CHARGING AND DISCHARGING TEFLON*

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1. INTRODUCTION

In this paper we present some results selected from a program designed to measure the charging and discharging characteristics of several common satellite materials exposed to 0-30KV electrons. SGEMP related aspects of this experiment are described in Reference 1. We have chosen to discuss teflon in this paper because the charging characteristics are radically altered immediately after a spontaneous discharge.

In Section 2 we discuss the experimental configuration, in Section 3 we present experimental observations, and in Section 4 we offer a hypothesis to explain the observations.

2. EXPERIMENTAL DETAILS

The exterior geometry of the test structure is indicated in Figure 1. In all cases dielectric samples were 82 cm in diameter mounted on the front of a 120 cm diameter cylinder supported on an 85 cm, 0.95 cm thick plexiglass disc. Dielectric materials investigated were: back surface aluminized Kapton, back surface silvered Teflon, Silicon Alkyd white thermal control paint, and 50 cm by 50 cm array of 0.030 cm thick MgF_2 coated fused silica solar cell cover slips.

Spontaneous discharges and SGEMP emissions were measured with EG&G CMLX3B surface current probes and CT-2 current transformers. Fast transient data was transmitted to the recording instrumentation through HDL/DNA 400 MHz fiber optic data links, recorded on Tektronix 7912 transient digitizers and processed on a PDP/1140 computer.

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The test cylinder was connected to instrumentation ground through a 50 KΩ resistor chain. This provided a cylinder potential of less than 0.5 volts during charge, at measured current densities of approximately 10^{-9} A/cm^2. However, the RC time constant of this resistor string and cylinder capacitance to the tank was about 8 microseconds, so the test structure was effectively isolated during spontaneous discharges and exploding wire photon pulses. As indicated in Figure 1 the front of the cylindrical test object was surrounded by a square frame which supported small motors, pulleys and belts, (not shown) to drive a traverse carrying the probe of a TREK noncontacting electrostatic voltmeter, a Faraday cup, and an $\dot{E}$ sensor over the surface of the sample. The spatial resolution of the electrostatic voltmeter is estimated to be ± 3 mm, the Faraday cup was approximately 1 cm^2 and the $\dot{E}$ probe was used as an oscilloscope trigger in spontaneous discharge studies. Both the traverse frame and the aluminum rings surrounding the dielectrics were coated with colloidal graphite to inhibit dielectric charging and minimize photoelectric emission from the aluminum. The tank was lined with 2 cylindrical layers of 200 Ω/square carbon coated cloth to suppress tank wall photoemission and damp tank EM resonances. The test cylinder was suspended with nylon ropes from a rotary feed through near the center of the 10 foot diameter and 12 foot long vacuum tank.

The chamber was evacuated with a liquid nitrogen trapped, silicon oil diffusion pump and a mechanical roughing pump. In addition there was a liquid nitrogen cold wall in the tank. The tank pressure normally ranged about 2 - 5 x 10^{-6} torr. Rapid discharge (approximately 10^3 volts/sec) of all charged insulators was observed at $\sim$ 2 x 10^{-4} torr. This discharge was accompanied by a flash of light and a temporary reduction in pressure.

Samples were handled with gloves with more-than-normal care, but were unavoidably exposed to laboratory atmosphere for several weeks prior to testing. Close, careful visual examination of the reflecting kapton samples after several days of tests revealed traces of vacuum pump oil. Subsequently, all samples were washed with reagent grade ethyl alcohol after installation and before pumpdown.

Two electron guns were employed. Faraday measurements indicated that the DNA electron flood gun provided illumination which differed by less than a factor of two from the center to the edge of the sample. Acceleration potential was established by floating the gun filament to a negative potential with respect to a grounded fine wire grid. Gun current was regulated with a feed-back circuit which sensed emission current and modulated the filament power. We also employed an electrostatically focused and deflected cathode ray tube gun, focused to provide to a 2 cm diameter spot on the sample. For equal total gun current the beam current density was approximately 1600 times larger in the focused beam. Comparable potential distributions were produced with comparable total electron fluences from either gun. This indicates the charge build-up is not particularly sensitive to beam current densities over a range from approximately 10^{-10} to about 10^{-6} A/cm^2.

Figure 2 represents the electrical equivalent circuit of this experiment, where node 1 is the trapped electron charge layer, node 2 is the metal film on the back of the teflon, node 3 is the test cylinder and node 4 is the vacuum chamber. Current generator I_{12} represents a "punch-through" current, I_{14}

represents "blow off" from the dielectric to the tank wall. I_{34} represents charge emission from the test cylinder to the tank wall, and I_{13} represents charge transfer from the dielectric to the test object. I_{23} is the current actually measured with a Tektronix CT-2 sensor and is influenced by blow-off, edge and punch through currents. V_{out}, the body voltage, is proportional only to blow-off current. The indicated capacitances are self-explanatory. For teflon they are estimated to be $C_{12} \sim 70$ nf, $C_{13} \sim 40$ pf, $C_{14} \sim 100$ pf, $C_{34} \sim$ 60 pf.

3. EXPERIMENTAL OBSERVATIONS

The average surface potential of teflon charged with 15 kV electrons was 9.2 ± 1.0 kV, the average potential of teflon charged with 25 kV electrons was 9.6 ± 0.8 kV. We attribute the asymptotic behavior to leakage currents through the bulk dielectric to the metal substrate.

