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FINAL REPORT

IMPROVED STERILIZABLE MULTIPLIER PHOTOTUBES

Prepared for Jet Propulsion Laboratory

by

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JPL Contract Number 951555

EMR Project Number 2641-4476

July 26, 1968

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This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under contract NAS7-100.

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ABSTRACT

A multiplier phototube with visible response has been developed for use in scintillation counting applications where sterilization is required. The sterilizable phototube, the EMR Model 549A-4476, utilizes a newly developed, proprietary photocathode which has a high sensitivity in the blue well matched to the emission spectrum of NaI(Tl). This photocathode has good stability when exposed to the sterilization environment.

A test sample of four phototubes was subjected to three sterilization cycles of 145°C for 36 hours each. Test results are discussed.

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1. INTRODUCTION

EMR conducted a program for the Jet Propulsion Laboratory for the development and study of multiplier phototubes suitable for use in space applications requiring sterilization. The original program, carried out under JPL Contract Number 950682, was successfully completed in December 1965.

This report describes a follow-on effort to develop an improved sterilizable multiplier phototube with visible response for scintillation counting applications.

1.1 Prior Work on Sterilizable Multiplier Phototubes

In the previous program two EMR multiplier phototube types were studied--the Model 541N-01 with visible response and the Model 541F-08 with ultraviolet response.

The primary objectives were to develop phototubes which could successfully withstand the rigors of dry heat sterilization and to study the effects of sterilization on the operational characteristics. Each phototube was subjected to three sterilization cycles consisting of exposure to dry heat at 145°C for a period of 36 hours.

In addition, each tube was subjected to gas decontamination, thermal vacuum, static acceleration, vibration, shock, and an operational life test.

The Model 541F-08 with ultraviolet response was found to be well suited for applications requiring sterilization. The electrical characteristics were sufficiently stable that no further work on this phototube type was undertaken on the present program.

The standard Model 541N-01 with visible response had a high initial photocathode sensitivity, but after one or more sterilization cycles the photocathode became highly resistive and performance was degraded. The photocathode processing technique was altered to improve its conductivity and stability, but as a result

of these changes the initial photocathode sensitivity was decreased. The modified photocathodes were found to be suitably stable although of reduced sensitivity.

1.2 Description of the Present Program

The objectives of this program were to further improve and study sterilizable multiplier phototubes with visible response. Of particular interest were the sensitivity and energy resolution prior to sterilization, stability of these characteristics after sterilization, and prediction of changes due to sterilization.

The first approach was an experimental study of the bialkali photocathode processed on a conductive substrate. This was found to be generally unsuccessful.

The second approach was a study of a newly developed photocathode processed without a substrate. This photocathode, the EMR type U developed under a company sponsored photocathode development program, was suggested for use as a sterilizable photocathode because of its good stability after short term exposure to high temperature.

2. PHOTOMULTIPLIER CHARACTERISTICS AND THEIR MEASUREMENT

2.1 Spectral Response

2.1.1 Definitions

Two terms that are particularly useful in specifying the sensitivity of a photocathode are cathode radiant sensitivity, $S_k(\lambda)$, and quantum efficiency, $Q(\lambda)$. The cathode radiant sensitivity is a measure of the sensitivity of the photocathode to monochromatic light at a particular wavelength λ expressed in units of Amperes/Watt. The quantum efficiency at a wavelength λ (in Angstroms) is the sensitivity of the photocathode expressed in units of photoelectrons per incident photon. The cathode radiant sensitivity and quantum efficiency at a given wavelength λ are related by

$$Q(\lambda) = \frac{1.24 \times 10^4 \; S_k(\lambda)}{\lambda}$$

The spectral response characteristic of the photocathode is a plot of cathode radiant sensitivity as a function of wavelength. In practice the measurements of cathode radiant sensitivity and quantum efficiency include the effects of absorption or reflection in the window because the measurements are based on the light flux incident on the window of the photomultiplier.

2.1.2 Measurement Techniques

The cathode radiant sensitivity is measured by directing a beam of monochromatic light of known intensity on the window of the tube and measuring the resulting photoelectric current. The tube is connected as a diode as shown in Figure 1. The photocathode is normally placed at a negative potential of from 150 to 300 V (as required for saturation), while the first dynode and remaining dynodes are used for collection. The first dynode is tied

