INCIDENT ION EFFECTS ON POLYMER SURFACE DISCHARGES*

M. Gossland and K.G. Balmain
Department of Electrical Engineering
University of Toronto, Toronto, Canada M5S 1A4

Abstract

Samples of Mylar and Teflon film were exposed to various combinations of a monoenergetic 20 keV electron flux and a low energy lithium ion flux in ion-to-electron flux ratios of 0, 5%, 10% and 20%. The samples' discharge rates and strengths were found to diminish as the ion proportion increased, but the discharge durations were unaffected.

Introduction

The charging by electrons of spacecraft insulating surfaces in synchronous orbit must be accompanied by a contribution from ambient positive ions. Experiments in space (References 1, 2, 3) indicate that background proton fluxes are normally less than 5% of the electron fluxes, but under charging (eclipse) conditions the relative proportion of protons can rise to 10%, or sometimes as high as 50% under acceleration by negative spacecraft pre-charge. The laboratory experiments to be described here make use of ion-to-electron current density ratios of 0, 5%, 10% and 20% in an attempt to observe ion effects on the properties of the surface arc discharges which result from charge accumulation. The current density magnitudes used in the laboratory experiments are much higher (of the order of 50 times higher) than would be observed in synchronous orbit, in order to shorten experimental waiting time. However the materials tested (Mylar and Teflon) have been shown (Reference 4) to exhibit discharge properties which are independent of incident electron current density over the relevant range, so it is reasonable to postulate independence of combined electron and ion current densities provided their ratio remains fixed, and then to test this postulate.

Experimental Technique

Two types of dielectric film were used, 75 μm plain Mylar and 125 μm silvered Teflon. Samples were cut from sheet stock, rinsed in trichloroethylene, blown dry, and mounted in the sample holder depicted in Fig. 1. The samples were sandwiched between a copper mask with a 1 cm² circular aperture and a copper substrate, each connected separately through a 2.5 ohm resistor to ground. The experiment consists of two parts and in both parts the current flowing through the substrate resistor during a discharge was monitored as the resistor voltage. In the first part, this voltage provided a trigger for pen motion on a chart recorder resulting in a permanent record of discharge occurrences in time. In the second part, this voltage was displayed on a 400 MHz oscilloscope, and a photograph of the voltage versus time was taken from which the peak currents were obtained.

The electron source was a hot filament followed by a 20 kV accelerator electrode; the beam was magnetically deflected through 90 degrees to permit arc photography. The ion source is an alkali metal oven intended for application as a surface neutralizer in scanning electron microscopes. The source produces positive lithium ions which have been accelerated through a potential difference of approximately 100 V. Upon close approach to a specimen which has been pre-charged by an electron beam, the ions would be further accelerated. Rough calculations indicate that the total deposition of lithium on a sample was approximately 100 times less dense than a monolayer so no coating effects were expected.

The electron and ion fluxes quoted in the experiment were defined as those incident on a grounded Faraday cup located behind the mask aperture (see Fig. 1). Because this position was normally occupied by the sample itself, it was unavailable during the tests. Therefore initially the quoted fluxes were calibrated against those currents which were still available for monitoring during the experiment. The electron flux was calibrated against the current into the side Faraday cup and the ion flux was calibrated against the ion current intercepted by an accelerating grid in the ion source.

In the first part of the experiment in which discharges were recorded with the chart recorder, each sample was exposed to a constant electron flux for the entire duration of its irradiation sequence. After 5 minutes of electron exposure (10 minutes on a few occasions with less responsive samples), the ion beam was turned on at a constant flux, then off, then on, then off and finally on again, each time for the same interval as the initial electron exposure period. Thus the only difference between adjacent intervals was the presence or absence of the ion beam. At the end of this sequence the sample was removed and replaced with a fresh one.

For Mylar, the following combinations of fluxes were used: electrons at 100, 50, 25 and 50 nA/cm² with ions at 5, 5, 5 and 10 nA/cm² respectively, giving ion-to-electron ratios of 5%, 10%, 20% and 20%. For Teflon, the combinations were electrons at 100, 50 and 50 nA/cm² with ions at 5, 5 and 10 nA/cm² respectively giving the ion-to-electron ratios of 5%, 10% and 20%.