Unlike kapton, which exhibited the tendency to produce fewer and fewer spontaneous discharges under extended irradiation, teflon continued to exhibit spontaneous discharges at nearly constant rate. By repeatedly measuring the surface potential after radiation ceased, we obtained indications that the charge leak rate of teflon, charged to approximately 10 kV, diminished from about 0.6%/min in the first minute after irradiation to approximately 0.03%/min after 40 minutes.

During the course of this investigation we observed a wide variety of responses, and individual charge transfer of up to 500 μC. It should be noted that for this geometry, at most approximately 800 nC could be discharged to infinity (blown off) because the removal of that amount of charge would raise the body potential to such an extent that no further charge could be expelled. Therefore, on very large discharges, the bulk of the charge must be returned to the test object itself (we call these edge currents). Figure 3 (a-b-c) represent substrate current I_{23} for three successive discharge events. The integral of the substrate current (Q_{23}) is the sum of "blow-off" charge and "edge" charge. The (transient) increase in the test object potential is proportional to the blow-off divided by the capacitance of the object to the tank. For the first event, in Figure 3, the integral of the substrate current and the body voltage (not shown) indicate a charge release of approximately 9 ± 1 nC. In the second event the charge release was 0.4 ± 0.4 nC and the third event approximately 3 ± 1 nC. For these three specific events virtually all the charge was blown off to the tank walls. Notice that all three of these events exhibit an early time high-frequency ring which is determined by the LC product of the inductance of the wire connecting the substrate to the body (to measure I_{23}) and the capacitance between the dielectric and the body. The net charge released in the high frequency portion of these signals is nearly zero. According to these records, the charge actually blown off starts to leave the body at approximately 0.4 μs and persists for approximately 0.5 to 1.0 μs. We will soon suggest that the blow-off pulse width is determined by propagation rate of an ion wave front.

In addition to these transient measurements we periodically measured the surface charge state of the dielectric with the TREK electrostatic voltmeter. Sweeping the sensor across the surface of the sample in a tic-tac-toe pattern, Figures 4 a-h show one series of measurements in which the teflon sheet was charged in steps, by 15 kV electrons, at a current density of approximately 8 nA/cm^2. Figure 5a indicates the degree of nonuniformity of the incident electron beam. The surface potential approached an asymptotic value of approximately 9 kV (Figure 5d and 5e). This sample was then intentionally discharged by admitting gas, raising the pressure to approximately 8×10^{-4} torr. The discharge was accompanied by a flash visible light which covered the entire exposed surface. The light visually resembled the glow of a gas flame. We note that spontaneously discharging samples exhibited both these flame-like flashes as well as dendritic sparks. The TREK probe was located at x,y coordinates of 24 cm and 20 cm during the discharge. As indicated in Figure 4f the discharge was incomplete in the vicinity of the electrostatic probe because the external electric field was near zero at that location. Figures 4g and 4h show that it took much longer to recharge the teflon surface after it had been intentially discharge than it initially had. Figure 5 shows the average surface potential as a function of exposure time indicating that the sample originally approached 90% of the asymptotic limit in approximately seven seconds while after discharge the same charging process took about 7 minutes.

Figure 6a - 6f is another series of potential profiles. Figure 6a shows a sample which had been charged with 3 nA/cm^2 of normally incident 25 kilovolt electrons. Figure 6b shows a traverse measured immediately after a spontaneous charge transfer of approximately 400 μC (inferred from $C\Delta V$ and size of the discharged area). Figures 6c, d, e indicate that, as with the gas discharged sample, the spontaneously discharged area was difficult to recharge. The chamber pressure at the time of the spontaneous discharge was approximately 4×10^{-6} torr, which is much too low for gas induced discharge.

4. HYPOTHESIS

We note two similarities between the spontaneous discharge and the one produced by the presence of gas, the first is the visual appearance of the discharge, the second is the diminished tendency to accept recharge. In the gas discharge case, we know that the charged dielectric surface was neutralized by ionized gas molecules. The surface was bombarded with approximately 6×10^{11} $ions/cm^2$ accelerated to approximately 10 kilovolts. Only the first few microns of the surface participate in this discharge process. Therefore any changes in the material response must be attributed to changes in the sample surface rather than the bulk dielectric. The spontaneously discharged dielectric exhibited similar characteristics, even though the ambient pressure was too low to be attributed to gas discharge. Consequently we speculate that the reduced recharge rate is because the secondary emission coefficient of a freshly ion bombarded surface is substantially greater than for an aged or dirty surface and the spontaneous discharge involves the generation and propagation of a wave front of ions of the dielectric itself. Thus the propagation velocity of the dielectric ions in the pre-existing electric field of the charged dielectric determines the rate of the spontaneous discharge. This accounts for the comparatively slow emission of blow off charge noted in Figure 3. This model is also supported by the calculations presented in reference 2.

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5. REFERENCES

1. van Lint, V.A.J., et. al.: The Effect of Electron Precharging on SGEMP Response of Insulators. IEEE Trans Nuclear Science, Vol. NS-26, No. 6, December 1979, pp. 5024-5029.

