A PHOTO-MULTIPLIER TESTING DEVICE

P. K. Bhattacharya*

University of Indore, Indore

(*Received* 2 *September* 1970)

The paper reports the design of a photo-multiplier testing device constructed to assess long term stability and suitability of 53 AVP photo-multipliers for use with singles counting, scintillation counter arrays and large plastic scintillation counter arrays (in coincidence) in high energy physics experiments (with muons). The device can be used for routine checking of such phototubes in laboratory.

An experimental requirement to design and fabricate several scintillation telescopes for singles counting and other large counter arrays†, for accurate angular distribution determination of muons, led to a survey of photo-multiplier tubes (from a bank of 153, 53 AVP tubes), for those tubes which could be used for such purposes. The 53 AVP tube was selected in comparison to its counter part 56 AVP of 42 mm diameter—2 ns anode rise time, and having a gain of 10^8 at 2200 V, because of its low sensitivity to Čérenkov light and hence less demands for complex light guide and mechanical mounting[1], both physically and economically unacceptable. Even when the tube is comparatively slower (5 ns), it was decided to use it in conjunction with a scintillator of increased thickness to overcome lower tube current gain. However, it was an essential requisite to see and select the photo-multiplier tubes carefully and amplify photo-multiplier output signals, if one has to maintain particle detection efficiency $\eta > 99\%$ without working the tubes in excess of normal operating characteristics.

REQUISITES OF THE SCINTILLATION COUNTER

Scintillation counters to be used for detecting minimum ionizing muons should be capable of detecting them with an efficiency greater than 99%. The photo-multipliers are normally operated at a gain much above the 99% working point and thereby do not get affected by any reasonable variation in operating factors.

Large scintillation counters usually respond more efficiently to the particles closer to the photocathode of the tube and less efficiently to those who have passed near the remotest corners of the scintillator. A coincidence set-up is used and the whole surface area of the scintillator scanned under such circumstances. If the coincidence counting rate is same everywhere, the counter is efficient. All these requirements necessitated designing and construction of a photo-multiplier testing unit capable of operating at $\eta \geqslant 99\%$ efficiency, and good enough to be taken as a standard.

PHOTO-MULTIPLIER TESTING DEVICE

Mechanical

The testing device was made of a simple demountable mounting on an aluminium box of suitable size to accommodate a standard 53 AVP base, and capable of sliding into any of the channels of the neutrino shield, if required to be pushed up for a muon flux distribution scan. A cast iron cylinder containing within a mu-metal shield, could be screwed in-and-out on the aluminium box for changing the test photo-multiplier tube. A clamping fixture to hold a light collecting head and the scintillator was screwed on each test phototube by using silicon oil as joining cement for simplicity in mounting and avoiding constraints on the tube. The whole testing device alongwith the tube is called 'testing unit'.

---

*Present address :—Station Officer, High Altitude Research Laboratory, Gulmurg, Kashmir.]

†This work was done under the auspices of CERN European Orgn. for Nucl. Res., in Beam Studies Group of Nuclear Phys. App. Divn.

Electrical

The voltage divider for high output pulse operation [Fig. 1 (b)] of the testing unit was designed on type B voltage divider principle*, so that the voltage of the accelerating grid is adjusted for maximum pulse output. The pulse height depends much on the voltage between the cathode and the accelerating grid and becomes practically independent of this voltage if it is greater than about 9% of the full tube voltage. In the type of divider used for the unit this accelerator-to-cathode voltage is about 14% of the full tube voltage. Small storage capacitors have also been used and the values of the resistors in the chain are so chosen that a low parallel current of 1 mA flows at moderate intensities (where singles counting is not possible).

