NATIONAL BUREAU OF STANDARDS REPORT

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21P-19/55

Sensitivity and Current Leakage
of
Twenty-one Cold Cathode Electron Tubes, Type WL-759
and
Thirty-one Photoelectric Tubes, Type WL-919

By
Photometry and Colorimetry Section
Optics and Metrology Division

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NBS PROJECT | **NBS REPORT**

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For
Instrument Division
Weather Bureau
Department of Commerce
Washington 25, D. C.

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Sensitivity and Current Leakage of Twenty-one Cold-Cathode Electron Tubes, Type WL-759 and Thirty-one Photoelectric Tubes, Type WL-919

Manufactured by
Westinghouse Electric Corporation
Elmira, New York

Tested for
Instrument Division
Weather Bureau
Department of Commerce
Washington 25, D. C.

1. SCOPE

The National Bureau of Standards was requested by the Instrument Division, Weather Bureau, by letter of June 15, 1954, to test 17 cold-cathode electron tubes, type WL-759 (also called "trigger tubes"), and 16 photoelectric tubes, type WL-919, to determine their suitability for use in transmissometer pulse-amplifier units. Verbal requests were made later to include 4 additional trigger tubes and 15 additional photoelectric tubes. This report gives the results of tests of sensitivity, of plate-voltage plateau, and of current leakage for the 21 trigger tubes, and the results of tests of sensitivity to incident radiant flux, of dark current, and of current leakage for the 31 photoelectric tubes. All tubes were manufactured by the Westinghouse Electric Corporation.

2. INTRODUCTION

2.1 Analysis of Trigger-Tube Operation.

The WL-759 tube is a cold-cathode, starter-anode, gas triode tube and is used in the pulse amplifier to generate pulses at a rate proportional to the current of the phototube. The minimum starter-anode voltage at which the discharge through the tube will be triggered with a plate voltage of 255 volts is defined as the firing voltage. To maintain a constant relation between photoelectric current and pulse rate, it is essential that the firing voltage be independent of the voltage applied to the plate of the tube over the range of plate voltages encountered in service.

The range of plate voltages over which the firing voltage is constant is defined as the plate-voltage plateau. The sensitivity of a trigger tube is a function of the difference between the firing voltage and the voltage of the starter anode at the moment the arc discharge within the tube is extinguished. If the relation between the phototube current and firing voltage varies slightly from pulse to pulse, the tube will exhibit varying degrees of stability in operation. If there is leakage over the internal or external surfaces of the envelope of the trigger tube, or if there is a continuous gaseous conduction between the starter anode and the other electrodes, the pulse rate will not be proportional to the incident flux at low flux levels since (assuming a perfect phototube)

$$I_c = I_p - I_L = C(E_f - E_d)/T \qquad (1a)$$

or

$$I_c = I_p - I_L = C(E_f - E_d)r \qquad (1b)$$

where

I_c is the current charging the starter-anode circuit,
I_p is the photoelectric current,
I_L is the leakage current of the trigger tube generated by the phototube (leakage current from grid to ground or to cathode is considered positive and leakage current from anode to grid is negative),
C is the capacitance of the starter-anode circuit (the capacitance of the charging capacitor plus the internal capacitance of the tubes and the wiring),
E_f is the voltage at which the starter anode triggers the tube,
E_d is the voltage of the starter anode at the time the discharge is extinguished,
T is the time between pulses in seconds, and
r is the pulse rate in pulses per second.

Equations 1a and 1b may be rewritten as

$$I_c = C/(S_T T) \qquad (2)$$

and

$$I_c = Cr/S_T$$

where S_T is defined as the sensitivity of the trigger tube.

2.2 Analysis of Phototube Operation.

The type WL-919 phototube is a high-vacuum photoelectric tube with a type S-1 spectral response.

If F is the light flux in lumens incident on the phototube,

then $$I_p = S_p F$$

where S_p is the sensitivity of the phototube in microamperes per lumen.

Because of leakage over the surfaces of the phototube and thermionic emission, some current may flow across the tube even when no radiant flux is falling on the photosensitive surface of the tube and pulses will be generated by the pulse-amplifier unit. This current is known as the "dark current" of the tube. If there is leakage of the photoelectric current to ground, then the pulse rate of the pulse-amplifier unit will be reduced. If the phototube is not perfect, equation 1b must be written as

$$I_c = I_p + (I_D' - I_L') - I_L = C(E_f - E_d)r \qquad (3)$$

where I_D' is the true dark current and I_L' is the leakage current to ground of the phototube. These two currents cannot be measured independently; only their difference, net dark current, can be determined. The net dark current I_D is defined as

$$I_D = I_D' - I_L'$$

then $$I_c = I_p + I_D - I_L \qquad (4)$$

Note that I_D may be either positive or negative, depending upon the relative values of I_D' and I_L'. In general, I_D is positive.