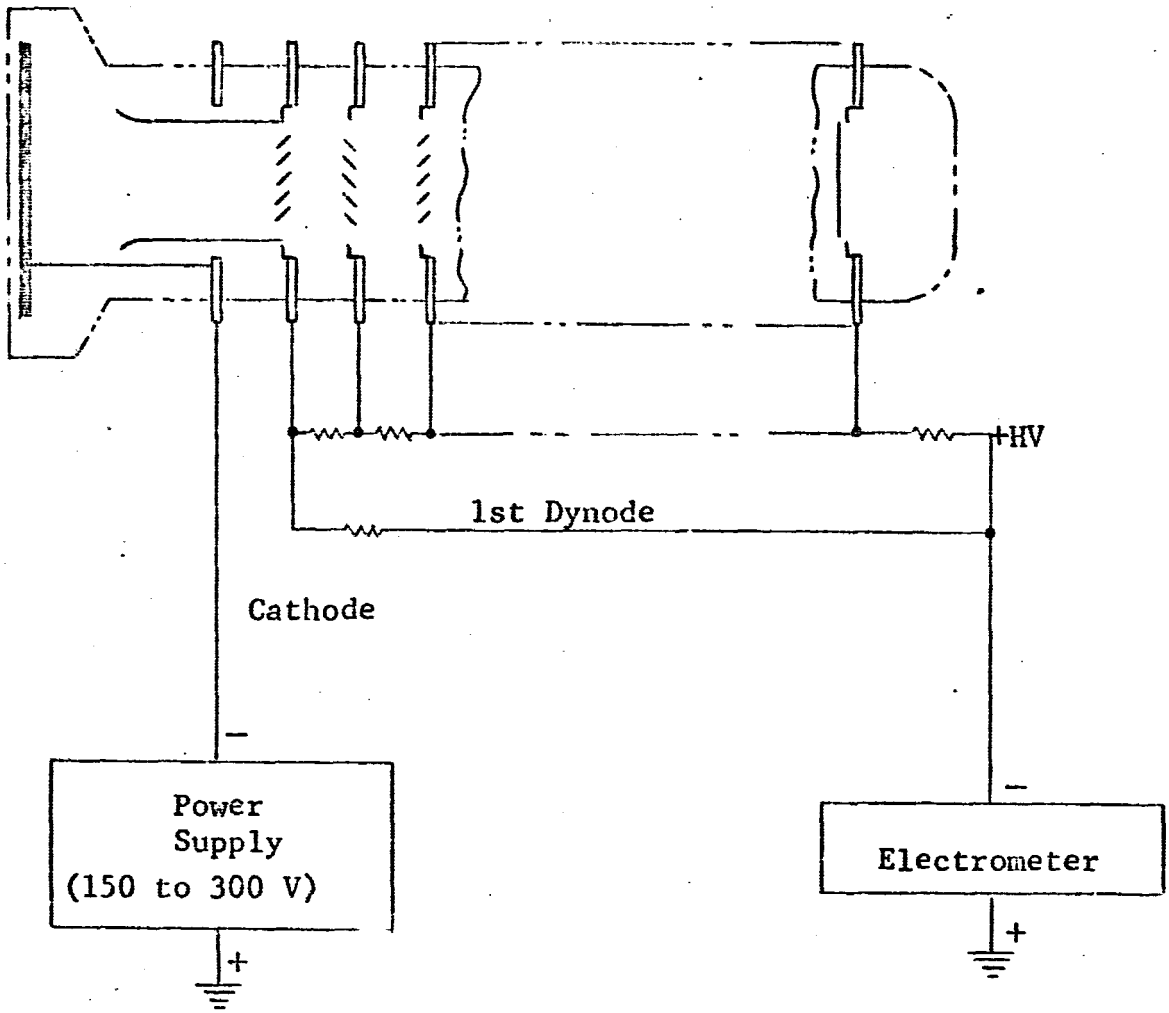


FIGURE 1. Schematic diagram showing the electrical connections for measuring cathode radiant sensitivity.

to the input of an electrometer such as Keithley Picoammeter which is used to measure the photoelectric current.

A Perkin-Elmer monochromator is used for measurements of the spectral response in the visible region. The light source is a tungsten lamp. The monochromatic light input to the tube is measured by means of a calibrated thermocouple. The light level is adjusted for a desired output from the thermocouple; the light beam is deflected onto the face of the tube; and the photocathode current is read.

2.2 Gain

The current gain of a photomultiplier is defined as the ratio of anode current to cathode current. The gain is strongly dependent on the overall voltage. Current gain is normally plotted as a function of overall voltage on a semi-log graph with gain plotted on the logarithmic scale. Useful gains range from approximately 10^4 to 10^8.

If the average gain due to secondary emission for one dynode in a photomultiplier is δ and the gain is equal for each of the n dynodes, then the total gain will be $G = \delta^n$. Since the number of stages is large, a very slight variation in the average gain per dynode can result in significantly large changes in the total gain G.

The gain measurement is made in two steps. With the tube connected as a diode the light input is adjusted to produce a convenient cathode current (in the range of approximately 10^{-12} amperes). Then without changing the light input or the orientation of the tube with respect to the light spot, the tube is connected as a multiplier, and the anode current is measured as a function of the overall applied voltage.

2.3 Resolution

2.3.1 The Scintillation Detector

A scintillation detector consists of a suitable scintillation crystal optically coupled to the faceplate