In the second part of the experiment in which the current pulses were photographed, each sample was exposed to a constant electron flux for the duration of its irradiation sequence. After 3 discharges occurred under electron exposure, the ion beam was turned on at a constant flux until 3 more discharges occurred, at which point the ions were turned off and 3 more discharges were recorded with electrons only. At the end of this sequence the sample was removed and replaced with a fresh one.

For Mylar, electron fluxes of 50, 100, 50 and 50 nA/cm² were combined with ion fluxes of 0, 5, 5 and 10 nA/cm² respectively giving ion-to-electron ratios of 0, 5%, 10% and 20%. For Teflon the combinations were electrons at 50, 100 and 50 nA/cm², with ions at 0, 5 and 5 nA/cm² respectively, giving ratios of 0, 5% and 10%.

*Work supported by the U.S. Air Force Weapons Laboratory and by NASA, through Grant NSG-7647, and by the Natural Sciences and Engineering Research Council of Canada, through Grant A-4140.

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Results

With the data obtained in the first part of the experiment, the numbers of discharges occurring in each time interval were expressed as "rates", by dividing them by the time interval itself. Typically these numbers ranged from 3 to 18 per 5-min initial interval (electron exposure), with an average of 7 or 8. Aside from fatigue effects (in which samples tend to discharge less frequently over time) and random fluctuations in discharge occurrences, changes in discharge rates from one period to the next were attributed to the ions. Randomness was reduced in the final results by averaging all samples subjected to like conditions. Before averaging, the discharge rates were normalized so that the rates during the first interval were set to unity. This enabled easier comparisons and gave equal weight during averaging to the rates themselves, rather than to the individual numbers of discharges.

The normalized discharge rates for 4 ion-to-electron ratios on Mylar are shown in Figs. 2 to 5, and for 3 ion-to-electron ratios on Teflon in Figs. 6 to 9. The horizontal plateaus represent the rates and the oblique joining lines enable one to both trace the individual samples' histories and observe the overall trends in the samples' behaviour. In some instances an artificial separation of one line width between samples has been introduced for clarity. The dots represent the averages of the rates of all of the samples. Also included in each figure caption is a list of the normalization factors. Multiplying each sample's normalized rate by its factor yields the number of discharges actually occurring on the sample during the time interval.

In Fig.2 the ion-to-electron ratio is 5% and no ion effect is visible. The slight overall decline in the average rates indicates sample fatigue. In Fig.3 the ratio is 10% and in addition to fatigue a consistent reduction in discharge rate upon ion exposure is evident. In Fig.4, the ratio is 20% and the ion effect is increased. In Fig.5, the ratio is also 20% but both currents are double those in Fig.4. The ions do not serve to eliminate the discharges as effectively as in Fig.4, but do reduce the number of discharges per unit time by the same amount. It is evident that for the higher currents in Fig.5 the Mylar continues to discharge at a more uniform rate when the ions are off (i.e. normalized averages are approximately unity) and so the reduction due to the ions appears less effective. Acknowledging this change in fatiguing behaviour, it is still reasonable to assume that the ion effects are less dependent on absolute beam current magnitudes tnan on the ion-to-electron ratio. Nevertheless, it can also be said that the ions become more effective as the currents are reduced.

Figure 6 shows the results for Teflon with a 5% ratio. The evidence suggests a slight increase in discharge rate due to the ions. However as the ion ratio is increased to 10 and 20% in Figs.7 and 8, the effect is a reduction in discharge rate similar to the case of Mylar.

In the second part of this experiment, the discharge pulse heights were read from the oscilloscope photographs and normalized with the average of the first three pulse heights to facilitate comparison. These results are shown as normalized pulse heights versus discharge number in Figs.9 to 13 for Mylar and Figs.14 to 17 for Teflon. The ions were turned on only during discharges 4, 5, and 6. Each dot represents a single discharge, and the horizontal lines show the averages of all of the samples. No lines are drawn to connect discharges belonging to the same sample, but it was found that each sample does indeed behave similarly to the averages shown. In Figs.9 to 12 the ion proportion is increased from 0 through 5%, 10% and 20%. Consistently, as the ion ratio increases, the pulse heights of the ion-exposed discharges decrease. A summary graph displaying these averages is presented in Fig.13.