3. TEST PROCEDURE

3.1 Choice of Test Methods.

The measurement of some of the tube currents characteristic of the tubes under test requires the use of sensitive galvanometers or electrometers which are not generally available. Therefore, the procedures outlined below were developed to utilize available transmissometer equipment to determine the performance

of the tubes under service conditions rather than to obtain absolute measurements of the tube characteristics. In general, both the dark current of the phototube and the leakage current of the trigger tube are not constant throughout the charging cycle but will vary with the potential of the starter anode. Therefore, a check of the effect of these currents under operating conditions is often more useful than direct measurements under other conditions.

3.2 Tests of Type WL-759 Trigger Tubes.

3.2.1 Sensitivity. In determining trigger-tube sensitivity use was made of a pulse-amplifier test unit and a portable transmissometer indicator. The test unit has a pulse-amplifier unit (with a 22-microfarad sensitivity capacitor) in one end and a lamp whose intensity can be continuously varied by a variable autotransformer at the opposite end. Power for the pulse-amplifier unit is supplied by the portable indicator. The portable indicator also measures the rate of the pulses generated by the pulse amplifier. The lamp intensity was adjusted to obtain a pulse rate which produced a convenient reading on the portable indicator when the standard trigger tube was installed in the pulse amplifier. Each test trigger tube was then substituted in turn for the standard tube; the ratio of the reading obtained to the reading obtained with the standard trigger tube is defined as the relative sensitivity. The standard trigger tube was frequently reinstalled as a check on the stability of the system.

Note: Instead of using the lamp and phototube as a current source, a 600-megohm resistor can be connected between the B+ voltage of the portable indicator and the trigger-tube grid cap. The sensitivity can then be obtained in the same manner as outlined in the preceding paragraph.

3.2.2 Firing Voltage. To perform this test and the tests described in the following paragraph, use was made of the special tube tester reported in NBS Report No. 2567, "Development of a Special Test Set for Transmissometer Use," dated June 22, 1953. The voltage applied to the plate of the tube was adjusted to 255 volts. Then the minimum starter-anode voltage necessary to trigger the tube (initiate intermittent flashes of the neon indicating lamp of the test set) was determined.

3.2.3. Plate-Voltage Plateau. The plate-voltage plateau was found by determining the range of plate voltages for which the firing voltage (as determined above) was just sufficient to trigger the tube regularly.

3.2.4 Leakage. A measure of the effects of leakage in the tube was obtained by using a pulse-amplifier test unit and a pulse-counting circuit. The tube under test and the "standard" phototube were installed in the test unit and the unit was covered so that no light was admitted. The pulse rate was then determined. If a tube did not generate pulses when used with the standard phototube, the photoelectric current was increased by allowing a small amount of light to fall on the phototube or by replacing this phototube with a phototube having a higher dark current until a current sufficient to make the trigger tube generate regular pulses was obtained. The leakage currents of trigger tubes which generate regular pulses at pulse rates in the range of one pulse in 30 seconds to one pulse in 60 seconds from the dark current of this phototube (0.00010 microampere) are rated as very satisfactory (V). The leakage current of the tubes which generate regular pulses from the dark current of the standard phototube at a rate slower than that of the very satisfactory tubes is rated as satisfactory (S). The leakage currents of the tubes which require a current greater than the dark current of the phototube in order to generate regular pulses are rated as fair (F) or unsatisfactory (U) depending upon the current required.

3.2.5 Stability. Tube stability is a subjective estimate of the constancy of the time interval between pulses (and hence the constancy of E_f) from moment to moment during the sensitivity check. Each tube was rated as being very stable (V), stable (S), or unstable (U) on the basis of the stability of the portable-indicator meter indication.

3.2.6 Anomalous Behavior. Trigger tubes were checked for anomalous behavior by varying light incident on the phototube, thereby varying the phototube current, so that the pulse rate of the trigger tube was varied continuously from about 60 pulses per second to about one pulse in 10 seconds. The presence of any regions in which the tube failed to operate was noted.

