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EVALUATION OF A LASER FOR USE AS A TRANSMISSOMETER CALIBRATOR

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FINAL REPORT

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16. Abstract

A laser transmissometer was evaluated for use in providing an objective method of calibrating the NBS-type transmissometer to the light transmission characteristics of the atmosphere in all weather and visibility conditions. The laser transmissometer was tested by using it to calibrate an NBS-type transmissometer. Visibility measurements from the laser (objectively) calibrated NBS-type system were compared with measurements from an identical system calibrated by the normal (subjective) method. Results indicate that the laser method tends to calibrate the NBS-type transmissometer to yield higher Runway Visual Range values than does the normal method of calibration. Deficiencies in the laser system made rigorous testing of the laser device impracticable. An appendix details performance specifications for an improved laser calibrator system.

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DISCLAIMER

The Weather Bureau of the Environmental Science Services Administration does not approve, recommend, or indorse any product except for its own use, and the evaluation and test results shall not be used in advertising, sales promotion, or to indicate in any manner, either implicitly or explicitly, indorsement by the Weather Bureau or ESSA.

INTRODUCTION

To insure the accuracy of the National Bureau of Standards (NBS)-type transmissometer system, several electrical and mechanical tests are specified in Federal Aviation Administration (FAA) and Weather Bureau publications (references 1-4). (The terms "transmissometer" and "transmissometer system" as used in this report refer to the unit described by Federal Aviation Administration Specification FAA-E-2269.) The electrical and mechanical checks for accuracy are objective methods which can be applied with equal results to any NBS-type transmissometer system. The basic calibration method of the transmissometer (described in references 3 and 4), however, is a subjective one. A human estimate of visibility is obtained at the transmissometer site. The system is then adjusted to yield a visibility measurement which corresponds to that estimate. This normal method of calibration is satisfactory only if:

1. The visibility is estimated to be five statute miles or more.
2. Sufficient visibility markers exist beyond five statute miles to give reasonable accuracy to the estimate.
3. Atmospheric transmission in the vicinity of the transmissometer is representative of that over the area at the time the visibility estimate is made.
4. The person making the visibility estimate is a good estimator, i.e., he can distinguish between visibility markers at various locations to arrive at an estimate having a minimum of subjective bias.

Whenever an inaccurate estimate of visibility is made, the transmissometer will be inaccurately calibrated and will therefore yield an erroneous measure of visibility. The potential error resulting from an inaccurate calibration is greatest at the higher visibilities. Error due to inaccurate calibration is not absolute, but is related to the visibility reported by the transmissometer.

For example, if a transmissometer were to be calibrated 10% in error when the visibility was six miles, (corresponding to atmospheric transmittance of .98), the error would decrease by one-half, or 5%, when the visibility decreased to 3/16 mile (an atmospheric transmittance of .49).

When visibilities are less than five miles and a catastrophic failure occurs to the transmissometer, the system must in all cases remain out of service until the visibility criteria for calibration can be met.

In addition to visibility criteria, accurate calibration of the transmissometer depends upon the skill of a human observer. Because such factors as skill at estimating visibility, visual acuity, and job interest are not equally distributed among people, the normal method of calibration does not apply equally to all transmissometer systems.

A laser visibility measuring system might prove useful as a transmissometer calibrator. One such device may itself be calibrated by means of an internal, objective method without reference to subjective observations of visibility. It is further designed to be used as a permanently mounted visibility measuring system intended to be operated in all types of weather and visibility conditions.

If such a system can be accurately calibrated by means of an internal, objective method, why cannot the laser measurement be used to replace the subjective visibility estimate presently needed for transmissometer calibration? In addition, assuming the laser method of transmissometer calibration to be satisfactory, can the method be employed in the form of a light-weight, portable, easy-to-use system? These are the questions to which this report on evaluation of a laser visibility measuring system is addressed.

FIELD TEST SITE DESCRIPTION

The laser field test site was located at the Sterling Research and Development Center (SR&DC), Virginia.

Two 250-foot baseline NBS-type transmissometer systems were installed for the tests. The systems were set-up adjacent to one another atop two pairs of 14-foot high towers, so that the parallel beams were separated by a distance of 10 feet. Both transmissometer projectors were aimed south, the receivers north. Figure 1 shows the arrangement of the receivers. The west transmissometer, to the right in the figure, was designated T1. The east transmissometer was labeled T2.

The laser transmissometer/calibrator was mounted on a steel frame atop the T2 towers. Figures 2, 3, and 4 show the laser system as it was positioned during the field tests. Note that the laser beam was aimed opposite to the direction of the T1 and T2 projectors. This was essential so that both the laser and T2 calibration controls would be on the same tower. The T2 receiver amplifier cabinet had to be rotated 180^{o} on its platform so that it would open on the same side as the laser system control panel.

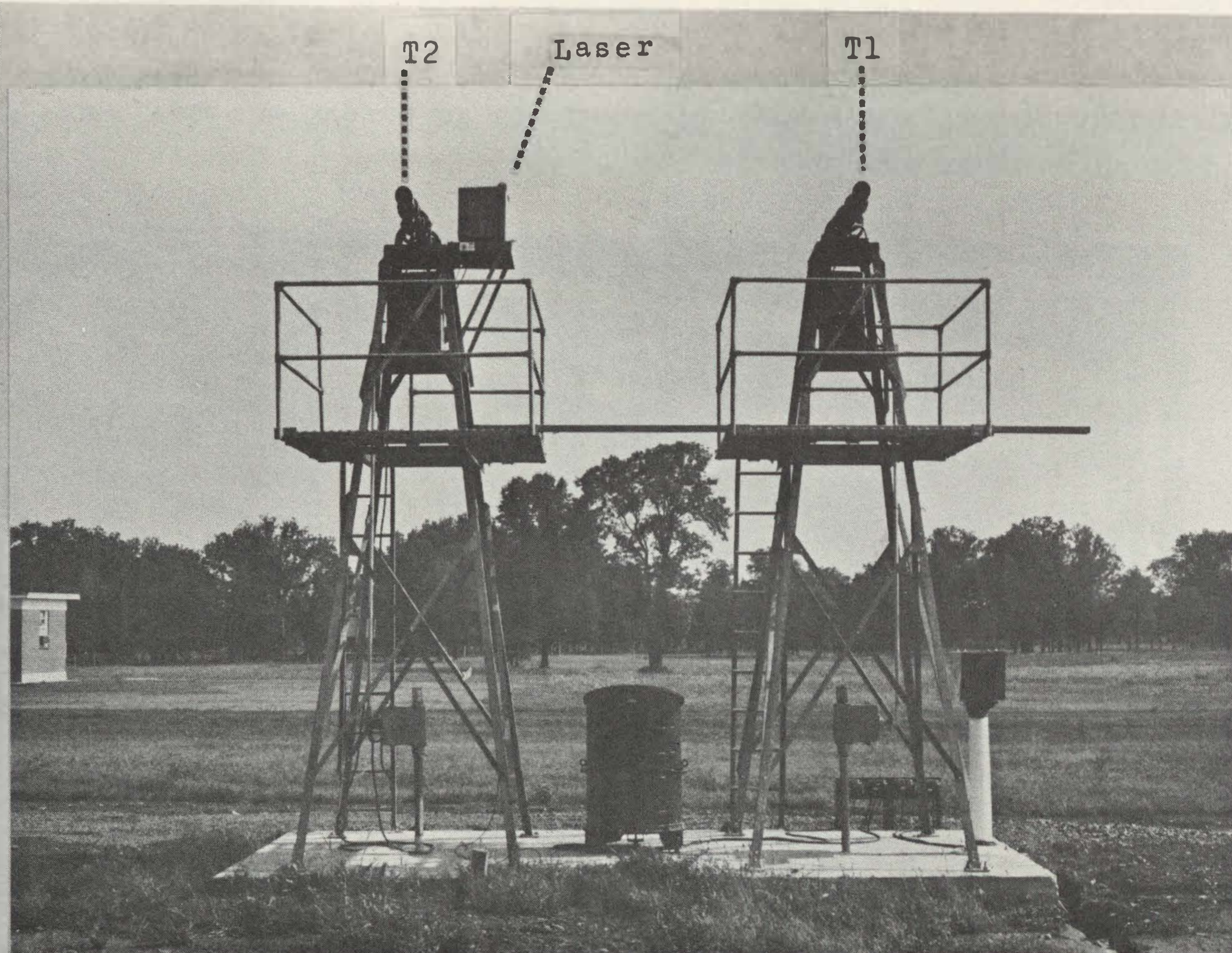

FIGURE 1 - Arrangement of the Two Transmissometer Receivers and the Laser Projector at the Field Test Site

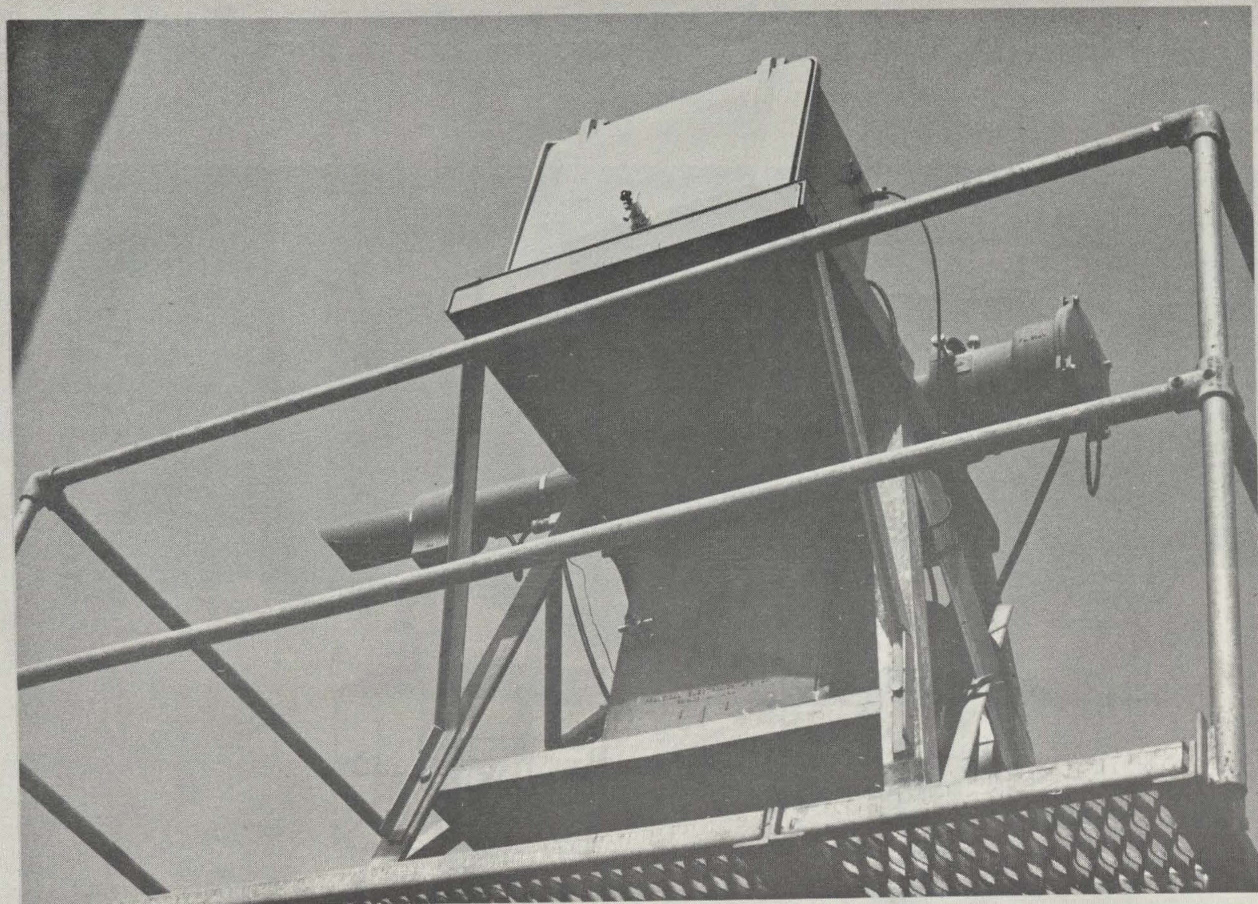

FIGURE 2 - View from the Ground of the Laser Projector Mounted Alongside the T2 Receiver