2. Mandell, M.J., Katz, I., Schnuelle, G.W., "Calculation of Surface Flashover of a Large Sample Under Grounded and Floating Conditions", Spacecraft Charging Technology Conference, November 14, 1980 (this conference)

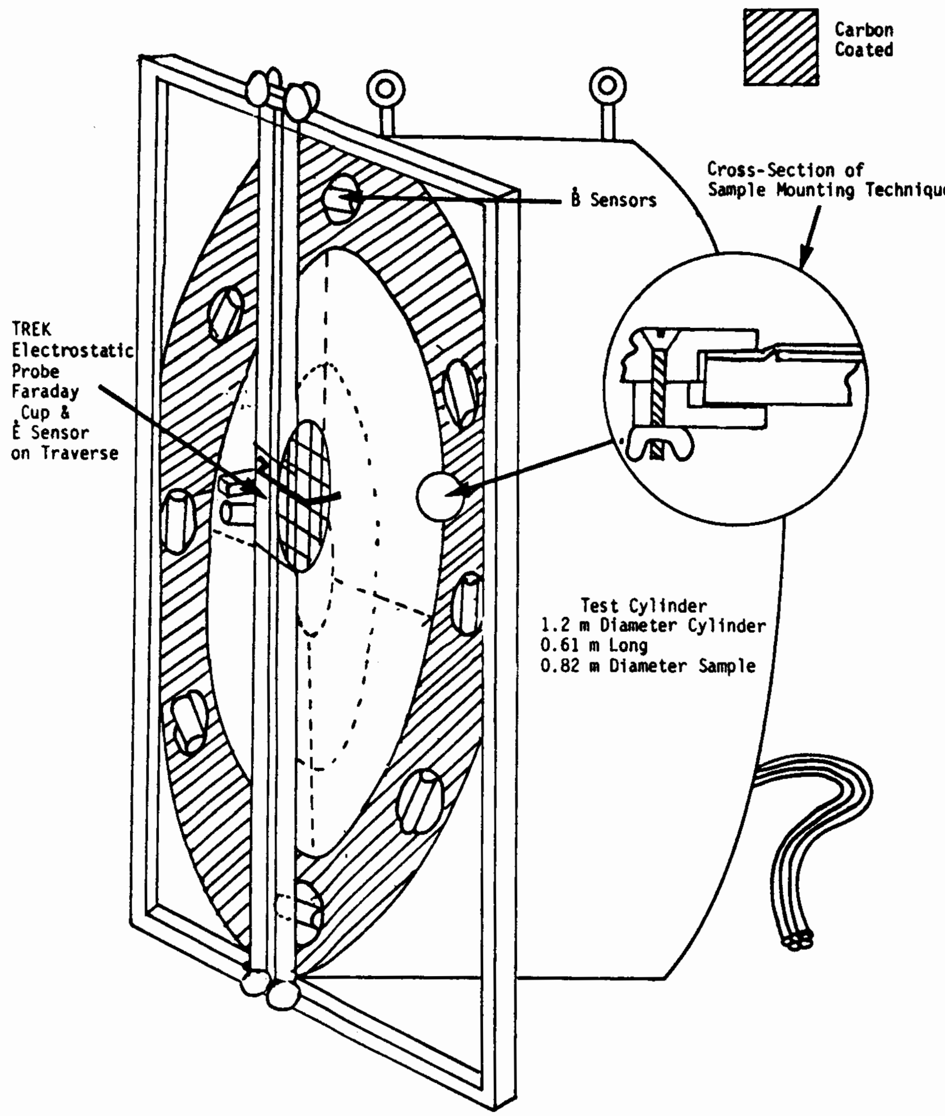
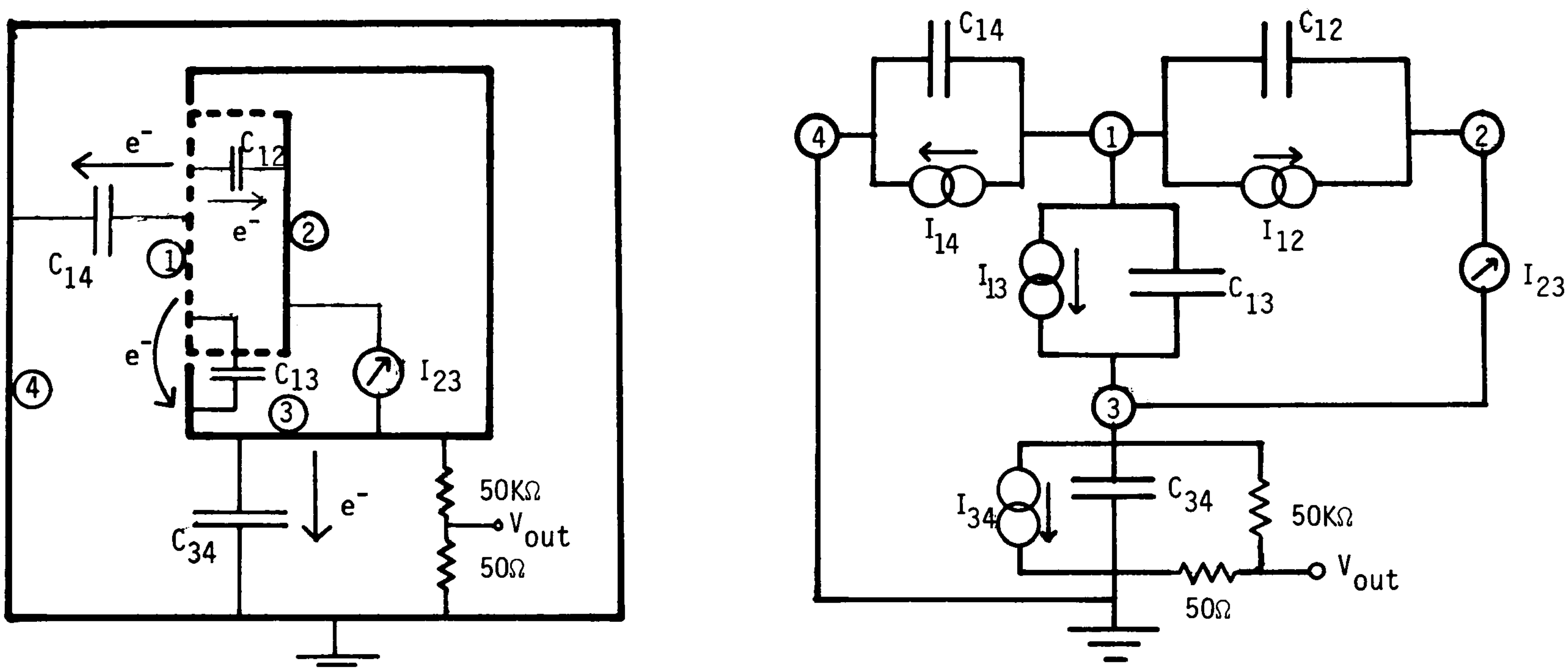


