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CLOUD ATTENUATION STUDIES

MOUNT WASHINGTON, NEW HAMPSHIRE

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By

G. A. Van Lear, Jr.  
/6-y Contractor's Report # 7/

Division 16 (Civil) Section 4  
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CONTRACTOR'S REPORT  
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N.D.R.C. Contract NDCrc-185  
E. F. Barker, Technical Representative  
University of Michigan  
Ann Arbor, Michigan  
October 25, 1945

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National Defense Research Committee  
Office of Scientific Research and Development  
Division 16 - Section 16.4  
Final Report

On

CLOUD ATTENUATION STUDIES  
MOUNT WASHINGTON, NEW HAMPSHIRE  
(Covering the period from July, 1943 to August, 1944)

By

G. A. Van Lear, Jr.

Submitted by: University of Michigan  
Ann Arbor, Michigan

Under Contract No. NDCrc-185

Project Control No. AC - 56

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Date: October 25, 1945

Section 16.4 - 71

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SUMMARY

The objective of the work described in this report was to obtain more reliable quantitative information than has been previously available on (1) the attenuation coefficient of clouds for visible and near-visible radiation, including a determination of the maximum value likely to be encountered; (2) the correlation between visual range and the attenuation coefficient. This information was desired specifically in connection with the NDRC program for developing equipments intended to send and receive such radiation through clouds.

The construction and operation of a Cloud Attenuation Meter developed for this purpose are described, and data obtained during approximately nine months of operation on the summit of Mount Washington, New Hampshire, are presented. These data are restricted to conditions of cloud or fog of high optical density, for which the visual ranges were between 50 and 300 feet. No observations were made on light, fog and haze, with which greater visual ranges would be associated, since data already available for such atmospheric conditions are reasonably satisfactory, and, moreover, they were not involved in the particular applications under consideration.

Values found for the attenuation coefficient,  $k$ , according to the Lambert-Bouguer law,  $I = I_0 e^{-kx}$ , were

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between 1.4 and 5.9 per hundred feet. The validity of this law under the conditions prevailing throughout the experiments was not investigated. A clear-cut, definite correlation, as suggested by Koschmieder's equation, between  $k$  values and visual range cannot be formulated from the data. For a given visual range, especially at the higher values, there is a considerable spread in the measured values of  $k$ . In general, the results for visual ranges between 100 and 150 feet indicate a contrast value intermediate between the values previously reported by Hulbert and by Houghton on the basis of Koschmieder's law, and for visual ranges between 50 and 100 feet a contrast value even smaller than that established by Hulbert and others for visual ranges of 10<sup>3</sup> to 10<sup>5</sup> feet, approximately.

Certain difficulties which are inevitably encountered in such measurements, and possible sources of error in these results are briefly discussed.

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## II. INTRODUCTION

The studies here reported were initiated under Project Control Number AC-56, "Infrared Device for Determining the Position of a Glider With Respect to a Towplane", in connection with the development of devices intended to send and receive a beam of visible or near-visible radiation through clouds. Quantitative information concerning the attenuation to be expected under a wide variety of conditions was required. The condition of a cloud with reference to the transmission of radiation is described by the attenuation coefficient,  $k$ , in the expression

$$I = I_0 e^{-kx} , \quad (1)$$

where  $I_0$  and  $I$  are the intensities of a parallel beam of radiation before and after traversing the distance  $x$ . The value of  $k$  is an index of the optical density of a cloud. Following Langmuir and Westendorp<sup>1</sup>, we shall also use the "mean free light path",

$$\lambda_0 = 1/k , \quad (2)$$

the distance in which the intensity falls to the fraction  $1/e$  of its initial value. It will be convenient to express  $\lambda_0$  in feet, but  $x$  in hundreds of feet, and  $k$  correspondingly

---

<sup>1</sup> I. Langmuir and W. F. Westendorp, Physics 1, 273-317 (1931).

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per hundred feet. For these units, of course, the factor 100 must be introduced into Eq. (2).

The observation which is most readily made related to optical density is the visual range, or "visibility", i.e., the distance at which a large dark object can be seen on the skyline. Of course, the visual range is determined by the effects of the scattering medium on visible light, but it is well known that for clean clouds and fogs, as distinct from fine-particle hazes and smokes, the attenuation is substantially non-selective in the neighborhood of the visible spectrum. Visual range observations can, therefore, be used to characterize clouds and fogs from the near ultraviolet through the near infrared, regardless of the wavelength band under consideration it is necessary to have a correlation between the visual range and the attenuation coefficient, or something equivalent to it.

Middleton<sup>2</sup> discusses at length the theoretical and experimental aspects of the relationship between visual range and attenuation coefficient. He gives the equation due to Koschmieder,

$$x_m = \frac{1}{K} \log_e \frac{1}{C} = \lambda_0 \log_e \frac{1}{C}, \quad (3)$$

where  $x_m$  is the visual range, and  $C$  the contrast between the dark object and its surround when it can just be distinguished

<sup>2</sup> W. E. K. Middleton, "Visibility in Meteorology," 2d Ed., University of Toronto Press (1941).

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by the eye. The classical value of  $\epsilon$  is 0.02, and experimental determinations by Hulburt<sup>3</sup> have confirmed the applicability of Eq. (3) with this value at visual ranges between approximately  $10^4$  and  $10^5$  feet, with one observation at about 1200 feet in fair agreement. However, Houghton<sup>4</sup> has reported that observations taken in clouds on Mount Washington at visual ranges between 90 and 200 feet called for an  $\epsilon$  of 0.065, with values of  $\lambda_0$  ranging down to 35 feet ( $k$  up to 2.9 per 100 feet).

Since interest for the NDRC applications centered on optical densities equal to, and possibly greater than, those measured by Houghton, and since there appeared to be no theoretical grounds for expecting a different value of  $\epsilon$  to be applicable under these conditions, it was considered necessary to conduct further investigations.

In studying the results of correlated observations of optical density and visual range, it is more convenient to deal with the ratio  $x_m/\lambda_0$ , rather than with the value of  $\epsilon$  implied through Eq. (3). It is helpful to fix in mind the values of  $x_m/\lambda_0$  corresponding to the values of  $\epsilon$  given above which are as follows:

|                 |      |       |
|-----------------|------|-------|
| $\epsilon$      | 0.02 | 0.065 |
| $x_m/\lambda_0$ | 3.9  | 2.7   |

3 E. O. Hulburt, Journ. Opt. Soc. Am. 31, 467-476 (1941).

4 H. G. Houghton, J. Aer. Sci. 2, 103-107 (1942).

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Thus, one object of the work was to study the ratio  $x_m/\lambda_0$ , and to see whether the unexpectedly small value found by Houghton would be continued under conditions comparable to his. If a reliable correlation between  $x_m$  and  $\lambda_0$  could be established, simple observations of visual range could be used to predict beam attenuations.

### III. RESULTS OBTAINED WITH TEMPORARY SETUP

In connection with other tests being conducted on Mount Washington in July, 1943, a short series of simultaneous observations of visual range and optical density was obtained. The equipment was essentially the cloud attenuation meter to be described in Part IV of this report, but was an earlier model. It was used in the location shown on the map, Fig. 1. The visual range observations were secured by sighting on the southwest roof peak of the Mount Washington Club from points along the railroad track extending generally southwest from the Mount Washington Club.

The results obtained are shown in Table I, which yields 2.65 for the average value of  $x_m/\lambda_0$ , in good agreement with Houghton's determination. It may also be remarked that the spread in values for these observations is comparable with that shown by Houghton's which he kindly allowed the writer to see although they have not been published in detail.

A point of major interest was the maximum optical density to be expected in clouds. The highest value occurring in Table I is 2.9 per 100 feet for  $k$ , or 35 feet for  $\lambda_0$ , and

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this is in line with the results obtained by Houghton. Moreover, Langmuir and Westendorp<sup>1</sup> give 30 feet as their estimate of the shortest mean free path to be expected, which corresponds to 3.3 per 100 feet for  $k$ . However, none of these results sets a sufficiently conclusive upper limit for  $k$ .

In order to obtain much more extensive data on the optical densities occurring in clouds, and also to secure further information on the relationship between optical density and visual range, arrangements were made to install a Cloud Attenuation Meter in the Mount Washington Observatory.

#### IV. THE CLOUD ATTENUATION METER AS INSTALLED IN MOUNT WASHINGTON OBSERVATORY

##### A. Principles of Operation

As shown in Fig. 2, the Cloud Attenuation Meter consists of a Source-Detector Unit, a Reflector Unit, and a Control-Meter Cabinet. In the Source Detector Unit is a sealed beam flashing signal lamp which sends, along the external path, an unmodulated beam of radiation to the Reflector Unit, located about 60 ft. away. The Reflector Unit is a group of three retrodirective reflectors mounted at the corners of an equilateral triangle as shown in Fig. 6. A motor driven modulating shutter is mounted on an axis passing through the center of this triangle, its three blades successively covering and exposing the three reflectors simultaneously. A second shutter with three blades, mounted on the same axis, may be thrown into either the "open" or

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the "closed" position by means of electrical controls operated at the Source. The retrodirective reflectors send much of the radiation, now modulated, back to the close neighborhood of the source. A parabolic mirror (with auxiliary plane mirror), focuses this radiation on a diffusing glass, behind which is a thelofide photoconductive cell. The output is measured by a meter reading decibels below a reference level determined by an arbitrary variable sensitivity setting (not calibrated). When the shutter control switch is shifted from "EXT." to "INT.", the external path is effectively closed, and the internal path opened. The internal path consists of segments of a Lucite rod spaced to permit interruption of the path by a shutter and a modulator, but which otherwise "conducts" radiation directly from the lamp filament to the diffusing glass, providing a reference signal to which all readings are referred in terms of decibel differences. This feature is considered especially important, for the internal and external readings are effected identically by changes in lamp characteristics, lamp voltage, photo cell responsivity ("sensitivity"), unmodulated masking flux received either from daylight or by back-reflection from the beam, and amplifier gain. The necessity for an absolute calibration of the amplifier is thus eliminated. With a thelofide cell as a detector this automatic correction for the effect of masking flux on responsivity is essential. When masking conditions are changing very rapidly, there may

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still be some difficulty in obtaining internal and external readings at nearly enough the same time, and it is advantageous to use a thaloflue cell which has been selected for minimum dependence of responsivity on masking flux.

