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SUBJECT

TESTS AT COVE POINT OF THE GENERAL MOTORS RADIANT HEAT DETECTOR IN TRACKING LANDING CRAFT

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NAVY DEPARTMENT

Report on

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ABSTRACT

Measurements of the flux of radiation from LCT and LCI landing craft as a function of range were made with the General Motors Radiant Heat Detector in clear weather to ranges of 4000 and 4500 yards on an LCT and 5800 yards on an LCI. The instrument detected and automatically tracked LCT targets at ranges of about 5000 yards, and the LCI at ranges in excess of 8000 yards. Temperature measurements on the surfaces of the ships and on the sky-sea background permitted computation of total net emission by the targets. Tracking ranges computed from these results, neglecting atmospheric absorption, led to a value of 5200 yards expected range on LCT comparable with an observed range of 5100 yards where tracking was strong. Radiation measurements led to a calculated tracking range of 6600 yards in agreement with an observed threshold tracking range of 6800 yards. Similarly, for LCI, temperature measurements indicated a tracking range of 7400 yards in fair agreement with the observed range of 11000 yards, while radiation measurements indicated tracking ranges of 8300 to 9800 yards. It was concluded that easily obtained temperature measurements might be used for computing ranges for a given instrument in clear weather, but that radiation measurements on targets at greater distances would provide a better basis for the prediction of instrument performance. The temperature measurements are more easily made and the results obtained from them agree with conservative positive ranges in clear weather.

The radiation from the moon at zenith distance 60 degrees, 0.93 full, was measured with the Heat Detector to be 9.45 ergs/cm^{2}sec leading to atmospheric transmission 0.36 for air mass 2 in agreement with the integrated value 0.33 for 400° K radiation through an atmosphere containing 6 mm of precipitable water.

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CHAPTER 1

INTRODUCTION AND SUMMARY OF RESULTS

This report discusses results obtained with the original General Motors Radiant Heat Detector in the quantitative measurement of radiation intensities from Diesel powered landing craft and in the detection and automatic tracking of these vessels from a shore station on Cove Point, Maryland, on the nights of 6 and 7 January, 1944 in clear calm weather. Measurements were made on Landing Craft, Tanks (LCT) about 112 feet long, Landing Craft, Infantry (LCI), about 157 feet long, and on a 12 foot dinghy with three men rowing. Surface temperature measurements were made on LCT and LCI and on the horizon background against which the ships were seen. The results constitute both a target survey of these ships and a new test of the General Motors Heat Detector as a detector of them at ranges of several thousand yards.

Summary of Results

Detailed radiation measurements are given in Tables 2, 3 and 4 together with logs of tracking operations. These are the main results:

(a) The instrument was capable of detecting a target and tracking it automatically at ranges in excess of those permitting quantitative measurement of the radiation from the target; and tracking ranges calculated from radiation measurements are in general agreement with actual tracking ranges. For example, from the data of Table 3, the total net hemispherical emission of an LCT, stern view, was calculated to be 1800 watts leading to a calculated detection range of 10,000 yards in agreement with that seemingly achieved by the instrument. The radiation measurements in this case extended over the range 2480 to 5800 yards.

The same ship, bow view, was detected at 6800 yards and automatic tracking was considered to be very strong at 5100 yards while radiation measurements, bow view, over the range 4000 to 2100 yards led to a calculated total net emission of 785 watts from which calculated tracking range was 6600 yards. Temperature measurements on bow and horizon were also employed to compute the total emission, 485 watts and corresponding tracking range of 5200 yards, neglecting atmospheric absorption. The temperature difference between bow and horizon was about 2.5° C. It was concluded that under the favorable weather conditions of that night a range of 5000 yards on any aspect of the LCT might be considered certain.

(b) Measurements of radiation from the LCI as a function of range did not show a regular dependence on distance due, presumably, to the more complex thermal pattern of this larger ship. Radiation measurements were made from 2300 yards to 4500 yards (Table 4) and the ship was tracked automatically to 11000 yards. Selected radiation measurements indicated a total emission of 1250 to 1700 watts leading to calculated tracking ranges of 8300 to 9800 yards in fair agreement with actual instrument performance. From temperature

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measurements which showed that the sides or bow of the ship were about 4° C warmer than the horizon, the total emission was calculated to be 1000 watts and the corresponding tracking range, 7400 yards. Again, the temperature measurements obviously did not include warm spots which were effective, but the calculated ranges were in general agreement with those actually obtained. It appears that a safe range can be predicted for a clear atmosphere from easily obtained temperature measurements of the ship's surface and of the horizon.

(c) The Heat Detector displayed itself as a reliable detector of unsuspected vessels which from time to time crossed the line of sight nearer than the target so that they were selected and automatically followed by the Detector.

(d) The dinghy with three men rowing was tracked to 1490 yards.

(e) The radiation from the moon, 0.93 full, was measured at zenith distance 60 degrees to be 9.45 ergs/cm^2sec net against the sky at -10° C. Assuming the moon's temperature to be 400° K, the radiation from the moon was calculated as a 400° K target in a 263° K background. The ratio of observed to calculated flux resulted in a transmission factor of 0.38 by the atmosphere. An integrated transmission coefficient employing data of Adel and Lampland on the telluric spectrum for 6 mm of water was 0.33.

Conclusions

It was concluded that the original model of the General Motors Radiant Heat Detector was quite effective against LCT targets at 5000 yards and against LCI at 8000 yards under conditions of clear weather and a temperature difference of 3 to 5 degrees centigrade between target and background.

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CHAPTER II

THE GENERAL MOTORS RADIANT HEAT DETECTOR

Optical System

The apparatus which was used in the survey of targets and in the detection and automatic tracking of them was the original demonstration model delivered to NRL by General Motors in January, 1942. It has been unmodified except that an April, 1942 model of the GM breaker amplifier was used. The Detector has been described in references (1), (2) and (3). Details of the optical system are pertinent.

The searchlight quality front silvered mirror is 12 inches in diameter, 6 inches in focal length. It is mounted in a balsa wood housing closed at the front by Pliofilm 0.0012 inches thick.

The dimensions of the bismuth-silver thermopile are shown on Plate 1. Approximately, each receiving area of the compensated pair of thermopiles is 1.6 mm wide and 6.4 mm high. The field of each thermopile is about 0.6 degree horizontally and 2.5 degrees vertically. The two thermopiles are separated in the focal plane by 2.9 mm corresponding to 1.1 degrees, edge to edge, or 1.7 degrees, center to center.

The balsa wood mirror housing is packed in a luggage type carrying case which also contains the telescope drive motor and serves as a pedestal for the telescope when in use.

Calibration

The instrument has been calibrated in two ways. By one method, a hot source of such dimensions and at such a distance that its image was a little smaller than the thermocouple area was focused in turn on each thermocouple, and the emfs in the thermocouple were measured with a galvanometer for a known flux of energy. The result was that 0.65 ergs/cm^2sec at the telescope mirror produced an internal emf of 1 microvolt. The General Motors amplifier is normally used at such a gain that 0.01 microvolt produces a 100 microampere meter deflection sufficient to operate the control relays in the tracking system. It then follows without great accuracy that the apparatus automatically tracks a target when the net flux of energy from the target is 0.0065 ergs/cm^2sec.

