DEVELOPMENT OF DU MONT PHOTOMULTIPLIER TUBES

Report No. 21 for December 1, 1954 to May 31, 1956

By

Bernard R. Linden
Philip A. Snell
Robert E. Rutherford

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Tube Research Laboratories
Allen B. Du Mont Laboratories, Inc.
Passaic, New Jersey

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Development of Du Mont Photomultiplier Tubes

Report No. 21

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Atomic Energy Commission

By

Bernard R. Linden
Philip A. Snell
Robert E. Rutherford

Period Covered by Report
December 1, 1954 to May 31, 1956

Approved by: Stanley J. Koch

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Tube Research Laboratories
2 Main Avenue
Passaic, New Jersey
INTRODUCTION

This report covers the last 18 months work on development of multiplier phototubes. As such it will summarize the main lines of work followed. Details of the work will be found in Quarterly Reports nos. 16-20.

The discussion of the work may be divided up into various lines of endeavor as follows:

1. 3/4 ten stage multiplier phototubes
2. Large area multiplier phototubes
3. Linear structure tubes
4. Transit time spread measurements
5. Miscellaneous
   a) Light intensifiers
   b) Potassium free multiplier phototubes
   c) Ultra-violet sensitive multipliers
   d) Plug-in glass stems
   e) Epoxy-resin seals
   f) Secondary Emission Surfaces and Pulse Height Shift

The subjects will be considered in the order given above.
DEVELOPMENT OF PHOTOMULTIPLIER TUBES

1. 3/4" ten stage multiplier phototubes (K1193 and K1382)

Much effort has been expended into developing this tube for use in the scintillation counter field. At this time it can be reported that the tube has passed from the developmental stage to the production stage and has been released for general use in the field.

One of the main difficulties was the elimination of leakage on the stem. The problem was solved very nicely with the development of special stems with high glass pant-legs on the leads. A second difficulty was the lack of gain in the tubes using Ag-Mg dynodes (K1193). Because of this difficulty it was decided to develop tubes using Cs-Sb dynodes also (K1382). This was done while work was simultaneously carried on with Ag-Mg dynodes. The work on the K1382 led fairly rapidly to a satisfactory gain. At the time of writing this report the K1193 has also been brought to a stage where it is in production. The tentative specification sheets of these tubes are shown at the end of this report. A photograph of the tube is shown in Figure I.

It will be noted that the tube has no base since no standard base or socket exists for this size. Accordingly the stem was potted in an epoxy-resin compound and the leads themselves were covered with insulation. This makes it impossible to have any leakage across the outside of the tube envelope. If reasonable care is taken in soldering the leads into the circuit it is possible to limit the inter-electrode leakage to only that of the internal leakage paths in the tube.
2. LARGE AREA MULTIPLIER PHOTOTUBES

Three different sizes of large area multiplier phototubes were worked on during the period covered by this report. The sizes were the 12 1/2" diameter tube (K1384), the 16" diameter tube (K1328), and the 22" diameter tube (K1386). The K1384 and K1328 were brought to a final development state and turned over to the production group. These two tubes are now standard multiplier phototubes available to the general field of scintillation counting. The work on the K1386 was discontinued after three tubes had been built because it was felt that the K1384 and K1328 tubes would cover the main applications at this particular time. In spite of the small number of K1386 tubes which were built two of the tubes operated reasonably well, although some improvement would still be called for before the tube was ready for release as a production item. The work on the K1328, however, solved most of the problems which are to be expected from the K1386 so that these latter tubes could be developed rapidly if a need for them arose.

Many of the difficulties involved with the large area tubes were due to the mechanical setup in the metal cones used for their construction. Initially it was necessary to seal the faceplate into the cone after the multiplier structure had been sealed in. This invariably led to poor gain and poor cathodes in these tubes. To circumvent this difficulty the metal cones were split in a plane perpendicular to the axis of symmetry of the cone. Both parts were then flanged on the edges where they join. In this manner the faceplate was sealed into one end and the multiplier with the other. The final seal was then a heli-arc weld along the edge of the flange. This eliminated both unnecessary heating of the multiplier structure and the water vapor from the sealing - in flames. With this modification the development went along smoothly.