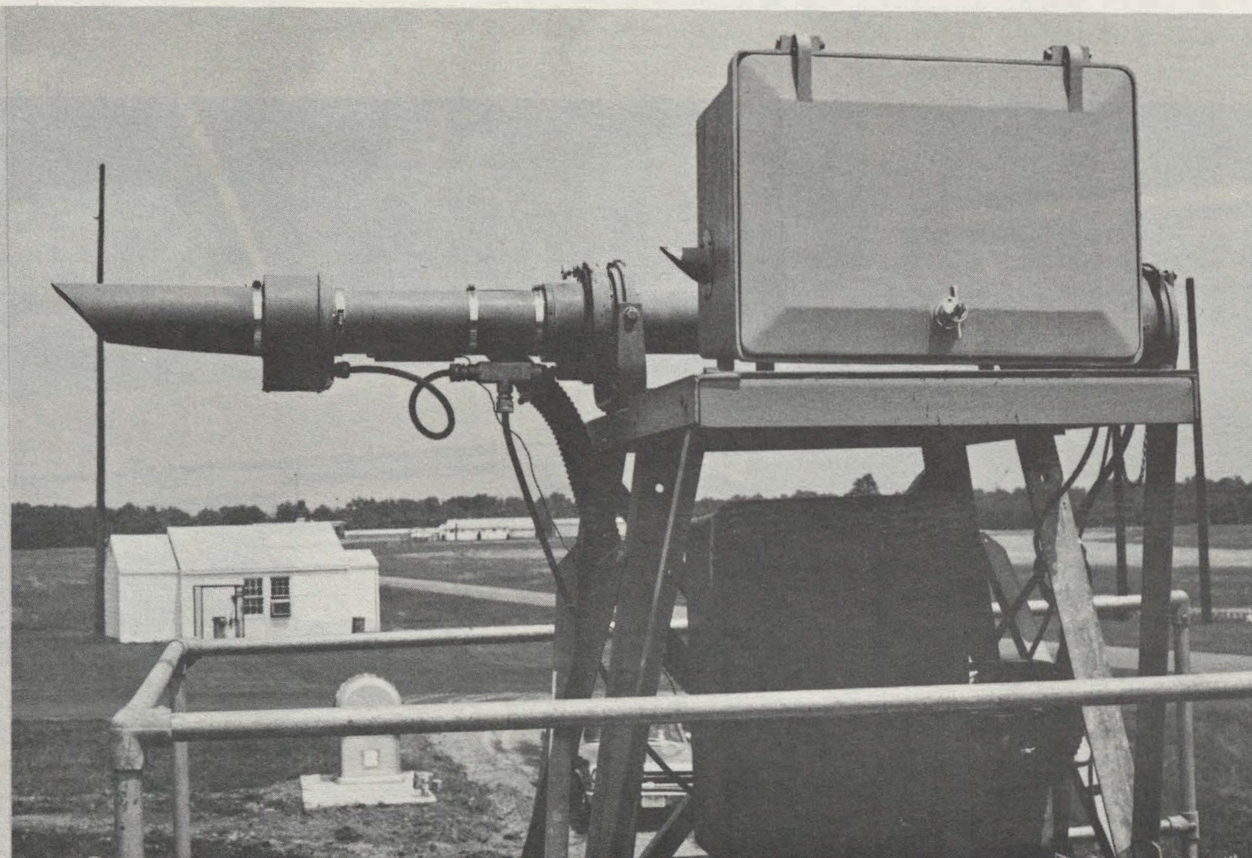

FIGURE 3 - Side View of the Laser Projector Fixed Atop the T2 Tower

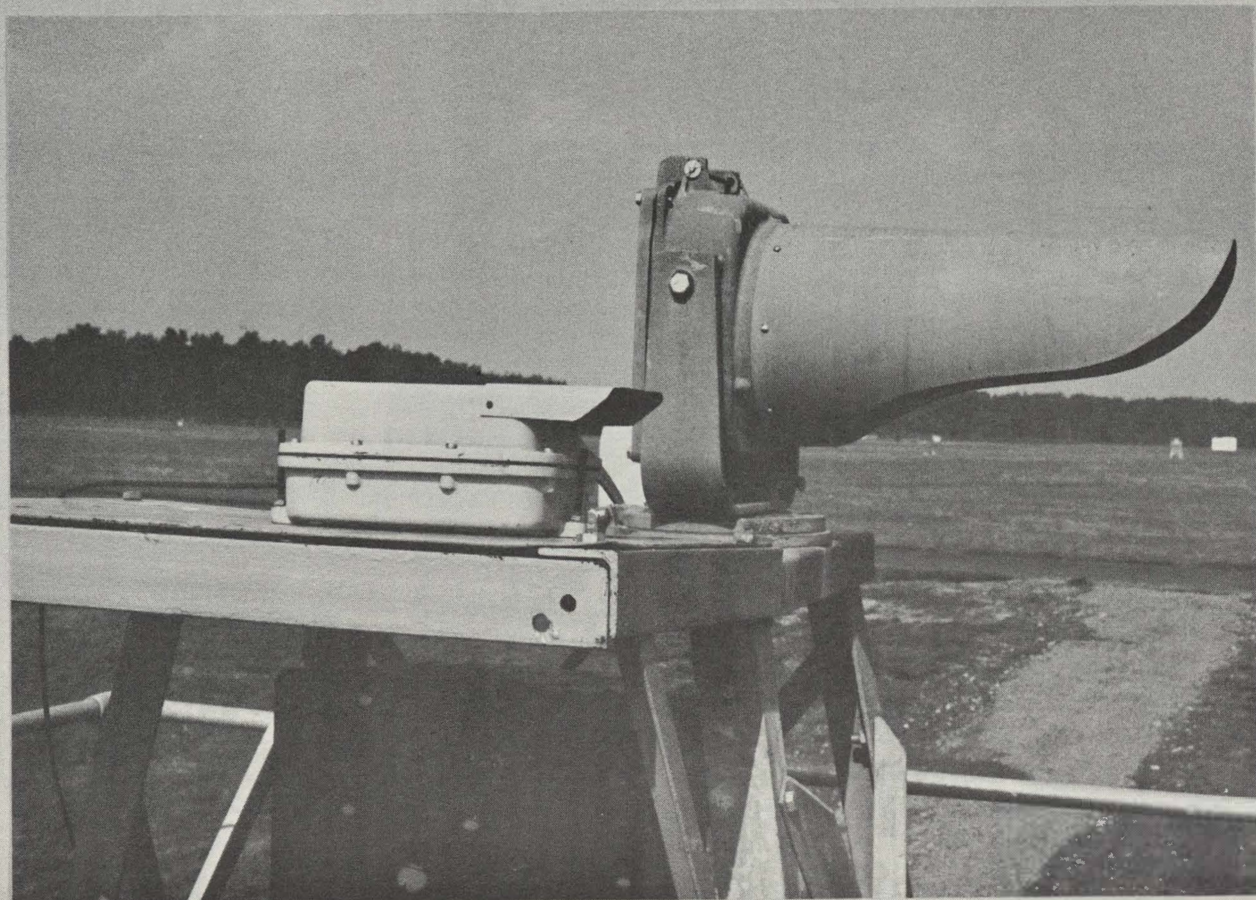

FIGURE 4 - The Laser Remote Detector in Position Alongside the T2 Projector

DATA ACQUISITION EQUIPMENT

Output from each of the NBS-type transmissometer receivers was fed approximately 2000 feet to a pair of strip chart recorders (figure 5) and to a photo-pack data acquisition system (figure 6). The recorders, which gave an analog presentation of transmittance versus time, were standard units used with the NBS-type transmissometer system. The photo-pack, which photographically recorded transmissometer pulse counts, has been used successfully in previous transmissometer studies (reference 5).

The photo-pack unit made one photograph per minute. Each frame recorded the following information:

- frame number
- data period number
- date of the year
- time of day
- transmissometer T1 pulse counts per preceeding 55 sec.
- transmissometer T2 pulse counts per preceeding 55 sec.

EQUIPMENT MAINTENANCE

The two NBS-type transmissometers received regular maintenance checks by SR&DC electronic technicians. Both units conformed to exisiting FAA specifications. No maintenance was necessary on the laser system during its test and evaluation.

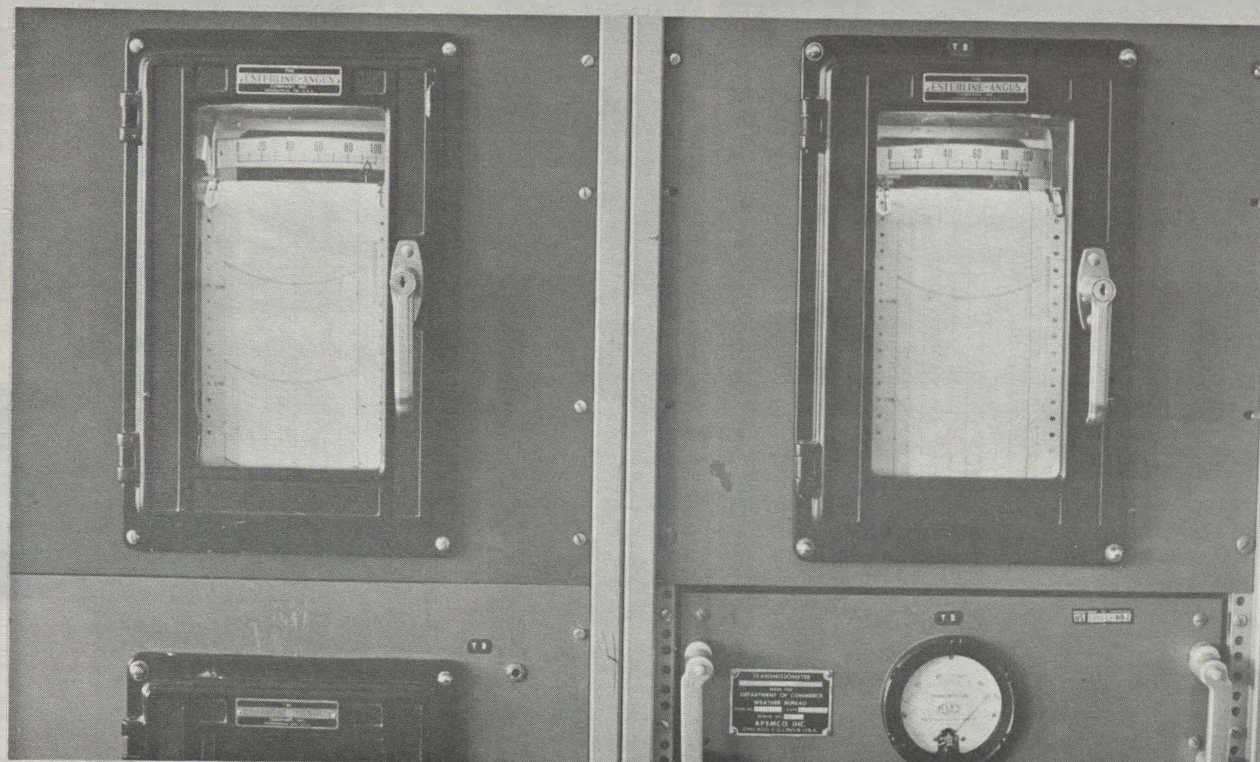

FIGURE 5 - Strip Chart Recorders for Transmissometers T1 (on left) and T2 (on right)

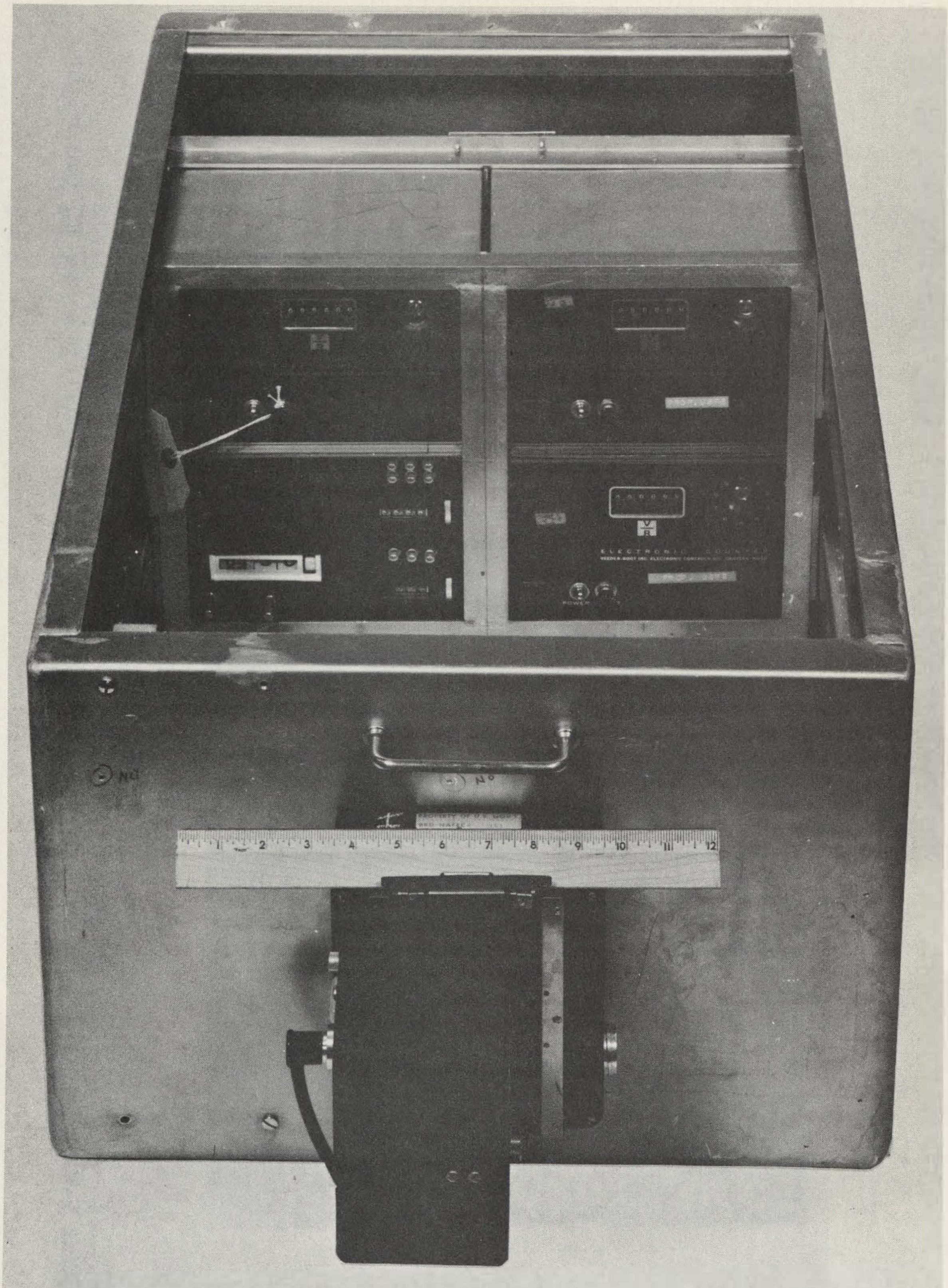

FIGURE 6 - The Photo-Pack Data Acquisition System for Recording Transmissometer Pulse Counts

DESCRIPTION OF THE LASER DEVICE

(A) Physical Description.- The laser visibility measuring system consists of the two packages shown in figure 7. On the top is the source housing. In the lower part of the figure is the remote photoelectric detector housing. Figure 8 shows the source housing with the control panel door open. The laser plasma tube, power supply, indicating amplifier, and calibration photoelectric detector are labeled for future reference in this report. Figure 9 shows the arrangement of the collimating telescope and beam expander, beam splitter, and the source photoelectric detector in the source housing. The remote detector housing is shown with the housing disassembled in figure 10.

System dimensions and characteristics are listed in Table 1.

(B) Functional Description.- The laser system was designed to perform the same function as the NBS-type transmissometer, i.e., to measure atmospheric transmittance along a fixed path length or baseline as it is commonly called.

(1) Function of the laser light source.- The laser produces light which is propagated continuously along a given path through the atmosphere. A measure of atmospheric transmittance is obtained by comparing the intensity of light at the end of the path with the intensity at the source. In performing its function, the laser has several advantages over the transmissometer light. The laser produces light which is essentially monochromatic. By chosing filters which admit only light at the laser wavelength to the photoelectric detector, interference and noise at non-laser wavelengths are virtually eliminated. The laser beam may be easily altered by optical means to product coherent light rays of small cross-sectional area. Thus, all of the laser light beam may be seen by the photo detector. The He-Ne laser which has evaluated operates at 6328A, in the red portion of the visible light spectrum. This is near the peak response (7000 A to 9000A) of the spectrum observed by the NBS-type transmissometer receiver. Thus, the laser system can be expected to produce a measure of atmospheric transmittance similar to that of the transmissometer.

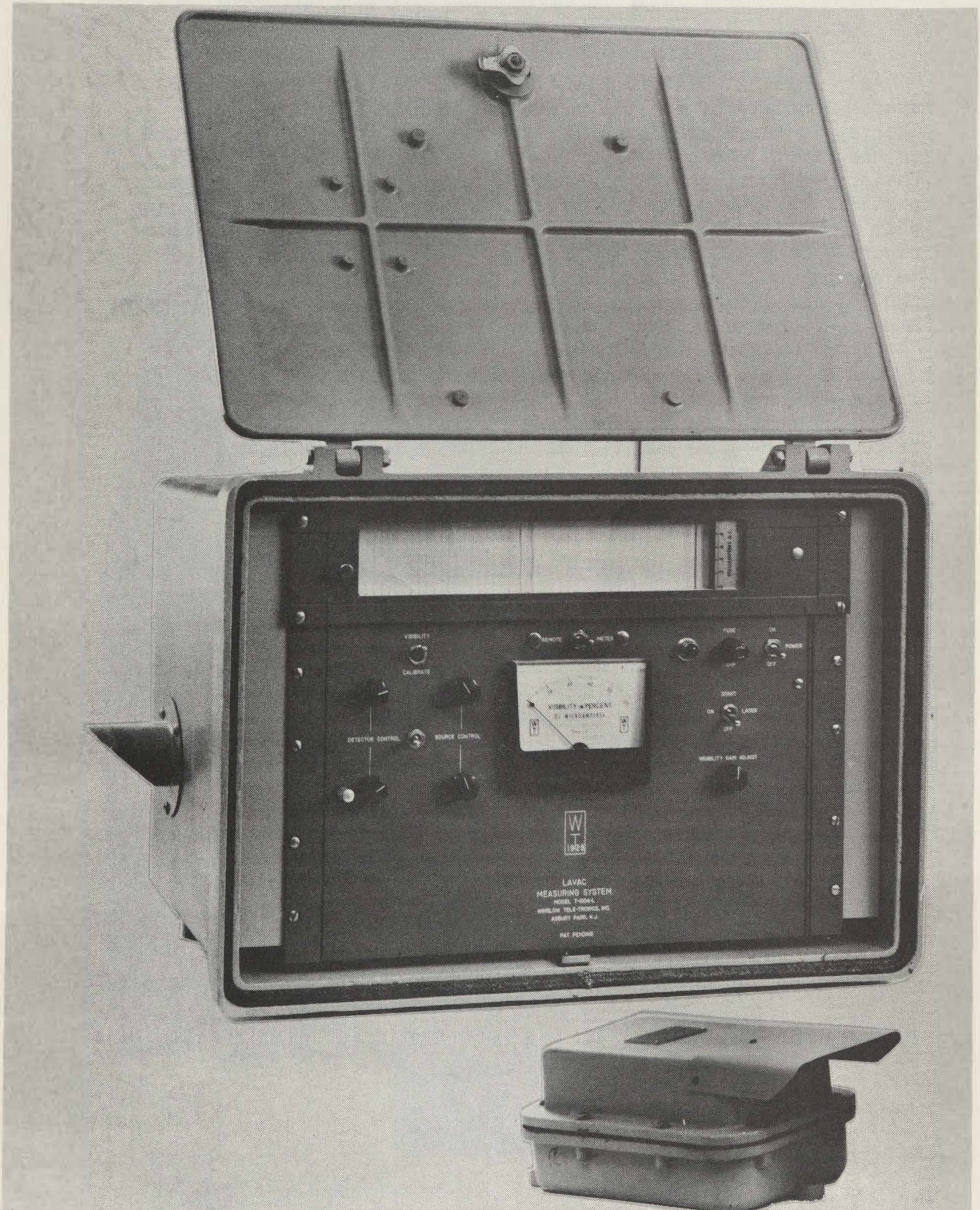

FIGURE 7 - The Laser System Consists of the Source Housing (at top) and the Remote Detector Housing (at bottom)