The second quite recent calibration was determined by a method due to H. L. Clark, BuShips (4), which permits a calibration to be made with the thermopile connected to the amplifier at full sensitivity. A brass cylinder 3 inches in diameter and 3 inches high, painted to assure a surface of constant emissivity nearly equal to one, heated by an internal nichrome heater was placed before a canvas background 25 feet high and 50 feet wide 200 feet from the telescope. The intensity was reduced to a measurable value with a sectored disc with sym-

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metrical open sectors in opposite quadrants which was placed over the front of the telescope. The flux of energy from the source was measured in the laboratory for several operating voltages, and, hence, the flux at the range of 200 feet was known. The transmission factor of the sectored disc could be determined by two methods, viz, by measuring the angular opening A of the disc from which the transmission factor was A/360 or, preferably, by making measurements of thermocouple voltage first with the amplifier at reduced gain and with the sectored disc removed and then with the amplifier at full gain and the sector in place. The General Motors Amplifier has an arrangement for applying signals of known voltage with which signals from the source can be compared; hence, this method of determining thermocouple emf is not dependent upon linearity of the amplifier.

With the sectored disc in place and with the amplifier at full gain the response of the instrument was measured as it swept across the source at 60 degrees per minute. Signals were recorded with a 5 MA Esterline-Angus recording milliammeter, and by means of the standardizing voltages and the transmission factor of the sectored disc the thermal emfs developed by several known values of effective flux were measured. This calibration led to the result that an emf of 1 microvolt is produced by a flux of 0.7 ergs/cm^{2}sec $\pm$ 20 percent. This value has been used in calculations following later in the report. Details of the calibration are given in Table 1.

Use of the sectored disc allowed the source at 200 feet to be quite hot and reduced background discontinuities to unmeasurable values. But it is of interest that background discontinuities did exist at the midsection where two individual canvases overlapped. The signals recorded by the General Motors Detector at reduced gain and at full gain as it scanned the background with the source removed are shown in Plate 2. This discontinuity, of course, was not measurable when the sectored disc was over the telescope.

Errors in the calibration probably arose from the use of a small source subtending 4.5 minutes of arc at the receiver while the thermocouples are quite large, as has been noted, so that only a minute area of a thermocouple was illuminated by the source, and the sections of the thermocouples on which the image fell in several experiments may have differed in response to radiation. A small source was used in order to meet the requirements of other receivers included in the tests and described in reference (4). But it is difficult to choose an appropriate source for calibration because real targets may present any condition from that of a hot stack which at useful ranges subtends a very small angle at the receiver to that of the silhouette of the length of a ship which may or may not completely cover the width or heigth of the thermal element. The calibration is therefore adequate for field measurement. which are of necessity subject to many variations of target and atmosphere beyond the control of the observer.

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CHAPTER III

TARGET MEASUREMENTS

Method of Measurement

The General Motors Heat Detector was set up on a platform about 10 or 15 feet above sea level at Cove Point. The view eastward across the Bay presented a land background about 5 miles away. The targets followed a southeast course relatively free of land background, beginning their runs at close range.

As a target moved away the radiation from it was measured by allowing the telescope to sweep over it at 60 degrees/minute and recording the double signal produced as first one and then the other thermopile received the image. A 5 milliampere Esterline-Angus recording meter was used. Typical records are shown in Plates 3 to 5. Plate 3, LCT at close range, shows that the principal effect was due to the edges of the ship against the sky with secondary signals from the superstructure, marked "bridge". Plates 4 and 5, LCI at greater ranges, show again that the silhouette of the ship was effectively the target. Under any condition of measurement the system was calibrated by applying standardizing voltages of 0.1, 1, or 10 microvolts, depending on sensitivity, so that the voltage represented by any double signal could be determined with fair independence of amplifier linearity of response. One-half the double signal was taken to be the voltage in a single thermopile and this was multiplied by the factor 0.70 ergs/cm^{2}sec per microvolt to obtain the net effective flux from the target.

Throughout these measurements an observer looked through a peep sight attached to the infra-red telescope and called out the instant of passage over the target, which carried running lights. A second observer then could identify the signal positively, particularly near the end of the range of measurement, and no time was lost in searching for the target. This procedure is allowable in a program of measurement where every aid to the interpretation of results should be utilized.

When signals became too weak for measurement on the recording meter, automatic tracking was begun with a meter-relay sensitivity requiring 100 microampere signals for operation. The method of finding the target was more rigorous; the telescope swept the area in which the target was known to be while the operator watched the output meter for the characteristic reversal of deflection due to the double signal. Upon finding it, he switched the instrument to automatic tracking and if it were tracking he then confirmed by eye that the telescope was on the correct target. That being established, the instrument was left alone except for occasional notice to insure that a second nearer target had not crossed the line of sight carrying the Detector with it. This occurred several times, and the performance of the instrument as a detector of unsuspected targets was satisfactory.

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When the characteristic flashing of the red and green signal lights which indicate right or left tracking became erratic or changed from flashing red to flashing green indicating a change in target direction, a visual inspection was made to learn whether the instrument was on target or whether there was interference. It happened in some runs that the ships got in line with projecting piling at the end of a small nearby pier and tracking would be interrupted until they were in clear view again. If the line of sight was free of other targets and if upon relocating the target by watching the meter the tracking was erratic or uncertain the end of the range had been reached. Longer limiting ranges can be obtained with this instrument by the method of letting the telescope sweep the target area while the operator watches only the meter and switches to automatic tracking at the time when the target is on one of the thermopiles. The tracking motor will then generally make one correction of bearing, but no more. Repetition of this process of searching each time for the target may extend the range considerably. Such limiting ranges would be of great uncertainty. Those which were recorded in these experiments were as nearly as they could be determined the distances at which the instrument would track the targets without aid from the operator.

<u>Measurements on LCT's.</u>

Landing Craft, Tanks (LCT) were observed on the nights of 6 January and shortly after midnight on 8 January. The results of the radiation measurements and the ranges to which the ships were tracked automatically together with observed radiation temperatures of background and targets are given in Tables 2 and 3.

The temperature measurements were made with a small radiation telescope made up of a 45 mm diameter 30 mm focal length mirror and a single junction 2.5 ohm, copper-cupron thermocouple. The field of view was 4 degrees. The instrument was used in connection with a General Motors amplifier and a 0 -10 milliammeter of about 40 ohms resistance. The amplifier sensitivity was adjusted so that 10 μV input produced 10 MA output current. In use, the instrument was balanced against a surface at air temperature and indicated temperature differences were added to air temperature to obtain true temperature.

The temperatures were determined while the LCT's were beached permitting 4 degree diameter sections of the sides and the bridge to be measured from a distance of about 100 feet. It will be noted in Tables 2 and 3 that sky temperatures above the horizon were considerably lower than at the horizon. At long ranges the 2.5 degree vertical field of view of the Detector unquestionably received background radiation at about horizon temperature.

On 6 January, Table 2, little tracking was done because the ship got nearly in line with the pier, which interfered. When the LCT was near the pier measurements still could be made by sweeping the telescope over the target from the seaward side so that signals from the ship could be clearly distinguished from those due to the pier.

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The final column of each table represents the flux from a point source which would produce the observed thermocouple voltage. The first four data of Table 2 are of little value; the range of 11000 yards at Mark 2 seems certainly to be wrong, and at Mark 3 both the range finders and the instrument operators were observing the wrong ship. From Mark 9, 4800 yards to Mark 16, 550 yards the LCT was returning to beach and presented approximately a bow view, and these data are fairly consistent.

Measurements on the second LCT observed under nearly the same conditions on the following night are given in Table 3. Measurements were made as the ship moved away to 5800 yards, but the target was out of tracking range at 7200 yards. After Mark 5 at 7200 yards the ship changed course and moved southward, passing in line with the obstructing pier. Tracking was positive at Mark 7, 10000 yards, but it is preferred to describe the "certain" range on the receding target in this case as the last range at which measurements were made, namely, 5800 yards. The meter deflection for a single thermocouple at this range was 450/2 = 225 microamperes which would have operated the tracking relays positively.