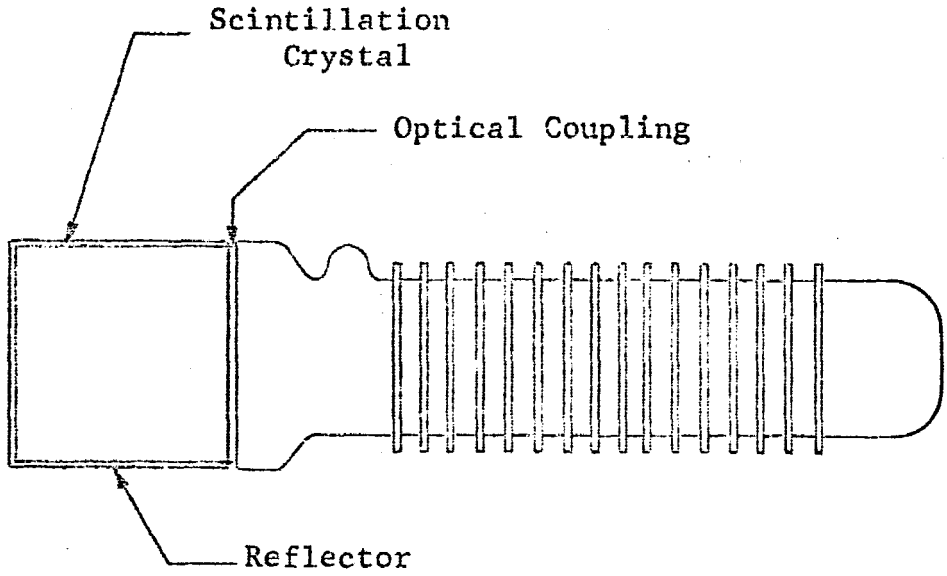
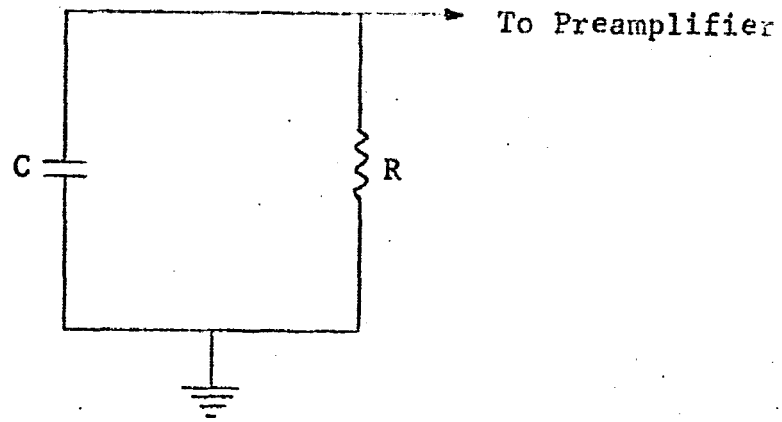


FIGURE 2. A scintillation detector.



$C = C_A + C_P + C_S$

C_A = anode capacitance

C_P = input capacitance of preamplifier

C_S = stray capacitance

FIGURE 3. Equivalent circuit for the photomultiplier anode circuit.

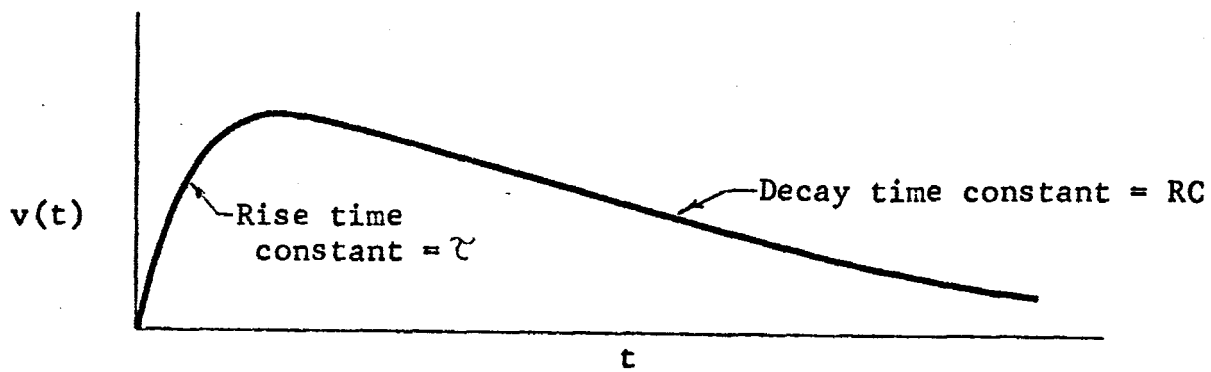


FIGURE 4. Voltage pulse appearing at the anode of the photomultiplier.

of a photomultiplier as shown in Figure 2. An incident gamma ray is absorbed within the scintillation crystal, and the gamma ray energy which is given up to the crystal is then re-emitted as a short burst of visible light. By means of the optical coupling, the photocathode sees the scintillation, and a number of photoelectrons are emitted. The photoelectrons collected on the first dynode of the photomultiplier are multiplied through the dynode structure resulting in a current pulse at the anode of the tube.

The equivalent circuit of the anode of the photomultiplier is shown in Figure 3. The capacitance shown is the sum of the anode capacitance, stray capacitance in the circuit, and the input capacitance of the premaplifier. The load resistor is selected to give the proper time constant. The last three dynode stages are bypassed by capacitors to stabilize the interdynode potential distribution during high current pulse operation.

The voltage pulse at the input of the preamplifier is shown in Figure 4. It has a rise time which is determined by the decay time τ of the crystal (in the case of thallium activated sodium iodide, τ = 0.25 μsec). The decay time of the pulse is determined by the RC time constant of the anode circuit. In general the RC time constant should be very long in comparison to the decay time constant τ of the scintillation crystal. This insures that all of the charge from the current pulse is integrated at the input of the preamplifier to give the maximum pulse amplitude which is determined by $V = Q/C$ where Q is the total charge per pulse and C is the capacitance of the anode circuit.

The amplitude of the output pulse is determined by the number of photons emitted by the crystal for each incident gamma ray, the transfer coefficient for photons from the scintillation crystal to the cathode of the photomultiplier, the quantum efficiency of the photocathode, the collection efficiency of the photomultiplier (i.e., the

fraction of photoelectrons per pulse that is collected onto the first dynode), the average gain of the photomultiplier, and the anode capacitance.