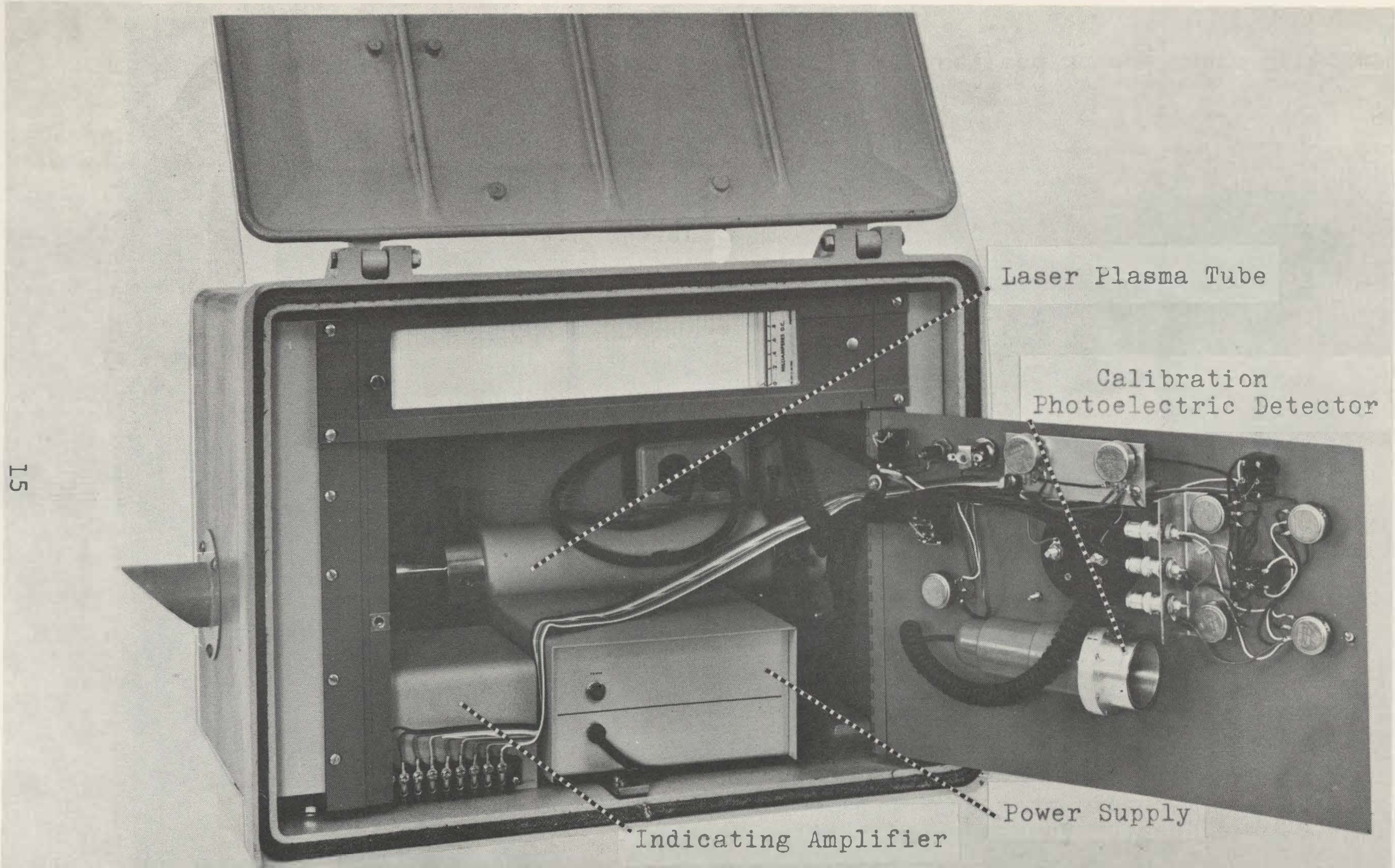

FIGURE 8 - The Interior of the Laser Source Housing

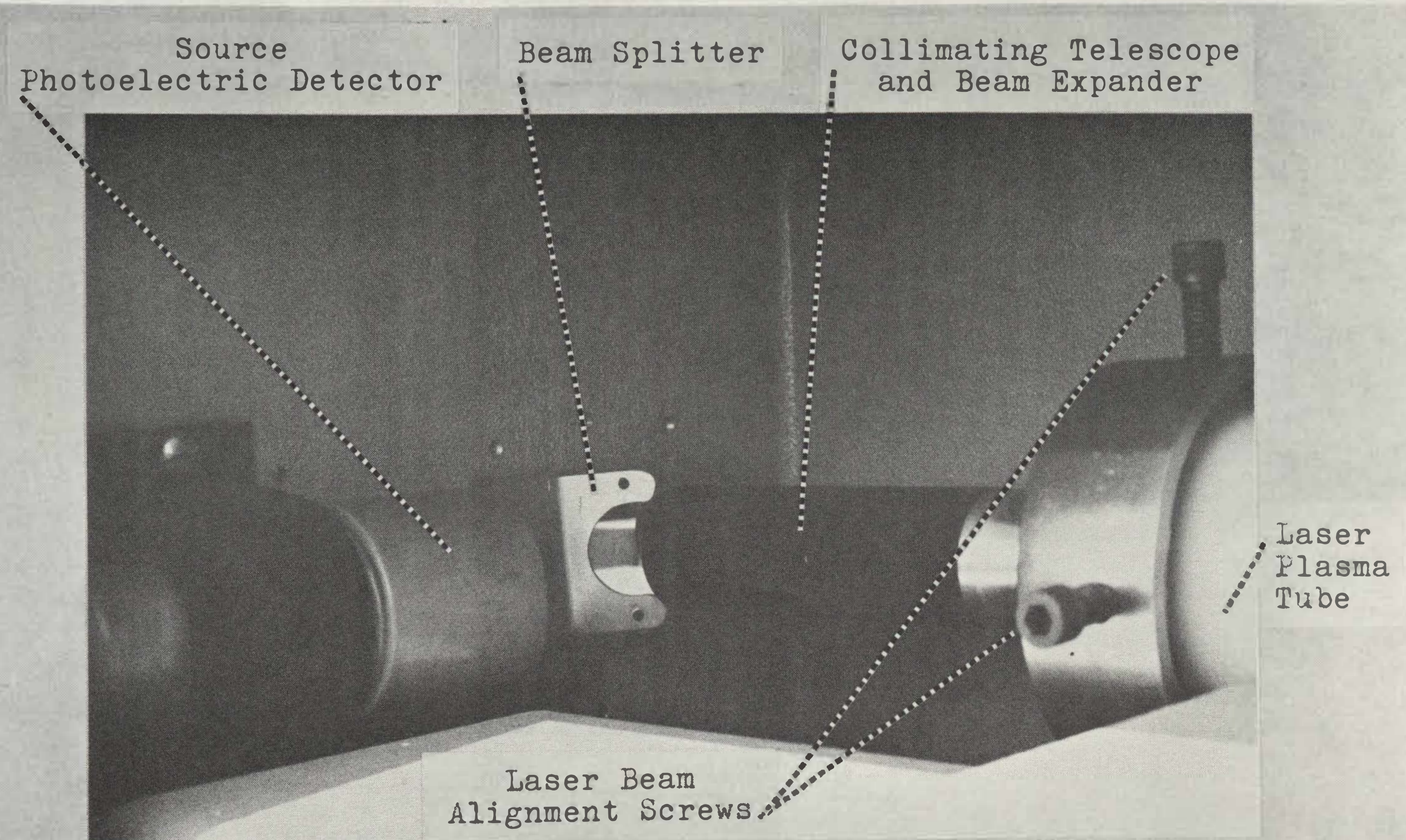

FIGURE 9 - Positions of the Laser Plasma Tube, Optics, and Source Photo Detector in the Source Housing

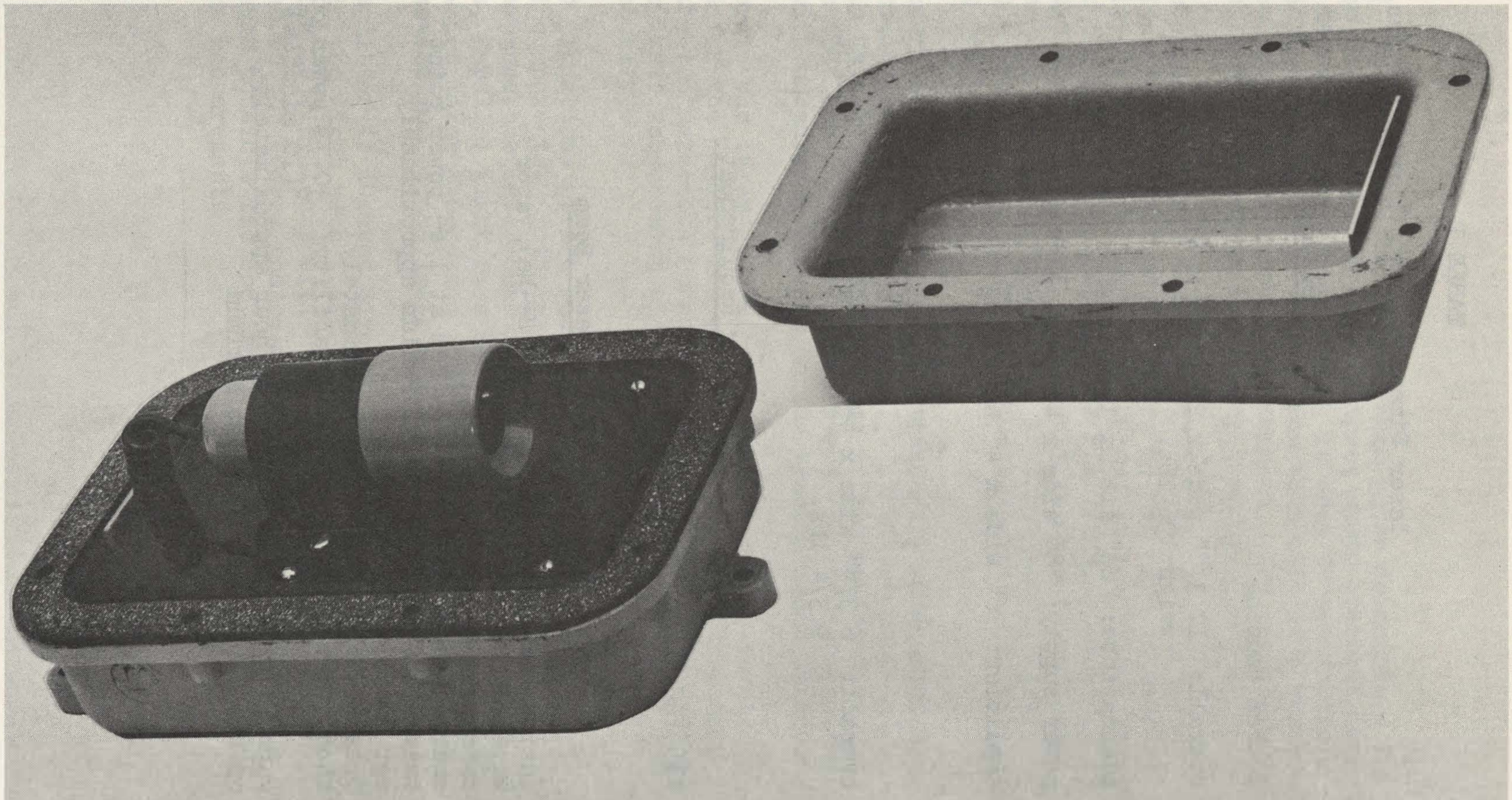

FIGURE 10 - The Remote Photoelectric Detector Housing Disassembled

TABLE I

Laser Dimensions and Characteristics

Dimensions

Source Housing

overall: 17 3/8" wide x 23" high x 13" deep
weight 96 lbs.

plasma tube: $2\frac{1}{2}$" dia. x $13\frac{1}{2}$" long

power supply: 8" wide x $4\frac{1}{2}$" high x 7" deep

amplifier: 6" wide x 4" high x $5\frac{1}{2}$" deep

Detector Housing

overall: 6 3/4" wide x $4\frac{1}{2}$" high x $15\frac{1}{2}$" deep weight
9 3/4 lbs.

Power Requirement

115 VAC single phase 60 Hz

Laser Beam

lasing material: Helium-Neon (He-Ne) vapor
wavelength: 6328 Angstroms
emergent power: 1 milliwatt
emergent beam diameter: 0.2 cm at $1/e^2$ power point
beam divergence: 0.5 milliradian approximately
net power: 0.3 milliwatt
beam diameter: 1.35 cm approximately
short term output amplitude stability: $\pm$0.7% power output (10 minutes)
warm up time to stability: 1 hour approximately
operating range: 500 feet maximum

(2) Functions of the laser system photo detectors.- The laser system which was tested employs three photo-electric detectors. The source detector, shown in figure 9, is used to continuously monitor the laser light. The output from this unit is a reference to which the other two detectors are compared. The source detector is permanently mounted inside the source housing.

The second photoelectric detector, the calibration detector (shown in its storage position in figure 8), is used to measure the intensity of the laser light leaving out of the source housing. Output from the calibration detector is electrically compared to that from the source detector. The result is used to calibrate the laser system for measuring atmospheric transmittance. Figure 11 shows how the detector is temporarily fastened to the source housing hood during calibration.

Measurements of atmospheric transmittance are made using the remote photoelectric detector (figure 7). This detector is electrically matched by the manufacturer to the calibration detector so that one unit could, if desired, be substituted for the other with no adverse effects on the transmittance measurement.

To calibrate the laser system, the remote detector is electrically substituted for the calibration photo detector, an action made possible by having the two detectors connected in parallel. Thus, any adjustment of the laser measurement circuitry will affect both of the matched detectors equally.

(3) Functions of the laser system optics.- The system employs two optical components. Both are shown in figure 9. The collimating telescope expands the laser beam from 0.2 cm diameter to 1.35 cm. In the process, parallel light rays are formed. It is the collimating telescope which makes the system able to measure the intensity of the entire cross-section of the laser beam.

A beam splitter is located directly in front of the collimating telescope in the light path inside the laser source housing. The beam splitter is fixed in position so that it deflects one-third of the light to the source photoelectric detector. Use of the beam splitter makes possible the continuous referencing of the laser transmission measurement.

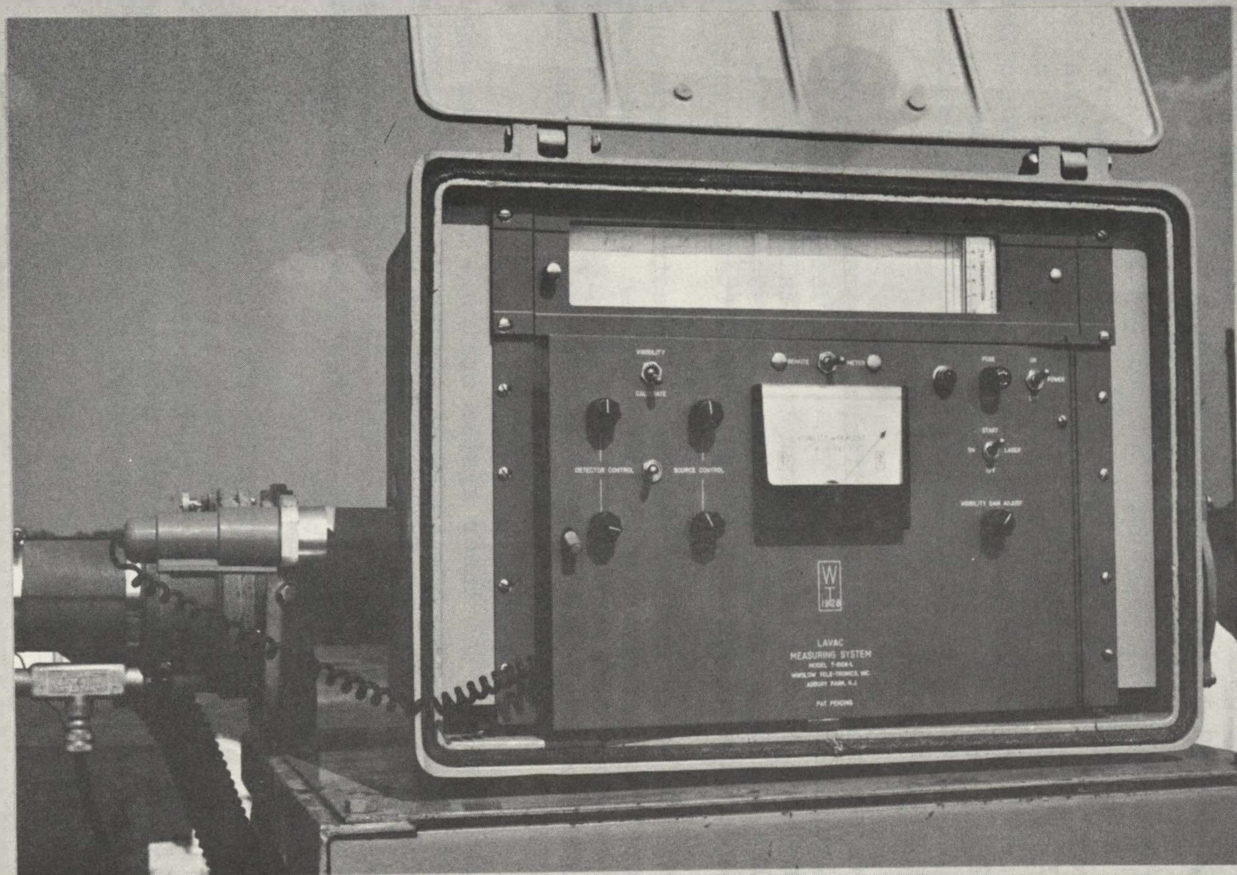

FIGURE 11 - The Calibration Detector Fixed in the Laser Beam Path During System Calibration

LASER CALIBRATION

The laser transmissometer was designed to be capable of being calibrated under all visibility conditions without reference to other instruments or observations.