On the reciprocal course, bow view, the target was detected at 6800 yards, but the signals were not strong enough for automatic tracking without frequent search by the operator. Automatic tracking was positive at 5100 yards. Signals were not strong enough for reliable recording until the target was at 4000 yards.

Analysis of Target Measurements

The relations between geometry of target and optical system have been described by Estey[5]. For a system employing two compensating thermopiles, as in the present instrument, the net energy per second arising from the target image on one thermopile is

$$P_{net} = \frac{d^2}{4R^2}(J_t - J_o)WH \quad ,$$

$$\frac{Wf}{R} \leq a; \quad \frac{Hf}{R} \underset{<}{=} b \qquad (1)$$

where
d = mirror diameter
R = range
J_t = σT^4 for the target
J_o = σT^4 for the background
σ = 5.7×10^{-5} ergs cm^{-2} sec^{-1} deg^{-4}
W = width of target
H = height of target
f = effective focal length of the mirror
a = width of thermopile
b = height of thermopile

[redacted]

When the target is nearby so that its width completely fills the width of a thermopile but its height does not fill the height of the thermopile,

$$\frac{Wf}{R} \geq a, \frac{Hf}{R} \leq b,$$

$$P_{net} = \frac{d^2 aH}{4Rf} (J_t - J_o) \quad . \qquad (2)$$

Target Sizes

Approximate dimensions of the LCT follow:

Over all length	112 feet
Beam	32
Heights:	
Waterline to gunwale	5.5
Waterline to deckhouse	8
Total Height	15

The target was a point source, i.e., completely imaged on the thermopile, when

$$R = \frac{Wf}{a} = 9 \times 10^4 \text{ cm} = 1000 \text{ yards.}$$

The length of the ship would be completely imaged on the width of a thermopile at distances greater than R = 3300 yards. No measurements were made when it was clearly known that the ship was seen broadside at distances greater than about 1000 yards. The data of greatest value were those determined with the targets on a steady course away from or toward the observation point when nearly constant aspect was presented. The ranges at which these data were obtained have been converted to cm^{-2} and plotted against observed flux in Plate 6. From Table 3, stern view, solid points represent data at Marks 1 to 4. Open circles are for the bow view, Marks 14 to 18. Crosses are from Table 2, Marks 9 to 12. Straight lines have been drawn through these sets of points; the measurements were not sufficiently accurate to disclose atmospheric absorption.

The data of Blate 6 may be used to evaluate the total emission by the ships. Dividing Eq. (1) by the mirror area $\pi d^2/4$,

$$F_{net} = \frac{(J_t - J_o)WH}{\pi R^2} \qquad (3)$$

The slopes of the straight lines of Plate 4 are

$$m = \frac{(J_t - J_o) \; WH}{\pi}$$

$$\text{Let } WH = 32 \times 15 \text{ square feet}$$
$$= 4.3 \times 10^5 \text{ cm}^2$$

[redacted]

For the stern view

$$m = 5.8 \times 10^9 \text{ ergs/sec}$$

$$(J_t - J_o)\, WH = \pi m = 1.8 \times 10^{10} \text{ ergs/sec}$$

$$= 1800 \text{ watts} \quad .$$

For the bow view, Table 3 data,

$$m = 2.5 \times 10^9 \text{ ergs/sec}$$

$$(J_t - J_o)\, WH = 785 \text{ watts}$$

These results may be compared with the computation of total emission employing the temperatures recorded in Table 3 for the bow.

$$(J_t - J_o)\, WH = (272^4 - 269.5^4)\; 4.3 \times 10^5$$

$$= 4.85 \times 10^9 \text{ ergs/sec}$$

$$= 485 \text{ watts}$$

The results for the bow of the ship differ by a factor 785/485 = 1.6. It is probable that warm areas of the ship were effective which escaped observation in the sparse temperature measurements, and these warm areas were apparently better exposed in the stern view. But agreement between the computations for the bow only requires an effective temperature of 273.5° K, 1.5 degree higher than the measured value. The measured flux from the stern would require a uniform temperature over 15 x 32 square feet of 278.5° K, or 5.5° C.

While the direct measurements of flux from the target were on radiation filtered by the atmosphere, the temperature measurements were not, and the disagreement is of contrary sign to that which would be expected if a detailed examination of surface temperatures were made. But a target survey cannot offer precise estimates of ranges, for ranges depend upon atmospheric conditions as well as target characteristics, and all determining factors may change in the course of a night. It is sufficient that a target survey provide an estimate within fairly wide limits of the distance at which a known detector will function.

It is of interest to compute the ranges at which the General Motors Heat Detector would be expected to track automatically, employing the three values of total emission given above, for all of these values were based on measurements at distances less than final tracking range.

The instrument required

$$F = 7 \times 10^{-3} \text{ ergs/cm}^2\text{sec}$$

for automatic tracking under the operating conditions in these experiments. Employing Eq. (3)

[redacted]

Stern view, 1800 watts, R = 10000 yards;
bow view, 785 watts, R = 6600 yards;
bow view, 485 watts, from temperature measurements,
R = 5200 yards.

The same computations based on the data of Table 2 follow. From Plate 6,

$$m = 2.15 \times 10^9 \text{ ergs/sec},$$

$$(J_t - J_o)WH = \pi m = 6.75 \times 10^9 \text{ ergs/sec}$$

$$= 675 \text{ watts;}$$

Tracking range = 6200 yards.

From temperature measurements

$$(J_t - J_o)WH = \sigma(273.5^4 - 270^4)4.3 \times 10^5$$

$$= 6.9 \times 10^9 \text{ ergs/cm}^2\text{sec}$$

$$= 690 \text{ watts.}$$

While agreement in this case is no doubt fortuitous, it is clear upon comparison with the tracking ranges recorded in Table 3 that the estimates of range arrived at in the several calculations are reliable. The LCT apparently was tracked at 10000 yards, stern or quarter view, and it was relocated at 6800 yards, bow view. At 5100 yards tracking was quite strong. The measurement of surface temperature and background temperature therefore led to a calculated range less than maximum values but in agreement with a "certain" value. This is desirable, for it has been traditional experience that estimated operating ranges of infra-red detectors arrived at by whatever means their designers may have employed have been in conspicuous excess of ranges achieved when the instruments have been tried under field conditions approximating, but less dificult than, shipboard use.

Radiation from LCI

This ship was 157 feet in overall length, beam 23 feet, and 25 feet tall from water line to the top of the bridge. It apparently presented a complex thermal pattern, for the radiation measurements in Table 4 do not show the regularity of dependence on range that was found for measurements on the LCT's.

Temperatures of the sides of the ship given in Table 4 were determined from another LCI which beached nearby during maneuvers on the preceding night.

The LCI gave strong signals, and it was tracked automatically from 5400 yards to 11000 yards. At maximum range the target was following a southerly course and presented a starboard quarter view. At this range the operator of

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the Heat Detector became aware that the direction of tracking had reversed and that the signals were stronger, whereupon it was established by visual search for running lights that a nearer ship had crossed the line of sight and had been selected as the stronger target by the Detector.

The target ship proceeded to 15000 yards and returned on a reciprocal course. It was detected again at 9500 yards as it maneuvered waiting instructions to return. At the next measured range of 11000 yards the Detector was tracking well, but at 9500 yards the ship got in line with the pier and was not in clear view again until a range of 3650 yards had been reached.

<u>Calculated Emission from the Target</u>

Computations based on measurements of this ship are perhaps of little significance except in order of magnitude. The total emission may be estimated in three ways.