Light collecting head on and above a light guide was used (Fig. 2) to converge the amount of light produced in the plastic scintillator uniformly on the photo-cathode surface. The light collecting head and the light guide coupling was milled out in one piece, from a 5 cm thick plexi-glass sheet of 21 × 9 cm^2 size as suggested by Akimov[2] to reduce production of Čerenkov radiation and provide homogeneity in light collection from all the points within the scintillator. A logarithmic spiral type light collecting head of rectangular cross-section (6·2 × 2 cm^2) at the input end and a circular cross-section at the photo-multiplier end designed to a compound shape of a paraboloidal bulb and a hut combination, was found to have good collection efficiency and uniformity. Pulse height spread because of multiple reflections and on account of Landau fluctuation in the ionization loss was observed negligible. Considering only the statistics of the number of photo electrons, one can attribute the broadening of the peak to a spread $\sqrt{N}$ in the number N of photo electrons. One should expect the ratio of peak width to peak position, i.e. relative width to be proportional to $\sqrt{N}/N = 1/\sqrt{N}$. This collection system became specially successful because the employed scintillator was a large and thick one and the number of incident minimum ionizing particles being greater and producing larger pulses, yielded smaller relative width. The scintillator was fixed permanently to collecting head and wrapped loosely by aluminium foil. A final wrapping with black tape was given to avoid any slightest possibility of light leakage. Scintillator dimensions were 6·2×6×2 cm^3, as this size was left with the need of using it for a coincidence set-up to check performance of large scintillation counters, employing a method sowewhat similar to Alleyn[3] method.

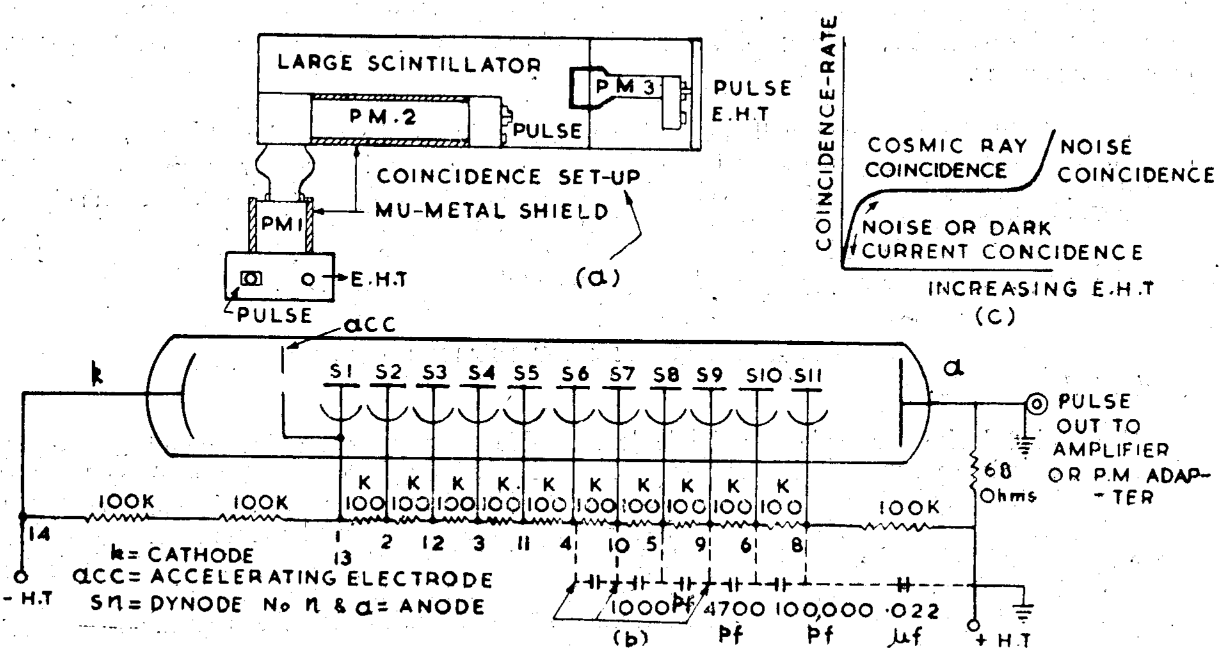

Fig. 1—(a) Coincidence set-up using photo-multiplier testing device.
(b) Voltage divider for 53 AVP Phillips tubes.
(c) Coincidence behaviour with applied overall voltage.

---

*Phillips data book—Electron tubes (Part 6, 1968).

PERFORMANCE CHARACTERISTICS

The performance of each tube is given in Fig. 3 was obtained using the following technique:

(a) Every photo-multiplier put for test was first mounted properly and carefully in the testing device.

(b) The testing unit was supplied with an overall average working voltage (EHT) of 1·6 KV, and its dark noise etc. was studied with a 585A Tektronix oscilloscope during the warm up period.

(c) A final estimate of noise pulse height was made after a warm up period of four hours, which was found enough for warming nearly 80% of the tubes given, and EHT was increased or decreased for better efficiency thereafter.