The method of calibration relies upon the use of two electrically equivalent photoelectric detectors. One detector (the calibration detector) is used to calibrate the visibility measurement circuitry. The other matched detector (the remote detector) is used for the actual visibility measurement. A third unit (the source detector), which operates continuously, is used as a reference to which the equivalent sensors are electrically compared.

The system functional diagram, figure 12, shows the relationship of components in the model tested.

The internal calibration of the laser transmissometer is successful when the following criteria are met:

(1) The remote photoelectric detector and the calibration photoelectric detector must have identical electrical response characteristics so that one may be substituted for the other during system calibration.

(2) A negligible amount of laser light is attenuated in the short distance (2 inches) from the beam splitter to the source photoelectric detector.

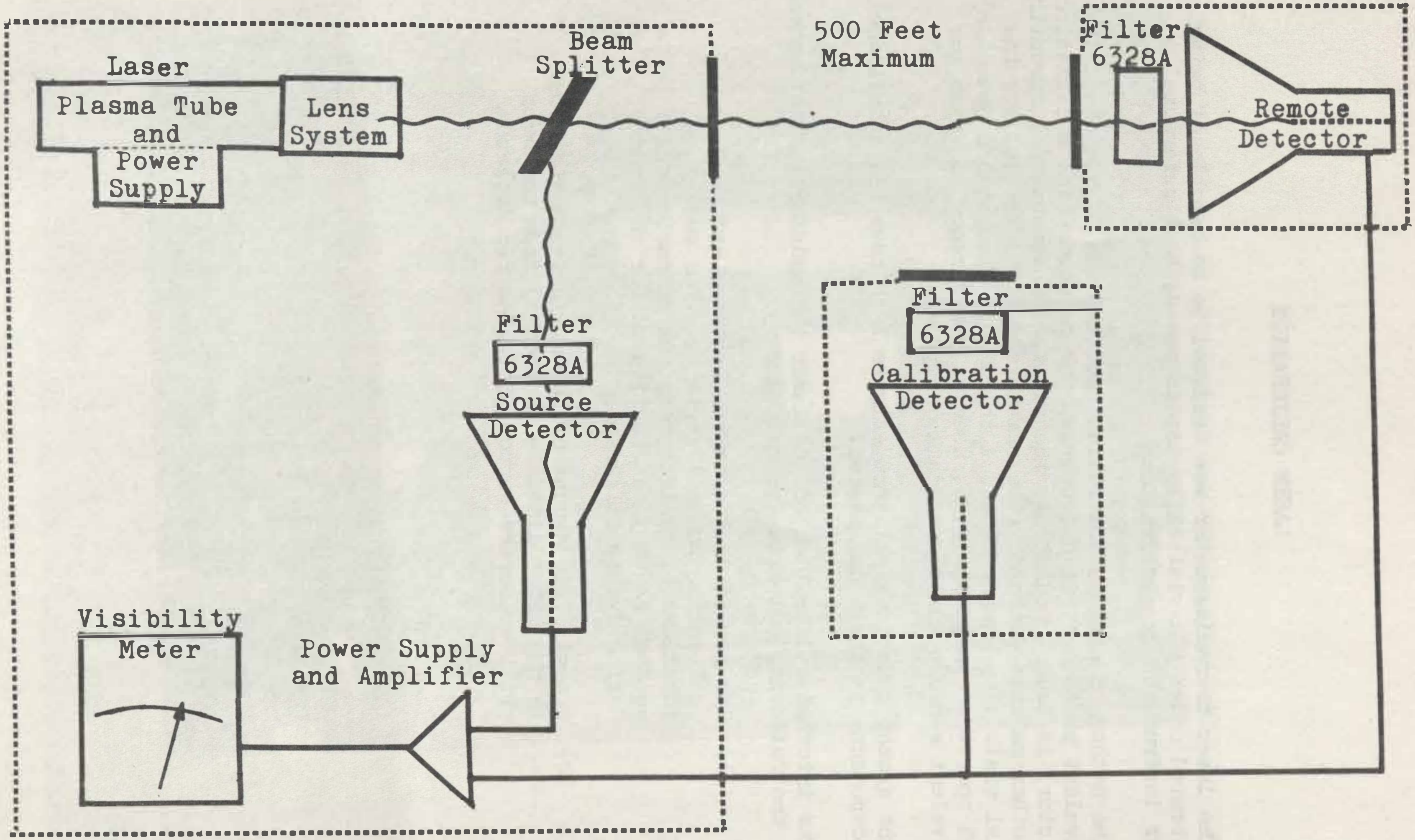

FIGURE 12 - Functional Diagram of the Laser Transmissometer Calibrator System

LASER SAFETY

Helium-Neon continuous wave lasers have been used successfully by the Environmental Science Services Administration Coast and Geodetic Survey (C&GS) as geodimeters. In that application, carefully trained and experienced technicians operate the laser atop towers 37 or more feet above ground level. The C&GS lasers are three to five times more powerful than the tested laser system and are sighted over distances up to 10 miles.

By contrast, the laser transmissometer calibrator would be operated by electronic technicians whose full time and attention are not directed toward routine laser operation. Also, the calibrator would be used during inclement weather in which poor working conditions will be common. For these reasons, safety from laser hazards is a most important consideration for those who would be working with the calibrator.

Prior to designing safety precautions for the laser system, we consulted with the Environmental Science Services Administration (ESSA) Safety Engineer and with the C&GS Scientific Advisor. The information gained from these consultations and from references 6-9 were used as bases for determining safety precautions.

(A) Laser Beam Description.- The laser beam emerges from the plasma tube with a diameter of approximately 0.2 cm and a power of 1 milliwatt. The beam passes through the optics which expands and splits the beam. The portion of the laser beam leaving the source housing has a power of approximately 0.3 milliwatts. It is this effective source power against which eye protections is required.

(B) Safety Hazards.- Several hazards dealing with lasers have been reported in the literature (references 6 & 7). Most laser associated hazards are ocular in nature and pertain to the intense beam emitted by these devices. Just as important as ocular hazards however are the so-called "common sense" dangers; those associated with any type of electronic equipment.

(C) Ocular Hazard Computations.- Ocular dangers from a particular continuous wave laser involve the power, focus and siting of the laser beam. Equations used to compute beam parameters are straightforward and are generally accepted by laser authorities. Table II presents the information necessary to compute this laser system beam safety parameters.

TABLE II

Information Required for Computing

Laser Beam Parameters

Power Output	(E)	0.3×10^{-3} Watts
Beam Divergence	(f)	0.5×10^{-3} radians
Beam Diameter	(d)	1.35 cm
Baseline, or Range	(b)	in centimeters
Atmospheric Attenuation*	(u)	10^{-7}/cm

*$u = 10^{-7}$/cm is a clear air value, the worst hazard condition for transmission of laser light. $U = 10^{-5}$/cm is a value comparable to a meteorological visual range of 1 mile.

(1) Average beam intensity.- Average beam intensity is a measure of laser power averaged over the beam cross-section. It is this power which can be focused by the lens of the eye onto the retina. The potential for ocular lesions, or burns, is thus related to average beam intensity.

Average beam intensity, $$I = \frac{1.27\ E\ e^{-ub}}{(d + bf)^2}$$

The values and meanings of the terms in the average beam intensity equation are defined in Table II. Table III lists the results of several computations of I. At a range of 0 feet, or directly in front of the source housing, the laser system average beam intensity is 2.1×10^{-4} Watts/cm^2. At a range of 1290 feet, it has decreased to 10^{-6} Watts/cm^2. Figure 13 shows the relationship of the system's average beam intensity to range up to a distance of 1290 feet.

(D) Eye Hazard Evaluation.- The danger of eye injury applies when the eye is located along the primary beam at a distance sufficiently near the laser source. Though there is not yet a set of closely defined laser exposure standards, there is some agreement as to the content standards should include. Theoretical considerations and medical experiments indicate that retinal burns may result with exposure to laser intensities of 10^{-3} Watts/cm^2. Since the greatest laser system power intensity is about one-fifth that of the suggested exposure limit, the danger of eye damage resulting from accidently viewing the beam is greatly reduced.

Because the full effects of laser induced eye damage are not completely understood, routine exposures to beam intensities of 10^{-3} to 10^{-6} Watts/cm^2 are discouraged. Table III indicates that the intensity drops to 10^{-6} Watts/cm^2 at a range of 1290 feet. Therefore, eye protection should be used along the entire baseline when the laser system is used as a transmissometer calibrator.

(E) Laser Safety Precautions.- Safety precautions developed and used during the test period were possibly more stringent, in some respects, than necessary. However, the lack of specific laser hazard exposure criteria made conservative action desirable.

TABLE III

Laser Range (or Baseline) Versus Average Beam Intensity

Range ft.	Average Beam Intensity Watts/cm^2
0	2.1×10^{-4}
50	8.6×10^{-5}
125	3.6×10^{-5}
250	1.4×10^{-5}
500	4.7×10^{-6}
750	2.3×10^{-6}
1000	1.4×10^{-6}
1290	10^{-6}

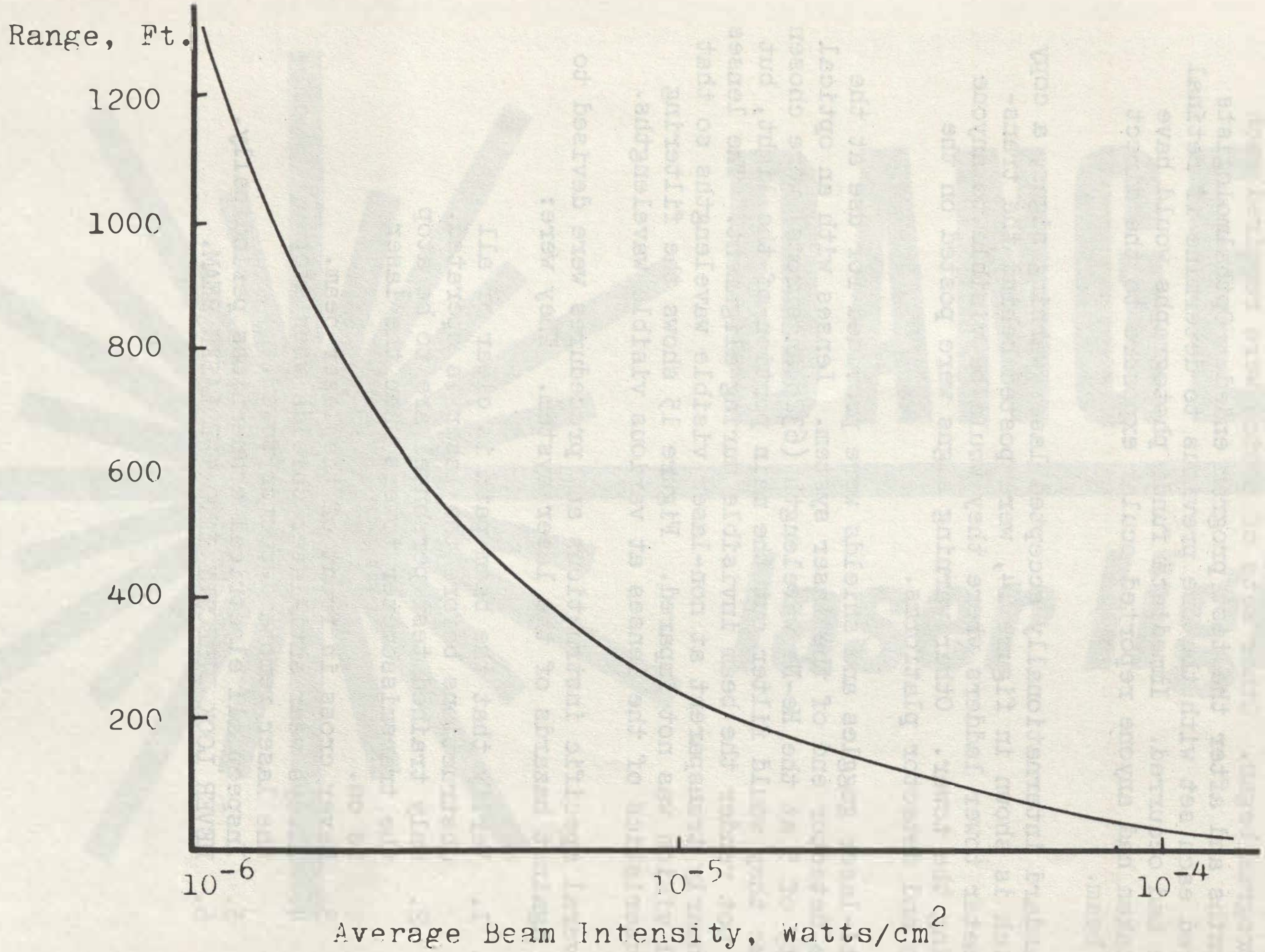

FIGURE 13 - Average Laser Beam Intensity Versus Range

The number of personnel assigned to operate the laser system was kept to a minimum. This reduced total training time and made it possible to impress the importance of strict adherence to safety regulations.

Test personnel received ocular fundi photographs before the test program began. Other sets of photos were required each six months and after the test program ended. Opthalmologists compared each set with the one previous to determine if retinal damage had occurred. Immediate fundi photographs would have been taken had anyone reported ocular exposure to the direct laser beam.

Standard internationally accepted laser warning signs, a copy of which is shown in figure 14, were posted behind the transmissometer tower ladders where they would be visible to anyone climbing the tower. Other warning signs were posted on the source and detector platforms.

Anti-laser goggles and shields were provided for use at the remote detector end of the laser system. Lenses with an optical density of 5 at the He-Ne wavelength (6328 Angstroms) were chosen because they would filter out the main portion of the light, but would not render the beam invisible during alignment. The lenses were nearly transparent at non-laser visible wavelengths so that normal vision was not impared. Figure 15 shows the filtering characteristics of the lenses at various visible wavelengths.

Several specific instructions and procedures were devised to guard against hazards of the laser system. They were:

1. Verify that the beam path is clear of all obstructions before the laser is operated.
2. Only trained test personnel are to be atop the transmissometer towers when the laser is on.
3. Never cross in front of the laser beam.
4. Always wear anti-laser shields when atop the laser remote detector tower.
5. Inspect all electrical connections periodically.
6. NEVER LOOK DIRECTLY INTO THE LASER BEAM.

FIGURE 14 - The Type of Laser Warning Sign Used to Designate the Test Area

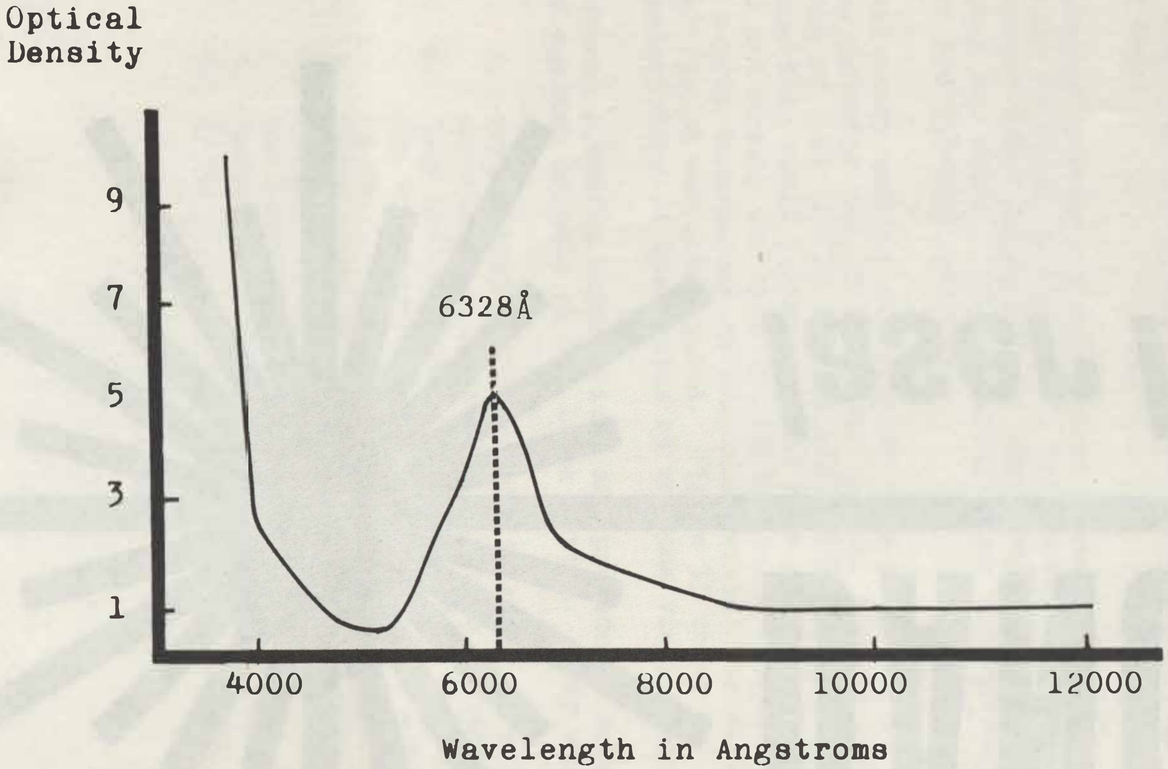

FIGURE 15 Filtering Characteristics, Wavelength Versus Optical Density, of the Anti-Laser Goggles Used With the Laser System

OPERATING THE LASER SYSTEM

(A) Turning on the System.- The following describes steps required to turn on, or lase, the plasma tube. The purpose and result of each step is discussed.