Since the pulse amplitude is inversely proportional to the anode capacitance, it is advantageous to have the anode capacitance as low as possible. For this reason a preamplifier is commonly placed in close proximity to the photomultiplier output. The preamplifier can drive a long cable to the pulse height analyzer without having the signal pulse degraded by the cable capacitance.

2.3.2 Pulse Height Spectra

A typical differential pulse height spectrum obtained using a sodium iodide scintillation crystal and a Cs^{137} gamma source is shown in Figure 5. The axes in this figure are labeled as they would be for data obtained from a multichannel pulse height analyzer. The abscissa in channel number corresponds to pulse height.

The shape of the pulse height spectrum may be explained by a consideration of the absorption processes in the crystal. In the photoelectric process a gamma photon interacts with an electron in the crystal giving up all of its energy to the electron. The electron energy is completely given up to the crystal, and a fraction of this energy is emitted in the form of light. In the case of the photoelectric interaction the total energy of the gamma photon is given up to the crystal, and the number of photons per scintillation is directly proportional to the gamma ray energy. The result is a photo-peak as shown in Figure 5 with the pulse amplitude proportional to the energy of the incident gamma ray.

A competing absorption process is that of Compton scattering. In this case an incident gamma photon gives up only a fraction of its energy to an electron within the crystal, and the lower energy scattered photon may escape from the crystal volume. In this case only the fraction of

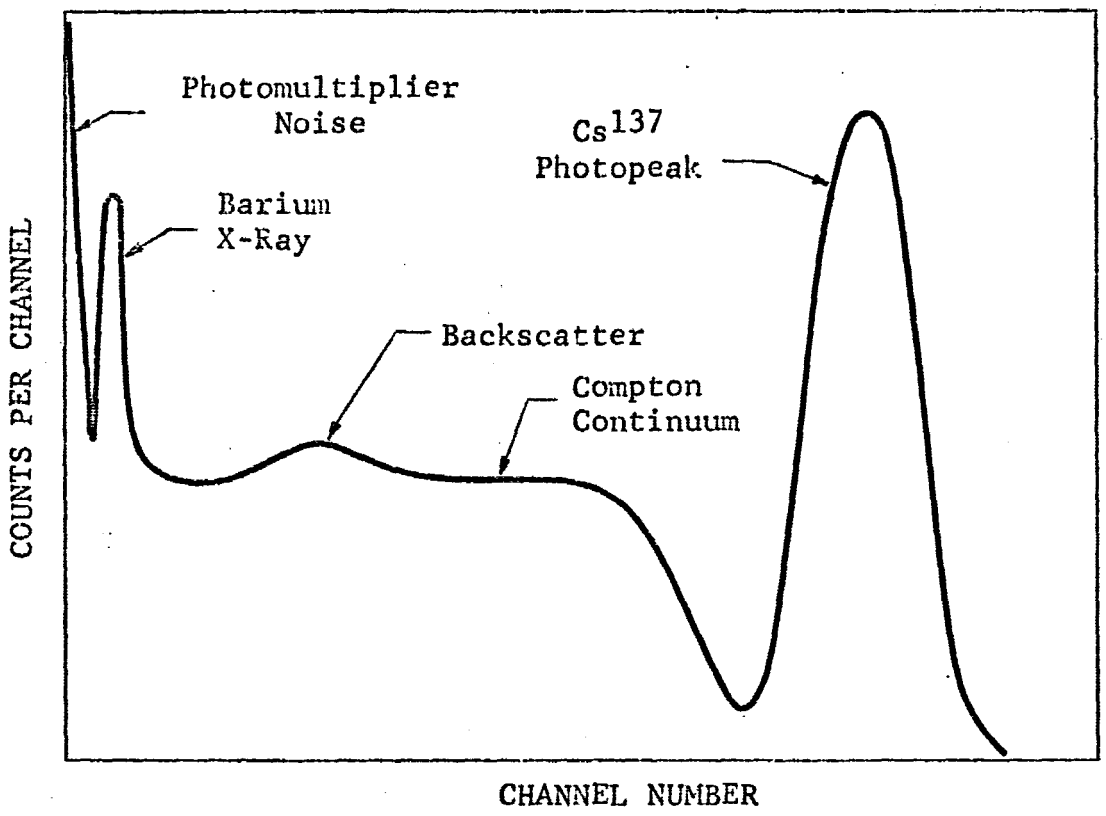


FIGURE 5. A typical differential pulse height spectrum using a NaI(Tl) scintillation crystal and a Cs^{137} source.

the incident gamma energy which was given up to the electron is seen by the photomultiplier as visible light. This results in a lower amplitude pulse than was seen with the photoelectric effect. Since the energy of the scattered gamma is a function of the energy of the primary gamma and the scattering angle, a pulse height continuum is seen due to the Compton scattering process.

Two other peaks are seen in the spectrum. Superimposed on the Compton continuum is a small peak due to back-scattered photons. The photo-peak corresponding to 32 kev is due to the barium K x-ray. Photomultiplier noise pulses are seen at pulse amplitudes below that of the barium x-ray.

2.3.3 Resolution

The width of the photo-peak is a measure of the statistical variation in pulse height for a given monoenergetic gamma and an indication of the ability of the system to resolve two different gamma rays closely spaced in energy. The resolution W_T is defined as

$$W_T = \frac{\Delta E}{E} \times 100\%$$

where E is the position of the photo-peak and ΔE is the width of the photo-peak at half-maximum. The shape of the photo-peak is closely approximated by a Gaussian distribution.