The results obtained for Teflon are shown in Figs. 14 through 16 for ratios of 0, 5% and 10% with a summary graph shown in Fig.17. As in the case of Mylar, as the ion proportion increases, the pulse heights of the ion-exposed discharges decrease.

The photographs for Mylar and Teflon were also observed for changes in pulse duration and no significant change was found.

Conclusions

The results suggest that low-energy ions when drawn to electron-charged regions on exposed spacecraft dielectrics serve to reduce both discharge frequency and strength, without affecting pulse duration. These reductions become more pronounced as the ion-to-electron flux ratio is increased and are independent of the samples' exposure histories. Similar behaviour is obtained with plain Mylar and silvered Teflon.

References

1. S.E. DeForest, "Spacecraft charging at synchronous orbit", J. Geophys. Res., Vol.77, pp.651-659, Feb. 1972. See also E.C. Whipple, "Potentials of surfaces in space", Rep. Prog. Phys., Vol.44, pp.1197-1250, 1981.

2. J.B. Reagan, R.W. Nightingale, E.E. Gaines, R.E. Meyerott, and W.L. Imhof, "Role of energetic particles in charging/discharging of spacecraft dielectrics", Spacecraft Charging Technology 1980, NASA CP 2182/AFGL-TR-81-0270, pp.74-85.

3. J. Wilkenfeld, C. Mallon, and J. Horne, "Conduction and charge storage in electron-irradiated spacecraft insulators", RADC-TR-81-198, July 1981.

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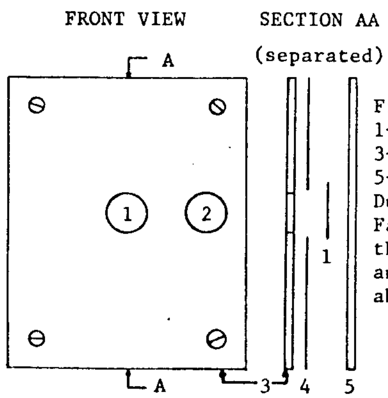

Fig. 1
1-Sample, 2-Faraday Cup, 3-Mask, 4-Insulator, 5-Substrate.
During calibration, a Faraday cup was behind the mask aperture (1) and the substrate was absent.

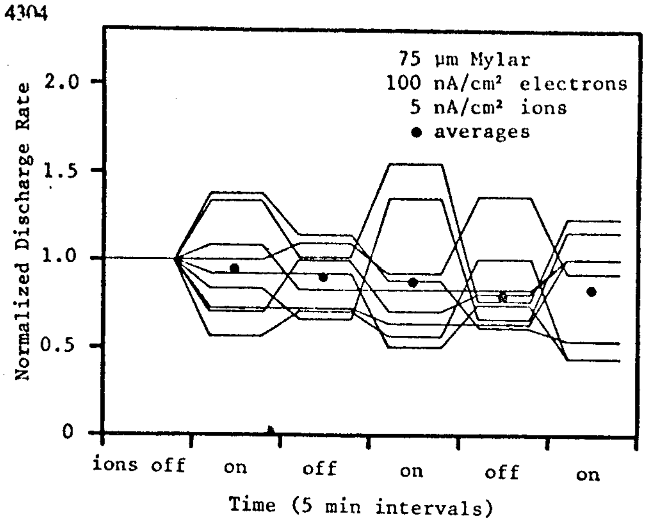

Fig.2 Normalized discharge rates for Mylar with an ion-to-electron ratio of 5%. The normalization factors given top to bottom during the first ion period are: 8,9,11,11,12,6,11,10,7.