1. The system power switch is flipped up (ON) after the necessary safety precautions have been taken. This master switch supplies power to the amplifier circuitry.
2. The three position LASER control switch is placed to the center (ON) position. This supplies filament voltage to the plasma tube.
3. After 10 seconds the LASER switch is flipped up to START. This position supplies the high voltage necessary to ignite the plasma tube.

(1) Time required to turn on the system.- Less than one minute is required to set the proper switches for turning on the system. After the switches are set, from one to three minutes is required until the plasma tube ignites, or produces light. The longer time is characteristic at temperatures near freezing. The shorter time is usual when the system is at room temperature.

(B) Laser Beam Alignment.- Beam alignment of the system tested is a time consuming and challenging experience. There are three reasons for this. First, the system provides no means of optically siting the beam to the remote detector. Instead, the beam must be located at the detector tower by a second technician who directs the operator in aiming the light. This arrangement greatly increases the danger of accidental exposure to intense laser light.

Second, the beam alignment mechanism in the laser system, even when operating properly, has only a small, limited range of adjustment. As a result, the entire 100 lb. source housing must be moved until the beam is nearly aligned. This trial and error process can require as much as an hour of labor before the light is aligned with the detector.

Third, the beam cross-section is nearly equal to that of the remote photo detector window area. This causes alignment to be both difficult to achieve and sensitive to even small movements.

(1) Initial alignment.- Two technicians were required to align the beam of the model tested. One was stationed at the source housing to operate and aim the laser. The other was atop the remote detector tower (the transmissometer projector tower) to locate the laser beam and direct its alignment with the detector.

We found that the beam is best located by holding a large sheet of white paper or some other light colored (but non-reflecting) surface in the laser beam. The laser light will show up as a bright spot on the white paper. A sheet of paper about three feet on a side gives both large coverage when searching for the beam and yet is small enough to handle conveniently.

Once located, the beam is aimed toward the remote detector and adjusted until the laser system visibility meter reaches maximum deflection. When the system tested is first aligned after set up, the entire source housing must be moved until the beam is about 3 ft. from the detector. Shims may be needed under some of the housing supports to change beam elevation. The source housing must be secured to its platform before final beam alignment.

(2) Final alignment.- The plasma tube alignment screws, two of which are visible in figure 9, may be used once the beam is within three feet of the remote detector. There are four screws, set at 90° intervals around each of two steel rings. The rings fit loosely around the ends of the plasma tube. The adjusting screws are turned through the rings until the plasma tube is held snugly and the laser beam properly aligned.

Alignment of the beam is verified by gently pushing on the sides, top, and bottom of the source housing while observing visibility meter deflections. If the meter reading decreases whenever the housing is pushed, the beam is in alignment. If the meter reading should increase when the housing is pushed in any direction, the beam is misaligned and must be adjusted.

Because the laser beam diameter is small relative to the baseline, small movements of the adjusting screws produce large movements of the beam at the remote detector 250 to 500 feet away. Such movements are particularly disturbing when tightening the screws to hold the plasma tube after the beam is aligned.

(3) Time required to align the laser beam.- We found that from two to four hours were needed to align the laser beam after the system is set up. Most of this time was spent in initial alignment. Final adjustments using the alignment screws generally require from 5 to 25 minutes. Alignment time was dependent upon the level of experience of the two technicians. As the test period progressed, we found that the device could regularly be aligned in about two hours.

The time to align the system could have been greatly reduced by providing an optical siting device atop the plasma tube. This would also eliminate the need for a second technician atop the remote detector tower.

(C) Calibrating the System.- The following describes the steps used during calibration. The purpose and result of each step is discussed.

1. The REMOTE-METER switch should be in the METER position. The output will then be displayed as percent transmittance on the visibility meter. All calibration settings are made with reference to the meter.
2. The VISIBILITY-CALIBRATE switch must be set at CALIBRATE during the initial steps of system adjustment. When the switch is in this position, only the source detector output is fed to the amplifier.
3. The source detector is adjusted while the DETECTOR/SOURCE CONTROL switch is set at SOURCE. The SOURCE CONTROL knob is turned until the meter shows 100% transmittance. This means that the source detector output is properly calibrated.
4. To adjust the calibration detector, the DETECTOR/SOURCE CONTROL switch must be set at DETECTOR. At this setting, the amplifier will receive the input from the calibration detector.

   The calibration detector is fitted onto the laser source housing hood (figure 16). It is positioned directly in the laser beam path only a few inches in front of the plasma tube.

   The DETECTOR CONTROL knob is adjusted until the visibility meter reading reaches 100%. This indicates that the calibration detector output is correctly adjusted to the source detector output.

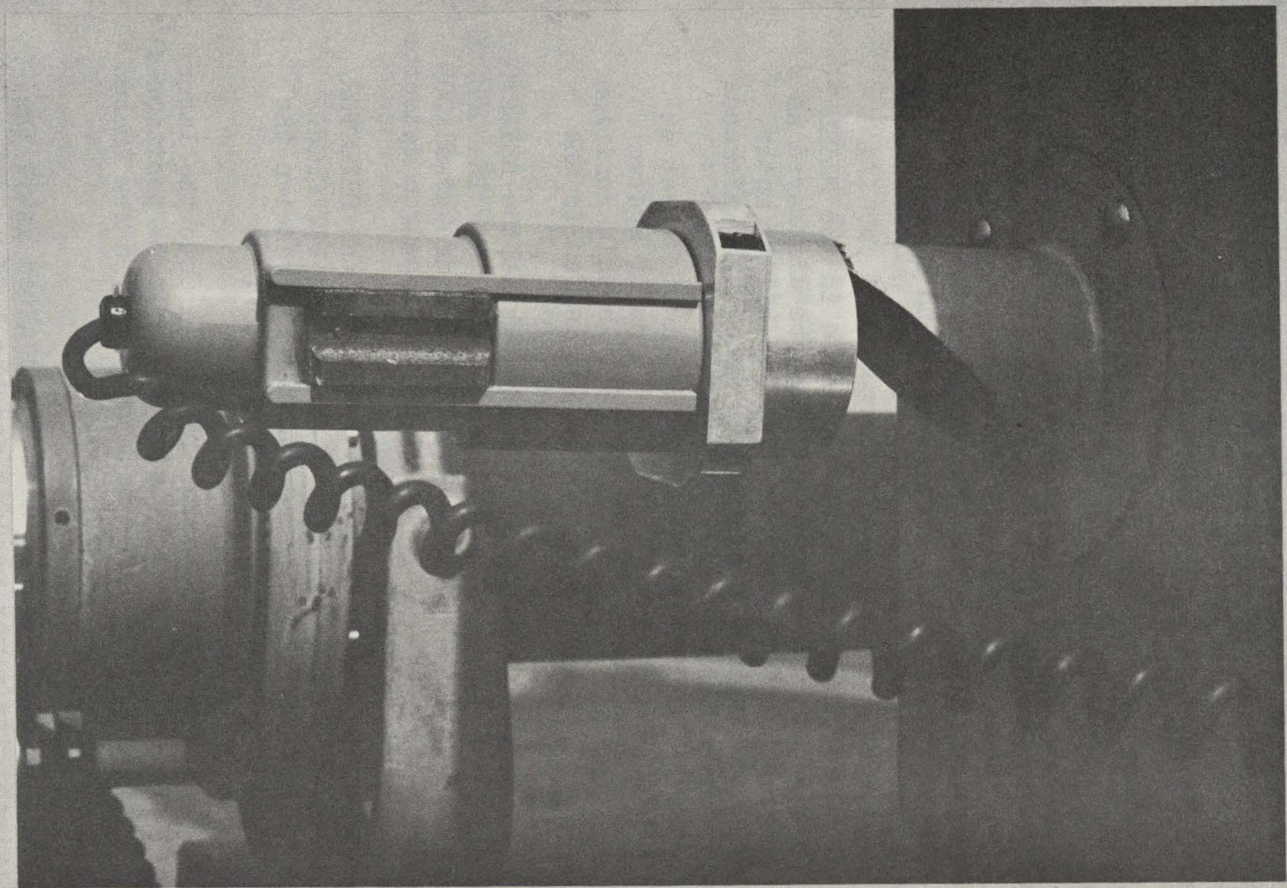

FIGURE 16 - The Calibration Detector Fastened onto the Laser Source Housing Hood

5. The final step in the calibration is to adjust amplifier output to a full scale meter reading. To do this, the VISIBILITY/ CALIBRATE switch must be set at VISIBILITY. The VISIBILITY GAIN ADJUST knob is manipulated until the visibility meter indicates 100%.

The laser transmissometer is now calibrated to yield a measure of atmospheric transmittance. After the calibration detector is removed from the source housing hood, the meter will show the percent of laser light transmitted along the baseline, and received by the remote photo detector.

(1) Time required to calibrate.- Calibration can be performed in from 2 to 4 minutes after the unit is turned on. Successive calibrations require less time, generally 1 to 2 minutes.

FIELD TESTS

Two identical NBS-type transmissometer systems were used to field test the laser method of calibration. Both systems were maintained according to current standards and specifications so that the two units differed only in the methods by which they were calibrated. Transmissometer T1 was calibrated using the normal 5-mile daytime visibility method. T2 was calibrated using the laser system measurement as a reference.

(A) Test procedure.- The laser method of transmissometer calibration was tested as follows. The two NBS-type systems, the photo-pack data acquisition unit and the laser were verified to be in proper working order. Transmissometer T2 was decalibrated by turning the iris adjustment knob (figure 17) until the transmittance meter indicated a low value, one that was obviously in error.

The time required to calibrate the laser system, and its visibility meter reading, were recorded on a data form. A copy of the form and an explanation of its use is given in figure 18.

Transmissometer T2 was calibrated using the laser visibility meter reading as a reference. The T2 iris was adjusted until the transmittance meter indicated a reading as near identical as possible to that noted for the laser. The time required for transmissometer T2 calibration was then recorded. The laser visibility meter reading after T2 calibration was also noted as a check for laser stability.

One to three minutes were allowed between each of the steps so that the photo-pack could record sufficient data.

(B) Data acquisition periods.- We acquired transmissometer calibration data during seven separate periods from May through July 1969. Six of the periods were daytime observations. Fog, ground fog, haze, and very light rain occurred during the test periods.

Table IV lists the time/date, weather occurrences and special operational problems encountered during each data period.

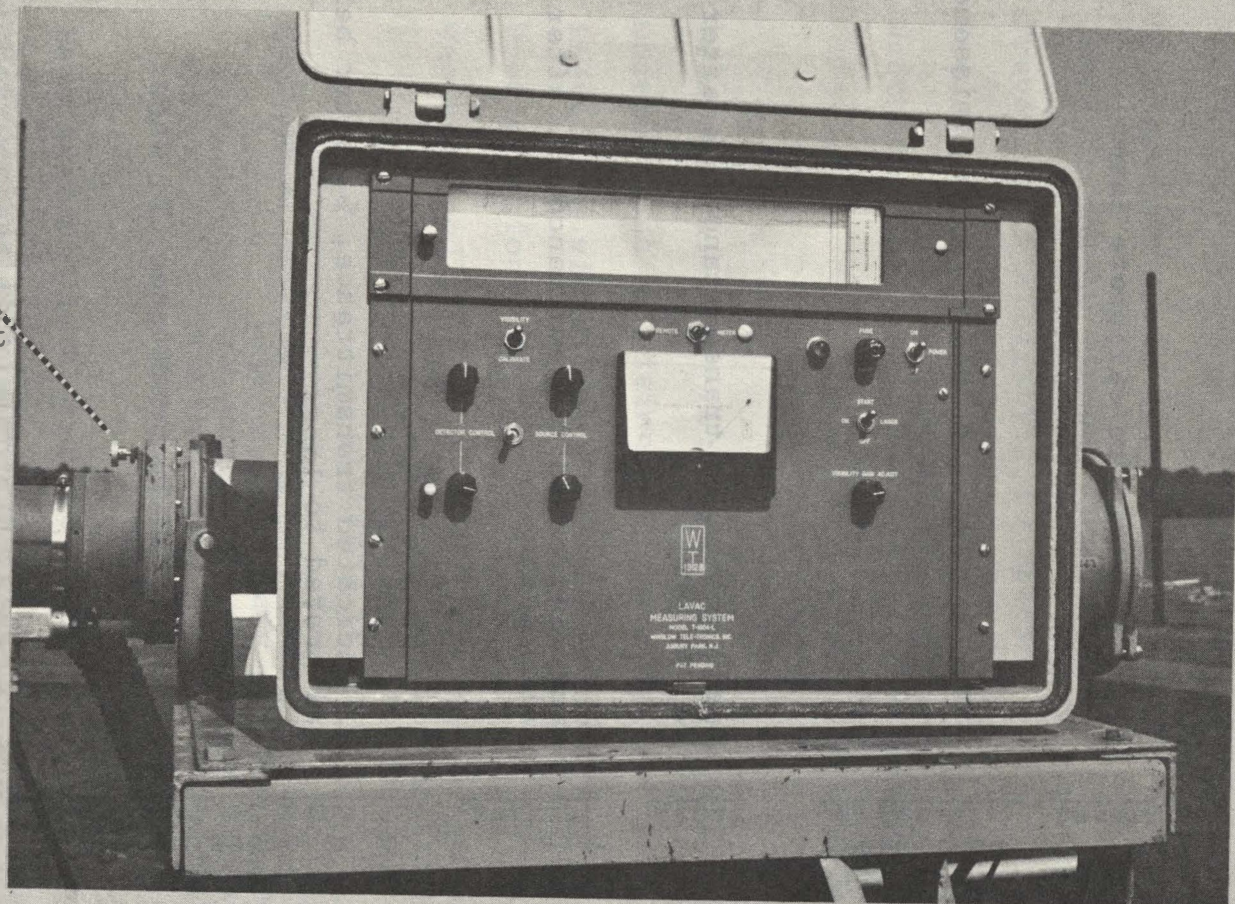

FIGURE 17 - The T2 Iris Adjustment Knob Location Relative to the Laser System

Laser Transmissometer Field Data

Date ____ Acquisition Period L-____

Obstruction to Vision		Obstructions to vision according to Circular N, Manual of Surface Observations.[10]
Indicated Transmittance, % — Transmissometer 2	initial	T2 indicated transmittance, %, when decalibrated
	final	T2 indicated transmittance, %, after being calibrated to laser
Indicated Transmittance, % — Laser	initial	Laser indicated transmittance, %, after calibration
	final	Laser indicated transmittance, %, after T2 calibration
Time to Calibrate — Transmissometer 2		Time, minutes, to calibrate transmissometer T2 using the laser
Time to Calibrate — Laser		Time, minutes, to calibrate laser
Remarks		Additional information, such as weather changes and operational difficulties

FIGURE 18 - Laser Field Test Data Acquisition Log

TABLE IV

Summary of Laser System Data Acquisition Periods

Data period: L-1 12:45-1:40 pm EST 6-2-69

Obstructions to vision: none

Prevailing visibility: 10 miles

Precipitation: none

Weather conditions: Period L-1 occurred on a day with bright sunshine and scattered clouds. A small amount of haze was in the atmosphere.

Data period: L-2 10:45 pm 6-9-69 to 00:25 am EST 6-10-69

Obstructions to vision: ground fog

Prevailing visibility: 7 miles decreasing to 4 miles

Precipitation: none

Weather conditions: A very light northwest wind blew during L-2. Ground fog drifted through the field test site causing indicated transmittance to vary rapidly.