<u>From maximum tracking range</u>

Let the maximum tracking range be 11000 yards $= 9.9 \times 10^5$ cm. The exposed area of the ship at this range and the detailed surface temperature pattern are unknown. The effective flux required for tracking was 7×10^{-3} ergs/cm^{2}sec. From Eq. (3), the total effective emission was

$$(J_t - J_o)WH = \pi \times (9.9 \times 10^5)^2 \times 7 \times 10^{-3} \text{ ergs/sec}$$

$$= 2160 \text{ watts.}$$

<u>From measured flux at ranges where the target was a point source</u>

At Mark 11, $R = 3200$ yards $= 2.8 \times 10^5$ cm, $F = 7 \times 10^{-2}$ ergs/cm^2 sec. The result is

$$(J_t - J_o)WH = 1700 \text{ watts.}$$

This estimate of total emission leads to a tracking range for $F = 7 \times 10^{-3}$ ergs/cm^{2}sec of $R = 8.8 \times 10^5$ cm $= 9800$ yards. At Mark 13, $R = 4000$ yards $= 3.6 \times 10^5$cm, $F = 3.1 \times 10^{-2}$ ergs/cm^{2}sec, whence,

$$(J_t - J_o)WH = 1250 \text{ watts.}$$

If this value is used to estimate tracking range for $F = 7 \times 10^{-3}$ ergs/cm^{2}sec, the result is that $R = 7.5 \times 10^5$cm $= 8300$ yards.

<u>From temperature measurements</u>

From Table 4 choose the warmest section at 3° C, horizon −1° C, and assume that the effective area at all times was a cross section about 25 feet square, $WH = 5.6 \times 10^5$ cm^2,

$$(J_t - J_o)WH = \sigma(276^4 - 272^4)5.6 \times 10^5 = 10^{10} \text{ ergs/sec} = 1000 \text{ watts}$$

[redacted]

This would lead to a predicted tracking range of $R = 6.7 \times 10^5$ cm

$= 7400$ yards

As in the case of the LCT this estimate is smaller than those obtained from direct measurement of effective flux, but again the actual range of the instrument was a little larger than the calculated values.

Dinghy with three Men

The dinghy rose and fell on the swell, but it was tracked to 1490 yards. Radiation measurements at 1250 yards indicated a total emission of 290 watts which is perhaps too large a value for three heavily clothed men in a boat.

Radiation from the Moon

The radiation from the moon was measured on 7 January at zenith distance about 60°, air mass 2. The recorded meter deflections are shown in Plate 7. Using the maximum recorded signal of 4100 μA where 10 μV = 1500 μA, the double emf was 27 μV, and the emf in a single thermopile was 13.5 μV corresponding to a flux of 9.45 ergs/cm^{2}sec. Radiation reaching earth from the moon consists of two parts, reflected sunlight constituting about 2 ergs/cm^{2}sec, and thermal radiation from the hot surface. The latter may be calculated approximately by assuming the moon temperature of 400° K to exist over the whole illuminated area. The transmission of the atmosphere is neglected for the present.

$$F = \frac{\sigma(400^4 - 263^4)}{\pi R^2} A$$

where σ is the Stefan-Boltzman constant, R is the mean distance of the moon = 3.84×10^{10} cm, and A is the apparent area of the illuminated part.

$$A = \frac{1 - \cos\varphi}{2}(\pi r^2)$$

where φ is the moon's elongation and r the radius.

On 7 January at 1900 EWT the moon's age was about 11.75 days, $\varphi = 151^\circ$ and $A = 0.93\pi r^2$. The result of the calculation is that $F_{calc} =$ 24 ergs/cm^{2}sec. The apparent transmission of the atmosphere is the observed flux of 9.45 ergs/cm^2 divided by the calculated flux $T = \frac{9.45}{26} = 0.36$ for air mass 2. This may be compared with, for example, the integrated transmission coefficient for 400° K radiation using Adel and Lampland's (6) transmission coefficients for the atmosphere containing 6 mm of precipitable water. A rough integration gave the result $T = 0.33$ for this case, for air mass about 1.3.

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Fowle's[7] statistical formula for the precipitable water in a cm^2 column of the atmosphere is

$$Q = mhe$$

where Q = cm of precipitable water
e = vapor pressure of water at the surface in cm
m = air mass
h = a factor depending on the altitude of the place (for example, 1.6 at Flagstaff, 1.8 at Mt. Hamilton)

The relative humidity was about 60 percent and the air temperature, 2° C. The corresponding value of e was 0.32 cm, whence, $Q = 2 \times 0.32h \simeq 0.62h$. The minimum value of Q is 0.62 cm of precipitable water if $h \simeq 1$; probably the total moisture content of the air between earth and moon was greater. But the formula describes average conditions at a station over a long period of time and amounts of water in the atmosphere are subject to wide fluctuations for a given surface moisture content. The measurement of atmospheric transmission, therefore, is primarily of interest in indicating that the calibration of the Heat Detector was not greatly amiss.

At the surface, consideration of the atmospheric transmission involved in the detection of targets against a clear sky background is complex. The apparent temperature of the background in the 9 – 11μ region may be negative when it is positive on either side of this band in regions of stronger atmospheric absorption.[8] That is, the spectral emission curve of the background contains a depression at 9 – 11μ while the spectral emission curve of the target does not, and the result is that on clear nights the transmission of the atmosphere for radiation from the cold target may be quite high.

Hence, on overcast nights when background temperature is nearly equal to air and target temperatures the ranges would be less except in the case of ships for which radiation from hot stacks is the preponderant part of the signal.

[redacted]

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(5). Memorandum of 14 January 1944 by R. S. Estey, 660d, BuShips, "Geometrical Photometrics of Radiation Telescopes."

(6). Adel and Lampland, Astrophys. Jour. 91, pp. 1 and 481 (1940).

(7). F. E. Fowle, Astrophys. Jour. 37, 359 (1913).

(8). John Strong, "Heat Radiation Investigations at the California Institute of Technology, January 1 through July 31, 1942", NDRC Report of August 20, 1942.

[redacted]

TABLE 1

CALIBRATION OF GENERAL MOTORS RADIANT HEAT DETECTOR

Voltage	Flux ergs/cm^{2}sec at 200 ft.	Transmission of sectored Disc	Effective flux	Signal Single Thermopile microamperes	Sensitivity of Amplifier (μV = μA)	Signal microvolts	Flux/μV
15	0.2	1.0	0.2	150	1 μV = 600 μA	0.25	0.8
15	0.2	1.0	0.2	550	1 = 2200	0.25	0.8
15	0.2	1.0	0.2	75	1 = 500	0.14	1.4*
15	0.2	0.084	0.017	200	0.1 = 900	0.22	0.77
15	0.2	0.064	0.013	87.5	0.1 = 900	0.0096	1.35*
30	0.7	1.0	0.7	1050	1 = 550	1.9	0.37
30	0.7	1.0	0.7	87.5	10 = 600	1.45	0.48
30	0.7	0.053	0.037	625	0.1 = 900	0.069	0.53
30	0.7	0.028	0.0196	310	0.1 = 900	0.034	0.58
30	0.7	0.016	0.0112	75	0.1 = 900	0.0083	1.35*
30	0.7	1.0		1550	1 = 1400	1.1	0.64
30	0.7	to be determined		50	0.1 = 1000	0.005	
		T = 0.005/1.1 = 0.0046					
40	1.4	0.0046	0.006	75	0.1 = 1000	0.0075	0.80
50	2.3	0.0046	0.011	125	0.1 = 1000	0.0125	0.85
60	3.7	0.0046	0.017	190	0.1 = 1000	0.019	0.90
						Average	0.68 ± 0.15
						= 0.70 ±20%	

*Starred values excluded from average.