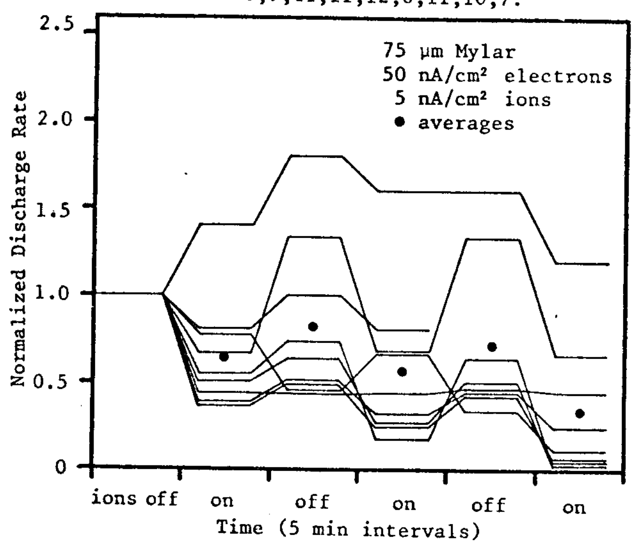

Fig.3 Normalized discharge rates for Mylar with an ion-to-electron ratio of 10%. The normalization factors given top to bottom during the first ion period are: 5,5,9,3,11,16,7,16,8.

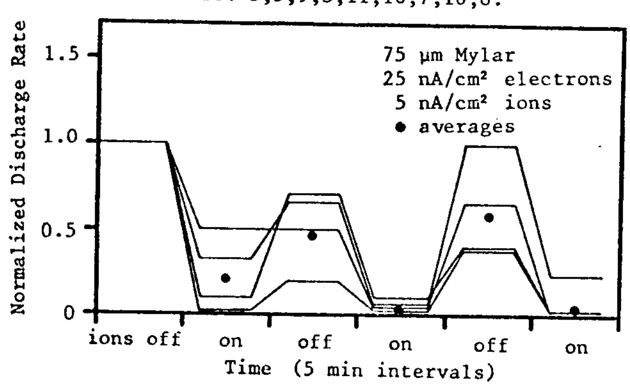

Fig.4 Normalized discharge rates for Mylar with an ion-to-electron ratio of 20%. The normalization factors given from top to bottom of the first ion period are: 4,3,10,5.

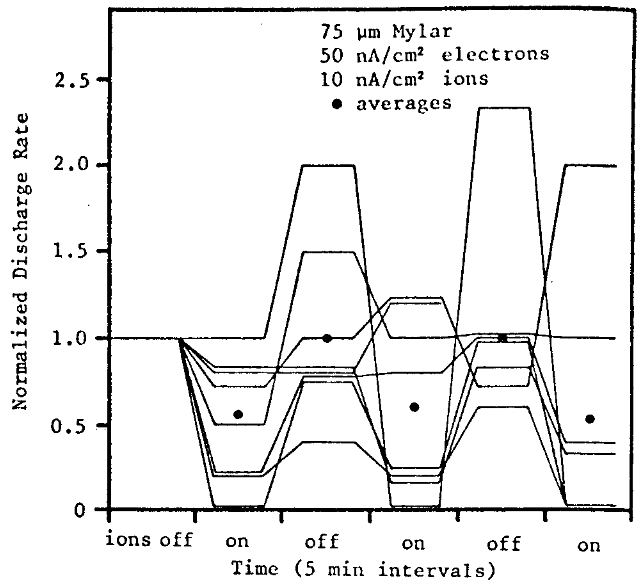

Fig.5 Normalized discharge rates for Mylar with an ion-to-electron ratio of 20%. The normalization factors given from top to bottom of the first ion period are: 3,6,5,7,4,5,5,4.

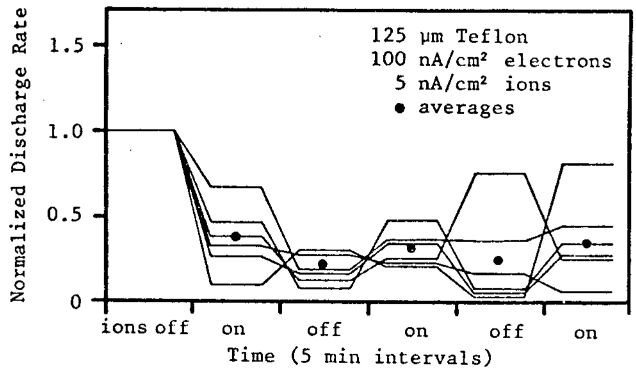

Fig.6 Normalized discharge rates for Teflon with an ion-to-electron ratio of 5%. The normalization factors given from top to bottom of the first ion period are: 6,12,8,18,11,10.