Problem areas: Drifting ground fog caused indicated transmittance to vary rapidly. It was difficult to accurately calibrate transmissometer T2 to the laser. Frequent beam realignments were required.

Data period: L-3 8:45-10:50 am EST 6-11-69

Obstructions to vision: Haze

Prevailing visibility: 3 to 5 miles

Precipitation: none

Weather conditions: Overcast skies and haze blocked much of the morning sunlight. Prevailing visibility decreased from 4 to 3 miles but increased to 5 miles by 10:30 am.

TABLE IV con't

Data period: L-4 12:10-1:50 pm EST 6-18-69

Obstructions to vision: fog and haze

Prevailing visibility: 3 miles increasing to 6 miles

Precipitation: light rain showers

Weather conditions: Light rain fell intermittently from overcast skies. Thin spots appeared in the overcast near the end of L-4. Surface prevailing visibility increased steadily from 3 to 6 miles during the test period. Winds were from the south at about 5 knots.

Problem areas: Frequent beam alignment was necessary during the first half of the observation period. The strip chart marking needle failed to operate during L-4.

Data period: L-5 8:00-9:35 am EST 6-23-69

Obstructions to vision: Haze

Prevailing visibility: 2½ miles increasing to 4 miles

Precipitation: none

Weather conditions: Skies were overcast. Breaks in the overcast formed midway through L-5.

Problem areas: Laser beam realignment was required before each of the first nine observations of period L-5.

Data period: L-6 5:30-7:20 am EST 6-26-69

Obstructions to vision: Fog, haze

Prevailing visibility: 5/8 mile increasing to 1½ miles

Precipitation: none

Weather conditions: Overcast skies were partially obscured due to fog and haze. Winds blew from the south at about 5 knots.

TABLE IV con't

Data period: L-7 7:40-9:55 am EST 6-27-69

Obstructions to vision: Fog, haze

Prevailing visibility: 3/4 mile increasing to 1¼ miles

Precipitation: none

Weather conditions: Overcast skies were partially obscured by fog and haze. Winds were from the south at about 5 knots.

DATA ANALYSIS

Data recorded by the photo-pack system were reduced onto the forms as in figures 19 through 21. Laser field data were included on the forms and the information was analyzed.

Three analyses were performed on the data. First, the data was studied to determine how closely the NBS-type transmissometer could be adjusted to the laser visibility meter reading. Second, the accuracy of the laser calibrated transmissometer was determined using the normally calibrated transmissometer as a standard. Finally, the laser device was compared to the standard NBS-type transmissometer to evaluate the accuracy of the laser visibility measurement.

(A) Accuracy of the T2 Calibration Adjustment.- We first determined the accuracy of the NBS-type transmissometer calibration adjustment. This data is presented in Table V which compares the laser visibility meter reading before T2 calibration with the T2 transmittance meter reading after transmissometer calibration.

Of the 113 observations taken, the NBS-type transmissometer was calibrated to equal the laser visibility meter reading 111 times. Only two adjustments of the T2 iris failed to result in indicated transmittance equal to the laser measurement. Both of the iris adjustments took place during data period L-2.

Table IV states that during L-2 drifting ground fog at the field test site caused indicated transmittance to vary rapidly. It appears that transmittance did change during the time the T2 iris was being adjusted so that the laser indicated transmittance did not remain constant.

Two conclusions can be based upon this finding. First, the physical adjustment of the NBS-type transmissometer iris is fine enough to allow accurate matching of indicated transmittance with the laser calibrator. Second, the laser transmittance indication during the 113 observations was stable during calibration of transmissometer T2. The T2 indicated transmittance would have seldom equaled the laser visibility meter reading had the laser output been unstable or the T2 iris difficult to adjust accurately.

(B) Accuracy of the Laser Calibrated Transmissometer T2.- The second and most important analysis involves determining the accuracy of the laser calibrated transmissometer T2 compared to a normally (5-mile daytime visibility) calibrated transmissometer T1. Table VI shows the test data

Accuracy to which Transmissometer T2 was Calibrated to the Laser Transmissometer

Indicated Transmittance, %

Data Period	Laser before Calibration	Transmissometer T2 after Calibration	Difference L - T2

Laser indicated transmittance before transmissometer T2 calibration

Transmissometer T2 indicated transmittance after calibration using the laser as a reference

Difference in indicated transmittance between the laser reference measurement and the laser calibrated transmissometer T2

FIGURE 19 - The Method Used to Determine T2 Iris Adjustment Accuracy

Accuracy of the Laser-Calibrated Transmissometer (T2) Compared to the Standard NBS Transmissometer (T1)

Data Period	Transmissometer Pulse Counts after Calibration		Equivalent RVR in Hundreds of Feet L.S. 5			Number of Reportable RVR Values
	T1	T2	T1	T2	T2-T1	T2-T1

NBS type transmissometer 55 sec. pulse counts after T2 calibration. Data reduced from Photo-Pak acquisition unit.

55 sec. pulse counts converted to equivalent Runway Visual Range (RVR) in Hundreds of Feet at Light Setting 5 (L.S.)

Difference in Reportable RVR Values between T2 and T1 pulse counts after T2 Calibration

FIGURE 20 - The Method Used to Determine T2 Versus T1 Runway Visual Range (RVR) Differences After T2 Calibration

Accuracy of the Laser Transmissometer (L)
Compared to a Standard NBS Transmissometer (T1)

Data Period	Indicated Transmittance, % after Calibration		Equivalent RVR in Hundreds of Feet L.S. 5			Number of Reportable RVR Values
	L	T1	L	T1	L - T1	L - T1

Indicated transmittance, %, after T2 calibration

T1 data converted from 55 sec. pulse counts

Laser data from laser Field Data sheets

Indicated transmittance, %, converted to equivalent Runway Visual Range (RVR) in Hundreds of Feet at Light Setting 5 (L. S. 5)

Difference in Reportable RVR Values between L and T1 indicated transmittance after transmissometer T2 calibration

FIGURE 21 - The Method Used to Determine Differences Between Laser and T1 Reported Runway Visual Range (RVR)

TABLE V

Accuracy to Which Transmissometer T2 was Calibrated to the Laser Transmissometer

Data Period	Indicated Transmittance, % Laser before Calibration	Transmissometer T2 after Calibration	Difference L - T2
L-1	99	98	1
	97	97	0
	96	96	0
L-2	75	75	0
	50	50	0
	48	48	0
	28	29	-1
	67	67	0
	72	72	0
	68	67	1
	72	71	1
	72	72	0
	83	84	-1
	84	83	1
	85	85	0
	87	87	0
	82	82	0
L-3	92	92	0
	90	90	0
	90	90	0
	95	95	0
	96	96	0
	95	95	0
	95	95	0

TABLE V continued

Accuracy to Which Transmissometer T2 was Calibrated to the Laser Transmissometer

Data Period	Laser before Calibration	Transmissometer T2 after Calibration	Difference L - T2
	Indicated Transmittance, %		
L-3	94	94	0
	95	95	0
	94	94	0
	94	94	0
	96	96	0
	94	94	0
	94	94	0
	93	93	0
	96	96	0
	97	97	0
	97	97	0
	97	97	0
	96	96	0
	97	97	0
	97	97	0
	98	98	0
	98	98	0
	97	97	0
	97	97	0
L-4	93	93	0
	93	93	0
	93	93	0
	93	93	0
	95	95	0

TABLE V continued

Accuracy to Which Transmissometer T2 was Calibrated to the Laser Transmissometer

	Indicated Transmittance, %		
Data Period	Laser before Calibration	Transmissometer T2 after Calibration	Difference L - T2
L-4	94	94	0
	97	97	0
	97	97	0
	96	96	0
	96	96	0
	96	96	0
	95	95	0
	95	95	0
	95	95	0
L-5	94	94	0
	95	95	0
	95	95	0
	96	96	0
	94	94	0
	95	95	0
	95	95	0
	94	94	0
	95	95	0
	97	97	0
	98	98	0
	96	96	0
	95	95	0
	96	96	0

TABLE V continued

Accuracy to Which Transmissometer T2 was Calibrated to the Laser Transmissometer

	Indicated Transmittance, %		
Data Period	Laser before Calibration	Transmissometer T2 after Calibration	Difference L - T2
L-5	96	96	0
	96	96	0
	97	97	0
	96	96	0
	97	97	0
	97	97	0
L-6	91	91	0
	90	90	0
	89	89	0
	89	89	0
	90	90	0
	90	90	0
	89	89	0
	90	90	0
	93	93	0
	95	95	0
	95	95	0
	96	96	0
	96	96	0
	96	96	0
	96	96	0
	96	96	0
	96	96	0

TABLE V continued

Accuracy to Which Transmissometer T2 was Calibrated to the Laser Transmissometer

	Indicated Transmittance, %		
Data Period	Laser before Calibration	**Transmissometer T2 after Calibration**	**Difference L - T2**
L-6	96	96	0
	96	96	0
	96	96	0
L-7	92	92	0
	91	91	0
	92	92	0
	91	91	0
	91	91	0
	92	92	0
	92	92	0
	94	94	0
	94	94	0
	95	95	0
	95	95	0
	95	95	0
	95	95	0
	94	94	0
	95	95	0
	95	95	0

arranged for comparison. Pulse counts of the two NBS-type transmissometers after T2 was calibrated with the laser were converted to Runway Visual Range (RVR) values. The differences in the values were computed and the number of reportable RVR values represented in the difference was noted. Light setting 5 (L.S. 5) was used as the basis for all RVR computations.

Table VII summarizes the test data in classes of RVR as reported by the standard NBS-type transmissometer T1. The class of T1 RVR values less than 3000 feet is too small from which to draw meaningful conclusions as the lack of low visibility conditions during test periods severely limited the number of these observations. The larger class, T1 RVR between 3000 and 6000 feet, offers evidence that the laser calibrated T2 did report higher RVR values than the normally calibrated T1.

In 16 of the 36 observations, transmissometer T2 yielded RVR two values higher than T1. Similarly in 15 other cases, T2 RVR was one reportable value higher than T1 RVR.

The third class of observations, T1 RVR greater than 6000 feet, shows further evidence of possibly greater RVR values from the laser calibrated NBS-type transmissometer.

Though the quantity and coarseness of data precludes rigorous mathematical analysis, a main conclusion can be advanced. The LAVAC calibrated NBS-type transmissometer tends to yield higher RVR values than does a similar system calibrated by the usual 5-mile daytime visibility method.

(C) Accuracy of the laser Versus Transmissometer T1.- The third laser analysis compares the accuracy of the laser transmissometer L with that of the normally calibrated NBS-type transmissometer T1. Table VIII lists test data used for this comparison. As you might expect, the data appears quite similar to that in Table VI used for determining the accuracy of T2.

The distribution of Table VIII test data is given in Table IX. As earlier, the distributions are classified according to RVR as reported by transmissometer T1. The class of observations T1 RVR less than 3000 feet is too small from which to form conclusions. The class from T1 RVR 3000 to 6000 feet however shows a predominance of observations in which the laser reported RVR one and two values greater than did transmissometer T1. In 20 of 47

TABLE VI

Accuracy of the Laser Calibrated Transmissometer (T2) Compared to the Standard NBS Transmissometer (T1)

Data Period	Transmissometer Pulse Counts after Calibration		Equivalent RVR in Hundreds of Feet L.S. 5			Number of Reportable RVR Values
	T1	T2	T1	T2	T2 - T1	T2 - T1
L-1	3464	3586	60+	60+		0
	3462	3526	60+	60+		0
	3453	3490	60+	60+		0
L-2	2966	2768	60+	60+		0
	802	1791	18	35	17	7
	2211	3118	45	60+		4
	1445	3468	26	60+		9
	2215	2322	45	50	5	1
	2887	2521	60+	55		-2
	3084	2470	60+	55		-2
	3173	2483	60+	55		-2
	3152	2514	60+	55		-2
	3174	2977	60+	60+		0
	3171	2957	60+	60+		0
	3158	3020	60+	60+		0
	3152	3067	60+	60+		0
	3189	2883	60+	60+		0
L-3	3255	3290	60	60+		1
	3239	3226	55	55	0	0
	3239	3217	55	55	0	0
	3250	3417	60	60+		1
	3256	3452	60	60+		1
	3262	3415	60	60+		1
	3263	3403	60	60+		1
	3271	3343	60+	60+		0

TABLE VI continued

Accuracy of the Laser Calibrated Transmissometer (T2) Compared to the Standard NBS Transmissometer (T1)

Data Period	Transmissometer Pulse Counts after Calibration T1	T2	Equivalent RVR in Hundreds of Feet L.S. 5 T1	T2	T2 - T1	Number of Reportable RVR Values T2 - T1
L-3	3271	3430	60+	60+		0
	3265	3402	60+	60+		0
	3269	3373	60+	60+		0
	3272	3466	60+	60+		0
	3263	3360	60+	60+		0
	3264	3354	60+	60+		0
	3251	3305	60+	60+		0
	3265	3460	60+	60+		0
	3265	3498	60+	60+		0
	3269	3508	60+	60+		0
	3283	3504	60+	60+		0
	3263	3494	60	60+		1
	3263	3521	60	60+		1
	3264	3505	60	60+		1
	3276	3557	60+	60+		0
	3268	3560	60+	60+		0
	3265	3515	60	60+		1
	3276	3476	60+	60+		0
L-4	3253	3341	60	60+		1
	3278	3356	60+	60+		0
	3269	3342	60+	60+		0
	3269	3370	60+	60+		0
	3283	3455	60+	60+		0
	3268	3413	60+	60+		0
	3254	3526	60	60+		1
	3274	3524	60+	60+		0

TABLE VI continued

Accuracy of the Laser Calibrated Transmissometer (T2) Compared to the Standard NBS Transmissometer (T1)

Data Period	Transmissometer Pulse Counts after Calibration T1	T2	Equivalent RVR in Hundreds of Feet L.S. 5 T1	T2	T2 - T1	Number of Reportable RVR Values T2 - T1
L-4	3293	3466	60+	60+		0
	3292	3463	60+	60+		0
	3284	3438	60+	60+		0
	3275	3451	60+	60+		0
	3290	3417	60+	60+		0
	3294	3442	60+	60+		0
L-5	3229	3365	55	60+		2
	3207	3437	55	60+		2
	3203	3408	55	60+		2
	3207	3453	55	60+		2
	3220	3113	55	45	-10	-2
	3217	3425	55	60+		2
	3208	3414	55	60+		2
	3222	3388	55	60+		2
	3233	3411	60	60+		1
	3218	3508	55	60+		2
	3212	3531	55	60+		2
	3216	3469	55	60+		2
	3217	3420	55	60+		2
	3219	3457	55	60+		2
	3214	3466	55	60+		2
	3213	3485	55	60+		2
	3219	3511	55	60+		2
	3236	3448	60	60+		1
	3226	3253	55	60	5	1
	3214	3507	55	60+		2

TABLE VI continued

Accuracy of the Laser Calibrated Transmissometer (T2) Compared to the Standard NBS Transmissometer (T1)

Data Period	Transmissometer Pulse Counts after Calibration T1	T2	Equivalent RVR in Hundreds of Feet L.S. 5 T1	T2	T2 - T1	Number of Reportable RVR Values T2 - T1
L-6	3045	3329	40	60+		5
	3291	3235	60+	60		-1
	3282	3207	60+	55		-2
	3399	3236	60+	60		-1
	3415	3268	60+	60+		0
	3427	3266	60+	60+		0
	3444	3227	60+	55		-2
	3481	3275	60+	60+		0
	3496	3403	60+	60+		0
	3522	3474	60+	60+		0
	3525	3469	60+	60+		0
	3510	3519	60+	60+		0
	3534	3535	60+	60+		0
	3519	3521	60+	60+		0
	3510	3523	60+	60+		0
	3521	3526	60+	60+		0
	3541	3540	60+	60+		0
	3543	3717	60+	60+		0
	3524	3730	60+	60+		0
	3531	3536	60+	60+		0
L-7	3308	3305	60+	60+		0
	3347	3362	60+	60+		0
	3372	3327	60+	60+		0
	3399	3350	60+	60+		0
	3421	3360	60+	60+		0

TABLE VI continued

Accuracy of the Laser Calibrated Transmissometer (T2)
Compared to the Standard NBS Transmissometer (T1)

Data Period	Transmissometer Pulse Counts after Calibration		Equivalent RVR in Hundreds of Feet L.S. 5			Number of Reportable RVR Values
	T1	T2	T1	T2	T2 - T1	T2 - T1
L-7	3428	3404	60+	60+		0
	3422	3426	60+	60+		0
	3442	3478	60+	60+		0
	3451	3518	60+	60+		0
	3461	3500	60+	60+		0
	3477	3499	60+	60+		0
	3496	3505	60+	60+		0
	3479	3515	60+	60+		0
	3495	3484	60+	60+		0
	3479	3461	60+	60+		0
	3489	3503	60+	60+		0

TABLE VII

Number of Reportable RVR Values T2-Tl Between a Laser-Calibrated Transmissometer (T2) and a Normally-Calibrated Transmissometer (Tl)

1800 Ft. ≤ Tl RVR ≤ 3000 Ft.

Number of RVR Values Differences T2-Tl

Differences per Period	7	8	9	Data Period	Total Observations
	1		1	L-2	14

3000 Ft < Tl RVR ≤ 6000 Ft.

Number of RVR Values Differences T2-Tl

-2	-1	0	1	2	3	4	5	6	Data Period	Total Observations
			1			1			L-2	14
		2	9						L-3	26
			2						L-4	14
1			3	16					L-5	20
							1		L-6	20
1	0	2	15	16	0	1	1	0		

Tl RVR > 6000 Ft.