(d) The output pulse from the photo-multiplier was put into an integrating amplifier, and then to a 1024 channel multi-channel analyser (MCA). The MCA system was from time to time checked for its linearity between input voltage to the integrating amplifier and the channel number corresponding to it.

The integrating amplifier was first tentatively designed and later on constructed for this scintillation counting system incorporating some minor modifications (Fig. 4). This amplifier when fed with 10^{-10} coul. input charge, gave a full output of 5 V, with an integrating time constant of 1 micro-second. Its linearity was better than 1% and had 1% base line shift upto 100 kc/s. It recovered from 200 times overload in less than the normal pulse lengths and can be left either unterminated or terminated by a 50 ohm terminator at the output. It could accept equally well a negative or a positive pulse and give as an output for the MCA, a bipolar pulse from which either the first or the second peak can be used. The second peak is 62% of the first peak, and the whole amplifier has both low noise and minimal sensitivity at low frequency disturbing signals, if any.

Tests have been usually carried out using cosmic-rays, because of its being an independent and convenient method of test to check the performance of the system under different working conditions and background. In each case, the pulse distribution from the photo-multiplier was recorded on a MCA and the position of a 'hump' or a peak on a gradually but fast falling noise, was used as a measure of gain or light reaching at the photo-cathode. From [Fig. 3 (a_1, b_1) and (a_2, b_2)] it can be seen vividly that the tube No. 10839 was slightly better than the tube No. 19150, because of its higher gain (channel No. 21 of the peak) but was perhaps having the same noise level. These tubes were, therefore, somewhat identical in performance and were chosen for replacement in the pair of large scintillators used for singles counting at the end of the neutrino shield. Similarly from the [Fig. 3 (a_3, b_3) and (a_4, b_4)] one can easily assess that the noise pulse distribution and its spread can be attributed as a disqualification of tube No. 11179 in comparison to 8217. Tube No. 8218 was found even much better on this standpoint and

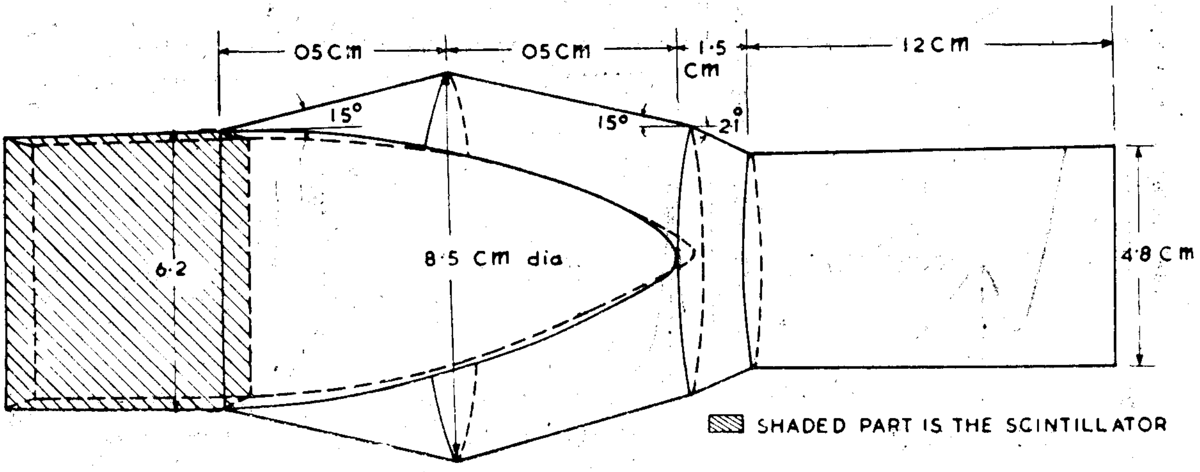

Fig. 2—An asymmetric view of the paraboloidal cone for coupling the light guide to photo-multiplier.

was selected for further testing of a large scintillator by forming a simple telescope coincidence arrangement [Fig. 1 (a, c)], in conjunction with a 40 cm^2 standard (ν) scintillation counter [Fig. 3 (a_6)]. Before performing the coincidence test the gain of the latter two and the large counter was arranged for nearly same values [Fig. 3 (a_7, b_5)] and were kept one over the other. The solid angle A_1A_2/d^2, subjected by the telescope formed by either of the two was made the same. Area of measurement was gradually shifted