[redacted]

TABLE 2

LCT ON 6 JANUARY 1944; WEATHER CLEAR, LIGHT BREEZES

Temperatures

Air	+2° C
Horizon	-3.0
LCT	
Bow	+0.5
Midship section	+1.0
Bridge	-0.5
Sky	
Zenith distance 60°	-13.0
Zenith distance 75°	- 9.0
Zenith distance 90°	- 3
Zenith distance 120°	- 3.8

Mark	Range Yards	Amplifier Sensitivity	Meter Deflection for double signal	EMF Double Signal	EMF in one thermocouple	Equivalent point source ergs/cm²sec
1	1530	1µV = 1600µA	600µA	0.37µV	0.185	0.13
2	11000	0.1 = 700	850	0.12	0.06	0.042
3	wrong ship	0.1 = 900	850	0.095	0.047	0.033
4	3600	0.1 = 900	275	0.03	0.015	0.010
5	5000	Tracking automatically; not positive because of interference				
6	6000	by the pier				
7	6300					
8	4900	Bow view				
9	4800	0.1 = 900	300	0.033	0.016	0.011
10	4300	0.1 = 900	450	0.05	0.025	0.017
11	3700	0.1 = 900	500	0.055	0.027	0.019
12	3100	0.1 = 900	600	0.067	0.033	0.023
13	2600	Tracking automatically at 1/10th full sensitivity				
14	2150	0.1 = 900	550	0.061	0.03	0.021
15	1120	0.1 = 900	off scale			
	800	1µV = 2000µA	4800	2.4	1.2	.84
16	550	1 = 2000	off scale			
17	260	1 = 400	3600	9.0	4.5	3.15 port side
18	500	1 = 400	2000	5.0	2.5	1.75 making rt. turn
19	950	1 = 400	700	1.75	0.87	0.61 stern

[redacted]

TABLE 3

LCT ON 8 JANUARY 1944
WEATHER CALM WITH LITTLE HAZE AT THE SURFACE BUT
WITH LIGHT HAZE OVERHEAD.
THE MOON WAS EASILY VISIBLE THROUGH THE OVERCAST

Temperatures

Air	-1° C
LCT	
Bow	-1
Midship section	-1
Port side at stern	$+0.5$
Horizon	-3.5

Mark	Range Yards	Amplifier Sensitivity	Meter Deflection for double signal	EMF Double Signal	EMF in one thermocouple	Equivalent point source ergs/cm^{2}sec
1	2480	1µV = 1300µA	300µA	0.23	0.115	0.08
	(3200)	0.1 = 400	850	0.21	0.10	0.07
2	3500	0.1 = 450	950	0.21	0.10	0.07 stern
3	4800	0.1 = 750	850	0.11	0.05	0.035 view
4	5800	0.1 = 750	450	0.06	0.03	0.021
5	7200	Out of tracking range.				
6	9600					
7	10100	Tracking automatically. Correct target?				
8	8800					
9	6800	Tracking not well sustained but strong enough to show the				
10	5800	presence of a definite target.				
11	(5100)	Tracking automatically, bow view.				
12	4800	Tracking, but signals not strong enough for recording.				
13	4500	Strong automatic tracking				
14	4000	0.1µV = 900µA	500	0.056	0.028	0.019
15	3500	0.1 = 900	700	0.078	0.039	0.027
16	3000	0.1 = 900	800	0.089	0.044	0.031
	(2850)	0.1 = 900	750	0.083	0.041	0.029
17	2700	0.1 = 900	1100	0.122	0.061	0.043
18	2100	0.1 = 900	1800	0.20	0.10	0.07

[redacted]

DECLASSIFIED

TABLE 4

LCI ON 7 JANUARY 1944
WEATHER: SLIGHT UNIFORM OVERCAST THROUGH WHICH THE MOON WAS EASILY VISIBLE. NO HAZE AT THE SURFACE

Temperatures (on a different LCI)

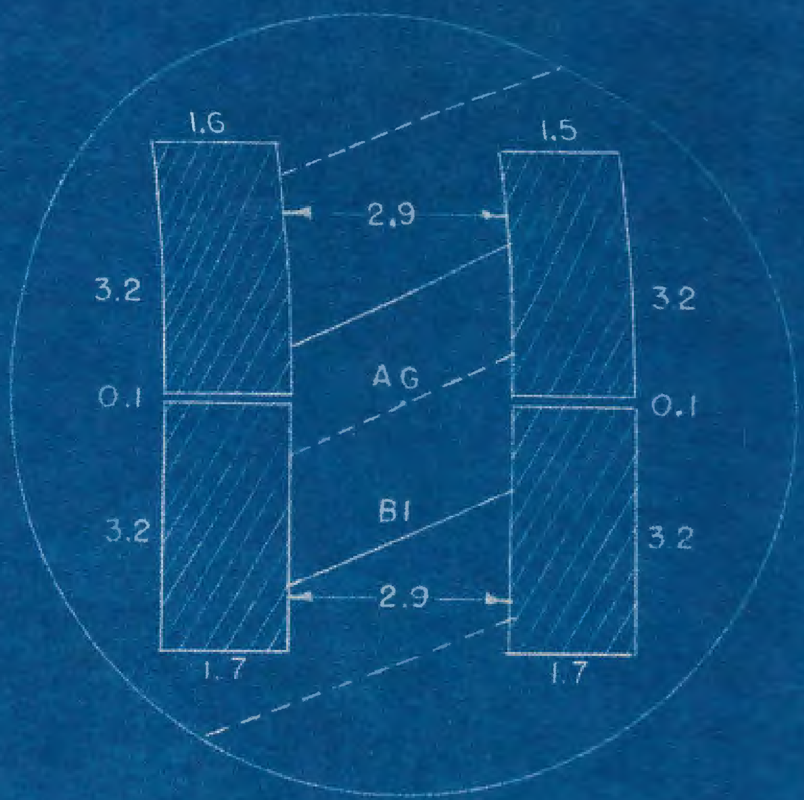
Air	0° C
Horizon	-1
LCI	
Bow	+2
Midship Section	+3
Side near Stern	+2.25

Mark	Range Yards	Amplifier Sensitivity	Meter Deflection for double signal	EMF Double Signal	EMF single thermocouple	Equivalent point source ergs/cm^{2}sec
1	2300	$1\mu V$ = 1700 μA	600	0.35	0.17	0.12
	2450	1 = 1600	1500	0.94	0.47	0.33
2	2600	1 = 1600	1250	0.156	0.078	0.055
3	2100	0.1 = 250	1950	0.78	0.39	0.27
	2100	1 = 4000	1950	0.49	0.245	0.17
	(1800)	0.1 = 350	2800	0.80	0.40	0.28
4	1500	0.1 = 350	off scale			
	(1400)	1 = 200	1600	8.0	4.0	2.8
5	2000	0.1 = 450	1500	0.33	0.165	0.11
	(1200)	1 = 2500	2500	1.0	0.5	0.35
6	1000	1 = 2500	off scale			
	1000	1 = 1200	1950	1.6	0.8	0.56
7	1500	1 = 3000	1300	0.43	0.21	0.15
8	1650	1 = 3000	1550	0.52	0.26	0.18
9	2600					
10	3000	1 = 3000	600	0.2	0.10	0.07
11	3200	0.1 = 800	1600	0.2	0.10	0.07
12	3500	0.1 = 800	1300	0.16	0.08	0.056
13	4000	0.1 = 1000	900	0.09	0.045	0.031
14	4500	0.1 = 1000	100	0.01	0.005	0.0035
15	5400	Recording was suspended and automatic tracking begun. Track-				
16	6100	ing was positive to Mark 19 when the signals became stronger.				
17	10700	It became evident that a second ship nearer by had crossed the				
18	8500	line of sight and had been detected and followed by the instru-				
		ment.				
19	11000	End of tracking range. Starboard quarter view.				
20	15000					
21	9500	Just tracking - gain was found to be low.				