Number of RVR Values Differences T2-Tl

Differences per Period	-2	-1	0	Data Period	Total Observations
			3	L-1	3
	4		6	L-2	14
			15	L-3	26
			12	L-4	14
	2	2	15	L-6	20
			16	L-7	16
	6	2	67		

TABLE VIII

Accuracy of the Laser Transmissometer (L)

Compared to a Standard NBS Transmissometer (T1)

Data Period	Indicated Transmittance, % after Calibration		Equivalent RVR in Hundreds of Feet L.S. 5			Number of Reportable RVR Values
	L	T1	L	T1	L - T1	L - T1
L-1	98	94	60+	60+	0	0
	94	94	60+	60+	0	0
	95	94	60+	60+	0	0
L-2	77	80	60+	60+	0	0
	44	21	30	18	12	6
	47	60	30	45	-15	-3
	28	40	20	26	-6	-3
	67	60	55	45	10	2
	72	78	60	60+		-1
	70	84	60	60+		-1
	72	86	60	60+		-1
	74	86	60+	60+	0	0
	83	86	60+	60+	0	0
	85	86	60+	60+	0	0
	85	86	60+	60+	0	0
	88	87	60+	60+	0	0
	81	86	35	50	-15	-3
L-3	94	89	60+	60		1
	89	88	60	55	5	1
	91	88	60+	55		2
	95	89	60+	60		1
	96	89	60+	60		1
	95	89	60+	60		1
	95	89	60+	60		1

TABLE VIII continued

Accuracy of the Laser Transmissometer (L)
Compared to a Standard NBS Transmissometer (T1)

Data Period	Indicated Transmittance, % after Calibration L	T1	Equivalent RVR in Hundreds of Feet L.S. 5 L	T1	L - T1	Number of Reportable RVR Values L - T1
L-3	94	89	60+	60		1
	95	89	60+	60		1
	94	89	60+	60		1
	94	89	60+	60		1
	96	89	60+	60		1
	94	89	60+	60		1
	94	89	60+	60		1
	93	89	60+	60+	0	0
	96	89	60+	60+	0	0
	97	89	60+	60		1
	97	89	60+	60+	0	0
	97	90	60+	60+	0	0
	96	89	60+	60		1
	97	89	60+	60		1
	96	89	60+	60		1
	98	90	60+	60+	0	0
	97	89	60+	60		1
	97	89	60+	60		1
	98	90	60+	60+	0	0
L-4	92	89	60+	60		1
	93	90	60+	60+	0	0
	94	89	60+	60+	0	0
	93	89	60+	60+	0	0
	95	90	60+	60+	0	0
	94	89	60+	60+	0	0
	97	89	60+	60		1

TABLE VIII continued

Accuracy of the Laser Transmissometer (L)

Compared to a Standard NBS Transmissometer (T1)

Data Period	Indicated Transmittance, % after Calibration		Equivalent RVR in Hundreds of Feet L.S. 5			Number of Reportable RVR Values
	L	T1	L	T1	L - T1	L - T1
L-4	97	90	60+	60+	0	0
	96	90	60+	60+	0	0
	96	90	60+	60+	0	0
	96	90	60+	60+	0	0
	95	90	60+	60+	0	0
	95	90	60+	60+	0	0
	95	90	60+	60+	0	0
L-5	94	88	60+	55		2
	95	87	60+	55		2
	95	87	60+	55		2
	96	87	60+	55		2
	94	88	60+	55		2
	94	88	60+	55		2
	94	88	60+	55		2
	94	88	60+	55		2
	95	88	60+	60		1
	97	88	60+	55		2
	97	88	60+	55		2
	96	88	60+	55		2
	94	88	60+	55		2
	96	88	60+	55		2
	96	88	60+	55		2
	96	88	60+	55		2
	97	88	60+	55		2

TABLE VIII continued

Accuracy of the Laser Transmissometer (L)
Compared to a Standard NBS Transmissometer (T1)

Data Period	Indicated Transmittance, % after Calibration L	T1	Equivalent RVR in Hundreds of Feet L.S. 5 L	T1	L - T1	Number of Reportable RVR Values L - T1
L-5	96	88	60+	60		1
	97	88	60+	55		2
	97	88	60+	55		2
L-6	91	83	60+	40		5
	90	90	60+	60+	0	0
	89	89	60	60	0	0
	90	93	60+	60+	0	0
	90	93	60+	60+	0	0
	90	93	60+	60+	0	0
	89	94	60	60+		-1
	91	95	60+	60+	0	0
	93	95	60+	60+	0	0
	95	95	60+	60+	0	0
	94	96	60+	60+	0	0
	96	96	60+	60+	0	0
	96	96	60+	60+	0	0
	96	96	60+	60+	0	0
	96	96	60+	60+	0	0
	96	96	60+	60+	0	0
	96	97	60+	60+	0	0
	96	97	60+	60+	0	0
	96	96	60+	60+	0	0

TABLE VIII continued

Accuracy of the Laser Transmissometer (L)
Compared to a Standard NBS Transmissometer (Tl)

Data Period	Indicated Transmittance, % after Calibration L	Indicated Transmittance, % after Calibration Tl	Equivalent RVR in Hundreds of Feet L.S. 5 L	Equivalent RVR in Hundreds of Feet L.S. 5 Tl	Equivalent RVR in Hundreds of Feet L.S. 5 L - Tl	Number of Reportable RVR Values L - Tl
L-6	96	96	60+	60+	0	0
L-7	92	90	60+	60+	0	0
	91	91	60+	60+	0	0
	92	92	60+	60+	0	0
	91	93	60+	60+	0	0
	92	93	60+	60+	0	0
	92	93	60+	60+	0	0
	92	93	60+	60+	0	0
	94	94	60+	60+	0	0
	94	94	60+	60+	0	0
	95	94	60+	60+	0	0
	95	95	60+	60+	0	0
	96	95	60+	60+	0	0
	95	95	60+	60+	0	0
	95	95	60+	60+	0	0
	95	95	60+	60+	0	0
	95	95	60+	60+	0	0

observations, the laser device reported RVR two reportable values higher than T1. In another 23 observations, laser RVR was one reportable value greater.

The third class, T1 greater than 6000 feet covers too large a range of values to be useful in this evaluation.

As stated earlier, the data is both too coarse and too sparse to provide a basis for rigorous mathematical analysis. However, Table IX can be used to draw the conclusion that during the test periods the laser transmissometer tended to report RVR at least one reportable value higher than the normally calibrated NBS-type transmissometer.

(D) Data Periods L-2, -5, and -6.- Three particular data periods stand out in Tables VII and IX. The causes for the spread of reportable RVR differences in periods L-2, L-5, and L-6 were investigated.

Observational difficulties during period L-6 were noted in Table IV. Fog drifting across the test site deposited water droplets on the remote detector cover glass. Frequent cleaning of the glass was necessary during the test period. It is likely that droplets were present on the detector glass throughout acquisition period L-6. As a result, L-6 data is of doubtful value.

Table VII shows that L-6 T2-T1 RVR reportable values are biased toward lower T2 RVR values. This of course would be the case if the laser light were attenuated by water droplets on the remote detector cover glass while T2 was being calibrated.

A similar situation may have occurred during period L-2 when 4 of 20 observations yielded lower T2 RVR values. Table IV states that fog was present and that a light southerly breeze did occur during the data acquisition. The cause of the large spread of T2-T1 RVR differences in Table VII from -2 to +9 during L-2 cannot be positively identified by analysis of the small data sample collected. It does appear probable that water droplets were again present on the remote photoelectric detector cover glass.

Data period L-5 is unique for the large number of observations in which T2 RVR was two reportable values higher than T1 RVR. From Table IV, L-5 was conducted with prevailing visibilities of 2½ to 4 miles and visibility restricted by haze. The haze restriction during L-5 was the greatest of such occurrences to be sampled throughout the laser field test program.

TABLE IX

Number of Reportable RVR Values L T1 Between the Laser Transmissometer (L) and the Standard NBS Transmissometer (T1)

1800 Ft. ≤ T1 RVR ≤ 3000 Ft.

Number of RVR Values Difference L-T1

Differences per Period	-3	0	3	6	Data Period	Total Observations
	1			1	L-2	14

3000 Ft. < T1 RVR ≤ 6000 Ft.

Number of RVR Values Differences L-T1

Differences per Period

-3	-2	-1	0	1	2	3	4	5	6	Data Period	Total Observations
2					1					L-2	14
				19	1					L-3	26
				2						L-4	14
				2	18					L-5	20
			1					1		L-6	20
2	0	0	1	23	20	0	0	1	0		

T1 RVR > 6000 Ft.

Number of RVR Values Differences L-T1

Differences per Period	-1	0	1	Data Period	Total Observations
		3		L-1	3
	3	5		L-2	14
		6		L-3	26
		12		L-4	14
	1	17		L-6	20
		16		L-7	16
	4	59	0		

Table VI shows that for 16 of the 20 L-5 observations, T2 RVR was 6000+ feet and T1 RVR was reported as 5500 feet. Stable weather conditions prevailed during the period so that rapidly changing RVR was not a factor in the T2-T1 differences.

Results from data period L-5 indicate that the laser calibrated transmissometer T2 is more likely to be calibrated high, i.e., to yield a higher than true RVR value, when the laser system is used as a calibrator during haze conditions.

LASER SYSTEM DEFICIENCIES

We noted several engineering deficiencies in the model tested. All are correctable and could be eliminated by carefully redesigning the system. The laser system is designed to be used as a permanent fixed transmissometer rather than as a portable calibrator. In its present form however, it is unlikely that the device could be successful as a calibrator.

(A) Packaging Deficiencies.- The following weaknesses of the laser system concern the outside package and the arrangement of components within the package.

1. Excessive weight and bulk.- The source housing weighs approximately 100 lbs. This is too heavy to be considered portable, even for two men, when climbing a 14 foot high transmissometer tower. A hoist was needed to lift the model tested onto the tower.

   The source housing measures 17 inches wide x 23 inches high x 13 inches deep. This volume is too large to be carried conveniently up a tower by one man. Regardless of weight, the unit could not be carried safely by one man up a 14 foot ladder. Figure 8 shows the large amount of unused volume which contributes to the bulkiness of the source housing.

2. Unfinished source housing supports.- The four legs which support the source housing have rough, unfinished surfaces. The supports, cut from one inch diameter aluminum rod, are fastened to the housing by 3/8 inch diameter bolts. The bottom and circular surfaces of the legs have several sharp burrs and uneven areas. The legs are rough enough to cut into rubber automobile trunk mats.

3. Exposed electrical connections.- The back of the control panel (figure 8) has many exposed electrical connections. In addition to being a safety hazard, the circuitry is unprotected from damage by falling and blown precipitation when the panel door is open.

Figure 8 also shows an exposed terminal board in front of the indicating amplifier inside the source housing. This board is a serious safety hazard as one of the connections carries 110 VAC current.

4. Complex control panel.- There are two knobs each for source control and detector control adjustments. The upper knobs are for fine adjustments, the lowers for coarse. Two knobs, or one knob and a switch, would have been sufficient.

5. Detector control knob location.- The lower detector knob is too close to the control panel door latch (figure 7). Great care must be taken when opening and closing the panel door not to bump the detector control knob, throwing the laser out of calibration.

6. Inadequate storage for calibration detector.- The calibration detector is held, when not in use, by a magnet to the back of the control panel door (figure 8) or to the top of the amplifier. The detector has no positive clamp to hold it in place. Also, the signal cable from calibration detector to amplifier becomes caught in the control panel door. This cable, too, needs adequate provision for storage.

(B) Operational Deficiencies.- The following drawbacks of the laser system affect the operation of the device as a transmissometer calibrator.

1. Location of the control panel.- The control panel is on the left side of the source housing. This is opposite from the control panel side of some NBS-type transmissometers. Adequate calibrations can be performed only if controls and meters for both instruments are on the same side of the transmissometer platform.

2. Non-lockable control knobs.- None of the control knobs have locking capability. The knobs turn easily when bumped, thus throwing the system out of calibration.

3. Inaccessible beam alignment mechanism.- The laser plasma tube is held within two steel rings, one at each end. Four cap screws are placed at 90° intervals in each ring. The plasma tube, and its laser beam, is aligned by adjusting the screws as required. Equipment in the source housing, however, interferes with three of the eight alignment screws. Beam alignment is therefore a time consuming and temporary process as the plasma tube cannot be tightly secured, nor precisely aimed with ease.

4. Inadequate environmental protection.- The source housing lens hood (figure 7) is only 2 3/4" long. The remote detector lens cover (figure 7) extends but 4½". Neither hood completely surrounds its lens, nor are the hoods equiped with blowers. The lens are not heated. Danger of contamination from precipitation, dust, and haze particles preclude use of the model tested during all types of weather. We have found some data gathered during fog periods to be of questionable value because water droplets collected on the remote detector lens.

5. Lack of an optical siting device.- The model tested had no provision for optically aiming the laser beam. As a result, much time is required to align the system. This deficiency also produces a safety hazard when the laser is operated during the alignment procedure without proof-positive of where the beam is aimed.

6. Small diameter remote detector housing window and photoelectric detector.- The glass cover of the remote detector housing and the photodetector itself are only 1 inch in diameter. As a result, the laser beam nearly covers the entire window and detector areas, thus making beam alignment both difficult to achieve and maintain.

7. Insecure calibration detector clamp.- Two concentric rings on the calibration detector housing fit around the source hood (figures 16 & 22). The detector can slip, or be bumped, out of position during system calibration without the operator's knowledge. The result would be improper calibration of the laser, and if not discovered, improper calibration of an NBS-type transmissometer.

FIGURE 22 - Two Concentric Rings Hold the Calibration Detector onto the Source Housing Hood

8. Inadequate strip chart recorder.- The laser strip chart recorder does not operate while the visibility meter is on. It would be helpful to have both types of output available during calibration tests of the laser transmissometer. The recorder trace in the model tested is also difficult to read. The recorder shunt is extremely sensitive to small adjustments.

9. Recorder shunt failure.- The potentiometer by which the strip chart recorder range is adjusted failed during field tests. The recorder was inoperative during the final month of field tests.

10. Inadequate water-proofing.- Water drops were found on the inside surface of the remote detector cover glass about a month after field tests ended and after a week of frequent rain showers. A layer of water, 1/8" deep was found in the detector housing when it was dismantled. Water drops on the glass would have reduced laser indicated transmittance and therefore that of the calibrated NBS-type transmissometer.

11. Poorly matched photoelectric detectors.- The two electrically matched photoelectric detectors were dismantled and compared after field tests were concluded. The remote detector was found to indicate 3% greater output than the calibration detector at full scale meter reading (100%). This difference, though linear, caused the laser to indicate incorrectly higher transmittance and therefore to calibrate the NBS-type transmissometer to an incorrectly high transmittance.

12. Lack of protection for calibration detector.- The calibration detector, when in its storage position, is not protected from measuring stray laser light which may be present inside the source housing. It is also possible to store the detector such that it is aimed at the beam splitter. When in this position, the detector will receive light reflections which the system will add to those from the remote detector. The laser will then indicate an erronously high atmospheric transmittance value.

Nearly all of the above deficiencies were discovered during field tests of the laser system. Because of the importance of the operational deficiencies, we decided that further field tests would add little useful information. As a result, field tests were concluded earlier than had originally been anticipated. In addition, based upon these test experiences, we believe that the variety and seriousness of the deficiencies made it impossible to adequately test the laser method of transmissometer calibration. On the other hand, the deficiencies were important in providing information to evaluate the laser as a calibrator system.

ADJUSTMENT FOR INACCURATELY MATCHED LASER PHOTO DETECTORS

The laser remote photoelectric detector was dismantled after field data acquisition had ended. It was found that the remote and the calibration detectors were inaccurately matched. The remote detector output was found to be 3% higher at full scale meter reading (100%) than the calibration unit, and as a result, the laser indicated transmittance was 3% higher at full scale than it should have been. The error introduced is a constant percentage, i.e., a linear function, of indicated transmittance so that at half scale (50%) the error would be 1½%.