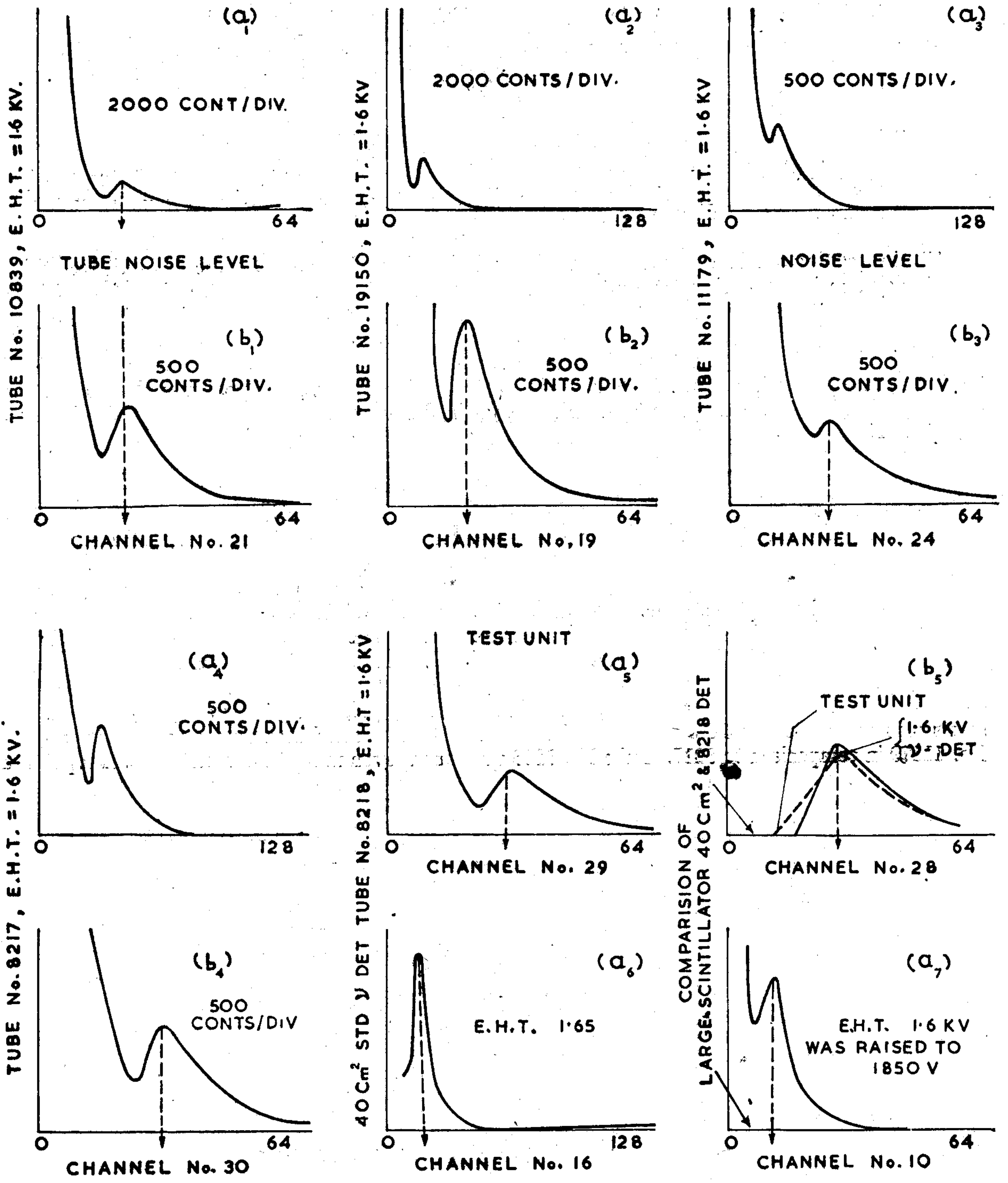

Fig. 3—Performance characteristics of various tubes.

on the large scintillation counter, to investigate if the light suffers inhomogeneity to reach the tube. Its scintillator area (630 × 380 cm^2) was backed by a highly polished slab of plexi-glass (380×380 cm^2) and a cone of plexi-glass upto the photo-cathode surface.