Figure 1. Picture of the test body showing traverse, sample and Ḃ sensors. Insert shows the way the sample was attached to the test body.



(1) = Charge layer on dielectric
(2) = Metal substrate
(3) = Test body
(4) = Vacuum Tank

Figure 2. Schematic and electrical equivalent circuit of a dielectric disk on the end of a cylinder in a vacuum chamber.

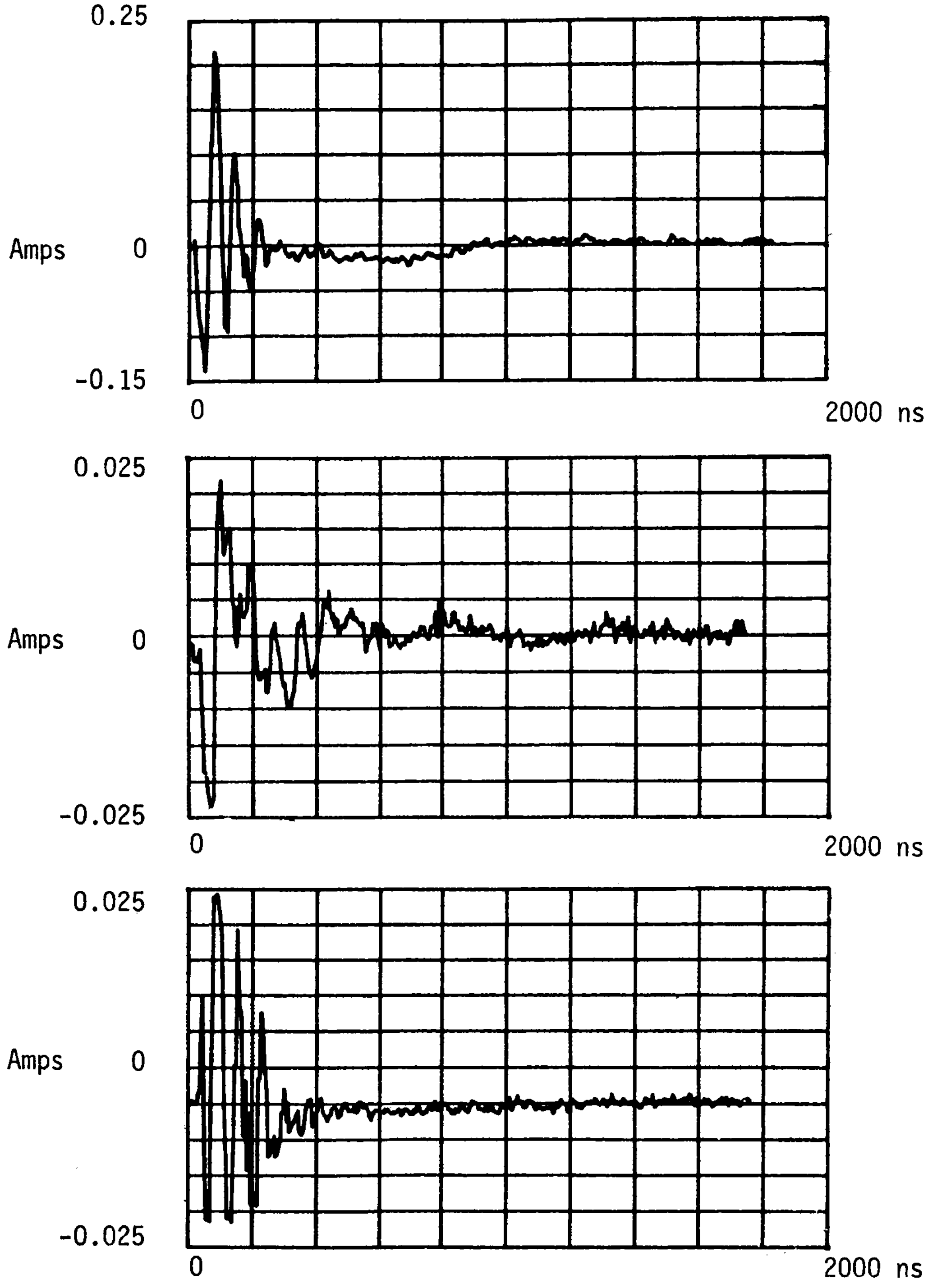


Figure 3. Substrate-to-body current record (I_{23}) for three spontaneous discharge events.