3.3 Tests of Type WL-919 Phototubes.

3.3.1 Sensitivity. The relative sensitivity of the phototubes was determined in a manner similar to that used in determining the relative sensitivity of the trigger tubes except that the standard phototube was used in combination with the phototubes under test. Because the conditions of illumination on the photosensitive surface and the color temperature of the lamp in the pulse-amplifier test box did not duplicate service conditions, the relative sensitivities determined in this manner will differ somewhat from the relative sensitivites in service. (A new test unit which duplicates service conditions of illumination has been designed and constructed.)

3.3.2 Dark Current. The dark-current pulse interval was measured using the arrangement used for the determination of trigger-tube leakage except that the standard trigger tube was used in the unit in combination with the test phototubes. The average time in seconds between pulses was taken as the dark-current pulse interval.

3.3.3 Leakage. If more than 500 seconds elapsed without a pulse being generated by the dark current, sufficient light was applied to the tube to produce regularly spaced pulses at a minimum rate. The standard phototube was then substituted for the test phototube and, without changing the intensity of the light, the pulse rate with this tube was then determined. This pulse rate, when corrected for the dark current of the standard phototube, is proportional to the leakage current of the test phototube.

4. REDUCTION OF TEST DATA

The measurements obtained by the test procedure outlined above are all dependent upon the characteristics of the standard phototube and the standard trigger tube. Since, if the minimum acceptable relative sensitivities are known, the relative sensitivity is as useful an index of tube quality as absolute sensitivity, relative sensitivities were not reduced. Measurements of leakage and dark currents are, however, more useful if the effect of the leakage of the standard trigger tube is removed from the dark-current measurements and the effect of the dark current of the standard phototube is removed from the leakage-current measurements. This was done in the following manner.

If the phototube is dark,

$$I_D - I_L = CS_T r \qquad (5)$$

Note that the product CS_T is the charge, in microcoulombs, removed from the charging capacitor during each discharge of the trigger tube.

The charge per pulse of the standard trigger tube, installed in the receiver test unit, was determined from the relation

$$I_c = I_p + I_D - I_L = CS_T r$$

by direct measurement of I_p and by computing the corresponding pulse rate, r, from the reading of the portable indicator. The

current I_P was made large enough so that I_D and I_L are negligible in comparison to it. This measurement was made by connecting a photoelectric galvanometer with an Ayrton shunt into the anode circuit of the phototube. Careful attention to electrostatic shielding and the use of a reversing key was required. (An alternative method to generate the current is the use of a suitably high resistor, about 600 megohms, in place of the phototube.) A charge of 0.0035 microcoulomb per pulse was passed by the standard trigger tube when a 22 micromicrofarad capacitor was used for the charging capacitor.

Neither the phototube dark current or the trigger-tube leakage current could be measured with the galvanometer connected into the B+ lead of the pulse amplifier because at these slow pulse rates the discharges of the trigger tube and the high galvanometer sensitivity required produced large disturbances in the galvanometer system. Instead, the dark current of the standard phototube was measured by connecting the photoelectric galvanometer and the phototube in series with a 90-volt battery. The minimum voltage applied to the phototube during the charging cycle is about 90 volts. The photoelectric galvanometer with with the Ayrton shunt in the X1 position has a sensitivity of 1.4×10^{-5} microampere per millimeter. This is adequate for dark-current measurement of the standard phototube. A dark current of $1.0_3 \times 10^{-4}$ microampere was measured.

The dark-current pulse rate when the standard phototube was used with the standard trigger tube was one pulse in 500 seconds. Therefore the leakage current of the standard trigger tube may then be computed from equation 5 as follows:

$$1.0_3 \times 10^{-4} - I_L = 0.0035 \times 1/500 \qquad (7)$$

and

$$I_L = 0.9_6 \times 10^{-4}$$

As a check, the trigger tube was installed in the pulse amplifier without the phototube. The charging capacitor was connected to the starter anode. The starter anode was then connected to the 255-volt B+ supply through a chain of high-value resistors. The resistance of the chain was adjusted until the current through it was so nearly equal to the leakage current of the tube that the pulse rate was very slow (1 pulse in about 5 minutes, and erratic). The current flowing was then only slightly greater than the leakage current of the tube. A resistance of 4×10^{12} ohms

was required for the standard trigger tube. As the average voltage drop across the resistor chain was about 120 volts, the current flowing was approximately 0.3×10^{-4} microampere.

That these two determinations of leakage current differ by a factor of 3 is not unexpected since the operating conditions differ considerably and the trigger tubes are very sensitive to variations in the starter-anode circuit. In reducing the data, the leakage current obtained under service conditions, $0.9_6 \times 10^{-4}$ microampere, was used as the leakage current of the standard trigger tube.