The statistical variation in pulse heights for monoenergetic gamma rays is a result of statistical variations in the number of photons emitted by the scintillator per absorbed gamma and statistical variations due to the photomultiplier. The total line width W_T consists of two components, W_P due to statistical variations in the photomultiplier and W_C due to an intrinsic resolution of the

scintillation crystal. The total resolution W_T is related to the photomultiplier resolution and the resolution of the crystal by

$$W_T^2 = W_P^2 + W_C^2$$

The resolution of the photomultiplier Wp can be measured directly using a light pulser. A cathode ray tube with the proper phosphor can be pulsed in such a way as to simulate the light pulses from a scintillation crystal. Knowing the resolution of the photomultiplier W_P, the resolution of the crystal can be determined from the total resolution using the above equation.

The contribution to the total resolution which is intrinsic to the crystal is determined by such factors as the crystal size, geometry, quality and packaging of the crystal, and the type reflector material used. The optical coupling between the scintillation crystal and the photomultiplier must be maximized for the best total resolution.

The total resolution is inversely proportional to the square root of the number of photoelectrons per pulse arriving at the first dynode of the photomultiplier. For this reason the best resolution is obtained when the quantum efficiency is high and the collection efficiency for electrons to the first dynode is close to one.

2.3.4 Measurement

For all the resolution measurements made during this study, the scintillation crystal was optically coupled to the photomultiplier using Dow Corning C-20057 compound. Care was taken to insure that there were no bubbles between the crystal and the faceplate.

In resolution measurements, factors which contribute to total resolution must be considered. The counting geometry must be optimized for best resolution. In our resolution measurements placing the Cs^{137} source in contact

with the end of the crystal can and in line with the axis of the crystal was found to be the most suitable geometry. The counting rate with the source in this position was approximately 2000 counts/second.

Several precautions must be observed to insure proper operation of the electronics. When excessive photomultiplier gains are used, especially with high quantum efficiency tubes, the preamplifier may be overdriven introducing distortion in the pulse height spectrum. A gain of 1×10^5 is commonly used. The output of the linear amplifier in the multichannel analyzer should be observed with an oscilloscope to insure that the amplifier is not being overdriven. The zero of the multichannel analyzer should be checked using a calibrated pulse generator to insure that zero channel corresponds to zero pulse height.

2.4 Dark Current

2.4.1 Definition

The dark current of a photomultiplier is the anode current that is measured when the tube is operated in total darkness.

Sources of dark current are electrical leakage, thermionic emission, field emission, residual gas ionization, and tube fluorescence. The two major components are thermionic emission and electrical leakage. The component of dark current which is due to electrical leakage can be reduced effectively by thorough cleaning and dessication of the tube followed by potting in a high resistivity potting compound which hermetically seals the tube. The thermionic component of dark current is readily identified by plotting dark current as a function of temperature.

2.4.2 Measurement

In practice the measurement of photomultiplier dark current requires considerable care in order to achieve reproducible results. In the case of low work-function cathodes such as the bialkali, the major component of dark current is that due to thermionic emission. For this reason it is important that the temperature be recorded along with the dark current data.

In the measurement of dark current the tube is placed in a completely light tight box and connected as a multiplier. The most convenient arrangement is to operate the tube with negative high voltage; that is, the cathode is at a negative high voltage, and the anode, being at ground potential, can be tied directly to the input of an electrometer. One precaution that should be observed when this arrangement is used is that the cathode should not be placed in the vicinity of an external ground potential. When a tube is operated at negative high voltage and the ground potential is brought in contact with or in close proximity to the faceplate of the tube, an increased dark current will be observed.

The dark current is a function of the time which a tube is aged in the dark. For accurate and reproducible measurements the tube should be aged until the dark current settles to a constant value.

3. DEVELOPMENTAL PROGRAM

The bialkali photocathode processed for maximum sensitivity in the standard Model 541N-01 has an average quantum efficiency of about 21 percent at 4100 Å. From previous work with this phototube it was found that the photocathode became highly resistive following one or more sterilization cycles, and, disregarding resistivity effects, the photocathode sensitivity decreased to about two thirds its initial value after one cycle and to about one third its initial value after three cycles.

The modifications in photocathode processing developed under the previous contract resulted in a much more stable photocathode, but the average initial quantum efficiency was only 13.5 percent.

The primary objective of this program was to develop a more stable, high sensitivity photocathode which would maintain its conductivity following sterilization.

3.1 Photocathodes on Conductive Substrates

The purpose of the conductive substrate was to improve the conductivity of the photocathode and allow the photocathode to be processed for the maximum sensitivity without regard to the conductivity of the photocathode itself. Using this approach a quantum efficiency of close to the average value of 21 percent was expected.

The first experiments were made using vacuum evaporated substrates of chromium. A dual electrical evaporator, designed for evaporation of the substrate as a first step in the processing of the photocathode, is shown in Figure 6. The thickness of the substrate was controlled by monitoring its transmission for white light during evaporation.

A number of technical problems were encountered which limited the photocathode sensitivity in early experiments. These were solved by redesign of the electrical evaporators to eliminate excessive heating of the supporting structure and subsequent outgassing which affected the photocathode formation.