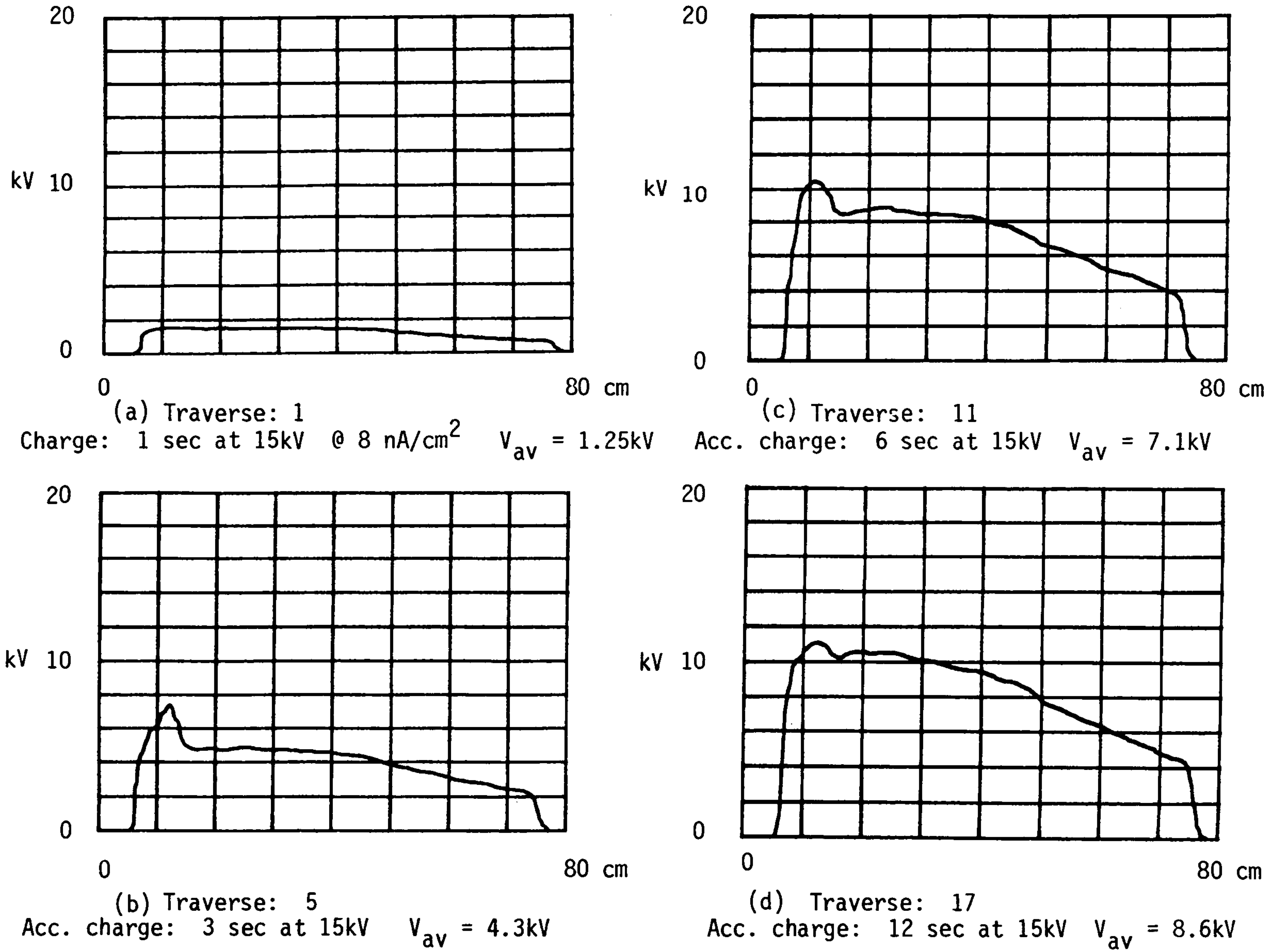
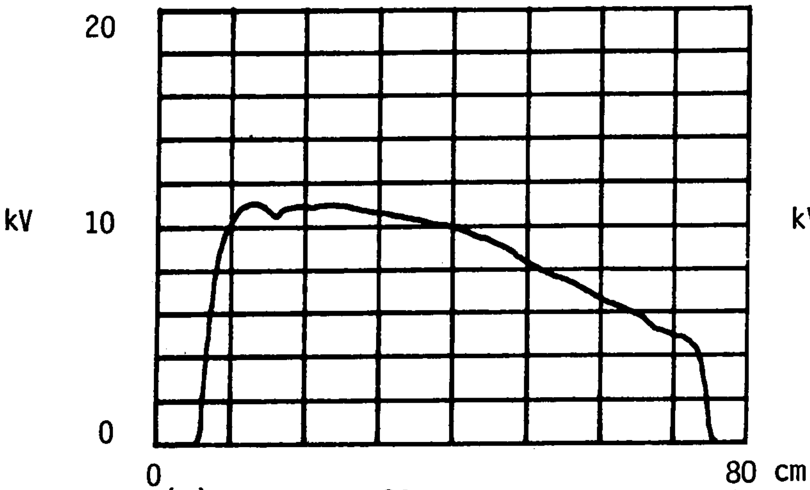
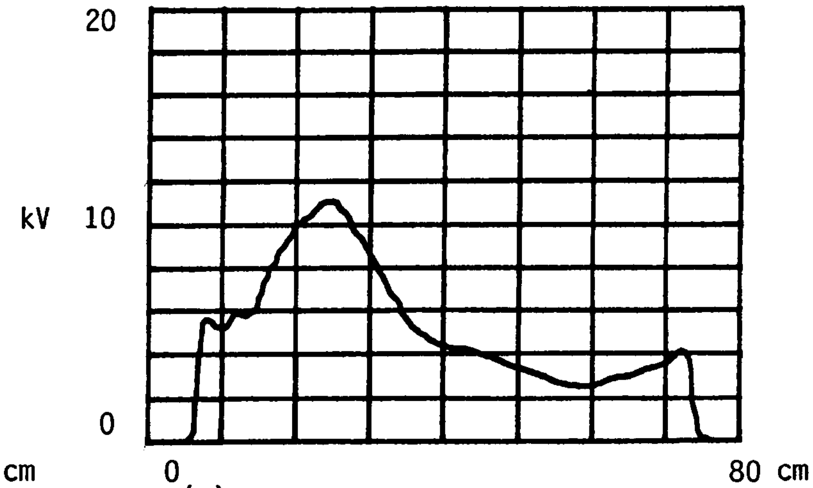