In the "noise" position the shutter control switch closes both shutters, and gives a check reading with no signal. Another type of noise reading is obtained with the shutter control switch on "EXT." and the lamp off; this will reveal whether a spurious signal is being registered due to daylight returned by the reflectors.

In using the Cloud Attenuation Meter, it is necessary to obtain "clear" readings in the absence of an appreciable attenuation in order to establish a reference level for the apparatus, from which the attenuation existing when "fog" readings are obtained may be computed. Since the clear reference condition may be separated by hours from the condition of fog or cloud for which the attenuation measurement is desired, the necessity for providing the internal reference signal is apparent. For convenience, the apparatus is so adjusted that the internal reading lies between the clear reading and the usual fog readings.

#### B. Reduction of Observations

The loss of flux caused by the fog is given in terms of the meter readings by

$$db_f = (ab_e - ab_1) + (ab_1^0 - ab_e^0), \quad (4)$$

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where  $ab_c$  = external fog reading,  $ab_c^0$  = external clear reading  
 $ab_i$  = internal fog reading,  $ab_i^0$  = internal clear reading.

Let  $I_0$  and  $I$  be the amounts of flux received back at the Source-Detector Unit through clear air and through fog, respectively. Then

$$I/I_0 = e^{-2ky} = e^{-2y/\lambda_0}, \quad (5)$$

where  $y$  is the distance between the units occupied by fog, and is traversed twice. Since  $ab_f$  is the decibel measure of this ratio ( $I$  and  $I_0$  being treated as voltages in the electrical circuit),

$$ab_f = -40 (\log_{10} e) y/\lambda_0 = 17.4 y/\lambda_0. \quad (6)$$

Thus

$$= 17.4 y/ab_f \quad (7)$$

For the particular installation on Mount Washington,  $y = 58.3$  feet, and to good approximation,  $17.4 y = 1000$ . Finally, then,

$$\lambda_0 = 1000/ab_f \quad (8)$$

### C. Construction and Installation

The three units are pictured together in Fig. 3, and interior views are shown in Figs. 4, 5 and 6. Figs. 7 and 8 show all the circuits involved. The Source-Detector Unit was installed in the basement of the Mount Washington Observatory, facing the Reflector Unit in the near end of Yankee House. Each unit was placed in a specially-constructed window box which replaced a window sash and projected into the building. Each window box was provided with internal

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doors, and with external doors which were opened during operation. Thus, there was no glass or other window material between the windows of the units themselves, and they were shielded from precipitation as well as possible. The Control-Meter Cabinet was installed in the instrument room of the Observatory.

Visual ranges were determined on a number of skyline points at known distances from an observer's station in front of the Observatory. During most of the investigation, one operator took readings of the Cloud Attenuation Meter and recorded also the visual ranges noted by the other observer. Rather late in the investigation, the Observatory staff coupled a General Electric Recording Meter to the decibel meter, and thus obtained continuous recordings of the external reading. This permitted the selection of periods of relatively constant attenuation during the time interval required for a complete set of observations.

#### V. RESULTS

All observations were taken by the staff of the Mount Washington Observatory, and recorded in an NDRC data book. Carbon copies of these records were mailed periodically to the writer. The results in this report have been obtained from these carbon copies, and from the General Electric Recorder strips transmitted in the same manner. Because of the urgency of other work it was not possible to study the data as they were furnished, or to correspond with the

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Observatory staff regarding the conduct of the work.

The general nature of the observations and results is represented in Table II, which contains sample observations chosen to cover substantially the entire region of visual ranges represented. The results are expressed in terms of both  $k$  and  $\lambda_0$ , and it is to be noted that optical densities considerably greater than those contemplated during the preliminary tests described in Section III of this report were found. With regard to the values shown for the ratio  $x_m/\lambda_0$ , however, no definite conclusions should be drawn from Table II, since these sample data have been more or less arbitrarily selected from the complete results which will now be discussed.

All the readings of optical density and observed visual range are presented in Table III, except that in the later part of the study, readings at visual ranges greater than 125 feet were ignored. The spread in observed values was so great as to make the labor of correlation not worth while for such data. The correlation has been examined by obtaining for each observation the indicated value of the ratio  $x_m/\lambda_0$ . As has already been remarked, this ratio has been reported as approximately 3.9 for relatively small optical densities and 2.7 for the densities found in clouds. It is at once apparent from Table III that the value of this ratio varies rather widely, and an attempt has been made to study this variation by plotting the ratio against visual range

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in Fig. 9. Also shown in Fig. 9 are the earlier data of Table I, the outlying points being connected into an irregular polygon to facilitate examination.

Data taken from the General Electric Recording Meter strips are presented in Table IV, and are represented in Fig. 9 by X's. On account of the large spread which had been found in the manually recorded data, and which seems to be attributable in a considerable degree to unsteadiness in fog conditions, attention was restricted to those portions of the record which indicated steady conditions. It is therefore believed that the X's should be given appreciably more weight than the dots.

The original data include information on meteorological conditions. Almost invariably, the wind velocity was 30-60 miles per hour while observations were being taken. Information on temperature, precipitation, and particle size is enclosed in the original records, but can not here be given in detail.

## VI. DISCUSSION

### A. Indications from the Data.

From the data plot, Fig. 9, it is apparent that the values obtained for the ratio,  $x_m/\lambda_0$ , hardly give a clear-cut picture. The pattern shows the following characteristics:

1. The experimental values of the ratio for a given visual range scatter considerably--seriously at the greater visual ranges. This is generally

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to be expected, since the path of measurement extended somewhat less than 60 feet, and all but the shortest visual ranges had to be observed over a path distinctly different from that for which the instrumental attenuation measurement was made. The smaller values would, therefore, have the greater reliability..

2. The ratio shows an apparent trend toward larger values at the greater visual ranges. This is generally in accord with the indications of earlier work, but occurs at smaller visual ranges, and is of much greater degree, than expected.
3. The values of the ratio are, on the whole, considerably higher than those reported in Section II for the temporary setup (which agreed with Houghton's results), although all three sets of data seem to have been obtained under similar conditions.
4. Whereas it had been intended that the results should enable a choice to be made between the values 0.02 and 0.065 for  $\epsilon$ , the indications are for an intermediate value for visual ranges between 50 and 100 feet, and for a value less than 0.02 for visual ranges between 100 and 150 feet. The latter indication, in particular, seems hardly plausible.

#### B. Sources of Error.

The determination of corresponding values of visual range and mean free light path  $\lambda_0$ , or attenuation coefficient  $k$ , is unavoidably beset with difficulties which lead to errors. We consider the following sources of error:

1. Differences between path of instrumental measurement and line of visual range observation, both with regard to length and location. When the cloud is non-uniform, and particularly when there is considerable wind (as there almost invariably is on Mount Washington), this is a possible source of serious error, the more so for the greater discrepancies in length. The steadiness or unsteadiness of the readings gives an index of this effect. Shielding by buildings and consistent vertical variation in cloud density would introduce systematic errors.

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2. In the Cloud Attenuation Meter itself, non-linearity in response of the thalofide photocell could introduce a systematic error. Actually, thalofide cells are known to give non-linear response, but this difficulty was faced in the selection of the cell and the adjustment of the equipment, experimental checks being made with satisfactory results. However, it is possible that the cell characteristics changed with time, or with changes in ambient conditions.
3. Condensation on either or both of the windows covering the Source-Detector Unit and the Reflector Unit would lead to erroneously low values of  $\lambda$ , and thus to erroneously high values of the ratio plotted in Fig. 9.
4. It is perhaps possible that some change occurred in the db calibration of the output meter circuit upon which measurements of the db differences between the internal reference level and the external readings, for either clear or cloudy conditions, depend.

#### VII. CONCLUSIONS

In view of the apparent discrepancies between the earlier and the later data, it does not seem possible to draw any definite conclusion with regard to either the optical densities of clouds found at the summit of Mount Washington, or the correlation between such cloud densities and the observed visual ranges. However, the data tend to support the existence of a trend in this correlation, in the direction to require at the greatest densities a higher contrast between test object and surroundings than the classical value of 0.02.

In order to secure really satisfactory simultaneous data on optical density and visual range, the path of measurement and the line of range observation should be identical.

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This requirement is, of course, difficult if not impossible to meet exactly, but in future experimental work every effort should be made to approximate it as closely as possible.

TABLE I

## Results Obtained with Temporary Setup

Determinations made 4:21 to 6:03 P.M. July 29, 1943, with Cloud Attenuation Meter as arranged for other tests. Observers were T. W. Hildebrandt and G. A. Van Lear, Jr. First 15 observations, 4:21-4:42 P.M., visual range observations by G. A. Van Lear, Jr. Last 7 observations, 5:52-6:03 P.M., visual range observations by T. W. Hildebrandt.

| $k$ ,<br>per 100 ft. | Mean Free<br>Light Path,<br>Feet | Observed<br>Visual Range,<br>$x_m$ , Feet | Ratio<br>$x_m/\lambda_0$ |
|----------------------|----------------------------------|-------------------------------------------|--------------------------|
| 1.8                  | 56                               | 180                                       | 3.2                      |
| 1.6                  | 62                               | 180                                       | 2.9                      |
| 1.5                  | 67                               | 190                                       | 2.8                      |
| 1.4                  | 72                               | 160                                       | 2.2                      |
| 1.8                  | 56                               | 250                                       | 4.5                      |
| 1.5                  | 67                               | 250                                       | 3.8                      |
| 1.9                  | 53                               | 140                                       | 2.7                      |
| 1.8                  | 56                               | 120                                       | 2.2                      |
| 1.8                  | 56                               | 120                                       | 2.2                      |
| 1.9                  | 53                               | 140                                       | 2.7                      |
| 2.0                  | 50                               | 120                                       | 2.4                      |
| 2.0                  | 50                               | 160                                       | 3.2                      |
| 1.8                  | 56                               | 140                                       | 2.5                      |
| 2.1                  | 48                               | 140                                       | 2.9                      |
| 2.0                  | 50                               | 160                                       | 3.2                      |
| 2.9                  | 35                               | 120                                       | 3.5                      |
| 2.5                  | 40                               | 100                                       | 2.5                      |
| 2.4                  | 42                               | 100                                       | 2.4                      |
| 2.5                  | 40                               | 100                                       | 2.5                      |
| 2.1                  | 47                               | 100                                       | 2.1                      |
| 2.5                  | 40                               | 100                                       | 2.5                      |
| 2.6                  | 38                               | 90                                        | 2.3                      |

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TABLE II

## Sample Observations and Results, Observatory Installation

Typical observations and results substantially covering the region of visual ranges represented in the observations are shown, without indication of spread in results at each visual range. Roman numerals heading columns correspond to numbers of columns in original data book. The attenuating properties of the cloud (fcg) are represented alternatively in terms of the attenuation coefficient  $k$ , and the mean free light path  $\lambda_o$ . Concerning the apparent trend in the ratio,  $x_m/\lambda_o$ , see Fig. 9, where this ratio is plotted against  $x_m$  for more complete data.