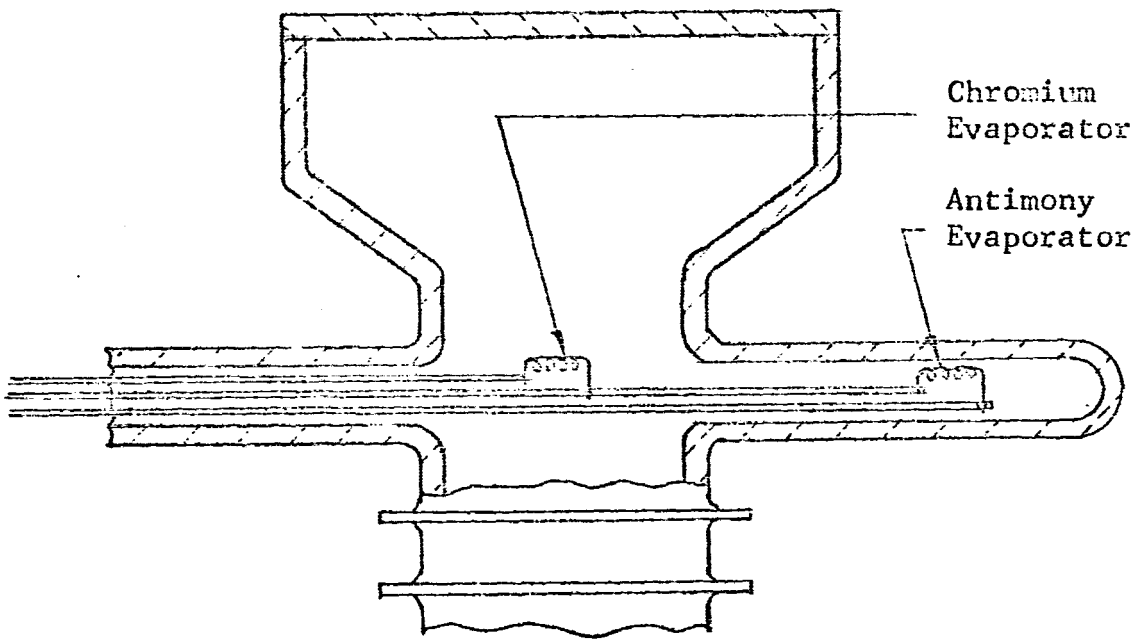


FIGURE 6. The dual electrical evaporator shown in position for evaporation of the conductive substrate.

A test sample of four tubes with an average quantum efficiency of 16 percent was subjected to three sterilization cycles. After the first cycle the average was 6 percent, and after three cycles it dropped to 5 percent. No evidence of high resistivity was observed.

It was concluded that the bialkali photocathode can be processed on conductive substrates of chromium; however, the sensitivity is lower than expected and the stability is poor.

Two additional tubes were processed with bialkali photocathodes on aluminum substrates. These were unsuccessful because of low photocathode sensitivity.

For program expedience the conductive substrate approach was abandoned. A newly developed photocathode, the EMR type U, showed good stability after short term temperature cycling and for this reason was considered to be a promising alternative approach.

3.2 U Photocathode

The first tube, made using a conductive substrate of chromium, had a low sensitivity which was attributed to the presence of the substrate. In the limited testing of the U photocathode it had shown no tendency to become resistive after high temperature exposure, so the conductive substrate was omitted on subsequent tubes.

The new photocathode was used on four tubes without substrates. These tubes, when subjected to three or more sterilization cycles, had high sensitivity and improved stability.

Test results for these tubes will be discussed in detail in Section 4.

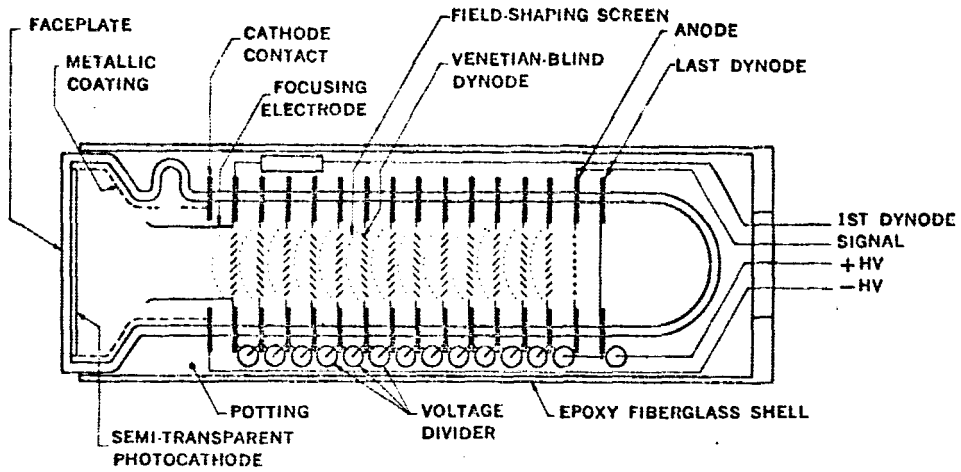
3.3 Description of the Improved Sterilizable Multiplier Phototube

The improved sterilizable multiplier phototube, designated EMR Model 549A-4476, has the basic Model 541 mechanical structure