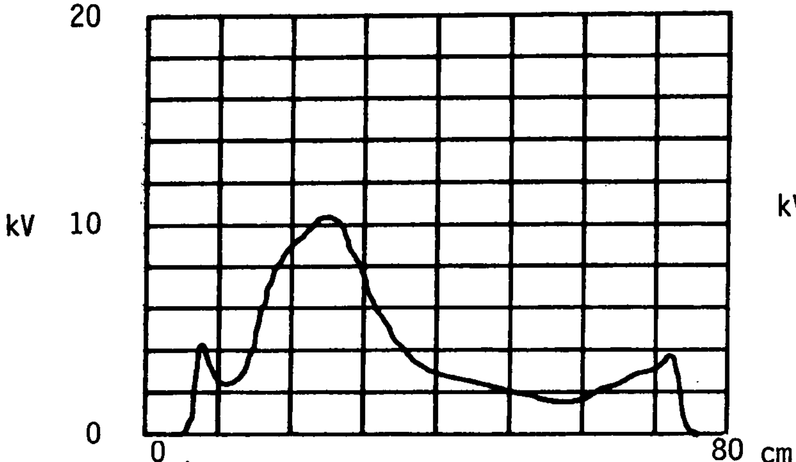
Figure 4. TEFLON - Charging at 15 kV - V(x) traverses x at y = 20 cm.



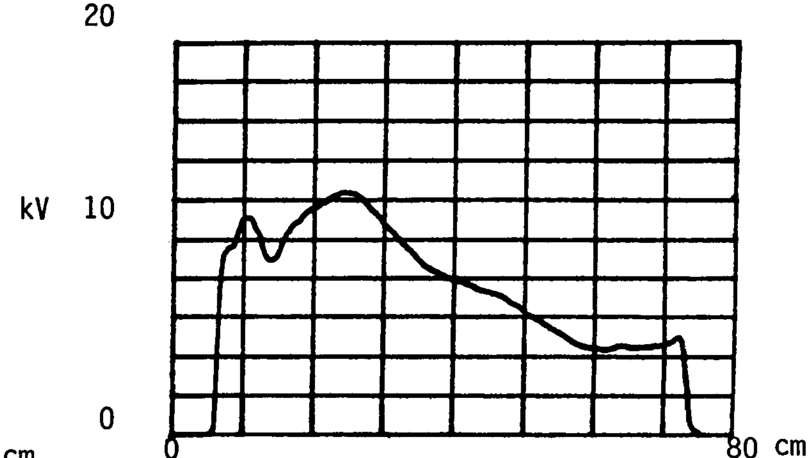
(e) Traverse: 23
Acc. charge: 72 sec at 15kV V_{av}= 8.6kV



(g) Traverse: 33
Acc. Charge: 75 sec at 15kV after discharge (total of 147 sec irradiation) V_{av}= 5.3kV



(f) Traverse: 29
First traverse after the pressure-induced discharge V_{av}= 4.3kV



(h) Traverse: 37
Acc. charge: 255 sec after discharge (total of 327 sec irradiation) V_{av}= 8.26kV

Figure.4. (cont.). TEFLON - Charging at 15 kV - V(x) traverses along x at y = 20 cm