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| -----Cloud Attenuation Meter Determination----- |                                  |                                       |                                             |                                                    |                                                |                          |
|-------------------------------------------------|----------------------------------|---------------------------------------|---------------------------------------------|----------------------------------------------------|------------------------------------------------|--------------------------|
| -----Observations-----                          |                                  |                                       |                                             |                                                    |                                                |                          |
| Clear<br>db <sub>c</sub> -<br>VII               | Fog<br>db <sub>f</sub> -<br>VIII | db <sub>f</sub> =<br>VII + VIII<br>IX | k,<br>per 100 ft.,<br>= db <sub>f</sub> /10 | $\lambda_o =$<br>1000/db <sub>f</sub><br>Feet<br>X | Observed<br>Visual Range<br>$x_m$ , Feet<br>XI | Ratio<br>$x_m/\lambda_o$ |
| (8.5)                                           | 11.1                             | 19.6                                  | 1.96                                        | 51                                                 | 230                                            | 4.5                      |
| (9.0)                                           | 20.0                             | 29.0                                  | 2.90                                        | 34                                                 | 140                                            | 4.1                      |
| (10)                                            | 31                               | 41                                    | 4.1                                         | 24                                                 | 100                                            | 4.1                      |
| (9.0)                                           | 33.2                             | 42.2                                  | 4.22                                        | 23.7                                               | 85                                             | 3.6                      |
| (10)                                            | 36                               | 46                                    | 4.6                                         | 22                                                 | 72                                             | 3.3                      |
| (10.0)                                          | 43.4                             | 53.4                                  | 5.34                                        | 18.8                                               | 60                                             | 3.2                      |
| (10.0)                                          | 49                               | 59                                    | 5.9                                         | 17.0                                               | 50                                             | 3.0                      |

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TABLE III

Observations and Results, Observatory Installation  
Data from Book

Roman numerals heading columns correspond to numbers of columns in original data book. Clear readings in parentheses are those used for reduction of data.

| Date     | Clear<br>$db_1^0 - db_2^0$<br>VII | Fog<br>$db_2 - db_1$<br>VIII | $db_F =$<br>VII+VIII<br>IX | Observed<br>Visual Range,<br>$x_m$ , Feet<br>XI | $x_m/\lambda_0$ |
|----------|-----------------------------------|------------------------------|----------------------------|-------------------------------------------------|-----------------|
| 11/8/43  | (8.5)                             | 24.0                         | 32.5                       | 130                                             | 4.2             |
|          |                                   | 27.4                         | 35.9                       | 127                                             | 4.5             |
|          |                                   | 24.5                         | 33.0                       | 145                                             | 4.8             |
|          | (8.5)                             | 14.0                         | 22.5                       | 270                                             | 6.1             |
|          |                                   | 12.0                         | 20.5                       | 280                                             | 5.7             |
|          |                                   | 14.0                         | 22.5                       | 210                                             | 4.8             |
| 11/9/43  | (8.5)                             | 3.0                          | 11.5                       | 320                                             | 3.7             |
|          |                                   | 10.0                         | 18.5                       | 300                                             | 5.6             |
|          |                                   | 12.2                         | 20.7                       | 270                                             | 5.6             |
|          |                                   | 14.0                         | 24.5                       | 250                                             | 6.1             |
|          |                                   | 11.1                         | 19.6                       | 230                                             | 4.5             |
|          |                                   | 20.0                         | 28.5                       | 148                                             | 4.2             |
|          |                                   | 25.0                         | 33.5                       | 140                                             | 4.7             |
|          |                                   | 33.0                         | 41.5                       | 100                                             | 4.2             |
| 11/12/43 | 9.0                               |                              |                            | infinity                                        |                 |
| 11/13/43 | (9.0)                             | 31.0                         | 40.0                       | 115                                             | 4.6             |
|          |                                   | 31.5                         | 40.5                       | 115                                             | 4.7             |
|          |                                   | 33.2                         | 42.2                       | 85                                              | 3.6             |
|          |                                   | 29.5                         | 38.5                       | 80                                              | 3.1             |
|          |                                   | 25.5                         | 34.5                       | 122                                             | 4.2             |
|          |                                   | 24.7                         | 33.7                       | 122                                             | 4.1             |
|          |                                   | 24.3                         | 33.3                       | 115                                             | 3.8             |
|          |                                   | 26.0                         | 35.0                       | 120                                             | 4.2             |
|          |                                   | 24.7                         | 33.7                       | 135                                             | 4.5             |
|          |                                   | 25.1                         | 34.1                       | 125                                             | 4.2             |
|          |                                   | 21.0                         | 30.0                       | 145                                             | 4.4             |
| 11/14/43 | (9.0)                             | 20.0                         | 29.0                       | 140                                             | 4.1             |
|          |                                   | 17.7                         | 26.7                       | 145                                             | 3.9             |
|          |                                   | 16.0                         | 25.0                       | 160                                             | 4.0             |
|          |                                   | 18.3                         | 27.3                       | 140                                             | 3.8             |
|          |                                   | 18.0                         | 27.0                       | 145                                             | 3.9             |
|          |                                   | 15.9                         | 24.9                       | 148                                             | 3.7             |
|          |                                   | 18.7                         | 27.7                       | 148                                             | 4.1             |

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| Date     | Clear<br>db <sub>1</sub> <sup>o</sup> -db <sub>e</sub> <sup>o</sup><br>VII | Fog<br>db <sub>e</sub> -db <sub>1</sub><br>VIII | db <sub>e</sub> =<br>VII+VIII<br>IX          | Observed<br>Visual Range,<br>x <sub>m</sub> , Feet<br>XI        | x <sub>m</sub> /λ <sub>o</sub>         |
|----------|----------------------------------------------------------------------------|-------------------------------------------------|----------------------------------------------|-----------------------------------------------------------------|----------------------------------------|
| 11/15/43 | (9.0)                                                                      | 19.5                                            | 28.5                                         | 135                                                             | 3.8                                    |
| 11/16/43 | 9.0                                                                        |                                                 |                                              | infinity                                                        |                                        |
| 11/17/43 | 9.0<br>9.3<br>9.2                                                          |                                                 |                                              | infinity<br>infinity<br>infinity                                |                                        |
| 11/17/43 | 9.5<br>9.8                                                                 |                                                 |                                              | in nity<br>infinity                                             |                                        |
| 11/18/43 | (9.5)                                                                      |                                                 | 35.0<br>35.5<br>34.5                         | 127<br>127<br>125                                               | 4.4<br>4.5<br>4.3                      |
| 11/20/43 | 9.5<br>10.2<br>9.7<br>9.5<br>9.8<br>(9.5)                                  | 8.5                                             | 18.0                                         | infinity<br>infinity<br>infinity<br>infinity<br>infinity<br>145 |                                        |
| 11/12/43 | (9.5)                                                                      | 49.0<br>46.5<br>47.5<br>39.5                    | 58.5<br>56.0<br>57.0<br>49.0                 | 65<br>70<br>70<br>77                                            | 3.8<br>3.9<br>4.0<br>3.8               |
| 12/2/43  | (9.5)                                                                      | 41.9<br>39.5                                    | 51.4<br>49.0                                 | 75<br>77                                                        | 3.8<br>3.0                             |
| 12/3/43  | (9.5)                                                                      | 31.0<br>32.8                                    | 40.5<br>42.3                                 | 125<br>80                                                       | 5.1<br>3.4                             |
| 12/5/43  | (9.5)                                                                      | 7.0                                             | 16.5                                         | 160                                                             | 2.6                                    |
| 12/9/43  | (9.5)                                                                      | 40.5<br>41.0                                    | 50.0<br>50.5                                 | 75<br>75                                                        | 3.7<br>3.8                             |
| 12/9/43  | (9.5)                                                                      | 28.9                                            | 38.4                                         | 77                                                              | 3.0                                    |
| 12/10/43 | (9.5)                                                                      | 10.4<br>9.4<br>7.0<br>16.9<br>13.5<br>14.6      | 19.9<br>18.9<br>16.5<br>26.4<br>23.0<br>24.1 | 150<br>150<br>200<br>135<br>145<br>145                          | 3.0<br>2.8<br>3.3<br>3.6<br>3.3<br>3.5 |
| 12/12/43 | (9.5)                                                                      | 31.8<br>30.2                                    | 41.3<br>39.7                                 | 77<br>79                                                        | 3.2<br>3.1                             |