A photograph of the K1384 and K1386 is shown in Figure 2.
3. Linear Structures

An extensive program has been set up for the purpose of developing a fast high gain linear multiplier phototube. As was reported in QR 19 and QR 20 several tubes have been constructed, which have exhibited fairly high gains at normal operating voltages of 105 volts per stage. Further investigation of the front end design indicates that considerable improvement in the collection efficiency is attainable by using a larger first dynode accompanied by a focusing electrode and accelerators. A sketch of this design is illustrated by figure 3.

Tubes of this design are being constructed on a semi production basis in order that adequate tests might be conducted to determine the feasibility of the design. A special tube, whereby it is possible to make transit time spread measurements, has been constructed. Unfortunately, however, difficulties were encountered in the processing of the tube, and considerable damage was incurred to the dynodes. The result was extremely poor secondary emission, making the tube unusable. However, another such tube is under construction and it is anticipated that some results of transit time spread will shortly be available.

For the present, the use of accelerator electrodes at the last few dynodes of the tube has been abandoned since in all tests made they appeared to have little or no effect. The accelerators employed in the new front end have considerable effect in controlling the overall gain of the tube. It has been found that these accelerators also have some effect on the proper focusing of the electrons at the first dynode.

In varying the voltage on the focusing electrode, located beneath the shield, a definite peak in the output of the tube may be observed. It has been noted that this peak usually occurs when the applied voltage is approximately 50 to 70 volts positive with respect to the photocathode. This also appears to be the optimum operating point for the shield, thereby allowing the shield and focusing electrode to be tied together. The electron optics of the structure appears to bear out the field plots used to determine the geometry of the dynode design.
At this point no tests have been made concerning peak pulse output or resolution. However it is expected that the tube will exhibit resolutions similar to the standard 6292 multiplier phototube. After more of these tube types have been constructed more conclusive results will be available.

4. Transit Time Spread

The frequency response of secondary emission multipliers is limited by the dispersion in time delays. The actual time delay incurred by the electron stream is of no consequence, only the time dispersion places a limiting factor on the multiplier phototube. The dispersion time on transit time spread of the standard box type dynode, currently used in the manufacture of multiplier phototubes, was determined by means of a specially built tube, K1376, specifically designed for conducting this experiment. Figure 4 gives a detailed outline showing the various components of the tube.

Basically this experiment is a comparison of the pulse width of a short burst of primary electrons directed into dynode structure, as against the pulse width of the resultant pulse of secondary electrons being emitted at the anode of the secondary multiplier. Primary pulses of short duration are obtained by sweeping an electron beam across a 0.020 inch diameter aperture at an rf. rate. The electrons passing through the aperture are directed into the first dynode of a ten stage secondary emission multiplier. The resultant burst of secondary pulses are fed into a focusing and deflection system where the electron beam is focused and deflected at the same frequency as was the beam of primaries. Since the beam of secondary electrons is present during a finite portion of the secondary deflection cycle, a smearing of the secondary beam takes place. This smearing or distribution of the secondary beam represents a variation in current density as a function of time. This current density variation is at right angles to the direction of the electron beam and is displayed on a phosphor screen located at the end of the experimental tube.
Subsequent pulses of secondaries will fall on top of one another provided the rf. deflection voltages are maintained at a constant frequency and amplitude.

In order that a measurement of the current density of the secondary beam might be obtained, a wire probe is placed in front of the phosphor screen at right angle to the direction of deflection of the secondary beam. If this probe were moved across the secondary deflected beam at an audio rate it would be possible to obtain a signal from the probe for display on an oscilloscope. This is accomplished by superimposing an audio signal on the same set of secondary deflection plates where the secondary rf. deflection takes place.

The secondary pulse of electrons as obtained from the wire probe is fed to a high gain audio amplifier where it is amplified sufficiently to be displayed on an oscilloscope. Figure 5 is a photograph of the secondary pulse as viewed on a Du Mont 304H oscilloscope.

The primary pulse width is calculated by knowing the rf. deflection frequency, peak to peak rf. deflection voltage and the voltage difference between the half current points as the primary beam is deflected across the aperture. The secondary pulse width at half current points can be measured directly from the oscilloscope pattern as shown in figure 6. Figure 6 is a graph of primary and secondary pulse widths as a function of \( \Delta V \) where \( \Delta V \) is the peak to peak rf. deflection of the primary beam. The difference in the curves being the transit time spread.