Knowing the leakage current and the sensitivity of the standard trigger tube, the dark currents of all test phototubes having dark currents greater than the leakage current of this trigger tube were determined by using equation 5 to compute the dark currents from the dark-current pulse rates of these tubes.

Similarly, the leakage currents of the trigger tubes having leakage currents less than the dark current of the standard phototube were determined from the pulse rates obtained from the dark-current pulse rate of this phototube when used with the test trigger tube. As seen from equation 5, this requires knowledge of the absolute sensitivity of the test trigger tube. This sensitivity is the product of the absolute sensitivity of the standard trigger tube and the relative sensitivity of the test trigger tube, both of which had been determined.

Since the ultimate purpose of the transmissometer set is to obtain a measure of the visual range, the effect on this measure of the leakage current of the trigger tube or the dark current of the phototube must be considered. The leakage currents of trigger tubes and the dark currents of phototubes can be converted to transmission errors by dividing each by the current necessary to produce a 100% transmission reading.

Since $$I_c = I_p + I_D - I_L , \qquad (4)$$

if I_o is the photoelectric current which flows when the transmission is unity, then

$$I_c/I_o = I_p/I_o + I_D/I_o - I_L/I_o$$

or

$$t' = t + \Delta t_D - \Delta t_L$$

where t' is the indicated transmission,
t is the true transmission, and
Δt_D and Δt_L are the errors produced by the dark current and leakage current respectively.

For a 750-foot baseline transmissometer with tubes of average sensitivity, I_0 is approximately 0.2 microampere. The incremental transmission errors, Δt_D and Δt_L, were computed from the dark current of each phototube and the leakage current of each trigger tube, assuming a current of 0.2 microampere for I_0.

5. TEST RESULTS

The data obtained are summarized in table I, Test Results for Type WL-759 Trigger Tubes, and in table II, Test Results for Type WL-919 Phototubes. For the purpose of identification the tube number of each tube as listed in the first column of the tables has been engraved into the base of the corresponding tube.

6. DISCUSSION

It is difficult to give specific criteria which can be applied by rote in determining whether a particular trigger tube or phototube is satisfactory for transmissometer use. The effect of incremental errors in the transmission measurement resulting from the leakage current of the trigger tube and the dark current of the phototube upon the intended application of the transmissometer should be considered.

6.1 Effects of Incremental Transmission Errors.

The maximum permissible values of leakage and dark currents can be determined by computing the effect of the transmission errors produced by these currents on the indicated visual range. Figure 1 is a plot of indicated visual range against the true visual range when incremental errors in transmission measurements are superimposed on transmission readings. The family of curves for the plus-increments is applicable to most phototube dark currents and to the trigger-tube leakage current from the plate to starter anode. This condition is a relatively rare occurrence. The minus-increments are comparable to the usual starter anode-to-ground leakage currents of the trigger tubes. (Errors arising from incorrect readings or instrument inaccuracy may, of course, be of either sign.) Note that even very small increments of

either sign will cause large errors in the indicated visual range in periods of very clear weather or in very dense fogs. The effect of these errors will be considered in determining the maximum permissible leakage or dark currents.

6.2 Selection of Trigger Tubes.

6.2.1 Sensitivity. Experience has indicated that trigger tubes with relative sensitivities lower than 0.90 are not useful for transmissometers with baselines longer than 500 feet except when they can be paired with phototubes of unusually high sensitivity.

6.2.2 Stability. The particular application will determine whether or not a tube rated as S (stable) or V (very stable) is necessary. In the majority of cases, S (stable) tubes are adequate. There are few transmissometer applications for which U (unstable) tubes can be utilized. In general, unstable trigger tubes can be utilized only in circuits with exceptionally long time constants, in applications in which the time integral of flux is required and the period of integration is sufficiently long so that the irregularities in the pulse rate do not affect the result.

6.2.3 Plate-Voltage Plateau. It is essential that the plate-voltage plateau of each tube be sufficient to include the range of voltages normally found in service. A minimum range of from 245 vdc to 275 vdc is required because of the expected variations in the characteristics of the voltage-regulator tubes used in the receiver power-supply unit.

6.2.4 Leakage Current. The maximum permissible leakage current may be found by using the curves of figure 1 and the transmission error corresponding to this current to determine the effect of the leakage current on the indicated visual range. For most operational purposes a leakage current of 0.00002 microampere, producing a transmission error of 0.001, is permissible.