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| Date     | Clear<br>db <sub>10</sub> -db <sub>e</sub><br>VII | Fog<br>db <sub>e</sub> -db <sub>1</sub><br>VIII | db <sub>e</sub> =<br>VII+VIII<br>IX  | Observed<br>Visual Range,<br>x <sub>m</sub> , Feet<br>XI | x <sub>m</sub> /λ <sub>0</sub>  |
|----------|---------------------------------------------------|-------------------------------------------------|--------------------------------------|----------------------------------------------------------|---------------------------------|
| 12/15/43 | 9.2<br>9.2                                        |                                                 |                                      | infinity<br>infinity                                     |                                 |
| 12/17/43 | (9.2)                                             | 10.5<br>19.0<br>19.0<br>24.0<br>19.7            | 19.7<br>28.2<br>28.2<br>33.2<br>28.7 | 150<br>135<br>135<br>125<br>140                          | 3.0<br>3.8<br>3.8<br>4.1<br>4.0 |
| 12/18/43 | (9.2)                                             | 14.3<br>14.7<br>19.6<br>15.0<br>20.0            | 23.5<br>23.9<br>28.8<br>24.2<br>29.2 | 160<br>140<br>145<br>140<br>130                          | 3.8<br>3.3<br>4.2<br>3.4<br>3.8 |
| 12/20/43 | (9.2)                                             | 30.5<br>21.8                                    | 39.7<br>31.0                         | 80<br>140                                                | 3.2<br>4.3                      |
| 12/28/43 | 8.4<br>8.0                                        |                                                 |                                      | infinity<br>infinity                                     |                                 |
| 1/6/44   | (8.4)                                             | 15<br>12.1                                      | 23.4<br>20.5                         | 145<br>165                                               | 3.4<br>3.4                      |
| 1/7/44   | (8.4)                                             | -0.8                                            | 7.6                                  | 310                                                      | 2.4                             |
| 1/8/44   | 8.7<br>10.8<br>9.6<br>9.9<br>10.0                 |                                                 |                                      | infinity<br>infinity<br>infinity<br>infinity<br>infinity |                                 |
| 1/10/44  | (10.0)                                            | -1.5                                            | 8.5                                  | 220                                                      | 1.9                             |
| 1/10/44  | (10.0)                                            | 13.7<br>21.5<br>15.9                            | 23.7<br>31.5<br>25.9                 | 160<br>145<br>145                                        | 3.8<br>4.6<br>3.8               |
| 1/12/44  | (10.0)                                            | 21.8<br>17.2<br>9.9<br>12.1                     | 31.8<br>27.2<br>19.9<br>22.1         | 135<br>145<br>190<br>160                                 | 4.3<br>3.9<br>3.8<br>3.5        |
| 1/12/44  | (10.0)                                            | 21.8<br>9.1                                     | 31.8<br>19.1                         | 190<br>220                                               | 6.0<br>4.2                      |
| 1/13/44  | (10.0)                                            | 1.7<br>3.0                                      | 11.7<br>13.0                         | 250<br>240                                               | 2.9<br>3.1                      |

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| Date    | Clear<br>db <sub>1</sub> <sup>o</sup> -db <sub>e</sub> <sup>o</sup><br>VII | Fog<br>db <sub>e</sub> -db <sub>1</sub><br>VIII | db <sub>F</sub> =<br>VII+VIII<br>IX | Observed<br>Visual Range,<br>x <sub>m</sub> , Feet<br>XI | x <sub>m</sub> /λ <sub>o</sub> |
|---------|----------------------------------------------------------------------------|-------------------------------------------------|-------------------------------------|----------------------------------------------------------|--------------------------------|
| 1/14/44 | (10.0)                                                                     | 29.9                                            | 39.9                                | 110                                                      | 4.4                            |
|         |                                                                            | 30.1                                            | 40.1                                | 100                                                      | 4.0                            |
|         |                                                                            | 30.9                                            | 40.9                                | 105                                                      | 4.3                            |
|         |                                                                            | 29.1                                            | 39.1                                | 110                                                      | 4.3                            |
|         |                                                                            | 36.0                                            | 46.0                                | 75                                                       | 3.4                            |
| 1/14/44 | (10.0)                                                                     | 35.3                                            | 45.3                                | 90                                                       | 4.1                            |
|         |                                                                            | 35.6                                            | 45.6                                | 100                                                      | 4.6                            |
|         |                                                                            | 39.0                                            | 49.0                                | 75                                                       | 3.7                            |
|         |                                                                            | 32.2                                            | 42.2                                | 90                                                       | 3.8                            |
|         |                                                                            | 37.1                                            | 47.1                                | 75                                                       | 3.5                            |
|         |                                                                            | 43.4                                            | 53.4                                | 60                                                       | 3.2                            |
|         |                                                                            | 44.0                                            | 54.0                                | 50                                                       | 2.7                            |
|         |                                                                            | 44.3                                            | 54.3                                | 55                                                       | 3.0                            |
| 1/15/44 | (10.0)                                                                     | 4.5                                             | 14.5                                | 230                                                      | 3.3                            |
|         |                                                                            | 10.7                                            | 20.7                                | 170                                                      | 3.5                            |
|         |                                                                            | 11.0                                            | 21.0                                | 150                                                      | 3.1                            |
| 1/16/44 | 10.5                                                                       |                                                 |                                     | infinity                                                 |                                |
|         | 10.4                                                                       |                                                 |                                     | infinity                                                 |                                |
| 1/20/44 | (10.0)                                                                     | 30.3                                            | 40.3                                | 120                                                      | 4.8                            |
|         |                                                                            | 29.9                                            | 39.9                                | 125                                                      | 5.0                            |
|         |                                                                            | 31.8                                            | 41.8                                | 110                                                      | 4.6                            |

Observations at x<sub>m</sub> > 125 feet are omitted from the rest of this Table

|         |      |      |    |     |     |
|---------|------|------|----|-----|-----|
| 1/26/44 | (10) | 26   | 36 | 125 | 4.5 |
|         |      | 25   | 35 | 125 | 4.4 |
|         |      | 25   | 35 | 110 | 3.8 |
|         |      | 37   | 47 | 100 | 4.7 |
|         |      | 29.4 | 39 | 125 | 4.9 |
| 1/27/44 | (10) | 31   | 41 | 85  | 3.5 |
|         |      | 37   | 47 | 75  | 3.5 |
|         |      | 30   | 40 | 75  | 3.0 |
| 1/29/44 | (10) | 28   | 38 | 100 | 3.8 |
|         |      | 25   | 35 | 125 | 4.4 |
|         |      | 22   | 32 | 120 | 3.8 |
|         |      | 26   | 36 | 95  | 3.4 |
|         |      | 25   | 35 | 95  | 3.3 |
|         |      | 25   | 35 | 125 | 4.4 |
|         |      | 24   | 34 | 95  | 3.2 |

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| Date    | Clear<br>db <sub>1</sub> <sup>o</sup> -db <sub>e</sub> <sup>o</sup><br>VII | Fog<br>db <sub>e</sub> -db <sub>1</sub><br>VIII    | db <sub>r</sub> =<br>VII+VIII<br>IX                | Observed<br>Visual Range,<br>x <sub>m</sub> , Feet<br>XI | x <sub>m</sub> /λ <sub>o</sub>                              |
|---------|----------------------------------------------------------------------------|----------------------------------------------------|----------------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------|
| 2/24/44 | (10)                                                                       | 31<br>31                                           | 41<br>41                                           | 77<br>75                                                 | 3.2<br>3.1                                                  |
| 3/15/44 | 9.9<br>9.9<br>9.9                                                          |                                                    |                                                    | infinity<br>infinity<br>infinity                         |                                                             |
| 3/16/44 | (10)                                                                       | 27<br>23<br>27<br>24<br>26<br>24                   | 37<br>33<br>37<br>34<br>36<br>34                   | 125<br>110<br>125<br>125<br>95<br>75                     | 4.6<br>3.6<br>4.6<br>4.3<br>3.4<br>2.6                      |
| 3/16/44 | (10)                                                                       | 23<br>24<br>28<br>27<br>25<br>26<br>26<br>26<br>23 | 33<br>34<br>38<br>37<br>35<br>36<br>36<br>36<br>33 | 105<br>85<br>100<br>95<br>95<br>90<br>110<br>85<br>95    | 3.5<br>2.9<br>3.8<br>3.5<br>3.3<br>3.2<br>4.0<br>3.1<br>3.1 |
| 3/16/44 | (10)                                                                       | 27<br>27<br>28<br>25<br>26<br>24                   | 37<br>37<br>38<br>35<br>36<br>34                   | 80<br>95<br>80<br>80<br>100<br>80                        | 3.0<br>3.5<br>3.0<br>2.8<br>3.6<br>2.7                      |
| 3/17/44 | (10)                                                                       | 38<br>41<br>40<br>39<br>34<br>30                   | 48<br>51<br>50<br>49<br>44<br>40                   | 78<br>75<br>75<br>73<br>70<br>88                         | 3.7<br>3.8<br>3.7<br>3.6<br>3.1<br>3.5                      |
|         | (10)                                                                       | 40<br>39<br>30<br>36<br>33<br>29<br>31             | 50<br>49<br>40<br>46<br>43<br>39<br>41             | 75<br>73<br>90<br>77<br>80<br>85<br>84                   | 3.7<br>3.6<br>3.6<br>3.5<br>3.4<br>3.3<br>3.4               |
| 3/19/44 | 9.7<br>9.6<br>9.9<br>10.0                                                  |                                                    |                                                    | infinity<br>infinity<br>infinity<br>infinity             |                                                             |