[redacted]

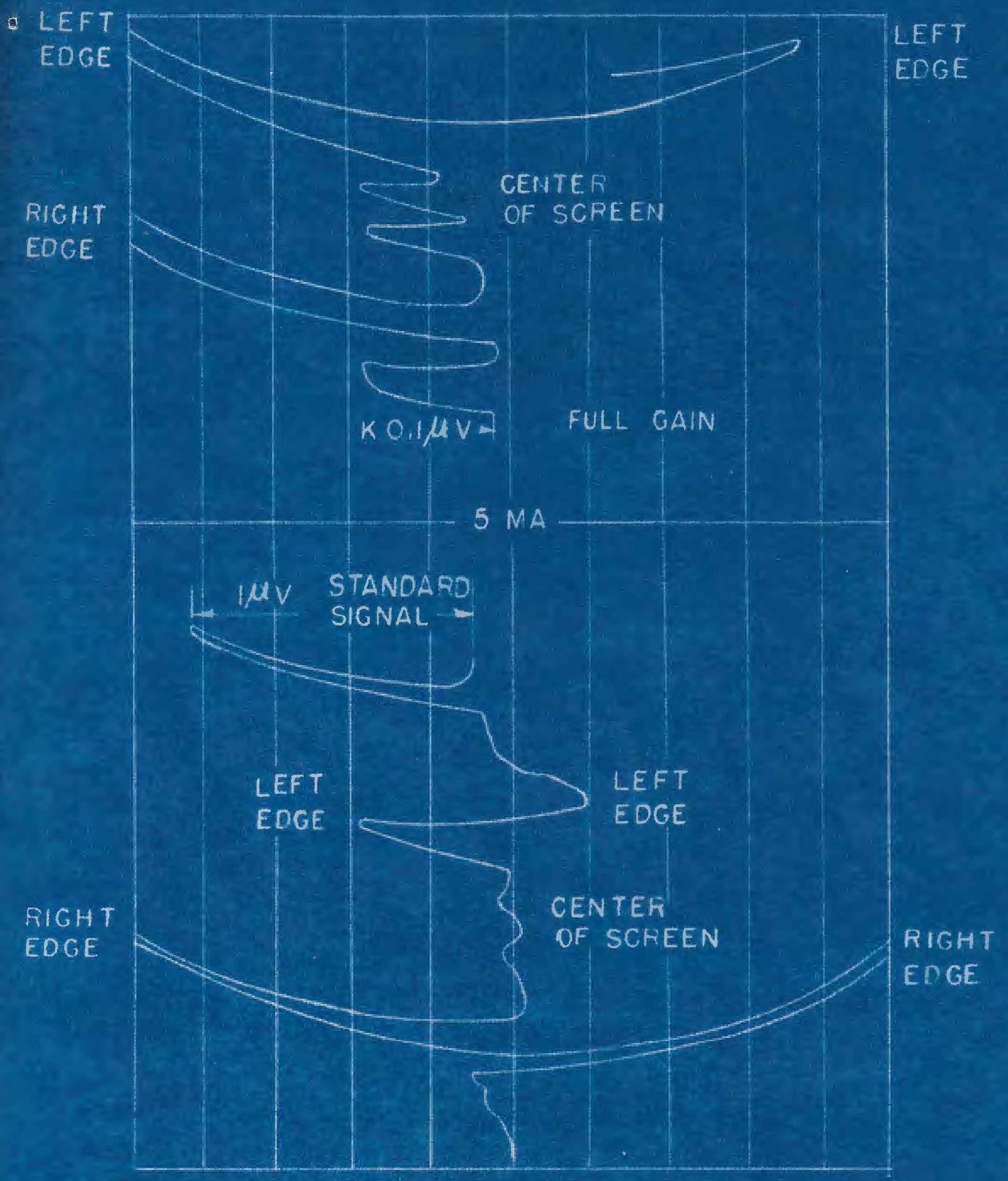
TABLE 4 (Continued)

Mark	Range Yards	Amplifer Sensitivity	Meter Deflection for double signal	EMF Double Signal	EMF single thermocouple	Equivalent point source ergs/cm^{2}sec
22	11100	Tracking well. Port bow view.				
23	11100					
24	9500	The ship got in line with the projecting piling at the end of a small pier and could not be tracked or measured because of strong signals from the piling.				
25	8800					
26	7400					
27	7000					
28	7000					
29	5400					
30	3650	Strong signals with positive tracking to Mark 39.				
31	3250					
32	3200					
33	2800	0.1μV = 350μA	3400	1	0.5	0.35
34	2350					
35	1600					
36	2000					
37	2000					
38	1800					
39	2000	1μV = 2600μA	1100	0.42	0.21	0.15 port side
40	2500	0.1 = 700	1000	0.14	0.07	0.05
41	2900					
42	2400	0.1 = 700	1400	0.20	0.10	0.07 stbd. side



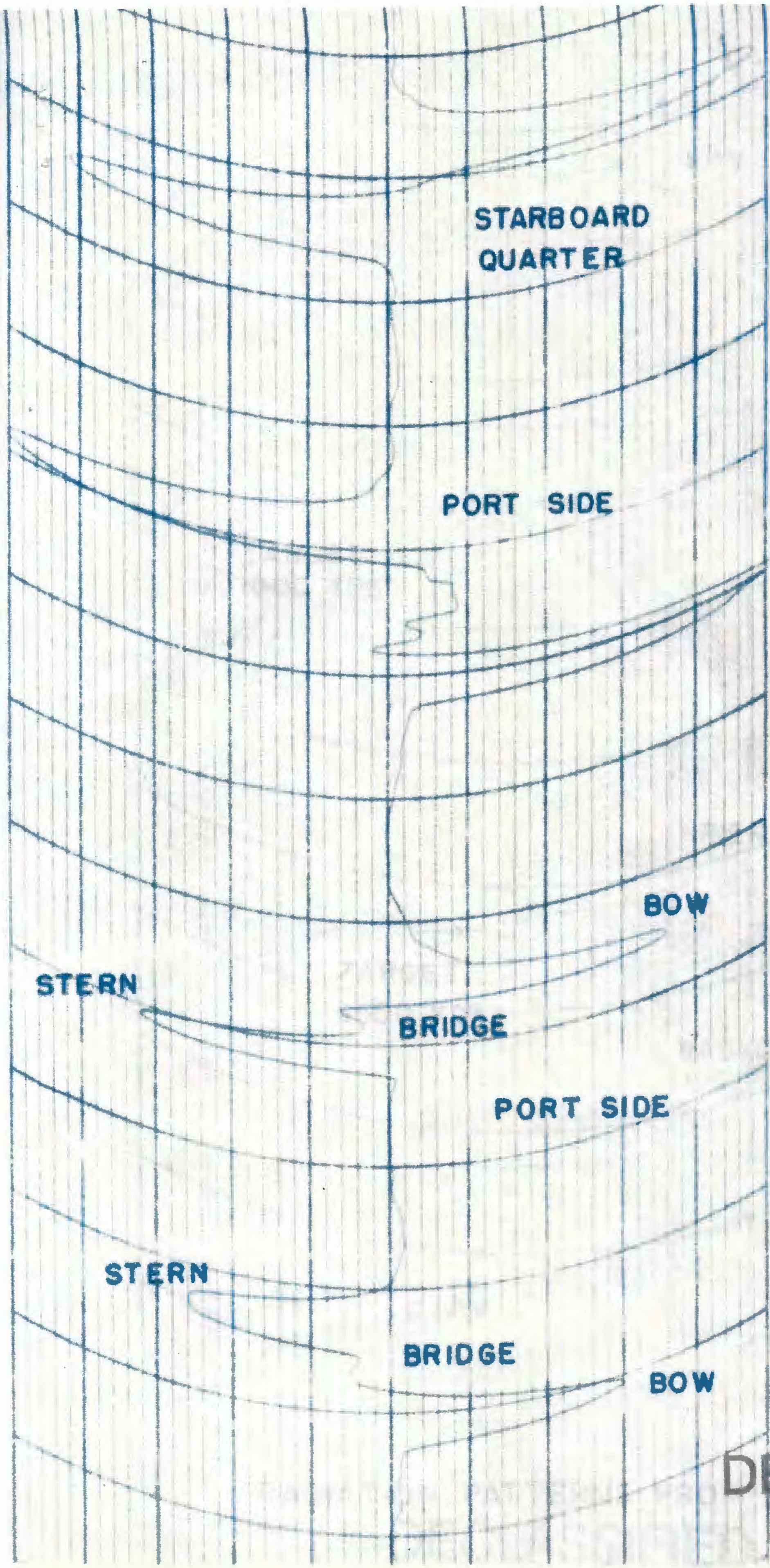
EPPLEY THERMOPILE IN GENERAL
MOTORS RADIANT HEAT DETECTOR
DIMENSIONS IN MM.