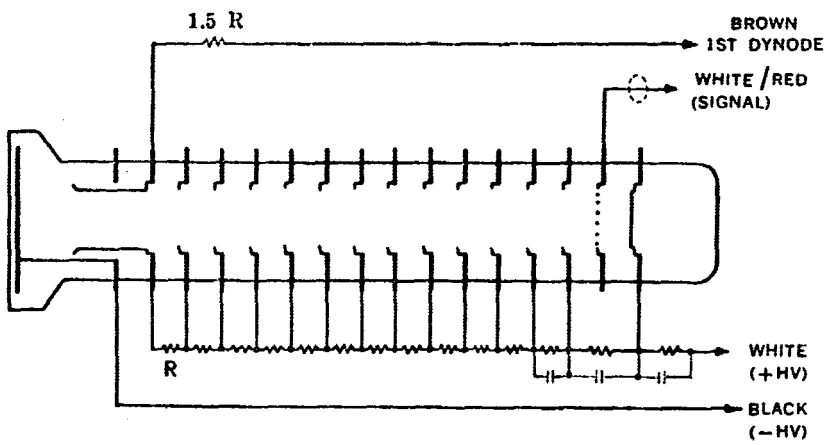
of fused kovar and glass. The U photocathode on a glass faceplate gives a spectral response in the visible with maximum sensitivity in the blue which matches the spectral emission characteristics of NaI(Tl) and makes it well suited for scintillation counting applications.

The useful photocathode has a diameter of one inch. The fourteen stage tube has silver magnesium venetian blind dynodes. The interdynode resistors are welded directly to the kovar rings. The last three stages are bypassed with capacitors for optimum operation in pulse counting applications.

The tube and voltage divider circuit are potted in a fiberglass shell resulting in a package that is compact and extremely rugged. The functional diagram and schematic are shown in Figure 7.



FUNCTIONAL DIAGRAM



SCHEMATIC DRAWING

FIGURE 7. Model 549A-4476 Sterilizable Multiplier Phototube.

4. TEST RESULTS

Test data on the four multiplier phototubes with U photocathodes are summarized in Table I.

These four tubes were processed as experiments during the development phase of the program. The original program schedule called for a study of these experimental tubes followed by the preparation and testing of a final test sample in which the processing would be carefully controlled to maintain as closely as possible uniform characteristics for each tube in the test sample. At the conclusion of the development phase, JPL requested that the final test sample not be fabricated and that the final report be written on the basis of test data available on the four developmental tubes.

Parameters of interest are quantum efficiency, resolution and gain. Each of these parameters was measured initially and after each sterilization cycle. The dark current is of secondary importance provided it does not exceed the allowable maximum value.

All testing was done on bare, unpotted tubes. The voltage divider network with bypass capacitors on the last three stages was wired into the test fixture.

A Harshaw Type 4D4 NaI(Tl) scintillation crystal was used in all the resolution measurements.

Sterilization was done in a temperature regulated oven at $145 \pm 2^{\circ}C$ for 36 hours.

A simple notation is adopted for ease of discussion. The parameters of interest, quantum efficiency at 4100 Å, resolution of the Cs^{137} gamma, voltage for 10^6 gain, and gain at 2600 volts are designated Q_i, W_i, V_i, and G_i respectively where i is the total number of sterilization cycles to which the tube has been subjected.

4.1 Photocathode Sensitivity

The spectral response of the U photocathode is well matched to the emission spectrum for NaI(Tl). The maximum sensitivity

of the photocathode occurs at about 4100 Å which coincides with the peak in the emission spectrum of NaI(Tl). For this reason the quantum efficiency at 4100 Å is used as the best indication of the photocathode sensitivity.

The photocathode sensitivity is the parameter that is most vulnerable to the high temperature sterilization environment since the photocathode is processed at temperatures comparable to those used for sterilization. At a temperature of 145°C any excess photocathode materials in the tube structure have a tendency to migrate and thus change the photocathode sensitivity.

The stability of the photocathode can be seen from the changes in quantum efficiency at 4100 Å. The quantum efficiency data, Q_i, are given in Table I for each of the four tubes. The average values, $\overline{Q}_i$, are 26, 21, 20, and 18 percent for i = 0, 1, 2, and 3 respectively.

The data for tube D11027 were reported incorrectly in an earlier report because of an error in the test setup. The reported values of Q_i were high.

The spread in Q_o for all tubes reflects variability in the photocathode processing. All values lie within the limits of 26 $\pm$ 2 percent. The maximum error in measurement is estimated to be 10 percent.

A useful parameter for the discussion of the effect of sterilization is the degradation ratio, Q_i/Q_o. Observed degradation ratios for the four tubes are given in Table II with averages. The average ratios were 0.83, 0.78, and 0.69 after one, two, and three cycles respectively.

The average degradation ratios can be used to predict the quantum efficiency of a similar tube from its initial quantum efficiency.