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| Date    | Clear<br>$db_1^o - db_e^o$<br>VII | Fog<br>$db_e - db_1$<br>VIII | $db_T =$<br>VII+VIII<br>IX | Observed<br>Visual Range, $x_m / \lambda_o$<br>$x_m$ , Feet<br>XI |     |
|---------|-----------------------------------|------------------------------|----------------------------|-------------------------------------------------------------------|-----|
| 3/24/44 | (10)                              | 33                           | 43                         | 78                                                                | 3.4 |
|         |                                   | 36                           | 46                         | 72                                                                | 3.3 |
|         |                                   | 33                           | 43                         | 70                                                                | 3.0 |
|         |                                   | 36                           | 46                         | 72                                                                | 3.3 |
|         |                                   | 34                           | 44                         | 72                                                                | 3.2 |
|         |                                   | 31                           | 41                         | 80                                                                | 3.3 |
|         |                                   | 36                           | 46                         | 70                                                                | 3.2 |
|         | (10)                              | 31                           | 41                         | 85                                                                | 3.5 |
|         |                                   | 31                           | 41                         | 100                                                               | 4.1 |
|         |                                   | 31                           | 41                         | 80                                                                | 3.3 |
|         |                                   | 38                           | 48                         | 74                                                                | 3.5 |
|         |                                   | 39                           | 49                         | 72                                                                | 3.5 |
|         |                                   | 37                           | 47                         | 71                                                                | 3.4 |
|         |                                   | 33                           | 43                         | 77                                                                | 3.3 |
|         |                                   | 38                           | 48                         | 71                                                                | 3.4 |
|         |                                   | 33                           | 43                         | 82                                                                | 3.5 |
| 4/8/44  | (10)                              | 21                           | 31                         | 125                                                               | 3.9 |
|         |                                   | 24                           | 34                         | 120                                                               | 4.1 |
|         |                                   | 23                           | 33                         | 120                                                               | 3.9 |
|         |                                   | 23                           | 33                         | 120                                                               | 4.0 |
|         |                                   | 21                           | 31                         | 122                                                               | 3.8 |
|         |                                   | 25                           | 35                         | 100                                                               | 3.5 |
|         |                                   | 20                           | 30                         | 125                                                               | 3.7 |
|         | (10)                              | 42                           | 52                         | 70                                                                | 3.6 |
|         |                                   | 42                           | 52                         | 70                                                                | 3.6 |
|         |                                   | 42                           | 52                         | 73                                                                | 3.8 |
|         |                                   | 42                           | 52                         | 70                                                                | 3.6 |
|         |                                   | 43                           | 53                         | 67                                                                | 3.5 |
| 5/8/44  | (10)                              | 25                           | 35                         | 80                                                                | 2.8 |
|         |                                   | 22                           | 32                         | 100                                                               | 3.2 |
|         |                                   | 18                           | 28                         | 100                                                               | 2.8 |
|         |                                   | 21                           | 31                         | 115                                                               | 3.6 |
| 6/14/44 | 8.9                               |                              |                            | infinity                                                          |     |
|         | 10.4                              |                              |                            | infinity                                                          |     |
|         | 10.8                              |                              |                            | infinity                                                          |     |
|         | 10.0                              |                              |                            | infinity                                                          |     |
| 6/17/44 |                                   | 24.2                         |                            | 125                                                               | 3.0 |
|         |                                   | 22.1                         |                            | 130                                                               | 2.9 |
| 6/18/44 | 9.2                               |                              |                            | infinity                                                          |     |
|         | 9.6                               |                              |                            | infinity                                                          |     |
| 6/20/44 | (10)                              | 23.1                         |                            | 120                                                               | 2.8 |
|         |                                   | 26.1                         |                            | 100                                                               | 2.6 |

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| Date    | Clear<br>db <sub>i</sub> <sup>o</sup> -db <sub>e</sub> <sup>o</sup><br>VII | Fog<br>db <sub>e</sub> -db <sub>i</sub><br>VIII | -24-<br>db <sub>f</sub> =<br>VII+VIII<br>IX | Observed<br>Visual Range,<br>x <sub>m</sub> , Feet<br>XI | x <sub>m</sub> /λ <sub>o</sub> |
|---------|----------------------------------------------------------------------------|-------------------------------------------------|---------------------------------------------|----------------------------------------------------------|--------------------------------|
| 6/22/44 | 10                                                                         | 37                                              | 47                                          | 85                                                       | 4.0                            |
|         |                                                                            | 33.6                                            | 44                                          | 105                                                      | 4.6                            |
|         |                                                                            | 33.5                                            | 43                                          | 95                                                       | 4.1                            |
|         |                                                                            | 30                                              | 40                                          | 95                                                       | 3.8                            |
| 7/22/44 | 10                                                                         | 34.4                                            | 44                                          | 78                                                       | 3.4                            |
|         |                                                                            | 34.2                                            | 44                                          | 90                                                       | 4.0                            |
| 7/25/44 | 10                                                                         | 49                                              | 59                                          | 50                                                       | 3.0                            |
|         |                                                                            | 49                                              | 59                                          | 50                                                       | 3.0                            |

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TABLE IV

Observations and Results, Observatory Installation,  
Data from Recorder Strips

Only such records as indicate stable conditions are used.  
Decibel calibration recorded just preceding run of 6/15/44,  
attached to letter of transmittal dated July 3, 1944.

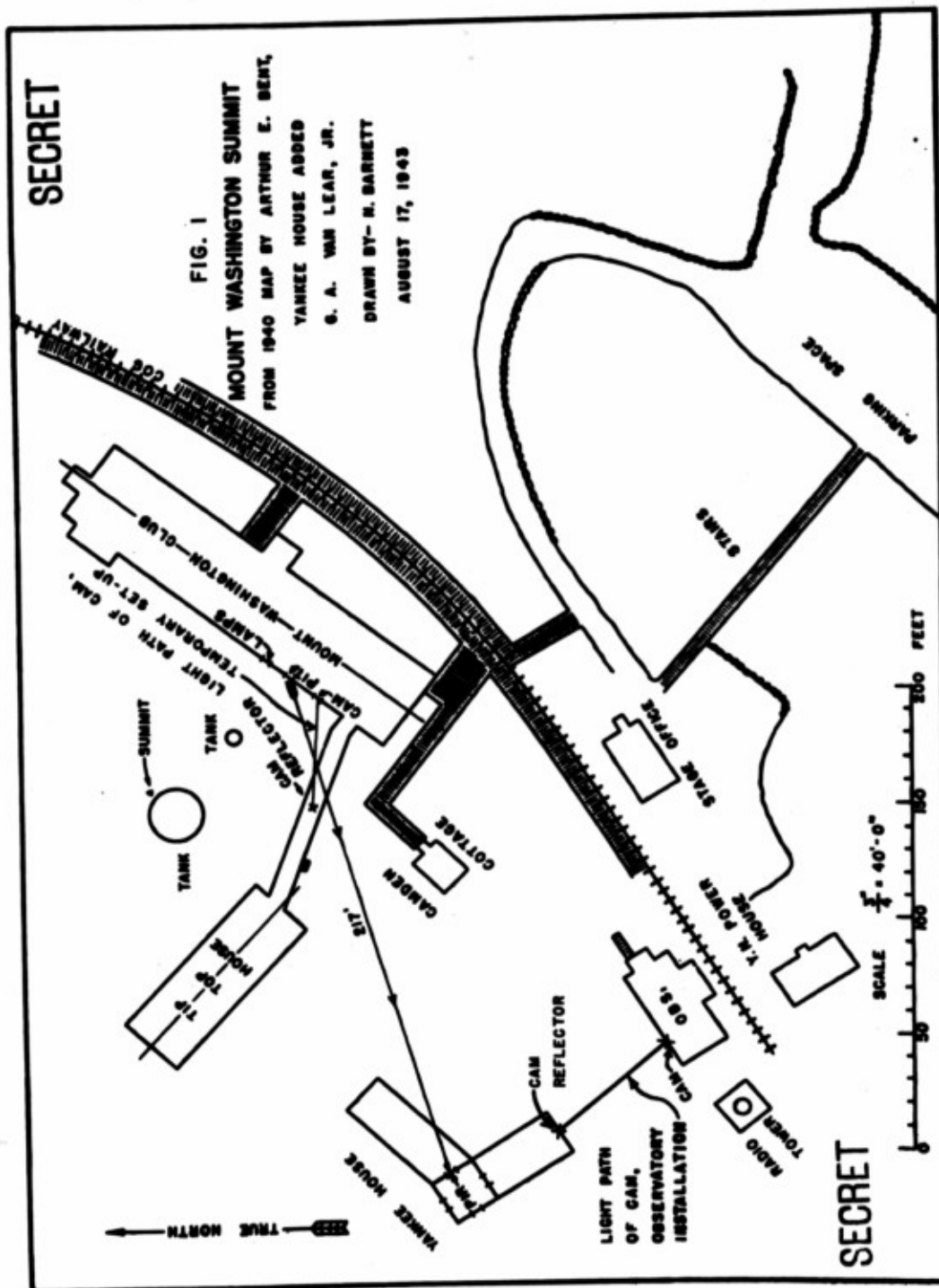
| Date    | Time          | Clear<br>db <sub>10</sub> -db <sub>e0</sub><br>VII | Fog<br>db <sub>e</sub> -db <sub>1</sub><br>VIII | db <sub>F</sub> =<br>VII+VIII<br>IX | Observed<br>Visual Range<br>x <sub>m</sub> , Feet<br>XI | x <sub>m</sub> /λ <sub>0</sub> |
|---------|---------------|----------------------------------------------------|-------------------------------------------------|-------------------------------------|---------------------------------------------------------|--------------------------------|
| 5/15/44 | 9:55A         | (10)                                               | 25.5                                            | 35.5                                | 120                                                     | 4.3                            |
|         |               |                                                    | 23.5                                            | 33.5                                | 130                                                     | 4.3                            |
|         |               |                                                    | 27.5                                            | 37.5                                | 115                                                     | 4.3                            |
|         |               |                                                    | 31.5                                            | 41.5                                | 95                                                      | 3.9                            |
|         | 10:32A        |                                                    | 30                                              | 40                                  | 90                                                      | 3.6                            |
|         |               |                                                    | 31                                              | 41                                  | 85                                                      | 3.5                            |
|         |               |                                                    | 32                                              | 42                                  | 80                                                      | 3.4                            |
|         | (1:30P)       |                                                    | 44                                              | 54                                  | 68                                                      | 3.7                            |
|         |               |                                                    | 45                                              | 55                                  | 75                                                      | 4.1                            |
|         |               |                                                    |                                                 |                                     |                                                         |                                |
|         | 5/16/44 1:18P | 10.0<br>10.0                                       |                                                 |                                     | infinity<br>infinity                                    |                                |
|         |               |                                                    |                                                 |                                     |                                                         |                                |
| 6/15/44 | 10:25A+       | (10)                                               | 31.5                                            | 41.5                                | 80                                                      | 3.3                            |
|         |               |                                                    | 32.5                                            | 42.5                                | 78                                                      | 3.3                            |
|         |               |                                                    | 29.5                                            | 39.5                                | 100                                                     | 4.0                            |
| 7/15/44 | 12:36P        | 9.9                                                |                                                 |                                     | infinity                                                |                                |
|         |               | 9.5                                                |                                                 |                                     | infinity                                                |                                |
|         |               | 9.4                                                |                                                 |                                     | infinity                                                |                                |
|         |               | 9.3                                                |                                                 |                                     | infinity                                                |                                |