PLATE I



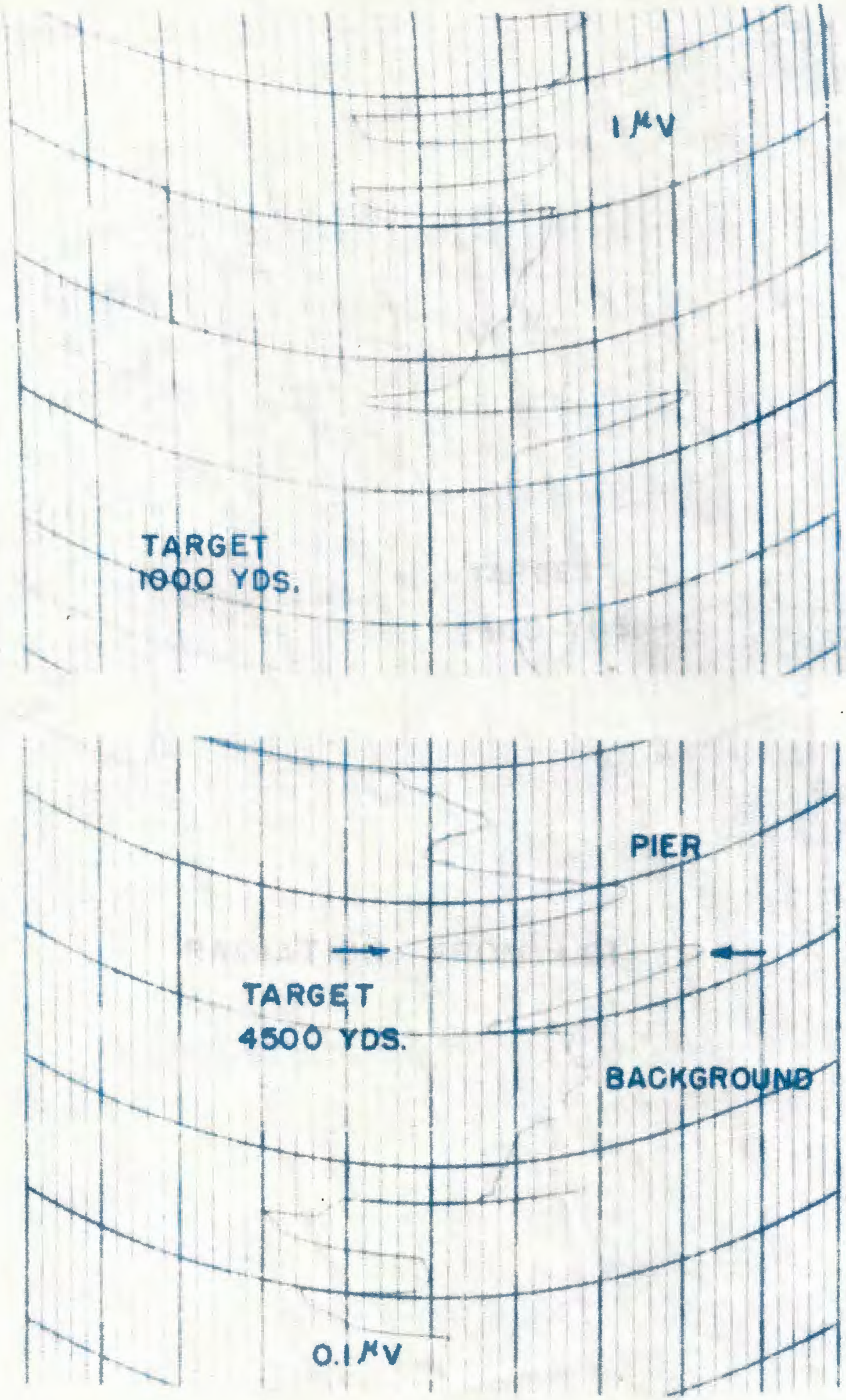
RADIATION PATTERN OF CANVAS BACKGROUND

PLATE 2



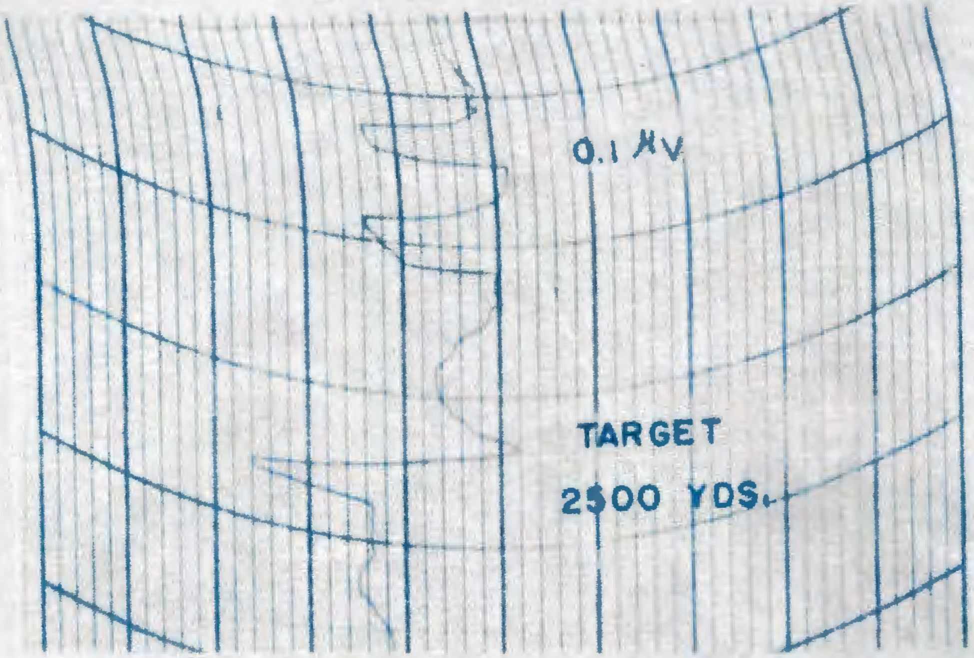
RADIATION PATTERN FROM NEARBY LCT
PORT. SIDE