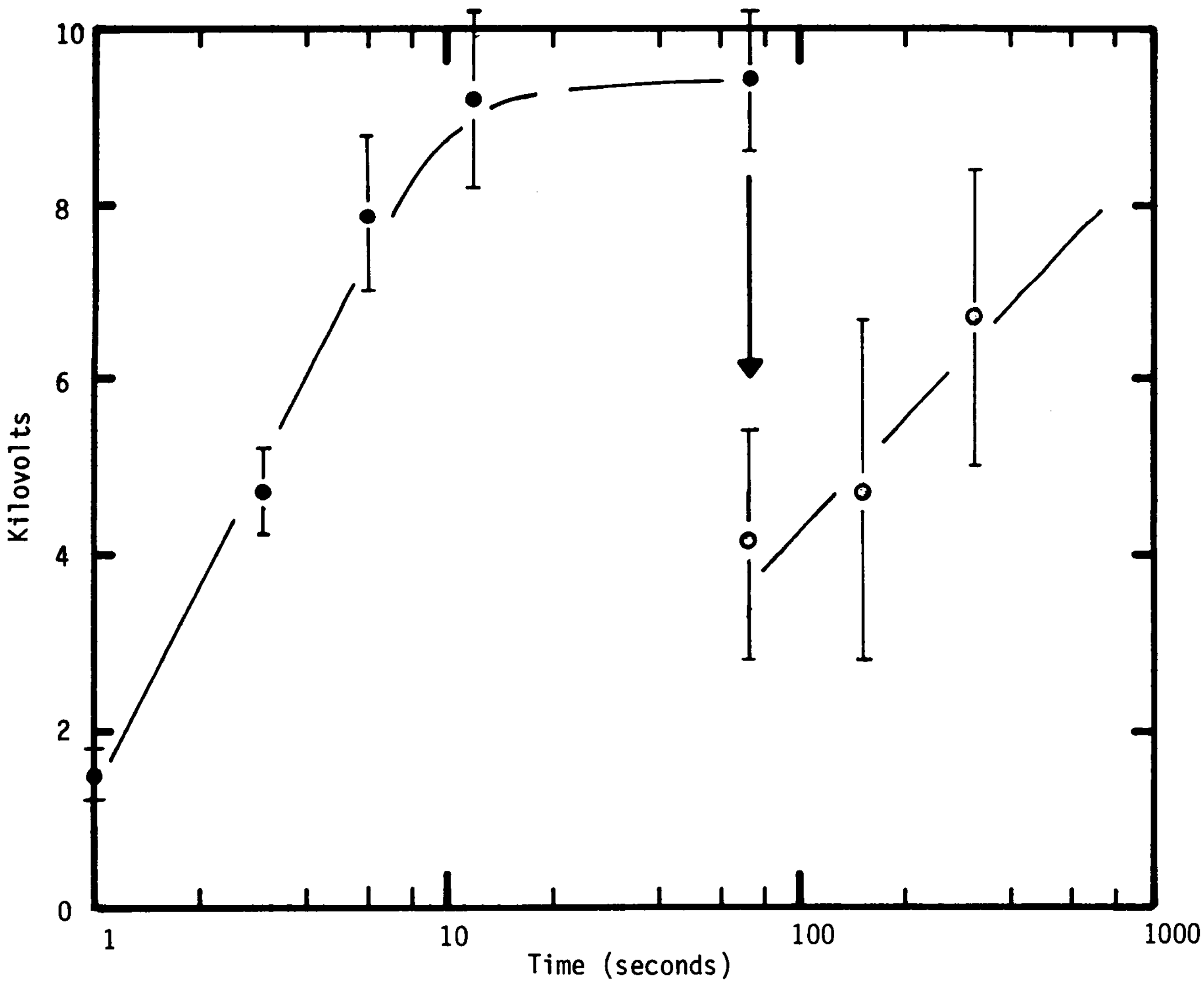
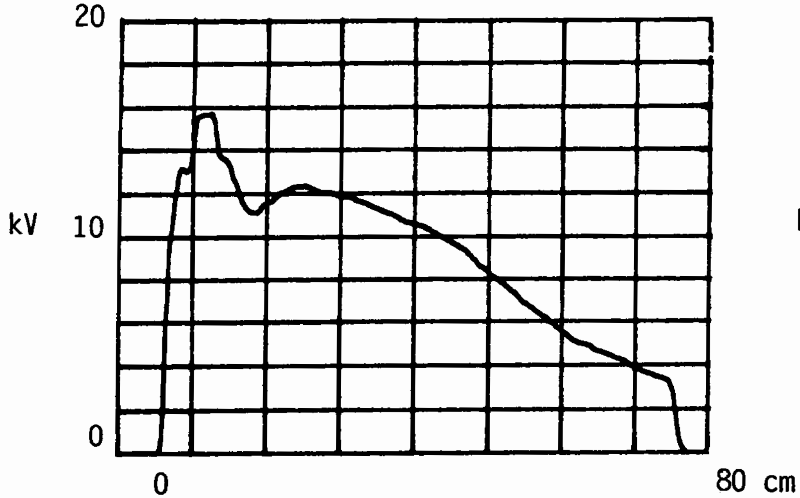
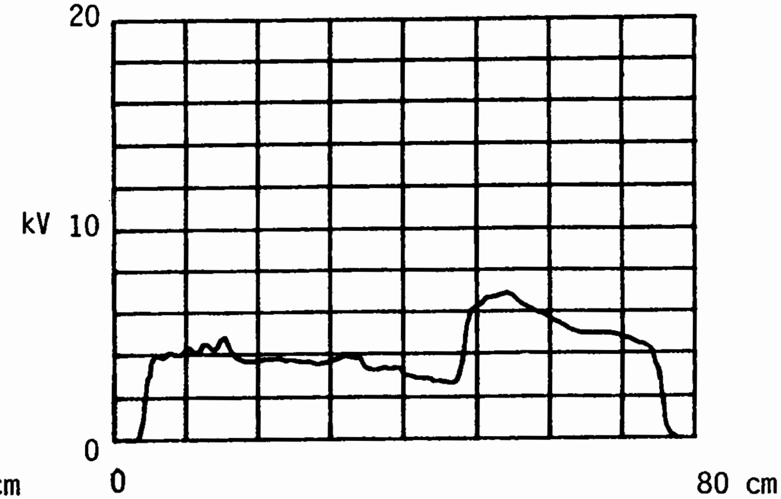


Figure 5. Surface potential of teflon as a function of charging time before and after a gas-induced discharge.