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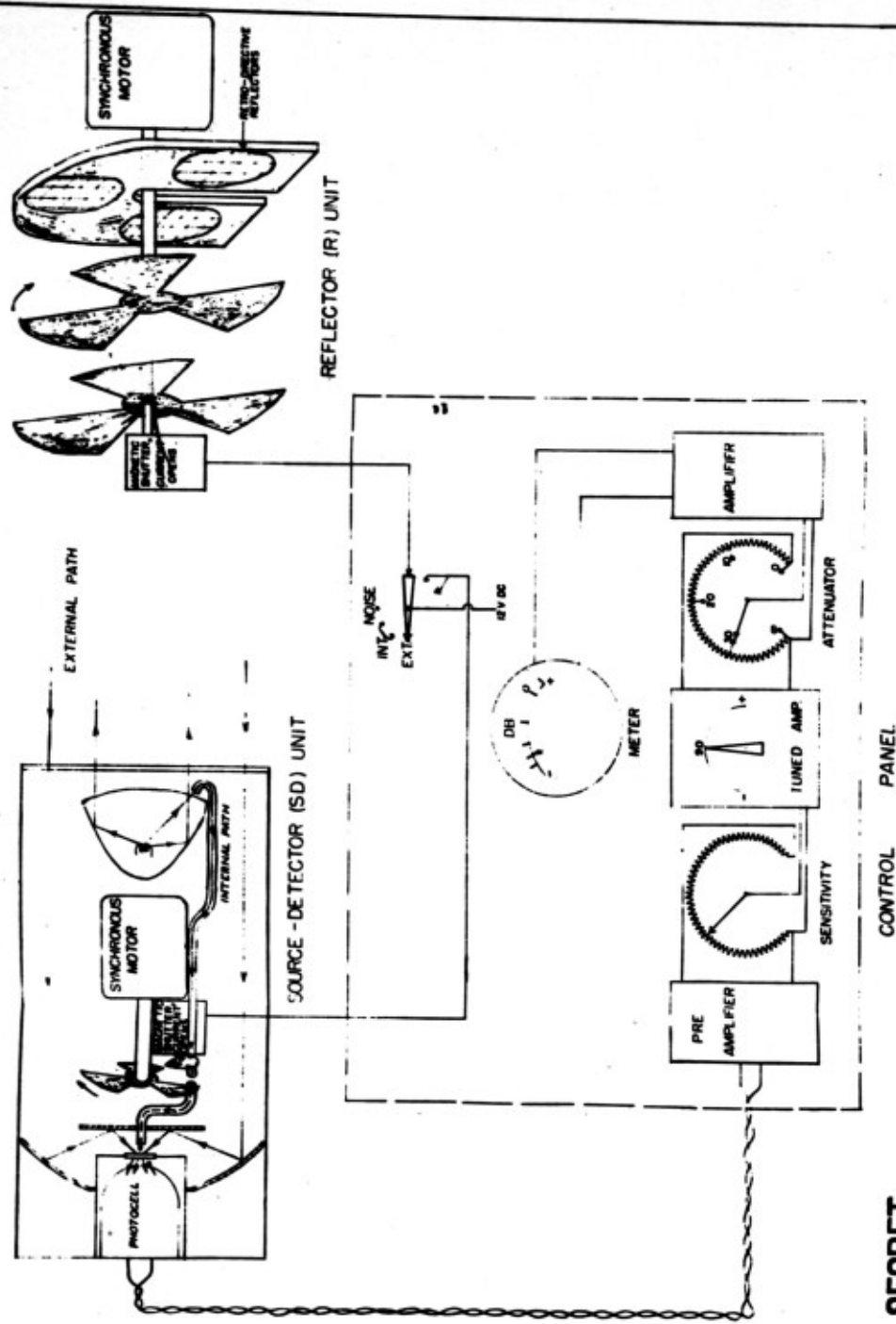
FIG. 1

MOUNT WASHINGTON SUMMIT  
FROM 1940 MAP BY ARTHUR E. BENT,  
YANKEE HOUSE ADDED  
S. A. VAN LEAR, JR.  
DRAWN BY- M. BARRETT  
AUGUST 17, 1943



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CONTROL PANEL

FIG. 2 SCHEMATIC DIAGRAM OF CLOUD ATTENUATION METER

SECRET FIG. 3

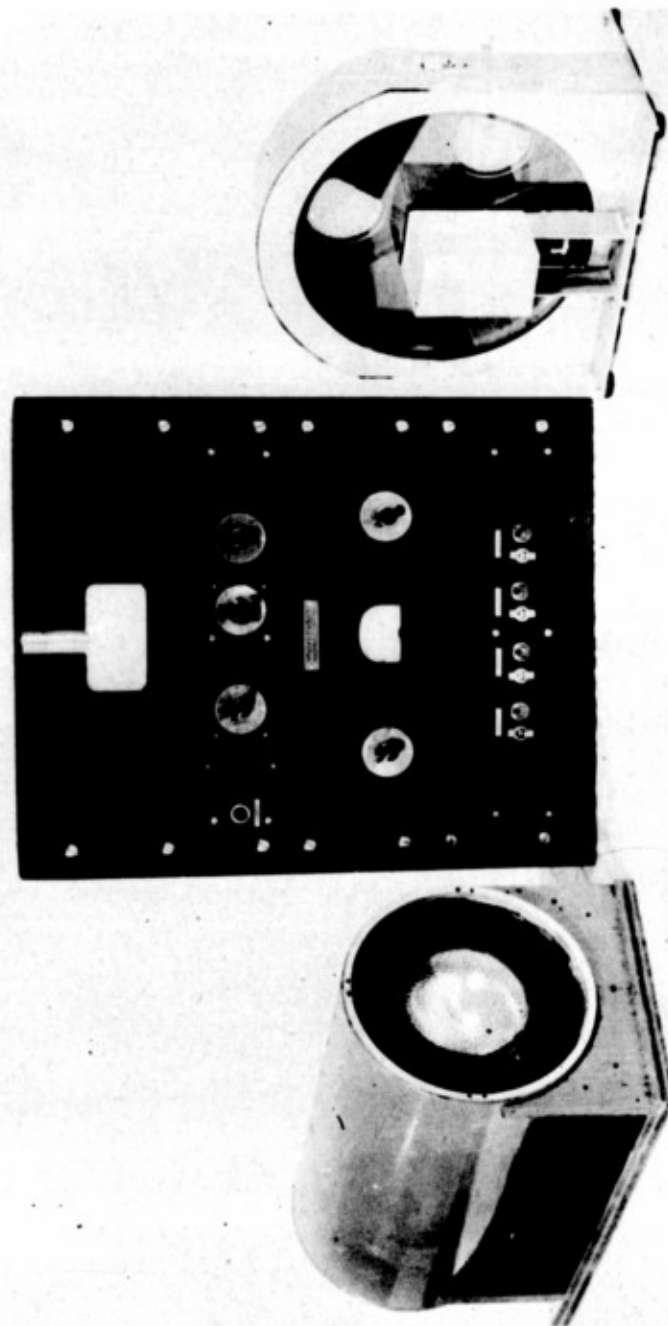
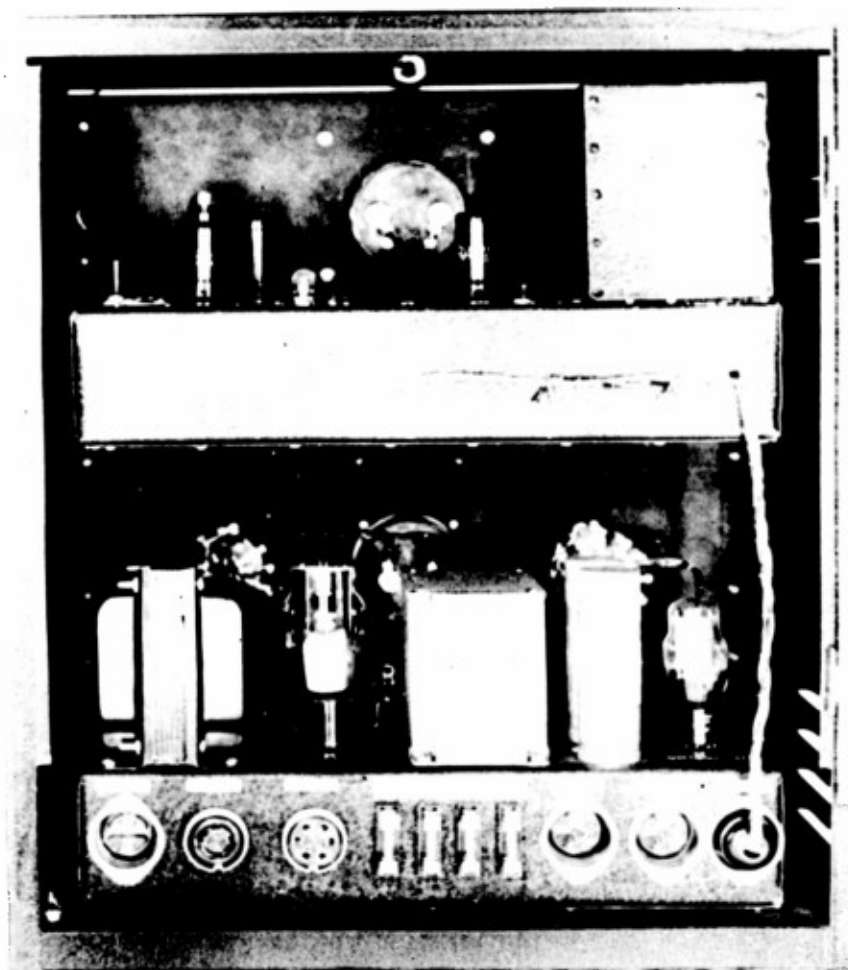