It was re-established that specially simple design of the large counter did not conform to conditions of optimal light transfer as found by Alleyn[3]. The best conditions for light collection as stipulated by Clark[4], were studied to prove if the distance between the photo-multiplier and the light reflecting surface placed opposite to it is of the same order as the scintillator dimensions. Energy loss for a muon in plastic of the scintillator 2 cm thick is 2×2 MeV/cm $= 4$ MeV, and the number of photons produced in the sensitive region of the photo-multiplier is (2000/MeV) $\times$ 4 MeV $= 8000$. Taking the specified values of the photo-cathode sensitivity ($\sim 0{\cdot}08$), the current gain, and the decay time etc., absolute pulse height for 99% efficiency is expected to be about 0·2 V. It was measured experimentally, and all the scintillators (as each one was 2 cm thick) worked over this operating characteristics for an EHT of 1·6 KV. The telescope was made to perform with and without the coincidence requirement at about 1·6 KV, (exception being the large scintillator because separation between the cosmic-ray and the background pulses was poor, and the 40 cm^2 standard (ν) scintillation counter, which was pushed to a gain identical to the testing unit). Low shift discriminator was used in such a way that the counting rate, $I \times \Omega$, (using total vertical Intensity $= 1{\cdot}14 \times 10^{-2}$ cm^2 sec^{-1} $sterad^{-1}$) tallied very closely to the calculated value. Coincidence counting rate per channel within the large scintillation counter and a 40 cm^2 (ν) scintillation counter was found to be equal, but little more than that obtained for the same solid angle, for coincidence in between the large scintillation counter and the testing unit just below it. The theoretical value was found to be 0·138 count/sec and the experimental 0·137 and 0·130, respectively. These measurements were automatically recorded after periods of 96 hours with a statistical accuracy of 0·1%. It can be said that the difference noted might be because of a rapid decrease of cosmic-ray intensity with height. Through out the whole scan, by measurements at various locations, there was no significant variation found in the coincidence rate, and it can be concluded that the large scintillator was looked at by the photo-multiplier by more than 99% efficiency.

INDIVIDUAL PHOTO-MULTIPLIER PERFORMANCE

For this purpose the output from the photo-multiplier was processed through a standard low shift discriminator (CERN-NP, 6016-8A1, designed by Bambrilla, F. et al) set to trigger at 200 mV, for better than 99% efficiency ($\eta > 99\%$). This low shift discriminator converted the signals into standard pulses of