Laser indicated transmittance was adjusted for the error caused by the mismatched photo detectors. A word of caution should be taken on the adjusted indicated transmittances. It is impossible to determine if the error was present in the laser system from the time of its manufacture or if the error was the result of drift or aging of the photo detectors. The adjusted transmittances are what would have been obtained had the error been built into the system at manufacture.

The adjusted transmittances were converted to RVR L.S. 5 and compared with Tl RVR. The comparisons of L-Tl RVR differences are shown in Table X. Comparison of this table with Table IX (unadjusted laser data) shows that RVR differences between the two systems were decreased when the laser values were adjusted. Table X presents a more widely distributed pattern of RVR differences than does Table IX.

The differences reported in Table X remain skewed toward higher laser RVR however. Therefore, the conclusion derived earlier continues to hold. The laser transmissometer tended to indicate higher RVR than did the standard NBS-type transmissometer.

TABLE X

Number of Reportable RVR Values L-Tl Between the Laser Transmissometer (L) and the Standard NBS Transmissometer (Tl)

1800 Ft. ≤ Tl RVR ≤ 3000 Ft.
Number of RVR Values Differences L-Tl

Differences per Period

-3	1	3	5	Data Period	Observations per Period
1			1	L-2	14

3000 Ft. ≤ Tl RVR ≤ 6000 Ft.
Number of RVR Values Differences L-Tl

Differences per Period

-3	-2	-1	0	1	2	3	4	Data Period	Observations per Period
1				1				L-2	14
		1	1	18				L-3	26
			1	1				L-4	14
				2	18			L-5	20
	1					1		L-6	20
1	1	1	2	22	18	1	0		

Tl RVR > 6000 Ft.
Number of RVR Values Differences L-Tl

Differences per Period

-3	-2	-1	0	1	Data Period	Observations per Period
			3		L-1	3
	1	3	6		L-2	14
			6		L-3	26
			12		L-4	14
2	4		12		L-6	20
		4	12		L-7	16
2	5	7	51	0		

SUMMARY

The NBS-type transmissometer cannot at present be calibrated during all weather and visibility conditions. A laser transmissometer, by claim of its manufacturer, can be calibrated during any visibility and weather condition. For this reason, a laser transmissometer system was chosen to be evaluated as a possible portable transmissometer calibrator.

Results of field tests do not yield conclusive proof as to the potential usefulness of the laser method of transmissometer calibration. This evaluation indicates that the laser method of calibration does show promise as a potentially useful calibration technique.

Several shortcomings of the system which was evaluated precluded the opportunity to rigorously test and evaluate the laser method of transmissometer calibration. Short-comings of greatest significance are:

1. Frequent laser beam alignment drift resulted from an inaccurate and partially inaccessible beam alignment mechanism.
2. External glass surfaces of the laser source and remote detector housings lacked adequate environmental protection and thus became water covered during periods of fog and rain.
3. Water entered the remote detector housing during periods of rain because of inadequate weather-proof seals.
4. Inaccurately matched photo electric detectors introduced an upward bias to system measure-ments of atmospheric transmittance.

Performance specifications for a laser calibrator system which would overcome these deficiencies are given in Appendix A of this report.

CONCLUSIONS

It is concluded that:

1. From the limited field tests performed, it is concluded that the laser system in its present configuration is not suitable for use as a transmissometer calibrator.

2. The concept of a transmissometer calibrator system employing a laser, does appear to show potential usefulness.

REFERENCES

1. Federal Aviation Administration, Handbook 6990.1 Maintenance of Runway Visual Range (RVR) Equipment, Washington, reprinted September 1967.

2. Federal Aviation Administration, Directives Systems Handbook 1320.1, Washington, October 1966.

3. ESSA-Weather Bureau, Instruction Manual Transmissometer System, Washington, August 1966.

4. National Bureau of Standards, Report 2588 Instruction Book for Transmissometer Set AN/GMQ-10, Washington, revised November 1959.

5. Schlatter, Ernest E., Lefkowitz, Matthew, August 1968: Evaluation of Multi-transmissometer Systems, ESSA-Weather Bureau for FAA, SRDS Report No. RD-68-49, Atlantic City, New Jersey.

6. Goldman, Leon, 1963: Protection of Personnel Operating Lasers, The American Journal of Medical Electronics, Vol. 3, pgs. 335-338.

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9. U. S. Army, Environmental Hygiene Agency, Laser Hazards Special Study No. 42-50-68/69, Edgewood Arsenal, Maryland, June 1968.

10. ESSA-Weather Bureau, Circular N, Manual of Surface Observations, Washington, May 1969.

APPENDIX A

PERFORMANCE SPECIFICATIONS

LASER TRANSMISSOMETER CALIBRATOR

PERFORMANCE SPECIFICATION

LASER TRANSMISSOMETER CALIBRATOR

1. SCOPE

1.1 Scope.- This specification covers a portable laser system to be used to calibrate the National Bureau of Standards (NBS)-type transmissometer.

2. APPLICABLE DOCUMENTS

2.1 FAA Documents.- The following FAA specifications, standards, and handbooks of the issues specified in the invitation for bids or request for proposals, form a part of this requirement and are applicable to the extent specified herein.

2.1.1 FAA Specifications

FAA-D-2129 Contractor Prepared Technical Reports, Research and Development Contracts

FAA-E-2269 Runway Visual Range System

2.1.2 FAA Handbooks

6990.1	Maintenance of Runway Visual Range (RVR) Equipment
1320.1	FAA Directives Systems Handbook

2.1.3 FAA Final Report

FAA-RD-68-51	Transmissometer Calibration Techniques

2.2 ESSA-Weather Bureau Specifications.- The following Environmental Science Services Administration, Weather Bureau specifications of the number, title, and date given below form a part of this specification.

451.9161	Transmissometer (NBS-type) revised August 16, 1966
450.6161	Recording Milliameter (Graphic-Type) revised March 29, 1965

2.3 Other Publications.- The following publications, of the issue in effect on this date, form a part of this specification, and are applicable to the extent specified herein.

National Bureau of Standards Report 2588 - Instruction Book for Transmissometer Set AN/GMQ-10

National Bureau of Standards Report 7706 - Development of a Transmissometer Calibrator

National Bureau of Standards Report 4558 - Theory of Transmissometer Photometric System

ESSA-Weather Bureau Instruction Manual - Transmissometer System August 1966

3. GENERAL

3.1 The Transmissometer.- The NBS-type transmissometer is a system which was developed to provide a continuous measurement of the percent of atmospheric transmission along a horizontal path between two fixed points. A representation of horizontal visibility or runway visual range may be determined from this measurement by the application of empirical mathematical relations. The transmissometer is used to provide objective, repeatable and more accurate measurements of visibility in an airport runway complex. Using remote sensors, it is possible to obtain continuous measurements of visibility without having human observers stationed in areas of active airfield operations.

3.2 Transmissometer Calibration.- The transmissometer system is calibrated by visually estimating the visibility at a time when it is five miles or greater, and bringing the system into agreement with the visibility estimate. This calibration, known as the atmospheric transmission calibration, relates the transmissometer reading to the human visibility estimate. The transmissometer is adjusted so that a reading of 100% would be obtained if the air were perfectly clear. Since a perfectly clear condition never occurs, an extrapolation procedure is used to determine the setting. The accuracy of this setting is determined by the accuracy of the visibility estimate.

3.2.1 Limitations of Transmissometer Calibration.- The normal method of transmissometer calibration is satisfactory if:

(1) The visibility is five statute miles or more calibration is required.

(2) Sufficient visibility markers exist beyond five statute miles to give a reasonable estimate of visibility.

(3) Atmospheric transmission in the vicinity of the transmissometer is representative of the conditions over the area where the visibility estimate is made.

3.3 Requirement for a Transmissometer Calibrator.- A method of transmissometer calibration is required which shall accurately and effectively calibrate a transmissometer in all types of weather and all ranges of visibility conditions. The method shall employ objective rather than subjective techniques, shall provide a standard and repeatable measurement, shall be self-contained and not rely on other aids such as visibility markers, and shall be easy to use so that operators need not be trained in meteorological observations. The calibrator shall be easily portable and designed so that it can be used to calibrate any NBS-type transmissometer.

3.3.1 Requirement for a Laser Calibrator System.- The laser method of transmissometer calibration shows promise as a portable device which will provide objective, standard measures by which the transmissometer can be calibrated. A laser system can be designed so that it is compact, lightweight, and easy to operate. A laser calibrator employing a constant intensity light source may be used along a path equal to and very near that of a transmissometer. The laser light beam may be designed to have little divergence, thereby enabling a detector to receive the entire light field. In addition, the characteristics of the laser beam permit the system to be internally calibrated regardless of weather and visibility conditions.

4. PERFORMANCE REQUIREMENTS FOR A LASER CALIBRATOR SYSTEM

4.1 General Description.- The laser system shall be so designed that it can be easily carried, set-up and operated by one person. The fundamental principle of operation shall be based on the attenuation of its own light in the same manner as the principle of the transmissometer system. Sampling by the laser calibrator shall be as identical as possible to the sampling path of the transmissometer to be calibrated.

The calibrator may be constructed in three functional units. These units are:

(a) Laser source. In operation, this unit will be positioned at the transmissometer receiver.

(b) Visibility detector. In operation, this unit will be positioned at the transmissometer projector.

(c) Output indicator. In operation, this unit will be positioned at the transmissometer receiver.

4.1.1 Accuracy of the Laser System.- The laser calibrator shall be so designed that its measurement shall track, under identical conditions, within 3 percent of the atmospheric transmittance measured by an NBS-type transmissometer which is maintained, calibrated and operated in accordance with existing standards.

4.1.2 Calibration of the Laser System.- The laser system shall be capable of self-calibration so that its output is an accurate measurement of atmospheric transmittance along a transmissometer sampling path as stated in paragraph 4.1.1.

The self-calibration feature shall be based solely upon objective measurement of laser light, and shall not rely upon visual estimates. The calibration operation shall be such that it may be performed quickly and easily by one person, and at the option of the laser system operator. Total time required for system calibration shall not exceed five minutes.

4.2 Laser Source

4.2.1 Plasma Tube.- The laser plasma tube shall be a hot cathode type and shall produce a continuous wave of light visible to the human eye. The plasma tube shall operate single mode and shall have suitable characteristics to achieve the accuracy requirement noted in paragraph 4.1.1.

4.2.2 Power Intensity.- Average power intensity of the laser beam shall be no greater than 10^{-3} watts/cm² nor less than 10^{-6} watts/cm². Average power intensity is to be measured between the $1/e^2$ power points at a distance not greater then three inches from the outside surface of the laser source housing. Power intensity shall be computed using the equation:

$$I = \frac{1.27\ E}{d^2}$$

where I is the average power intensity in watts/cm², E is the laser beam power in watts, and d is the beam diameter in centimeters between the $1/e^2$ power points.

4.2.3 Output Amplitude Stability.- Output amplitude of the laser beam, measured during any ten minute period, shall vary no more than 0.7% of power output.

4.2.4 Translation Pointing Stability.- Translation pointing of the laser beam shall vary no more than 10^{-4} inch/13 inches/hour during the first hour after the plasma tube is lased. Translation pointing stability is defined in terms of transverse movement of the laser beam per distance from plasma tube exit aperture to measurement location per hour.

4.2.5 Emergent Beam Diameter.- Laser beam diameter at the plasma tube exit aperture shall be no larger than 0.2 cm measured between the $1/e^2$ power points.

4.2.6 Beam Expander and Collimator.- A lens system shall be attached to the plasma tube. The lens system shall expand the emergent laser beam to a diameter no less than 1.0 cm nor greater than 2.5 cm measured between the $1/e^2$ power points.

The beam exiting from the lens system shall have a divergence no greater than 0.5 milliradians.

4.2.7 Source Cover Glass.- The laser source shall have a cover glass which may be fixed to the source housing. The glass shall be so protected that no condensation, fogging, or contamination of the glass surfaces occur when the laser system is operated as a portable transmissomter calibrator. The method of protection shall not affect the operation of the laser calibrator. The cover glass shall be readily and easily accessible for cleaning and replacement.

4.2.8 Laser Source Housing.- A weatherproof housing shall enclose the laser and associated components. The housing with its contents shall be portable and weigh not more than 20 pounds. A suitable means for carrying the unit up and down transmissometer towers shall be fixed to the housing. Exterior dimensions of the housing shall not exceed 24 inches long by 10 inches high by six inches wide. Design of the housing shall be such that components and assemblies are readily and easily accessible for maintenance and replacement.

The housing shall have means for temporary but rigid mounting atop the transmissometer receiver platform. The mounts shall be such that the position of the entire housing may be adjusted to accurately align the laser beam to the detector at distances up to 500 feet. Vertical and horizontal adjustments of the source housing shall be possible while the laser is operating and the source housing closed.

4.3 Visibility Detector.- The function of the visibility detector is to receive laser light and to convert the light intensity to an electrical signal. The sensing area of the detector shall have dimensions greater than the laser beam diameter at a distance of 500 feet. The detector shall be provided with filters centered at the peak laser wavelength and having a bandpass of not more than 20 Ångstroms. The visibility detector may be provided with an optically flat cover glass.

4.3.1 Visibility Detector Housing.- A weatherproof housing shall enclose the visibility detector and associated components. The housing with its contents shall be portable and weigh no more than five pounds. Exterior dimensions of the housing shall be such that components and assemblies are readily accessible for maintenance and replacement.

The detector face, filters, and cover glass surfaces shall be so protected that no fogging, condensation, or contamination occurs when the laser system is operated as a portable transmissometer calibrator. The method of protection shall not affect the operation of the laser calibrator.

The detector housing shall have means for temporary but rigid mounting atop the transmissometer projector platform. The mounts shall include a means for vertical and horizontal adjustments to point the detector sensing area at right angles to the impinging laser beam. A means for carrying the unit up and down transmissometer towers shall be attached to the housing.

<u>4.4 Output Indicator.-</u> The laser calibrator output indicator shall be a meter having a scale length of no less than three inches. The scale shall be graduated from 0 to 100 percent in fifty divisions with every fifth division identified by a larger and heavier line and every tenth division appropriately numbered. The scale shall be suitably illuminated for nightime use. The meter reading shall represent the percentage of atmospheric transmittance as measured by the laser system. The reading will be used as the sole basis for transmissometer calibration.

The output indicator and its controls shall be located at the transmissometer receiver. The indicator and controls shall be weatherproof. They may be a part of the source housing. The indicator and controls shall be easily and readily accessible for maintenance and replacement.

<u>4.5 Electrical Requirements</u>

<u>4.5.1 Power.-</u> The laser calibrator system shall operate from a 105-130 volt 59-61 hertz single phase AC power source. Power consumption shall not exceed 10 amperes.

<u>4.5.2 Cabling.-</u> Cabling between laser source and visibility detector shall be 600 feet in length and shall terminate at both ends with weatherproof mating connectors. All cables shall be flexible and shall be provided with suitable insulation for outdoor use. Cabling must be shielded from pick-up and noise, and have such characteristics that it does not adversely affect performance of the system. The system shall be so designed that similar cable of lengths

less than 600 feet can be substituted at the option of the operator without adverse effects on the performance of the calibrator.

4.6 Electronic Requirements

4.6.1 Circuitry.- All circuit components of the laser calibrator system shall be constructed of solid state materials in-so-far as practicable.

4.6.2 Circuit Protection.- Circuit protection shall be provided to prevent damage to wiring and components in case of electrical short-circuits or overloads.

4.7 Environmental Performance

4.7.1 Operating Performance.- The laser system shall be capable of operating out-of-doors during visibility and weather conditions, such as rain, snow, sleet, fog, dust, etc. The system shall accurately calibrate the transmissometer while operating in the temperature range from -30°F to +120°F and in the relative humidity range from 15% to 100%. The system shall be able to withstand shock and vibration encountered during road transportation, loading and unloading from vehicles, carrying up and down transmissometer towers, and shipping.

4.7.2 Storage Environment.- The laser system shall be capable of storage without performance degradation in environments having temperature ranges from -30°F to +120°F and relative humidities of 15% to 100%.

5. SAFETY

5.1 Safety.- The laser transmissometer calibrator shall be designed such that system operators and maintenance technicians are not exposed to harmful laser radiation, electrical connections, and high voltages.

6. MODIFICATIONS

6.1 Modifications.- Modifications to the NBS-type transmissometer, its towers, and its platform necessary for mounting the laser system shall be accurately described by the manufacturer. Detailed drawings shall also be provided by the laser system manufacturer.

7. MANUALS

7.1 Manuals.- The manufacturer shall supply all operating and installation instructions, safety directives, maintenance manuals and system diagrams.