FIGURE 3. CLOUD ATTENUATION METER, GROUP VIEW

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SECRET FIG. 4



SECRET FIGURE 4. CONTROL-METER CABINET, INTERIOR

SECRET FIG. 5

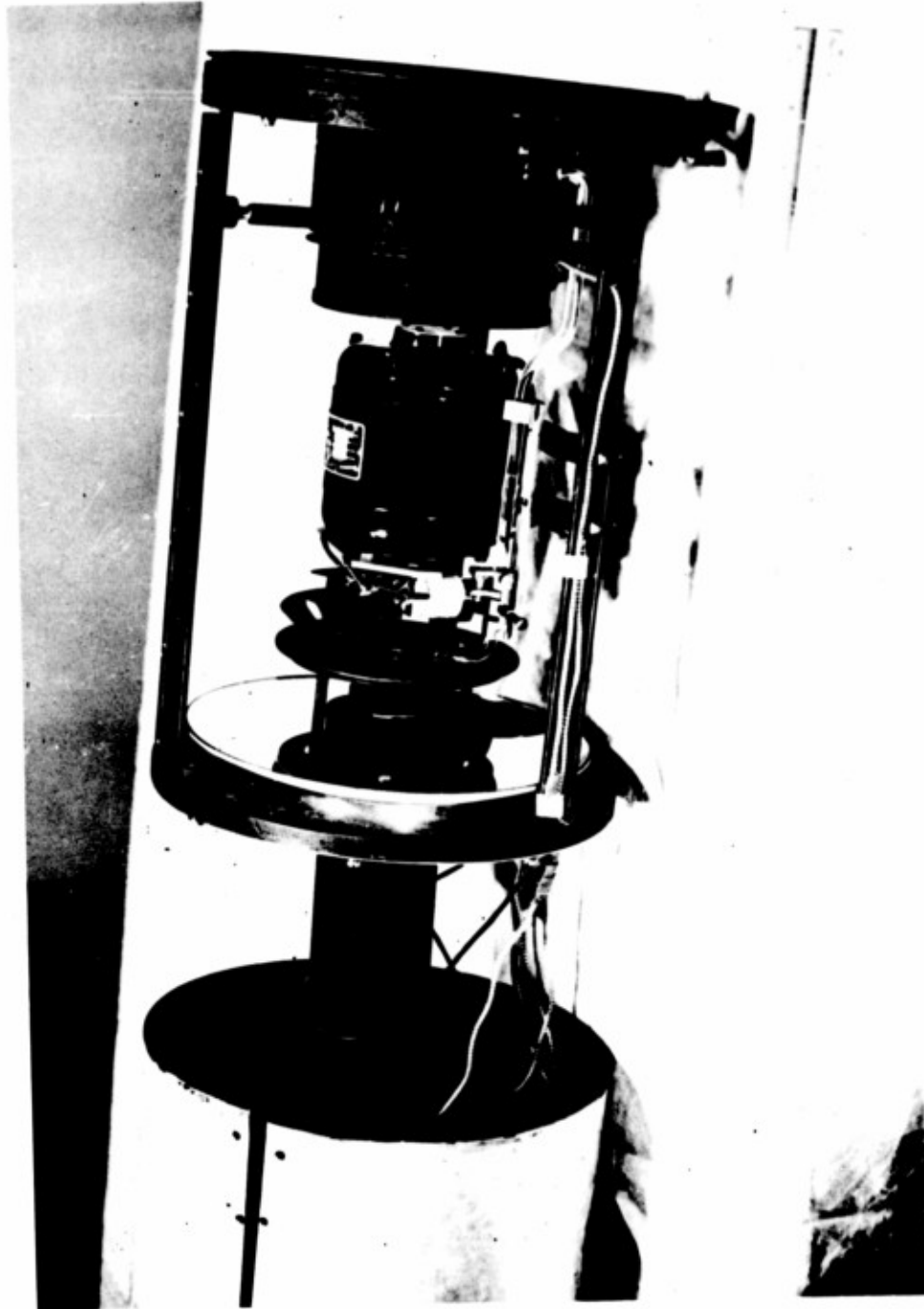
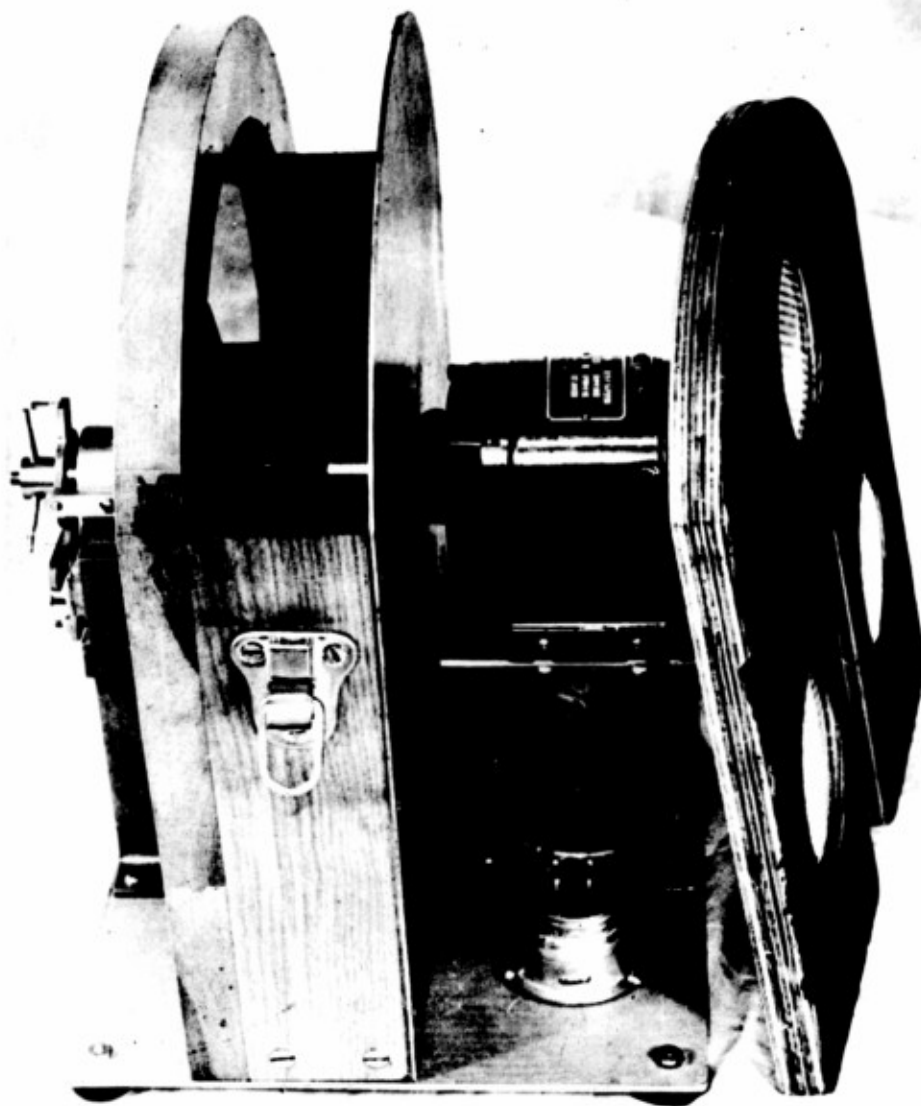