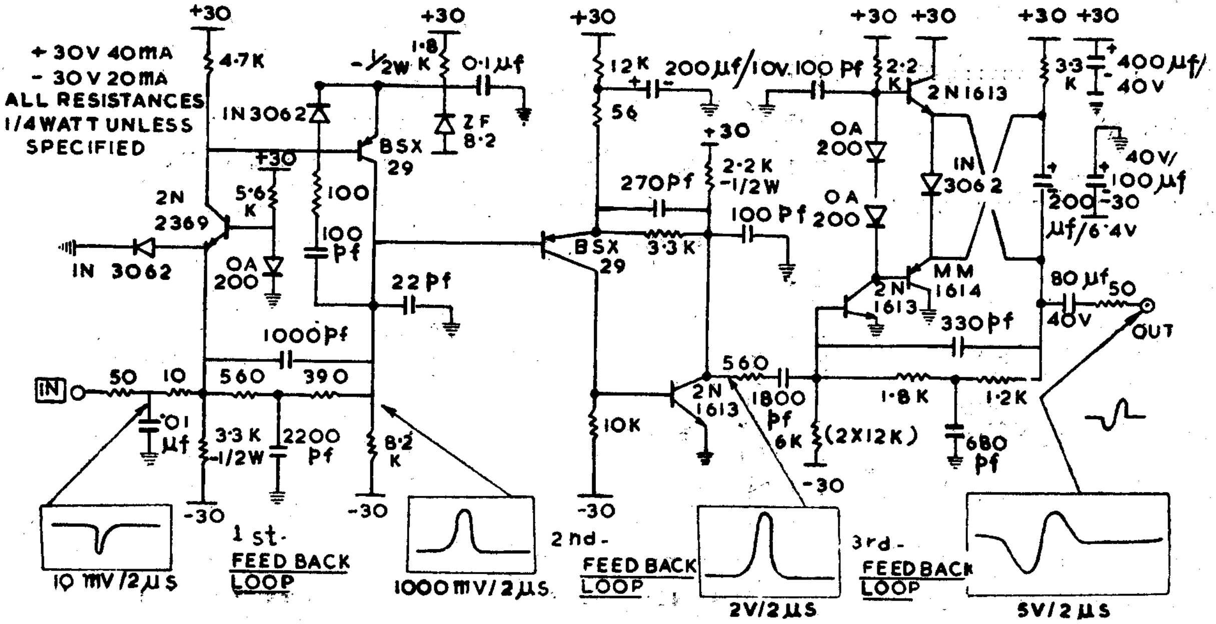

Fig. 4—Circuit of the integrating amplifier.

10 mA and adjustable width (2·5 to 100 nano-sec). All the tubes were found to cross-over the above threshold at EHT of 1·6 KV, with $\eta > 99\%$. Cosmic-rays gave about 0·7V pulses at the output of the tubes associated with 2 cm thick scintillator of decay time about 3 nano-sec (NE 102A). However, some of them because of some inherent defects (unconventional handling or sudden experience of rise of temperature) in the photo-cathode had a very high noise and were totally rejected. The noise obtained for 90% of the tubes did not exceed 40-50 mV even after running them hard upto 1·8 KV. The distribution of working voltages obtained when the counting efficiency was greater than 99% is shown by Fig. 5.

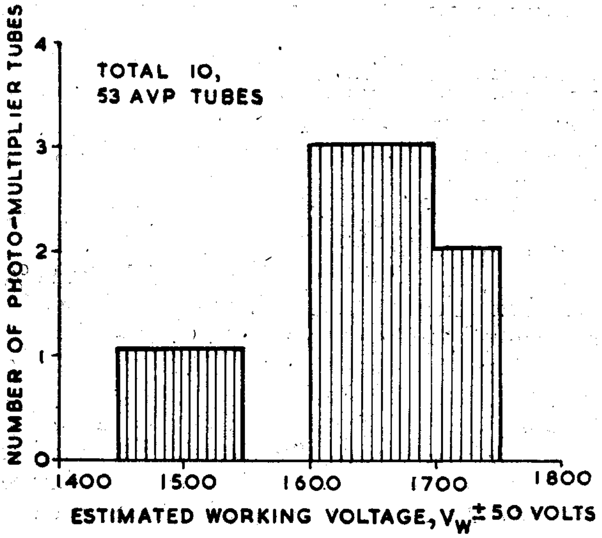

Fig. 5—Distribution of photo-multiplier tube working voltages for counter efficiency better than 99%.

FIGURE OF MERIT FOR PHOTO-MULTIPLIER SELECTION

The utility and quality of any individual photo-multiplier for use in singles counting of muons (1 muon/cm^2/burst) depends upon the overall value of the product of N_a the overall anode sensitivity and N_k the overall cathode sensitivity. These are related to the current gain G by the relation $N_a = G.N_k$ at a particular operating voltage. For this case the value of G ranges from 10^6 to 10^7 in most of the tubes between 1400 to 1650 voltages. Manufacturers specifications show that these tubes which have to be driven over 1·8 KV to attain a value of the product (N_a. N_k or the figure of merit) $= 2 \cdot 8 \times 10^4$ (A/lm)^2. 10^{-6}, which corresponds to gain in terms of a peak at channel number ten by cosmic-rays in our set-up are either deteriorating or are faulty tubes.

ACKNOWLEDGEMENTS

Thanks are due to Dr. J. B. M. Pattison, Leader, Beam Studies Group, for motivation and interest during the work. I thank Director General of CERN and Dr. H. W. Wachsmuth for hospitality.

REFERENCES

1. Dougan, P., Towelemb, K., Lugner, K., Ramsay, W. & Stiefler, W., "Report LUCY 6903", July, 1969.
2. Akimov, Yu. K., "Scintillation Counters in High Energy Physics", (Translated & Edited by D. H. White), (Academic Press, New York, London), 1965.
3. Alleyn, E., Faissner, H., Gerber, H. J., Heer, E. & Reinharz, M., "CERN, Yellow Report", CERN 64-4, 1964.
4. Clark, G. W., 1969, 'I.R.E. Trans.', NS-7, No. 2-3, 1964.