Upon constructing several of these transit time spread tubes it was determined that the transit time spread of the 10 stage box type secondary emission multiplier was approximately \( 18 \times 10^{-9} \) sec.

Figure 7 is a photograph of the entire system required for the operation of the transit time spread tube in making the required measurements.
5. Miscellaneous

a) Light Intensifiers

Several tubes were constructed which consisted of two essential elements - a photocathode and a phosphor screen. When voltage was applied between the cathode and phosphor screen the photoelectrons striking the phosphor gave rise to emitted light. This light then fed back to the cathode resulting in a regenerative effect. The purpose was to see if low level light signals could be detected in this way. By including a mesh in the tube which could be pulsed negative it was possible to quench the regeneration. Such a tube showed regeneration to low level steady light sources. At this writing it has not yet been tested for pulsed light sources. If such a tube can be made to work with a scintillation crystal it maybe possible to use it instead of a multiplier phototube in certain instances.

b) Potassium Free Multiplier Phototubes

As was reported in Quarterly Report #20, various materials employed in the construction of multiplier phototubes, have been sent to Oak Ridge and Argonne National Laboratories for testing of potassium content. Since low intensity gamma ray radiation was suspected to emanate from some of the materials employed in the construction of multiplier phototubes, it was necessary to carry out a detailed investigation. The following report was received from Argonne National Laboratories. "The soda lime glass #0080 contains 0.2 of 1% K by weight. That is the 100 g. sample contained 0.2 g. of K. The specific activity is so low that a 100 g. sample does not give sufficient counts above background in the spectrum to definitely state that it is all due to K and not partly due to Ra. However, if the total activity is due to K, the sample contains 0.2 of 1% K. Sample #0012 glass contains 3.84% K; #7052 glass contains 2.4% K and #9010 contains 1.73% K. A sample of Kimble lead glass contained 4.7%."
Tests were also conducted on the tube basing compound which indicated high K and Ra content." Oak Ridge reported that the tube bases also contained radioactive materials. However, it was not stated whether the materials were Ra or K, nor was the content indicated.

Due to the presence of background from these materials it is extremely difficult to make accurate measurements of the low intensity gamma radiation present in the human body. It seems likely that tubes using fused silica faceplates and having no base may show a lower K activity however this has not yet been checked out. Some experiments have been conducted in constructing tubes without bases and using direct glass to metal pin contacts similar in construction to 9 pin miniature radio tubes.

We are indebted to Dr. C. Miller of Argonne National Laboratory and Dr. P. R. Bell of Oak Ridge National Laboratory for making the tests and passing the information along to this laboratory.

6. Ultra-violet Sensitive Multiplier Phototubes

The availability of high purity fused silica in faceplates has made possible the construction of multiplier phototubes with a spectral response out as far as 1800 Å. These tubes use the standard Cs-Sb photocathodes. The possibility of using these tubes with various new scintillators under investigation should make the study of these scintillators easier. The tubes were originally built in the 2\(\text{g}\) size with the same mechanical dimensions as the type 6292. They have been used successfully with un-activated NaI crystals at liquid air temperatures. It seems probable that they will also find use with such scintillators as liquid xenon.
d) Plug-in Glass Stems

In conjunction with the program of developing multiplier phototubes which are as free of potassium containing materials as possible, the use of Multiform plug-in glass stems was investigated. A complete discussion of the methods of manufacturing such stems is given in Quarterly Report Number 17. Such a stem has been tried and it has worked successfully in several tubes built in these laboratories. Although the stems used on the 3/4" ten stage tubes do not have stiff leads for direct plug-in, these stems are also manufactured using multiform techniques.

One difficulty standing in the way of putting plug-in stems on all multiplier phototubes is the lack of standard sockets for such tubes. It seems probable however that one of two things can be done to solve this problem. First the standard sockets can be adapted to hold the smaller diameter leads from the glass stem. Second a multiform socket can be made which will match the multiform stems.

e) Epoxy-resin Seals

To check the possibility of using epoxy-resin for sealing the stems onto the envelope in multiplier phototubes, several multiplier phototubes were constructed using such a method. Modifications to commercial epoxy-resins were made which allow baking the material out at 300°C with no ill effects. These tubes which were constructed over six months ago are still good and show no sign of poor vacuum. It appears that the combination of multiform stems and epoxy-resins may work a great simplification in the manufacture of multiplier phototubes.

g) Secondary Emission Surfaces and Pulse Height Shift

Recent measurements in scintillation counting have revealed that the secondary emission ratio of both Ag-Mg and Cs-Sb dynodes varies with the density of the primary beam of electrons. This characteristic has led to the so-called pulse height shift where the pulse height put out by the multiplier phototube is a function of the counting rate.
Because of the difficulties which this effect raises in the making of precise measurements it was felt that it should be investigated further.

