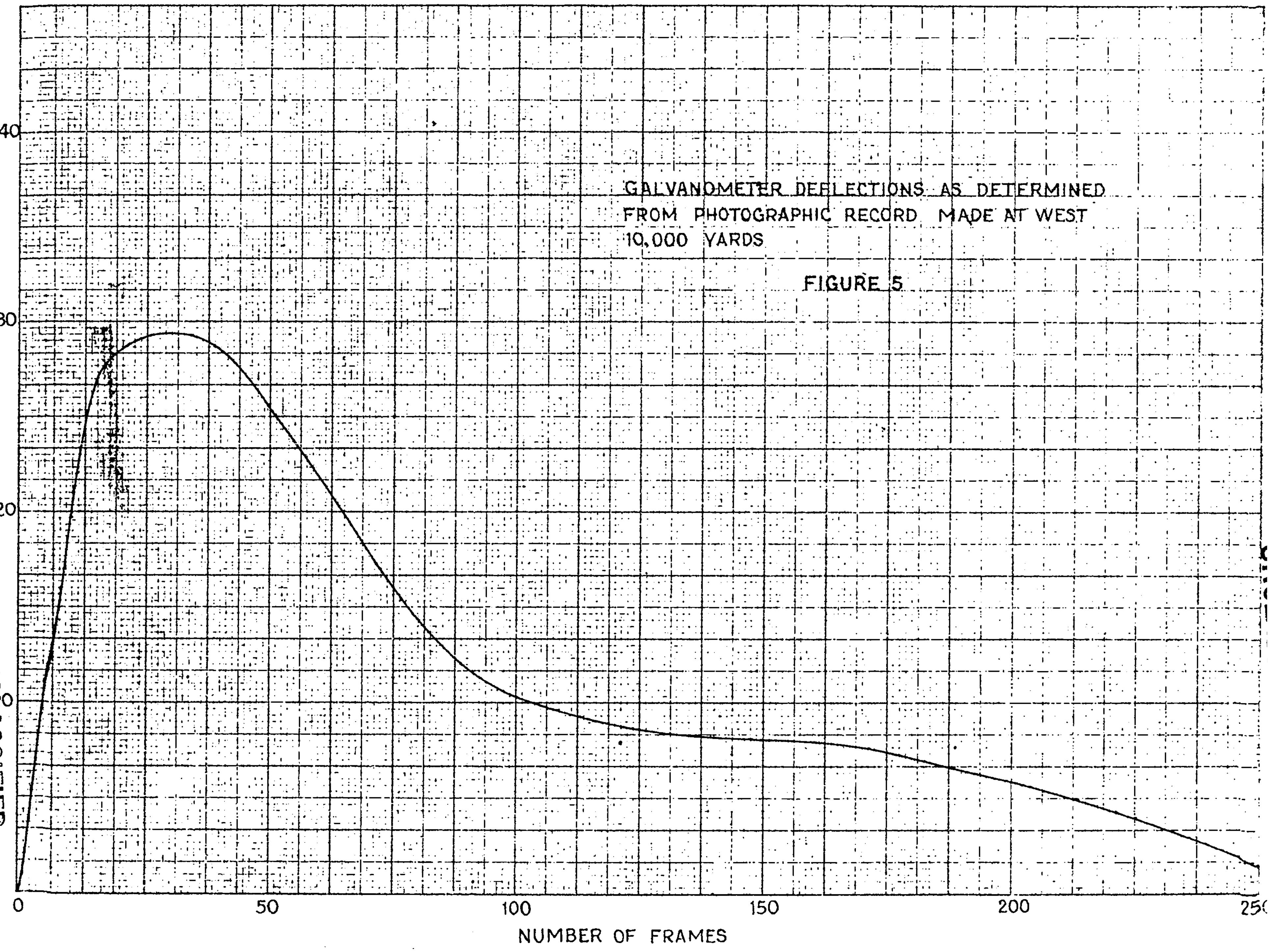


FIGURE 4
GALVANOMETER DEFLECTIONS AS DETERMINED
FROM PHOTOGRAPHIC RECORD MADE AT
NORTH 10,000 YARDS.
40
30
20
0
0
50
100
150
200
NUMBER OF FRAMES


GALVANOMETER DEFLECTIONS AS DETERMINED
FROM PHOTOGRAPHIC RECORD MADE AT WEST
10,000 YARDS
FIGURE 5
GALVANOMETER DEFLECTION (mm)
NUMBER OF FRAMES
0
50
100
150
200
250
10
20
30
40

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