Summary of Test Results on Model 549A-4476 Sterilizable Multiplier Phototube

Tube No.	i	Q_i(%)	Q_i/Q_o	G_i	V_i(Volts)	W_i(%)
D10068	0	27	1.00	7.7×10^5	2700	8.1
	1	21	0.78	4.0×10^5	2850	8.5*
	2	18	0.67	3.9×10^5	2940	8.7*
	3	14	0.52	4.6×10^5	2860	9.4*
	4	14	0.51	4.8×10^5	2860	9.7*
	5	13	0.48	5.4×10^5	2800	9.4*
D11030	0	24	1.00	1.2×10^6	2520	8.4*
	1	20	0.85	1.6×10^6	2460	9.4*
	2	20	0.85	1.2×10^6	2560	9.7*
	3	17	0.70	1.5×10^6	2520	10.7*
	4	15	0.64	1.3×10^6	2500	11.0*
	5	12	0.53	1.5×10^6	2480	10.8*
D11027	0	27	1.00	3.2×10^6	2280	8.3*
	1	23	0.85	3.5×10^6	2240	8.6*
	2	22	0.81	3.7×10^6	2220	8.2
	3	21	0.78	3.4×10^6	2240	8.4
	4	20	0.74	3.7×10^6	2220	8.3
	5	18	0.67	3.5×10^6	2220	8.3
D11026	0	25	1.00	4.3×10^6	2200	8.1
	1	21	0.82	4.9×10^6	2160	9.0
	2	20	0.78	5.1×10^6	2160	8.8
	3	19	0.75	5.3×10^6	2160	8.7

Q_i = Quantum Efficiency at 4100 Å after the i-th cycle.

V_i = Voltage for 10^6 gain after the i-th cycle.

W_i = Resolution after the i-th cycle (*corrected for new crystal).

TABLE II

Summary of Q_i/Q_o for the Model 549A-4476

Sterilizable Multiplier Phototubes

i	D11068	D11030	D11027	D11026	Average
1	0.78	0.85	0.85	0.82	0.83
2	0.67	0.85	0.81	0.78	0.78
3	0.52	0.70	0.78	0.75	0.69
4	0.51	0.64	0.74		0.63
5	0.48	0.53	0.67		0.56

Q_i = Quantum efficiency after i sterilization cycles.

Q_o = Initial quantum efficiency.

The accuracy with which Q_i for a new test sample can be estimated is a function of the reproducibility of the photocathode processing. The distribution in Q_o for a new sample will give the best indication of this. No estimate for the accuracy in predicted values is given from the limited data available.

4.2 Resolution

The resolution of the Cs^{137} gamma was measured for each tube initially and after each cycle. The data are given in Table I.

Early resolution data were somewhat higher than expected for tubes with the observed quantum efficiencies. The scintillation crystal was found to be defective and was replaced. The resolution of a multiplier phototube was measured using a CRT light pulser. The resolution of each crystal was calculated from total resolution data, and the data taken with the defective crystal were then corrected. The corrected data are identified with an asterisk.

The initial value for D10068 was not corrected because the measurement was made before the crystal was damaged.

The average values of W_i are are 8.2, 8.9, 8.9, and 9.3 percent for $i = 0, 1, 2$, and 3 respectively. Errors in measurement are estimated to be not greater than 0.2 percent for uncorrected data and 0.6 percent for the corrected data.

After the first cycle the resolution for tube D11030 is considerably worse than average. The current gain characteristic was found to be abnormal at high values of gain which was indicative of poor vacuum or contamination in the tube envelope. The poor resolution is attributed to this instability.

4.3 Gain

Gain data for the four tubes are given in Table I. The current gain, G_i, at 2600 volts and the voltage, V_i, for a gain of 1×10^6 are reported.

A relatively large variation is observed for D10068 after the first cycle. The gain drops by almost 50 percent. This variation could easily be within the maximum uncertainty in measurement of G_i since the initial measurement and the measurement after the first cycle are separated by about six months.

The gain is related to the applied voltage by

$$G = (KV)^n$$

Fractional changes in gain are related to fractional changes in applied voltage by

$$\Delta G/G = n \Delta V/V$$

where n = 14 for these tubes. The power supplies used for gain measurements have an accuracy of ± 2 percent. The resulting error in measured gain may be as great at ± 30 percent. Such large variations between measured values would normally occur if power supplies are changed or if the two measurements are separated by a long period of time during which the power supply output could drift over its maximum permissible range.

The abnormal gain characteristic for D11030 was discussed in the previous section. The cause of this instability is unknown, but it appears characteristic of tubes with poor vacuum.

4.4 Dark Current

Extensive dark current measurements were not made because of the difficulties of making absolute measurements on unpotted tubes. Checks of dark current were made during gain measurements and in each case the dark current at a gain of 1×10^6 was not greater than 1×10^{-9} amperes.

5. SUMMARY AND CONCLUSIONS

In the developmental phase of the program, photocathodes processed on conductive substrates were generally unsuccessful in meeting the objectives of high sensitivity and good stability. An alternative approach, the EMR type U photocathode without substrate, was found to meet the program objectives.

Four multiplier phototubes with U photocathodes, designated the EMR Model 549A-4476, were given three or more sterilization cycles, and the quantum efficiency, gain, and resolution were observed after each cycle.

The average initial quantum efficiency of 26 percent for the new tubes is an improvement over the average of 13.5 percent observed for multiplier phototubes developed under the previous contract. Stability of photocathode sensitivity is also improved. Average degradation ratios were 0.83, 0.78, and 0.69 for the present program as compared to 0.75, 0.63, and 0.62 for the previous program. The average quantum efficiency after three sterilization cycles is even higher than the initial quantum efficiency observed on the previous program.

As a result of the increased sensitivity, the energy resolution was significantly improved. An average resolution of 8.2, 8.9, 8.9, and 9.3 percent was observed after 0, 1, 2, and 3 cycles respectively as compared to the 10.1, 10.8, 11.7, and 11.5 percent for the previous program.

The EMR Model 549A-4476 is a significantly improved multiplier phototube designed specifically for scintillation counting in space applications where sterilization is required.