The first experiment to be performed was the construction of several tubes to determine in what part of the tube the shift takes place. The tubes had half the dynodes made of Ag-Mg and the other half made of Cs-Sb. The position of the two types of dynodes in the multiplier structure was varied, i.e. one type had the Cs-Sb dynodes in the front and Ag-Mg at the back of the multiplier structure; another had the Cs-Sb dynodes at the back; a third had the Cs-Sb dynodes in the middle. Because the time characteristic of the pulse height shift is different for Ag-Mg as compared to Cs-Sb it was possible to determine at what stage in the multiplier the shift was taking place. The data indicated fairly conclusively that the shift took place at the last few dynodes where the current density was highest.

Experiments were performed with other surfaces such as Al-Be. After determining a satisfactory activation procedure these dynodes were included in a tube for test. The tube was sent to Mr. W. Bernstein of Brookhaven National Laboratory for test. He reported a pulse height shift of the same order of magnitude as observed with Ag-Mg tubes.

To investigate this problem in a more detailed manner it is desirable to set up equipment such as a demountable tube system where many materials and differently processed surfaces can be investigated.
PHOTO-MULTIPLIER TUBE
TYPE K1193K1382

DIRECTION OF LIGHT INTO END
OF BULB
BOTTOM VIEW

1 - DYNODE NO. 1
2 - DYNODE NO. 3
3 - DYNODE NO. 5
4 - DYNODE NO. 7
5 - DYNODE NO. 9
6 - ANODE
7 - DYNODE NO. 10
8 - DYNODE NO. 8
9 - DYNODE NO. 6
10 - DYNODE NO. 4
11 - DYNODE NO. 2
12 - INTERNAL CONNECTION
13 - INTERNAL CONNECTION
14 - CATHODE AND SHIELD
PINS 1-13 HAVE BLACK INSULATION
PIN 14 HAS RED INSULATION.

-POTTED SECTION

2 NOM.
The Du Mont K1193 is a 10-stage multiplier phototube with a flat end-window type photocathode having an S-11 spectral response. The diameter of this tube is \( \frac{3}{4} \) inch, making it ideal where space considerations are of major importance. This tube type employs silver magnesium dynodes.

**GENERAL CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Electrical Data</th>
<th>Min.</th>
<th>Avg.</th>
<th>Max.</th>
<th>Units</th>
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<td>Spectral response</td>
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<tr>
<td>Cathode luminous sensitivity at 210 volts, 0 cycles between cathode and all other electrodes</td>
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<td></td>
<td></td>
<td>( \mu A/\text{lumen} )</td>
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<tr>
<td>Anode luminous sensitivity</td>
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<td></td>
<td>A/\text{lumen}</td>
</tr>
<tr>
<td>Cathode sensitivity at maximum response at 210 volts between cathode and all other electrodes</td>
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<td></td>
<td>( \mu A/\mu W )</td>
</tr>
<tr>
<td>Anode dark current at 105 volts/stage (25°C)</td>
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<td></td>
<td>( \mu A )</td>
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<tr>
<td>Current amplification at 105 volts/stage</td>
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<td>Wavelength at maximum response</td>
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<td></td>
<td>Angstroms</td>
</tr>
<tr>
<td>Wavelength at 10% of maximum response on long wavelength side</td>
<td>6125 ( \pm 275 )</td>
<td></td>
<td></td>
<td>Angstroms</td>
</tr>
<tr>
<td>Wavelength at 10% of maximum response on short wavelength side</td>
<td>3250 ( \pm 250 )</td>
<td></td>
<td></td>
<td>Angstroms</td>
</tr>
</tbody>
</table>

**Mechanical Data**

| Window dimensions, minimum | \( \frac{1}{2} \) |       |       | In. Dia. |
| Tube diameter | \( \frac{3}{4} \pm \frac{1}{16} \) |       |       | In. |
| Overall length | \( 4\frac{3}{8} \pm \frac{1}{4} \) |       |       | In. |
| Base—Resin (potted) flexible leads | Any |       |       |           |
| Mounting position | Any |       |       |           |
| Window index of refraction | 1.5 |       |       |           |