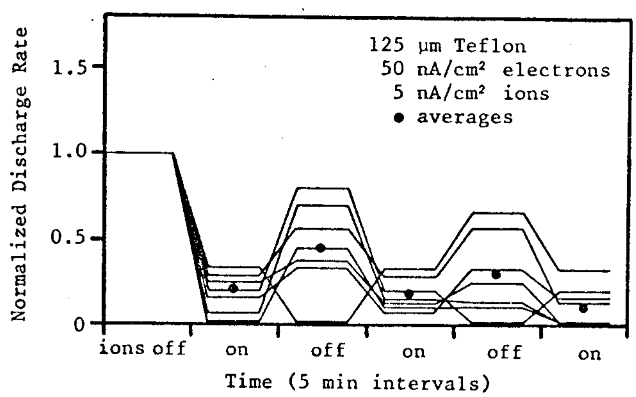

Fig.7 Normalized discharge rates for Teflon with an ion-to-electron ratio of 10%. The normalization factors given from top to bottom of the first ion period are: 3,7,8,5,12,13,9.

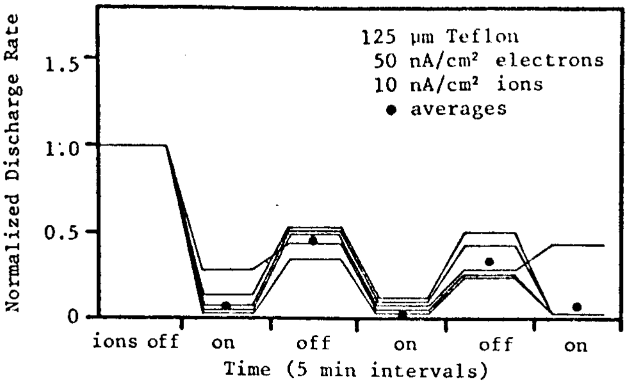

Fig.8 Normalized discharge rates for Teflon with an ion-to-electron ratio of 20%. The normalization factors given from top to bottom of the first ion period are: 7,8,8,4,12. The levels have been distorted for clarity and all 5 samples are at zero for the second ion period.

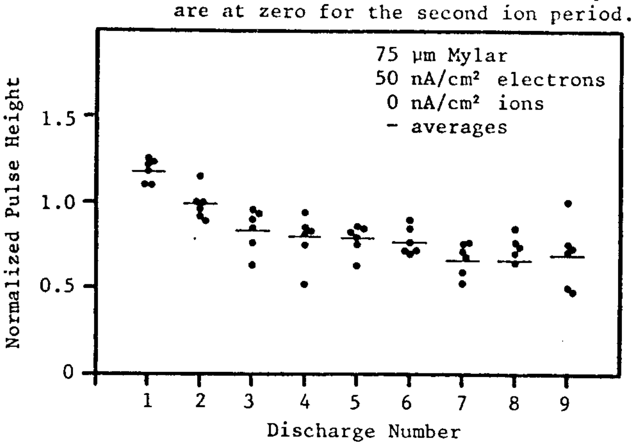

Fig.9 Normalized discharge pulse heights for Mylar with no ions.

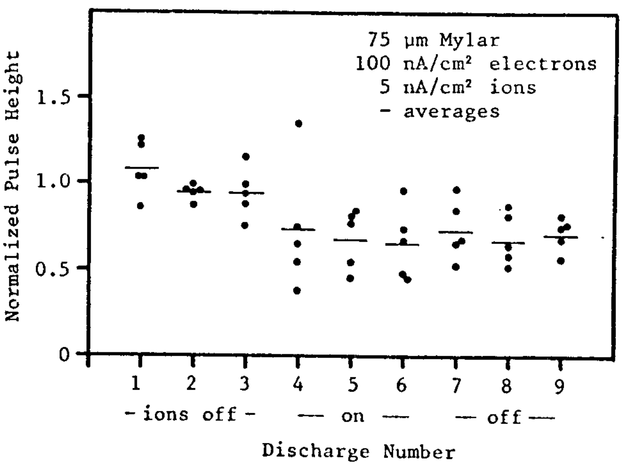

Fig.10 Normalized discharge pulse heights for Mylar with an ion-to-electron ratio of 5%.