6.3 Individual Selection of Phototubes.

6.3.1 Sensitivity. Experience in service has indicated that phototubes with sensitivities lower than 0.9 are not useful in most transmissometer applications. When possible, it is more desirable to use phototubes with higher sensitivity than to reduce the capacitance of the sensitivity capacitor of the photo-pulse unit below 20 μμf.

6.3.2 Dark Current. The maximum permissible dark current may be found from figure 1 by a method similar to that used in finding the maximum permissible leakage current of trigger tubes. As with the trigger tubes, for most operational purposes a dark current of 0.0002 microampere, corresponding to a transmission error of 0.001 and a "dark" pulse rate of one pulse in 15 seconds is the maximum permissible.

It should be noted that if the value of C1201 is adjusted to the maximum capacitance permitted by the sensitivity of the phototube, it is permissible to use high-sensitivity phototubes which have a somewhat higher dark current than that of tubes of average sensitivity. If C1201 is adjusted, I_0 is then approximately equal to 0.2 times the relative sensitivity of the tube. Consequently, the permissible dark current is also equal to the product of the tube sensitivity and the permissible dark current for tubes of average sensitivity.

6.4 Pairing Tubes.

It is frequently desirable to use phototubes of high sensitivity with trigger tubes of low sensitivity, and conversely, in order to reduce the variations in sensitivity from receiver to receiver and to reduce the number of tubes to be discarded. Similarly, since the errors produced by the phototube dark current and the trigger-tube leakage current are of opposite sign, a pairing of tubes with errors of approximately the same magnitude is desirable. However, the degree of compensation for leakage and dark currents which can be obtained in this manner is limited.

Table I

Characteristics of Type WL-759 Trigger Tubes

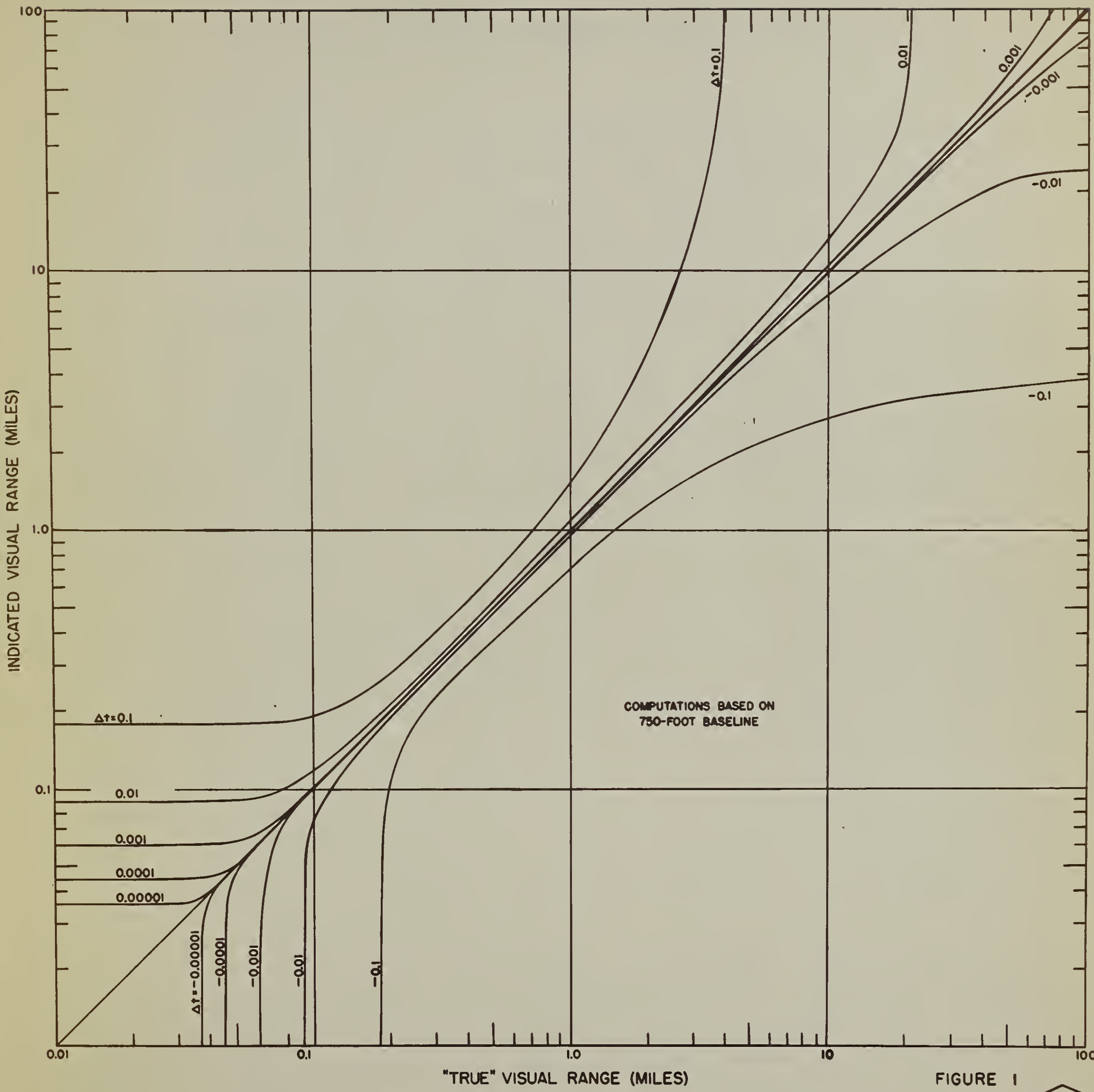
Tube No.	Relative Sensitivity	Firing Voltage (volts)	Plate-Voltage Plateau (max volts/ min volts)	Leakage Current: Rating	Leakage Current: Equivalent Transmission	Stability
WB-1	1.00	160	>300/240	V	0.00003	U
WB-2	1.20	165	>300/184	V	0.0002	V
WB-3	1.08	160	295/200	F	>0.0005	U
WB-4	1.00	165	280/190	S	0.0003	S
WB-5	1.16	149	290/178	S	0.0003	U
WB-6	1.04	171	285/165	S	0.0004	S
WB-7	1.26	170	297/160	U	>0.0005	V
WB-8	1.14	168	290/200	U	>0.0005	V
WB-9	1.04	165	295/195	U	>0.0005	S
WB-10	1.40	160	285/190	F	>0.0005	S
WB-11	0.84	183	300/190	S	0.0002	S
WB-12	1.04	153	295/185	V	0.00004	U
WB-13	1.04	160	300/225	U	>>0.0005	V
WB-14	1.04	154	274/200	F	>0.0005	S
WB-15	1.16	145	290/180	S	0.0004	S
WB-16	1.18	165	295/180	S	0.0004	S
WB-17	0.90	179	300/180	U	>0.0005	V
WB-18	1.22	160	300/220	V	0.0001	U
WB-19	0.86	173	300/225	V	0.0002	S
WB-20	0.90	175	300/209	V	-0.00002	S
WB-21	1.64	148	300/205	V	-0.00008	S