**MAXIMUM RATINGS**

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>Avg.</th>
<th>Max.</th>
<th>Units</th>
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<tr>
<td>Peak cathode current (Note 1)</td>
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<td>( \mu A )</td>
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<td>Average anode current (Note 2)</td>
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<td>Peak anode current</td>
<td>5</td>
<td></td>
<td></td>
<td>mA</td>
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MULTIPLIER PHOTOTUBE

TYPE K1193

TENTATIVE

MAXIMUM RATINGS (Cont'd)         Min.     Avg.     Max.     Units

Average anode dissipation (Note 2) 0.5      W
Peak anode dissipation            2.0      W
Supply voltage between anode and 1300     Volts
  cathode (DC or peak AC)
Supply voltage between last dynode 125      Volts
  and anode (DC or peak AC)
Supply voltage between cathode and 250      Volts
  1st dynode (DC or peak AC)
Ambient temperature               75       °C

NOTES

1. The cathode current given here is that current at which the response of the cathode current ceases to be a linear function of the light intensity because of cathode resistance. In general, the cathode current must be kept well below this value in order to satisfy the maximum ratings on the anode current.

2. Averaged over a 30 second interval maximum.
MULTIPLIER PHOTOTUBE

TYPE K1382

TENTATIVE

The Du Mont K1382 is a 10-stage multiplier phototube with a flat end-window type photocathode having an S-11 spectral response. The diameter of this tube is $\frac{3}{4}$ inch, making it ideal where space considerations are of major importance. This tube type uses cesium antimony dynodes.

GENERAL CHARACTERISTICS

**Electrical Data**

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<td>Spectral response</td>
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<td>Cathode luminous sensitivity at 210 volts, 0 cycles between cathode and all other electrodes</td>
<td>30</td>
<td>50</td>
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<td>$\mu$A/lumen</td>
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<tr>
<td>Anode luminous sensitivity at 105 volts/stage, 0 cycles</td>
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<td>15</td>
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<td>A/lumen</td>
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<td>Cathode sensitivity at maximum response at 210 volts between cathode and all other electrodes</td>
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<td>$\mu$A/\muW</td>
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<td>$\mu$A</td>
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<td>Current amplification at 105 volts/stage</td>
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<tr>
<td>Wavelength at maximum response</td>
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<td></td>
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<td>In.</td>
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<td>Overall length</td>
<td>In.</td>
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<tr>
<td>Base-Resin (potted) flexible leads</td>
<td>Any</td>
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<tr>
<td>Window index of refraction</td>
<td>1.5</td>
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**MAXIMUM RATINGS**

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<th>Description</th>
<th>Unit</th>
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<td>Peak Cathode current (Note 1)</td>
<td>$\mu$A</td>
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<tr>
<td>Average anode current (Note 2)</td>
<td>mA</td>
</tr>
<tr>
<td>Peak anode current</td>
<td>mA</td>
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MULTIPLIER PHOTOTUBE

TYPE K1382

TENTATIVE

<table>
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<tr>
<th>MAXIMUM RATINGS (Cont'd)</th>
<th>Min.</th>
<th>Avg.</th>
<th>Max.</th>
<th>Units</th>
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<td>W</td>
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<td>W</td>
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<td>Supply voltage between anode and cathode (DC or peak AC)</td>
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<tr>
<td>Supply voltage between last dynode and anode (DC or peak AC)</td>
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<tr>
<td>Supply voltage between cathode and 1st dynode (DC or peak AC)</td>
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<td>Volts</td>
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<tr>
<td>Ambient Temperature</td>
<td>75</td>
<td>°C</td>
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</tbody>
</table>

NOTES

1. The cathode current given here is that current at which the response of the cathode current ceases to be a linear function of the light intensity because of cathode resistance. In general, the cathode current must be kept well below this value in order to satisfy the maximum ratings on the anode current.

2. Averaged over a 30 second interval maximum.
Figure 3

Linear Dynode Structure

Focusing Electrode

Eight Dynodes This Type

Accelerators

Collector

Wire Mesh
Figure 4—Transit Time Spread Tube. (Drawing #TD 43/1A/B).
Figure 5
Figure 6