FIGURE 5. SOURCE-DETECTOR UNIT, INTERIOR

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SECRET FIG. 6

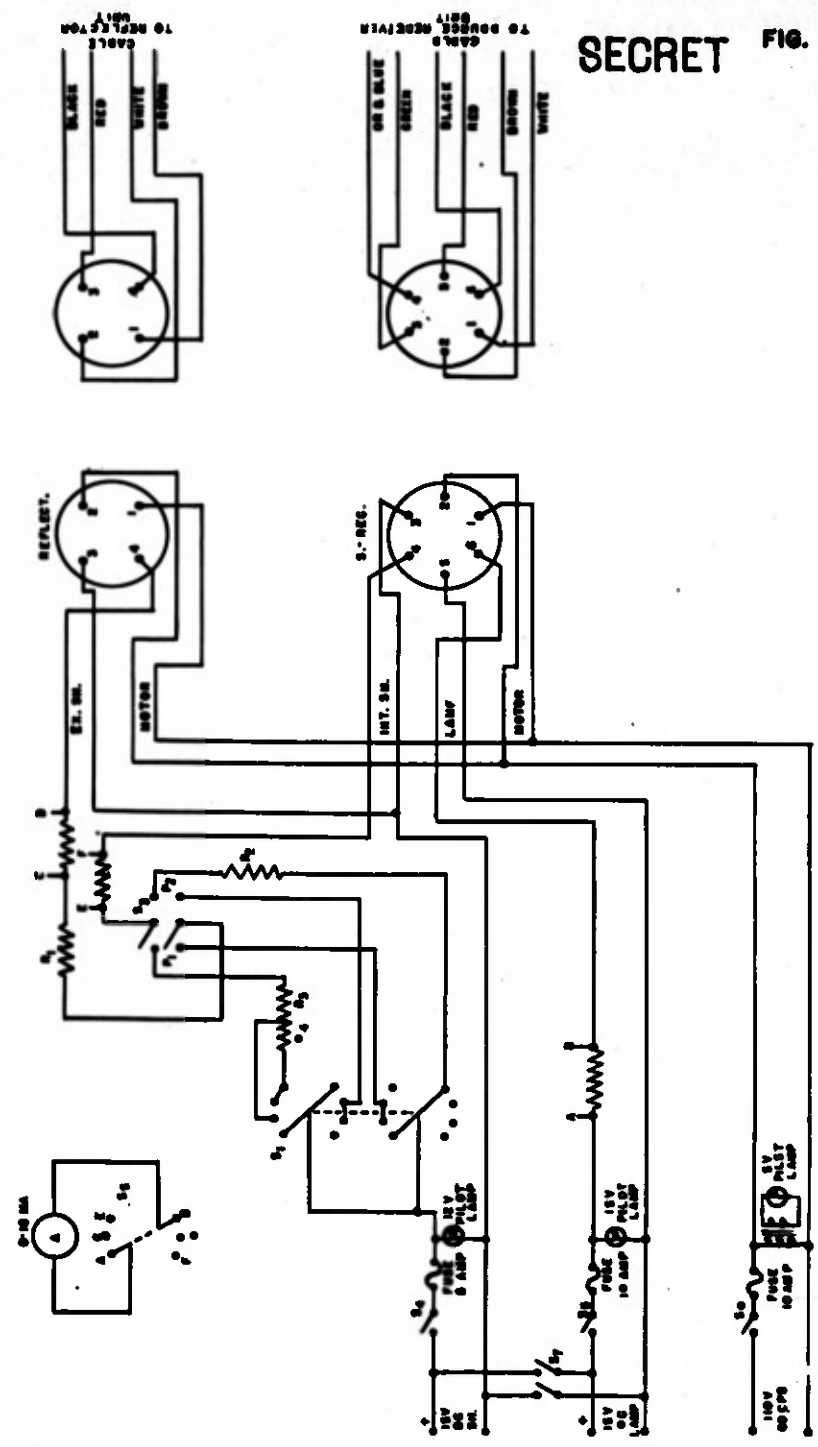


SECRET FIGURE 6. REFLECTOR UNIT, INTERIOR

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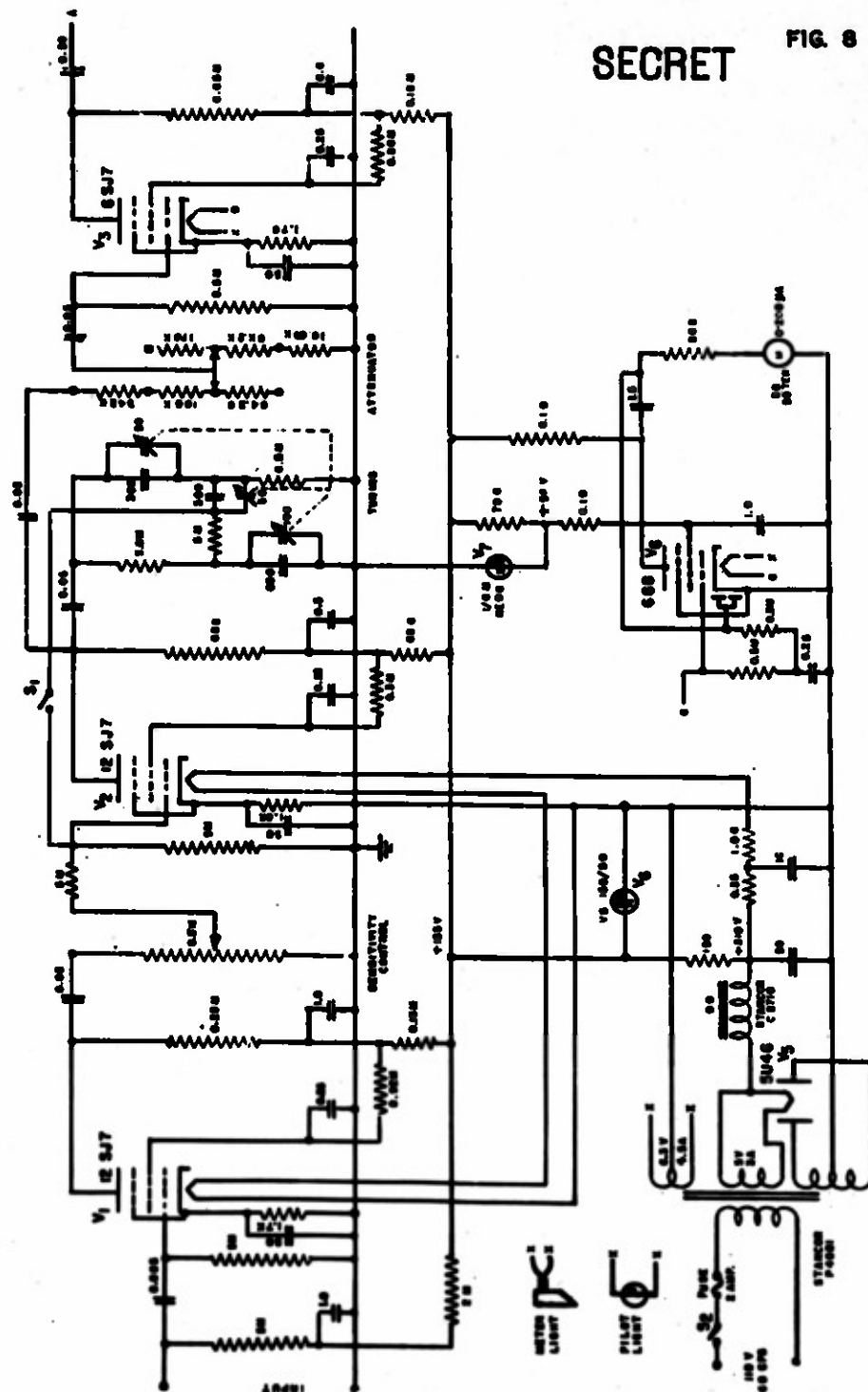
SECRET FIG. 7



SECRET FIG. 7 DIAGRAMS, CONTROL CIRCUIT

**SECRET**

FIG. 8



**FIG. 8** **CIRCUIT DIAGRAM, AMPLIFIER**

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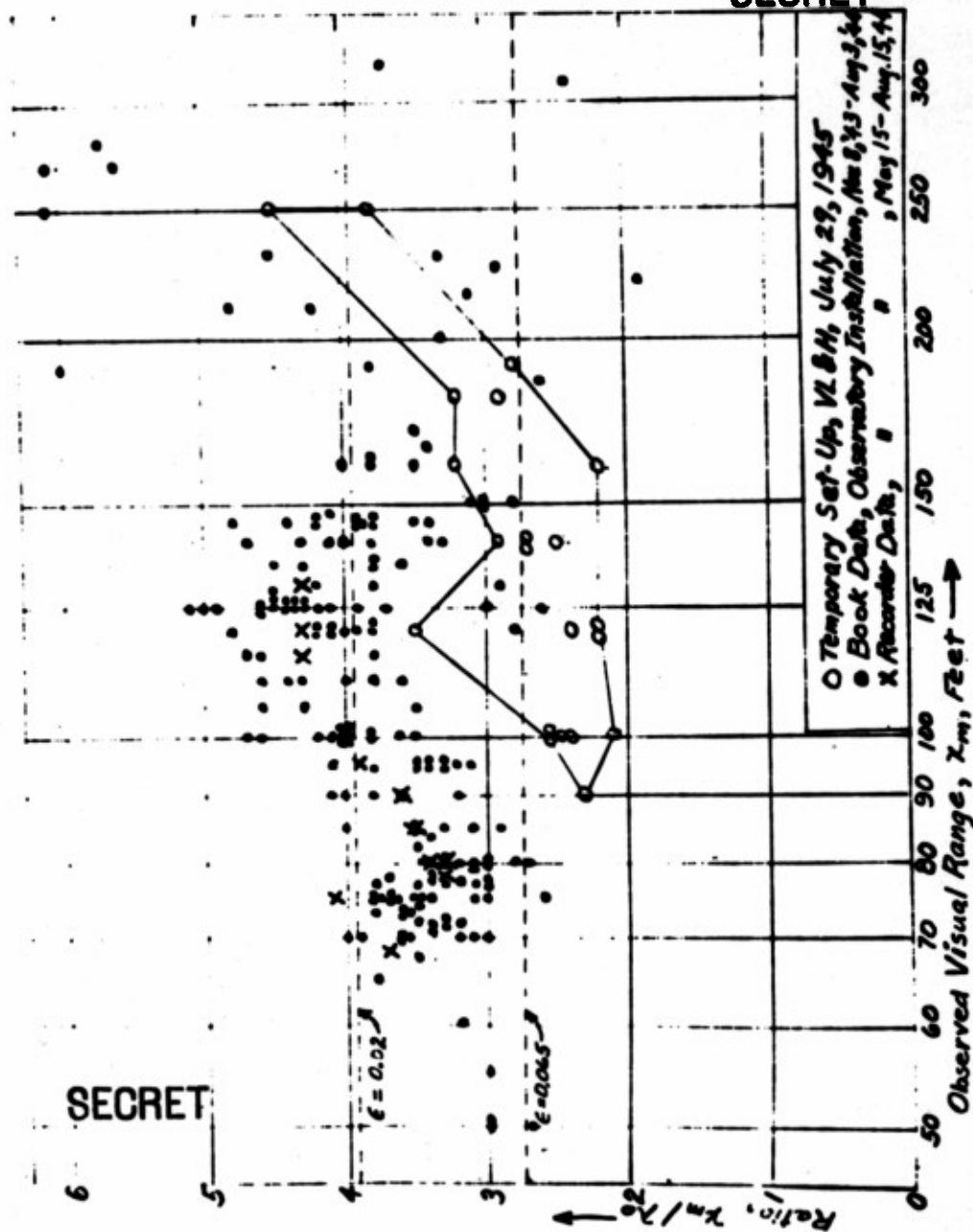


Fig. 9 Data Plot, Ratio  $\lambda_m/\lambda_0$  vs  $\lambda_m$ .

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## ABSTRACT:

The objective of the work described was to obtain more reliable quantitative information than was available on the attenuation coefficient of clouds and to obtain the correlation between visual range and the attenuation coefficient. A cloud attenuation meter consisting of a source-detector unit, a reflector unit and a control-meter cabinet was used to make simultaneous observations of visual range and optical density. Values found for the coefficient, according to the Lambert-Bouguet law, were between 1.4 and 5.9 per hundred feet.

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