V: Very good
S: Satisfactory
F: Fair
U: Unsatisfactory

Table II

Characteristics of Type WL-919 Phototubes

Tube No.	Relative Sensitivity	Dark Current (Equivalent Transmission)
WB-A	1.36	0.0008
WB-B	1.40	0.0014
WB-C	1.46	0.0007
WB-D	1.34	0.0006
WB-E	1.48	0.0015
WB-F	1.68	0.0017
WB-G	1.32	0.0008
WB-H	0.90	0.0006
WB-I	0.90	0.0063
WB-J	1.34	0.0007
WB-K	1.48	0.0024
WB-L	1.38	0.0017
WB-M	1.40	0.0016
WB-N	1.56	0.0010
WB-O	1.52	0.0024
WB-P	0.94	0.0008
WB-Q	1.20	0.0018
WB-R	1.08	0.0020
WB-S	1.06	0.0017
WB-T	1.11	0.0012
WB-U	1.22	0.0063
WB-V	1.36	0.0049
WB-W	1.40	0.0040
WB-X	1.00	0.0027
WB-Y	1.32	0.0027
WB-Z	1.12	0.0027
WB-AA	1.32	0.0011
WB-AB	1.18	0.0011
WB-AC	1.22	0.0023
WB-AD	1.04	0.0007
WB-AE	0.98	0.0015



INDICATED VISUAL RANGE (MILES)
"TRUE" VISUAL RANGE (MILES)
COMPUTATIONS BASED ON
750-FOOT BASELINE
Δt=0.1
0.01
0.001
0.0001
0.00001
Δt=-0.00001
-0.0001
-0.001
-0.01
-0.1
-0.001
-0.01
-0.1
0.01
0.001
Δt=0.1
0.01
0.1
1.0
10
100

FIGURE 1

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The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

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