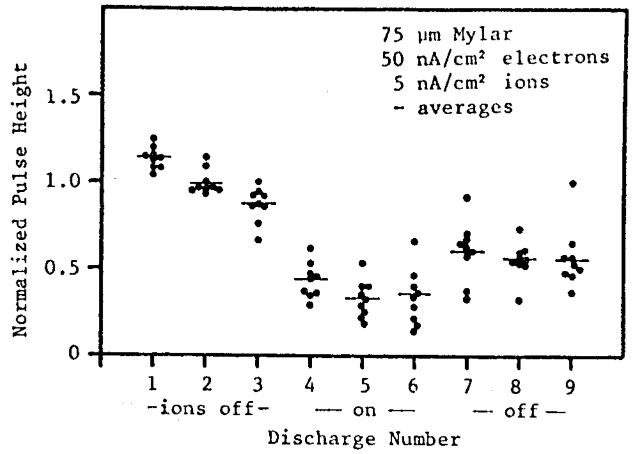

Fig.11 Normalized discharge pulse heights for Mylar with an ion-to-electron ratio of 10%.

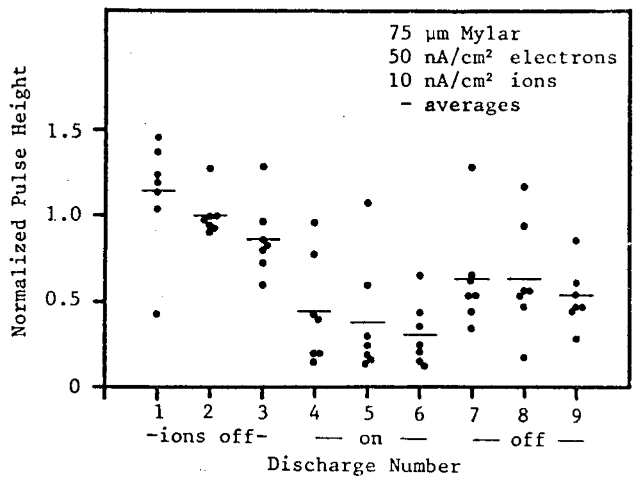

Fig.12 Normalized discharge pulse heights for Mylar with an ion-to-electron ratio of 20%.

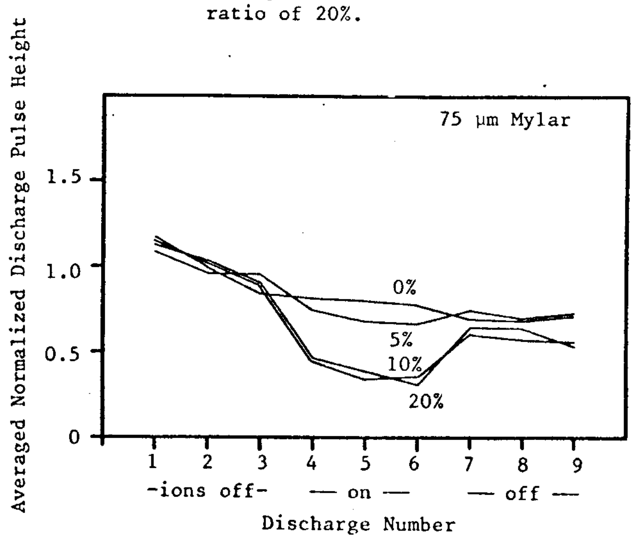

Fig.13 Summary of the averages of normalized discharge pulse heights on Mylar for ion-to-electron ratios of 0,5%,10% and 20%.