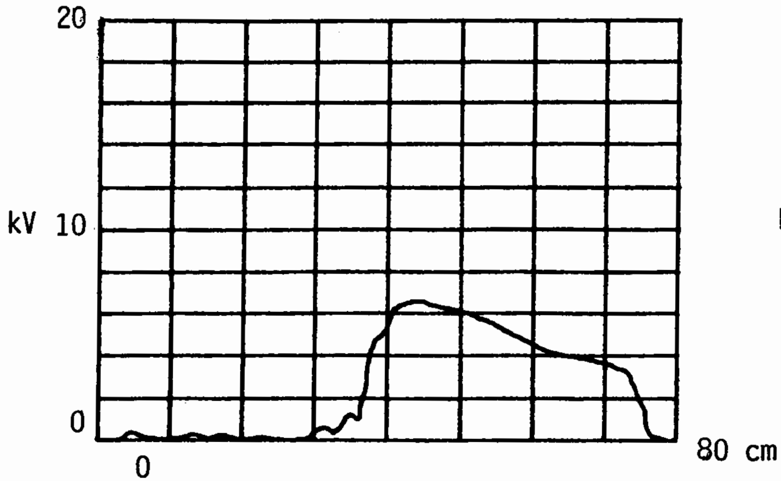
(a) Traverse: 48

Charge: 60 sec at 25kV at 3 nA/cm^2 V_{av} = 9.3kV



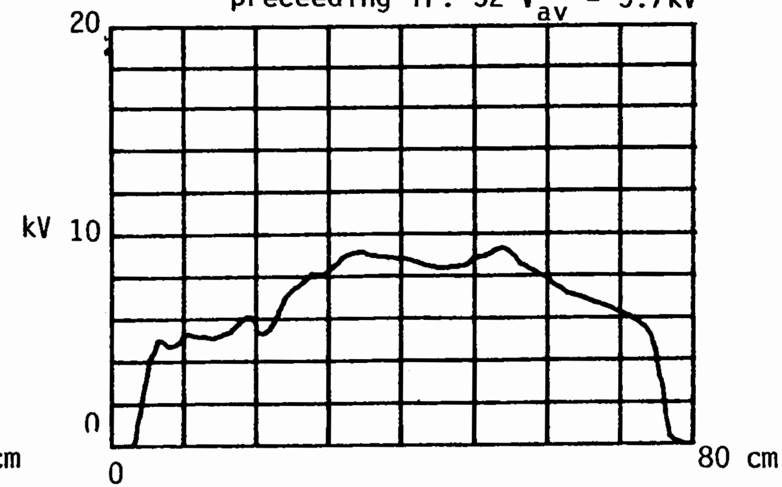
(c) Traverse: 56

Charge: 5 min at 25kV after discharge preceeding Tr. 52 V_{av} = 5.7kV



(b) Traverse: 52

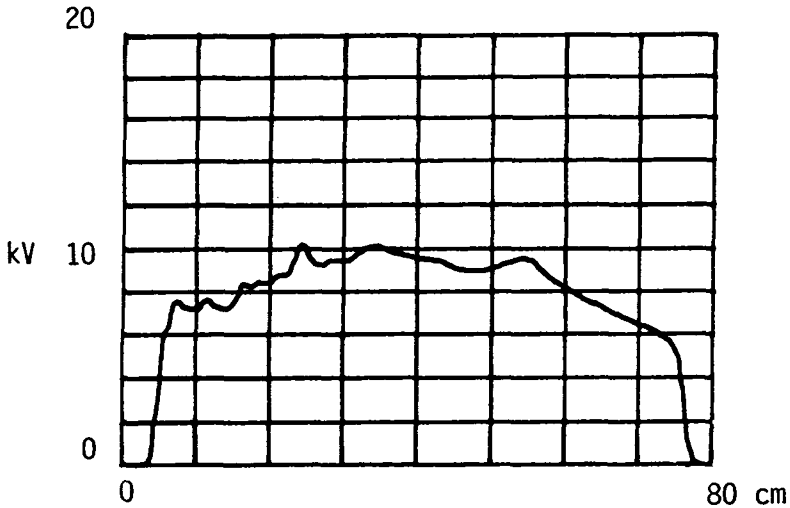
Charge: spontaneous discharge during traverse immediately after Tr. 48; V_{av} = 2.5kV



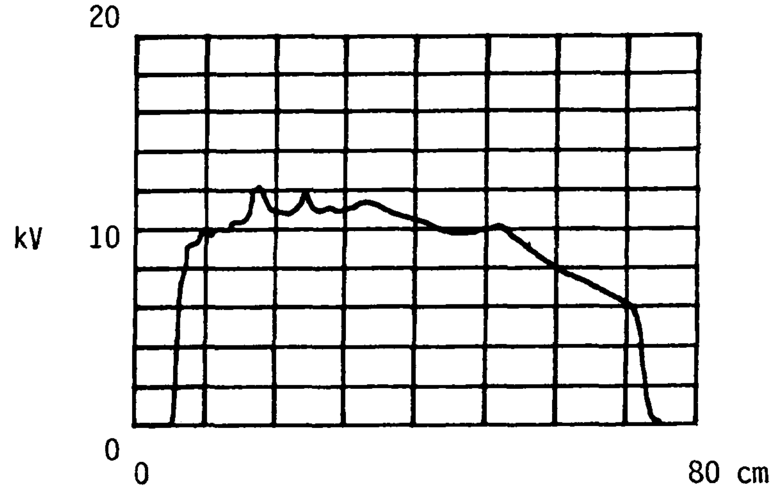
(d) Traverse: 63

Charge: 30 sec at 25kV after Tr. 65 V_{av} = 9.3kV

Figure 6. TEFLON - 25kV charging after spontaneous discharge in high vacuum. V(x) traverses along x at y = 20 cm.



(e) Traverse: 65
Charge: 20 sec at 20kV after Tr. 63 V_{av} = 8.5kV



(f) Traverse: 67
Charge: 30 sec at 25kV after Tr. 65
V_{av} = 9.3kV

Figure 6. (cont.) TEFLON - 25kV Charging after spontaneous discharge in high vacuum. V(x) Traverses along x at y = 20 cm.