PLATE 3



RADIATION PATTERNS FROM LCI

PLATE 4



RADIATION FROM LCI

PLATE 5

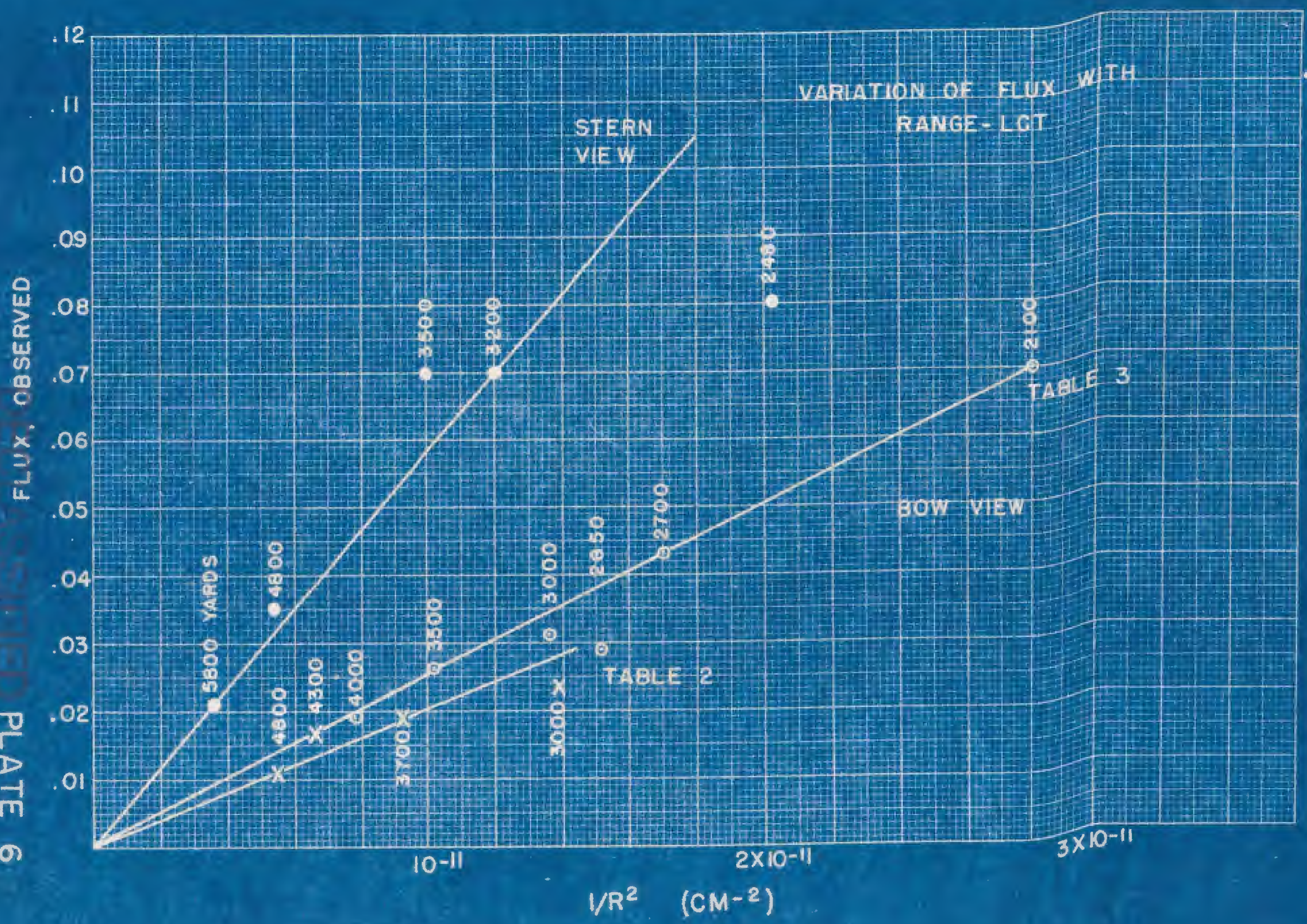
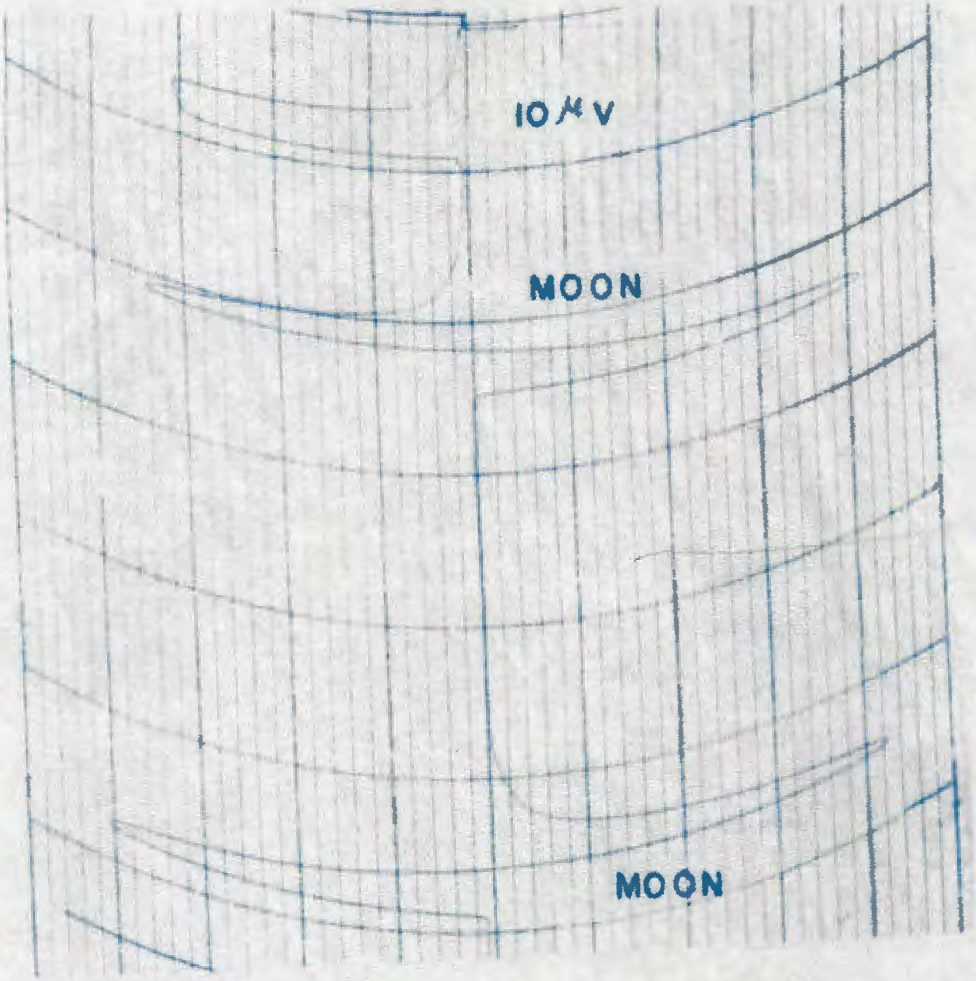

VARIATION OF FLUX WITH
RANGE - LCT
FLUX, OBSERVED
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
10-11
2X10-11
3X10-11
1/R² (CM-²)
STERN
VIEW
BOW VIEW
TABLE 3
TABLE 2
5800 YARDS
4800
4800
4300
4000
3700
3500
3500
3200
3000
3000
2850
2700
2480
2100

PLATE 6



THE MOON

PLATE 7