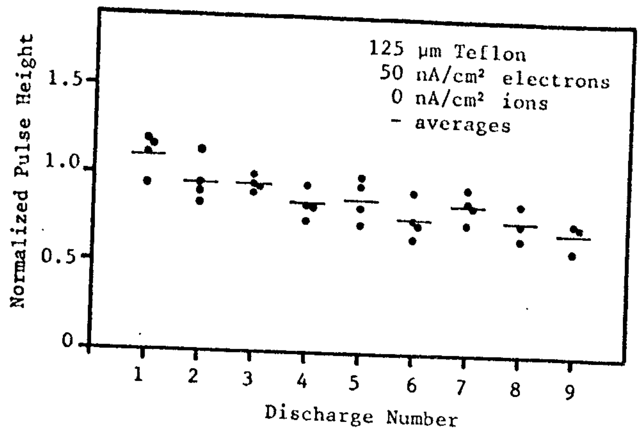

Fig.14 Normalized discharge pulse heights for Teflon with no ions.

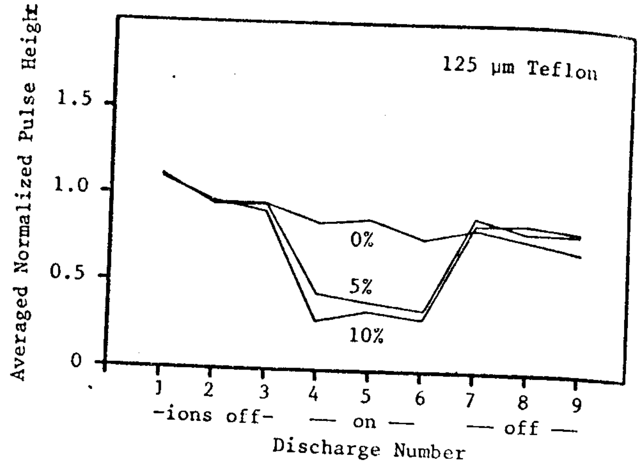

Fig.17 Summary of the averages of normalized discharge pulse heights on Teflon for ion-to-electron ratios of 0%,5% and 10%.

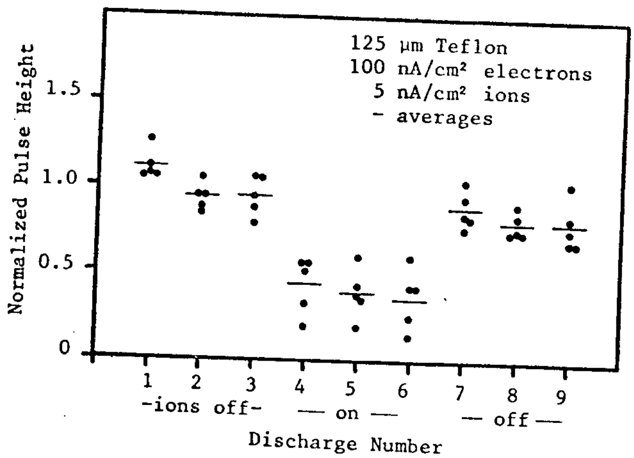

Fig.15 Normalized discharge pulse heights for Teflon with an ion-to-electron ratio of 5%.

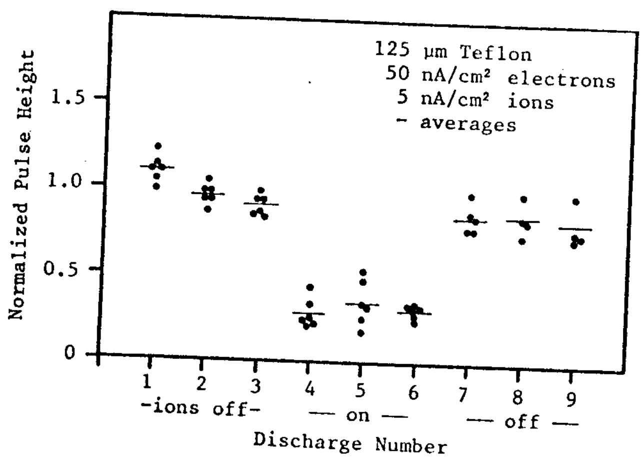

Fig.16 Normalized discharge pulse heights for Teflon with an ion-to-electron ratio of 10%.